

The Commonwealth of Massachusetts

Highway Design Manual

Massachusetts Highway Department



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CHAPTER 1

HIGHWAY DESIGN PROCESS

1.1 INTRODUCTION

One of the most important production activities in the Massachusetts Highway Department (MHD) is to plan, develop, and design to the construction stage, projects for which the MHD is responsible. Not only is this process important from the perspective of production, but public perception of the Department is also heavily influenced by the effectiveness of this process and the sensitivity shown to public concerns. This chapter specifies the process used to develop highway design construction projects in Massachusetts. The process is applicable to all highway construction plans developed by MHD, consultants or municipal personnel and to all projects which are funded with federal, state and/or municipal funds.

Highway design can be a very complicated process with different projects requiring different combinations of personnel and skills. The design process outlined in this chapter has been condensed and simplified for the sake of presentation. The chapter begins by presenting a brief overview of the MHD highway design process. Second, each activity in this process is described with reference given to other sections of the manual for more in-depth discussion. The final section of this chapter provides copies of the 25%, 75%, and 100% highway design submission guidelines. Where applicable, other design publications and documents approved by the MHD for use in certain circumstances are identified.

1.2 STEPS IN THE HIGHWAY DESIGN PROCESS

The flow chart in Figure 1-1 shows the major steps in developing a project from planning to construction. These steps, sometimes referred to as the "project pipeline," describe the important activities that, in most cases, must occur. However, in some instances, projects do not have to follow each step.

As seen in the flow chart, the highway design process consists of four major steps: planning, project development and the 25% design phase; 75% design phase; and 100% design phase. Important characteristics of each step are:

Planning - The Department Bureau of Transportation Planning and Development (BTP&D) is responsible for coordinating all transportation planning activities in the Commonwealth. Important project needs are often identified in each of the planning regions which are then submitted to the Department for initiation. The Executive Office of Transportation and Construction is responsible for coordinating transportation policy of all state transportation agencies and in this role often initiates projects. Major sources of project ideas include MHD District Offices, state legislators, local officials and citizen groups.

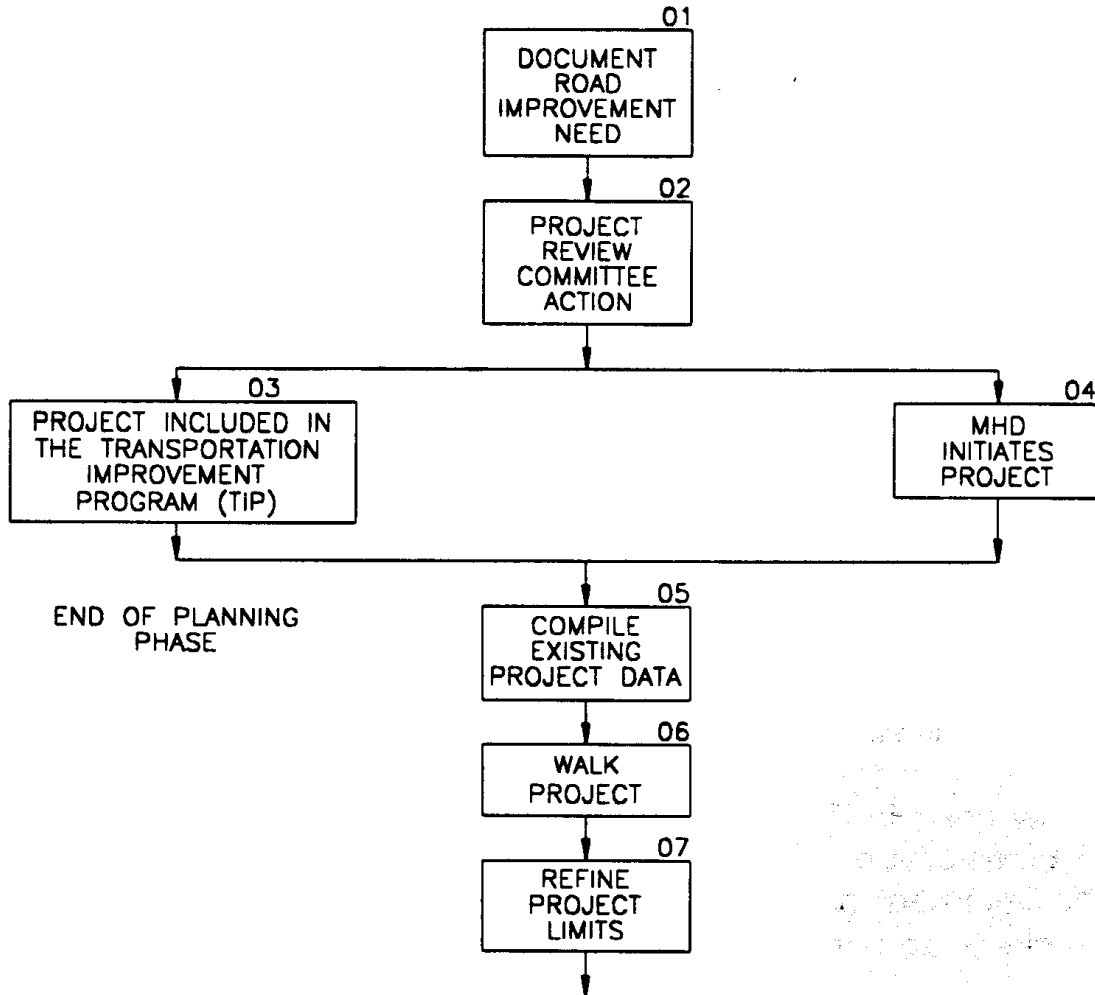


Figure 1-1. Highway Design Process

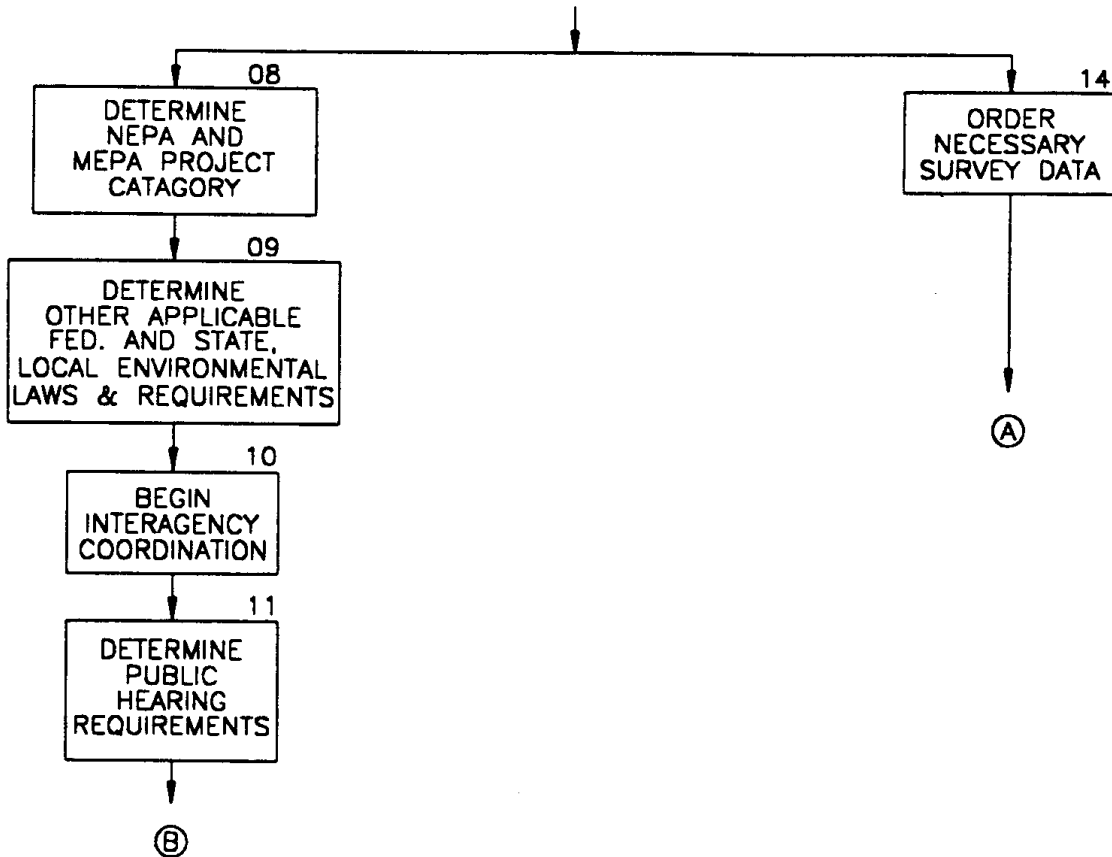


Figure 1-1 (Continued)

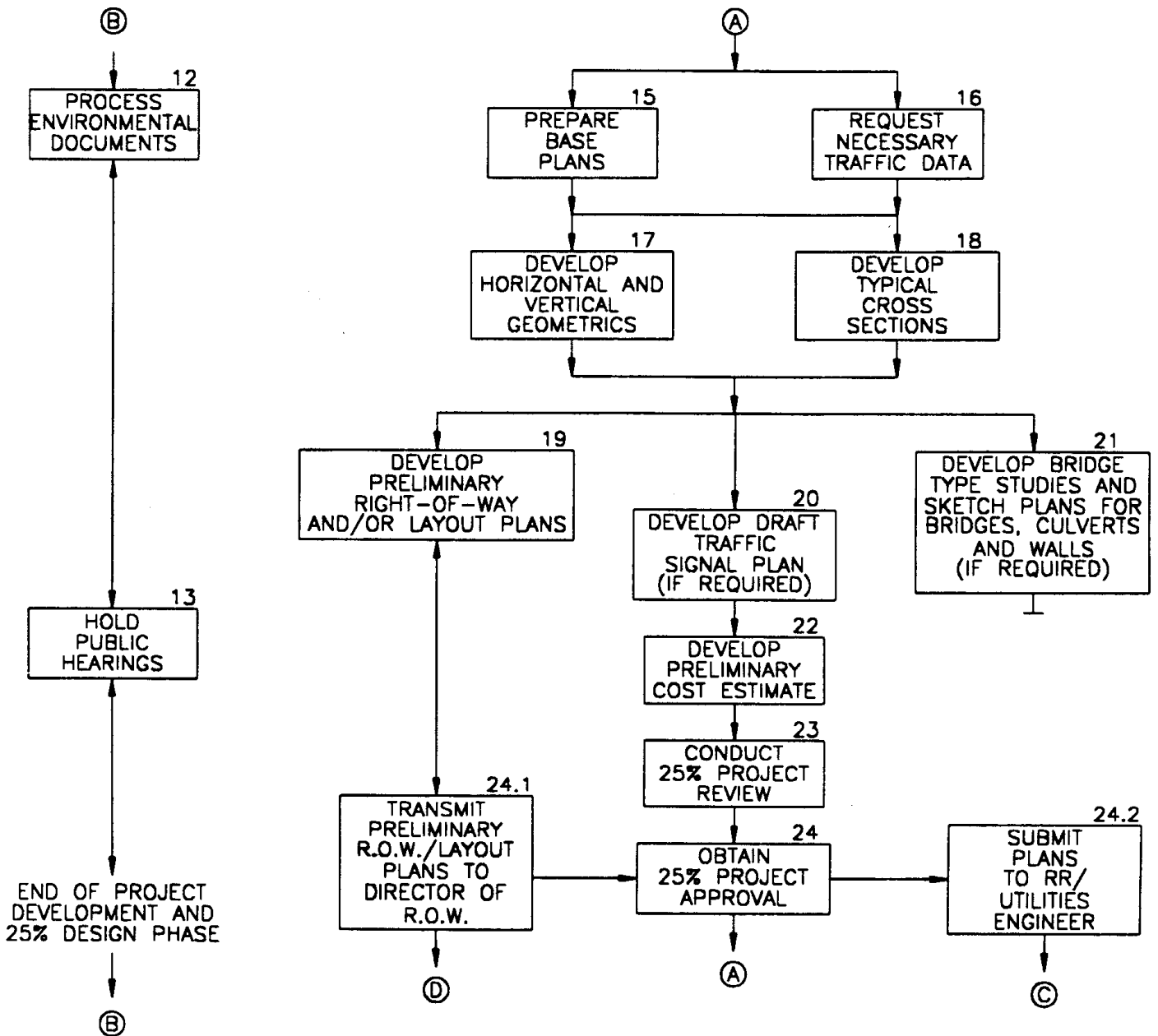


Figure 1-1. (Continued)

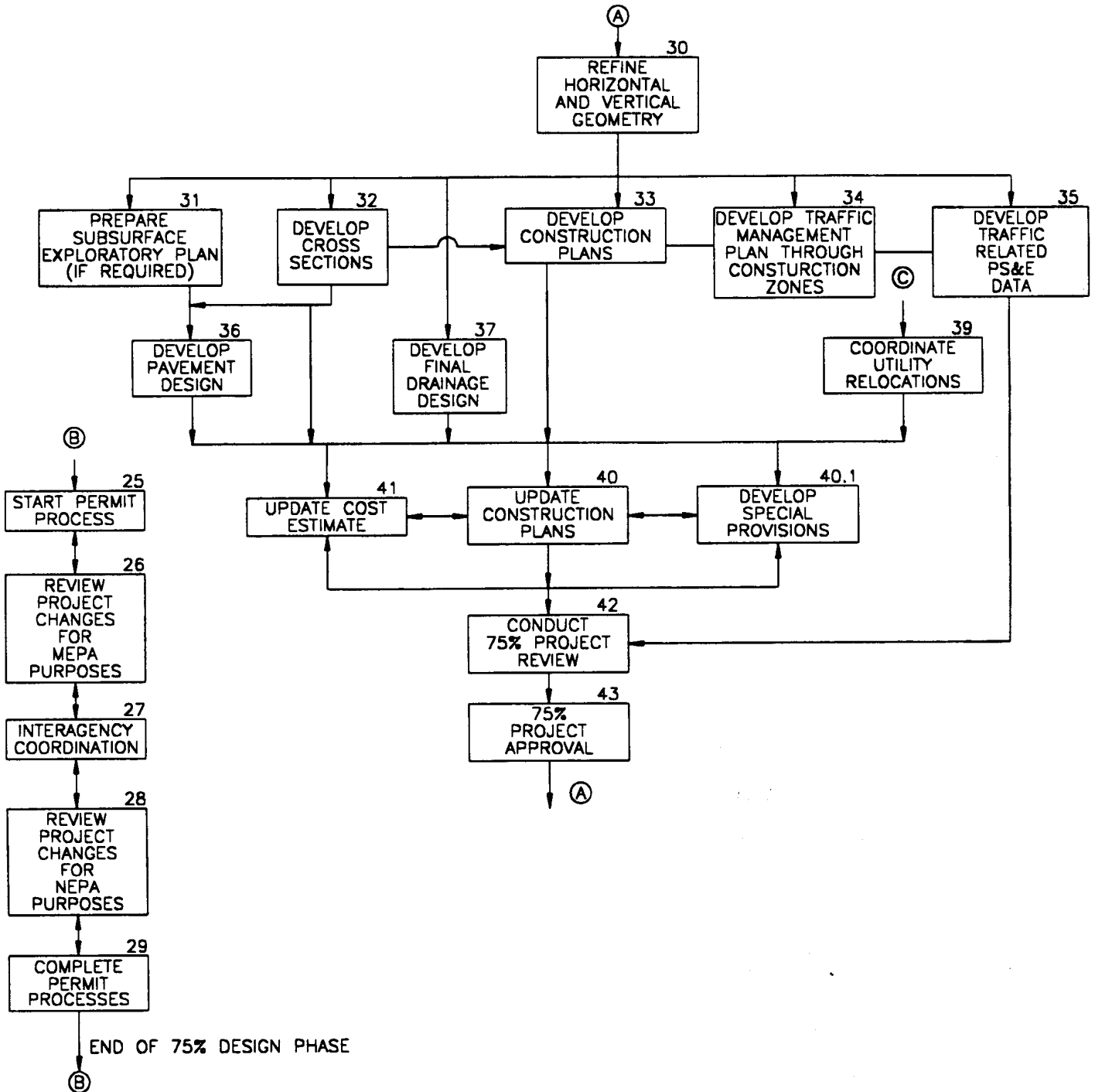


Figure 1-1. (Continued)

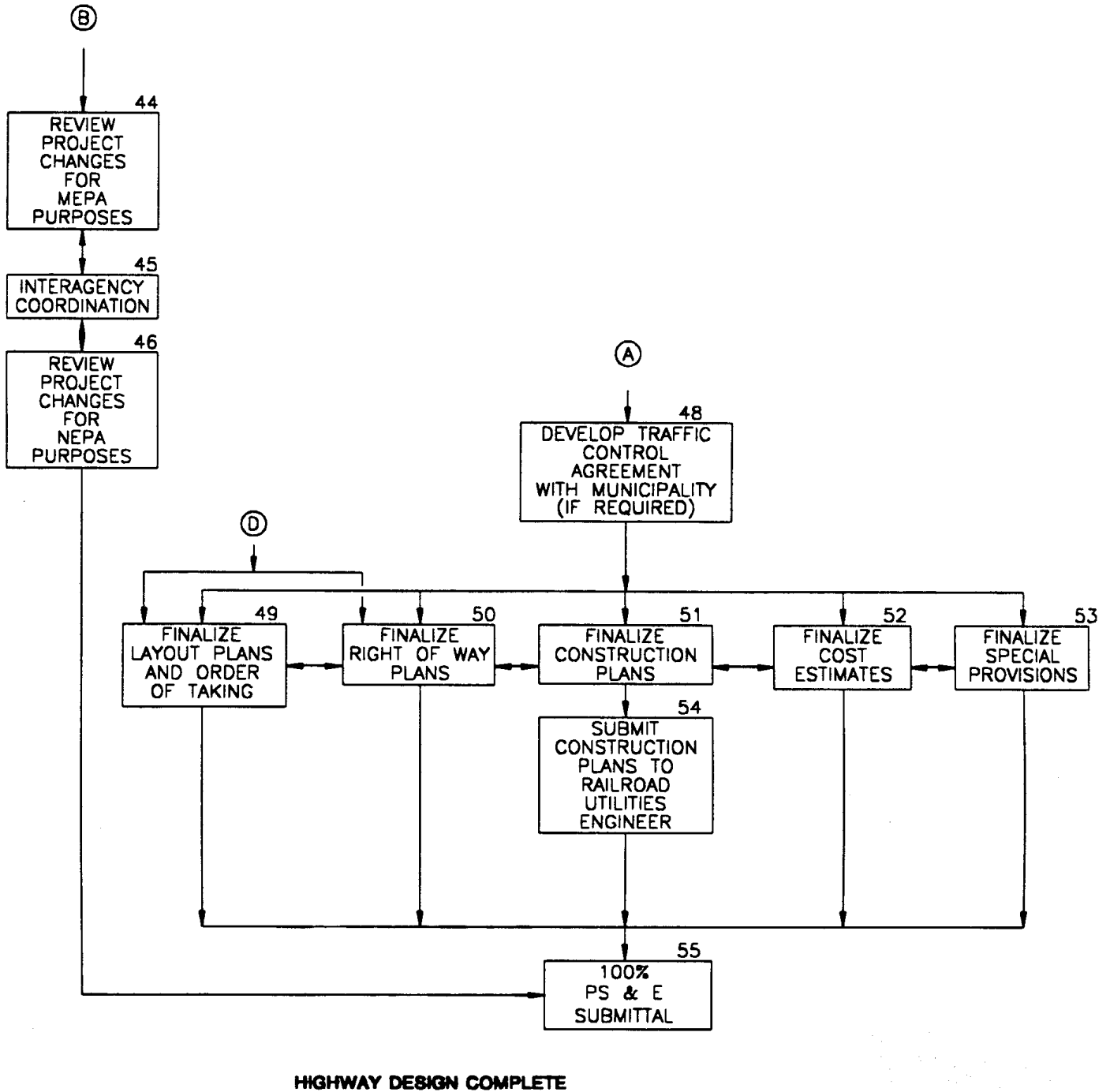


Figure 1-1. (Continued)

Project Development and Twenty-five Percent Design - The Project Development phase and 25% design phase provide basic information on design parameters, public concerns, and environmental impacts, all of which are important factors in completing highway design projects.

Seventy-five Percent Design - The 75% design phase uses the preliminary information provided from the 25% design phase and develops more detailed design plans and specifications relating to such principles as pavement and drainage design. In addition, all necessary permitting and clearances needed for constructing a project should commence during this phase.

One Hundred Percent Design - The 100% design phase consists of finalizing all construction-related documents associated with the project. These include right-of-way plans, construction plans, specifications, estimates, utility agreements, and traffic management plans.

Several characteristics of the project pipeline should be noted. First, the flow chart illustrates the general sequence of activities but does not necessarily show relative timing between activities. Activities may occur earlier than shown on the chart or occur concurrently.

Second, the flow chart also shows activity dependencies by arrows (i.e., before the designer can complete any activity, all activities which feed into the activity being considered must be completed). In general, activities should be developed as soon as possible.

Third, the flow chart has been developed based on the knowledge of experienced MHD engineers. This experience indicates that projects developed following the flow chart tend to have fewer problems. However, changing the sequence of activities may sometimes be necessary due to specific project circumstances. Good judgment must be used when making changes to the sequence of activities. However, the adjustment must be made within the constraints of the 25%, 75% and 100% stage approvals.

Finally, because the number of projects proposed often exceeds the ability of the MHD to produce design plans, decisions are often made during the design process to focus effort on some projects over others. These decisions are made at key points in the process and reflect the need of the Department to establish priorities and to balance funding availability.

The following sections provide more detail on the major activities in each step of the design process.

BOX 01 DOCUMENT ROAD IMPROVEMENT NEED

The Department prepares the necessary report and recommendations. This is usually done through the District Highway Director for most state highway improvements.

The District Office reviews the problem, and based on the reviews and discussions with local representatives, possible solutions are identified. The project proponent prepares a letter outlining the problem, preferred solution and community support. The letter is sent to the regional planning agency for its consideration and determination of the impact the project will have on regional planning objectives.

The District will meet with the municipality to discuss and review the project parameters, design criteria, the requirements for a Functional Design Report (Safety and Design Report) and the need for strong community support with the municipality. The District will also determine whether design waivers may be required, what environmental permits may be needed, and whether the project will require full size plans.

After determining the scope of the project, the District will then make a recommendation to the municipality on how to proceed. This may include a recommendation to use Chapter 90 funding rather than requesting other Department funds. The District may also recommend that an additional meeting be held to determine the degree of community support prior to formally requesting the project. After satisfactory completion of this review, the municipality will send a formal written request to the District and the RPA.

In addition to the local elected official, there are number of other officials who may request that the MHD undertake an improvement project. These include the Governor, Secretary of Transportation, Commissioner, Chief Engineer, Deputy Chief Engineers, Department Heads, regional planning agencies and elected officials such as State Senators and Representatives.

Based on the above input, the District Highway Director presents the proposed improvement for the consideration of the MHD Project Review Committee. The District will notify the PRC whether any design waivers may be required, the specific waiver(s) requested, and the magnitude of the deviation from the minimum standards. (See Box 02 on the flow chart.) In addition, the MHD District Office and/or municipality (for non-state highways) will select the project type. This may be:

1. *New Construction* - new horizontal and vertical alignment.
2. *Major Reconstruction* - addition of travel lanes and/or significant changes to the existing horizontal and vertical alignment, but essentially within the existing highway layout.

3. *Minor Reconstruction* - construction essentially on the existing highway alignment which includes improvements to highway geometrics (roadway widening, flattening horizontal curves, adjusting vertical profile intersection improvements etc.)
4. *Resurfacing, Restoration, or Rehabilitation* - reconstruction essentially on the existing highway alignment.
5. *Spot Safety Improvements* - correction of an identified safety hazard at an isolated location (intersection, horizontal curve, etc.). (See Section 9-1.02)

At this point, a draft description of all anticipated components of the project is prepared.

BOX 02 PROJECT REVIEW COMMITTEE ACTION

The Project Review Committee, which is composed of senior Department officials, considers requests for a capital improvement on a periodic basis. The Committee will also review the project scope of work recommendation. Their review is based on:

- Documented need
- Feasibility
- General availability of funding
- Local, regional, and state priorities
- Commitment of the local community
- Social, economic, and environmental effects
- A consistency with adjacent sections and the network

The findings of the Project Review Committee are transmitted to the appropriate Department or municipal official. If the findings are positive, the project is placed in the Future Element of the Transportation Improvement Program (TIP) at the request of the Department.

BOX 03 PROJECT INCLUDED IN THE TRANSPORTATION IMPROVEMENT PROGRAM (TIP)

There are 13 regional planning agencies in the Commonwealth most of which receive funds to conduct regional transportation improvement planning. For urban areas with a population of more than 50,000, the planning agency, the transit agency, the Department and EOTC are required to produce a Transportation Improvement Program (TIP).

The TIP is a regionally prioritized and approved listing of transportation projects proposed for implementation during the five upcoming fiscal years. It provides guidance for the Department in deciding which projects to develop. The TIP is composed of two distinct parts-the Annual Element (which covers projects proposed for the upcoming fiscal year) and the Future Element (which covers the following four fiscal years). Projects are listed by funding category, and priorities are established within each funding category.

All federally funded projects must be included in the Annual Element before receiving any funding. New projects are initially placed in the Future Elements and are advanced to the Annual Element only after the project has received the 25% design review approval.

BOX 04 MHD INITIATES PROJECT

The Director of the Capital Expenditure Program Office (CEPO), as Secretary of the Project Review Committee, issues an Engineering Work Order which authorizes work to begin on the project. The work order is issued concurrently with the letter of approval.

BOX 05 COMPILE EXISTING PROJECT DATA

The designed must first accumulate all available information concerning the project. The purpose is to assemble all project data into one location and to enable the design engineer to become familiar with the project requirements. The data should include, but not be limited to, the following:

- Letters and other correspondence concerning the project
- Ground and aerial surveys
- For anything other than new construction, existing as-built plans
- Accident data (past 3 or more years)

- Traffic data (current and future ADT, peak hours volumes, turning movements, truck percentage, etc.)
- Available documentation of any public meetings or hearings
- Utility location information
- Existing layout plans and Orders of Taking

BOX 06 WALK THE PROJECT

The designer must visit the location of proposed work to understand the specifics of preliminary engineering. It is best done by walking the job and noting important conditions and features which affect the design. No project should be designed without the designer visiting the site.

BOX 07 REFINE PROJECT LIMITS

The designer should review the proposed project limits. Based on what the designer has learned in the previous activity, logical project limits are established.

BOX 08 DETERMINE MEPA AND NEPA PROJECT CATEGORY

The designer, in coordination with the Environmental Division, will be responsible for determining the MEPA and NEPA project category. The designer should obtain or develop the necessary information to enable this determination to be made. The type of information needed is discussed with the MHD Environmental Division. All environmental review and permit submissions and coordination with the agencies shall be made through the MHD Environmental Division.

A determination should be made, in compliance with the MEPA regulations, whether the project: (1) does not trigger MEPA jurisdiction, (2) exceeds the ENF review thresholds, or (3) is a categorical inclusion and requires an EIR.

Some of the ENF review thresholds are based on the amount of wetland impact proposed. Therefore it is critical for the designer to know the exact number of hectares of wetland alteration at the time of the determination of MEPA project category. This information will help the designer to determine whether (a) a variance from the Wetland

Protection Act is needed or (b) a Superseding Order of Conditions is needed. If a variance or Superseding Order of Conditions is needed, then MEPA review is required

If it is determined that the project exceeds the MEPA review thresholds, the designer must prepare an Environmental Notification Form (ENF) and submit it to the Environmental Division for processing to EOE (MEPA Unit). After the consultation and scoping period EOE will determine whether an Environmental Impact Report (EIR) is required. If, prior to filing, it is determined that the project is a categorical inclusion, an ENF and an EIR is required. A decision will be made, at that time, if the designer or the Environmental Division will be responsible for the preparation of the ENF and EIR. Classification of a project in accordance with the MEPA review thresholds should be discussed with the MHD Environmental Division.

If the project involves federal funds or other federal action, a determination should also be made regarding compliance with NEPA. A determination should be made, in accordance with the lead federal agency regulations (in most cases, FHWA) whether the project: (1) is a categorical exclusion (CE) (Class II action) and does not require federal agency approval or documentation, (2) is a (CE) (Class II action) but requires additional documentation and FHWA approval, (3) requires preparation of an Environmental Assessment (EA) (Class III action) or (4) requires preparation of an EIS. As indicated in the "Begin Interagency Coordination Section", an agreement should be reached with the appropriate federal agencies on the NEPA project category. The MHD Environmental Division will facilitate such an agreement.

The designer will be responsible for the preparation of the necessary CE documentation. The details about CE documentation, EAs, EISs, and the NEPA process are discussed with the MHD Environmental Division.

BOX 09 DETERMINE OTHER APPLICABLE FEDERAL, STATE AND LOCAL ENVIRONMENTAL LAWS AND REQUIREMENTS

The designer, in coordination with the Environmental Division, will be responsible for identifying and complying with all other applicable federal, state and local environmental laws and requirements. A listing of the most common laws and requirements follows. The designer should consult with the Environmental Division to determine if other less common laws or requirements are applicable.

Federal Laws and Requirements

Section 4(f) of 1966 U.S. D.O.T. Act - FHWA (or other federal agency, as applicable) approval is needed for any Federal-aid (Department of Transportation only) highway project using land from a publicly-owned park, recreation area, historic property or wildlife and waterfowl refuge. A historic property may be a bridge structure, site, or district. An individual or programmatic Section 4(f) evaluation document must be prepared. There must also be coordination with the public official having jurisdiction over the Section 4(f) property. Additional details about Section 4(f) process are discussed with the MHD Environmental Division.

Section 404 of 1972 Clean Water Act (33USC1344) - A permit is required from the U.S. Army Corps of Engineers (ACOE) for highway projects involving discharge of dredged or fill material into waters of the United States. Jurisdiction under this law extends to all wetlands and waters of the United States. There are three classes of permits issued: Programmatic General Permit (PGP) Category I and Category II, and Individual Permit/Class III

A PGP II and an individual permit involves consultation by the ACOE with the other Federal Resource agencies including U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service. Other federal approvals such as a water quality certification and a coastal zone consistency statement (if applicable) is needed before the U.S. Corps of Engineers will issue the Section 404 permit.

Additional details about the Section 404 permit process should be discussed with the MHD Environmental Division.

Section 401 of 1972 Clean Water Act - A water quality certification is required from the Massachusetts Department of Environmental Protection (DEP) for any federal permit (e.g., Section 404 permit, Coast Guard Bridge Permit) to conduct an activity which may result in a discharge into waters of the United States. Additional details about the water quality certification process should be discussed with the MHD Environmental Division.

1972 Coastal Zone Management Act - A coastal zone consistency review and statement is required from the Massachusetts Coastal Zone Management (CZM) Office for Federal-aid highway projects or projects requiring other federal actions located within the designated coastal zone. This review is to ensure consistency with the state coastal zone policies. Additional details about CZM statement process should be discussed with the MHD Environmental Division.

Section 9 of River and Harbor Act of 1899 - A permit is required from the U.S. Coast Guard for certain highway projects involving bridges or causeways over tidal or otherwise navigable waters. Other federal approvals such as water quality certification and a coastal zone consistency statement (if applicable) are needed before the U.S. Coast Guard will issue the Bridge Permit. Projects which are funded by FHWA and are "replacement in kind" may be eligible for an exemption from a Coast Guard Permit. The Consultant should obtain data on boat length and size from the local harbormaster, and other knowledgeable agencies, and consult with the Environmental Division. Additional details about the Coast Guard Bridge Permit process should be discussed with the MHD Environmental Division.

Section 10 of River and Harbor Act 1899 - A permit is required from the U.S. Army Corps of Engineers for highway projects requiring construction in or over navigable waters, the excavation from, or dredging or disposal of materials in such waters, or any obstruction or alteration in a navigable water (e.g. stream channelization). Additional details about the Section 10 permit process should be discussed with the MHD Environmental Division.

Section 106 of the 1988 National Historic Preservation Act - Section 106 is a process involving FHWA, the Department, Massachusetts Historical Commission and the Advisory Council on Historic Preservation which must be followed for any Federal-aid highway project affecting bridges, districts, structures, or sites (including archaeological sites) potentially eligible, eligible, or on the National Register of Historic Places. Additional details about the Section 106 process should be discussed with the MHD Environmental Division.

State Laws and Requirements

Bridge projects which are funded by the State Transportation Bond, which are functionally equivalent and which are in a similar location are exempt from the WPA, Chapter 91, and MEPA. See the Environmental Division for a determination.

Massachusetts Wetland Protection Act (WPA) - This act applies to highway projects which remove, fill, dredge, or alter a resource area defined in the Wetland Regulations. Resource areas are defined as:

- (A) Bordering Vegetated Wetlands or salt marsh
- (B) Any bank, or any water body or waterway or a Coastal Bank
- (C) Land under any water body, waterway, the ocean or a salt pond
- (D) Riverfront Area - Extends 61 meters (7.6 meters in municipalities with large populations and in densely developed areas) on each side of perennial rivers or streams

- (E) Land subject to coastal storm flowage
- (F) Isolated or bordering land subject to flooding
- (G) Coastal Beaches and tidal flats
- (H) Coastal Dunes
- (I) Designated Port
- (J) Banks or land under a Fish Pier
- (K) Barrier Beaches
- (L) Land containing shellfish

A buffer zone is defined as land within 30.5 meters horizontally of any resource area listed in (A) above. If work is proposed within a resource area or a buffer zone, then a Request for a Determination of Applicability must be filed to determine if an Order of Conditions must be obtained from the local conservation commission.

Appeals of Conservation Commission Orders are made to DEP. DEP is also the authority to whom variance requests are made. Variances are required if the general performance standards of the WPA cannot be met, such as if 464.5 square meters or more of Bordering Vegetated Wetland is proposed for filling. Details regarding appeals or variances are discussed with the MHD Environmental Division.

Chapter 91 - A license is required from DEP for highway projects that do not qualify for the bridge exemption and which involve construction, dredging and filling performed in private and Commonwealth tidelands, as well as great ponds and certain rivers and streams. Additional details about the Chapter 91 process are discussed with the MHD Environmental Division.

Chapter 152 - A process involving the Massachusetts Historical Commission which must be followed for highway projects affecting bridges, districts, structures or sites (including archaeological sites) on the State Register of Historic Places. All properties eligible for or on the National Register of Historic Places are on the State Register. In most cases, the Section 106 process for a Federal-aid highway project will satisfy the requirements of the Chapter 152 process. Additional details about the Chapter 152 process are discussed with the MHD Environmental Division.

BOX 10 BEGIN INTERAGENCY COORDINATION

Project delays can be minimized by early and continuous coordination with Federal, state, and local agencies with jurisdiction by law or special expertise. Consult with the Environmental Section regarding this effort.

The early steps of the design phase offer a key opportunity to perform necessary interagency coordination with resource agencies to:

1. Reach agreement on the determination of NEPA project category
2. Perform field investigations
3. Use its technical expertise
4. Reach agreement on techniques used and level of detail necessary to analyze environmental impacts
5. Determine what issues and concerns are important
6. Discuss avoidance alternatives and minimization measures
7. Determine what appropriate mitigation measures should be evaluated
8. Determine the likelihood of obtaining any necessary permits

For projects involving Environmental Impact Statements, the appropriate time to initiate interagency coordination is during scoping. Scoping is the required process of determining the range of alternatives and impacts that will be considered in that document.

For other projects, a consultation meeting scheduled with EOE is a good time to begin interagency coordination.

All interagency coordination should be documented.

BOX 11 DETERMINE PUBLIC HEARING REQUIREMENTS

Public participation in the design process is an essential ingredient in all work of the Department. A public hearing, or opportunity for a public hearing, is required by FHWA for Federal-aid highway projects as part of a process that also encourages a variety of citizen

involvement techniques such as informal public meetings, briefings, and workshops. Public hearings are legally recognized formal meetings held at particular times during the project development and design phases. Public meetings, briefings or workshop are informal gatherings of Department officials, public officials, and local citizens to share and discuss proposed actions. These meetings provide an opportunity for public participation before final decisions are made. The frequency of public meetings is not predetermined and may be held at any time during the project development or design phases.

A notice for an Opportunity for a Public Hearing is required for any project that:

- Requires significant amounts of right-of-way
- Substantially changes the layout or functions of connecting roadways or of the facility being improved
- Has a substantial adverse impact on abutting property
- Has a significant Environmental, Social or Economic (ESE) or other effect
- Identification of significant ESE effects or design details not considered at earlier Public Hearings

A public hearing is held if sufficient interest is expressed in writing to the Department, or if the Department or the FHWA believes a public hearing is in the public interest.

An additional opportunity for a public hearing will be provided when there has been:

- A significant change in the proposed project
- Substantial unanticipated development in the project area
- An unusually long time lapse since the last public hearing

If a federal or state environmental document is required, the public hearing should not be held until the document is available for public review. The public would then have the opportunity to comment on the impacts of the project as well as the project design. Since it is not known whether a state Environmental Impact Report is required until after an Environmental Notification Form (ENF) has been processed, public hearings should not be scheduled until a decision is made by the Executive Office of Environmental Affairs on the ENF.

There are four types of public hearings - Location Public Hearing, Design Public Hearing, Location/Design Public Hearing, and Special Hearing.

Location Public Hearing - A Location Public Hearing signals a major decision point and is held after the environmental document is circulated, but before the MHD is committed to a specific alternative from among the reasonable and feasible alternatives under consideration, including the No-Build alternative.

A Location Public Hearing provides the public the opportunity to provide input into the determination of the need for, and the location of, a proposed project. It also serves as a means of summarizing any previous comments and concerns relative to the alternatives under consideration, and provides a formal review of the major points being addressed in the draft environmental document.

Design Public Hearing - A Design Public Hearing, is held around the 25% Project Approval Stage.

Combined Location/Design Hearing - In lieu of separate Location and Design Public Hearings, a Combined Location/Design Public Hearing may be held.

A Combined Hearing is usually approved when broad public participation is apparent throughout the history of the project, when public acceptance of the project is evident, or when there are no alternate locations proposed.

Special Hearings - Special Hearings may be conducted for proposed projects that are categorical exclusions and do not require a hearing, or when significant changes are contemplated for a project. A Special Hearing may be held for the purpose of responding to community sentiment, or to provide additional input to the decision-making process. Additional details about public hearing notices and public hearings are to be discussed with the MHD Environmental Division.

BOX 12 PROCESS ENVIRONMENTAL DOCUMENTS

In this step, the environmental documentation needed for the MEPA and NEPA processes is prepared and processed. The designer or the Environmental Division will be responsible for preparing and processing environmental documentation.

For the MEPA process, the environmental documentation may include (1) an Environmental Notification Form and (2) A Draft Environmental Impact Report and a Final Environmental Impact Report. For the NEPA Process, the environmental documentation may be (1) documentation for a categorical exclusion, or (2) an Environmental Assessment, or (3) a Draft Environmental Impact Statement and a Final Environmental Impact Statement.

The environmental documentation is determined as described in the Determine MEPA

and NEPA Project Category section. Additional details about the MEPA and NEPA processes are discussed within the MHD Environmental Division.

BOX 13 HOLD PUBLIC HEARINGS

The designer is responsible for preparing the Notice of Public Hearing. This notice is to appear in local papers at least fourteen days and again at seven days prior to the Public Hearing. Appropriate federal, state, and local officials and agencies should also be notified.

The notice should be succinct, and contain the date, time, and place of the hearing and a brief description of the project. It must also describe the procedure for submitting written statements. Additional details on the format of the Notice of Public Hearing should be discussed with the MHD Environmental Division.

The Public Hearing should be held at the most appropriate place and time available with convenience to the public being the prime consideration. The designer is responsible for arranging for the public hearing location, a stenographer, and any other necessary audio and visual equipment. The meeting must be accessible to and accommodate the needs of the handicapped.

Typical information prepared for a hearing includes: lane and shoulder width, typical sections, profiles, locations of major drainage structures, tops and bottoms of slopes, layout lines, and property owners' names.

All comments received must be addressed during the development of the project. All written comments must be responded to in writing.

BOX 14 ORDER NECESSARY SURVEY DATA

If existing survey data is not adequate to design the project, additional survey data must be requested. This data may be in the form of either an aerial or ground survey. When making the request to the Survey Section, provide as much specific project location data as possible. All survey work must be in accordance with the MHD Survey Manual.

BOX 15 *PREPARE BASE PLANS*

This activity includes checking field notes, establishing coordinates, determining the scale used in plotting, and plotting the survey on base plans, base profiles, and base (Original Ground) cross sections. Work involved in plotting includes computing and adjusting the baseline, traverses and levels. A further discussion of this work is in Section 2.1.1.

BOX 16 *REQUEST NECESSARY TRAFFIC DATA*

The designer must request traffic operational characteristics from the Bureau of Transportation Planning and Development. Both existing and projected traffic data is requested, such as ADT, peak-hour volumes, directional distribution, K factor, design-hour volumes (DHV), and percentage of trucks. For more details, refer to Section 3.5.

BOX 17 *DEVELOP HORIZONTAL AND VERTICAL GEOMETRICS*

The designer must develop the basic roadway horizontal and vertical geometry. All geometric data must be calculated at this stage (stations, bearings, distances, horizontal and vertical curve data, PCs, PTs, PVI, Kvalues, etc.). The design criteria are discussed in Chapter 4. If the Landscape Section of Highway Engineering has not been previously involved in the project, it should be consulted at this point to integrate roadside, urban design and scenic consideration into geometric design (horizontal, vertical, and cross sectional elements).

BOX 18 *DEVELOP TYPICAL CROSS SECTIONS*

Based on design requirements, typical cross sections are developed. Typical cross sections show design elements that will predominate throughout the project. For additional detail, refer to Section 2.1.1.4 and Chapter 5.

BOX 19 DEVELOP PRELIMINARY RIGHT-OF-WAY PLANS AND/OR LAYOUT PLANS

When land taking is involved, the designer must develop ROW and/or Layout plans showing existing and proposed layout (locations) lines, easement, property lines, corner markings, names of property owners, access points, and the location of bounds, as well as other surface details. The plans shall be updated upon 75% approval and submitted to the Director of the ROW Bureau.

When land takings are made by the Department, ROW plans are required. These plans contain sufficient dimensional and angular data to permit easy identification of all fee parcels and easement areas that are required on the project. Additional information can be found in Chapter 2 Sections 2.2, 2.3 and 2.4.

When land takings are made by a municipality, and construction is paid for with federal funds, the process should be followed in accordance with The Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1978 as amended. Certification of this layout procedure by the MHD Right of Way Bureau is required before federal funds are provided.

BOX 20 DEVELOP DRAFT TRAFFIC SIGNAL PLAN (If required)

Based on guidelines provided in the Manual on Uniform Traffic Control Devices, a Draft Traffic Signal Plan is developed. This plan shows the proposed placement of traffic control devices and is based on traffic counts, turning movements, warrants, and capacity analyses. This is in accordance with the "25% Submission Guideline."

BOX 21 DEVELOP BRIDGE TYPE STUDIES AND SKETCH PLANS FOR BRIDGES, CULVERTS, AND WALLS (If required)

Based on guidelines provided in the MHD Bridge Manual, bridge type studies must be developed for bridges, culverts and/or walls which are not included in the MHD Construction Standards. The Type Studies are a preliminary presentation of the overall concept of the proposed structure which shows all pertinent details for the preparation of sketch plans and contract plans. (See the MHD Bridge Manual.)

BOX 22 DEVELOP PRELIMINARY COST ESTIMATE

Prepare an estimate based on the latest project information. Refinements are to be expected as the design develops, but this estimate should reflect project costs as accurately as they can be defined at the 25% design stage. Chapter 13 contains useful estimating data.

BOX 23 CONDUCT 25% PROJECT REVIEW

Available layout and geometric data obtained in activities (05 through 22) are assembled for review. The materials are reviewed by FHWA, municipalities, and MHD design personnel as necessary. The review is conducted to identify problems and to ensure that the project is advancing properly. Comments resulting from the review must be addressed prior to proceeding with the Design Public Hearing.

BOX 24 OBTAIN 25% PROJECT APPROVAL

This is the first written approval in the highway design process by MHD and/or FHWA. The designer must receive the 25% project approval before proceeding with the project. (See "25% Submission Guidelines," Section 1.3.)

BOX 24.2 SUBMIT PLANS TO RAILROAD-UTILITIES ENGINEER

As soon as possible after 25% approval, the construction plans should be submitted to the Utilities & Railroad Engineer as indicated in the Submission Guidelines.

BOX 25 START PERMIT PROCESS

When used in this Design Manual, the term "Permit Process" refers to any process or regulatory program that involves obtaining a permit or some other type of sign-off from a federal, state, or local agency. The following are examples:

- Section 4(f) Approval

- Section 404 Permit
- Coast Guard Bridge Permit
- Section 10 Permit
- Section 106 Memorandum of Agreement
- Water Quality Certificate
- Coastal Zone Management Consistency Statement
- Wetlands Order of Conditions
- Chapter 91 License

Each permit process is unique and involves interagency coordination, information submission, possible special public hearings, and specific forms or applications. Additional details of the permit process are obtained from the MHD Environmental Division.

BOX 26 AND 44 REVIEW PROJECT CHANGES FOR MEPA PURPOSES

After the initial MEPA project category determination and MEPA processing, the designer, in coordination with the Environmental Division, will be responsible to periodically review changes to the highway project during the design phase to determine whether future MEPA review is needed. If there have been changes to the original project and the project was statutorily exempt or categorically excluded from the MEPA regulations then the designer must determine whether the changed project is still statutorily exempt or categorically excluded. If so, then no further MEPA review is necessary at that time. If the changes are such that the project now exceeds the review thresholds, or is now a categorical inclusion, then further MEPA review is necessary. The designer should refer to the *Determine MEPA and NEPA Project Category* and to the MHD Environmental Division and take the appropriate action.

If the original project exceeded the MEPA review thresholds or was a categorical inclusion and the project has changed, then the designer must prepare a Notice of Project Change and submit it to the Environmental Division for processing. Additional details about the Notice of Project Change are discussed with the MHD Environmental Division. Based on information in the Notice of Project Change, EOEPA will determine whether the change in the project or change in the ambient environment significantly increases the environmental

consequences of the project and warrants resubmission of an ENF, rescoping, supplementary documentation, or a further EIR.

There are cases where a project involving wetlands originally did not exceed the MEPA review thresholds for highway projects and wetland permits (i.e., it was a categorical exclusion) but now requires further MEPA review because the wetland permit threshold is exceeded. This can happen when (1) the information about wetlands at the time of the determination of MEPA project category was unknown or incorrect (see Determine MEPA and NEPA Determine Project Category Section) or (2) when the project changes and the wetland impacts change.

Also, even if no changes are made to a project that requires an EIR, further MEPA review may be necessary. If more than three years have elapsed between the filing of a Final ENF and the filing of a Final EIR, or if more than five years have elapsed between the filing of a Final EIR and a substantial commencement of the project, the designer, through the Environmental Division, must notify EOE. EOE will consult with the Department, agencies, and persons who previously participated in project review and will determine whether the lapse in time or change in the ambient environment significantly increases the environmental consequences of the project and warrants resubmission of an ENF, rescoping, supplementary documentation or further EIR.

The MEPA process can be time-consuming and result in design changes to the project. It is, therefore, critical that the designer perform this periodic review often, whenever a project change is contemplated. At a minimum, the designer should perform this review more often than just at the 25%, 75%, and 100% design phases.

BOX 27 AND 45 INTERAGENCY COORDINATION

Continuous interagency coordination is imperative throughout the design phase to address issues that may affect the processing of permit applications. These issues can be discussed and resolved before they cause a critical disagreement or time delays on a specific project. Follow-up contact with resource agencies will determine whether additional information on the project is needed.

This coordination may also prevent an environmental issue from being reopened at the time the permit is applied for, which may be years after this issue was presumed to have been resolved in an environmental document. If interagency coordination is performed properly there should be no surprises during the permit process.

BOX 28 AND 46 REVIEW PROJECT CHANGES FOR NEPA PURPOSES

After approval of the categorical exclusion determination, FONSI, or Final EIS, the designer, in consultation with the Environmental Division and FHWA, will be responsible for periodically reviewing the highway project during the design phase to determine whether or not the approved environmental document or categorical exclusion determination remains valid. The periodic review should be documented when determined necessary by FHWA. This review should occur at the same time as the review of project changes for MEPA purposes and also prior to requesting any major project approvals from FHWA (i.e., authority to undertake final design, authority to acquire a significant portion of the right-of-way, or approval of plans, specifications, and estimates). The specific requirements for projects involving EIS's are the following:

A. Draft EIS Re-evaluation

If an acceptable final EIS is not received by FHWA within 3 years from the date of the draft EIS circulation, then a written evaluation is required to determine whether there have been changes in the project or its findings or new information which would require a supplement to the draft EIS or new information which would require a supplement to the draft EIS. The written evaluation should be prepared by the designer, in consultation with the Environmental Division and FHWA, and should address all current environmental requirements. The entire project should be revisited to assess any changes that have occurred and the effect on the adequacy of the draft EIS.

There is no required format for the written evaluation. It should focus on the changes in the project, its surroundings and impacts, and any new issues identified since the draft EIS. Field reviews, additional studies (as necessary), and coordination (as appropriate) with other agencies should be undertaken and the results included in the written evaluation. If, after reviewing the written evaluation, the FHWA concludes that a supplemental EIS or a new draft EIS is not required, the decisions should be appropriately documented. Since the next major step in the project development process is the preparation of a final EIS, the final EIS may document the decision.

B. Final EIS Re-evaluation

There are two types of re-evaluations required for a final EIS: consultation and written evaluation. For the first, consultation, the final EIS is reevaluated prior to proceeding with major project approval. The level of analysis and re-documentation, if any, should be agreed upon by the FHWA and the Department. The analysis and documentation should focus on and be commensurate with the changes in the project and its surroundings, potential for controversy, and length of time since the last environmental action. For example, when the

consultation occurs shortly after final EIS approval, an analysis should not be necessary. However, when it occurs nearly 3 years after final EIS approval, but before a written evaluation is required, the level of analysis should be similar to what normally would be undertaken for a written evaluation.

Although written documentation is left to the discretion of FHWA, it is suggested that each consultation be appropriately documented in order to have a record to show that the requirement was met.

The second type of re-evaluation is a written evaluation. It is required if major steps to advance the project have not been taken within any 3-year time period after approval of the final EIS, the final supplemental EIS, or the last major FHWA approval action. The written approval should be prepared by the designer in consultation with the Environmental Division and FHWA and should address all current environmental requirements. The entire project should be revisited to assess any changes that have occurred and the effect on the adequacy of the Final EIS.

There is no required format for the written evaluation. It should focus on the changes in the project, its surroundings and impacts and any new issues identified since the final EIS was approved. Field reviews, additional environmental studies (as necessary), and coordination with other agencies should be undertaken (as appropriate to address any new impacts or issues) and the results included in the written evaluation. If FHWA determines that a supplemental EIS is not needed, the project files should be documented appropriately. In those rare cases where an EA is prepared to serve as the written evaluation, the files should clearly document whether new significant impacts were identified during the re-evaluation process.

Additional details about written re-evaluations are discussed with the MHD Environmental Division.

BOX 29 COMPLETE PERMIT PROCESSES

The designer completes and submits all necessary forms or applications to the appropriate agencies for the required permits.

BOX 30 REFINE HORIZONTAL AND VERTICAL GEOMETRY

See Box 17 for a discussion of the requirements.

BOX 31 *PREPARE SUBSURFACE EXPLORATORY PLAN (If required)*

After the alignment, profile, location, and type of structures has been defined and approved (25% approval), a subsurface exploratory program is developed for the required design. Before developing the program, the designer should contact the Soils Unit of the Research and Materials Section to discuss the proposed program of investigations. Plans for the program are then developed and submitted to the Research and Materials Section for review and/or implementation. Information required to implement a subsurface exploratory program includes:

- Boring locations plotted on plans, including a schedule showing station, offset, highest bottom elevation, and a column for remarks and boring notes. Borings for proposed structures should also be plotted, including the footing outlines.
- The District Offices shall be furnished a list of all property owners with their mailing addresses so they can be notified.
- A list of all the utilities within the project limits (as well as the name, address, and telephone number of the appropriate utility or public official to contact) shall be made available to the Research and Materials Section to include in the special provisions of the boring contract.

For additional details, the designer is referred to the *MHD Materials Manual* and *MHD Bridge Manual*.

BOX 32 *DEVELOP CROSS SECTIONS*

The proposed roadway cross sections, based on the horizontal and vertical geometry, and the typical sections, are drawn on the base (original ground) cross sections. These cross sections are included as part of the contract documents. For additional details, see Section 2.1.2.4 and Chapter 5.

BOX 33 *DEVELOP CONSTRUCTION PLANS*

The horizontal and vertical geometry, including the location lines, developed in the preceding activities are developed as "cut sheets". The tracings include all drawings and data necessary for construction of the proposed project. See Chapter 2 for details.

BOX 34 DEVELOP TRAFFIC MANAGEMENT PLAN (TMP) THROUGH CONSTRUCTION ZONES

A Traffic Management Plan is required for any project which disrupts existing traffic movements during construction. If a project is on a local road or uses a local road for a detour, the municipality must review and approve the TMP. The MHD Traffic Engineer or District Highway Director reviews and approves TMP's as appropriate. Section 9.9 discusses traffic control through construction zones.

BOX 35 DEVELOP TRAFFIC-RELATED PS&E DATA

For projects involving lighting, traffic signals, signs, pavement markings, and traffic controls for construction operations, plans, special provisions and estimates are submitted to the Traffic Engineer for review and approval.

BOX 36 DEVELOP PAVEMENT DESIGN

The designer will conduct the pavement design analysis. All pavement designs will be reviewed and approved by the Department Pavement Design Engineer. The design must conform to approved Department methods and must include the documentation of all background data as detailed in Chapter 11.

BOX 37 DEVELOP FINAL DRAINAGE DESIGN

The designer is responsible for developing a comprehensive drainage plan that will adequately drain the roadway. In addition, the drainage plan must also protect the adjacent landowners and wetlands and public water supplies, from drainage related problems. The designer determines the sizes, types, locations, and construction details for each drainage appurtenance based on hydraulic calculations and environmental considerations. When a bridge or major culvert is involved, the Hydraulics Section, the Bridge Section and Environmental Division should be consulted. Chapter 10 discusses drainage design.

BOX 39 COORDINATE UTILITY RELOCATIONS

Although the Utilities and Railroad Engineer provides direct Department contact with the utilities, the designer may be involved in the process to ensure that the relocations are appropriate. The designer's level of effort for this activity varies with the project, the utility involved, and the type of relocation. In addition, the designer may also be involved in coordinating Force Account and Betterment Agreements. Utility pole relocations for safety benefits are discussed in Section 9.2.2 and Utility Force Accounts are discussed in Section 13.1.3.

BOX 40 UPDATE CONSTRUCTION PLANS

In addition to all of the known existing details, the plans should include the following proposed details.

- road surface
- roadway width
- centerline
- drives and walks
- traffic control devices
- edging, curbing, and berms
- drainage appurtenances
- ditches
- bicycle accommodations
- sub-drains
- water supply
- guardrail
- demolitions
- bridges
- slopes
- fences
- wheel chair ramps
- pedestrian access

Section 2.1.2 discusses the content of the construction plans.

BOX 40.1 DEVELOP SPECIAL PROVISIONS

The designer develops special provisions for the project. Special provisions are used to explain conditions or special construction practices not covered in the current edition of the Massachusetts Standard Specifications for Highways and Bridges or Supplemental Specifications to the Standard Specifications for Highways and Bridges. In the preparation of special provisions, refer to Standard Nomenclature and Designation of Items. A draft copy of the special provisions must be provided at the 75% submission.

Special provisions will include but not be limited to:

- Scope of Work
- Provisions for Travel and Prosecution of Work
- Work schedule
- List of Utility owners (with name and address, of contact person)
- List of Items which have material options
- Special Precautions (other facilities such as structural foundations, ponds, streams, etc.)
- Individual contract items not covered in Standard Specifications, or if deviations to the Standard Specifications are made. The MHD Standard Nomenclature booklet identifies those items specifically requiring a Special Provision
- Copies of Permits, Licenses, Certificates, or Orders of Conditions (when available)
- Scheduling requirements (milestones, completion dates)

The Specification Section will provide standard inserts ("boiler-plate") into the special provisions booklet.

BOX 41 UPDATE COST ESTIMATE

Definitive costs for some items previously uncertain (because they depend on design features impossible to specify earlier) can now be calculated. All costs should be consolidated so that the 75% estimate reflect total costs as accurately as the latest project data will allow.

BOX 42 CONDUCT 75% PROJECT REVIEW

All materials developed for the project are reviewed at this time. The materials are reviewed by FHWA, various MHD sections, and municipalities, when applicable.

BOX 43 75% PROJECT APPROVAL

The 75% approval is granted when the plans are approximately 90% complete, and all the steps between the 25% and 75% stages in the Submission Guidelines have been properly

addressed. After 75% approval, the designer can proceed with the preparation of the 100% PS&E for the project.

BOX 48 DEVELOP TRAFFIC CONTROL AGREEMENT WITH MUNICIPALITY (If required)

A Traffic Control Agreement is prepared for city or town roads, if necessary. It is not required for state highway projects or non-Federal-aid projects. The agreement will define the permanent traffic control, regulations, and devices needed to ensure the system will be operated and maintained as designed. The agreement will be signed by the highest elected local authority, by the Town or City Council, by the municipal legal counsel, and by the Department. Copies are distributed to the FHWA, City/Town, Department Secretary, Traffic Section, and the District Highway Director.

BOX 49 FINALIZE LAYOUT PLANS AND ORDER OF TAKING

As soon as feasible after the 75% project approval, Layout Plans and the Order of Taking are finalized by the designer. This involves checking the plans for completeness and preparing the Order of Taking. Layout Plans are discussed in Section 2.3.

BOX 50 FINALIZE RIGHT OF WAY PLANS

As early as possible, the designer finalizes the Right of Way plans. This involves updating and checking the plans for completeness. Right of Way plans are discussed in Section 2.4.

BOX 51 FINALIZE CONSTRUCTION PLANS

Construction plans are finalized and assembled during this activity. A complete set of construction plans includes.

- Title Sheet
- Index Sheet

- Key Plan
- Boring Logs
- Typical Sections
- Plans of Main and Side Roads
- Profiles of Main and Side Roads
- Ramp Profiles
- Grading and Tie Plans
- Drainage and/or Water Supply Details
- Special Construction Details
- Sign Plans
- Traffic and/or Lighting Plans
- Landscaping Plans and Details
- Special Details (e.g., pedestrian amenities)
- Utility Details
- Bridge Plans
- Cross Sections

Final construction plans are further discussed in Section 2.1.2.

BOX 52 FINALIZE COST ESTIMATES

Project quantity estimates are prepared using the computer. Based on a list of items compiled for the project, designer use the computer to produce a work sheet. Using this work sheet, the designer enters the quantities and unit prices and the computer produces cost estimates. The designer prepares the cost summary sheet. Chapter 13 describes MHD estimating procedures.

BOX 54 SUBMIT CONSTRUCTION PLANS TO UTILITIES & RAILROAD ENGINEER

The completed construction plans are transmitted to the Utilities & Railroad Engineer for distribution to the affected utilities. All betterments and special utility considerations are noted. For additional information, refer to the MHD *Utility Accommodations Policy* and the Submission Guidelines hereinafter included.

BOX 55 100% PLANS, SPECIFICATIONS AND ESTIMATE (100% PS&E) SUBMITTAL

The designer completes the project, checking to ensure that all information necessary to construct the project is complete and is in the proper format. All items in the 100% Submission Guidelines must be submitted at this time. Necessary copies are made and the plan is sent to the appropriate section manager for final processing.

The section manager must ensure that the following has been addressed:

- Project Funding
- Plan Set Finalization
- ROW Certificates
- Applicable Permits
- Special Provisions
- Estimate
- Required Local, State, and Federal Agency Approvals

The specifications and estimate are then forwarded to the Capitol Expenditure Program Office (CEPO) for processing and then to the Specifications Section for construction advertising. The plans are delivered to the Blueprint Room for printing after the project is advertised.

1.3 SUBMISSION GUIDELINES - 25% DESIGN PHASE

1. Preparation of a complete base plan from the survey data.
2. Computed Geometrics - Horizontal and vertical alignment data including layout lines, centerline stations, bearings, curve data, PCs, PTs, PIs, PVIs, K values, etc. Include traffic data, for lane requirements and shoulder widths.
3. Address cross culvert needs and pavement drainage discharge locations.
4. Typical cross sections of proposed road.
5. Cross sections showing the proposed top lines at critical areas.
6. Urban, landscape and visual sketch plans.

7. Traffic Control
 - a. *Traffic Counts*- all approaches and movements; manual counts, minimum of 8 hours, including A.M. and P.M. peak hours, and automatic traffic recorder (ATR) counts for a minimum of 48 hours.
 - b. *Safety Analysis* - review of accident history (latest 3 years) with documentation of trends, probable causes, geometric shortfalls, and potential remedial action as appropriate. Stopping sight distances should be reviewed when applicable.
 - 1) Accident Rates
 - a. Roadway Segments (HMVM)
 - b. Intersections (MEV)
 - 2) Collision Diagrams (if appropriate)
 - c. *Warrant Analysis* - specific data on all warrants for signal installation satisfied (or for intersection reconstruction, if signals remain warranted).
 - d. *Capacity Analysis* - all approaches, including a determination of level of service and 95th percentile queue lengths.
 - 1) Existing Traffic Volumes
 - a. Existing Geometry
 - b. Proposed Geometry
 - 2) Projected Traffic Volumes
 - a. Existing Geometry
 - b. Proposed Geometry
 - 3) Systems Analysis (for closely-spaced and/or coordinated signals)
 - a. Arterial Analysis
 - b. Network Analysis
 - e. *Basic Signal Strategy* - including signal housing locations, pavement markings, and proposed phasing.
8. Bridge Type Studies and Sketch Plans of bridges or major culverts showing plans, elevation views, profiles, cross sections, hydraulic details, and major structural details as described in the Department Bridge Manual.
9. Functional Design Report - A report documenting the justification for the proposed design should be submitted for all Transportation or Safety Improvement Projects, particularly if standards other than what is documented in AASHTO are used, or if the project is not "typical".
10. Design Waiver documentation if required.
11. Assemble all public participation documentation.
12. A preliminary cost estimate must be submitted at this stage.

13. Provide the necessary plans and above noted data to be distributed for review.

1.4 SUBMISSION GUIDELINES-75% DESIGN PHASE

1. Plans should be approximately 90% complete.
2. Draft specifications for all non-standard contract items.
3. Traffic control signals, pavement markings and signs.
 - a. *Complete Signal Strategy Plans*-including signal equipment location, pertinent signaling and pavement markings (stop bars), sequence and timing chart, phasing diagram, and a list of major items required.
 - b. *Signal Timing Calculations*-including calculation of cycle lengths, green times, and offsets.
 - c. *Time-Space Diagram*-for all interconnected signals.
 - d. Plans for signs and pavement markings.
 - e. *Special Provisions*-for signals, signs and pavement markings.
 - f. *Estimates*-for signals, signs and pavement markings.
 - g. Preliminary Traffic Management Plan.
 - h. Draft of Traffic Control Agreements.
4. Cross sections with proposed roadway, (if requested.)
5. Plans and data for all permits, licenses, certificates, or Orders of Conditions.
6. Design plans for bridges or major culverts based on sketch plans approved by the MHD Bridge Engineer.
7. Material to be submitted to the Utilities & Railroad Engineer.
 - a. Two sets of prints of the 75% review plans for each privately and municipally-owned company.

- b. One copy of the utility check list with names, addresses, telephone numbers, and the person to be contacted in each utility company. Fire Alarm and Police Signals are also considered utilities.
 - c. Copies of any letter or communications between the utility companies and the District Highway Director, Boston Office, or consultant.
8. Define areas of non-participating work, if any.
9. Updated preliminary cost estimates, including quantities and prices for contract items.
10. Documentation of various approvals received and pending.
11. Update all commitments made during public participatory process.
12. A written resolution to all previous comments (including 25% reviews) must be submitted.

1.5 SUBMISSION GUIDELINES-100% PS&E SUBMITTAL-100% DESIGN PHASE

1. Mylar Construction Plans along with CAD.DXF data files - see Chapter 2.
2. Cross Sections along with CAD.DXF data files - see Chapter 2.
3. Special Provisions along with word processor data files
4. Preliminary Estimates - Include standard forms and computer printouts with unit prices (see Chapter 13).
5. Preliminary Estimate of Quantity Detail Sheets - Include standard forms and computer printouts without unit prices (*see Chapter 13*) Including Utility Force Account Estimates.
6. Quantity Sheets - *see Chapter 13 including summary.*
7. Office Calculation Books - with calculations of quantities for the various items required to construct the project, including index, earthwork summaries, drainage summaries, etc.

8. Final Traffic Control Agreement submitted to the Department.
9. Copies of Permits, Licenses, certificates, or Orders of Conditions must be included in the Special Provisions.
10. Copy of the Right of Way Certificate.
11. Request for project funding.

CHAPTER 2

PREPARATION OF PLANS

2.1 CONSTRUCTION PLANS

2.1.1 Base Plans

Base plans show all man-made and natural features located within the proposed project limits. Examples of such details as they would be shown on a plan are indicated in Table 2.1. Base plans also show state, county, city, and town layouts, city/town lines, property lines, owners' names, deed references, and land court numbers. In addition to the plan symbols in Table 2.1, base plans also use numerous abbreviations to convey information. Table 2.2 lists some of the most commonly used abbreviations. Figure 2-1 shows an example base plan with symbols and abbreviations.

2.1.1.1 Survey Data

The MHD Survey Manual provides the Department's criteria and procedures for highway location and survey work, including the requirements for aerial photography, photogrammetry, and geodetic surveys. Following are the basic responsibilities of the design engineer related to surveying: Note that the following is based on "conventional" survey collection methods. When survey is collected with computerized "Total Station" survey equipment, the designer will be furnished digital base plan information for use in CADD systems. The designer should consult with the MHD Survey Section for more information.

1. *Field Notes* - After the field survey is completed, the designer will compute and plot the alignment data, details, bench level notes, and cross section notes. The designer will adjust all baseline data, traverses, and levels by the Department method and to the allowable limits of closure. The designer can use the method of weighted least squares, the compass rule, or the transit rule. However, the method of weighted least squares is the preferred method. All computations for baselines and traverses will be programmed for computer processing. All field notes should be checked. Any discrepancies which cannot be readily adjusted should be checked in the field. All survey books must have a plan number, date plotted, and the initials of the plotter. The initials are noted on a stamp on each page in the survey book.

**Table 2.1
PLAN SYMBOLS**

Roadway edges dash 6 mm long	
Cement concrete walks and drives, solid line	
Walks and drives (bituminous concrete, gravel, dirt, etc.)	
Dash line 3 mm long	
Paved gutter	
Curbing, edging double solid line	
Wood guard rail steel beam guard, wood or steel posts	
Cable guard rail, triangular concrete posts	
Cable guard rail, steel posts	
Concrete guard posts	
Balanced stone wall	
Retaining wall	
Double faced wall	
Pointed wall	
Railroad or street railway tracks	
Fence	
Barbed wire fence	

Note: All symbols noted apply to existing details. They are similarly shown on base plans and construction tracings in black ink, unless otherwise noted.

Table 2.1 (Continued)

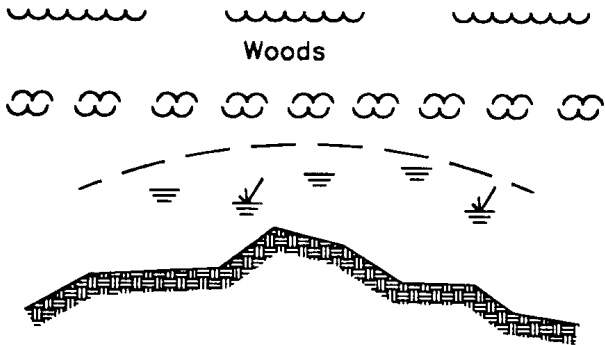
<p>Woods or Brush</p> <p>Hedge</p> <p>Swamp</p> <p>Rock</p> <p>Utility pole: telephone, power</p> <p>Guy pole</p> <p>Light pole</p> <p>Trolley pole</p> <p>Trees</p> <p>Property line, pencil if approx.</p> <p>State boundary line</p> <p>County Commissioner's line (layout)</p> <p>City or town layout line</p> <p>railroad sideline</p> <p>City, town, or county boundary line</p> <p>State hwy. layout line: on mylar roll on construction plan</p> <p>Stone bound</p> <p>Mass. highway bound</p> <p>County bound</p> <p>Town or city bound</p> <p>Mass. triangulation station</p>	<div style="text-align: center;">  <p style="text-align: center;">Woods</p> </div> <p>No. of pole & Type of Utility</p> <p>○ (500 mm diameter)</p> <p>Guy ○ (500 mm diameter)</p> <p>⊙ (500 mm diameter)</p> <p>○ (500 mm diameter)</p> <p>Diameter & Type</p> <p>● (to Scale)</p> <p>Mark Approx: If <u>Approximate</u> _____</p> <p>Name of State _____</p> <p>Name of State _____</p> <p>Co. Comm., <u>City</u>, <u>Town</u>, or <u>R.R. Layout</u> _____</p> <p>(Date)</p> <p>Name of <u>Town</u>, <u>City</u>, or <u>County</u> (Date) _____</p> <p>Name of <u>Town</u>, <u>City</u>, or <u>County</u> (Date) _____</p> <p>(Date) (Alteration etc.) _____</p> <p>(Date) (State Highway Layout) _____</p> <p>SB</p> <p>□ (500 mm Square) Type of Material</p> <p>MHB</p> <p>■ (500 mm Square) Type of Material</p> <p>Co. Bd.</p> <p>□ (500 mm Square) Type of Material</p> <p>Town or City Bd.</p> <p>■ (500 mm Square) Type of Material</p> <p>Number</p> <p>△ (Each Leg 500 mm)</p>
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Table 2.1 (Continued)

<p>Buildings, houses, etc.</p> <p>Drainage pipe</p> <p>Concrete box culvert</p> <p>Underground Utilities Black on prel. and const. plans</p> <p>Catch basin & curb inlet</p> <p>Manhole Label type, i.e. sewer, drainage, etc.</p> <p>Water gate</p> <p>Hydrant</p> <p>Gas gate</p> <p>Catch basin</p> <p>Drop inlet</p> <p>Concrete headwall (end) for culverts</p> <p>Stone headwall (end) for culverts</p> <p>Wheelchair ramp</p>	<div style="text-align: center;"> </div> <p>Size & Type of Material _____</p> <p>Width, Height Conc. Box Culvert _____</p> <p>Name of Utility (Tel. & Tel. etc.) _____</p> <p>CBCI (500 mm Each Side)</p> <p>MH (500 mm Diameter)</p> <p>WG (250 mm Diameter)</p> <p>Hyd. (500 mm Diameter)</p> <p>GG (250 mm Diameter)</p> <p>CB (500 mm Each Side)</p> <p>DI (Rectangle 1000 mm x 500 mm)</p> <p>Conc. Hdr 250 mm x Actual Length</p> <p>Stone Hdr. _____</p> <p></p>
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**Table 2.2
ABBREVIATIONS**

<p>AACT Annual Average Daily Traffic</p> <p>Aban. Abandon</p> <p>A.C. Asphalt Concrete</p> <p>A.C.C.M. Pipe</p> <p>Appr. Approach</p> <p>BD. Bound</p> <p>Bit. Conc. Bituminous Concrete</p> <p>⊕ Baseline</p> <p>Bldg. Building</p> <p>B.M.A. Bench Mark</p> <p>B.M. Bench Mark</p> <p>B.D. By Others</p> <p>Br. Bridge</p> <p>C.B. Catch Basin</p> <p>C.B.C.I. Catch Basin With Curb Inlet</p> <p>C.C. Cement Concrete</p> <p>C.C.M. Cement Concrete Masonry</p> <p>CEM. Cement</p> <p>C.I. Curb Inlet</p> <p>C.I.P. Cast Iron Pipe</p> <p>Cl. Class (Concrete, Excavation, etc.)</p> <p>⊖ Center Line</p> <p>⊕ Centerline of Construction</p> <p>C.M.P. Corrugated Metal Pipe</p> <p>C.S.P. Corrugated Steel Pipe</p> <p>Co. Bd. County Bound</p> <p>Conc. Concrete</p> <p>Const. Construct(ion)</p> <p>Cr. Gr. Crown Grade</p> <p>Culv. Culvert</p> <p>CM Cubic Meter</p> <p>D Delta Angle (Central Angle of Horiz. Curve)</p> <p>Δ Directional Percentage of DHV (Title Sheet)</p> <p>D.A. Drainage Area</p> <p>DHV Design Hourly Volume</p> <p>D.I. Drop Inlet</p> <p>D.I.P. Ductile Iron Pipe</p> <p>Dr. Drive</p> <p>E External</p> <p>E. Bd. East Bound</p> <p>Elev. (or El) Elevation</p> <p>Emb. Embankment</p> <p>Ent. Entrance</p> <p>Exc. Excavation</p>	<p>Exist. (or Ex.)</p> <p>F.A.S. Federal-Aid Secondary</p> <p>F.L.(or F) Flow Line</p> <p>Fldstn. Fieldstone</p> <p>Gar. Garage</p> <p>Gd. Ground</p> <p>G.C. Gas Gate</p> <p>G.I. Gutter Inlet</p> <p>G.I.P. Galvanized Iron Pipe</p> <p>Grav. Gravel</p> <p>Gran. Granite</p> <p>Grd. Guard</p> <p>Hd.w. Headwall</p> <p>H.I. Height of Instrument</p> <p>Ho. House</p> <p>Hor. Horizontal</p> <p>Hyd. Hydrant</p> <p>I.T. Intersection of Slopes or Profile Grade Lines</p> <p>Jct. Junction of Curve</p> <p>L Leaching Basin</p> <p>L.B. Light Pole</p> <p>L.P. Left</p> <p>Li. Mail Box</p> <p>M.B. Median</p> <p>Med. Manhole</p> <p>M.H. Massachusetts Highway Bound</p> <p>N.Bd. North Bound</p> <p>N.I.C. Not in Contract</p> <p>Pavt. Pavement</p> <p>P.C. Point of Curvature</p> <p>P.C.C. Point of Compound Curvature</p> <p>P.I. Point of Intersection</p> <p>Ⓟ (or Prop. line) Property Line</p> <p>P.O.C. Point On Curve</p> <p>P.O.T. Point On Tangent</p> <p>P.R.C. Point of Reverse Curvature</p> <p>Proj. Project</p> <p>Prop. Proposed</p> <p>P.T. Point of Tangency</p> <p>P.V.I. Point of Vertical Intersection</p> <p>P.V.C. Point of Vertical Curvature</p> <p>P.V.T. Paved Waterway</p> <p>P.W.W. Paved Waterway</p> <p>R Radius of Curvature</p>	<p>R.C. Reinforced Concrete</p> <p>Rd. Road</p> <p>Rdwy. Roadway</p> <p>Rem. Remove</p> <p>Ret. Retain</p> <p>Ret. Wall Retaining Wall</p> <p>R.O.W. Right-of-Way</p> <p>R.R. Railroad</p> <p>Rt. Right</p> <p>R/W Right-of-Way</p> <p>S.B. Stone Bound</p> <p>S.Bd. South Bound</p> <p>S.D. Subdrain</p> <p>Sec. Section</p> <p>Sects. Sections (End sections for pipes)</p> <p>Sh. Sheet</p> <p>Shld. Shoulder</p> <p>Sk. Skew</p> <p>S.M.H. Sewer Manhole</p> <p>SM Square Meter</p> <p>St. Street</p> <p>Sta. Station</p> <p>S.S.D. Stopping Sight Distance</p> <p>Surf. Surfacing or Surface</p> <p>S.W. Sidewalk</p> <p>T. Tangent Distance of Curve/ Truck Percentage</p> <p>Tan. Tangent</p> <p>Temp. Temporary</p> <p>T.P. Turning Point</p> <p>T.R. Top of Rail</p> <p>Tr. Sig. Traffic Signal</p> <p>T.S.C. Traffic Signal Conduit</p> <p>V Variable Speed (usually Design Speed)</p> <p>Var. Vertical Curve</p> <p>V.C.P. Vitrified Clay Pipe</p> <p>Vert. Vertical</p> <p>W. Bd. West Bound</p> <p>Wd. Wood</p> <p>W.G. Water Gate</p> <p>W.I.P. Wrought Iron Pipe</p> <p>W.M. Water Meter/Water Main</p> <p>X-Sect. Cross Section</p>
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Table 2.3
RELATION OF DATUM PLANES
NAVD 88
ELEVATION IN METERS

TOWN OF ORANGE.....	+132.560		
TOWN OF NORTH ATTLEBOROUGH.....	+51.962		
NEW ENGLAND POWER CO. (WESTBOROUGH).....	+32.051		
WESTERN MASS ELECTRIC CO. (GREENFIELD).....	+20.942		
CITY OF LOWELL.....	+16.579		
LOCKS AND CANALS CORP. (LOWELL).....	+1.339		
CITY OF LAWRENCE.....	+1.306		
MEAN HIGH WATER*.....	+1.290		
TOWN OF FRAMINGHAM.....	+1.006		AS OF 1978
CITY OF FALL RIVER.....	+0.571		
CITY OF TAUNTON.....	+0.541		
CITY OF NEW BEDFORD.....	+0.526		
CITY OF ATTLEBORO.....	+0.451		
CITY OF LEOMINSTER.....	+0.261		
CITY OF WORCESTER.....	+0.045		
NGVD 88 DATUM = 0.000 METERS			
MEAN TIDE LEVEL* = -0.164		0.164 m	
TOWN OF NATICK.....	-0.247		
CITY OF CHICOPEE.....	-0.328		AS OF 1978
CITY OF SPRINGFIELD.....	-0.361		
TOWN OF GREENFIELD.....	-0.421		
CITY OF HAVERHILL.....	-0.681		
CITY OF BROCKTON.....	-0.721		
HOLYOKE WATER POWER CO.....	-0.984		
CITY OF HOLYOKE.....	-1.005		
CITY OF SALEM.....	-1.576		
SOUTH ESSEX SEWAGE DISTRICT (SALEM).....	-1.606		
TOWN OF MANCHESTER.....	-1.607		
MEAN LOW WATER*.....	-1.621		
CITY OF PEABODY.....	-1.715		
BOSTON LOW WATER	-1.736		
LOGAN AIRPORT (WATERWAYS).....	-1.854		
CITY OF LYNN.....	-1.857		
LOGAN AIRPORT (HIGHWAYS).....	-1.876		
CITY OF SOMERVILLE.....	-1.890		
TOWN OF WELLESLEY.....	-1.916		
CITY OF BEVERLY.....	-1.933		
TOWN OF DEDHAM.....	-1.959		
BOSTON CITY BASE & WALTHAM CITY BASE.....	-1.968		
CITY OF NEWTON.....	-1.990		
TOWN OF STOUGHTON.....	-1.996		
TOWN OF BROOKLINE.....	-2.011		
CITY OF QUINCY.....	-2.020		
CITY OF REVERE.....	-2.023		
CITY OF EVERETT.....	-2.039		
CITY OF CHELSEA.....	-2.072		
TOWN OF NORWOOD.....	-2.078		
CITY OF CAMBRIDGE.....	-3.553		
TOWN OF WALPOLE.....	-7.334		
THIRD HARBOR TUNNEL.....	-30.726		
U.S. ARMY ENGINEERS (BOSTON).....	-30.833		
BOSTON NAVY YARD (BASIC BENCH).....	-32.274		
TOWN OF NEEDHAM.....	-32.433		
MASS. WATER RESOURCES AUTHORITY & BOSTON TRANSIT COMMISSION.....	-32.439		
MASS. BAY TRANSPORTATION AUTHORITY.....	-32.448		
MASS. BAY TRANSPORTATION AUTHORITY REDLINE (BOSTON).....	-32.515		

* Tidal Bench Marks located at Appraiser's Stores Building,
U.S. Custom House, Purchase and High Streets, Boston.

NOTE: Elevations shown are derived from NGS VERTCON PROGRAM, VERSION 2.0,
for NGVD 29 to NAVD 88 conversions. Tests of the predictive capability
of the physical model show a 2.0 cm RMS agreement. The VERTCON model
can be considered accurate at the 2 cm level nationwide, with better
accuracy in the eastern United States.

Table 2.3A
RELATION OF DATUM PLANES
NGVD 29
ELEVATION IN METERS

TOWN OF ORANGE.....	+132.747
TOWN OF NORTH ATTLEBOROUGH.....	+52.197
NEW ENGLAND POWER CO. (WESTBOROUGH).....	+32.266
WESTERN MASS ELECTRIC CO. (GREENFIELD).....	+21.110
CITY OF LOWELL.....	+16.825
LOCKS AND CANALS CORP. (LOWELL).....	+1.585
CITY OF LAWRENCE.....	+1.548
MEAN HIGH WATER*.....	+1.536
TOWN OF FRAMINGHAM.....	+1.238
CITY OF FALL RIVER.....	+0.829
CITY OF TAUNTON.....	+0.789
CITY OF NEW BEDFORD.....	+0.777
CITY OF ATTLEBORO.....	+0.689
CITY OF LEOMINSTER.....	+0.494
CITY OF WORCESTER.....	+0.235
MEAN TIDE LEVEL*.....	+0.082
NGVD 29 DATUM**.....	=0.000
TOWN OF NATICK.....	-0.012
CITY OF CHICOPEE.....	-0.110
CITY OF SPRINGFIELD.....	-0.140
TOWN OF GREENFIELD.....	-0.253
CITY OF HAVERHILL.....	-0.436
CITY OF BROCKTON.....	-0.479
HOLYOKE WATER POWER CO.....	-0.771
CITY OF HOLYOKE.....	-0.792
CITY OF SALEM.....	-1.329
SOUTH ESSEX SEWAGE DISTRICT (SALEM).....	-1.359
TOWN OF MANCHESTER.....	-1.362
MEAN LOW WATER*.....	-1.375
CITY OF PEABODY.....	-1.469
BOSTON LOW WATER.....	-1.490
LOGAN AIRPORT DATUM (WATERWAYS).....	-1.609
CITY OF LYNN.....	-1.612
LOGAN AIRPORT DATUM (HIGHWAYS).....	-1.631
CITY OF SOMERVILLE.....	-1.643
TOWN OF WELLESLEY.....	-1.676
CITY OF BEVERLY.....	-1.686
TOWN OF DEDHAM.....	-1.719
BOSTON CITY BASE & WALTHAM CITY BASE.....	-1.722
CITY OF NEWTON.....	-1.743
CITY OF STOUGHTON.....	-1.759
TOWN OF BROOKLINE.....	-1.762
CITY OF QUINCY.....	-1.774
CITY OF REVERE.....	-1.780
CITY OF EVERETT.....	-1.798
CITY OF CHELSEA.....	-1.829
TOWN OF NORWOOD.....	-1.838
CITY OF CAMBRIDGE.....	-3.304
TOWN OF WALPOLE.....	-7.096
THIRD HARBOR TUNNEL.....	-30.480
U.S. ARMY ENGINEERS (BOSTON).....	-30.587
BOSTON NAVY YARD (BASIC BENCH).....	-32.028
MASS. WATER RESOURCES AUTHORITY & BOSTON TRANSIT COMMISSION.....	-32.193
TOWN OF NEEDHAM.....	-32.193
MASS. BAY TRANSPORTATION AUTHORITY.....	-32.202
MASS. BAY TRANSPORTATION AUTHORITY REDLINE (BOSTON).....	-32.269

* Tidal Bench Marks located at Appraiser's Stores Building,
U.S. Custom House, Purchase and High Streets, Boston.
** Formerly referred to as MEAN SEA LEVEL.

2. *Aerial Surveys* - The photogrammetric aerial surveys are usually supplemented by field surveys. Field surveys supply critical elevations, utility details, surface types, property lines, etc., which are plotted on the photogrammetrics.
3. *Cross Section Field Data* - The designer should check the bench mark datum and transcription used in running a circuit of levels against the originally established references. Table 2.3 illustrates a datum table. A field bench mark should be checked arithmetically. If it is correct, a red ink check mark should be made in the field book. All corrections should be noted with red ink directly above the original.

These instructions also apply to the survey cross section data:

- a. The number of significant figures in the final computation will be determined by the degree of precision used in taking the rod readings.
- b. Check and underline the height of instrument in green ink. When an H.I. is adjusted, show the correction in green ink.
- c. Computed elevations should be shown directly under the rod readings with red ink.
- d. Green ink is used for checking and correcting office computations. A green check mark should be placed at the extreme right end of each line of elevations to indicate that they have been checked and corrected, if needed.
- e. The engineer's name and the date of calculations should be recorded at the end of each set of notes.

2.1.1.2 Plotting Base Plan

Base plans will be plotted on paper for review purposes. Figure 2-1 provides an example of a project base plan. The following criteria will apply in plotting the base plan:

1. Plans should not be longer than 3 meters, including 150 millimeters of unused space at both ends. Plans should be no wider than 1.2 meters.
2. Plans require a title.
3. The baseline shall be stationed at 100 meter intervals (100 meters = 1 station) and can break where necessary, but there should be an overlap of 100 meters.

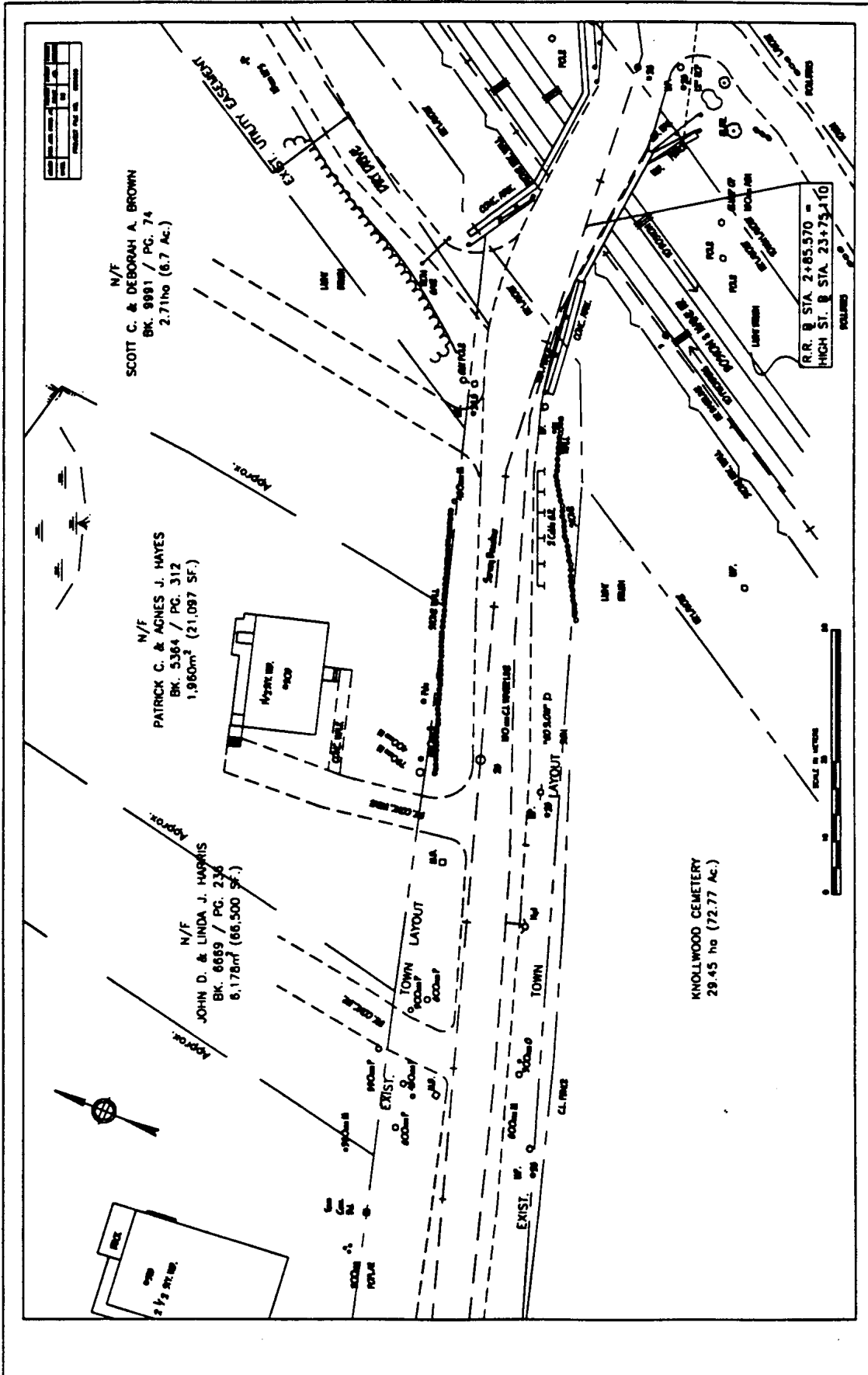


Figure 2-1 BASE PLAN

4. Plans should extend at least 100 meters beyond the anticipated beginning and end of the project.

5. All baselines and center lines are plotted by coordinates on the North American Datum 83 System as follows:

Size of

Scale

Coordinate

Squares

1:250

75 meters

1:500

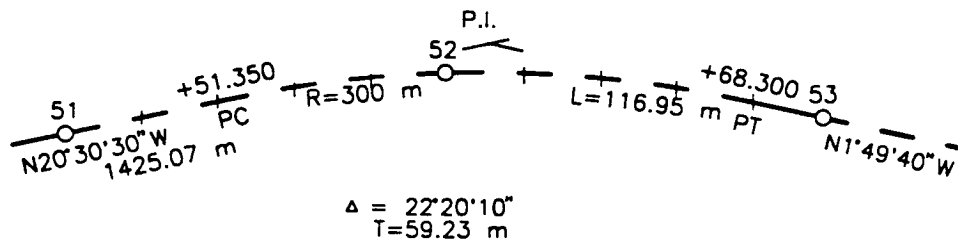
150 meters

1:1250

300 meters

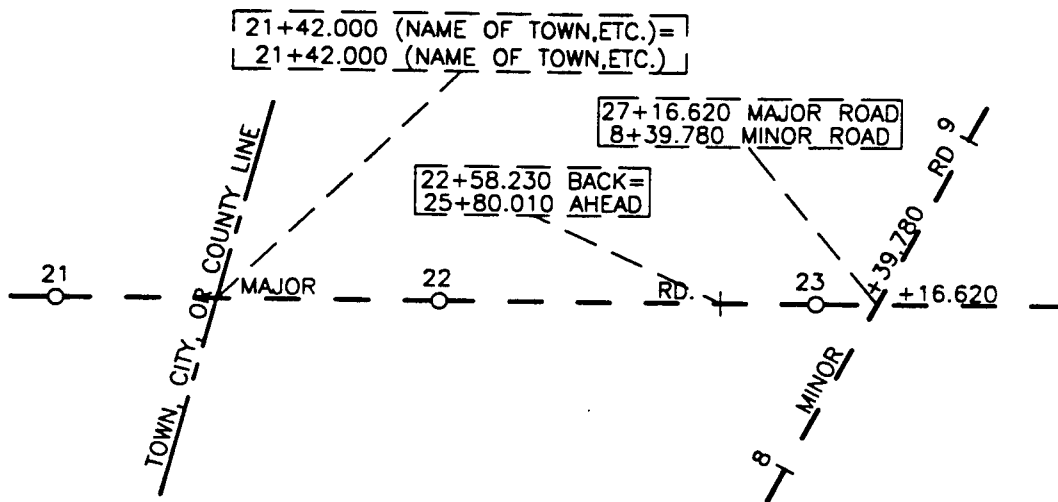
6. Indicate coordinate points by intersecting 50 millimeter lines. Describe these by noting at each point the coordinate values.

7. The baseline or center line is drawn as a dashed line, with the dashes about 15 millimeters long (see below). The 100 meter stations are indicated by small circles of 3 millimeters diameter, and the stations are noted above each circle with numerals 3 millimeters high with 2 millimeter ticks at 20 meter intervals. Points of curvature and tangency and angle points are marked with a short line intersecting the baseline at a right angle. The stations above the baseline or center line and the description of points (P.C., P.T.) below the baseline are 3 millimeters high. Bearings, length of tangents, curve number, and length and radii of curve are shown below the line. The remaining curve data (i.e., delta angle, length of curve tangent) are shown on the concave side of the curve. These data are located a sufficient distance from the baseline so that the curve data will not interfere with other plan details.



Other methods of providing a clear representation of geometric data (as from CADD systems) may be used as approved by the Project Manager.

- An equation may occur where baselines intersect or at a change in station (see diagram below). This is usually offset from the point to which it refers and is enclosed by a rectangle to the point. If the plan detail requires the equation to be removed from the point, the equation may be placed on the intersection lines.



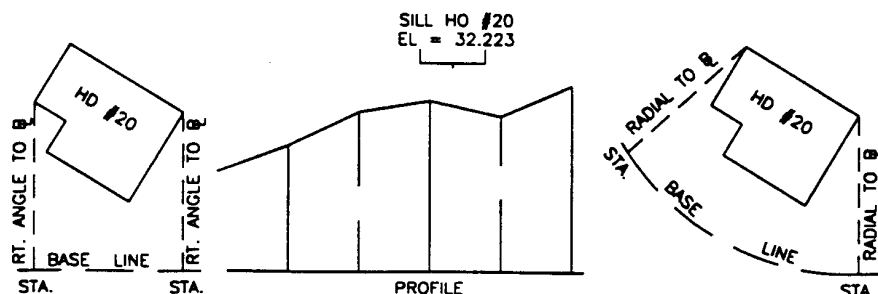
- Arrange the lettering so it can be read without turning the plan from its normal position (i.e., from bottom to top and from left to right).

2.1.1.3 Plotting Base Profiles

Basic profiles may be plotted on paper for review purposes. The following criteria apply:

- Scales of 1:500 horizontally and 1:100 vertically are usually used. Scales of 1:250 horizontally and 1:50 vertically may be used, depending upon the project.
- The stations at the beginning and end of each profile will coincide with those of the corresponding plan. Stations to be at 100 meter intervals.
- The horizontal profile scale shall be the same as the horizontal base plan scale.
- The plan and profile may be shown on the same sheet.

5. The base elevation should be in multiples of 2 meters.
6. A minus base value is indicated as "Base = Minus 10" and a zero base is shown "Base Zero."
7. Bench marks with datum noted are described on the profile approximately above the corresponding station on the profile.
8. Equations are noted below the datum line.
9. Broken profiles are permissible, when the ground rises or falls rapidly, to keep the profile within the limits of the sheet. They should be overlapped 100 meters horizontally.
10. Punchings in wetland areas are shown as a dashed dash line at the proper elevations and are designated "Approx. Hard Bottom".
11. Culverts which cross the baseline are shown in section on the profile. The field book usually provides the elevation of the flow line (invert), elevation of the end (header), width and height of a square or rectangular box culvert, and diameter of a pipe. The dimensions describing the square and rectangular structures are the width of opening first and height of opening second.
12. The clearance to the lowest wire of a high tension line will be shown on the profile. Plot the elevation of the lowest wire at the proper station location, and show this point as a heavy black ink dot. The number of wires, voltage, and clearance from the ground to the lowest wire will be indicated. The location of these wires is highlighted by a finger indicator next to it.
13. Water levels are shown as a thin dashed line, and the elevation and date of measurement are noted.
14. Sills of structures are plotted at their respective elevations. A dimension facing the baselines is determined by projecting the extremities of the structure at right angles or radial to the baseline stations (see example below).
15. Drives, walks, side streets, etc. should be shown on base profiles.



2.1.1.4 Cross Sections

All cross sections are drawn on standard cross section sheets. The sample sheet in Figure 2-2 shows the method of plotting existing ground sections and title block. Symbols for cross sections are illustrated in Table 2.4. The data for plotting sections is either obtained from field books, survey data collectors (digital terrain modules) or by interpolating from photogrammetric maps and contour plans. These last two methods are described in Section 2.1.1.1.

The following criteria apply for plotting cross sections:

1. The usual scale for cross sections is 1:50 horizontally and vertically. However, on multi-lane divided highways, a scale of 1:100 is more practical. The selection of the proper scale depends on the width of the cross section.
2. Cross sections shall be plotted at 20 meter intervals (also see below).
3. Cross sections are normally plotted along the length of the cross section sheet with the title on the left. The stations of cross sections increase from the bottom to the top of the sheet. The cross sections of very narrow roads may be plotted across the width of the sheet.
4. Existing ground line should be plotted as a thin line.
5. Sufficient space between cross sections should be provided so that the proposed highway template can be drawn without overlapping the adjoining section. To determine spacing, refer to the tentative grade line furnished by the designer. Additional space allowances may be needed if punchings or soundings are shown.
6. The heavy vertical line nearest the center of the sheet should be used as the baseline, when feasible. Base elevations are commonly chosen in multiples of ten and noted above the base elevation line to the left of the right-hand margin. The cross section station is noted below the base elevation line at the baseline.
7. A complete cross section must be shown on one sheet for estimating and continuity. This practice should be followed even if space is wasted.
8. Equations of stations are shown whether or not a cross section is drawn at that point.

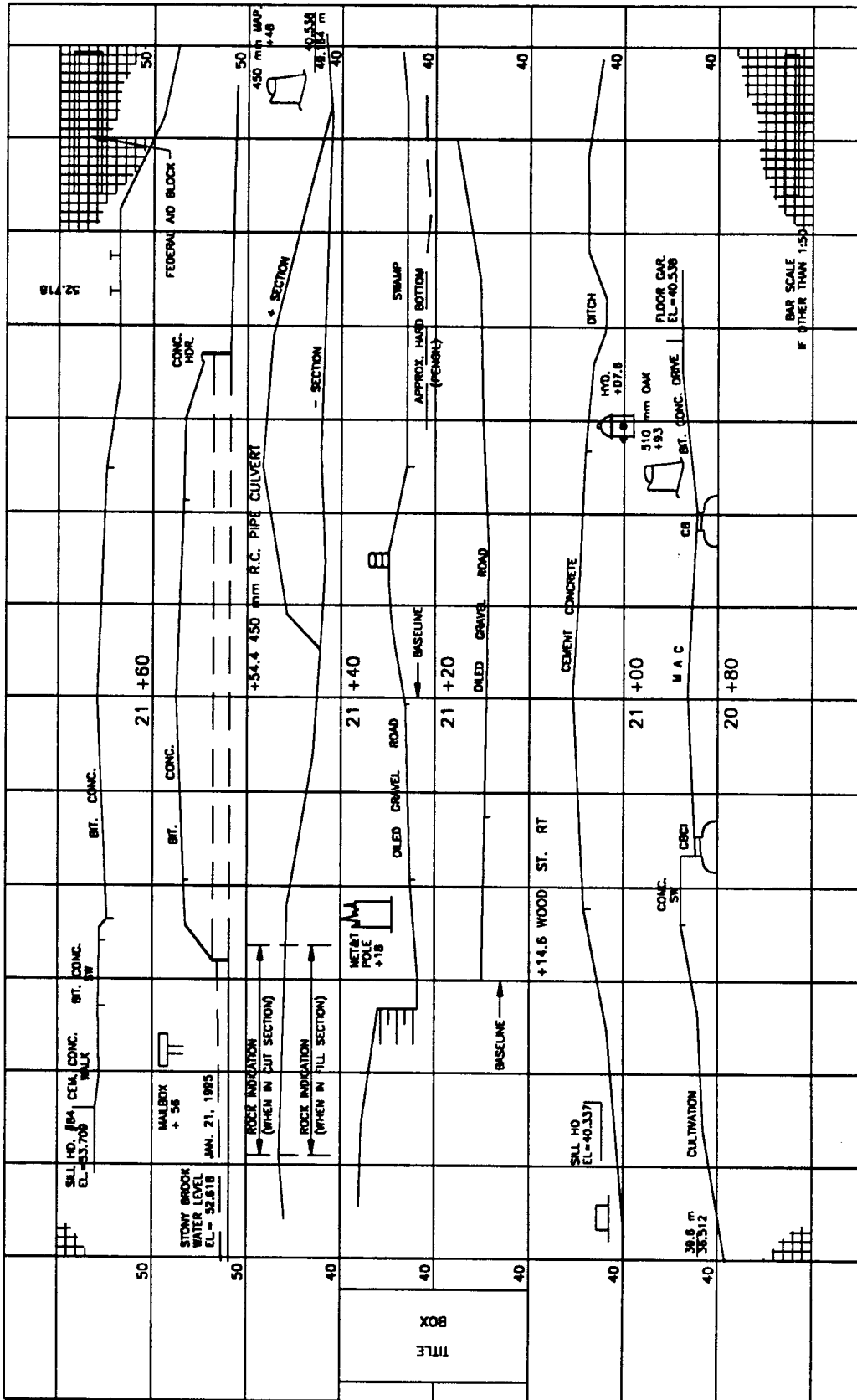


Figure 2-2. METHOD OF PLOTTING EXISTING GROUND SECTIONS

CROSS-SECTIONS - _____	
PRELIMINARY	
PLOTTED BY _____	DATE _____ 19 ____
CHECKED BY _____	DATE _____ 19 ____
NOTE BOOK NO. _____ PAGE _____	
TEMPLATES	
PLOTTED BY _____	DATE _____ 19 ____
CHECKED BY _____	DATE _____ 19 ____
CALC. BOOK NO. _____ PAGE _____	

FEDERAL AID BLOCK

STATE	FED.PROJ. AID NO.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
MASS.				
PROJECT FILE NO.				

(ACTUAL SIZE)

Figure 2-2. (Continued)

Table 2.4
SYMBOLS FOR DETAILING SECTIONS

Tree (200 mm and over)		Diameter & Type Station Offset
Pole		Type of Utility Pole, Number Station
Mail box		Mail Box Station
Well - cesspool		
Hydrant		Hydrant Station
Sill of structure (when plotted)	<hr/> Sill of (Type of Structure) EL. = _____ HO#	
Sill of structure (when beyond limits of sheet)	<hr/> Offset = _____ Sill of (Type of Structure) EL. = _____ HO#	
Retaining wall		
Balanced wall		
Punching	<hr/> Approx. Hard Bottom _____	

9. Profiles of intersecting streets, drives, roads, etc., are plotted in the sequence of the base or center line stationing. The reference baseline for intersecting streets, drives, walks, and steps may be offset from the regular cross section to allow more room for plotting the profiles. When streets, drives, and roads are indicated by stations along their profile, only the main baseline station is shown rather than an equation.
10. Often, the width of the cross section extends beyond the limits of the sheet. Extensions may be indicated by noting the next offset and elevation near the margin slightly above the cross section.
11. Plus and minus cross sections are plotted as one section. The plus and minus are indicated on the cross section lines. "Minus" always indicates the section back and "Plus" the section ahead.
12. The cross section limit should not be extended beyond the border of the sheet, and the data in the title box must be provided.

The following features should be shown on the preliminary cross sections:

1. Edges of roads, drives, walks, steps, wetlands, lawns, etc., should be plotted.
2. Walls should be plotted.
3. Hydrants, poles, and mailboxes are plotted by station and offset.
4. All trees 200 millimeters and over should be plotted. The diameter and type of tree, station and offset should be noted on the side of the tree away from the baseline or center line.
5. Punchings are shown as a dashed line and labeled "Approx. Hard Bottom."
6. Indicate elevation, station, and description of wells, cesspools and septic systems, and provide a description and elevation for sills of buildings. Plot sill elevation and offset to proper dimension, scaling offset from the plan when not shown in notes. Sills which fall between cross sections are shown by a vertical line at the correct distance from the baseline. The elevations are printed away from the baseline.
7. Culverts are shown as long dashed lines. (Dimensions in a field survey book indicate width first and height second.)
8. Water elevations are shown as a dashed line. The elevation and date recorded are noted.

9. Extremities of rock or rock under ground surface are indicated as shown in Figure 2.3 and labeled "Rock Indication" in pencil. To avoid interference with the proposed roadway cross section, the notation will appear either above or below the section, depending upon the type of earthwork involved.
10. Lines of bridge seats or tops of openings are shown as long dashed lines.
11. Rails are shown as a "T" with the horizontal line representing the elevation of top of rail. Indicate the elevation of the top of rail nearest the baseline for rails which run parallel to the main baseline. The elevation is printed vertically.
12. Roadway edges are indicated by short vertical lines about 3 millimeters long downward from the edge points on the cross section. Descriptions (type of surface, etc.) are shown on the bottom and top cross sections only if the description applies to all cross sections on the sheet. See Figure 2.2.
13. A Federal-aid block including a project file number must be shown.

2.1.2 Final Plans

2.1.2.1 Drafting Standards for Construction Plans and Cross Sections

The plans shall include all drawings and data necessary for proper construction of the proposed project. The plans will be plotted on the standard size translucent mylar (0.1 millimeter) matted on at least one side. Minimum height of all lettering is 3 millimeters. The density of screened mylars may be approved on a project-by-project basis.

These drafting procedures will ensure archival original quality drawings which will be suitable for microfilm for the reproduction of good quality prints. It is absolutely necessary to produce drawings with uniform density of line work.

The lettering line thickness shall not be less than 0.35 mm (LeRoy "O" pen).

2.1.2.2 Construction Plans

Figure 2-3 provides an example of a plan view. Figure 2-4 illustrates the necessary data for construction plans. Design symbols are illustrated in Figure 2-5. These criteria apply to preparing construction plans:

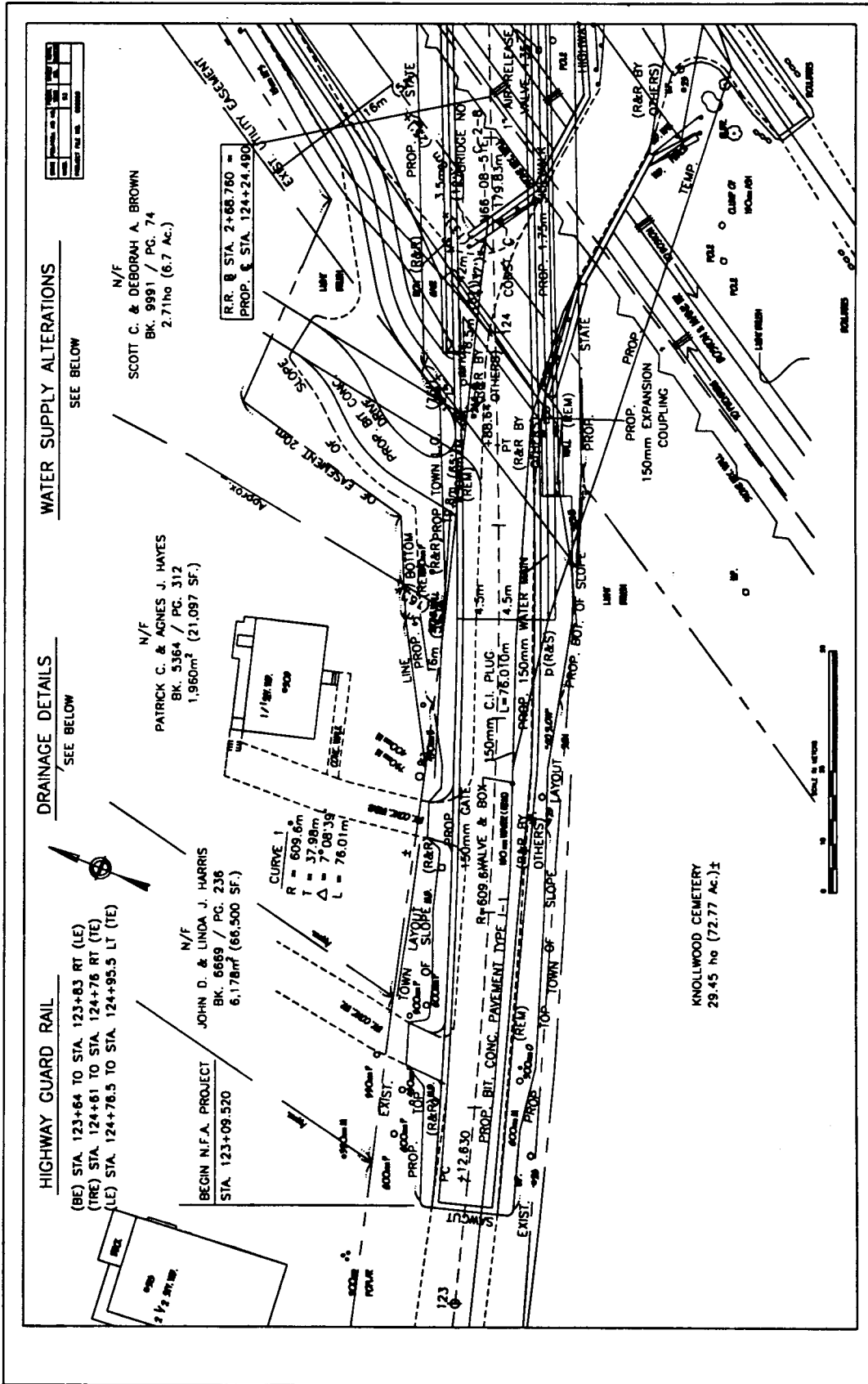
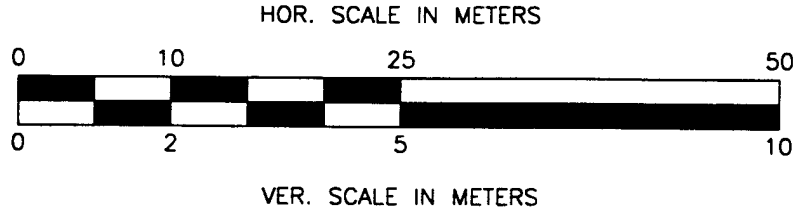


Figure 2-3. CONSTRUCTION PLAN

REFERENCE

BASELINE NB _____
 DETAIL NB _____
 SECTIONS NB _____

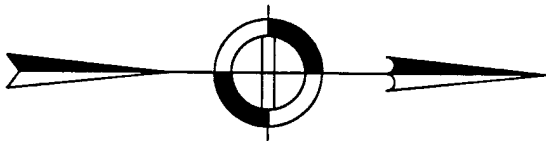


STATE	FED.PROJ. AID NO.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
MASS.				
PROJ. FILE NO.				

FEDERAL
AID

(ACTUAL SIZE)

TRUE NORTH OR MASS. CO-ORD SYSTEM



MAG. NORTH OR ASSUMED

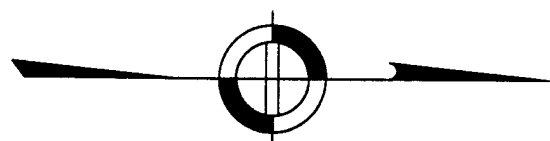


Figure 2-4. DATA FOR CONSTRUCTION PLANS

PROPOSED DRAINAGE	<p>LENGTH, SIZE & TYPE OF MATERIAL</p> <p>(SHOW DIRECTION OF FLOW)</p>
PROPOSED WATER MAIN	<p>LENGTH, SIZE & TYPE MATERIAL, WATER MAIN</p>
PROPOSED SEWER MAIN	<p>LENGTH, SIZE & TYPE MATERIAL, SEWER</p> <p>(SHOW DIRECTION OF FLOW)</p>
TRAFFIC SIGNAL CONDUIT	<p>LENGTH T S C</p>
MANHOLE	<p>MH</p> <p>(1.5 m DIAMETER)</p>
CATCH BASIN	<p>CB</p> <p>(1.5 m EACH SIDE)</p>
CATCH BASIN & CURB INLET SQUARE FRAME	<p>CBCI</p> <p>(1.5 m EACH SIDE)</p>
PAVED WATERWAY	<p>P.W.W. (TYPE)</p>
STATE HWY. LAYOUT LINE CONSTRUCTION PLANS	<p>LAYOUT LINE</p> <p>"NO ACCESS" (OR ACCESS)</p>
CITY OR TOWN LAYOUT LINE CONSTRUCTION PLANS	<p>LAYOUT LINE (CITY) OR (TOWN)</p>
FRAME & COVER	F & C
FRAME & GRATE	F & G
REMOVE & RESET	R & R
REMOVE & STACK	R & S
EASEMENT (TEMP. OR PERM.)	<p>TEMP. OR PERM. (TYPE)</p>

Note: STRUCTURES ETC. WHICH HAVE NO STANDARD SYMBOLS OR DESIGNATIONS ARE TO BE DESCRIBED AND MARKED PROPOSED. ALL SYMBOLS TO BE WITH BLACK INK

Figure 2-5. SYMBOLS FOR PROPOSED DESIGN

1. Existing detail information should be screened for clarity.
2. Construction plans are normally drawn at a scale of 1:500. Plans are normally drawn at a scale of 1:500. Plans at a scale of 1:250 may be used for clarity.
3. The corresponding profile is placed below the plan. If there is too much detail, the profile should be placed on a separate sheet.
4. Each succeeding plan is overlapped 25 meters and the plan information will extend 50 meters beyond the beginning and end of the project.
5. P.I.'s of curve tangents are not shown on final plans.
6. Only the proposed center line is shown, stationed at 100 meter intervals.
7. If there is a portion of a curve or tangent at either end of a plan more than 50 meters in length, indicate the curve data or bearing and distance.
8. Show the State Highway, City, Town, or County layout as a solid line. Do not show the radii, ties, etc., of layout lines. Show the beginning and end of the state highway layout, alterations of the layout, and the year recorded.
9. When the plan and profile are on the same sheet, the town, city, county, and State names are shown only on the plan portion. If on separate sheets, this data must be shown on each sheet.
10. Show a north arrow on all plan sheets. The direction of the north arrow can be determined from the coordinates.
11. Plans showing at-grade intersections should be drawn in a manner that provides the greatest amount of continuity and the least amount of repetition.
12. Bar scales will be shown on all construction plans.
13. Construction Plans which show only the roadway drawings must have profile sheet number references in the lower right edge of the sheet (inside the border). When the continuity of streets or ramps is broken, a sheet number reference should be noted at the breaks.
14. Denote the beginning and end of the project and the limit of work. Indicate the project number, associated stations, and coordinates. The beginning of a project is the southerly or westerly end; the end of a project is the northerly or easterly extremity, regardless of the direction of the line stationing and center line.

15. Proposed state highway location lines are drawn as solid lines labeled " Proposed State Highway Location Line." Town, city, or county locations are drawn as solid lines labeled " Proposed Location Line (town, city, or county)".
16. Easement lines are drawn as long dash lines and labeled drainage, slope, or construction easement, as appropriate. Designate whether the easement line is temporary or permanent.
17. Names of property owners are noted in the proper locations.

The following criteria apply to the presentation of the technical content in construction plans:

1. *Sight Distance* - Horizontal sight distances shall be noted on the plans in the vicinity of the horizontal curve.
2. *Roadway Widths* - All proposed roadway edges will be solid lines. The widths are indicated at the beginning and end of each sheet and at all other points where a change in width occurs. The offset from the center line at all of these points should be shown. All curved edges that are not concentric with the center line of construction should have the radius and any other data noted. All points of curvature and the tangency at the edge should be noted with ties to the center line.
3. *Center Line* - A construction center line will be used as the baseline for proposed projects. Previous baselines such as those used to collect survey data should not be shown on the final plans. The proposed center line shall be stationed and labeled with appropriate geometric data. Coordinates in NAD 83 shall be shown at the project limits along with ties to known reference points as appropriate to establish this new line in the field.
4. *Drives, Sidewalks, Walks* - Edges of drives, sidewalks and walks to houses are drawn as solid lines. The radii of drive curb returns are noted; other curve data is not necessary. The type of structure should be noted with the abbreviation "Prop." (proposed) before the description. The width of the sidewalk is also necessary.
5. *Wheel Chair Ramps* - Wheel chair ramps must be drawn as solid lines. Critical dimensions such as ramp length and curb transition length must be shown.
6. *Edging, Curbing, Berms* - The types of edging, curbing, and berms are shown without indicating lengths. Extremities of each type will be defined by arrows or similar notations. The abbreviation "Prop." (proposed) will appear before the description.

7. *Drainage* - The words "Drainage Details" with location reference such as "See Below" or "See Page No. ____" will be placed on the upper part of the sheet near the border. The above is noted whether or not drainage is required in the area shown on the sheet. Where there is no proposed drainage required, the word "None" is substituted for the location reference. The proposed drainage details, such as pipe, catch basins, manholes, etc., are shown directly on the roadway plan with heavy solid lines so the proposed detail will be easily distinguished from the existing. Where there is a considerable amount of detail on the plan that may obscure the proposed drainage, a separate plan showing the proposed drainage details is recommended. Any water supply alterations and other underground utility data should also be shown on the separate plan.

The length, size, direction of flow, and type of material will be noted at each pipe. Special drainage structures must be noted; the abbreviation "Prop." is not necessary before the description. The stations of the drainage structures are also noted. Details of all special drainage structures will be shown on a separate sheet. The type of material used for culvert ends will be noted at each end. To indicate which pipes or structures of the existing drainage system will be incorporated in the new system, the proper notations will be made, such as "retain", "adjust", "R&R", "abandon", "remove", etc.

8. *Ditches* - Ditches that are not part of the normal section are shown by two heavy broken lines. Note the appropriate payment item. The distance between the lines represents the width of the bottom of the ditch to scale. The abbreviation "Prop" is part of the description.

9. *Paved Waterways* - The type is identified and the abbreviation "Prop." is required. Paved waterways are drawn as heavy lines and cross-hatched with its description shown.

10. *Sub-Drains* - These are shown as heavy solid lines with their length and diameter of pipe; for example: " 90.4 m - 200 mm subdrain." The abbreviation "Prop" is required. When a grade line is broken, indicate direction of flow.

11. *Relocation of Streams* - The relocation of brooks, rivers, or other waterways is shown as a solid line. The lines defining the new location will be designated by cross-hatching.

12. *Water Supply* - The words "Water Supply Alterations," with a location reference such as "See Below" will be placed on the upper part of the sheet near the border. This is only noted when water supply changes are required in the area shown on the sheet. Where the proposed water supply system may be obscured by existing detail, a separate plan is recommended. This should be combined with the proposed drainage

details as discussed in #7. Heavy, solid lines designate any proposed water pipe. The length, size, type of material, kind of joints, direction of flow, and bends must be noted. Other details include hydrants, gates, etc. The abbreviation "Prop" is required before the description. The description will include any special materials such as insulation, etc.

13. *Traffic Signal Conduit* - The words "Traffic Signal Conduit," with a location reference such as "See Below," will be placed on the upper part of the sheet near the border. This is only noted when a traffic signal conduit is required in the area shown on the sheet. The conduit is indicated with a short, heavy, dashed line (about 5 millimeters long). The length and abbreviation "T.S.C." are noted on each length of conduit. Complex traffic signal installations should be shown on a separate plan.
14. *Demolition* - Buildings that will be demolished are designated with cross-hatching and marked "Structure No. ____." (Insert number shown on the demolition report or detail sheet).
15. *Bridges* - The outlines of all bridges will be shown on the construction tracings. The bridge number will be placed as close to the bridge as possible.
16. *Special Sloped Paving* - The area where special sloped paving is placed, such as on the slopes at open-end span bridges, should be indicated as "Special Sloped Paving."
17. *Highway Guard* - The type and station locations of guardrail are tabulated in the upper part of the sheet.
18. *Slopes* - Tops and bottoms of slopes are shown as dashed lines and marked "Prop.Top of Slope" or "Prop. Bottom of Slope."
19. *Fences* - Proposed fences are not indicated on the construction plans. They are, however, listed on the "Detail Sheets."
20. *Work by Others* - Work that is not performed by the MHD contractor but which is performed within the project limits either by or for a utility company or for other construction work, shall be clearly labeled " (type of work) by others."

2.1.2.3 Construction Profiles

Figure 2-6 provides an example of a construction profile on the sheet. The following criteria shall apply:

NAME OF CITY OR TOWN
NAME OF HIGHWAY
FEDERAL AID BOX
PROFILE

B.M. 108+80 60.96 m LT
2nd STEP HOUSE #34 CHARLES ST.
EL = 26.588
SEA LEVEL DATUM
OF 1929

FOR UNDIVIDED HIGHWAYS ONLY

STOPPING S.D. 204 m
PASSING S.D. 320 m

Note:
THE EXISTING DETAILS WERE OMITTED FOR CLARITY.

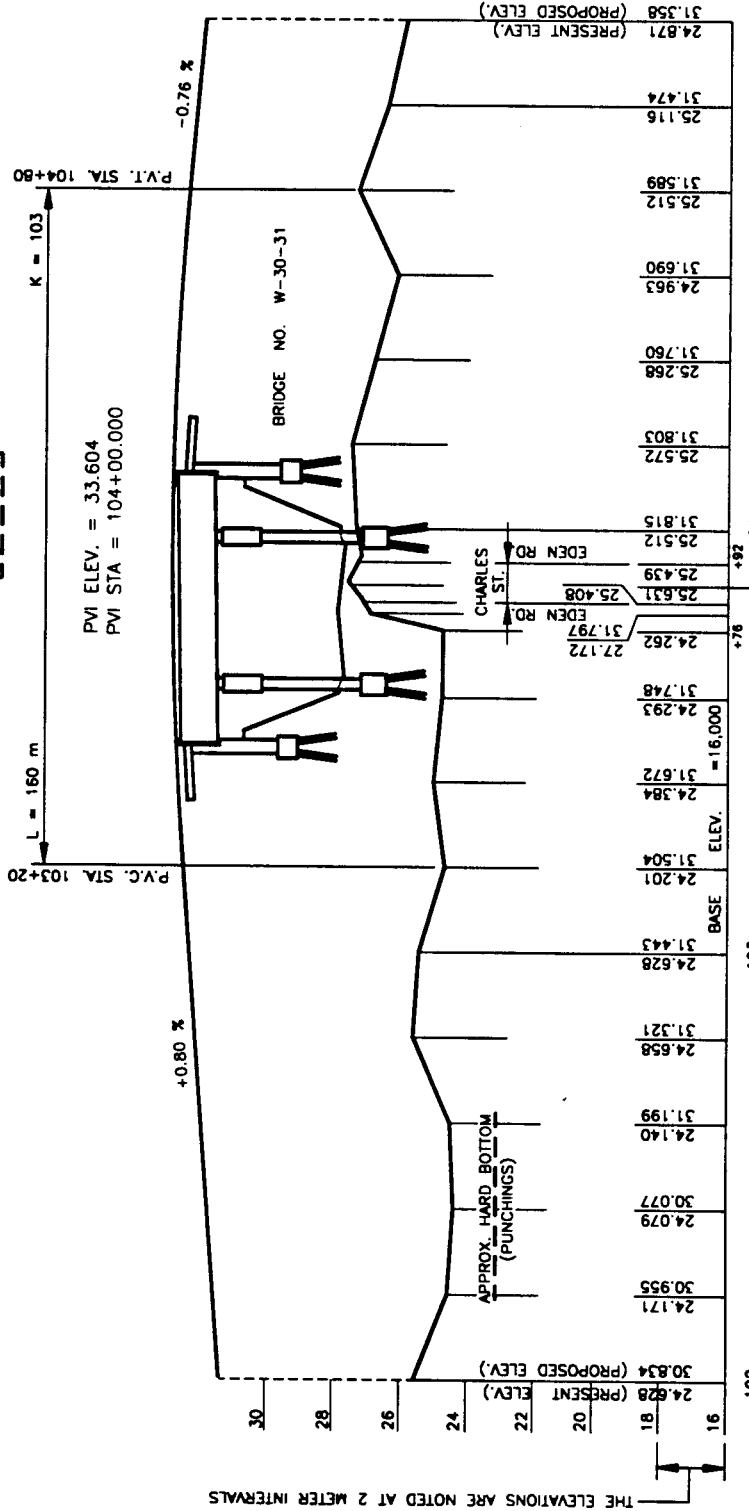


Figure 2-6. METHOD OF INDICATING PROFILE ON CONSTRUCTION TRACINGS

1. The method of presenting the data on the profile sheet is similar to that used on base plans. The base elevation (datum) need only be shown once in the middle of the sheet, unless the profile is broken.
2. When the profile is shown on the same sheet as the plan view, the length of the profile should be the same length in stations as the baseline of the plan, regardless of the available room. The datum line is placed 50 millimeters above the border line. When the profile is on a separate sheet, the length shown must be the same as the length of the corresponding plan in stations. An overlap of 50 meters is required for each profile.
3. Horizontal and vertical bar scales will be shown on construction profiles.
4. The proposed profile lines are drawn as heavy solid lines.
5. The proposed elevations are labeled to the right of the respective upright as shown in Figure 2-6.
6. The rates of grade, points of curvature and tangency, and vertical curve data (length of curve, K value, PVI station and elevation, etc.) must be labeled as shown in Figure 2-6.
7. The outline of each bridge and its bridge number is traced from the profile shown on the first sheet of the bridge plans.
8. The calculated lengths of vertical curve sight distances are labeled and described as "(distance in meters) Stopping S.D."
9. Sheets that show only profiles will have their corresponding plan sheet number placed on the lower right edge of the sheet inside the border.
10. The beginning and end of the project will be shown and the project number, stations, and coordinates indicated.
11. Profiles should extend 100 meters beyond the beginning and end of the project.

2.1.2.4 Grading and Tie Plans

Grading plans and tie plans are required for all ramp and major at-grade intersections. They may also be required to locate wheelchair ramps and drainage ditches. These criteria apply:

1. The elevation will be computed along each roadway edge at 10 meter intervals and at other intermediate points where required. The edge profiles for the grading plan are normally plotted to a scale of 1:500 horizontally and 1:100 vertically.
2. Ties will be computed and shown on the plans (at P.C., P.T., etc.) to properly locate the roadway edge in the field.
3. Contour plans may be required for special grading areas (drainage, landscaping, aesthetics, etc.).

2.1.2.5 Construction Cross Sections

Figure 2-7 provides an example of the construction cross section. The following criteria applies:

1. The proposed roadway cross sections are on the cross section sheets described in Section 2.1.1.4. The roadway cross section are to be plotted as a thick, dark lines.
2. The proposed profile elevation shall be noted on each roadway cross section. On a banked curve or a curve transition, the theoretical profile elevation is noted on the left side of the profile grade line, and the actual elevation is noted on the right side of the profile grade line (with "actual" noted in parentheses). Show actual edge elevations for banked curves and curve transitions.
3. Rate of bank and the P.C. or P.S. and P.T. stations of the horizontal curve in areas where normal cross slopes do not apply must be shown on each sheet that has any portion of the curve or transition of the curve on it. The above data is placed at a convenient location near the right-hand border of the sheet.
4. The cross section must show the limits of muck excavation, if any, as determined by the standard MHD methods.
5. The depth of existing topsoil to be excavated and stacked will be indicated with a dashed line and marked "Topsoil Stripping." This information is generally obtained from the boring logs or test pits.
6. Show details of rock excavation and special borrow in embankment areas.
7. The type of surface or subbase of the proposed roadway will not be indicated.

1. THE EXISTING DETAIL IS OMITTED FOR SIMPLICITY. THE PROPOSED TEMPLATES ARE TO BE SUPERIMPOSED ON THE CROSS SECTION SHOWN ON FIG. 2-2. THE WORDS EXISTING GROUND ARE OMITTED ON THE ACTUAL TEMPLATE.

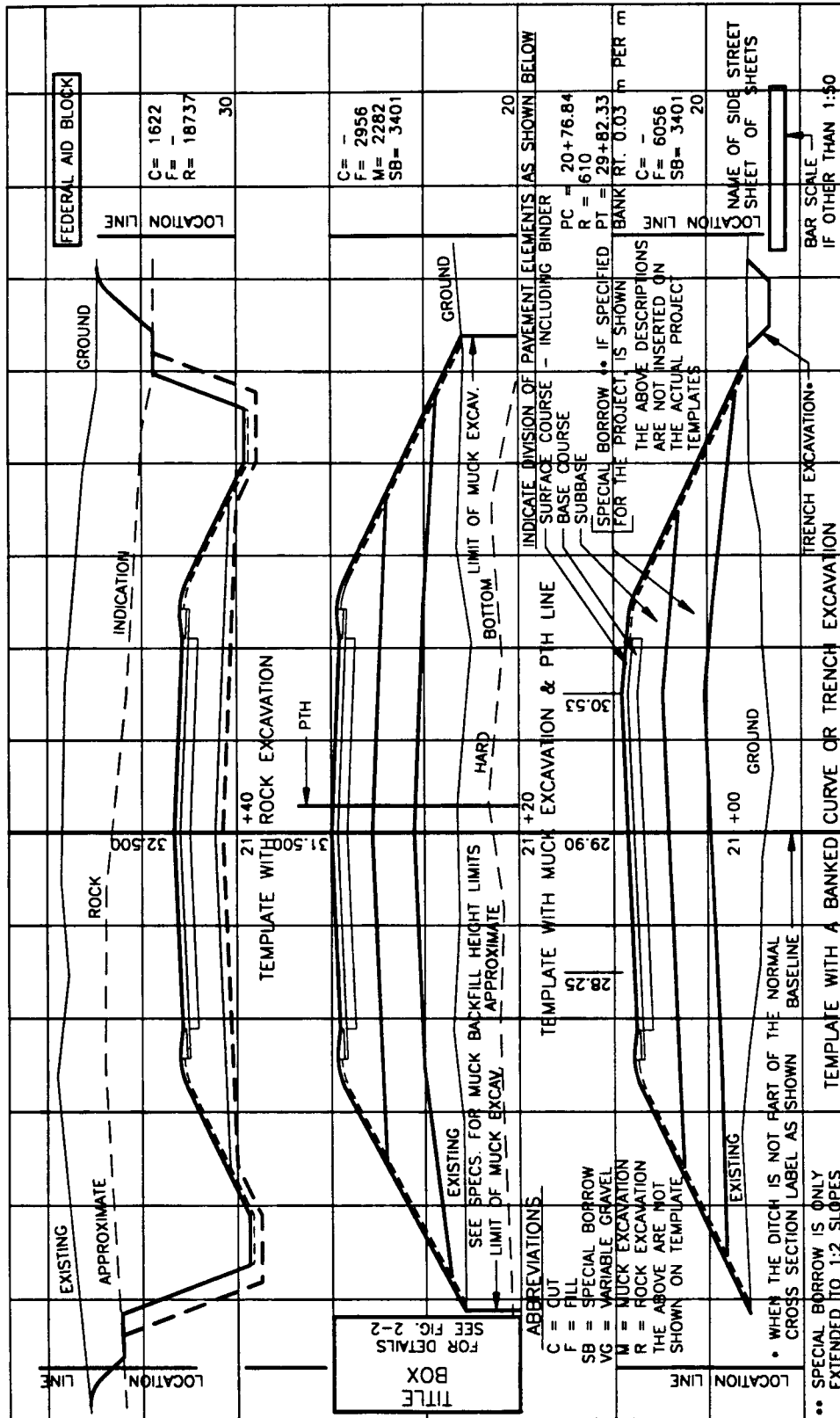


FIGURE 2-7. METHOD OF PLOTTING PROPOSED TEMPLATES

8. Proposed location lines will be shown on each cross section where the layout falls within the sheet limits. The location lines of the first and last cross section of each sheet shall be marked "Location Line."
9. P.T.H. (Planimeter to Here) lines will be indicated where required. The limits of bridge excavation and gravel backfill should always be indicated for estimating purposes.
10. Show all ditches within the limits of cross section sheets. Indicate the type of excavation for estimating purposes.
11. Record cut and fill (square meters) for each section to the right of the particular proposed roadway cross section so that the areas measured will be clearly defined.
12. The first sheet of the cross section will be labeled in letters about 25 millimeters high: "Estimated Shrinkage = +15%." A legend of terms (abbreviations) should be included on the first sheet.

2.1.2.6 Assembly of Construction Plans

A complete set of construction plans shall include:

1. *Title Sheet* - A title sheet is required for all projects (See Figure 2-8). The title sheet will show:
 - a. A locus plan reproduced from a topographic map without contours, or similar map or plan. The scale must be large enough to identify project location. The locus plan will show:
 - (1) stations of beginning and end of project and limits of work;
 - (2) coordinates of beginning and end of project;
 - (3) Federal-aid project number and an adjacent Federal-aid project number, if any;
 - (4) Route numbers of all roads in the vicinity of the project;
 - (5) Bridge numbers and stations of the bridges;
 - b. Conventional signs on lower left corner of sheet.

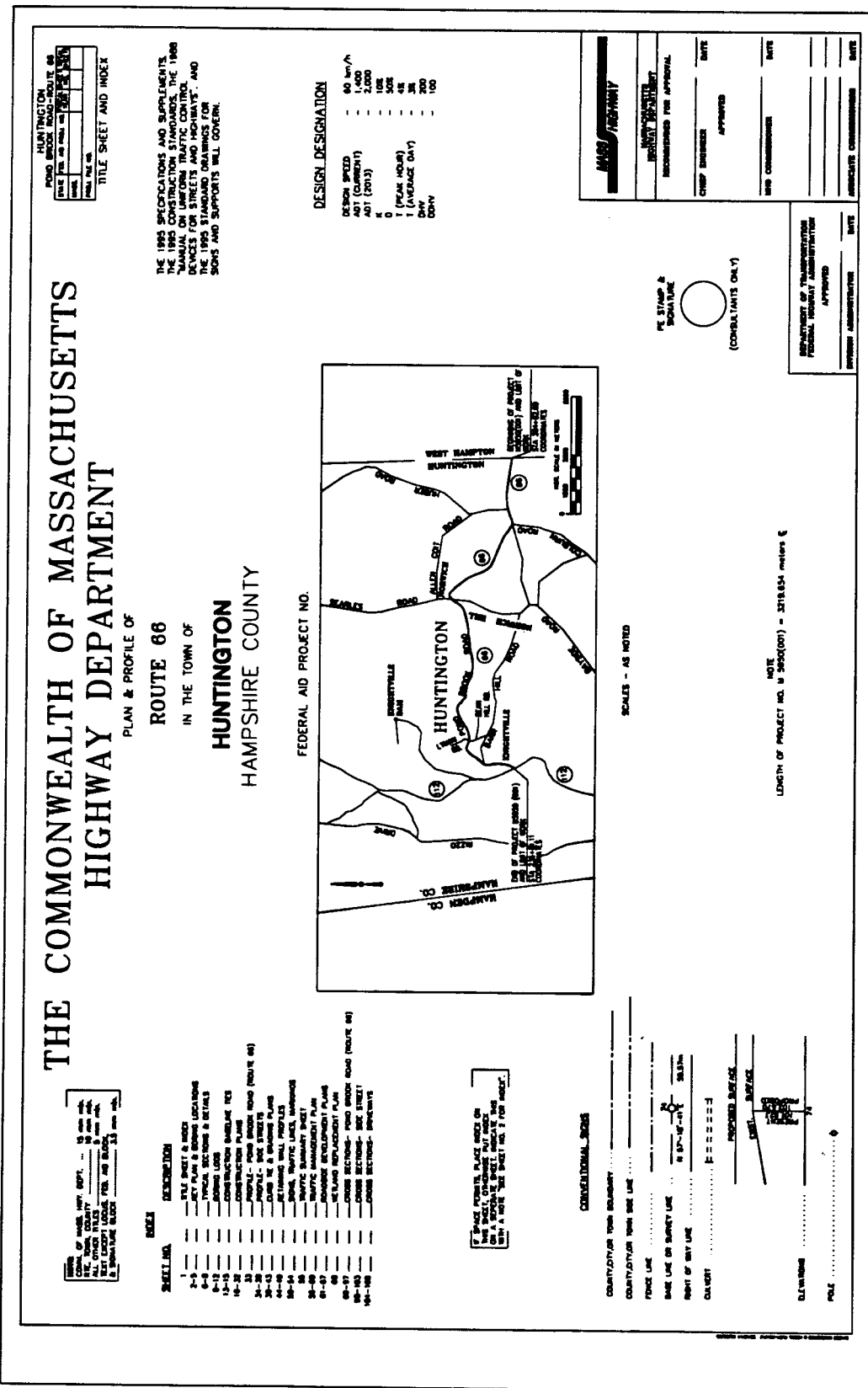


Figure 2-8. SAMPLE OF TITLE SHEET FOR CONSTRUCTION PLANS


	
MASSACHUSETTS HIGHWAY DEPARTMENT	
RECOMMENDED FOR APPROVAL	
_____ CHIEF ENGINEER	_____ Date
APPROVED	
_____ MHD COMMISSIONER	_____ Date
_____ _____ _____ _____	
_____ ASSOCIATE COMMISSIONERS	_____ Date
DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION	
APPROVED	
_____ DIVISION ADMINISTRATOR	_____ Date

Figure 2-8a. SAMPLE OF SIGNATURE BLOCK (ACTUAL SIZE)

- c. Project length. Project length of roadway is expressed to the nearest 0.001 meter and is the length of roadway measured along the center line of construction considering all equations. The length of divided highways will be the average length of each roadway.
- d. In the lower right corner of the sheet, blocks for the signature of the Chief Engineer and the Commissioners of the Highway Department; in the extreme lower right corner, a block for the signature of the FHWA Division Administrator; above the FHWA block, the P.E. seal and signature for the design consultant as well as the name of firm if applicable.
- e. Federal-aid Block in the upper right corner with project file number.
- f. Directly below the Federal-aid Block, place the following note:

"The (year latest) *Specifications*, the (year latest), *Construction Standards* and the (year latest) *Manual on Uniform Traffic Control Devices for Streets and Highways*," and the (year latest) *Standard Drawings for Signs and Supports*, and the (year latest) Edition of the *American Standard Nursery Stock* will govern."

- g. Listing of the Design Designation Data including all traffic data and Functional Classification of roadway(s) .
2. *Index Sheet (optional separate sheet)* - An index is required for all projects. Figure 2-10 provides an example.
 3. *Key Plan* - See Figure 2-11.
 4. *Boring Logs* - See Figure 2-12.
 5. *Typical Sections* - Show typical sections for all roads and ramps. In addition, indicate the following on the typical section sheets:
 - a. Descriptions of pavement and shoulder structures (see Table 2.4a),
 - b. Method of banking,
 - c. Special types of curbing, edging, berms, structures and details which have not been approved as standards.

Table 2.4
NOTES
PAVEMENT FOR (Name or Rte. No.)

Traveled Way and Shoulders

Surface Course 120 mm Class I Bituminous Concrete Pavement Type I-1 Placed in 3 Layers
40 mm Top Course Material Over 2 Layers of Binder Course Material, Each
40 mm.

Base Course 150 mm Class I Bituminous Concrete Pavement Type I-1 Base Course Material
Placed in 2 Layers, Each 75 mm.

Subbase 100 mm Dense Graded Crushed Stone over 200 mm Gravel.

All roads, ramps, etc., are similarly described on the typical section sheets. The thickness of the layers are only for illustration; they vary for each project, and must be approved by the Pavement Design Engineer. In addition, note other pertinent data such as the application of special borrow.

6. *Plans of Main Road. **

7. *Plans of Side Roads. **

8. *Profiles on Main Roads. **

9. *Profiles of Side Roads. **

10. *Ramp Profiles.*

11. *Grading and Tie Plans.*

12. *Drainage Details and/or Water Supply Details.*

13. *Sign Plans and Details.*

14. *Traffic Signal Plans*

15. *Pavement Markings.*

16. *Traffic Management Plans*

17. *Lighting Plans and Details.*

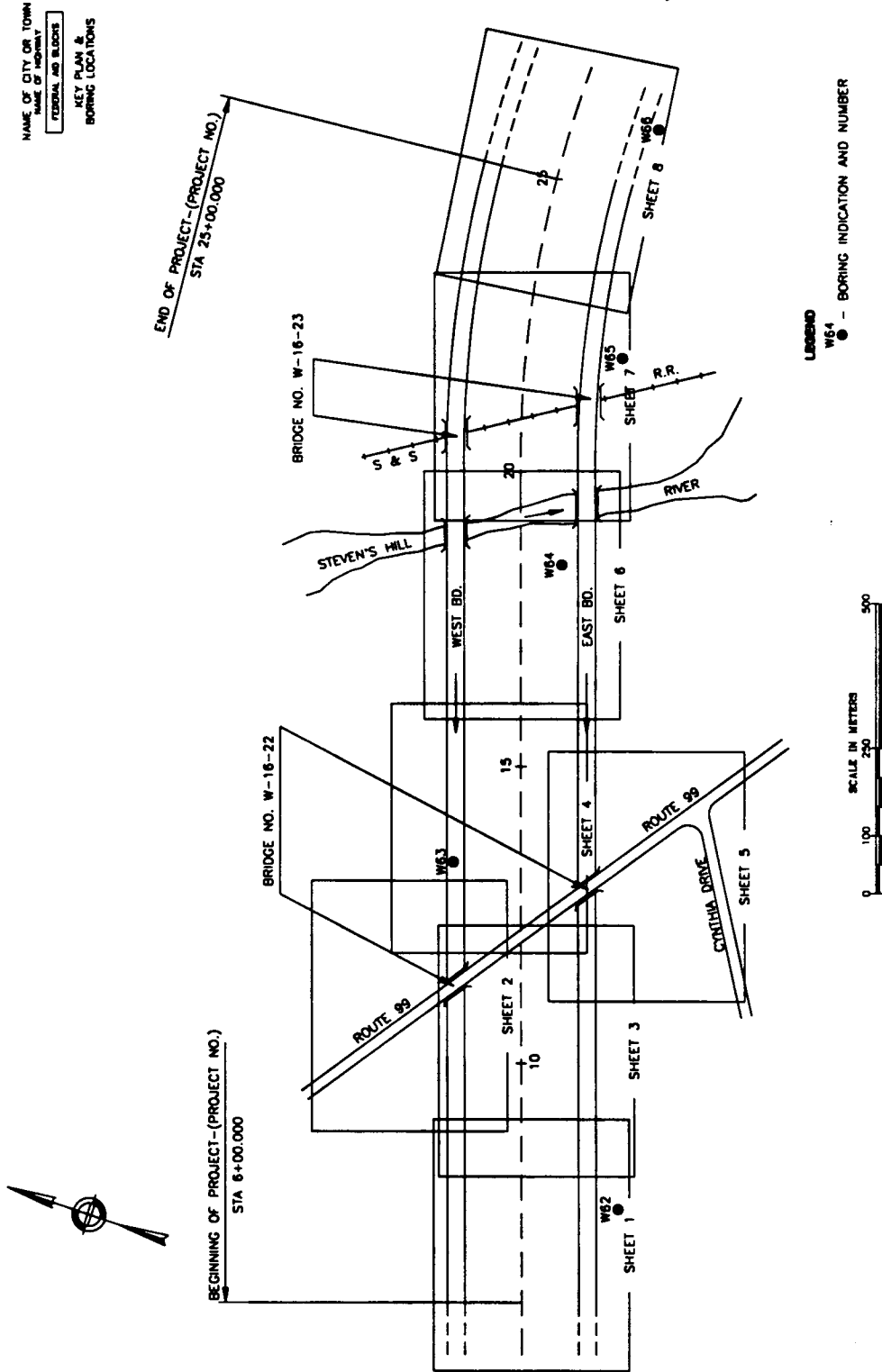
18. *Utility Details (if required).*
 19. *Landscaping Plans and Details*
 20. *Special Details (e.g. pedestrian amenities)*
 21. *Bridge Plans.*
 22. *Cross Sections.*
- * Plans and profiles may appear on the same sheet.

CITY OR TOWN
ROUTE NO.
FED. AID BLOCK

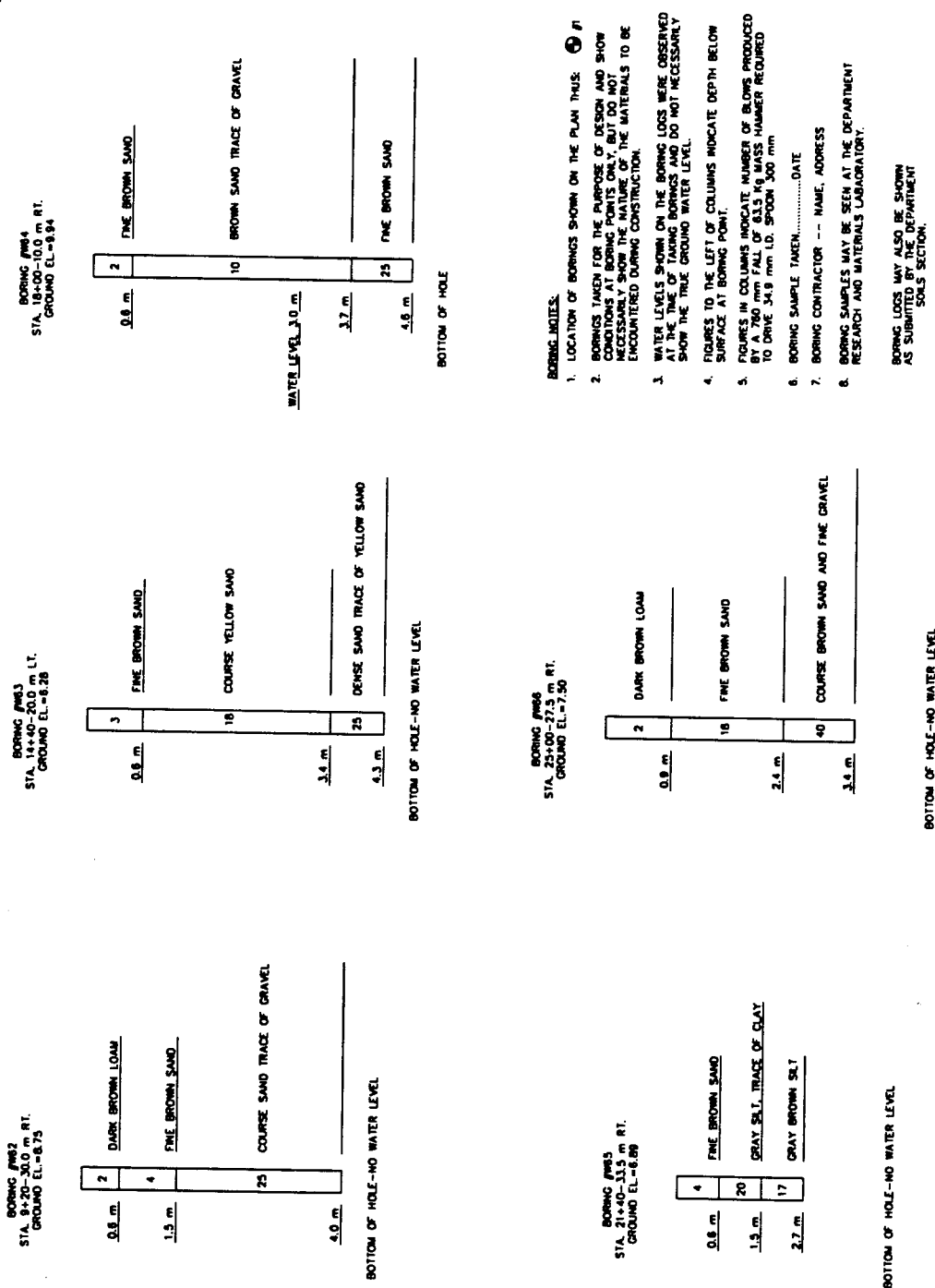
INDEX

SHEET NO.	DESCRIPTION	CITY OR TOWN ROUTE NO. FED. AID BLOCK
1	TITLE SHEET	
2	INDEX	
3	KEY PLAN AND BORING LOCATION	
4	BORING LOGS	
5-8	TYPICAL SECTION	
9-50	PLANS ROUTE 1-99	
51-56	PLANS SUSAN AVE.	
57-61	PLANS WILLIAMS ST.	
62-103	PROFILES ROUTE 1-99	
104-109	PROFILES SUSAN AVE.	
110-116	PROFILES WILLIAMS ST.	
117-118	PROFILES S.W. RAMP AT WILLIAMS ST.	
119-120	GRADING AND TIE PLAN S.W. RAMP AT WILLIAMS ST.	
121-123	PROFILES N.E. RAMP AT WILLIAMS ST.	
124-126	GRADING AND TIE PLAN N.E. RAMP AT WILLIAMS ST.	
127	DRAINAGE DETAILS (NOT SHOWN ELSEWHERE)	
128	WATER SUPPLY DETAILS	
129	SIGN PLANS AND DETAILS	
130	TRAFFIC LINES AND MARKINGS	
131	LIGHTING DETAILS	
132-136	BRIDGE NO. D-5-43, ROUTE 1-99 OVER SUSAN AVE.	
137-140	BRIDGE NO. D-5-43, ROUTE 1-99 UNDER WILLIAMS ST.	
141-201	CROSS SECTIONS ROUTE 1-99	
202-220	CROSS SECTIONS SUSAN AVE.	
221-239	CROSS SECTIONS WILLIAMS ST.	
240-249	CROSS SECTIONS S.W. RAMP AT WILLIAMS ST.	
250-261	CROSS SECTIONS N.E. RAMP AT WILLIAMS ST.	
		MINOR ROADS
		PLANS
	SUSAN AVE.-----SHEET NO. 51-56,72	SHEET NO. 104-109
	WILLIAMS ST.-----SHEET NO. 57-61,83	SHEET NO. 110-116
		RAMPs
		PLANS
	S.W. RAMPS AT WILLIAMS ST. SHEET NO. 16,17,18,58	SHEET NO. 117-118
	N.E. RAMPS AT WILLIAMS ST. SHEET NO. 16,18,19,60	SHEET NO. 110-116
		TEMPORARY ROADS AND DETOURS
		PLANS
	SUSAN AVE.-----SHEET NO. 22,23,53	SHEET NO. 71
	WILLIAMS ST.-----SHEET NO. 48,60	SHEET NO. 97

Figure 2-9. SAMPLE OF INDEX FOR CONSTRUCTION PLANS



NAME OF CITY OR TOWN
NAME OF HIGHWAY
FEDERAL AID BLOCKS
BORING LOGS



- BORING NOTES:**
1. LOCATION OF BORINGS SHOWN ON THE PLAN THIS: (Symbol) #1
 2. BORINGS TAKEN FOR THE PURPOSE OF DESIGN AND SHOW CONDITIONS AT BORING POINTS ONLY, BUT DO NOT NECESSARILY SHOW THE NATURE OF THE MATERIALS TO BE ENCOUNTERED DURING CONSTRUCTION.
 3. WATER LEVELS SHOWN ON THE BORING LOGS WERE OBSERVED AT THE TIME OF TAKING BORINGS AND DO NOT NECESSARILY SHOW THE TRUE GROUND WATER LEVEL.
 4. FIGURES TO THE LEFT OF COLUMNS INDICATE DEPTH BELOW SURFACE AT BORING POINT.
 5. FIGURES IN COLUMNS INDICATE NUMBER OF BLOWS PRODUCED BY A 760 mm FALL OF 63.5 kg MASS HAMMER REQUIRED TO DRIVE 34.9 mm I.D. SPOON 300 mm
 6. BORING SAMPLE TAKEN.....DATE
 7. BORING CONTRACTOR --- NAME, ADDRESS
 8. BORING SAMPLES MAY BE SEEN AT THE DEPARTMENT RESEARCH AND MATERIALS LABORATORY.
- BORING LOGS MAY ALSO BE SHOWN AS SUBMITTED BY THE DEPARTMENT SOILS SECTION.

Figure 2-11. METHOD OF PLOTTING BORING LOGS

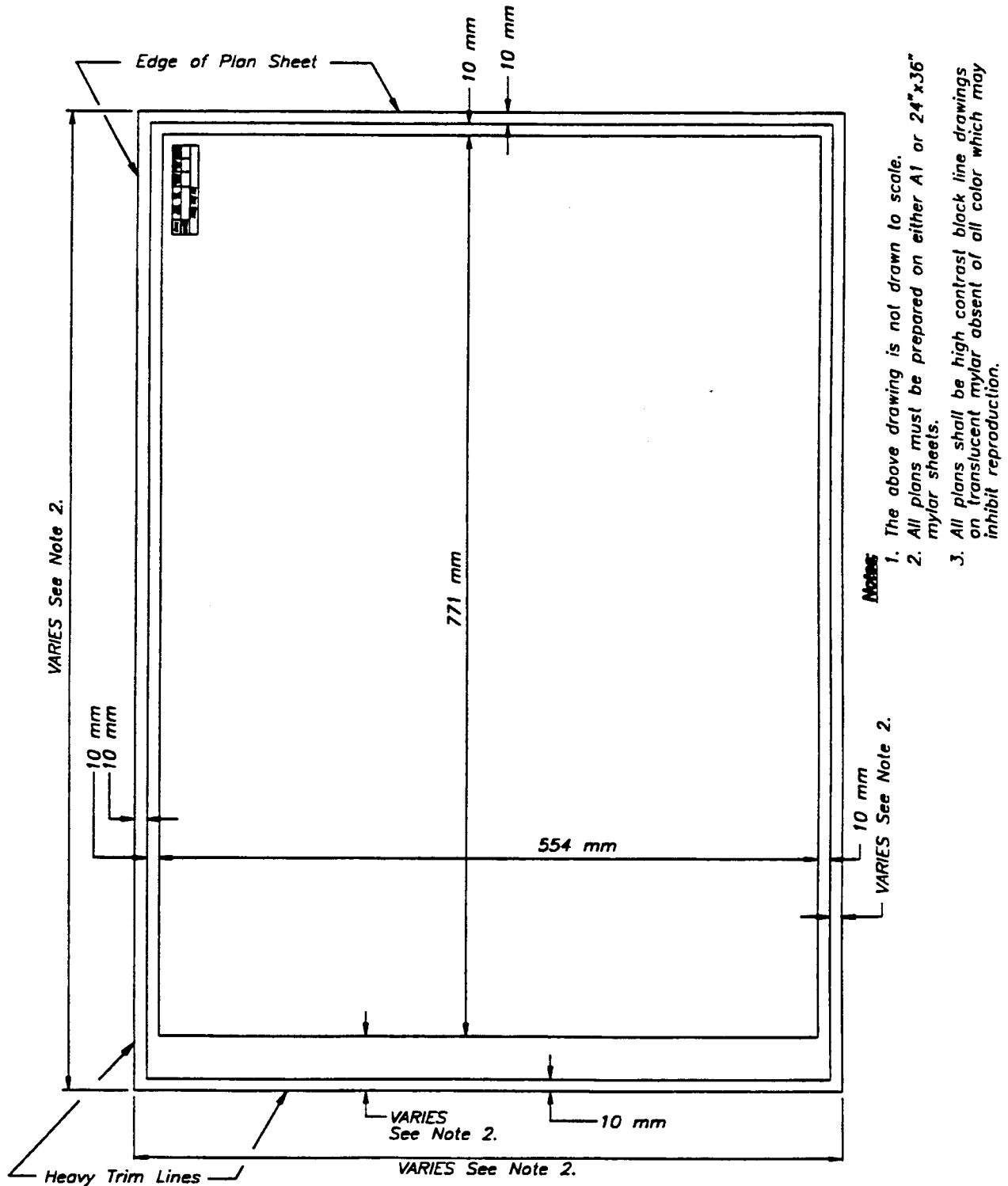


Figure 2-12. SIZES OF STANDARD TRACINGS

2.2 DECREE PLANS

MHD is required to make decree plans when existing railroad crossings are abolished or altered in conjunction with highway work. MHD has jurisdiction for abolitions on all public highways within the state for any alterations on state highways or direct continuations of state highways.

When a new state highway layout crosses a railroad where no crossing previously existed, a decree plan is not required - the layout plans will be sufficient.

A crossing is considered to be altered when:

1. an existing bridge has major structural changes to strengthen or improve it;
2. an existing highway layout at a grade crossing is widened; or
3. the grade crossing is resurfaced or repaired outside the state highway layout (changes to grade crossings within the existing state highway layout are not considered alterations).

Decree plans for alterations must show layouts, takings, major construction and design detail, bridge plans and plans of existing conditions. The plan should extend about 600 feet on either side of the crossing. Decree plans are not a part of the construction plans.

The following data must be shown on decree plans:

1. *Existing Conditions* - All existing detail and proposed edges.
2. *Proposed Surface* - The type of surface on pavements, walks, drives, etc. should be identified as "Proposed (kind) Pavement."

2.3 LAYOUT PLANS

Layout plans, descriptions, and orders of taking are required to establish highway right of way for all projects which involve land takings. The proposed layouts may result in changes to existing state highway layouts or to existing county, city, or town layouts, or may revise existing limited access provisions.

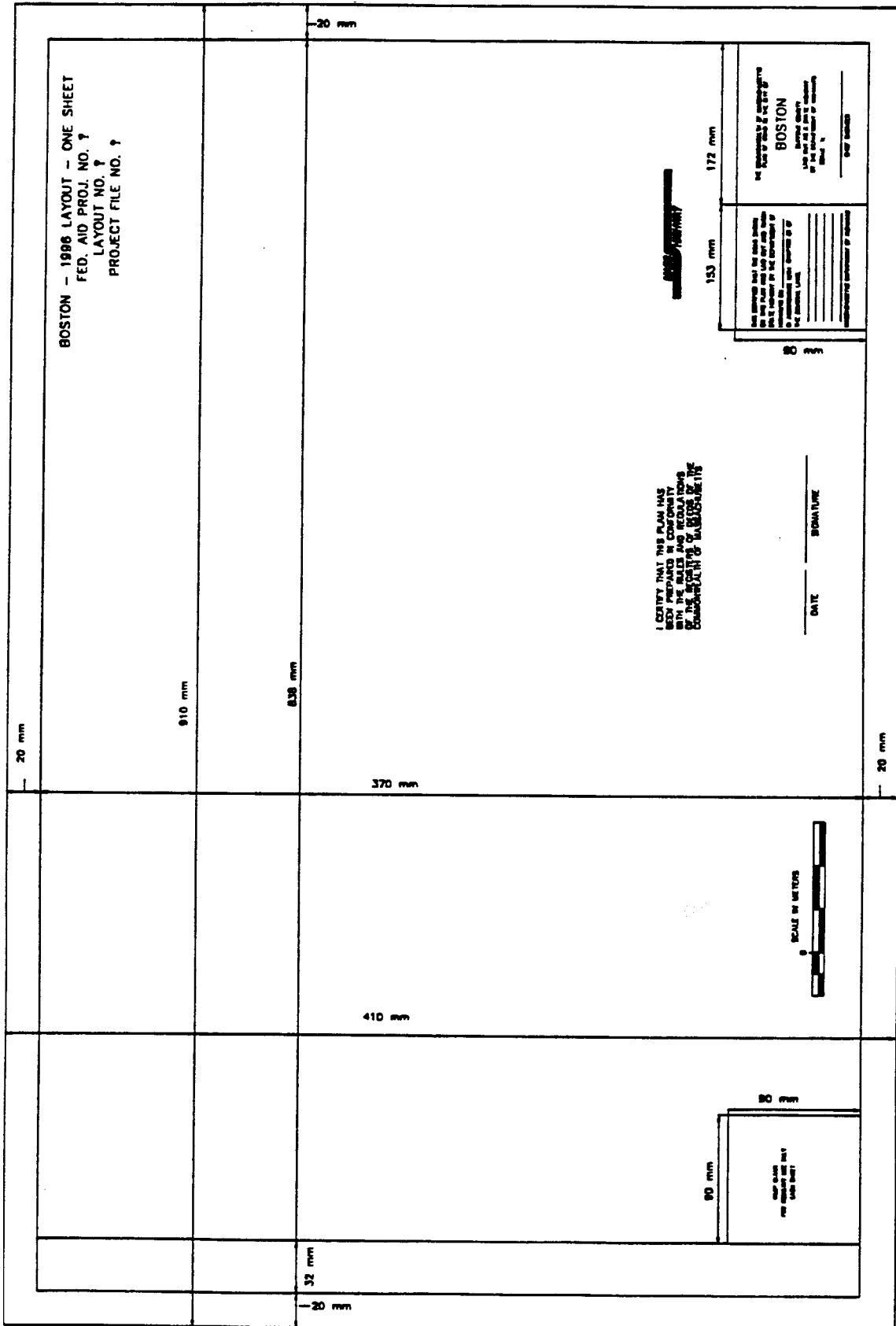
All proposed layouts must be accurately computed. A complete set of original calculations and a check set of calculations must be submitted. Where a project is in more than one municipality, separate layouts are required. Railroad baselines should be tied to the state highway layout.

The procedure and methods outlined below provide a guide for the preparation of layout plans:

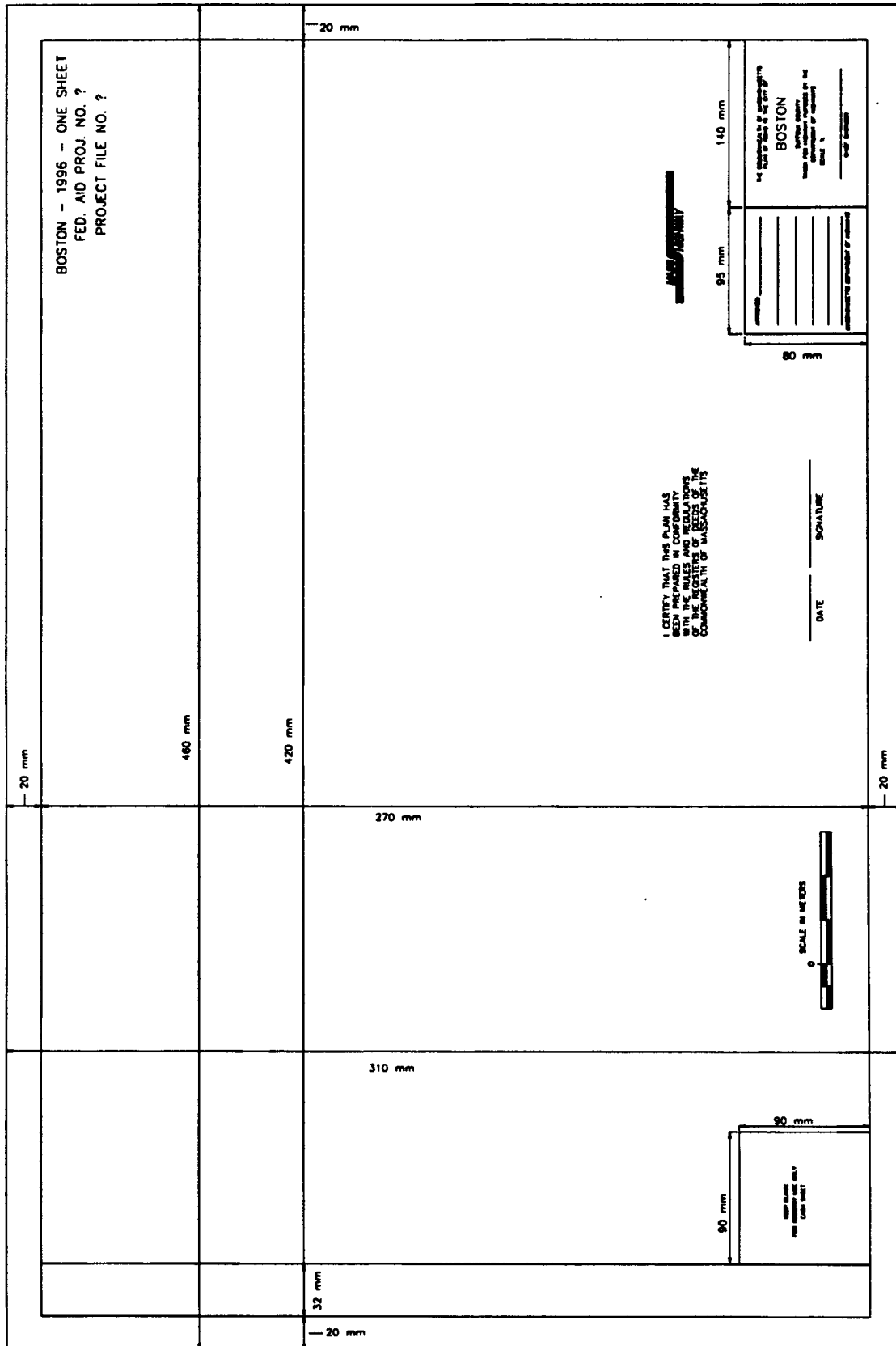
1. On the Right-of-Way Plans, the designer will furnish the tentative location of the layout line.
2. The tentative location is then definitely set and the computations of curves, lengths, bearings, etc., are made. The computed layout data is then shown on the Layout Plans along with Mass. State Plane Coordinates to all angle points, points of curvature, and points of beginning and ending. Deeds, existing state, county, city, and town layouts, survey ties into Mass. Coordinate system, and other sources of information may be needed to complete the above. If the Mass. State Plane Coordinate system is not readily available the MHD should be contacted for further instructions.
3. Layout plans will show proposed layout (location) lines in metric, property lines, corner markers, names of property owners, access and non-access (if limited access highway) points, and the locations of bounds. The plans will indicate existing surface details, such as trees, poles, structures, manholes, curbing, walls, fences, streams, existing streets, etc. All of the above details are shown in black. The proposed details are not shown.
4. The bearings and distances, or radii and lengths of all proposed layout lines are shown in metric, including Mass. State Plane Coordinates to all angle points, points of curvature, and the points of beginning and ending. When a record baseline exists in the area of proposed layout or alteration, it shall be shown on the plan to facilitate in determining locus. (Ties to this baseline are not to be used.)

Data on the layout plans are to be drawn as described below:

1. Layout plans are normally drawn to a scale of either 1:250 or 1:500.
2. Where a record baseline exists and is shown, points of curvature, points of tangency and the applicable description "Main Baseline" or "Auxiliary Baseline" will be shown along each baseline. The 100 meter stations are indicated by small circles with a 3 millimeter diameter. The stations are noted above each circle. Tick marks are shown at 20 meter intervals between the circles. All bearings, distances, and radii are marked below the line.

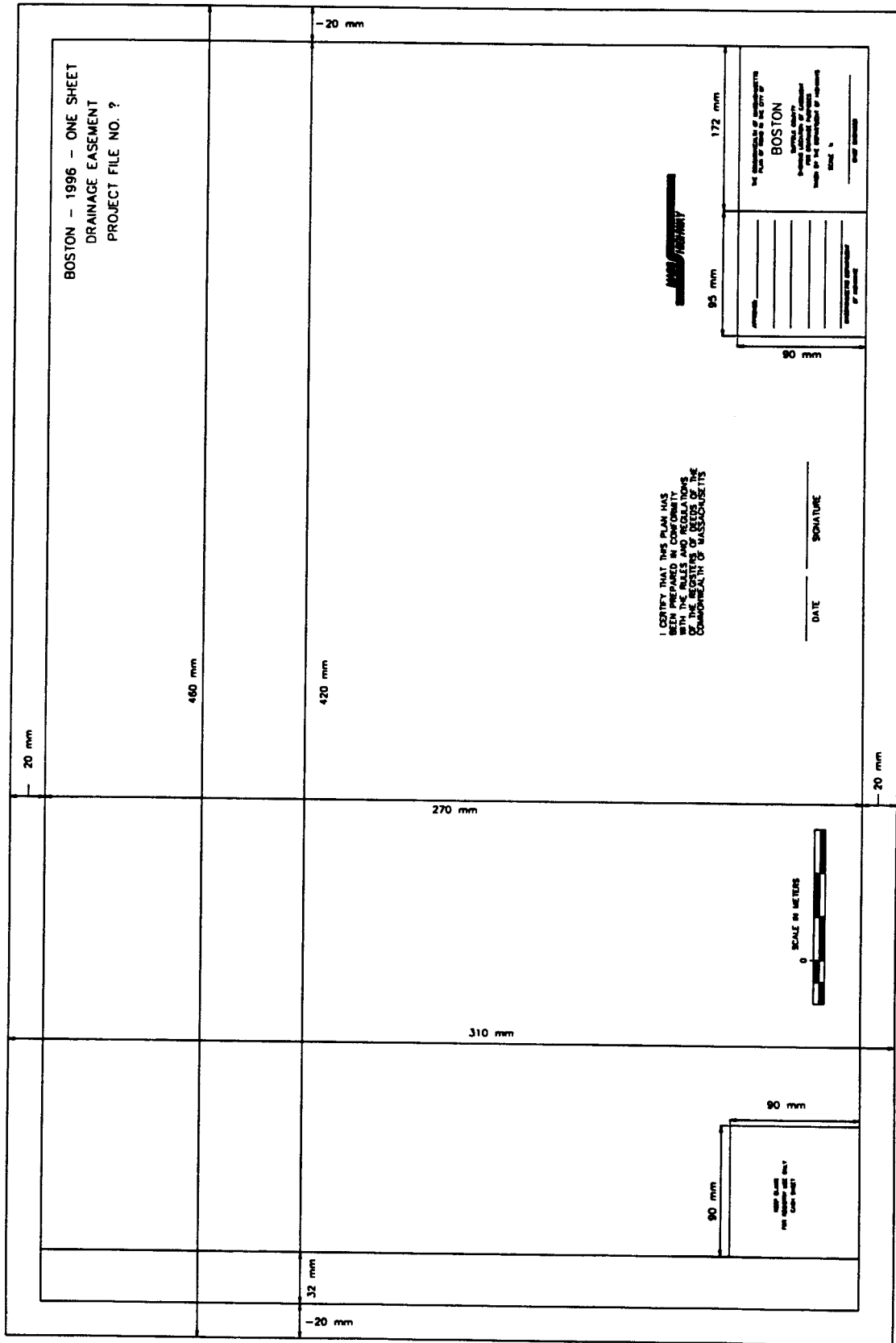


LAYOUT AND ALTERATIONS
Figure 2-13. SIZES OF STANDARD TRACINGS



LAYOUT AND ALTERATIONS
(SMALL SHEETS)

Figure 2-13A. SIZES OF STANDARD TRACINGS



**SPOT TAKINGS AND EASEMENTS
(LARGE SHEET)**

Figure 2-13B. SIZES OF STANDARD TRACINGS

3. The proposed state highway layout line is a heavy, solid line, with bearing, radius, and length indicated along the outside of the line. Access provisions are shown inside the location line.
4. The old state highway layout line, where superseded by a revised state highway location line, is a broken line.
5. The proposed town or city layout line is a solid line. The bearings, radii, and lengths, are indicated along the outside of the line.
6. The old town or city layout line is a broken line. The date that the existing layout line was made is noted along the line.
7. Property lines are shown as broken lines.
8. Each parcel of land to be taken must have its parcel number, owner's name, area and length of each course \pm distances noted. Registered land must show the parcel number, exact name of owner, the words "Registered Land", Land Court case number, Land Court certificate number, book and page number, the area, and the length of each course. Supplementary plans and traverses must be submitted to the Land Court to conform to Land Court Regulations for the land taken and land remaining. Easement locations taken in connection with the layout will be outlined in black, dashed ink lines marked "Line of Easement."
9. Existing state highway location lines shall be identified with the proper notation, as follows: Location Lines of December 20, 1995 State Highway Layout/Alteration (L.O. No. 5678).

In accordance with MHD practice, parcels are numbered in a manner that will indicate permanent or temporary takings and the nature of the rights taken. Locations where rights of access to or egress from existing ways are taken, but no land taking is involved will be designated by parcel numbers AT-1, AT-2, etc.

The written instrument for the Layout and Order of Taking will be prepared according to MHD practice. Four typewritten copies, double-spaced and carefully checked against the layout tracings, must be submitted. Separate plans and written instruments for advance taking and/or additional easements may be required.

All submissions of tracings to the Department shall be comprised of the original tracings and full-size wash mylar reproductions. Electrostatic mylar plots are unacceptable. The reproductions, to be acceptable to the registers of deeds, must meet the most recent Plan Regulations approved by the State Attorney General.

Among the requirements for recording are the following:

1. Plans must be on linen or single matte wash mylar having a thickness of 0.0762 mm. The matte surface and ink must be on the front of the mylar sheet.
2. Ink must be opaque and of archive quality. It is imperative that the ink used on mylar plans be specifically designed for mylar applications to prevent its chipping off.
3. The minimum letter height permitted on plans is 3.175 mm for hand-lettering and 2.54 mm when a machine or template is used.

In addition, the Federal Aid Project No. shall be shown on the upper right-hand corner of the first sheet; the Layout No. shall be shown in the upper right-hand corner of each sheet; and on Limited Access projects the notation "Limited data, parcel nomenclature and existing detail" shall be on one side only on both the original and the reproduction. Also, a key plan is needed for all layouts and alterations where sheets do not follow each other in successive numerical order. No reproductions are needed for key plans.

All layout tracings, supplementary plans and traverse computations for the Land Court will be stamped with the seal of a Massachusetts Registered Land Surveyor. All layout plans will show on the title sheets the words "Plans Prepared By," followed by the name and address of the person or organization responsible. Samples of the supplementary plans and traverses for registered land, general type of layout descriptions, and order of taking may be obtained from the Layout Engineer.

Titles of plans and necessary notes for signature by the Commissioners are shown in Figure 2-16. Table 2.5 provides symbols for layout tracings. Table 2.6 provides abbreviations for Layout Plans. Both of these tables also apply to right-of-way plans.

2.4 RIGHT OF WAY PLANS

These procedures for the preparation of "Right of Way" plans are consistent with the *Federal Aid Policy Guide (FAPG)*. Since these instructions are general, the designer must discuss the content requirements for each project with the Right of Way Bureau.

The "Right of Way" plans are not a substitute or replacement for the Department layout plans described in this manual; both are required.

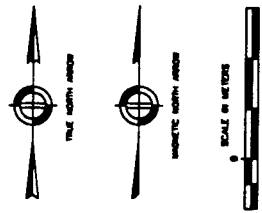
2.4.1 General

Preliminary and final ROW plans will be prepared by the designer as specified and as noted in the *Federal Aid Policy Guide (FAPG)*.

Preliminary and final ROW plans will include all pertinent data affecting the cost of ROW such as structures, land service or access roads, improvements, landscaping, drainage, and fences.

<p>THIS CERTIFIES THAT THE SECTIONS OF ROAD MARKED ON THIS PLAN "TOWN LAYOUT (NAME)" WAS LAD OUT IN BEHALF OF THE TOWN OF (NAME) BY (DATE) UNDER AUTHORITY OF CHAPTER 44B OF THE ACTS OF 1948</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>	<p>THIS CERTIFIES THAT THE SECTION OF ROAD MARKED ON THIS PLAN "ABANDONMENT" WAS ABANDONED BY THE HIGHWAY DEPARTMENT ON (DATE) IN ACCORDANCE WITH CHAPTER 81 OF THE GENERAL LAWS.</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>	<p>THIS CERTIFIES THAT THE SECTION OF ROAD MARKED ON THIS PLAN "DISCONTINUANCE" WAS DISCONTINUED BY THE HIGHWAY DEPARTMENT ON (DATE) IN ACCORDANCE WITH CHAPTER 81 OF THE GENERAL LAWS.</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>	<p>THIS CERTIFIES THAT THE SECTIONS OF ROAD MARKED ON THIS PLAN "TOWN LAYOUT (NAME)" BY (DATE) UNDER AUTHORITY OF CHAPTER 44B OF THE ACTS OF 1948</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>
<p>ABANDONMENT</p>	<p>DISCONTINUANCE</p>	<p>LIMITED ACCESS LAYOUT</p>	<p>LIMITED ACCESS ALTERATION</p>
<p>ALTERATION</p>	<p>ALTERED & AN ADDITIONAL SECTION LAD OUT</p>	<p>LAYOUT</p>	<p>LAYOUTS OR ALTERATIONS UNDER CHAPTER 44B OF 1948</p>
<p>THIS CERTIFIES THAT THE LOCATION OF THE ROAD SHOWN ON THIS PLAN WAS LAD OUT AND TAKEN CHARGE OF AS A STATE HIGHWAY BY THE HIGHWAY DEPARTMENT ON (DATE) IN ACCORDANCE WITH CHAPTER 81 OF THE GENERAL LAWS.</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>	<p>THIS CERTIFIES THAT THE LOCATION OF THE ROAD SHOWN ON THIS PLAN WAS LAD OUT AND TAKEN CHARGE OF AS A STATE HIGHWAY BY THE HIGHWAY DEPARTMENT ON (DATE) IN ACCORDANCE WITH CHAPTER 81 OF THE GENERAL LAWS.</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>	<p>THIS CERTIFIES THAT THE LOCATION OF THE ROAD SHOWN ON THIS PLAN WAS LAD OUT AND TAKEN CHARGE OF AS A STATE HIGHWAY BY THE HIGHWAY DEPARTMENT ON (DATE) IN ACCORDANCE WITH CHAPTER 81 OF THE GENERAL LAWS.</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>	<p>THIS CERTIFIES THAT THE SECTIONS OF ROAD MARKED ON THIS PLAN "TOWN LAYOUT (NAME)" BY (DATE) UNDER AUTHORITY OF CHAPTER 44B OF THE ACTS OF 1948</p> <p>_____ MASSACHUSETTS HIGHWAY DEPARTMENT</p>
<p>ALTERATION</p>	<p>ALTERED & AN ADDITIONAL SECTION LAD OUT</p>	<p>LAYOUT</p>	<p>LAYOUTS OR ALTERATIONS UNDER CHAPTER 44B OF 1948</p>
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<p>ALTERATION</p>	<p>ALTERED & AN ADDITIONAL SECTION LAD OUT</p>	<p>LAYOUT</p>	<p>LAYOUTS OR ALTERATIONS UNDER CHAPTER 44B OF 1948</p>
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<p>ALTERATION</p>	<p>ALTERED & AN ADDITIONAL SECTION LAD OUT</p>	<p>LAYOUT</p>	<p>LAYOUTS OR ALTERATIONS UNDER CHAPTER 44B OF 1948</p>
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<p>ALTERATION</p>	<p>ALTERED & AN ADDITIONAL SECTION LAD OUT</p>	<p>LAYOUT</p>	<p>LAYOUTS OR ALTERATIONS UNDER CHAPTER 44B OF 1948</p>
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<p>ALTERATION</p>	<p>ALTERED & AN ADDITIONAL SECTION LAD OUT</p>	<p>LAYOUT</p>	<p>LAYOUTS OR ALTERATIONS UNDER CHAPTER 44B OF 1948</p>

- BARNSTABLE COUNTY
- BERKSHIRE COUNTY
- BRISTOL COUNTY
- DUKES COUNTY
- ESSEX COUNTY
- FRANKLIN COUNTY
- HAMPDEN COUNTY
- HAMPSHIRE COUNTY
- MIDDLESEX COUNTY
- MANTUCKET COUNTY
- NORFOLK COUNTY
- PLYMOUTH COUNTY
- SUFFOLK COUNTY
- WORCESTER COUNTY



MASS HIGHWAY

THE COMMONWEALTH OF MASSACHUSETTS
PLAN OF ROAD
SECTION OF ROAD

BOSTON

SUFFOLK COUNTY
ALTERED AND LAD OUT AS A STATE HIGHWAY
BY THE DEPARTMENT OF HIGHWAYS

SCALE: 1: _____
DATE: _____
DRAWN BY: _____

Figure 2-14. DATA FOR LAYOUT PLAN AND TITLE SHEET

Table 2.5
SYMBOLS FOR LAYOUT TRACINGS

Proposed State Highway Layout Line	<u>Bearing & Length or Radius & Length</u> No Access / \ Access
Existing State Highway Layout Line	_____ <u>Date of Layout</u> _____
Line of No Transit	<u>Bearing & Length or Radius & Length</u> Line of No Transit
Proposed Town, City, or County Layout Line	<u>Bearing & Length or Radius & Length</u>
Existing Town or City Layout Line	_____ <u>Date of Layout</u> _____
Existing Railroad Sideline	_____ <u>R.R S/L</u> _____
Existing County Layout Line	_____ <u>Date of Layout</u> _____
Town or City Boundry Line	_____ <u>Bearing</u> _____
Property Line	_____ <u>ℙ</u> _____
Approximate Property Line (Cloth Plan Only)	_____ <u>Approximate ℙ</u> _____
Line of Easement	_____ <u>Line of Easement</u> _____

Table 2.6
ABBREVIATIONS FOR LAYOUT AND RIGHT-OF-WAY PLANS

Abbreviations for Fee Takings	
1	Taken in fee in behalf of the Commonwealth
1-C	Taken in fee in behalf of the City
1-T	Taken in fee in behalf of the Town
1-U	Taken in fee (ordinarily conveyed to utility)
1-RR	Taken in fee in behalf of the Railroad
1-X	Excess Land
M-1	Maintenance Area
D-1-F	Drainage Taking in Fee
C-1-F	Channel Taking in Fee
UR-1	Uneconomic Remainder
VP-1	Vehicular Parking
CVP-1	Commuter Vehicular Parking
FRL-1	Functional Replacement Land
RL-1	Replacement Land
Abbreviations for Easement Takings *	
AT-1	Access Taking
B-1	Bridge
BA-1	Bridge Abutment
C-1	Channel
CD-1	Channel Drainage
CL	Construction Limitation
D-1	Drainage
DS-1	Drainage and Slope
E-1	Highway Easement (Portion of Right-of-Way)
E-RR-1	Easement on behalf of Railroad
FB-1	Footbridge
FS-1	Flight of Steps
GD-1	Gravel Dike
GR-1	Guard Rail
GU-1	General Utility
HS-1	Highway Sign
HL-1	Highway Light
PL-1	Power Line
R-1	Right-of-Way taken in behalf of owner of land whose rights of access thereto and egress therefrom would otherwise be inoperative due to limited access provisions
R-B-1	Road and Bridge
R-B-S-1	Road, Bridge and Slope
RD-1	Drainage in connection for removal of demolition of certain structures
RR-1	Railroad Bypass
R-RR-1	Road and Railroad Bypass
RS-1	Slope in connection with Right-of-Way
RT-1	Temporary easement for removal or demolition of certain structures
S-1	Slope
SRE-1	Temporary Sign Removal
SS-1	Sanitary Sewer
SW-1	Sidewalk
SW-S-1	Sidewalk and Slope
TB-1	Tie Back
TE-1	Temporary Easement for various purposes
TR-1	Temporary Road
U-1	Utility Easement (ordinarily conveyed to a utility company)
W-1	Wall
WM-1	Watermain
WMD-1	Watermain and Drainage
WQM-1	Water Quality Monitoring Station
WS-1	Wall and Slope
Abbreviations for Disposition of State Property	
LL	Land Lease (Portion of State Highway)
LR	Land Lease (Not part of State Highway)
LU	Land Use (Portion of State Highway)
LS	Land Sale (Portion of State Highway)
SR	Land Sale (Not part of State Highway)
LA	Land Acquired by Department (usually by deed)

*Notes for Easement Takings:

1. Temporary easements are preceded by letter "T". (For example, TD-1, TW-1, etc.)
2. Easement in behalf of Town, City, Railroad or the M.D.C. are followed by letters: "T", "C", "RR", "MDC" (For example, D-1-T, D-1-C, D-1-RR, D-1-MDC, etc.)
3. EG-1. This symbol is used to delineate an area comprising a portion of State Property in which an easement is to be granted.
4. The symbols listed and described above may be preceded by a number prefix. (For example, 1-1, 1-D-1, 2-1, 2-D-1, etc.)
5. The symbols A, B, C, etc. designate "Spot Takings in Fee." The symbols B-11-1, B-11-2, etc. designate "Block Takings in Fee."

Reference: Massachusetts Department of Highways

The size, form and arrangement of preliminary and final ROW plans will conform to the general requirements of highway plans. They will contain sufficient dimensional and angular data to permit easy identification of all fee parcels and easement areas that are required by the highway project. The following symbols and/or identification information shown on the construction plans will also be shown on ROW plans:

1. Right of Way Federal-aid project number.
2. Scales to be used.
3. A north arrow for each plan sheet and for each insert plan included on any sheet.
4. Access symbols or any other symbols which may be used.
5. A date on each sheet.
6. A revision block to show any changes.
7. Symbols and abbreviations for Layout Plans (Tables 2.5 and 2.6) also apply to ROW Plans.

2.4.2 Preliminary Right of Way Plans

Preliminary ROW plans will be prepared to produce legible reproductions. Each sheet will be labeled "Preliminary Right of Way."

The preliminary ROW plan for Federal Aid projects will remain in the preliminary stage until FHWA has granted authority to the state to acquire ROW with Federal participation in land damage costs. For state funded projects the ROW plan will remain in the preliminary stage until accepted by the Right of Way Division. ROW acquisition information will be posted on the preliminary ROW plan by the designer when the designer obtains the information.

2.4.3 Final Right of Way Plans

After FHWA has granted authority to the state to acquire ROW with Federal participation and/or the ROW Division accepts the preliminary ROW plan, the preliminary ROW plan will become the final ROW plan. Each sheet of the plan will be labeled "Final Right of Way Plan," and the plan will be subject to any additions and revisions that may be required later. Any additions and revisions with dates will be noted.

2.4.4 The Right of Way Plan

The ROW plan shall include the following:

1. *Title Sheet* - The title sheet will include the same information as the title sheet prepared for highway construction drawings. Information noted on the construction plan title sheet which is not germane to the ROW plan should be removed. The following information will be noted on the title sheet of the ROW plan:
 - a. the ROW Federal-aid project number
 - b. project file number
 - c. an index
 - d. the termini baseline stations of the proposed acquisition
 - e. an indication of a preliminary or final ROW plan.
2. *Typical Cross Sections and Critical Profiles* - Typical cross sections with profiles for critical locations will be included in the ROW plan relative to the land damage involved.
3. *Parcel Summary Sheet* - A parcel summary sheet will show the following information:
 - a. all parcel numbers (prefix numbers are supplied by the Department)
 - b. the name of the owner of record
 - c. the areas of each property before taking
 - d. the areas of taking, noting whether the taking is made in fee or as a permanent or temporary easement
 - e. sheet numbers of where a subject property is shown on the location maps and the property plan sheets
 - f. the areas of all portions of an affected property which remain after the takings and the status of access on the remaining portions
 - g. a reference to the book and page where the title is recorded in the appropriate registry of deeds and/or probate court

4. *Location Maps* - A location map will be prepared for projects in which all properties' land damage cannot be entirely shown in baseline sequence on the property plan sheets. When required, a location map will be prepared whether or not a basic ROW plan is available. The location map will be to a scale that will produce legible reproductions, such as 1:2500 in rural areas or 1:1250 or 1:500 in suburban and urban areas. Location maps will be prepared by adding ROW plan information to the basic ROW plan. It will include the following:
 - a. ROW location limits (both existing and proposed), the baseline stations, and the width of the ROW. Any changes in the width should be noted. The type of existing layout should be indicated (State, County, City or Town), and the date of the layout should be indicated.
 - b. Each property affected by land damage resulting from acquisition or construction will be shown. If the entire property cannot be shown on the location map in the property baseline sequence, the entire property will be shown drawn as an insert on a location map sheet at an appropriate scale.
 - c. Every taking from each property will be shown with the parcel number of each taking, its area, the owner's name, the areas and perimeters of all severed parcels, and the remaining access for any severed parcels. A check set of taking computations must be made.
 - d. The areas of the affected parcels are computed.
 - e. All improvements to the property, such as structures, driveways, and fences will be shown.
 - f. Access control lines and approved points of access, where a limitation of access is involved with the acquisition, should be shown.
5. *Property Plan Sheets* - Property Plan Sheets will be prepared as discussed in Section 2.4.2. The following information will be shown for each property on the Property Plan sheets:
 - a. ROW limits and both existing and proposed baseline information with stations, bearings, and distance, and ties to the ROW location and curve data where applicable. The ROW width will be shown and any changes in width will be noted. Information relative to access provisions, if applicable, will be indicated with approved points of access clearly shown.
 - b. Every taking made from each property will be shown with the parcel number of each taking (whether made in fee or as a temporary or permanent easement), its

- area and dimensions, and the owner's name. A check set of computations must be made.
- c. The areas of the affected parcels are computed.
 - d. All improvements included within any taking, such as structures, driveways, landscaping, and fences will be shown.
 - e. The proposed tops and bottoms of slopes will be shown whether within or beyond the limits of the existing or proposed ROW.
 - f. New construction features, such as pavements, structures, and drainage.
 - g. All work to be performed to mitigate land damage.
 - h. All dimensions are to be shown in both the English system and the metric system. Bar scales for both systems shall also be provided.

CHAPTER 3

BASIC DESIGN CONTROLS

Many factors are incorporated into the design criteria used by highway engineers. These include the physical and psychological characteristics of roadway users; the physical dimensions of vehicles and topography; the safety and operating characteristics of the traffic stream; a desire to provide a level of service acceptable to the traveling public; the financial resources of the highway agency; the cost-effectiveness of alternative project designs; and maintenance feasibility and responsibility.

3.1 HIGHWAY SYSTEMS

The Federal-Aid highway system and its relationship to the project funding process cannot be discussed without first reviewing its origins in the concepts and criteria of functional classification.

3.1.1. Functional Classification

Functional classification is defined as the process by which streets and highways are grouped into systems according to the character of service they are intended to provide. Individual roads and streets do not serve travel independently. Each route may have certain specific operating characteristics, but it is the relationship of each individual route to the overall roadway network which defines its placement in the functional classification hierarchy.

The principles for classification of highways according to the function they perform are described in an FHWA publication entitled Highway Functional Classification: Concepts, Criteria and Procedures, revised in March 1989. A publication issued by FHWA in November 1982 reinforces the use of functional classification for Federal-Aid system designation and suggests other uses such as for transportation needs studies and in the proper assignment of highway administrative responsibility. There are three general categories of functional classification systems, as shown in Table 3.1.

The functional classification category of "Local" should not be confused with local jurisdiction or ownership of the roadway. Not all functionally-classified Local roadways in Massachusetts are under city/town jurisdiction, although most of them are.

Table 3.1
FUNCTIONAL CLASSIFICATION SYSTEMS

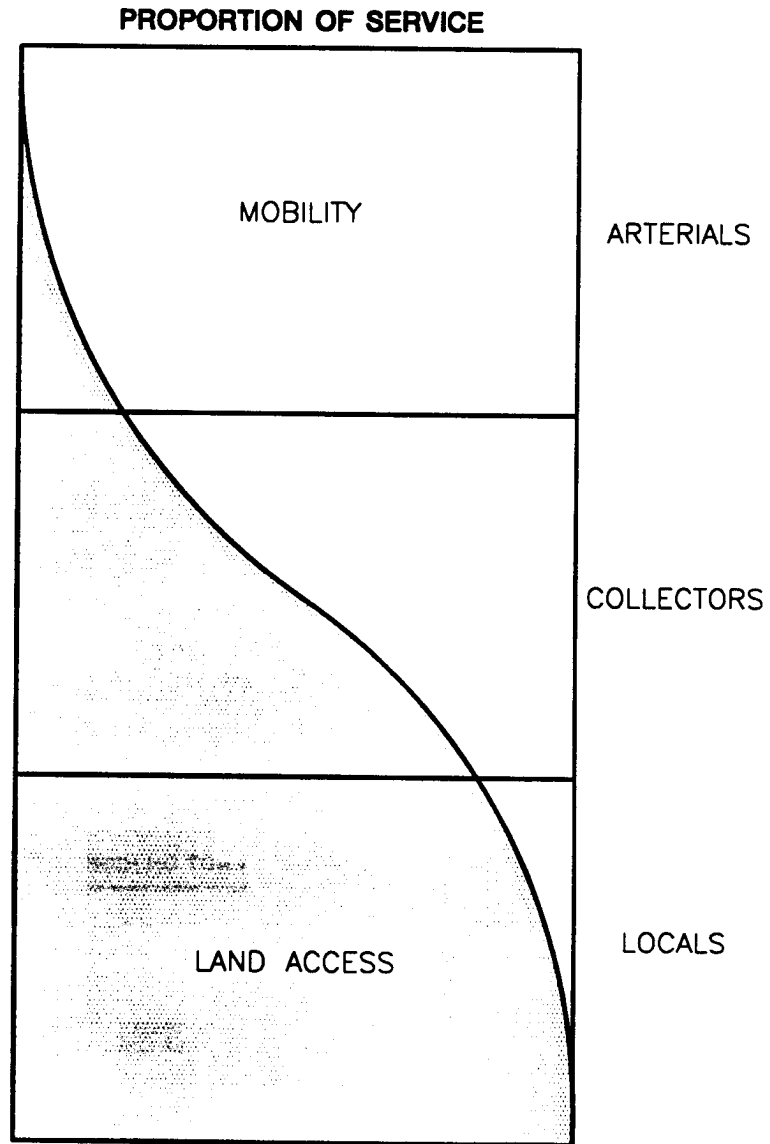
FUNCTIONAL SYSTEMS	TYPE OF SERVICES PROVIDED
ARTERIAL N.H.S./NON N.H.S.	PROVIDES THE HIGHEST LEVEL OF SERVICE AT THE GREATEST VEHICLE SPEED FOR THE LONGEST UNINTERRUPTED DISTANCE. ARTERIALS ARE FURTHER SUBDIVIDED INTO PRINCIPAL ARTERIALS, WHICH PROVIDE THE HIGHEST LEVEL OF SERVICE, AND MINOR ARTERIALS, WHICH SERVE AS ARTERIALS BUT ARE LESS IMPORTANT THAN PRINCIPAL ARTERIALS.
COLLECTOR N.H.S./NON N.H.S.	PROVIDES A LESS HIGHLY DEVELOPED SERVICE AT A LOWER SPEED FOR SHORTER DISTANCES. COLLECTS TRAFFIC FROM LOCAL ROADS AND FUNNELS INTO MAJOR COLLECTORS AND MINOR COLLECTORS IN URBAN AREAS. THERE IS ONLY ONE CATEGORY OF COLLECTOR ROADWAYS.
LOCAL NON N.H.S.	PROVIDES ACCESS TO ABUTTING LAND WITH LITTLE OR NO THROUGH MOVEMENT. CONSISTS OF ALL ROADS NOT CLASSIFIED AS ARTERIAL OR COLLECTORS.

The relationship between mobility and land access for these three general systems is shown in Figure 3-1. In general, it may be stated that arterials provide a high level of mobility and access control, while functionally-classified local roadways provide little mobility and a great deal of land access. Collector roadways serve to balance the need for mobility and land access.

The three general categories of arterial, collector and local are further subdivided into principal, major or minor categories to make them more detailed and useful for planning and engineering purposes, since the road types and quality of service provided can be extremely varied within each general category. The three systems also take on specific characteristics depending upon their geographic location in either Federal-Aid Urban or Rural areas.

The specific characteristics which identify the functional classification systems are shown in Tables 3.2 and 3.3. Table 3.2 lists the characteristics of rural systems, while Table 3.3 lists the characteristics of urban systems.

A set of maps depicting the functional classification of all roadways in Massachusetts is available for inspection at the Bureau of Transportation Planning & Development office. A limited number of copies have been distributed to other sections of the MHD and District Offices. Functional classification codes are also maintained in the Bureau's computerized roadway inventory file which has been linked to a Geographic Information System.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 3-1. MOBILITY AND ACCESS

**Table 3.2
RURAL FUNCTIONAL SYSTEM CHARACTERISTICS**

FUNCTIONAL SYSTEMS	GENERAL CHARACTERISTICS
<p>PRINCIPAL ARTERIAL* N.H.S.</p>	<p>-- SERVES STATEWIDE AND INTERSTATE TRAVEL</p> <p>-- SERVES VIRTUALLY ALL URBANIZED AREAS</p> <p>-- PROVIDES AN INTEGRATED, CONTINUOUS STATEWIDE NETWORK</p>
<p>MINOR ARTERIAL N.H.S./NON N.H.S.</p>	<p>-- LINKS CITIES AND TOWNS AND FORMS AN INTEGRATED NETWORK PROVIDING INTERSTATE AND INTERCOUNTY SERVICE</p> <p>-- SPACED AT PROPER INTERVALS SO THAT ALL DEVELOPED AREAS OF A STATE ARE WITHIN A REASONABLE DISTANCE OF AN ARTERIAL HIGHWAY.</p>
<p>MAJOR COLLECTOR N.H.S./NON N.H.S.</p>	<p>-- PROVIDES CONNECTION FOR URBAN AREAS AND OTHER TRAFFIC GENERATORS OF INTRACOUNTY IMPORTANCE THAT ARE NOT SERVED BY HIGHER SYSTEMS.</p> <p>-- LINKS THESE PLACES WITH NEARBY TOWNS AND CITIES, OR WITH ROUTES OF HIGHER CLASSIFICATION</p>
<p>MINOR COLLECTOR NON N..S.</p>	<p>-- SPACED AT INTERVALS, CONSISTENT WITH POPULATION DENSITY, TO COLLECT TRAFFIC FROM LOCALS</p> <p>-- SERVES ALL REMAINING SMALLER COMMUNITIES</p> <p>-- CONNECTS THE LOCALLY IMPORTANT TRAFFIC GENERATORS WITH THE LESS DEVELOPED PARTS OF THE STATE</p>
<p>LOCAL NON N.H.S.</p>	<p>-- PROVIDES ACCESS TO ADJACENT LAND</p> <p>-- SERVES TRAVEL OVER RELATIVELY SHORT DISTANCES AS COMPARED TO COLLECTORS OR OTHER HIGHER SYSTEMS</p> <p>-- COMPRISES ALL FACILITIES NOT ON HIGHER SYSTEMS</p>

* INCLUDES INTERSTATE AND OTHER PRINCIPAL ARTERIALS

Note: SEE C.E.P.O. FOR N.H.S. DETERMINATION

Table 3.3
URBAN FUNCTIONAL SYSTEM CHARACTERISTICS

FUNCTIONAL SYSTEMS	GENERAL CHARACTERISTICS
<p>PRINCIPAL ARTERIAL* N.H.S.</p>	<p>-- SERVES THE MAJOR TRAFFIC MOVEMENTS WITHIN URBANIZED AREAS SUCH AS BETWEEN CENTRAL BUSINESS DISTRICTS AND OUTLYING RESIDENTIAL AREAS, BETWEEN MAJOR INTERCITY COMMUNITIES, OR BETWEEN MAJOR SUBURBAN CENTERS</p> <p>-- SERVES A MAJOR PORTION OF THE TRIPS ENTERING AND LEAVING THE URBAN AREA, AS WELL AS THE MAJORITY OF THE THROUGH TRAFFIC DESIRING TO BYPASS THE CENTRAL CITY</p> <p>-- PROVIDES CONTINUITY FOR ALL RURAL ARTERIALS WHICH INTERSECT THE URBAN AREA</p>
<p>MINOR ARTERIAL N.H.S./NON N.H.S.</p>	<p>-- SERVES TRIPS OF MODERATE LENGTH AT A SOMEWHAT LOWER LEVEL OF TRAVEL MOBILITY THAN PRINCIPAL ARTERIALS</p> <p>-- PROVIDES ACCESS TO GEOGRAPHIC AREAS SMALLER THAN THOSE SERVED BY THE HIGHER SYSTEMS</p> <p>-- PROVIDES INTERCOMMUNITY CONTINUITY BUT DOES NOT PENETRATE IDENTIFIABLE NEIGHBORHOODS</p>
<p>COLLECTOR NON N.H.S.</p>	<p>-- COLLECTS TRAFFIC FROM LOCALS AND CHANNELS IT INTO THE ARTERIAL SYSTEM</p> <p>-- PROVIDES BOTH LAND ACCESS AND TRAFFIC CIRCULATION WITH RESIDENTIAL NEIGHBORHOODS, COMMERCIAL, AND INDUSTRIAL AREAS</p>
<p>LOCAL NON N.H.S.</p>	<p>-- COMPRISES ALL FACILITIES NOT ON HIGHER SYSTEMS</p> <p>-- PROVIDES ACCESS TO LAND AND HIGHER SYSTEMS</p> <p>-- THROUGH TRAFFIC USAGE DISCOURAGED</p>

* INCLUDES INTERSTATE, URBAN OTHER FREEWAY AND EXPRESSWAY AND OTHER URBAN PRINCIPAL ARTERIALS

Note: SEE C.E.P.O. FOR N.H.S./NON N.H.S. DETERMINATION

3.1.2 Federal-Aid System

The initial identification of a system of roads that were of Federal importance resulted from the passage of the Federal-Aid Highway Act of 1921. Although not referred to as functional classification at that time, the principles of functional classification were used to select a system of roads important for intrastate and interstate motor vehicle travel. This system of roads was designated the Federal-Aid Primary (FAP) system. The 1940's saw the selection of an interconnected system of principal secondary and feeder roads based upon the concepts of functional classification. This was designated the Federal-Aid Secondary (FAS) system. An interconnected system of roads in urban areas, known as the Federal-Aid Urban System (FAUS), was added in 1976.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) dramatically altered the former Federal-Aid systems. In place of the former, FAP, FAS and FAUS systems, a single new Federal-Aid system called the National Highway System (NHS) was created. The National Highway System was designed to consist of an integrated network of the most important roads and streets in the country that support interstate and interregional travel and commerce. The system provides links to the most important ports, airports, intermodal transportation facilities and public transportation facilities. All Interstate routes are included in the NHS, as well as most other principal arterial routes.

ISTEA also created a new, block-grant-type funding program called the Surface Transportation Program (STP). Under the Surface Transportation Program (STP), Federal aid that was formerly restricted to individual FAP, FAS and FAUS Federal-Aid systems became available for use on any roads (including the NHS) that were not functionally classified as local or rural minor collector. Roads functionally classified as rural minor collector and local are not eligible for Federal-Aid funding under the STP.

Maps showing highways and streets included in the NHS are available for inspection at the Bureau of Transportation Planning & Development, and copies have been distributed throughout the MHD and District Offices.

Table 3.4 shows the relationship between the NHS and STP Federal-Aid categories and highway functional classification.

Table 3.4

**RELATIONSHIP BETWEEN HIGHWAY FUNCTIONAL CLASSIFICATIONS,
FEDERAL-AID CATEGORIES AND STATE-AID SYSTEMS**

FUNCTIONAL CLASSIFICATIONS	FEDERAL-AID CATEGORY	STATE-AID SYSTEM
FEDERAL AID RURAL AREAS		
INTERSTATE**	NHS	--
OTHER PRINCIPAL ARTERIAL**	MOSTLY NHS	PRIMARY
MINOR ARTERIAL	MOSTLY STP	PRIMARY
MAJOR COLLECTOR	STP	PRIMARY
MINOR COLLECTOR	--	PRIMARY
LOCAL	--	LOCAL
FEDERAL AID URBAN AREAS		
INTERSTATE**	NHS	--
OTHER FREEWAY AND EXPRESSWAY**	MOSTLY NHS	PRIMARY
OTHER PRINCIPAL ARTERIAL**	NHS OR STP	PRIMARY
MINOR ARTERIAL	MOSTLY STP	PRIMARY
COLLECTOR	STP	PRIMARY
LOCAL	--	LOCAL

** DENOTES A PRINCIPAL ARTERIAL

Note: SURFACE TRANSPORTATION PROGRAM (STP) FUNDS MAY BE USED ON THE NATIONAL HIGHWAY SYSTEM (NHS)

A Federal-Aid urban boundary is defined as either:

1. An urban place as designated by the Bureau of the Census having a population of 5000 or more and not within any urbanized area; or
2. An urbanized area designated by the bureau of the Census.

The Federal-Aid Urban boundaries must encompass the entire area as designated above in either (1) or (2), as appropriate, plus that adjacent area as agreed upon by local officials in cooperation with the State. The urban boundaries were totally reviewed by the Bureau of Transportation Planning & Development in 1993 and revised to reflect the results of the 1990 U.S. Census of Population. Rural areas are those areas not considered urban by the above definitions.

3.1.3 Massachusetts' State-Aid Program

The State-Aid Primary system in Massachusetts consists of all roads under city/town jurisdiction that are functionally classified as arterials or collectors. Prior to the enactment of Chapter 33, Acts of 1991, State-Aid capital improvements on roads on the State-Aid Primary

system were eligible for 100% State funding, while roads not on this system (functional classification local) required a 25% funding match by cities and towns with the State paying the remaining 75%. Commencing with funds provided for under Chapter 33, Acts of 1991, the law was changed to eliminate the requirement for 25% local funding match on roads not on the State-Aid Primary System. State-Aid funds provided under Chapter 33, Acts of 1991 and Chapter 85, Acts of 1994, provide for 100% State reimbursement for eligible State-Aid capital projects.

In order for a road to be eligible for State-Aid funding, a road must be an accepted public road. Administrative system (jurisdiction) codes are contained in the computerized BTP&D road inventory file. Copies of these printouts are distributed to District offices and to cities and towns through District State-Aid Engineers upon request.

3.1.4. Route Selection and Approval

Functional Classification

The process of classifying roadways into functional classification categories is performed by the Bureau of Transportation Planning & Development (BTP&D) working in conjunction with Regional Planning agencies (RPA's). A statewide functional reclassification of highways in Massachusetts was performed in 1993, endorsed by the Metropolitan Planning Organization (MPO) within each region, and approved by FHWA.

Requests for changes in the functional classification are reviewed by the appropriate Regional Planning Agencies for conformance with established regional transportation plans, programs and policies. Proposed changes are then reviewed by BTP&D for conformance with the FHWA functional classification criteria and with FHWA guidelines for the percentage of total mileage within each category. Upon concurrence with the proposed changes or additions, the Bureau prepares the necessary documents and submits the proposal for MPO endorsement. After MPO endorsement, the proposed change is submitted to FHWA for its approval. Upon notification by FHWA of its approval, the change becomes effective and the Bureau notifies all affected parties with maps and documentation of the changes.

National Highway System

Routes proposed for inclusion in the Nation Highway System (NHS) were selected using FHWA criteria by BTP&D in 1993 following the functional reclassification. Maps showing the proposed NHS network were reviewed within MHD, District offices, RPA's and MPO's and

revisions were made based on comments received. Formal MPO endorsement of the NHS was not required. The proposed network was submitted to FHWA and approved with minor changes in mid-1993, at which time FHWA submitted the proposed system for all States to Congress for its approval. As of 1994, the proposed NHS in Massachusetts consists of 1866 miles. Procedures for making revisions in the NHS have not yet been adopted.

Maintenance of functional classification and National Highway System records and maps is the responsibility of the Bureau of Transportation Planning & Development.

3.2 ACCESS CONTROL

Access control is defined as the condition where the public authority fully or partially controls the right of abutting owners to have access to and from the highway. As discussed in Section 3.1, the functional classification of a highway is partially determined by the degree of access it allows. Access control may be exercised by statute, zoning, right-of-way purchases, driveway controls, turning and parking regulations, and geometric design (e.g., grade separations and frontage roads).

3.2.1 Full Control

Full control of access is achieved by giving priority to through traffic by providing access only at grade-separated interchanges with selected public roads. No at-grade crossings or private driveway connections are allowed. The freeway is the common term used for this type of highway. Full control of access maximizes the capacity, safety, and vehicular speeds on the freeway.

3.2.2 Partial Control

Partial control of access is an intermediate level between full control and regulatory restriction. Priority is given to through traffic, but a few at-grade intersections and private driveway connections may be allowed. Partial control of access may be provided for certain rural expressways. The proper selection and spacing of at-grade intersections and service connections will provide a balance between the mobility and access service and safety of the highway.

3.2.3 Statute, Zoning and Regulation

Most highways warrant some level of access control. If access points are properly spaced and designed, the adverse effects on highway capacity and safety will be minimized. These points should be located where they can best suit the traffic and land-use characteristics of the highway under design. The design should enable vehicles to enter and exit safely with a minimum of interference to through traffic.

Statutory control may be used, for example, on a rural or urban arterial highway to limit access only to public road crossings. Zoning may be used to effectively control the adjacent property development so that major generators of traffic will not develop. However, zoning restrictions are at the discretion of the local government. Driveway regulations and permits are used to control the geometric design of an entrance, driveway spacing, and driveway proximity to public road intersections. Section 7.4 discusses the applicable criteria for driveway designs. Local access is governed by the municipality.

3.3 HUMAN AND VEHICULAR FACTORS

Human and vehicular factors will greatly influence the design criteria which are used. When these are properly accommodated, the safety and serviceability of the highway system are greatly enhanced. When they are not accommodated, accidents and inefficient operation often result. In addition, there should be a consideration of highway serviceability to businesses and residential users and the economic health of the region.

3.3.1 Human Factors

People have varied operating skills, experience, intelligence, and physical condition. Human factors that are often considered in highway design include driving habits, the ability to make decisions, driver expectancy, decision and reaction time, conformance to the natural path of movement, and pedestrian and bicyclists use and habits. The AASHTO *Policy on Geometric Design of Highways and Streets* discusses human factors in detail.

3.3.2 Vehicular Factors

The characteristics of vehicles using the highway are important controls in geometric

design. These will vary according to the type of vehicle being considered. When a highway facility or intersection is under design, the largest design vehicle likely to use that facility with considerable frequency should be used to determine the selected design values. Typically, trucks have the greater influence on design. Table 3.5 presents basic information on dimensions for the standard design vehicles.

Following is a brief discussion of the vehicle characteristics used in arriving at design values:

1. Stopping sight distances depend on the vehicle braking characteristics and the coefficients of friction between tire and roadway. Horizontal curvature depends on the side friction between tire and roadway, among other factors.
2. Truck acceleration and deceleration rates are critical factors in the design of highway vertical alignment.
3. Vehicles are restricted in how sharply they can negotiate a turn. The minimum vehicle turning paths lead directly to the required curb radii at intersections, which are discussed in detail in Chapter 7. Another turning characteristic of vehicles is the transitional nature of its turning path. Vehicles cannot immediately turn to their desired turning radius but have an entering and exiting transition into that radius. This has led to the use of three-centered compound curves or spirals on highway mainlines.
4. The design of highway barriers and other safety appurtenances is directly or indirectly related to many vehicle characteristics. These include weight, crash characteristics, bumper height, vehicle interior, and suspension systems. The designer should realize that the state of the art does not currently provide safety appurtenances which will properly accommodate the entire range of vehicles within all performance measures and economic feasibility. In addition to safety appurtenances, the crash characteristics of vehicles are reflected in the design of all roadside elements such as side slopes and drainage ditches.

Table 3.5
VEHICLE DIMENSIONS
(See Figures 7-1 thru 7-7)

DESIGN VEHICLE TYPE	SYMBOL	WHEELBASE (m)	DIMENSION			
			OVERHANG		TOTAL	
			FRONT	REAR	LENGTH	WIDTH
PASSENGER CAR	P	3.4	0.9	1.5	5.8	2.1
SINGLE UNIT TRUCK	SU	6.1	1.2	1.8	9.1	2.6
SINGLE UNIT BUS	BUS	7.6	2.1	2.4	12.1	2.6
ARTICULATED BUS	A-BUS	5.5	2.6	2.9	11.0	2.6
SEMITRAILER COMBINATION, LARGE	WB-12	$4.0 + 8.2 = 12.2$	1.2	1.8	15.2	2.6
SEMITRAILER COMBINATION, LARGE	WB-15	$6.1 + 9.1 = 15.2$	0.9	0.6	16.7	2.6
SEMITRAILER - FULL - TRAILER, COMBINATION ¹	WB-18	$3.0 + 6.1 + 1.2^2 + 1.6^3 + 6.4 = 18.3$	0.6	0.9	19.9	2.6

1. CURRENTLY IN RESTRICTED USE IN MASSACHUSETTS, JANUARY 1988.
2. DISTANCE FROM THE REAR EFFECTIVE AXLE TO THE HITCH POINT
3. DISTANCE FROM THE HITCH POINT TO THE LEAD EFFECTIVE AXLE OF THE FOLLOWING UNIT.

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREET" AASHTO, 1994

3.4 SPEED

The highway should be designed to accommodate the speed desires of most highway users, within the limits of safety.

3.4.1 Design Speed

Design speed is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern. Design speed, perhaps more so than any other design control, will have a major impact on all facets of geometric design. Many design elements such as horizontal and vertical curvature, superelevation, and sight distances, are directly dependent on the design speed. Other features, such as lane and shoulder width and clear recovery zones, vary with design speed but are not a direct function of design speed.

The selected design speed should be a reasonable balance between topography, urban or rural character, and the functional use of the highway. The designer must weigh the benefits of a desired degree of safety, mobility, and efficiency against the environmental, right of way, and cost impacts. Design speeds fall between 30 km/h and 120 km/h at 10 km/h increments. Table 3.6 provides recommended design speeds for varying conditions. Higher or lower design speeds may be appropriate depending on site conditions.

**Table 3.6
DESIGN SPEEDS**

FUNCTIONAL CLASSIFICATION	U/R	DESIGN SPEED								
FREEWAY/EXPRESSWAY	URBAN	DESIGN SPEED SHOULD NOT BE LESS THAN 80 km/h								
	RURAL	110 km/h SHOULD BE USED. IN MOUNTAINOUS TERRAIN, A DESIGN SPEED OF 80 km/h OR 100 km/h MAY BE USED								
ARTERIAL	URBAN	MAY RANGE FROM 50 km/h TO 100 km/h. BELOW 70 km/h APPROPRIATE FOR BUILT-UP AREAS. ABOVE 80 km/h IS APPROPRIATE FOR OUTLYING AREAS.								
	RURAL	<table style="width: 100%; border: none;"> <tr> <td style="width: 150px;">LEVEL</td> <td style="width: 10px;">-</td> <td style="width: 100px;">110 km/h</td> </tr> <tr> <td>ROLLING</td> <td>-</td> <td>100 km/h</td> </tr> <tr> <td>MOUNTAINOUS</td> <td>-</td> <td>80 km/h</td> </tr> </table>	LEVEL	-	110 km/h	ROLLING	-	100 km/h	MOUNTAINOUS	-
LEVEL	-	110 km/h								
ROLLING	-	100 km/h								
MOUNTAINOUS	-	80 km/h								
COLLECTOR	URBAN	MINIMUM OF 50 km/h								
		OVER 2000 ADT: <table style="width: 100%; border: none;"> <tr> <td style="width: 150px;">LEVEL</td> <td style="width: 10px;">-</td> <td style="width: 100px;">100 km/h</td> </tr> <tr> <td>ROLLING</td> <td>-</td> <td>80 km/h</td> </tr> <tr> <td>MOUNTAINOUS</td> <td>-</td> <td>60 km/h</td> </tr> </table> SEE PAGE 461 OF 1994 AASHTO POLICY ON GEOMETRIC DESIGN FOR ADT BELOW 2000.	LEVEL	-	100 km/h	ROLLING	-	80 km/h	MOUNTAINOUS	-
LEVEL	-	100 km/h								
ROLLING	-	80 km/h								
MOUNTAINOUS	-	60 km/h								
LOCAL	URBAN	MAY RANGE FROM 30 km/h TO 50 km/h DEPENDING ON AREA CONTROLS.								
	RURAL	SEE PAGE 419 OF 1994 AASHTO POLICY ON GEOMETRIC DESIGN.								

The element of roadway user expectancy must be considered when selecting the design speed. The driver expects to be able to drive at certain maximum speeds based on the functional and rural or urban character of the highway. Therefore, the design speed should fit the travel classification desires and habits of the majority of roadway users.

Traffic volumes may also impact the selection of design speed. With all other factors equal, a higher volume highway may justify a higher design speed because of the increased capacity and savings in vehicle operating costs. However, the designer should consider that at low volumes, roadway users are likely to travel at higher speeds. Therefore, the values in Table

3.6 are applicable to a wide range of traffic volumes.

Design speed control applies to a lesser degree in highly-developed areas than in rural areas or freeways. Despite the design speed determined by horizontal and vertical alignment, the extent of roadside access to residences and businesses and frequency of signals will greatly affect the operating speed. Designing for greater design speeds higher than that which can be accommodated by abutting land use is undesirable.

3.4.2 Running Speed

Running speed is the speed of a vehicle over a specified section of highway. It is equal to the distance traveled divided by the running time. More often, Average Running Speed (ARS) is used, which is the distance summation for all vehicles divided by the time summation. Approximately half of all vehicles will travel faster or slower than the average running speed.

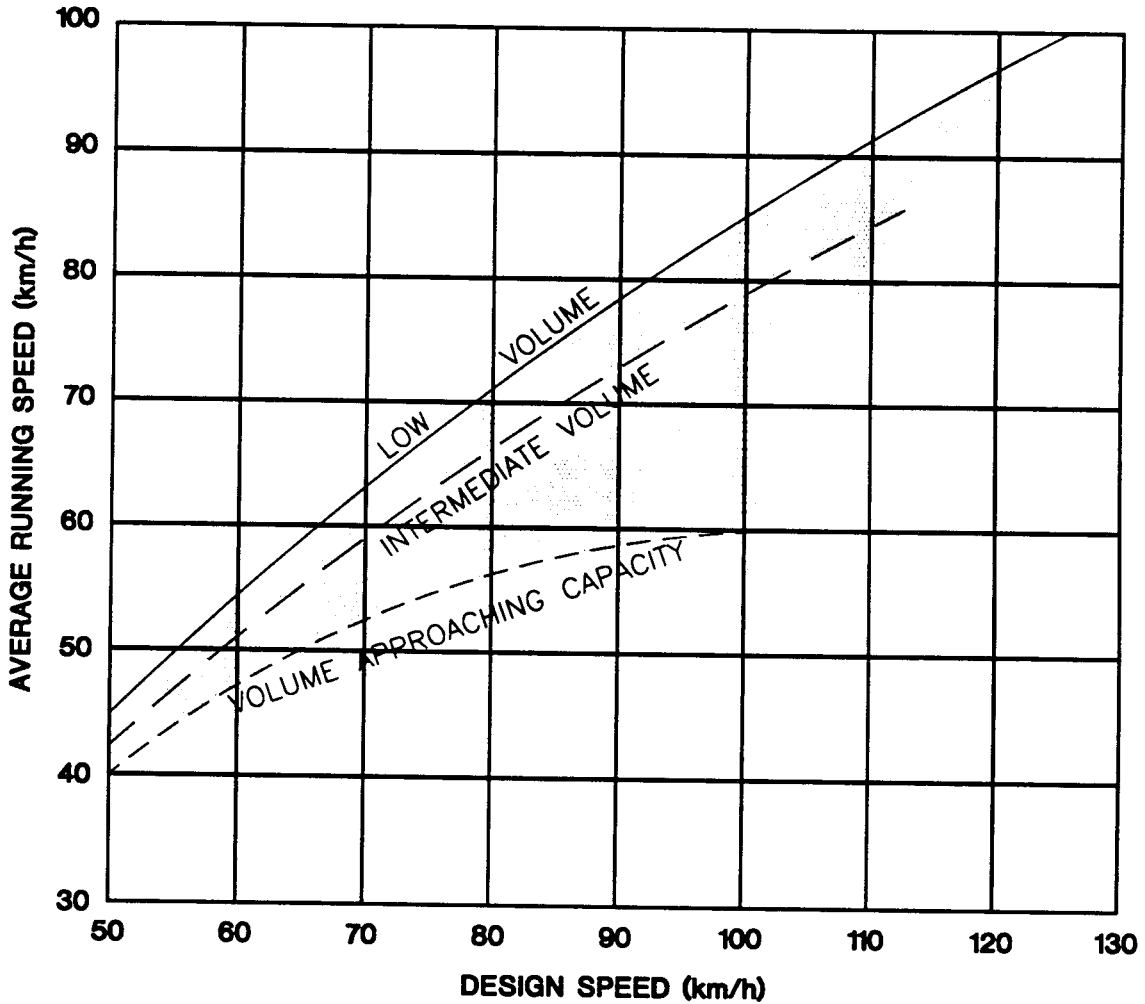
Running speed has an important place in design. It is a useful measure of highway service and provides a means to evaluate highway costs and benefits. The relationship between design speed and average running speed varies, as illustrated in Figure 3-2. At low volumes and low design speeds, average running speed may be very close to design speed; as volumes increase and design speed is higher, the differences increase and can become very large.

On urban highways and streets the running speed is a more important measure than the design speed. Urban streets should be designed and control devices regulated to permit running speeds of 30 km/h to 70 km/h. The lower range is appropriate for local and collector streets and arterials in the Central Business District (CBD), while the higher range should be achieved on arterials away from the CBD. A general approximation is that running speeds of 30 km/h to 70 km/h require design speeds of 50 km/h to 100 km/h.

3.4.3 Posted Speed

The posted speed limit may be determined in two ways:

1. The posted speed limit is based on an engineering evaluation of each site. The Department typically evaluates the sites according to the criteria in the *Manual on Uniform Traffic Control Devices*.
2. The statutory speed limit which is determined by state and local jurisdiction.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 3-2. AVERAGE RUNNING SPEED VERSUS DESIGN SPEEDS

3.5 TRAFFIC CHARACTERISTICS AND HIGHWAY CAPACITY

3.5.1 Traffic Characteristics

Many traffic operational characteristics have a significant impact on the applicable design criteria. The highway designer should attempt to provide a facility which will reasonably accommodate all anticipated traffic characteristics in the selected design year. The *Highway Capacity Manual* contains a more detailed description of the operational factors of highways, and the designer should refer to it as needed.

3.5.1.1 Volume

Traffic volumes indicate the total load a highway facility must accommodate. These definitions are important.

1. *Average Annual Daily Traffic (AADT)* - The total yearly volume divided by the number of days in the year.
2. *Average Daily Traffic (ADT)* - The calculation of average traffic volumes in a time period greater than one day and less than one year. ADT is often incorrectly used by interchanging it with AADT.
3. *Peak-Hour Traffic* - The highest number of vehicles passing over a section of highway during 60 consecutive minutes.
4. *Peak-Hour Factor (PHF)* - A ratio of the volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour. Typically, this is 5 minutes for freeways and 15 minutes for intersections.
5. *Design Hourly Volume (DHV)* - The 1-hour volume in the design year selected for determining the highway design. It results from the consideration of many traffic characteristics.

The ADT is useful in making design decisions related to the total user benefit of a proposed improvement. For example, the benefit of highway safety roadside improvements is directly related to the exposure (ADT) to which the roadside is subjected. For most geometric design elements, however, the peaking characteristics are more appropriately used. An analysis of peaking trends has led to the conclusion that, generally, the 30th highest hourly volume (30th HV) in the selected design year is a reasonable design control. The design hourly volume (DHV) will affect many design elements including the number of travel lanes, lane and shoulder width,

and intersection layout.

Traffic forecasts for DHV, AADT, D, K, T(PH), and T(AADT) are generally prepared by the Bureau of Transportation Planning and Development. A simple analysis would be predicting the 30th highest hourly volume in 20 years by applying the traffic growth factors to present volumes. The forecaster must also incorporate the impact of any anticipated land development or traffic diversions onto or away from the facility. In addition, the traffic characteristics of directional distribution (D), composition, and level of service must be addressed. For intersections and interchanges, DHV forecasts must be made for every possible through and turning movement.

A highway should be designed to accommodate the traffic that might occur within the life of the facility under reasonable maintenance. This involves projecting the traffic conditions for a selected future year. Traffic volume projections are usually made for the 15-25 year range, with 20 years from the expected facility completion date most often chosen. This is a reasonable compromise between a facility's useful life, the uncertainties of long range projections, and the consequences of inaccurate projections.

3.5.1.2 Directional Distribution (D)

ADT and DHV are expressed as 2-way volumes. Therefore, without data on the percentage of volume in each direction during the DHV, an assumption of a 50-50 split could lead to a serious design inaccuracy. Typically, the distribution in the predominant direction during the peak hour will vary from 55% to 70%. Occasionally, it will be as high as 80%.

3.5.1.3 Composition

Large vehicles such as trucks have different operating characteristics than passenger cars and bicycles. The impact of large vehicles on traffic operation will have the effect of several cars. Therefore, the percentage of truck traffic (T) must be determined. For highway capacity purposes, a truck is typically defined as all buses, single-unit trucks, and truck combinations other than light delivery trucks. Light delivery trucks have 2 axles with 4 tires. Normally, trucks have a gross vehicle weight of greater than 4100 kilograms. The designer must also determine the specific truck percentage during the peak hour, which is almost always less than the truck percentage for a 24-hr period. In addition, the stop and go impact of local city transit must be considered.

3.5.1.4 Levels of Service

The average highway user will tolerate a certain level of congestion and delay before he becomes frustrated or attempts unsafe driving maneuvers. This level will vary according to the type of facility. For instance, a user expects a relatively free-flow condition on a rural freeway, but will accept a certain number of stops and delays and heavier traffic volumes on a signalized urban arterial.

To characterize acceptable degrees of congestion, the level-of-service concept has been developed. The various levels have been subjectively determined and qualitatively described. From these descriptions, quantitative measures of volume-to-capacity ratio (v/c), operating speeds, and intersection load factors have been developed. Table 3.7 provides the information for levels of service from A to F.

The application of level of service involves choosing the appropriate level for the selected design year. The highway designer should attempt to provide the highest level feasible. Table 3.8 offers general guidelines for use in selecting the level of service.

Table 3.8
MINIMUM LEVEL OF SERVICE GUIDELINES

HIGHWAY TYPE	TYPE OF AREA AND APPROPRIATE LEVEL OF SERVICE			
	RURAL LEVEL	RURAL ROLLING	RURAL MOUNTAINOUS	URBAN AND SUBURBAN
FREEWAY ¹	B	B	B	C
ARTERIAL	B	B	C	C
COLLECTOR	C	C	C	C
LOCAL	C	C	C	C

Note: LEVEL OF SERVICE D, E, AND F ARE NOT NORMALLY USED FOR DESIGN.

1. SEE HIGHWAY CAPACITY MANUAL TO DETERMINE LEVEL OF SERVICE FOR FREEWAYS IN DESIGN YEAR.

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Table 3.7
LEVEL OF SERVICE BY HIGHWAY TYPE

LEVEL OF SERVICE	CONTROLLED ACCESS ¹ HIGHWAYS	MULTI-LANE RURAL W/O ACCESS CONTROL	TWO-LANE	URBAN AND SUB-URBAN ARTERIALS
A	Free flow. Operating speeds at or greater than 100 km/h. Service volume of 1400 passenger cars per hour on 2-lanes, one direction. Each additional lane serves volume of 1000 vph/lane.	Operating speeds of 100 km/h or higher. 75% of passing maneuvers can be made with little or no delay. Under ideal conditions, a service volume of 400 passenger vehicles/hour, two-way, can be achieved.	Operating speed 100 km/h or greater. Under ideal conditions, volume is limited to 600 passenger cars per lane per hour or 30 percent of capacity. Average speeds are likely to be influenced by speed limits.	Average over-all travel speed of 50 km/h or more. Free flowing with volume/capacity ratio of 0.80. Load factor at intersections near the limit of the 0.0 range. Peak-hour factor of about 0.70.
B	Higher speed range of stable flow. Operating speed of or greater than 90 km/h. Service volume on 2-lanes in one direction not greater than 2000 passenger vehicles per hour. Each additional lane above two in one direction can serve 1500 vph.	Operating speeds of 80 km/h or higher. Volumes may reach 45% of capacity with continuous passing sight distance. Volumes of 900 passenger cars per hour, two-way can be carried under ideal conditions.	Beginning of stable flow area. Volume at which actions of preceding vehicle will have some influence on following vehicles. Volume will not exceed 50% of capacity or 1000 passenger vehicles per lane per hour at 90 km/h operating speed under ideal conditions.	Average over-all speeds drop due to intersection delay and inter-vehicular conflicts, but remain at 40 km/h or above. Delay is not unreasonable. Volumes at 0.70 of capacity and peak-hour factor approximately 0.80. Load factor at intersections approx. 0.1.
C	Operation still stable, but becoming more critical. Operating speed of 80 km/h and service flow on two-lanes in one direction at 75% of capacity or not more than 5 min. flow rate of 3000 passenger cars per hour. Under ideal conditions each additional lane above two in one direction would serve 1800 vph.	Flow still stable. Operating speeds of 70 km/h or above with total volume under ideal conditions equal to 70% of capacity with continuous passing sight distance, or 1400 passenger vehicles per hour, two-way.	Stable flow to a volume not exceeding 75% of capacity or 1500 passenger cars per lane per hour, under ideal conditions, maintaining at least 80 km/h operating speed.	Service volumes about 0.80 of capacity. Average over-all travel speeds of 30 km/h. Operating conditions at most intersections approximate load factor of 0.3. Peak hour factor approximately 0.85. Traffic flow still stable with acceptable delays.
D	Lower speed range of stable flow. Operation approaches instability and is susceptible to changing conditions. Operating speeds approx. 70 km/h & service flow rates at 90% of capacity. Peak 5 min. flow under ideal conditions cannot exceed 3600 vph for 2-lanes, 1 direction; 1800 vph each added lane.	Approaching unstable flow. Operating speeds approx 60 km/h. Volumes, two-direction, at 85% of capacity with continuous passing sight distance, or 1400 passenger vehicles per hour, two-way.	Approaching unstable flow at volumes up to 90% of capacity or 1800 passenger cars per lane per hour at an operating speed of about 60 km/h under ideal conditions.	Beginning to tax capabilities of street section. Approaching unstable flow. Service volumes approach 0.90 of capacity. Average over-all speeds down to 25 km/h. Delays at intersections may become extensive with some cars waiting two or more cycles. Peak hour factor approx. 0.90; load factor of 0.7.
E	Unstable flow. Over-all operating speeds of 50-60 km/h. Volumes at capacity or about 2000 vph lane under ideal conditions. Traffic flow metered by design constraints and bottlenecks, but long back-ups do not normally develop upstream.	Operating speeds in neighborhood of 50 km/h but may vary considerably. Volumes under ideal conditions, two-way, equal to 2000 passenger vehicles per hour. Level E may never be attained. Operation may go directly from Level D to Level F.	Flow at 100% of capacity or 2000 passenger cars per lane per hour under ideal conditions. Operating speeds of about 50 km/h or less.	Service volumes at capacity. Average over-all traffic variable but in area of 25 km/h. Unstable flow. Continuous back-up on approaches to intersections. Load factor at intersections in range between 0.7 and 1.0. Peak hour factor likely to be 0.95.
F	Forced flow. Freeway acts as a storage for vehicles backed-up from downstream bottleneck. Operating Speeds range from near 50 km/h to stop-and-go operation.	Forced, congested flow with unpredictable characteristics. Operating speeds less than 50 km/h. Volumes under 2000 passenger cars per hour, two-way.	Forced flow, congested conditions with widely varying volume characteristics. Operating speeds of less than 50 km/h.	Forced flow. Average over-all traffic speed below 25 km/h. All intersections handling traffic in excess of capacity with storage distributed throughout the section. Vehicular back-ups extend back from signalized intersections, through unsignalized inter-sections.

1. SEE HIGHWAY CAPACITY MANUAL FOR LEVELS OF SERVICE ON FREEWAY.

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

3.5.2 Capacity and Design Service Volume

The highway or intersection must be designed to accommodate the selected DHV. This involves adjusting the various highway factors (lane width, lateral clearance, number of lanes, etc.) which affect capacity until a design is found that will handle the DHV. The detailed calculation factors and methodology are in the *Highway Capacity Manual (HCM)*. In reality, the design service volume of the facility, not capacity, will be calculated. Capacity assumes maximum volumes at a level of service E. Design service volume is the traffic volume that can be served at the selected level of service.

The highway designer will conduct the necessary capacity analyses by using the HCM.

3.5.2.1 Highway Mainline

Many factors affect the capacity of a highway mainline segment, including:

1. *Traffic Composition* -- As the percentage of trucks increases, the capacity decreases. The standard procedure is to convert the truck volume into a passenger car equivalent volume. The impact of local buses on capacity must also be considered in urban areas.
2. *Lane and Shoulder Width* -- As lane and shoulder width decrease, capacity decreases. Adjustment factors are used to calculate the influence of narrower pavement widths.
3. *Lateral Clearance* -- If roadside obstructions are less than 2 meters from the edge of the travel lane, capacity is decreased. The "shy" distance varies with design speed and 1-way or 2-way operation.
4. *Auxiliary Lanes* -- The presence or absence of auxiliary lanes will affect capacity. These include parking and turn storage lanes. Universal adjustment factors are not applicable to calculating their impact on capacity. Individual analyses are necessary.
5. *Alignment* -- Horizontal and vertical alignment will affect capacity. The frequency and sharpness of curves and steepness of grades are important factors. For traffic traveling at any given speed, the better the roadway alignment the more traffic it can carry. It follows that congestion will generally be felt at lower volumes if the design speed is low than if the design speed is high. The highway must be subdivided into sections of consistent geometric design characteristics for analysis using the HCM techniques. A single limiting curve or steep grade in an otherwise gentle will thus be identified as the critical feature limiting the capacity of the roadway. Chapter 4 discusses the impact of grades on capacity.

6. *At-Grade Intersections* -- These intersections, including driveways, have a major impact on the capacity of the highway mainline. In many cases, their influences on service volumes are so great that they govern the capacity determination of the entire segment. Therefore, intersection capacity analyses must be treated separately, rather than as an adjustment to uninterrupted flow.
7. *Freeway Interchanges* -- Weaving sections and ramp terminals at interchanges are usually the most important adjustments to freeway capacity. By definition these are the only allowable points of access onto a freeway. Operating conditions within weaving sections are affected by traffic volumes and the length and width of the section. The ramp exiting and entering points introduce capacity-reducing elements onto the freeway. These have the effect of reducing the maximum volume that can be carried in the outside lane through the interchange. The traffic-carrying potential of the ramp itself must also be addressed. Chapter 6 discusses the design details for ramps and weaving areas to provide sufficient capacity.

3.5.2.2 Signalized Intersections

The *Highway Capacity Manual* is used to analyze the capacity of a signalized intersection. The intersection should be designed to accommodate a selected level of service. Except for good and sufficient reason, the values in Table 3.8 should be met so that the highway facility will operate at a consistent level of service. At a minimum, the at-grade intersection should operate at no more than one level of service below the values in Table 3.8.

Capacity of signalized intersections depend on many factors, including:

1. Intersection geometry including the number and width of lanes, grades and lane-use allocations (including parking lanes, and bicycle lanes).
2. Percentage of heavy vehicles,
3. Location of and use of bus stops within the intersection area,
4. Distribution of vehicles by movement (left, through, right),
5. Pedestrian-crossing flows,
6. Peak-hour factor,

7. Signal phasing, turning and type of control (Pretimed, semiactuated or actuated operation) and evaluation of signal progression on each approach,

3.5.2.3 Unsignalized Intersections

The chapter entitled "Unsignalized Intersections" in the *Highway Capacity Manual* should be used for capacity calculations. The methodology is applicable to intersections controlled by 2-way stop signs or by yield signs; it is not applicable to uncontrolled intersections or those controlled by 4-way stop signs. The analysis calculates the available capacity of the minor road primarily based upon the traffic operating characteristics of the major road. An assumption is made that the major street traffic is not affected by the minor street movements.

Those factors which affect capacity at signalized intersections also influence unsignalized intersections; however, the most important factors at unsignalized intersections which lead to capacity adjustments are:

1. the type and volume of turning movements,
2. the critical gap in conflicting traffic needed to execute the desired maneuver,
3. the presence or absence of auxiliary lanes, and
4. the degree of congestion at the intersection.

3.6 SIGHT DISTANCE

Sight distance values affect the design of horizontal and vertical alignment, at-grade intersections, interchanges, and railroad/highway/bikeway crossings. The selected type of sight distance (stopping, decision, or passing) will depend upon the type of highway and the potential hazard. In addition, the selected height of object for measuring these distances will vary. This section will discuss the definition and derivation of the various sight distances; their applications are discussed under the appropriate topics in other chapters.

3.6.1 Stopping Sight Distance

Stopping sight distance is the absolute minimum sight distance that should be provided at any point on the highway. Minimum stopping sight distance must be provided for the vertical

and horizontal geometry of all roadways . Minimum stopping sight distance must be provided for at un-signalized and signalized intersections to allow for conditions where the signals are malfunctioning or are not observed. Greater distances should be made available wherever possible.

Stopping sight distance is the sum of two distances: the distance traveled during driver perception/reaction time, and the distance traveled during brake application. The perception/reaction time is usually 2.5 sec. This is sufficient for simple and moderately-complex highway situations. Where more complex conditions exist, greater times should be allowed for perception/reaction time (see Section 3.6.2 "Decision Sight Distance").

Braking distance is calculated by:

$$d = \frac{V^2}{254f}$$

Where: d = braking distance, meter

 V = initial speed, kilometer/hour

 f = coefficient of friction

Table 3.9 summarizes the stopping sight distance data. The desirable distances are computed by selecting V equal to the design speed. The minimum distances are found by setting V equal to the average running speed for low-volume conditions. Although the lower distances are allowable, every reasonable effort should be made to provide upper stopping sight distances. When determining stopping sight distances, the height of eye is 1070 millimeters and height of object is 150 millimeters.

Table 3.9
STOPPING SIGHT DISTANCES

DESIGN SPEED (km/h)	COEFFICIENT OF FRICTION	SIGHT DISTANCES (ROUNDED FOR DESIGN)	
		MINIMUM	DESIRABLE
30	0.40	30	30
40	0.38	45	45
50	0.35	58	63
60	0.33	75	85
70	0.31	95	111
80	0.30	113	140
90	0.30	132	169
100	0.29	157	205
110	0.28	180	247
120	0.28	203	286

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Increases or decreases in the distances in Table 3.9 are warranted for grades of 3% or more, calculated by the following formula:

$$d = \frac{v^2}{254(f + G)}$$

where G is the grade expressed as a decimal (e.g., 6% is 0.06). Downgrades are negative and upgrades are positive. Table 3.10 provides the adjustments to the level stopping sight distances due to grade.

Table 3.10
GRADE ADJUSTMENTS FOR STOPPING SIGHT DISTANCES

DESIGN SPEED (km/h)	STOPPING SIGHT DISTANCE (m) FOR DOWNGRADES			STOPPING SIGHT DISTANCE (m) FOR UPGRADES		
	3%	6%	9%	3%	6%	9%
30	30.4	31.2	32.2	29.0	28.5	28.0
40	45.7	47.5	49.5	43.2	42.1	41.2
50	65.5	68.6	72.6	55.5	53.8	52.4
60	88.9	94.2	100.8	71.3	68.7	66.6
70	117.5	125.8	136.3	89.7	85.9	82.8
80	148.8	160.5	175.5	107.1	102.2	98.1
90	180.6	195.4	214.4	124.2	118.8	113.4
100	220.8	240.6	256.9	147.9	140.3	133.9
110	267.0	292.9	327.1	168.4	159.1	151.3
120	310.1	341.0	381.7	190.0	179.2	170.2

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

3.6.2 Decision Sight Distance

In many cases, stopping sight distance is, by itself, inadequate to provide a safe highway situation. These include situations where a driver must handle a complex highway situation, the hazard is difficult to perceive, unexpected or unusual maneuvers are required, or an evasive maneuver is preferable to a hurried stop. Examples of where these situations are likely to occur include intersections and interchanges, railroad/highway grade crossings, lane drops, detours, and major changes in the highway cross section. The decision sight distance concept can also be used to determine the need for advance warning signs, although this is not a desirable substitute for the physical availability of sight distance.

Decision sight distance is the distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard or its threat potential, select an appropriate speed and path, and initiate and complete the required safety maneuver safely and efficiently.

Decision sight distance, as with stopping sight distance, is the sum of perception/reaction time and vehicle maneuver time (stopping or a lane change). The application of decision sight distance must be individually assessed at each location. Table 3.11 provides the necessary information to determine the required distance.

**Table 3.11
DECISION SIGHT DISTANCE**

DESIGN SPEED (km\h)	DECISION SIGHT DISTANCE FOR AVOIDANCE MANEUVER (METERS)				
	A	B	C	D	E
50	75	160	145	160	200
60	95	205	175	205	235
70	125	250	200	240	275
80	155	300	230	275	315
90	185	360	275	320	360
100	225	415	315	365	405
110	265	455	335	390	435
120	305	505	375	415	470

Notes:

- AVOIDANCE MANEUVER A: STOP ON RURAL ROAD.
- AVOIDANCE MANEUVER B: STOP ON URBAN ROAD.
- AVOIDANCE MANEUVER C: SPEED/PATH/DIRECTION CHANGE ON RURAL ROAD.
- AVOIDANCE MANEUVER D: SPEED/PATH/DIRECTION CHANGE ON SUBURBAN ROAD.
- AVOIDANCE MANEUVER E: SPEED/PATH/DIRECTION CHANGE ON URBAN ROAD.

Reference: " A POLICY ON GEOMETRIC DESIGN OF HGHWAYS AND STREETS" AASHTO, 1994

When applying the decision sight distance, a height level of eye of 1070 millimeters and height of object of 150 millimeters should be used.

3.6.3 Passing Sight Distance (2-Lane Highways)

A sufficient distance to allow a safe passing maneuver should be provided at relatively frequent intervals and for a major portion of the highway length for two-lane highways where feasible. This is the distance needed to enable a driver to pass a vehicle without interfering

with an oncoming vehicle which appears when the passing vehicle begins its maneuver. The percent of passing sight distance available affects the capacity of the highway. Passing sight distance is the sum of four distances:

- d_1 . Distance traversed during perception/reaction time and during the initial encroachment on the left lane.
- d_2 . Distance traveled while the passing vehicle occupies the left lane.
- d_3 . Distance between the passing vehicle at the end of its maneuver and the opposing vehicle.
- d_4 . Distance traversed by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane, or two-thirds of d_2 above.

Figure 3-3 illustrates the four distances which compose passing sight distance. Table 3.12 provides the design values for various design speeds. For application, use a 1070 millimeter height of eye and 1300 millimeter height of object.

Methods of Scaling Passing Sight Distances are demonstrated in Figure 3-4. Because the view of the highway ahead may change rapidly in a short distance it is desirable to measure and record sight distances from both directions of travel at every 25 meters. For two-lane highways, passing sight distance along with stopping sight distance criteria for horizontal and vertical curves must be met for marking passing zones. Table 3.12 provides the relation of passing sight distance to the design speed. Where achievement of adequate passing sight distance is not practical, auxiliary lanes, such as truck-climbing lanes or perhaps passing lanes, should be considered. No-Passing Zones should be established for special situations such as intersections, railroads, highway-grade crossings, narrow bridges, school zones, roadside development and high-volume opposing traffic.

Sight distance records for two-lane highways may be used to advantage to tentatively determine the marking of no-passing zones in accordance with criteria given in the MUTCD. Marking of such zones is an operational rather than a design problem. No-passing zones thus established serve as a guide for markings when the highway is completed: the zones so determined should be checked and adjusted by field measurements before actual markings are placed.

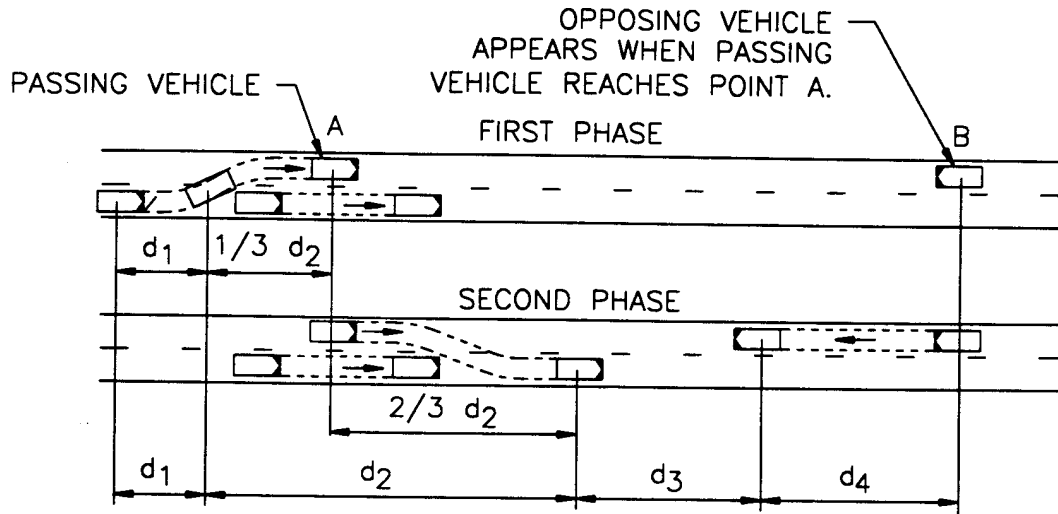


Figure 3-3. PASSING SIGHT DISTANCE ELEMENTS

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

**Table 3.12
PASSING SIGHT DISTANCES**

ASSUMED SPEEDS			MINIMUM PASSING SIGHT DISTANCE (m) FOR DESIGN
DESIGN SPEED (km/h)	PASSED VEHICLE (km/h)	PASSING VEHICLE (km/h)	
30	29	44	217
40	36	51	285
50	44	59	345
60	51	66	407
70	59	74	482
80	65	80	541
90	73	88	605
100	79	94	670
110	85	100	728
120	91	106	792

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

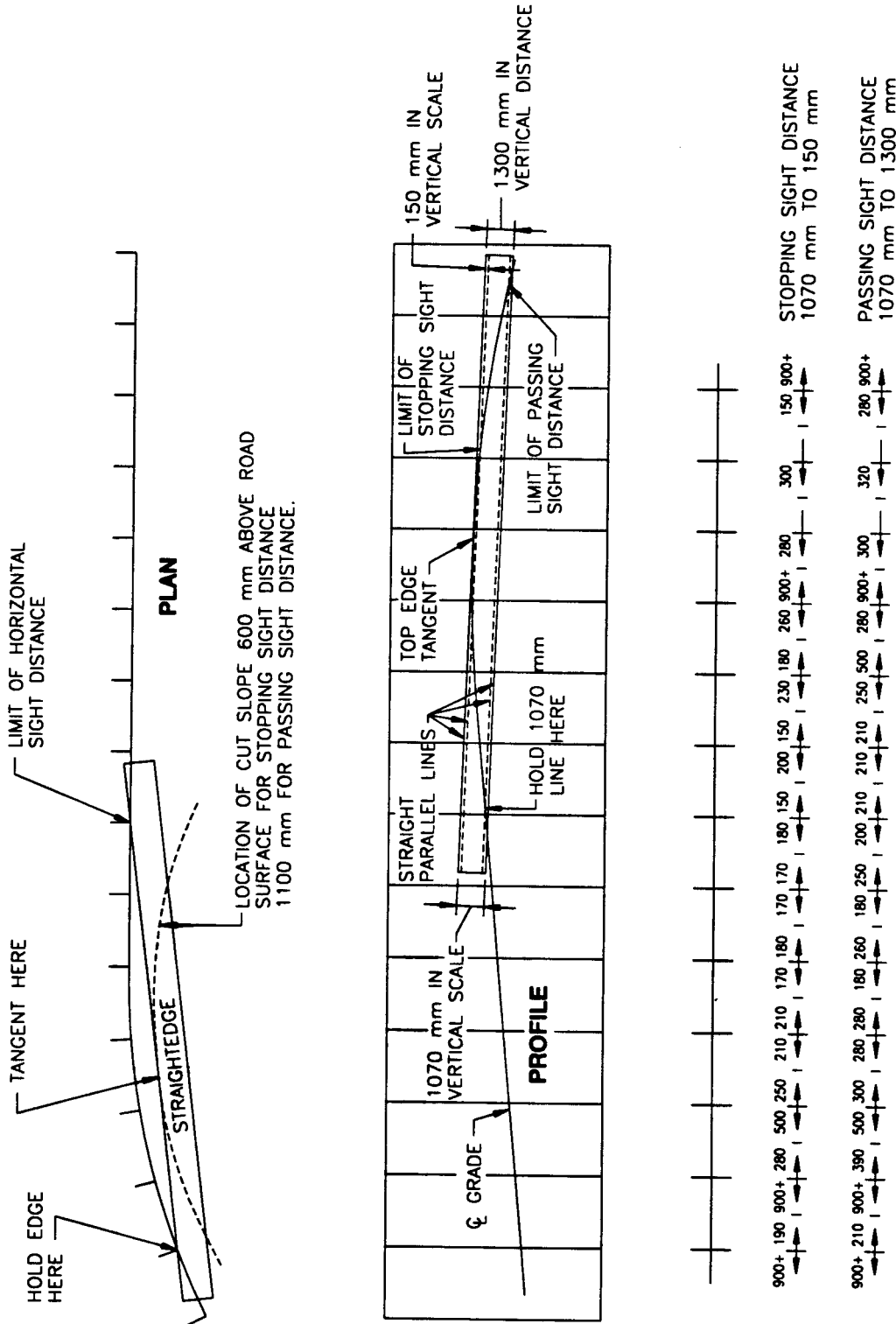


Figure 3-4. SCALING AND RECORDING SIGHT DISTANCES ON PLANS.

3.7 REFERENCES

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 1994.
- *Highway Capacity Manual*, Transportation Research Board.
- *Manual on Uniform Traffic Control Devices*, Federal Highway Administration,
- *Federal Aid Program Guide*, - Federal Highway Administration

CHAPTER 4

HORIZONTAL AND VERTICAL ALIGNMENT

4.1 HORIZONTAL ALIGNMENT

Horizontal alignment should meet these general considerations:

1. Horizontal alignment should be as smooth as possible and responsive to the topography. Flatter curvature with shorter tangents is generally preferable to sharp curves connected by long tangents. Angle points should be avoided.
2. Curves with small deflection angles (5 degrees or less) should be long enough to avoid the appearance of a kink. Curves should be 150 meters long for a central angle of 5 degrees and increased 30 meters for each degree decrease in central angle.

The minimum length of horizontal curves should be:

- (1) $L_{\min} = 6V$ (high speed freeways)
- (2) $L_{\min} = 3V$ (other arterials)

Where V = design speed in kilometers per hour (km/h)

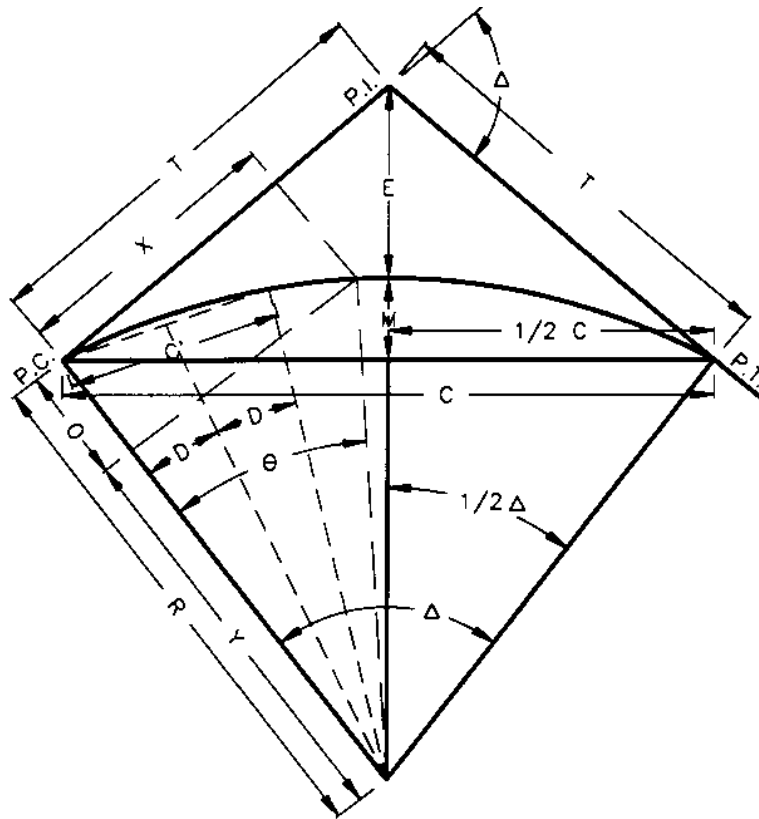
3. Broken back curvature (short tangent between two curves in same direction) should be avoided.
4. The horizontal alignment should be in balance with the vertical profile (See Section 4.3).
5. Horizontal curves should be avoided on the bridges whenever possible. These cause design, construction, and operational problems. Where a curve is necessary on a bridge, a simple curve should be used on the bridge and any curvature or superelevation transitions placed on the approaching roadway.

4.1.1 Types of Horizontal Curvature

Horizontal curves are circular or spiral. For Circular curves the radius definition is used with design curves expressed to the nearest 5 meters.

4.1.1.1 Simple Curves

A simple curve has a constant circular radius which achieves the desired deflection without using an entering or exiting transition. Because of their simplicity and ease of design, survey, and construction, this is the most frequently used curve. Figure 4-1 illustrates a typical simple curve layout.



R = RADIUS
 C = LONG CHORD
 C' = ANY CHORD LENGTH
 E = EXTERNAL DISTANCE
 M = MIDDLE ORDINATE
 L = LENGTH OF ARC
 Δ = INTERSECTION ANGLE = CENTRAL ANGLE

D = DEFLECTION ANGLE FOR CHORD C'
 T = LENGTH OF TANGENT
 O = TANGENT OFFSET
 P.C. = POINT OF CURVATURE
 P.I. = POINT OF INTERSECTION
 P.T. = POINT OF TANGENCY
 X = DISTANCE ALONG TANGENT

FORMULAS:

$$\begin{aligned}
 T &= R \tan 1/2 \Delta & C &= 2R \sin 1/2 \Delta & E &= R \operatorname{exsec} 1/2 \Delta \\
 M &= R \operatorname{vers} 1/2 \Delta & L &= \frac{\Delta}{360} (2 \pi R) & \sin D &= 1/2 C' \div R
 \end{aligned}$$

TANGENT OFFSET METHODS:

$$O = R - \sqrt{R^2 - X^2}$$

$$\begin{aligned}
 \sin \theta &= X/R \\
 Y &= R \cos \theta \\
 O &= R - Y
 \end{aligned}$$

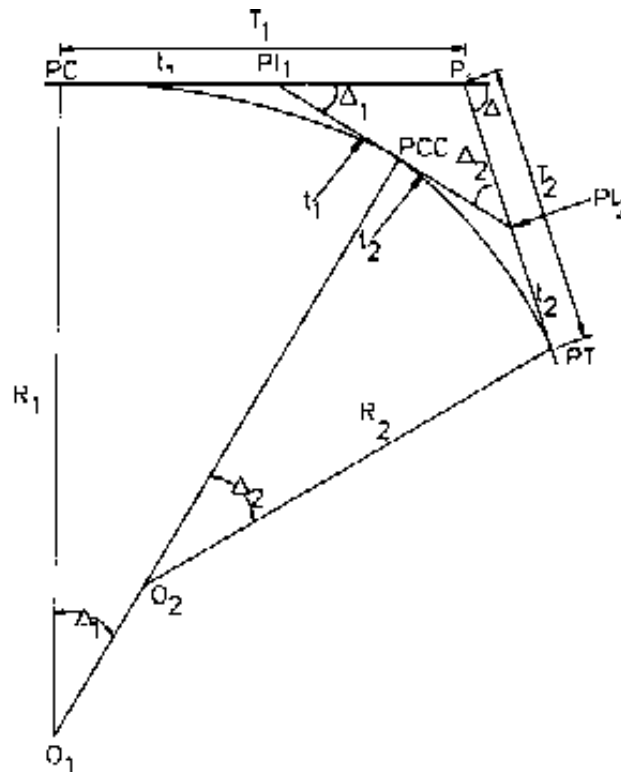
Figure 4-1 SIMPLE CURVE

4.1.1.2 Compound Curves

Compound curves are used to transition into and from a simple curve. These guidelines should be followed when using compound curves:

1. Compound curves are appropriate for intersection curb radii, ramps, and transitions into sharper curves.
2. As the curvature becomes successively sharper, the radius of the flatter circular curve should not be more than 50% greater than that of the sharper curve.
3. Superelevating compound curves requires careful consideration. This is discussed in Section 4.1.3.

Figure 4-2 and 4-3 illustrate a typical compound curve layout and warrants for compound curvature.



FORMULAS:

$$PI-PI_1 = \frac{\sin \Delta_2 (t_1 + t_2)}{\sin \Delta}$$

$$PI-PI_2 = \frac{\sin \Delta_1 (t_1 + t_2)}{\sin \Delta}$$

$$T_1 = t_1 + PI-PI_1$$

$$T_2 = t_2 + PI-PI_2$$

$$L_1 = \frac{\Delta_1}{360} \times 2 \pi R_1$$

$$L_2 = \frac{\Delta_2}{360} \times 2 \pi R_2$$

$$M_1 = R_1 \text{ VERS } 1/2 \Delta_1$$

$$M_2 = R_2 \text{ VERS } 1/2 \Delta_2$$

$$\Delta = \Delta_1 + \Delta_2$$

$$\Delta_2 = \Delta - \Delta_1$$

$$t_1 = R_1 \tan (\Delta_1 / 2)$$

$$t_2 = R_2 \tan (\Delta_2 / 2)$$

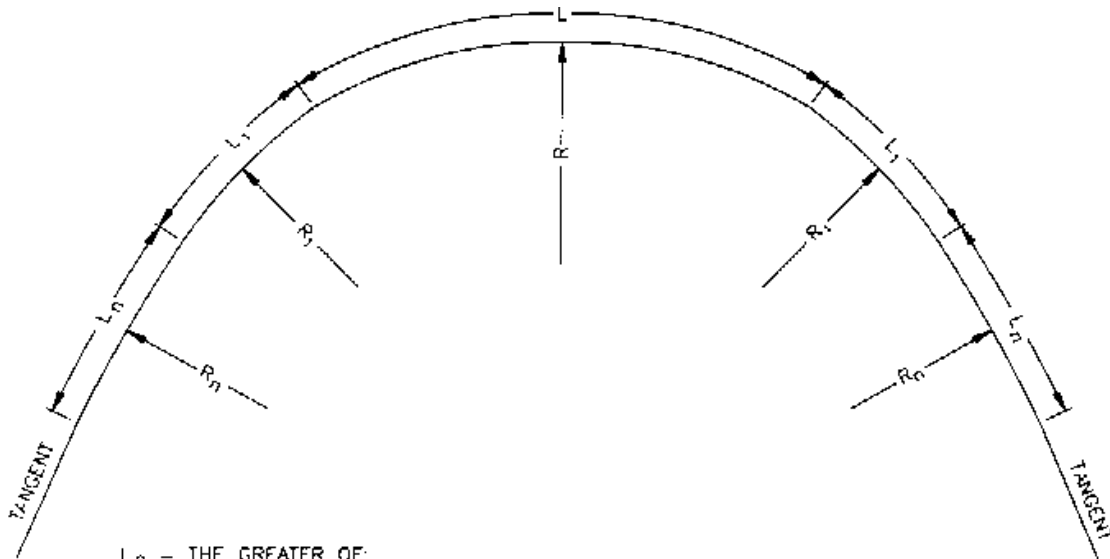
$$C_1 = 2R_1 \sin 1/2 \Delta_1$$

$$C_2 = 2R_2 \sin 1/2 \Delta_2$$

$$F_1 = R_1 \text{ EXSEC } 1/2 \Delta_1$$

$$F_2 = R_2 \text{ EXSEC } 1/2 \Delta_2$$

Figure 4-2. COMPOUND CURVE



L_n = THE GREATER OF:

- a) THREE SECONDS RUNNING TIME AT THE DESIGN SPEED,
- b) THE LENGTH OF RUNOFF PLUS THE LENGTH OF TANGENT RUNOUT, OR
- c) THE LENGTH OF RUNOFF PLUS THE LENGTH REQUIRED TO SUPERELEVATE TO CURVE R_1 .

L_1 = THE GREATER OF:

- a) THREE SECONDS RUNNING TIME AT THE DESIGN SPEED,
- b) THE LENGTH TO SUPERELEVATE CURVE R_1 AND R .

L = THE GREATER OF:

- a) THREE SECONDS RUNNING TIME AT THE DESIGN SPEED,
- b) TWO TIMES THE LENGTH REQUIRED TO SUPERELEVATE TO CURVE R , OR
- c) A MINIMUM LENGTH OF 100 m.

MINIMUM ALLOWABLE RADII WITHOUT TRANSITION

DESIGN SPEED (km/h)	80	90	100	110	120
RADIUS (m)	1200	1400	2000	2000	2500

WHERE THE HORIZONTAL CURVES ARE OF RADII LESS THAN "R" SHOWN IN TABLE ABOVE:

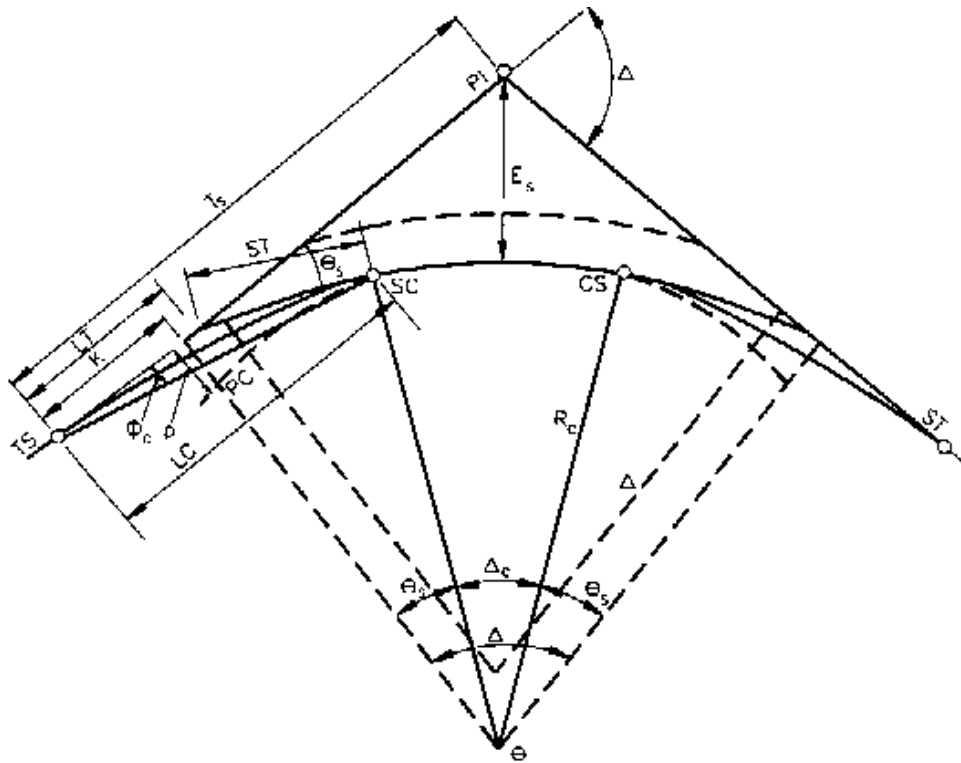
1. CURVES R_1 R_n ARE INTRODUCED FOR THE PROPOSE OF MAKING THE TRANSITION FROM THE TANGENT TO CURVE "R".
2. CURVES R_1 R_n ARE COMPOUNDED WITH "R"
3. THE RADIUS OF CURVES R_1 R_n IS TO BE NO MORE THAN 1.5 TIMES THE RADIUS OF THE PRECEDING CURVE, i.e. $R_1=1.5R$, etc., STARTING FROM EACH END OF CURVE "R".
4. THE CURVES ARE INCREASED IN RADIUS UNTIL " R_n " IS AT LEAST EQUAL TO THE VALUES INDICATED FOR THE RESPECTIVE SPEEDS SHOWN ON THE TABLE ABOVE.
(R FOR $e < 3\%$ WHEN $E_{MAX} = 6\%$)
5. SUPERELEVATION SHOULD BE DEVELOPED AS DISCUSSED IN SECTION 4.1.3

Figure 4-3. COMPOUND CURVE TRANSITION

4.1.1.3 Spiral Curves

Spiral curves provide a gradual, continuous increasing rate of curvature from a straight to a circular path. They also provide a convenient desirable arrangement for superelevation runoff; they facilitate the transition in width where the pavement is to be widened around a circular curve, and they also enhance the appearance of the highway or streets. These can often be used in place of compound curves. Because spiral curves provide smoother horizontal transition and improved superelevation design, their use is encouraged. Computer programs facilitate the spiral curve design. Figure 4-4 illustrates the layout for spiral curves. Table 4.1 provides P and K values for spiral curve layout. A circular curve with simple spirals at both ends, having the same parameter value, is referred to as symmetrical. Symmetrical spiraled curves are normally used.

Figure 4-5 illustrates the spiraled as related to the unspiraled curve.



PI = PT OF INTERSECTION
 TS = TANGENT SPIRAL
 SC = SPIRAL CURVE
 CS = CURVE SPIRAL
 ST = SPIRAL TANGENT
 Rc = RADIUS OF CIRCULAR CURVE
 LT = LONG TANGENT
 S.T. = SHORT TANGENT
 Ls = LENGTH OF SPIRAL
 L = LENGTH TO ANY PT ON SPIRAL FROM TS
 LC = CHORD DISTANCE - TS TO SC
 θs = CENTRAL ANGLE OF SPIRAL, "SPIRAL ANGLE"
 θ = CENTRAL ANGLE OF ARC L
 φ = DEFL. ANGLE FOR ANY PT ON SPIRAL

φc = DEFL. ANGLE FOR SC
 Δ = INTERSECTION ANGLE, TOTAL CENTRAL ANGLE
 Δc = CENTER ANGLE OF CIRCULAR ARC
 Lc = LENGTH OF CIRCULAR ARC
 Dc = DEGREE OF CURVE OF SHIFTED CIRCLE
 Es = EXTERNAL DIST. FROM PI TO CIRCULAR CURVE
 P = OFFSET DIST. OF CIRC. CURVE PRODUCED
 k = DIST. FROM TS TO PC OF CIRC. CURVE PRODUCED

FORMULAS:

$$L_s = 1.6 \frac{V^3}{R_c} \quad \text{WHERE } V = \text{DESIGN SPEED}$$

$$\theta_s = \frac{L_s D_c}{200}$$

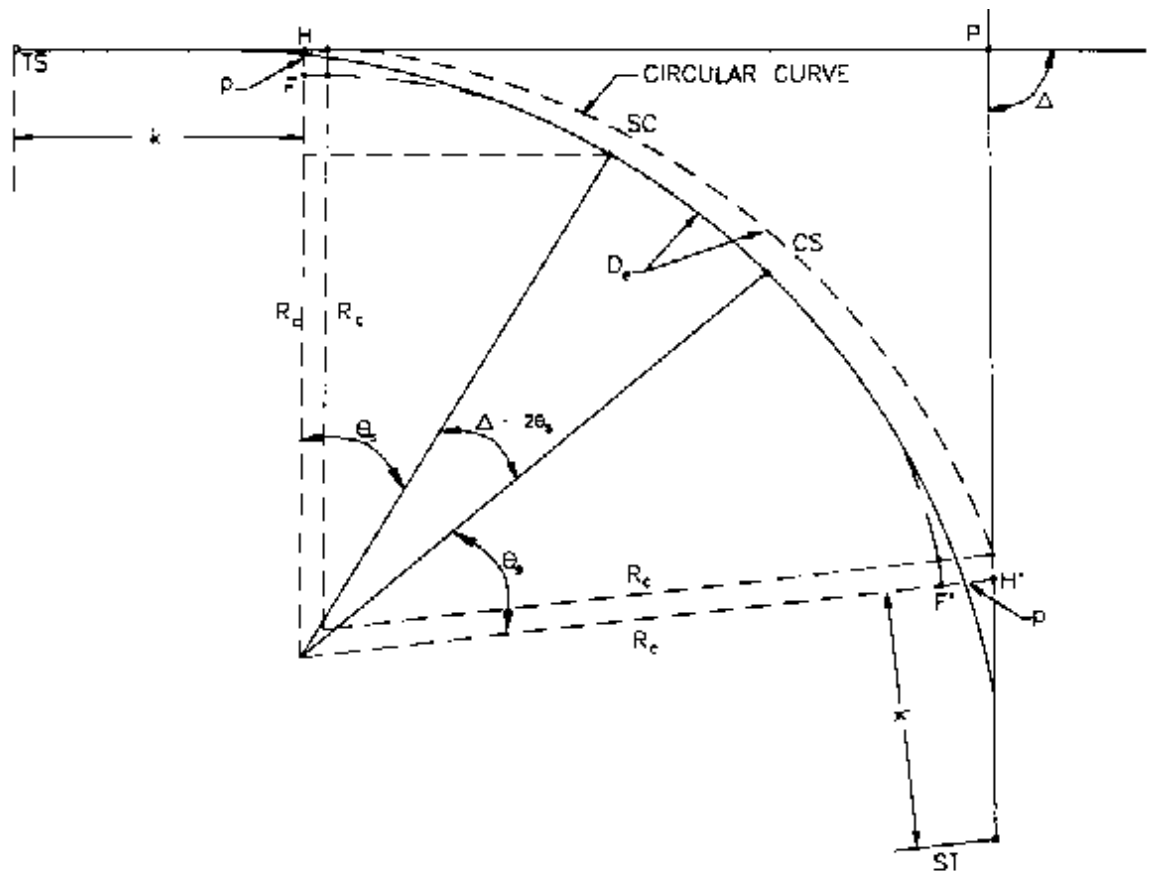
$$E_s = (R_c + p) \left[\sec \frac{\Delta}{2} + 1 \right]$$

$$T_s = (R_c + p) \tan \frac{\Delta}{2} + k$$

$$\phi = \frac{\theta_s}{3} \left(\frac{L}{L_s} \right)^3$$

$$E_s = (R_c + p) \left[\frac{1}{\cos \frac{\Delta}{2}} - 1 \right] + \phi$$

Figure 4-4. SPIRAL CURVE



TS = TANGENT TO SPIRAL
 SC = SPIRAL TO CURVE
 CS = CURVE TO SPIRAL
 ST = SPIRAL TO TANGENT
 L_s = TOTAL LENGTH OF SPIRAL TS TO SC
 θ_s = SPIRAL ANGLE
 Y_s = TANGENT OFFSET AT THE SC
 E_s = TOTAL EXTERNAL DISTANCE

k = ABSCISSA OF THE SHIFTED PC REFERRED TO THE TS
 p = OFFSET FROM THE INITIAL TANGENT TO THE PC OF THE SHIFTED CURVE
 R_c = RADIUS OF CIRCLE
 D_c = DEFLECTION ANGLE FOR SHIFTED CIRCLE
 Δ = INTERSECTION ANGLE
 X_s = TANGENT DISTANCE FOR THE SC
 L_s = TOTAL TANGENT DISTANCE
 V = SPEED, KM/HR
 C = RATE OF INCREASE OF CENTRIPETAL ACCELERATION, M/S³

FORMULAS:

$$L_s = \frac{0.0702V^3}{RC}$$

$$\theta_s = \frac{L_s}{2R_c}$$

$$Y_s = \frac{L_s^2}{6R_c}$$

$$E_s = (R_c + p) \sec 1/2 \Delta - R_c$$

$$T_s = (R_c + p) \tan 1/2 \Delta + k$$

$$P = Y_s - R_c \text{ VERS } \theta_s$$

$$K = X_s - R_c \sin \theta_s$$

Figure 4-5. THE SPIRALED AS RELATED TO THE UNSPIRALED CURVE

Table 4.1
p AND k VALUES FOR SPIRAL CURVES

DESIGN SPEED (KM/HR)	MINIMUM RADIUS (METERS)	p (METERS)	k (METERS)
30	30	1.48	16.19
40	55	1.31	20.68
50	90	1.12	24.54
60	135	.98	28.19
70	195	.82	30.94
80	250	.87	36.01
90	335	.73	38.24
100	435	.62	40.38
110	560	.52	41.73
120	755	.36	40.18

4.1.2 Minimum Radius of Horizontal Curvature

The values for horizontal curvature are derived from the design speed, superelevation rate, and side friction factors. The basic equation is:

$$R = \frac{V^2}{127(e+f)}$$

Where: R = radius of curve, meters
 e = superelevation rate, m/m
 f = side friction factor
 V = vehicle speed, km/h

Tables 4.2 provides the minimum radii for varying design speeds and a maximum superelevation rate of 0.06. Table 4.2 is for all rural highways and high-speed urban highways.

S = sight distance, meter.

The values in Table 4.2 are minimum radii; the designer should provide flatter curves wherever possible. It may be necessary to provide flatter curvature when the minimum radius will not provide the lower stopping sight distance (See Section 4.1.4).

See Tables 6.4 and 6.5 for minimum radii for ramp design.

Table 4.2
HORIZONTAL CURVATURE FOR RURAL HIGHWAYS
AND HIGH SPEED URBAN HIGHWAYS

DESIGN SPEED (km/h)	MAXIMUM e %	MINIMUM RADIUS ROUNDED FOR DESIGN (m)
30	6.00	30
40	6.00	55
50	6.00	90
60	6.00	135
70	6.00	195
80	6.00	250
90	6.00	335
100	6.00	435
110	6.00	560
120	6.00	755

Note: DESIGN SPEEDS BELOW 50 km/h SHOULD NOT NORMALLY BE USED.

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

4.1.3 Horizontal Stopping Sight Distance

Safe sight distance must be provided on the inside of horizontal curves. Obstructions which interfere with the needed sight distance should be removed, if possible.

On horizontal curves, a designer must provide a "middle ordinate" between the center of the inside lane and the sight obstruction. The basic equation is:

$$M = R \frac{(1 - \cos 28.65S)}{R}$$

Where: M = middle ordinate, or distance from the center of the inside lane to the obstruction, meter.

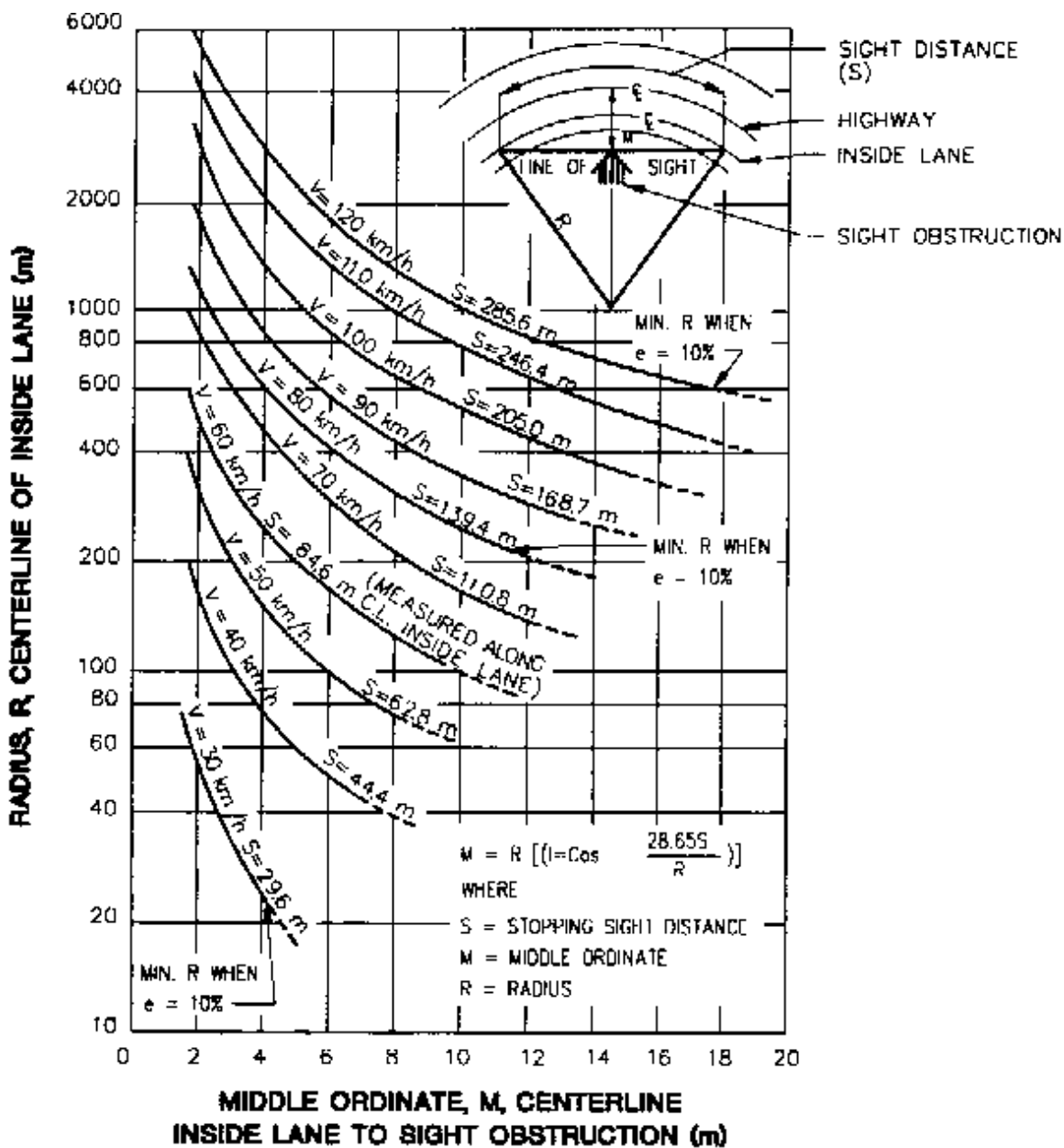
R = radius of curve, meter

S = sight distance, meter

The designer should use the following:

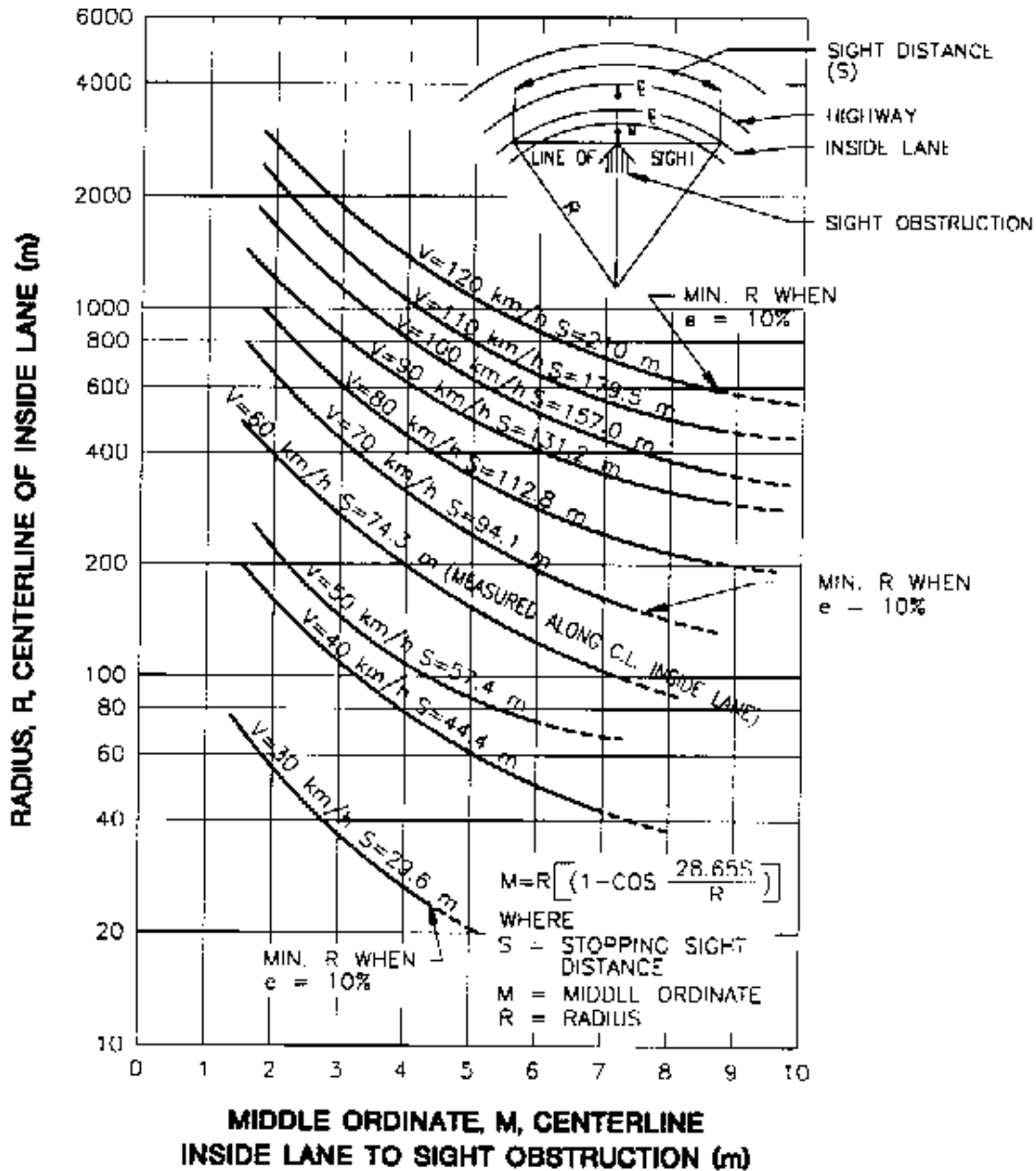
1. Figures 4-6 and 4-7 provide the criteria for upper and lower stopping sight distances. *The designer should make every practical effort to achieve the upper stopping sight distance criterion.* The height of eye is 1070 millimeters and the height of object is 150 millimeters. The line-of-sight intercept with the view obstruction is at the midpoint of the sight line and 610 millimeters above the center of the inside lane.
2. If a designer concludes that decision sight distance is needed, greater distance will have to be provided. Section 3.6 discusses those highway conditions where decision sight distance is appropriate and provides procedures for determining the distance. The calculated value would then be used in the basic equation for determining the middle ordinate on the horizontal curve.
3. Normally, it is not practical to provide passing sight distance on horizontal curves. These values yield very large numbers for the middle ordinate. In addition, many drivers will not pass on horizontal curves regardless of the available sight distance.

Figure 4-8 illustrates the method of attaining sight distance in cut sections.



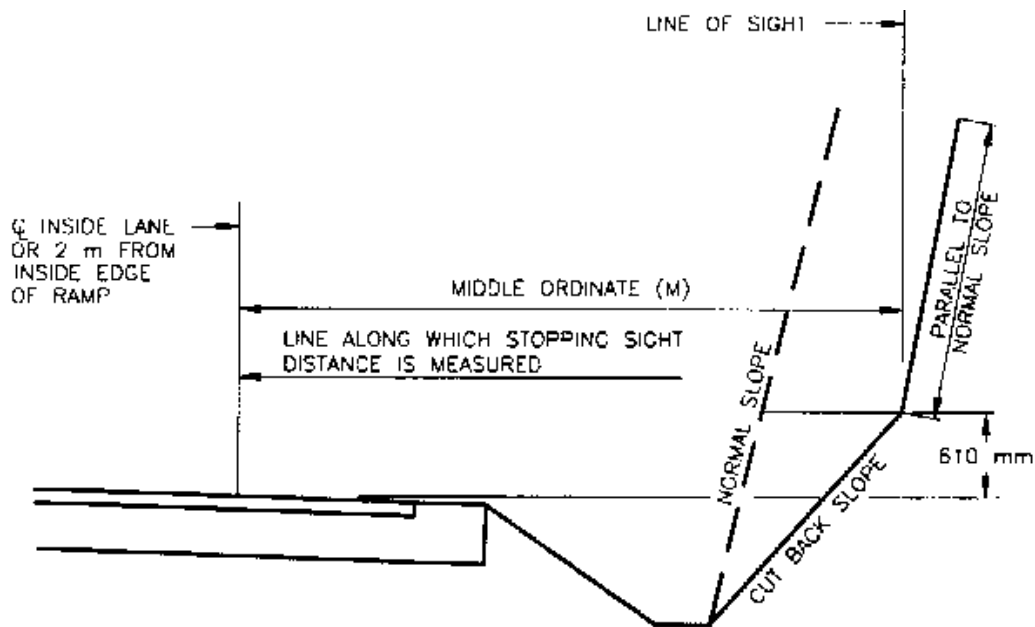
Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 4-6. HORIZONTAL SIGHT DISTANCE (DESIRABLE STOPPING)



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1995

Figure 4-7. HORIZONTAL SIGHT DISTANCE (MINIMUM STOPPING)



Note: SEE FIGURES 4-16 AND 4-17 FOR DEFINITION OF TERMS

Figure 4-8. METHOD OF CUTTING SLOPE FOR HORIZONTAL SIGHT DISTANCE

4.2 VERTICAL ALIGNMENT

The highway vertical alignment is controlled by topography, traffic volumes and composition, highway functional classification, safety, sight distance, drainage, economics and aesthetics. Where a highway crosses a waterway, the vertical profile of the highway must be consistent with the design flood frequency (See Chapter 10).

4.2.1 Grades

Table 4.3 presents the recommended maximum highway grades. Flatter grades should be used where possible. On a long ascending grade it is preferable to place the steepest grade at the bottom and flatten the grade near the top. The highway must have a minimum longitudinal gradient of 0.4% and preferably 0.5%.

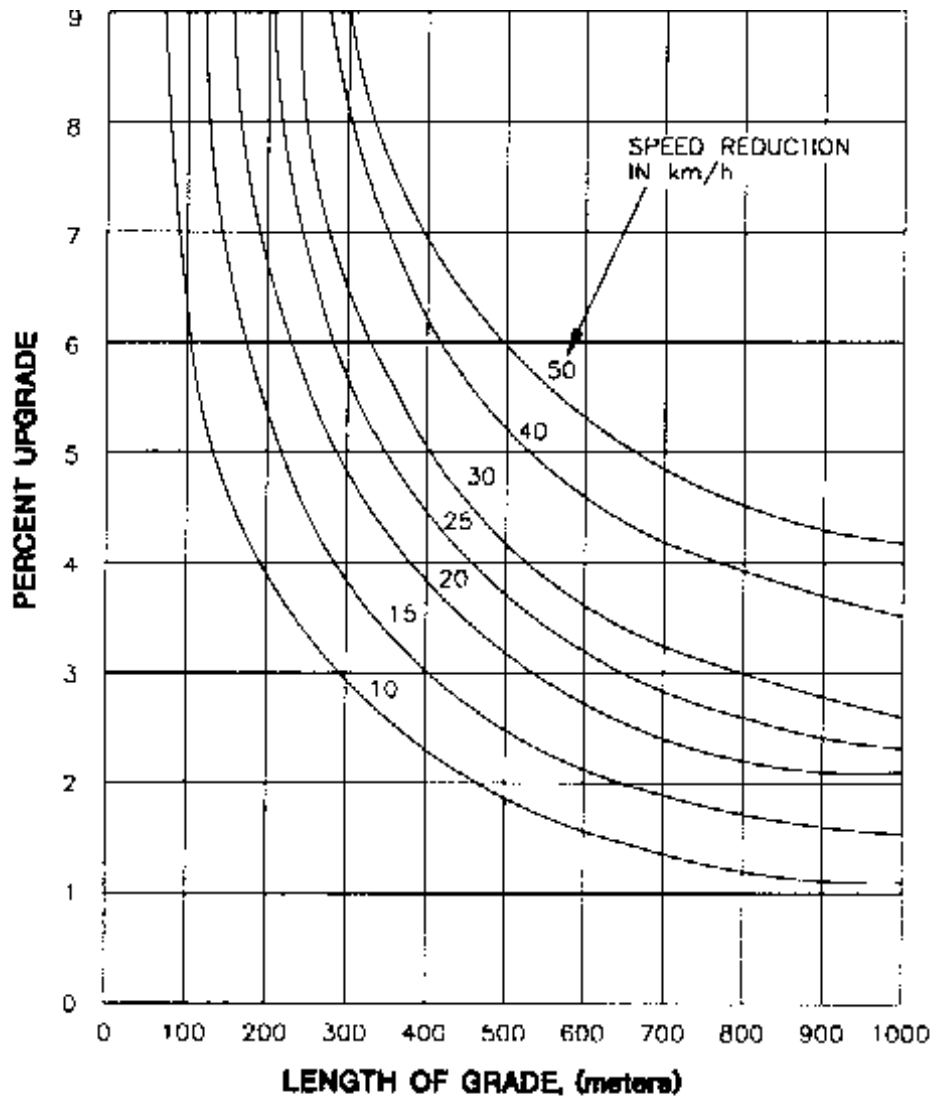
Table 4.3
RECOMMENDED MAXIMUM GRADES¹

FUNCTIONAL CLASSIFICATION	U/R	TERRAIN	DESIGN SPEED (km/h)									
			30	40	50	60	70	80	90	100	110	120
FREEWAY/ EXPRESSWAY	URBAN	LEVEL	--	--	--	--	--	4	4	3	3	3
		ROLLING	--	--	--	--	--	5	5	5	4	4
		MOUNTAINOUS	--	--	--	--	--	6	6	6	5	--
	RURAL	LEVEL	--	--	--	--	--	4	4	3	3	3
		ROLLING	--	--	--	--	--	5	5	5	4	4
		MOUNTAINOUS	--	--	--	--	--	6	6	6	5	--
ARTERIAL	URBAN	LEVEL	--	--	8	7	6	6	5	5	--	--
		ROLLING	--	--	9	8	7	7	6	6	--	--
		MOUNTAINOUS	--	--	11	10	9	9	8	8	--	--
	RURAL	LEVEL	--	--	--	5	5	4	4	3	3	3
		ROLLING	--	--	--	6	6	5	5	4	4	4
		MOUNTAINOUS	--	--	--	8	7	6	6	6	5	5
COLLECTOR	URBAN	LEVEL	9	9	9	9	8	7	7	7	5	--
		ROLLING	12	12	11	10	9	8	8	8	6	--
		MOUNTAINOUS	14	13	12	12	11	10	10	10	7	--
	RURAL	LEVEL	7	7	7	7	7	6	6	5	4	--
		ROLLING	10	10	9	8	8	7	7	6	5	--
		MOUNTAINOUS	12	11	10	10	10	9	9	8	6	--
LOCAL	URBAN	LEVEL	SEE NOTE 4									
		ROLLING										
		MOUNTAINOUS										
	RURAL	LEVEL	8	7	7	7	7	6	6	5	--	--
		ROLLING	11	11	10	10	9	8	7	6	--	--
		MOUNTAINOUS	16	15	14	13	12	10	10	--	--	--

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

- Notes:**
- FOR GRADES OF LENGTH LESS THAN 150 m AND FOR 1-WAY DOWNGRADES, THE MAXIMUM GRADE MAY BE 1% STEEPER THAN TABLE VALUES. FOR LOW-VOLUME RURAL HIGHWAYS, GRADES MAY BE 2% STEEPER.
 - IN URBAN AREAS, GRADES 1% STEEPER MAY BE USED FOR EXTREME CASES WHERE (A) EXISTING DEVELOPMENT PRECLUDES USING FLATTER GRADES, OR (B) 1-WAY DOWN GRADES IN LEVEL OR ROLLING TERRAIN.
 - GRADES SHOWN FOR RURAL AND URBAN CONDITIONS OF SHORT LENGTH, (LESS THAN 150 m), ON ONE-WAY DOWN GRADES AND ON LOW-VOLUME RURAL COLLECTORS MAY BE 2% STEEPER.
 - GRADES SHOULD BE AS FLAT AS IS CONSISTENT WITH THE SURROUNDING TERRAIN AND LAND USE IN THE AREA. IN RESIDENTIAL AREAS. THE MAXIMUM GRADE SHOULD BE 15% IN COMMERCIAL AND INDUSTRIAL AREAS WHERE TRUCK USE IS EXPECTED, THE MAXIMUM GRADE SHOULD BE 8% AND DESIRABLY 5%.

In addition to the maximum grade, the designer must consider the length of the grade. The gradient in combination with its length will determine the truck speed reduction on upgrades. Figure 4-9 provides the critical length of grade for a given percent grade and acceptable truck speed reduction. For general design purposes, the 15 km/h speed reduction curve should be used.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

- Notes:**
1. FOR DESIGN, THE 15 km/h SPEED REDUCTION CURVE WILL NORMALLY BE USED
 2. THIS FIGURE ASSUMES A TYPICAL HEAVY TRUCK OF 180 KG/KW, ENTERING SPEED - 90 km/h, BUT MAY ALSO BE USED FOR OTHER TRUCK SPEEDS.

Figure 4-9. CRITICAL LENGTHS OF GRADE

Where an upgrade is preceded by a downgrade, trucks will often increase speed to make the climb. A speed increase of 10 km/h on moderate downgrades (3-5%) and 15 km/h on steeper grades (6-8%) of sufficient length are reasonable adjustments. These can be used in design to allow the use of a higher speed reduction curve. However, these speed increases may not be attainable if traffic volumes are high enough that a truck is likely to be behind a passenger vehicle when descending the grade.

4.2.2 Truck Climbing Lanes

If the critical length of grade in Figure 4-9 is exceeded, then a truck climbing lane may be warranted provided the construction costs and environmental impact are reasonable. The Highway Capacity Manual and the AASHTO A Policy on Geometric Design of Highways and Streets presents the detailed methodology for truck climbing lanes on two-lane highways. On freeways and expressways, the Highway Capacity Manual presents the accepted methodology.

When determining if a truck climbing lane is warranted, the designer must select a level of service. Preferably, the level of service should not be allowed to fall below the guidelines in Table 3.8. At restricted locations, the ascending roadway facility may be allowed to operate one level below these guidelines before a truck climbing lane is warranted. However, not below a level of service D.

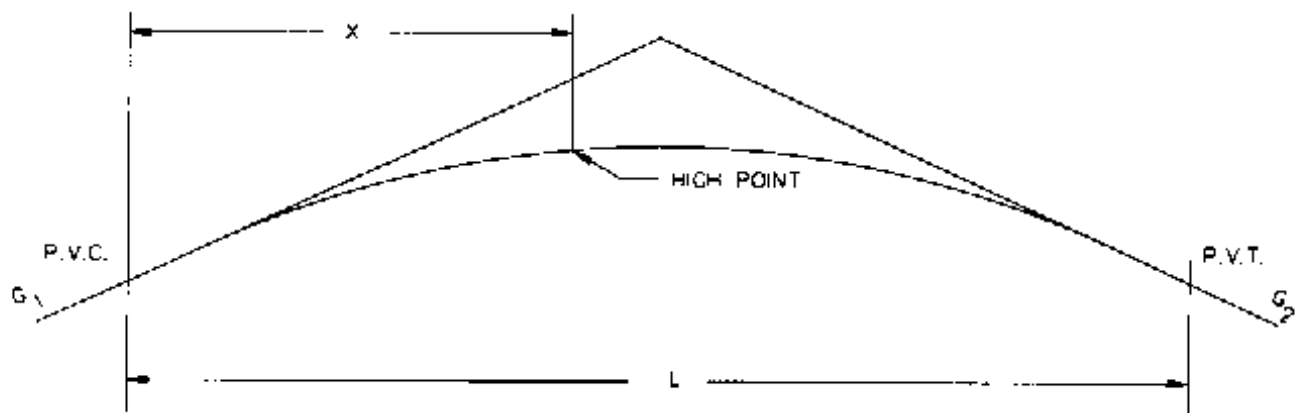
If a truck climbing lane is warranted and the costs are reasonable, the following criteria should be followed for designing the lane:

1. Lane width should be the same as the adjacent lane, but not less than 3.5 meters. The useable shoulder width should be at least 1. meter.
2. The full width of the climbing lane should be achieved at the point where a truck will have reduced its speed by 15 km/h.
3. The full width of the climbing lane should, when feasible, extend to the point where the truck speed is within 15 km/h of the typical auto speed. As a minimum it should extend to a point where full passing sight distance becomes available.
4. The entering taper should preferably be 25:1 and at least 50 meters long.
5. An exiting or merging taper not sharper than 50:1 is preferred. It should be 60 meters or more in length.

4.2.3 Vertical Curves

All vertical curves are in the shape of a parabola. The computations for vertical curves are shown in Figures 4-10, 4-11, and 4-12. Design controls for vertical curves are generally based on the formula $K = L/A$ where L is the length of curve in meters and A is the algebraic difference in grades expressed as a percent. The designer's use of K values facilitates geometric design. The tables are calculated to provide the minimum sight distances for the corresponding design speed.

TO FIND LOW POINT OR HIGH POINT ON A CURVE



G_1, G_2 = RATES OF GRADES EXPRESSED IN % WITH PROPER SIGN

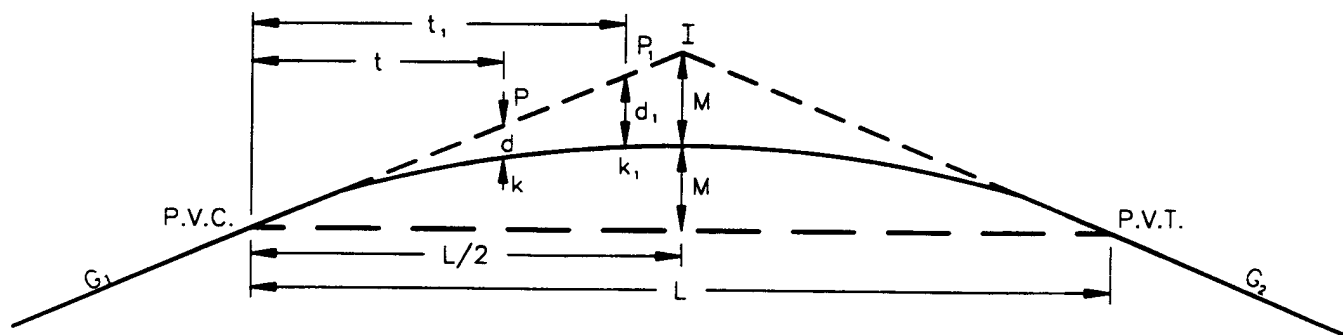
x = { DISTANCE OF HIGH POINT OF A CREST CURVE FROM P.V.C. IN METERS.
DISTANCE OF LOW POINT OF A SAG CURVE FROM P.V.C. IN METERS

L = LENGTH OF CURVE IN METERS

$$x = \frac{L(G_1)}{G_1 - G_2}$$

Note: IN ALL OF THE ABOVE FORMULAS ($G_1 - G_2$) IS THE ALGEBRAIC DIFFERENCE IN %

Figure 4-10. PARABOLIC VERTICAL CURVES



G_1, G_2 = RATE OF GRADE EXPRESSED IN PERCENT, WITH PROPER SIGN
 $A = (G_1 - G_2)$ ALGEBRAIC DIFFERENCE OF RATES OF GRADES EXPRESSED IN PERCENT
 L = LENGTH OF CURVE IN STATIONS (THE LENGTH IS MEASURED ON A HORIZONTAL PLANE)
 M = MIDDLE ORDINATE IN METERS
 d, d_1 = CORRECTIONS (OFFSETS) FROM GRADE LINE TO CURVE IN METERS
 t, t_1 = DISTANCE IN STATIONS FROM P.V.C. OR P.V.T. THAT POINTS k, k_1
 ON THE CURVE ARE LOCATED
 a = CORRECTION FACTOR, CONSTANT FOR ANY ONE CURVE

$$M = \frac{L(G_1 - G_2)}{8} \quad \text{OR} \quad M = \frac{1}{2} \left(\text{ELEV. POINT I} - \frac{\text{ELEV. AT P.V.C.} + \text{ELEV. AT P.V.T.}}{2} \right)$$

$$a = \frac{M}{\left(\frac{L}{2}\right)^2} = \frac{A}{2L}$$

$$d = at^2, d_1 = at_1^2 \text{ etc.}$$

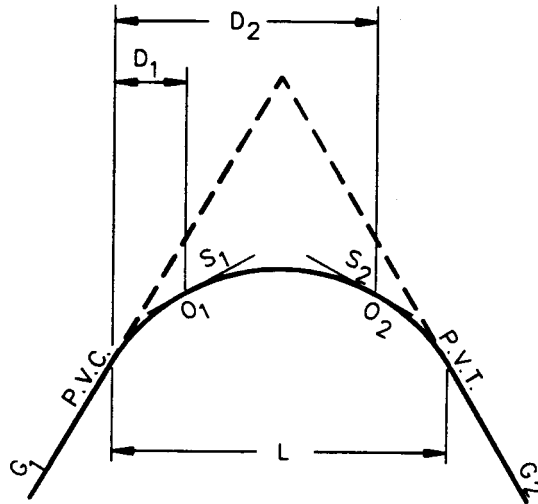
ELEV. OF k = ELEV. OF $P \pm d$, ELEV. OF k_1 = ELEV. OF $P_1 \pm d_1$, ETC.

WHEN THE ALGEBRAIC DIFFERENCE OF GRADES IS POSITIVE,
THE OFFSETS d, d_1, \dots ARE SUBTRACTED FROM THE ELEVATIONS P, P_1, \dots
ON THE TANGENT

WHEN THE ALGEBRAIC DIFFERENCE OF GRADES IS NEGATIVE,
THE OFFSETS d, d_1, \dots ARE ADDED TO THE ELEVATIONS P, P_1, \dots
ON THE TANGENT

Figure 4-11. PARABOLIC VERTICAL CURVES

TO FIND SLOPE OF CURVE AT ANY POINT



G_1, G_2 = RATE OF GRADE EXPRESSED IN PERCENT WITH PROPER SIGN

$(G_1 - G_2)$ = ALGEBRAIC DIFFERENCE IN RATES OF GRADES

S_1 & S_2 = SLOPE IN PERCENT, OF A TANGENT DRAWN AT POINTS O_1, O_2 ...
AT DISTANCES, D_1, D_2 ... FROM P.V.C. OF VERTICAL CURVE

D_1, D_2 ... = DISTANCE IN STATIONS

L = LENGTH OF VERTICAL CURVE IN STATIONS

$$S_1 = G_1 \pm D_1 \frac{|G_1 - G_2|}{L}, \quad S_2 = G_1 \pm D_2 \frac{|G_1 - G_2|}{L}$$

THE SIGN OF $|G_1 - G_2|$ IS ALWAYS POSITIVE (ABSOLUTE VALUE)

*ASSIGN THE PROPER SIGN TO G_1

\pm BECOMES A PLUS (+) FOR SAG CURVES

\pm BECOMES A MINUS (-) FOR CREST CURVES

Note: THE ABOVE FORMULA MAY BE USED TO FIND THE RATE OF GRADE OF A TANGENT AT ANY POINT ON A VERTICAL CURVE AND TO CHECK SLOPES OF CURVES FOR DRAINAGE PURPOSES.

Figure 4-12. PARABOLIC VERTICAL CURVES

4.2.3.1 Crest Vertical Curves

The primary control for crest vertical curves is providing adequate stopping sight distance (see Section 3.6.1). Table 4.4 shows computed K values for lengths of vertical curves as required for the range of values of **stopping sight distances** for each design speed.

Table 4.4
DESIGN CONTROLS FOR CREST VERTICAL CURVES
BASED ON STOPPING SIGHT DISTANCE

DESIGN SPEED (km/h)	ASSUMED SPEED FOR CONDITION (km/h)	COEFFICIENT OF FRICTION f	STOPPING SIGHT DISTANCE FOR DESIGN (m)	RATE OF VERTICAL CURVATURE, K (LENGTH (m) PER % OF A)*	
				COMPUTED	ROUNDED FOR DESIGN
30	30-30	0.40	29.6-29.6	2.17-2.17	3-3
40	40-40	0.38	44.4-44.4	4.88-4.88	5-5
50	47-50	0.35	57.4-62.8	8.16-9.76	9-10
60	55-60	0.33	74.3-84.6	13.66-17.72	14-18
70	63-70	0.31	94.1-110.8	21.92-30.39	22-31
80	70-80	0.30	112.8-139.4	31.49-48.10	32-49
90	77-90	0.30	131.2-168.7	42.61-70.44	43-71
100	85-100	0.29	157.0-205.0	61.01-104.02	62-105
110	91-110	0.28	179.5-246.4	79.75-150.28	80-151
120	98-120	0.28	202.9-285.6	101.90-201.90	102-202

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO 1994

* Desirable and minimum curve lengths are calculated using the formula $L=KA$. Where L is the curve length in meters, A is the algebraic difference in grades and K is the rate of vertical curvature from Table 4.4.

For the design of crest vertical curves, the following will apply:

1. **Stopping Sight Distance**—The desirable stopping sight distance should be available on crest vertical curves; lower stopping sight distance is acceptable only where the upper distance cannot reasonably be provided. A height of eye of 1070 millimeters and a height of object of 150 millimeters are used. A minimum length curve should be used for driver comfort and vehicular control.

Where: $L_{\min} = 0.6V$
 L_{\min} is in meters, V is in km/h

Flat vertical curves of less than 0.3% for distances of 15 meters or greater from the crest require careful drainage design. This equates to a K value of 50 or greater.

4.2.3.2 Sag Vertical Curves

Headlight sight distance (see Section 7.2) is the primary design control for sag vertical curves. The height of the headlights is assumed to be 600 millimeters. The upward divergence of the beam is 1 degree from the longitudinal axis of the vehicle. The curvature of the sag should be such that the headlights will illuminate the pavement sufficiently to provide adequate sight distance.

Table 4.5 shows the range of rounded values of K selected as design controls which provide for minimum headlight sight distance. Minimum lengths of vertical curves for flat gradients are equal to 0.6 times the design speed.

Table 4.5
DESIGN CONTROLS FOR SAG VERTICAL CURVES
BASED ON HEADLIGHT SIGHT DISTANCE

DESIGN SPEED (km/h)	ASSUMED SPEED FOR CONDITION (km/h)	COEFFICIENT OF FRICTION f	STOPPING SIGHT DISTANCE FOR DESIGN (m)	RATE OF VERTICAL CURVATURE, K (LENGTH (m) PER % OF A)*	
				COMPUTED	ROUNDED FOR DESIGN
30	30-30	0.40	29.6-29.6	3.88-3.88	4-4
40	40-40	0.38	44.4-44.4	7.11-7.11	8-8
50	47-50	0.35	57.4-62.8	10.20-11.54	11-12
60	55-60	0.33	74.3-84.6	14.45-17.12	15-18
70	63-70	0.31	94.1-110.8	19.62-24.08	20-25
80	70-80	0.30	112.8-139.4	24.62-31.86	25-32
90	77-90	0.30	131.2-168.7	29.62-39.95	30-40
100	85-100	0.29	157.0-205.0	36.71-50.06	37-51
110	91-110	0.28	179.5-246.4	42.95-61.68	43-62
120	98-120	0.28	202.9-285.6	49.47-72.72	50-73

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO 1994

* Desirable and minimum curve lengths are calculated using the formula $L=KA$. Where L is the curve length in meters, A is the algebraic difference in grades and K is the rate of vertical curvature from Table 4.5.

As in crest curves careful drainage design must be made for K values of greater than or equal to 50.

4.2.4 Vertical Clearances

Table 4.6 provides the required vertical clearances for all highway types and other clearance criteria. Refer to the MHD Bridge Manual for the method of determining clearances.

**Table 4.6
VERTICAL CLEARANCES**

MINIMUM ^{1,4} (m)	COMMENTS
5.0	Bridges over expressway/freeway
5.0	Bridge over arterial
5.0	Bridge over collector
5.0	Bridge over local road
See note 2.	Roadway bridge over railroad
5.3	Sign bridge or pedestrian bridge over roadway
See note 3.	Highway in the vicinity of an airport

- Notes:**
1. The Chief Engineer shall approve any clearance less than the minimum clearance in writing
 2. The MHD Bridge Engineer will coordinate clearance over railroads with the railroads.
 3. Clearance in the vicinity of an airport will be coordinated with the FAA through the FHWA
 4. Minimum values allow 100 millimeters for paving overlays in all cases.

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO 1994

4.2.5 Establishing Profiles

When establishing the vertical profile, use the following criteria:

1. A smooth grade line with gradual changes should be provided. Roller-coaster and broken back profiles should be avoided. On freeways, a minimum distance of 460 meters should be provided between points of intersection. On other major highways, 360 meters is the minimum distance. On urban and local roads, the existing topography and engineering judgment will determine the distance between points of intersection.
2. The vertical profile should be in balance with the horizontal alignment (See Section 4.4).
3. On divided highways with a median less than 9 meters, including shoulders, the median edges should be at the same elevation. For wider medians, the profiles for the two roadways should be established independently.
4. The vertical profiles of urban and local roads are determined considering the existing topography, construction costs, safety, and the abutting properties. The

evaluation should establish the critical abutting locations. Buildings, driveways, and steps are especially important when establishing profiles.

4.3 Superelevation

Superelevation counterbalances the centrifugal force, or outward pull, of a vehicle traversing a horizontal curve. This outward pull can be counterbalanced by the roadway being superelevated, the side friction developed between tires and surface, or some combination of the two. This allows a vehicle to negotiate curves safely at higher speeds than would otherwise be possible. The maximum useable rate for superelevation (e_{\max}), is controlled by several factors: climate conditions; terrain conditions; type of area and the frequency of slow moving vehicles.

4.3.1 Superelevation Rates

Because of winter snow and icing conditions, the maximum rate of superelevation (e_{\max}) used in Massachusetts is 6.0%.

For all high-speed roadways (above 60 km/h design speed), use Table 4.7 that provides the superelevation rate (e) for a given design speed and radius.

For all low-speed roadways (60 km/h and below design speed), use Table 4.8 which provides the minimum radii for four rates of superelevation; 0.0 percent, 2.0 percent, 4.0 percent and 6.0 percent. The rate of -2.0 percent is included to establish the minimum radii required with no superelevation. Section 4.3.7 discusses superelevation design in detail for low-speed roadways.

Table 4.7
RATE OF SUPERELEVATION AND MINIMUM LENGTH OF SUPERELEVATION RUNOFF
(High-Speed Roadways)

(m)	V _a = 30 km/h		V _a = 40 km/h		V _a = 50 km/h		V _a = 60 km/h		V _a = 70 km/h		V _a = 80 km/h		V _a = 90 km/h		V _a = 100 km/h		V _a = 110 km/h		V _a = 120 km/h	
	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)	e (%)	L (m)
7000	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3000	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1400	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1300	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1200	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	NC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	RC	17	26	2.5	22	3.3	28	4.2	4.0	3.3	50	4.7	39	5.9	4.8	4.4	6.6	5.4	5.0	7.5
300	RC	17	26	3.1	22	3.3	3.9	2.8	4.2	4.6	3.3	5.0	5.4	3.9	5.9	4.4	6.6	5.9	5.0	7.5
250	2.3	17	26	3.5	22	3.3	4.2	2.8	4.2	5.0	3.3	5.0	5.7	3.9	5.9	4.4	6.6	5.9	5.0	7.5
200	2.8	17	26	3.9	22	3.3	4.7	2.8	4.2	5.5	3.3	5.0	6.0	3.9	5.9	4.4	6.6	5.9	5.0	7.5
175	3.0	17	26	4.1	22	3.3	5.0	2.8	4.2	5.8	3.5	5.2	6.0	3.9	5.9	4.4	6.6	5.9	5.0	7.5
150	3.3	17	26	4.4	23	3.4	5.3	2.9	4.3	5.9	3.5	5.3	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
140	3.5	17	26	4.5	23	3.5	5.4	2.9	4.4	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
130	3.6	17	26	4.6	24	3.6	5.6	3.0	4.5	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
120	3.8	18	27	4.8	25	3.7	5.7	3.1	4.6	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
110	3.9	19	28	5.0	26	3.9	5.8	3.1	4.7	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
100	4.1	20	29	5.2	27	4.0	5.9	3.2	4.8	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
90	4.2	20	30	5.4	28	4.2	6.0	3.2	4.9	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
80	4.5	22	32	5.6	29	4.3	6.0	3.2	4.9	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
70	4.7	23	34	5.8	30	4.5	6.0	3.1	4.6	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
60	5.0	24	36	6.0	31	4.6	6.0	3.1	4.6	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
50	5.4	26	39	6.0	31	4.6	6.0	3.1	4.6	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
40	5.8	28	42	6.0	29	4.3	6.0	2.9	4.3	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5
30	6.0	29	43	6.0	29	4.3	6.0	2.9	4.3	6.0	3.6	5.4	6.0	3.6	5.4	4.4	6.0	5.6	5.0	7.5

NOTE: THE MINIMUM SUPERELEVATION RUNOFF LENGTHS FOR ROADWAYS WIDER THAN TWO-LANES SHOULD BE AS FOLLOWS:
 a) THREE-LANE TRAVELED WAYS, 1.2 TIMES THE CORRESPONDING LENGTH FOR TWO-LANE TRAVELED WAYS.
 b) FOUR-LANE UNDIVIDED TRAVELED WAYS, 1.5 TIMES THE CORRESPONDING LENGTH FOR TWO-LANE TRAVELED WAYS.
 c) SIX-LANE UNDIVIDED TRAVELED WAYS, 2.0 TIMES THE CORRESPONDING LENGTH FOR TWO-LANE TRAVELED WAYS.

e_{max} = 6.0%
 R = RADIUS OF CURVE
 V = ASSUMED DESIGN SPEED
 e = RATE OF SUPER ELEVATION
 L = MINIMUM LENGTH OF RUNOFF (DOES NOT INCLUDE TANGENT RUNOUT)
 NC = NORMAL CROWN SECTION
 RC = REMOVE CROWN, SUPERELEVATE AT NORMAL CROWN SLOPE (TYPICALLY 2.0%)
 NOTE: LENGTHS ROUNDED IN MULTIPLES OF 10 m PERMIT SIMPLER CALCULATIONS

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

4.3.2 Superelevation Transitioning

The development of superelevation on a horizontal curve requires a transition from a normal crown section, which is accomplished by rotating the pavement. The pavement may be rotated about the centerline or either edge of the travel lanes.

There are five basic cross section controls (-a-) thru (-e-), involved in transitioning the pavement to obtain full superelevation (See Figure 4-14):

Cross section (-a-)

Is the normal crown section where the transitioning begins.

Cross section (-b-)

Is reached by rotating half the pavement until it is level.

Cross section (-c-)

Is attained by continuing to rotate the same half of pavement until a plane section is attained across the entire pavement section, at a cross slope equal to the normal crown slope.

Cross section (-d-)

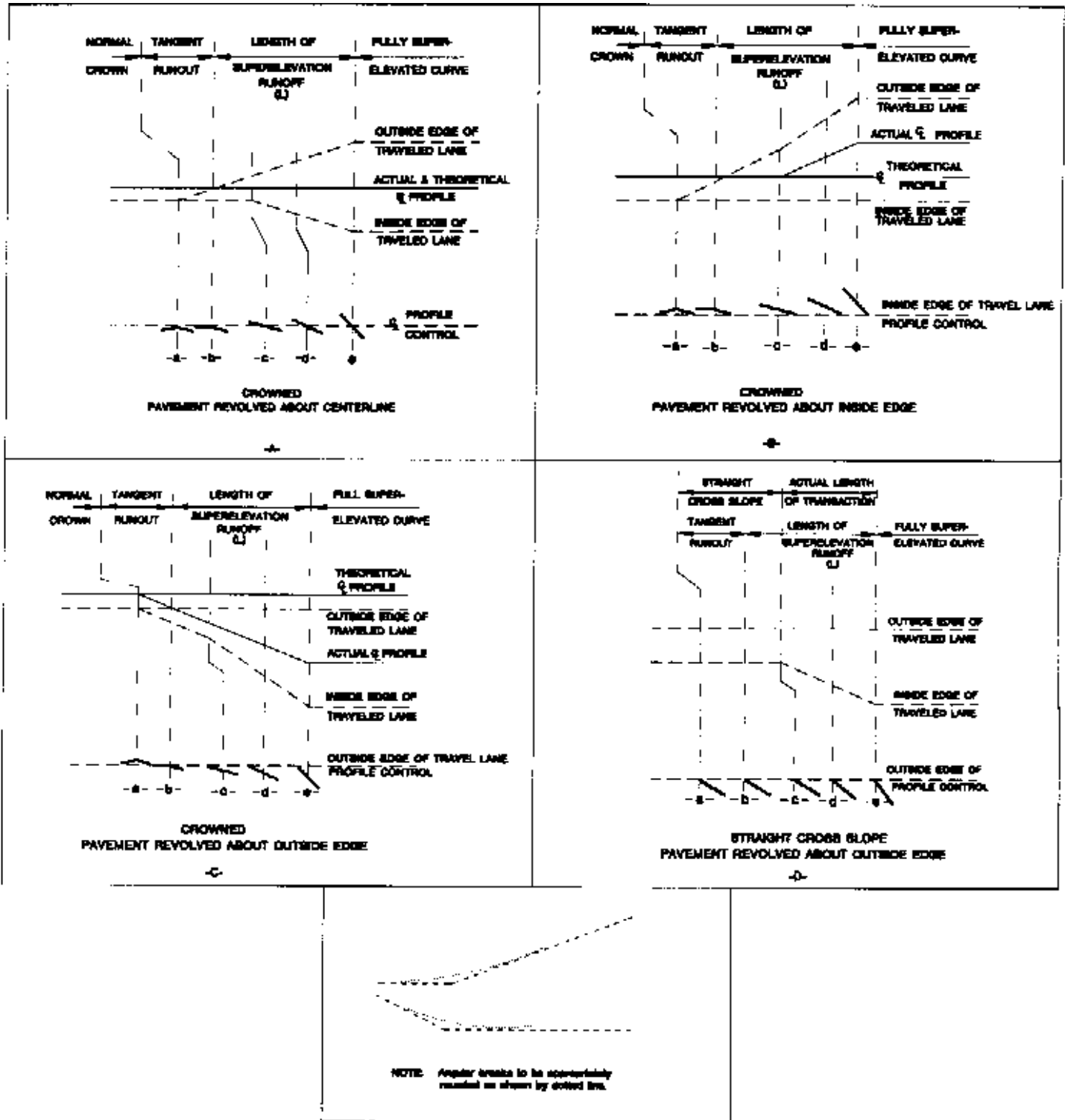
Is the rate of cross slope at any intermediate cross section between (-c-) and (-e-) is proportional to the distance from Cross section (-e-).

Cross section (-e-)

Is achieved by further rotation of the planar section, the entire pavement section, to attain the full superelevation at a cross slope equal to (e).

Superelevation runoff is the general term denoting the length of highway needed to accomplish the change in cross slope from a section with adverse crown removed (-b-) to a fully superelevated section (-e-), or visa versa.

Tangent runout is the general term denoting the length of highway needed to accomplish the change in cross slope from a normal section (-a-) to a section with the adverse crown removed, or vice versa (-b-) (See Figure 4-14).



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

FIGURE 4-14 DIAGRAMMATIC PROFILES SHOWING METHODS OF ATTAINING SUPERELEVATION FOR A CURVE TO THE RIGHT

Design Considerations:

1. Superelevation is introduced or removed uniformly over the lengths required for comfort and safety.
2. Place approximately two-thirds of the runoff on the tangent section and one-third on the horizontal curve.
3. Angular breaks occur in the vertical profile in the superelevation transition areas. To smooth these breaks, when the vertical angle points are greater than 1%, short vertical curves are required. The minimum vertical curve length in meters can be used as numerically equal to the design speed in kilometers. Greater lengths should be used where possible.
4. On compound curves the following criteria should be met:
 - a. Full superelevation for the sharpest curve should be attained at the PCC.
 - b. If the flatter entering curve is less than or equal to 150 meters, a uniform longitudinal gradient should be used throughout the transition.
 - c. If the flatter entering curve is longer than 150 meters, it may be preferable to consider the two curves separately. Superelevation for the entering curve would be developed by the 2/3rd-1/3rd distribution method. This rate would be maintained until it is necessary to develop the remaining superelevation for the sharper curve.

Figure 4-20 illustrates the two transition methods for compound curves.
5. When spiral transitions are used the following criteria should be met:
 - a. The adverse crown is completely removed at the beginning of the spiral. The tangent runout length occurs prior to the beginning of the spiral transition. The rate of transition used in the removal of the adverse crown (tangent runout) should be the same rate used to effect the superelevation runoff.
 - b. The transition for the superelevation runoff will be effected over the entire length of spiral, with full superelevation developed at the horizontal curves's PSC.
 - c. Depending on the formula and factors used, the length of spiral for a particular curve and design may be greater or less than the length required for the superelevation runoff. For simplicity, use the length of spiral equal to the length required for the superelevation runoff. (See Figure 4-21).

6. The minimum superelevation runoff lengths for roadways wider than two lanes should be as follows:
 - a. Three-lane traveled ways; 1.2 times the corresponding length for two-lane traveled ways.
 - b. Four-lane undivided traveled ways; 1.5 times the corresponding length for two-lane highways.
 - c. Six-lane undivided traveled ways; 2.0 times the corresponding length for two lane traveled ways.

4.3.3 Axis of Rotation

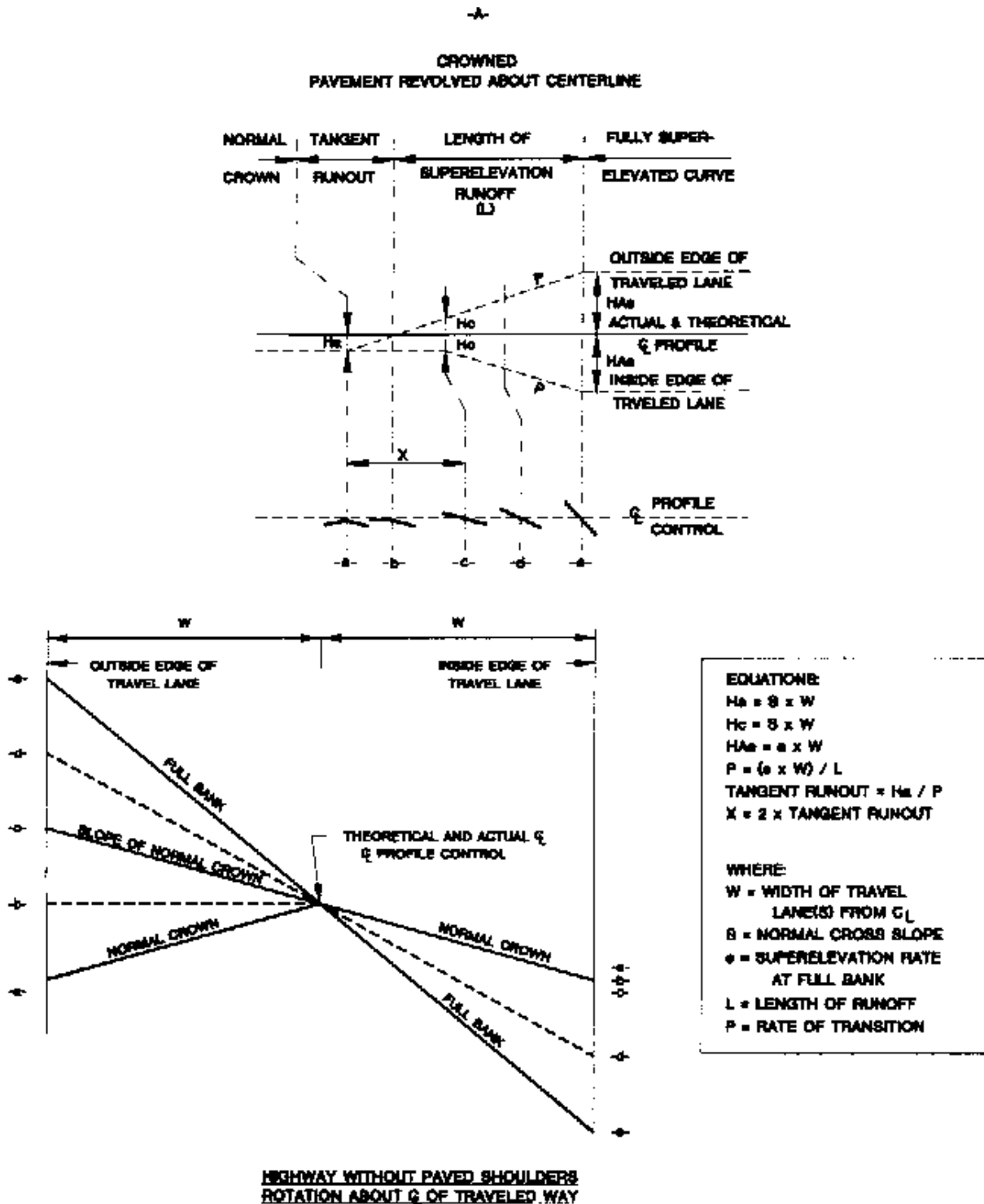
To attain superelevation an axis must be selected about which the pavement is rotated. In general there are four methods that may be selected:

1. Rotation about the centerline profile of traveled way -- This is generally the preferred method when the elevations of the outside of roadway must be held within critical limits, such as in an urban area to minimize the impact on adjoining properties. This is also the method that distorts the edge line profiles the least. Figure 4-15 graphically demonstrates how the roadway superelevation is developed for this method.

2. Rotation about the inside-edge profile of traveled way -- This is generally the preferred method when the lower edge profile is of concern, such as when the profile is flat and the inside edge of the roadway needs to be controlled for drainage purposes. Figure 4-16 graphically demonstrates how the roadway superelevation is developed for this method.

3. Rotation about the outside-edge profile of traveled way -- This method is similar to inside edge rotation except that the change is effected below the outside-edge profile instead of above the inside edge profile. This method is used when the higher edge profile is critical, such as on divided highways where the median edge profiles are held. Figure 4-17 graphically demonstrates how the roadway superelevation is developed for this method.

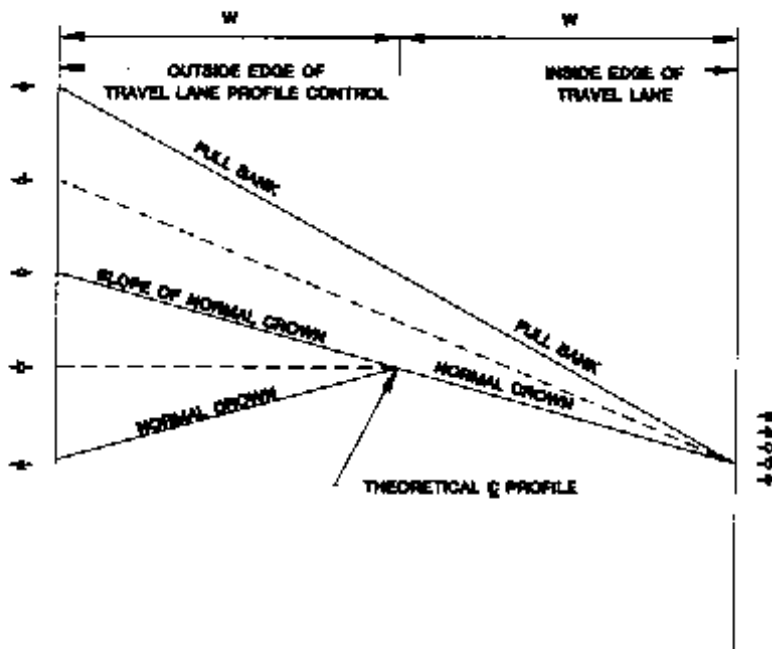
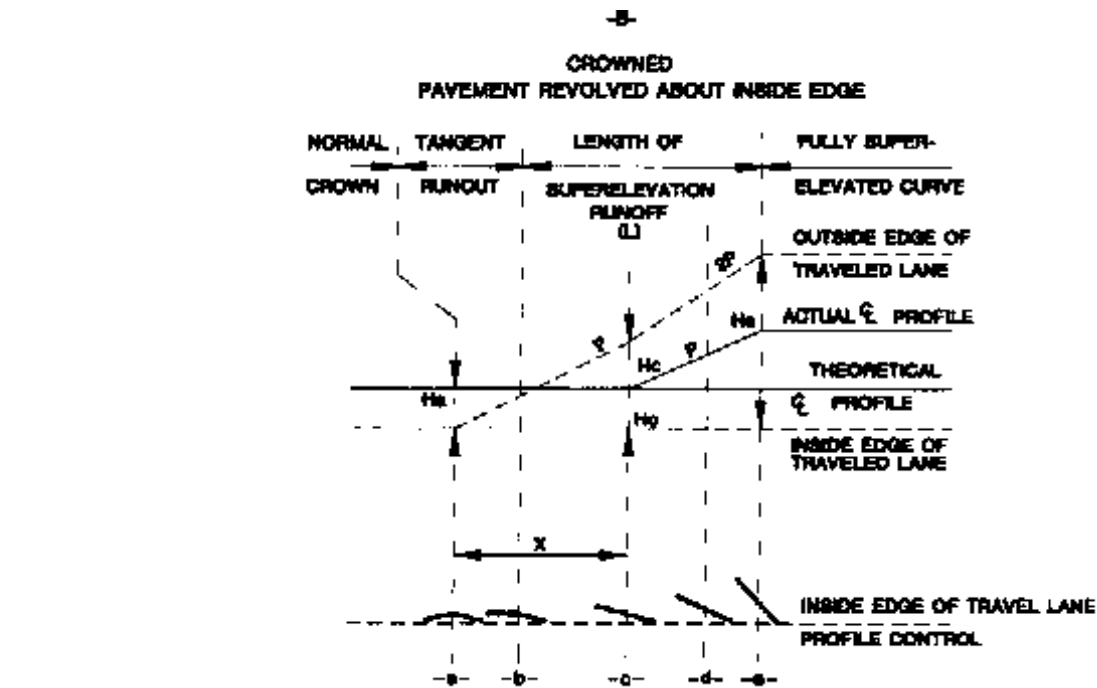
4. Rotation about the outside-edge profile of traveled way when the roadway has a straight cross-slope at the beginning of transition (-a-) -- The outside-edge rotation is shown because this point is most often used for revolvment of two-lane one-way roadways, with profile along the median edge of traveled way or for the traveled way having a typical straight cross-slope. Figure 4-18 graphically demonstrates how the roadway superelevation is developed for this method.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

**Figure 4-15 METHODS OF BANKING UNDIVIDED HIGHWAYS -
ROTATION ABOUT CENTERLINE**

(FOR A CURVE TO THE RIGHT)



EQUATIONS:

$$H_a = \delta \times W$$

$$H_c = \delta \times W$$

$$H_p = 2 \times e \times W$$

$$P = (e \times W) / L$$

$$\text{TANGENT RUNOUT} = H_a / P$$

$$2P = 2 \times P$$

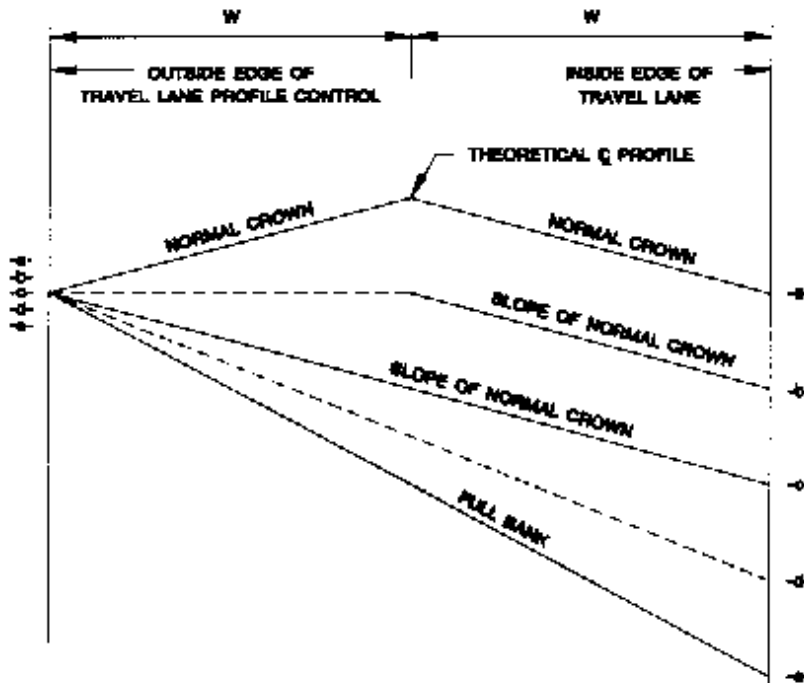
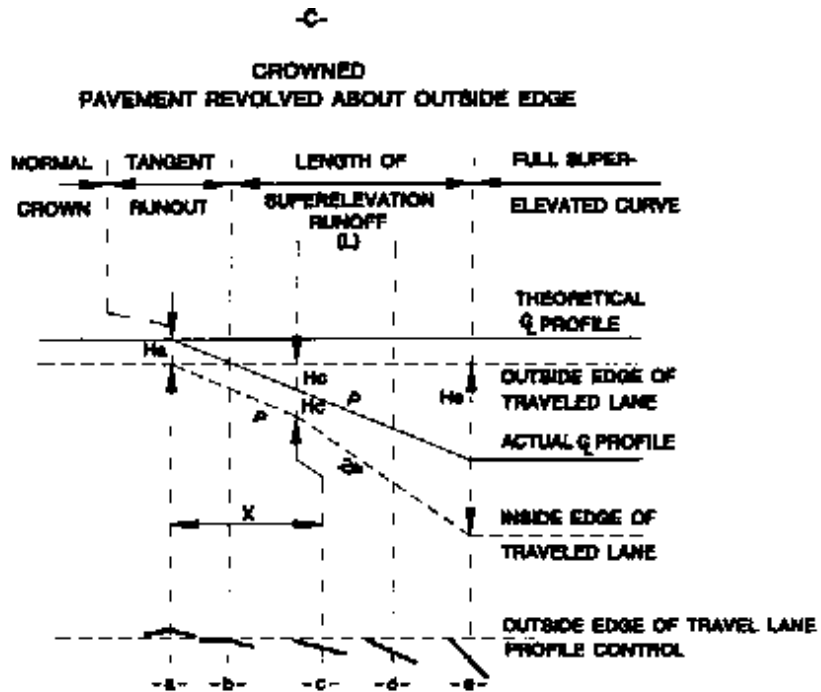
$$X = 2 \times \text{TANGENT RUNOUT}$$

WHERE:

- W = WIDTH OF TRAVEL LANE(S) FROM C
- δ = NORMAL CROSS SLOPE
- e = SUPERELEVATION RATE AT FULL BANK
- L = LENGTH OF RUNOFF
- P = RATE OF TRANSITION

**HIGHWAY WITHOUT PAVED SHOULDERS
ROTATION ABOUT INSIDE EDGE OF TRAVELED WAY**

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994
**Figure 4-16 METHODS OF BANKING UNDIVIDED HIGHWAYS -
ROTATION ABOUT INSIDE EDGE
(FOR A CURVE TO THE RIGHT)**



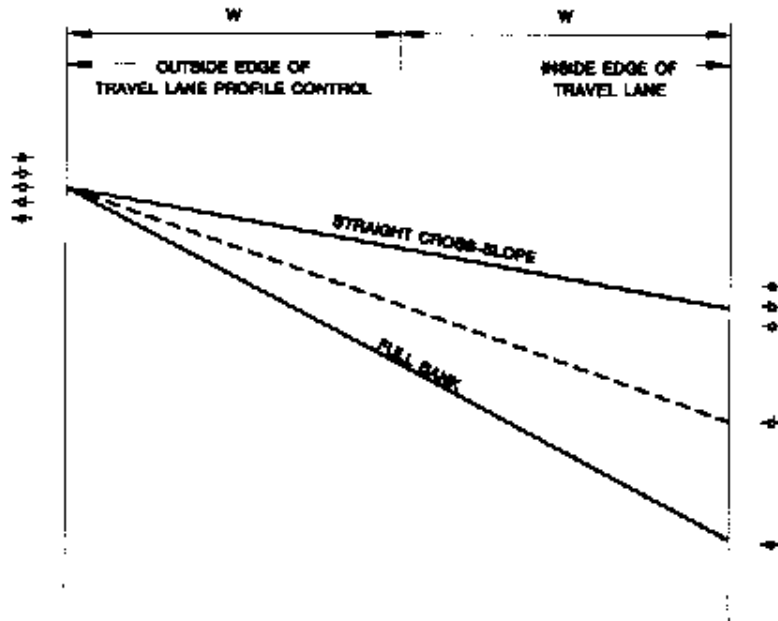
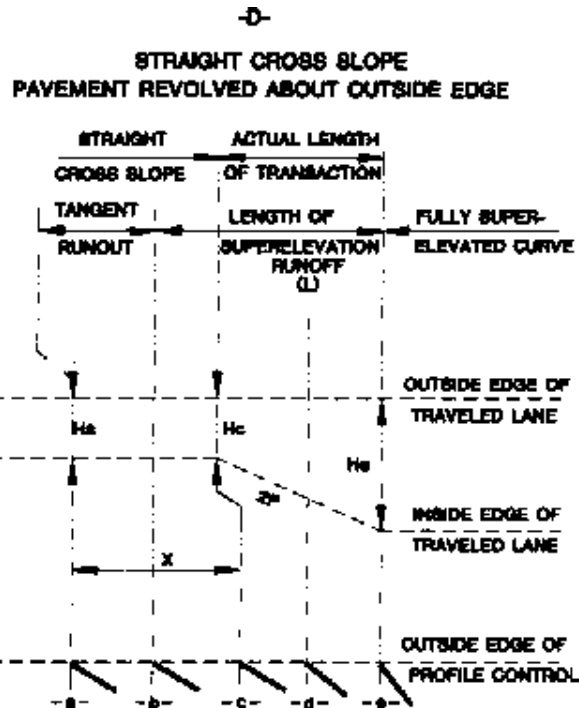
EQUATIONS:
 $H_c = S \times W$
 $H_c' = S \times W$
 $H_c'' = 2 \times p \times W$
 $P = (S + p) / L$
 TANGENT RUNOUT = H_c / P
 $2P = 2 \times P$
 $X = 2 \times \text{TANGENT RUNOUT}$

WHERE:
 W = WIDTH OF TRAVEL LANE(S) FROM C
 S = NORMAL CROSS SLOPE
 p = SUPERELEVATION RATE AT FULL BANK
 L = LENGTH OF RUNOFF
 P = RATE OF TRANSITION

**HIGHWAY WITHOUT PAVED SHOULDERS
ROTATION ABOUT OUTSIDE EDGE OF TRAVELED WAY**

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

**Figure 4-17 METHODS OF BANKING UNDIVIDED HIGHWAYS -
ROTATION ABOUT OUTSIDE EDGE
(FOR A CURVE TO THE RIGHT)**



EQUATIONS:
$H_a = s \times W$
$H_c = s \times W$
$H_e = 2 \times s \times x$
$P = (s \times W) / L$
TANGENT RUNOUT = H_a / P
$2P = 2 \times P$
$X = 2 \times \text{TANGENT RUNOUT}$
WHERE:
W = WIDTH OF TRAVEL LANE(S) FROM C
s = NORMAL CROSS SLOPE
s = SUPERELEVATION RATE AT FULL BANK
L = LENGTH OF RUNOFF
P = RATE OF TRANSITION

**HIGHWAY WITHOUT PAVED SHOULDERS-STRAIGHT CROSS SLOPE
ROTATION ABOUT OUTSIDE EDGE OF TRAVELED WAY**

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994
**Figure 4-18 METHODS OF BANKING UNDIVIDED HIGHWAYS -
 STRAIGHT CROSS SLOPE - ROTATION ABOUT OUTSIDE EDGE
 (FOR A CURVE TO THE RIGHT)**

4.3.4 Minimum Lengths for Superelevation Runoff for High-Speed Roadways (Design Speed above 60 km/h)

Superelevation runoff lengths should be long enough so that the rate of change (slopes) of the edges of pavement relative to the centerline do not exceed empirically developed controls. These maximum relative gradients, (which provide a minimum length of runoff) are given in Table 4.8. To avoid undesirable abrupt edge-of-pavement profiles, another minimum length of runoff is approximated by the distance traveled in 2 seconds at the design speed. This 2 second criterion will taken precedence over the maximum relative slope values given in Table 4.8. In general, for lower superelevation rates (e) the minimum length of runoff is based on the 2 second travel time, while for the higher superelevation rates (e) the minimum length of runoff is based on the maximum relative gradients between the edge line profiles and the center line.

Table 4.8
RELATIONSHIP OF DESIGN SPEED TO MAXIMUM
RELATIVE PROFILE GRADIENTS

DESIGN SPEED V_D (km/h)	MAXIMUM RELATIVE GRADIENTS (AND EQUIVALENT MAXIMUM RELATIVE SLOPES) FOR PROFILES BETWEEN THE EDGE OF TWO-LANE TRAVELED WAY AND THE CENTERLINE (%)
30	0.75 (1:133)
40	0.70 (1:143)
50	0.65 (1:150)
60	0.60 (1:167)
70	0.55 (1:182)
80	0.50 (1:200)
90	0.48 (1:210)
100	0.45 (1:222)
110	0.42 (1:238)
120	0.40 (1:250)

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO 1994

The maximum relative gradients between profiles of the edges of two-lane traveled ways are double those given in Table 4.8.

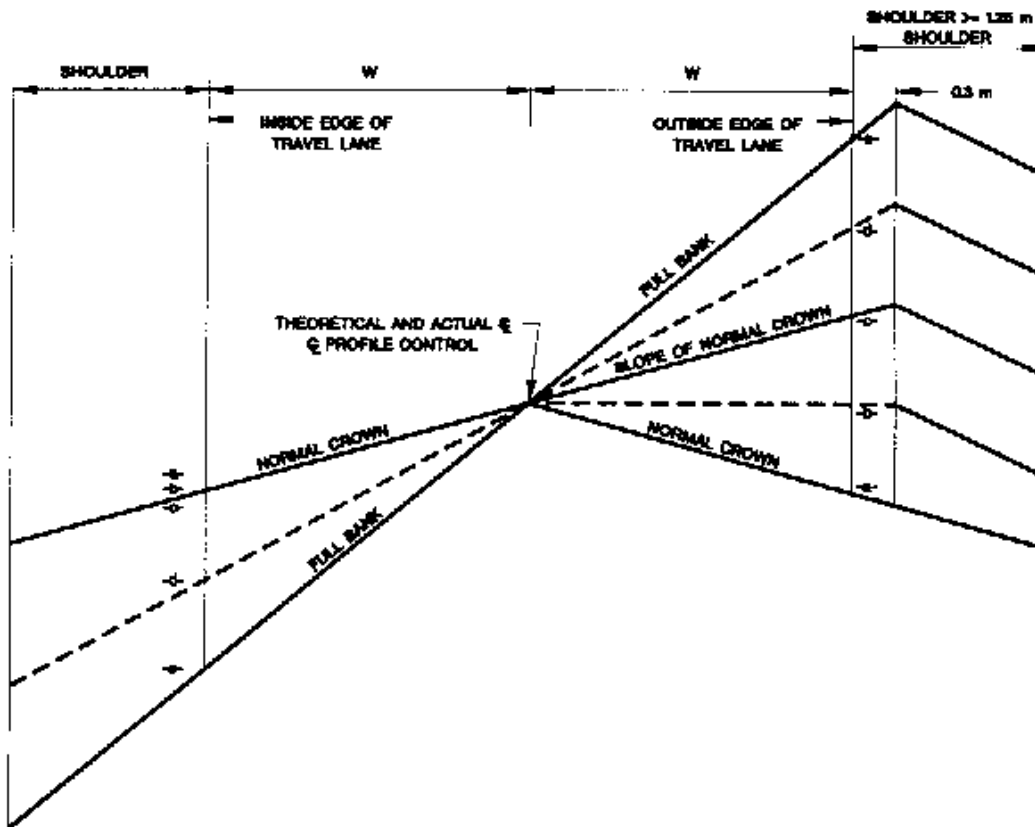
Table 4.7 can be used to determine superelevation rate (e) and the minimum length of superelevation runoff based on (e_{max}), a given radius, and a design speed.

4.3.5 Shoulder Superelevation

All outside shoulders and median shoulders of 1.25 meter or greater should slope away from the travel lanes on superelevated curves. The maximum algebraic difference between the travel lane slope and shoulder slope ("rollover") is 0.09 m/m. Shoulders less than 1.25 meter should slope in the same direction as the travel lane. (See Figure 4-19)

An additional 0.25 meters must be added to the outside travel lane dimension to calculate shoulder edge profiles.

SHOULDER TREATMENTS (FOR CURVE TO THE LEFT)



NOTE:
SHOULDER TREATMENTS ARE TYPICAL FOR ALL METHODS OF SUPERELEVATION.
SHOULDER LESS THAN 1.25 m SHOULD SLOPE IN THE SAME DIRECTION AS THE TRAVEL LANE.
"ROLL-OVER" BETWEEN TRAVEL LANE AND SHOULDER CANNOT EXCEED 0.09

Figure 4-19 HIGHWAY WITH PAVED SHOULDERS

KEY: e_f = REQUIRED SUPERELEVATION FOR FLATTER ENTERING CURVE.
 e_s = REQUIRED SUPERELEVATION FOR SHARPER CURVE.

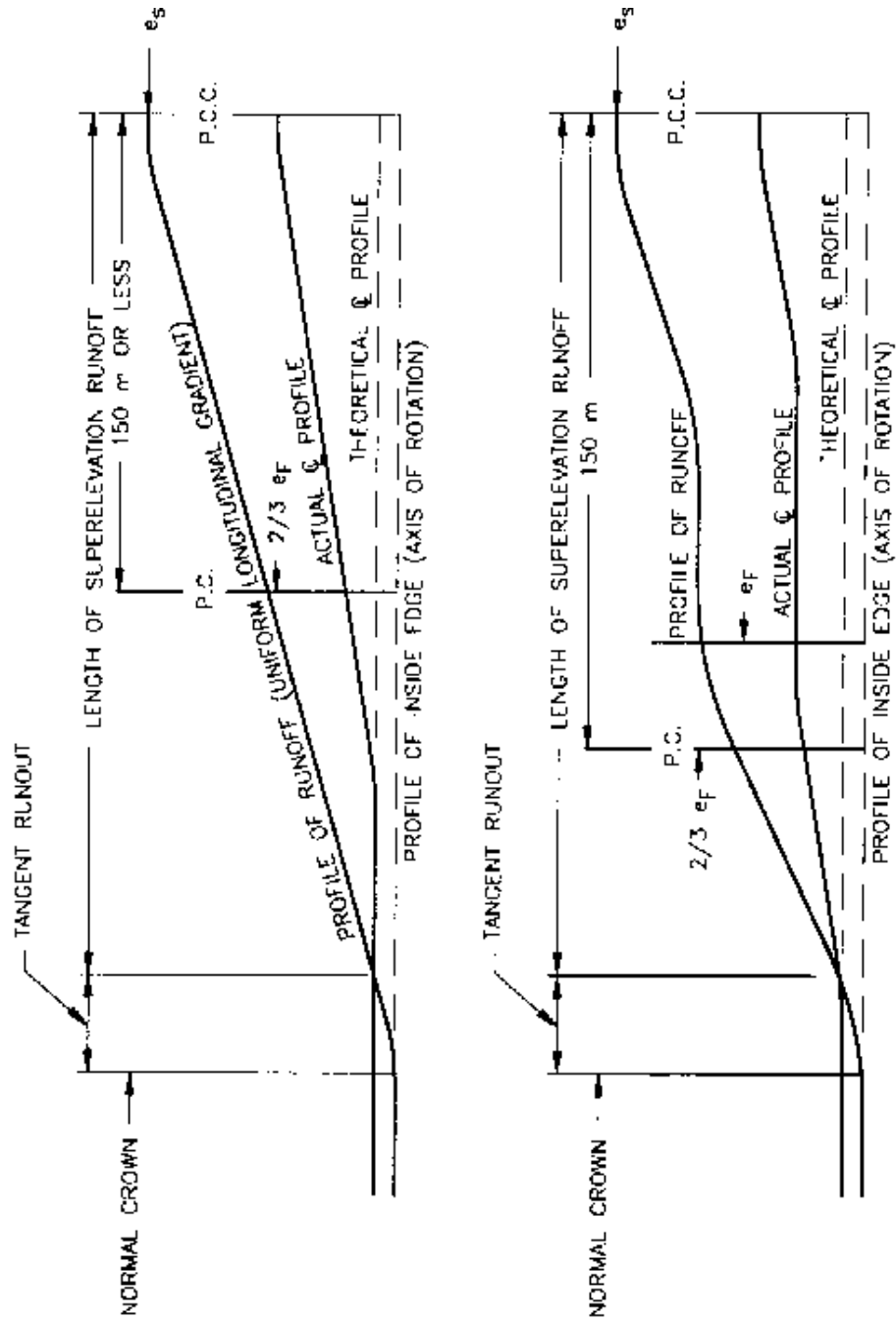
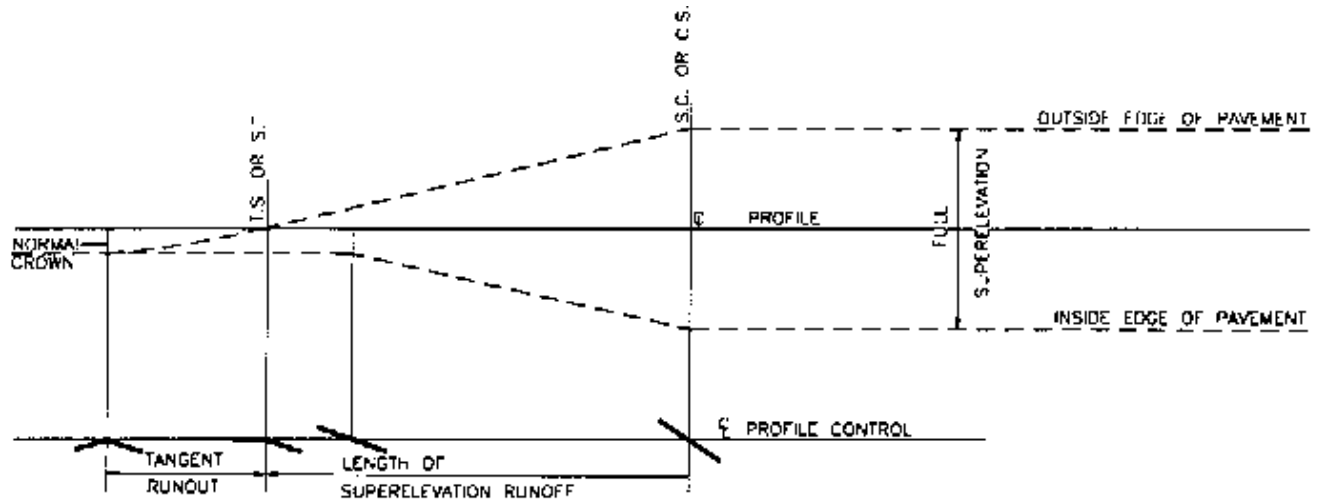
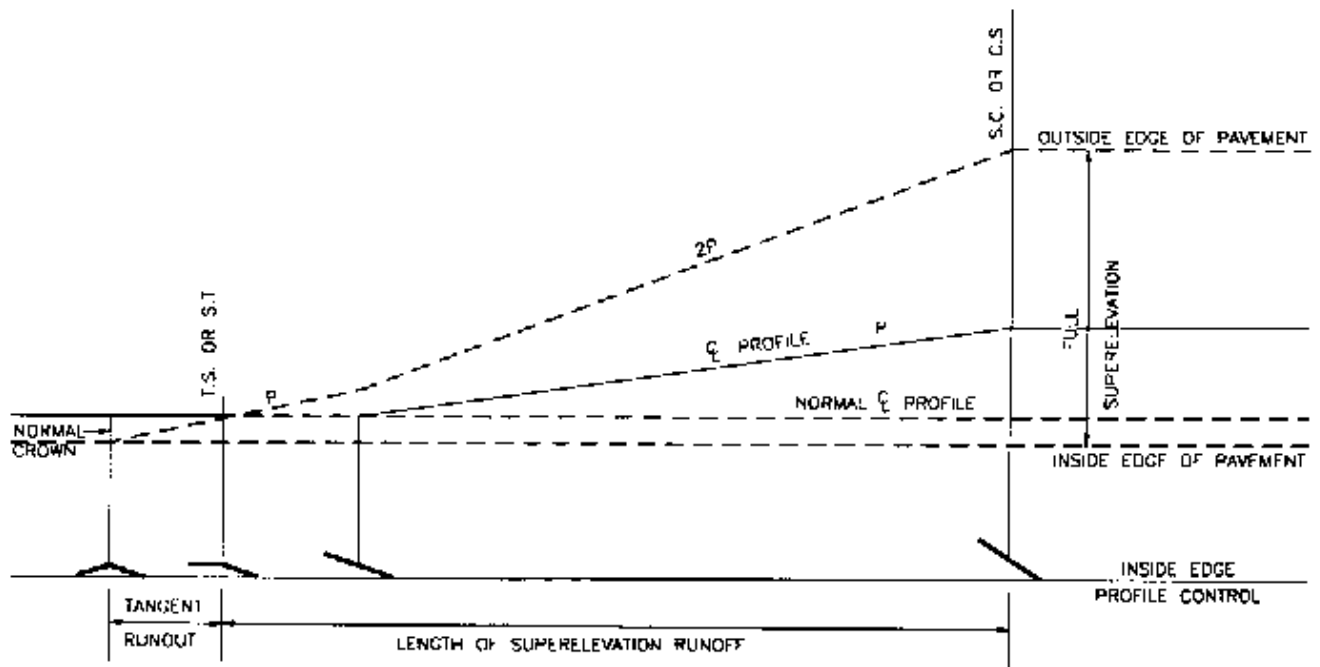


Figure 4-20. SUPERELEVATION ON COMPOUND CURVES



Pavement Revolved About Center-line



Pavement Revolved About Inside Edge

- T.S. - tangent to spiral
- S.T. - spiral to tangent
- S.C. - spiral to curve
- C.S. - curve to spiral

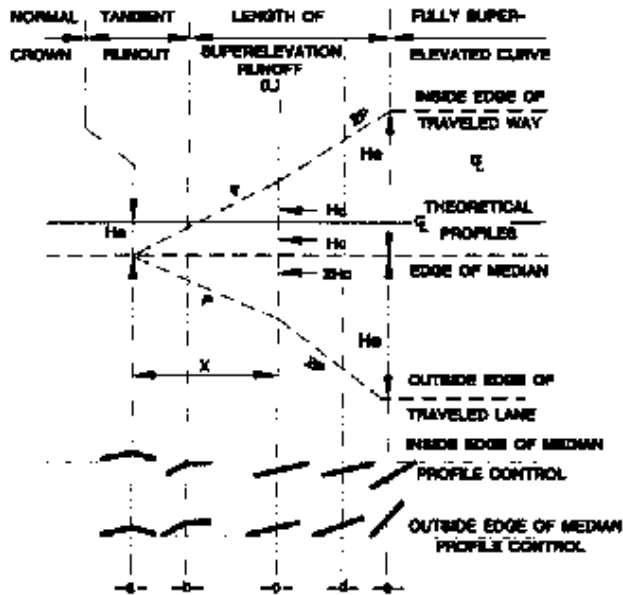
**Figure 4-21. DEVELOPMENT OF SUPERELEVATION
WITH TRANSITION (SPIRAL) CURVE
FOR A CURVE TO THE RIGHT**

4.3.6 Divided Highways with Medians

Divided highways with medians require special consideration.

1. Medians of less than 3 meters -- To minimize the distortion between the two outside edges of the median, the cross section may be used as the axis, with the whole roadway rotated about the center line of the median as a plane section. This method is limited to moderate superelevation rates.
2. Medians wider than 3 meters -- Where both roadways are crowned separately, the axis of rotation should be at the median edges for each side of the roadway, or the gutter lines where applicable. In this case the median is held in a horizontal plane. This method is illustrated in Figure 4-22.
3. Medians wider than 12 meters -- It may be preferable to develop the superelevation on each roadway independently with medians greater than 12 meters. The rotation may be made for each side of the roadway using any of the methods illustrated in Figures 4-15 to 4-18 as considered appropriate by the designer.

**CROWNED WITH MEDIAN
PAVEMENT REVOLVED ABOUT OUTSIDE AND INSIDE EDGES OF MEDIAN**



EQUATIONS:

$$H_s = S \times W$$

$$H_c = e \times W$$

$$H_s = 2 \times e \times W$$

$$P = (S \times W) / L$$

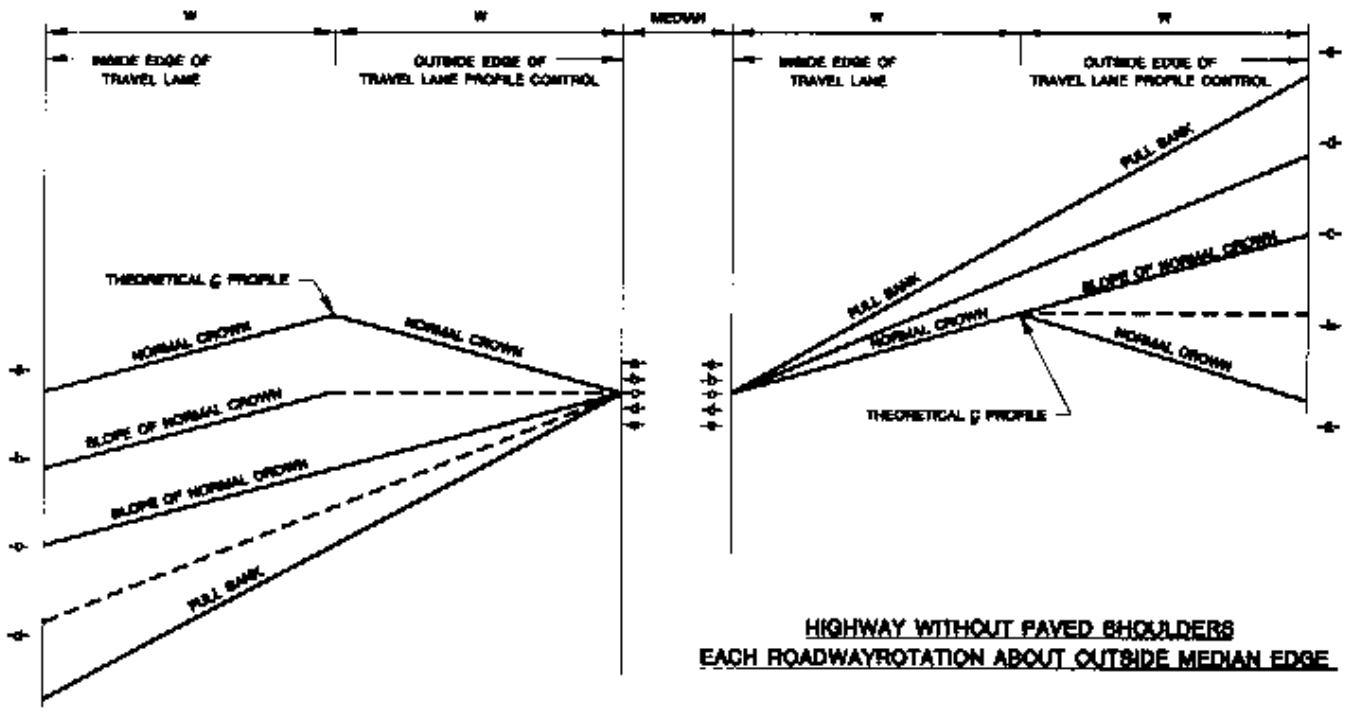
TANGENT RUNOUT = H_s / P

$$X = 2 \times \text{TANGENT RUNOUT}$$

$$2P = 2 \times P$$

WHERE:

- W = WIDTH OF TRAVEL LANES FROM Q
- S = NORMAL CROSS SLOPE
- e = SUPERELEVATION RATE AT FULL BANK
- L = LENGTH OF RUNOFF
- P = RATE OF TRANSITION



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

**Figure 4-22 METHODS OF BANKING UNDIVIDED HIGHWAYS -
ROTATION ABOUT MEDIAN EDGE**

(FOR A CURVE TO THE LEFT)

4.3.7 Low-Speed Roadways (Design Speed 60 km/h and below)

Although superelevation is advantageous for traffic operation, various factors often combine to make its use impractical in many built-up areas. Such factors include wide pavements areas, the need to meet the grade of adjacent property, surface drainage considerations, and frequency of cross streets, alleys, and driveways. Therefore, horizontal curves on low-speed roadways in urban areas may be designed without superelevation, counteracting the centrifugal force solely with side friction. The minimum radius or sharpest curve without superelevation is reached when the side friction factor developed to counteract centrifugal force and adverse cross slope reaches the maximum allowable value based on safety and comfort considerations. For travel on sharper curves, superelevation is needed. A maximum superelevation rate of 4.0 percent is commonly used. A maximum superelevation rate of 6.0 percent may be justified on sharper curves where adequate transition lengths are available. In some cases, it may also be appropriate to use a 2.0 percent or 0.0 percent rate to fit existing conditions.

Table 4.9 gives the minimum radii for four rates of superelevation; 0.0 percent, 2.0 percent, 4.0 percent and 6.0 percent. The designer should use the most appropriate rate to fit existing conditions. (When using the formulas to calculate a value of e , the designer should round up to use at least the next higher superelevation rate for design purposes). The rate of -2.0 is included to establish the minimum radii required with no superelevation. In addition, the table contains the minimum lengths of superelevation runoff for each superelevation rate and design speed. These lengths are based on revolving the traveled way around the centerline of the street. On flat grades the traveled way should be revolved about the inside edge to avoid low spots on the inner edge.

Table 4.9 may also be used to calculate the minimum desirable length of tangent between two reversing curves of minimum radii. The superelevation rate of zero may be used to determine the intervening length of tangent between reversing curves even if neither is superelevated. Because two-thirds of the maximum superelevation should be provided at the PC and PT of the curves, the minimum tangent length is two-thirds of the sum of the superelevation runoff lengths.

Table 4.9
MINIMUM RADII AND MINIMUM LENGTHS OF SUPERELEVATION RUNOFF
FOR LIMITING VALUES OF e AND f (LOW-SPEED STREETS)

DESIGN SPEED (km/h)	MAX e/100	MAX f	TOTAL (e/100+f)	MIN R (m)	MAX f	TOTAL (e/100+f)	MIN R (m)	MAX e/100	MAX f	TOTAL (e/100+f)	MIN R (m)	MIN L (m)	G
30	0.06	0.312	0.372	20	0.312	0.352	20	0.04	0.312	0.352	25	30	120
40	0.06	0.252	0.312	40	0.252	0.292	45	0.04	0.252	0.272	45	25	15
60	0.06	0.214	0.274	70	0.214	0.254	80	0.04	0.214	0.234	85	20	100
80	0.06	0.186	0.246	115	0.186	0.226	125	0.04	0.186	0.206	140	30	100
70	0.06	0.163	0.223	175	0.163	0.203	193	0.04	0.163	0.183	210	30	100

Reference: "A HANDBOOK ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" MASHITZ, 1994

NOTE: $L_{min} = 2.72 \frac{f_{max} V_0^3}{C}$

WHERE:

L_{min} = MINIMUM LENGTH OF SUPERELEVATION RUNOFF.

f_{max} = MAXIMUM ALLOWABLE SIDE FRICTION FACTOR.

V_0 = DESIGN SPEED IN km/h, AND

C = RATE OF CHANGE OF f IN m/s²

AND: $e + f_{max} = \frac{V_0^2}{127R}$

WHERE:

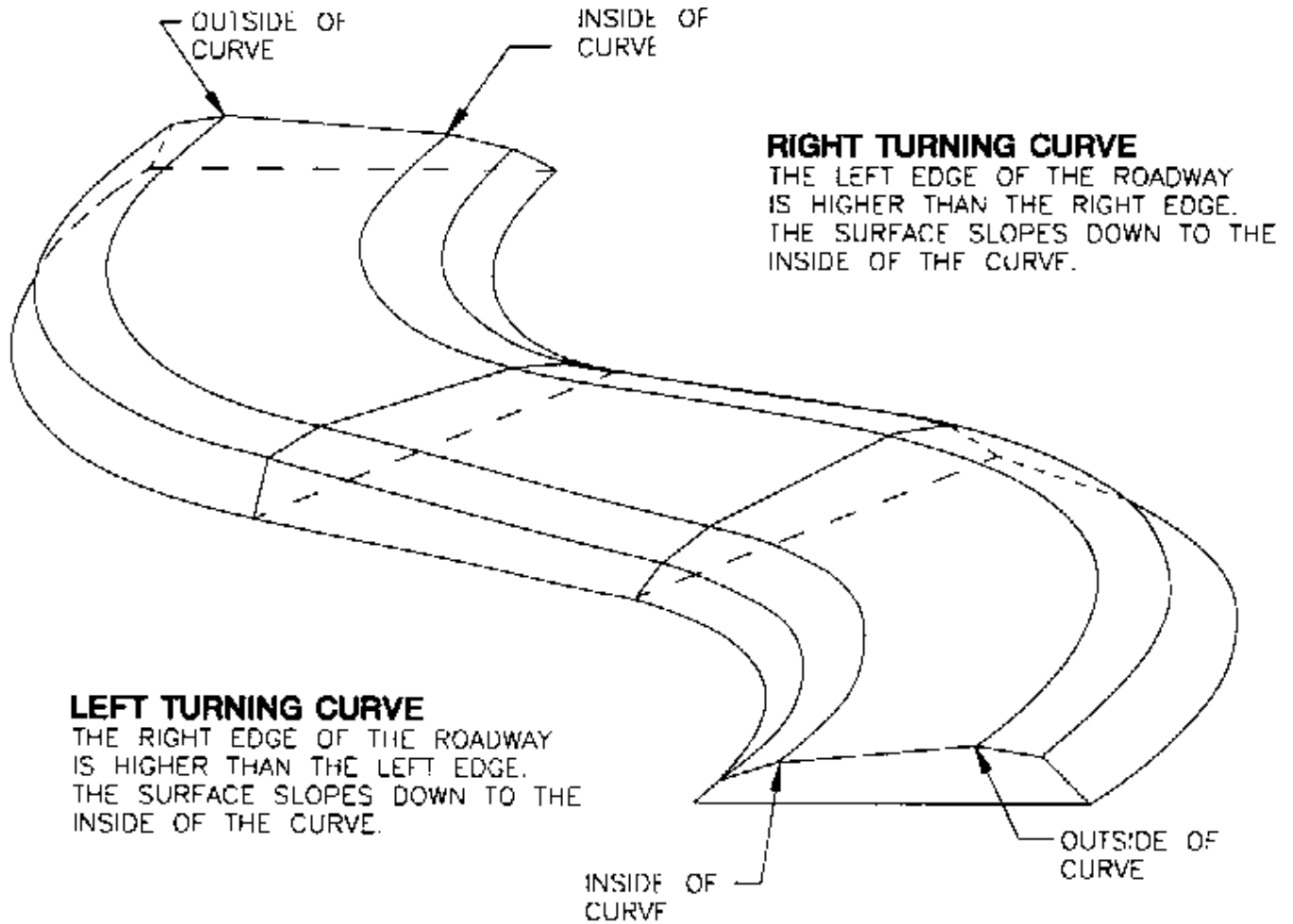
e = THE ACTUAL (MINIMUM) SUPERELEVATION RATE

f_{max} = MAXIMUM ALLOWABLE SIDE FRICTION VALUES GIVEN ABOVE

V_0 = DESIGN SPEED IN km/h, AND

R = GIVEN DESIGN RADIUS, IN METERS

DESIGN SPEED (km/h)	MAX e/100	MAX f	TOTAL (e/100+f)	MIN R (m)
30	-0.02	0.312	0.292	25
40	-0.02	0.252	0.232	55
60	-0.02	0.214	0.194	100
80	-0.02	0.186	0.166	170
70	-0.02	0.163	0.143	270

**Figure 4-23. LEFT AND RIGHT-TURNING CURVES**

4.4 COMBINATION OF HORIZONTAL AND VERTICAL ALIGNMENTS

Horizontal and vertical alignments should not be designed independently. They complement each other, and poorly designed combinations can spoil the good points and aggravate the deficiencies of each.

Horizontal alignment and profiles are among the most important of the permanent design elements. Excellence in their design, and in the design of their combination, increase usefulness and safety, encourage uniform speed, and improve appearance.

The following general controls should be considered in balancing horizontal alignment and profiles:

1. Curvature in the horizontal plane should be accompanied by comparable length of curvature in the vertical plane.
2. Awkward combinations of curves and tangents in both the horizontal and vertical planes should be avoided (ie: "broken back" curves).
3. Horizontal and vertical curvatures should be coordinated to avoid combinations that appear awkward when viewed from a low angle. Ideally the vertices of horizontal curves (PI) and vertical curves (PVI) should coincide or be within 1/4 phase of each other.
4. Horizontal curvature should lead vertical curvature. ie: the horizontal curve should be longer than the vertical curve and the PVT and PC should not be at the same point.

The designer is directed to use the guidelines found in the *AASHTO Policy on Geometric Design of Highways and Streets*, Chapter 3: "Elements of Design, and other applicable publications.

4.5 REFERENCES

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 1994.
- *Highway Capacity Manual, Special Report No. 209*, Transportation Research Board
- *Practical Highway Esthetics*, ABCE, 1977
- *Cross Section and Alignment Design Issues*, TRB No. 1445, 1994

CHAPTER 5

HIGHWAY CROSS SECTION

5.1 ROADWAY SECTION

Table 5.1 presents the recommended design widths for the various roadway section elements. These dimensions apply for new construction or major rehabilitation projects. The criteria presented in this chapter are based on established practices and supplemented by recent research from AASHTO and the Transportation Research Board. The intent of the design values in Table 5.1 is to provide guidance to the designer, in many cases by referencing a recommended range of values. The designer should consider each design as an independent case with specific design values dependent upon social, economic, and environmental conditions, as well as engineering considerations. Where appropriate, flexibility is permitted to encourage independent designs tailored to particular situations. As noted in AASHTO's *A Policy on Geometric Design of Highways and Streets*, 1994, "These guidelines are intended to provide operational efficiency, comfort, safety and convenience for the motorist. The design concepts were also developed with consideration for environmental quality. The effects of the various environmental impacts can and should be mitigated by thoughtful design processes. This principle, coupled with that of aesthetic consistency with the surrounding terrain and urban setting, is intended to produce highways that are safe and efficient for users, acceptable to non-users, and in harmony with the environment."

5.1.1 Travel Lanes

The number of travel lanes is primarily based upon a capacity analysis for the selected design year. The techniques and formulas from the *Highway Capacity Manual* should be used for this calculation.

The width of the travel lane will vary according to the functional class of the highway, traffic volumes, design speed and level of development as presented in Table 5.1. Turning lanes should range in width from 3.0 to 3.75 meters, depending on the percentage of trucks.

**Table 5.1
RECOMMENDED ROADWAY SECTION WIDTHS**

FUNCTIONAL CLASS	U/R	NUMBER OF LANES	TRAVEL LANE (min)		USABLE SHOULDER ³		
			Desir. ²	min.	RIGHT (min)	LEFT (min)	
FREEWAY	URBAN	4 - 8	3.75		3.0		1.25 ¹
	RURAL	4 - 8	3.75		3.0		1.25 ¹
			Desir.	min.	Desir. ²	min	
ARTERIAL	URBAN	WITH MEDIAN	3.75	3.5	3.0	2.5	1.25 ¹
	URBAN	WITHOUT MEDIAN	3.75	3.5	3.0	2.5	N/A
	RURAL	WITH MEDIAN	3.75	3.5	3.0	2.5	1.25
	RURAL	WITHOUT MEDIAN	3.75	3.5	3.0	2.5	N/A
			Desir.	min.			
COLLECTOR	URBAN		3.75	3.25	2.5	1.25	N/A
	RURAL		3.75	3.25	2.5	1.25	N/A
LOCAL ²	URBAN		3.75	2.75	1.25	0.75	N/A
	RURAL	N/A	3.75	2.75	1.25	0.75	N/A
SPECIAL PURPOSE ROADS		SEE AASHTO DESIGN CRITERIA					

- Notes:
1. USE 3.0 METERS WHEN 3 OR MORE LANES IN EACH DIRECTION.
 2. WIDTHS ARE TO BE DETERMINED BASED ON TRAFFIC, BICYCLE AND PEDESTRIAN VOLUMES, PARKING REQUIREMENTS, RIGHT OF WAY RESTRICTIONS AND ENVIRONMENTAL IMPACTS. THE WIDER SHOULDER WIDTH IS PREFERRED FOR PARKING AND TURNING, AND/OR BICYCLE OR PEDESTRIAN USE.
 3. SHOULDER DIMENSIONS ARE FOR "USABLE" SHOULDER. THE OFFSET DIMENSION (0.5 M MINIMUM) IS TO BE ADDED TO THE USABLE SHOULDER DIMENSION TO ALLOW FOR VERTICAL ELEMENTS (GUARDRAIL, BRIDGE RAIL, CONCRETE BARRIER, ETC.) OVER 200 MM HIGH AT THE EDGE OF THE "GRADED" SHOULDER.
 4. DESIGN WAIVERS MUST BE OBTAINED FOR ROADWAY WIDTHS BELOW THESE MINIMUM STANDARDS. SEE CHAPTER EIGHT OR INFORMATION ON DESIGN WAIVERS.

STANDARD WIDTHS TO BE USED (METERS)

<u>LANES</u>	<u>SHOULDERS</u>	<u>ABSOLUTE MINIMUM OFFSET</u>
3.75	3.50	BEYOND USABLE SHOULDER TO
3.50	3.00	VERTICAL ELEMENT (OVER 200mm)
3.25	2.50	(OR BEYOND TRAVEL LANE IF USABLE
3.00	1.25	<u>SHOULDER NOT PROVIDED</u>)
2.75	0.75	0.50 m

5.1.2 Shoulders

Shoulders serve several functions. They include:

1. An area for emergency stopping.
2. An area for evasive action and recovery.
3. Improvements to highway capacity, safety and driver comfort.
4. A paved area for bicycle travel.
5. Lateral support and drainage for the pavement.
6. Lateral clearance for highway appurtenances and for snow removal and temporary storage.

The usable width of shoulder is the actual width that can be used when a driver makes an emergency or parking stop. Where the side slope is 1v:6h or flatter the "usable" shoulder width is the same as the "graded" width since the usual rounding at the shoulder break will not lessen its useful width appreciably. See Figure 5-1.

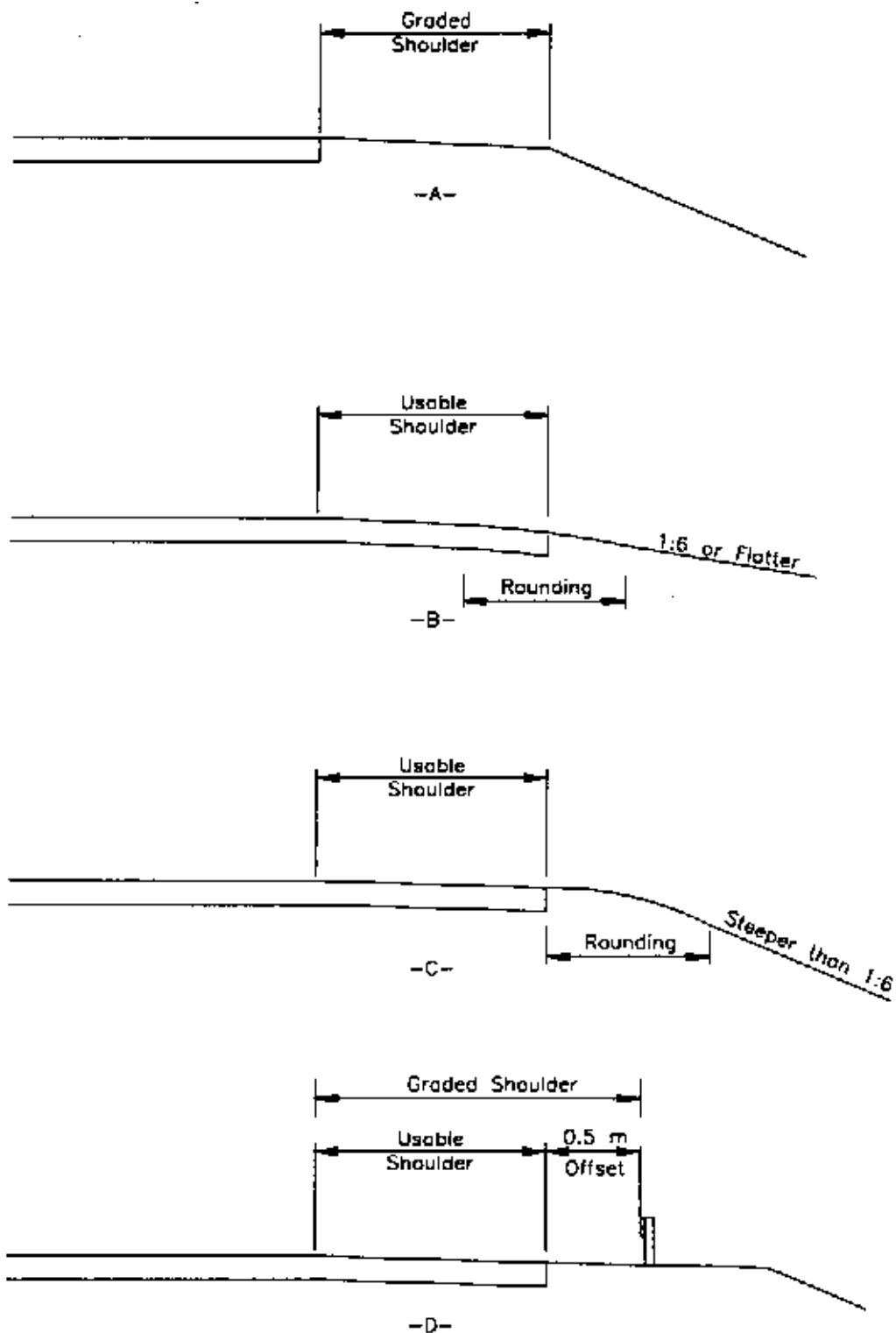


Figure 5-1. GRADED AND USABLE SHOULDERS.

Usable shoulders must be cleared of snow and ice during the winter months in order to function properly.

Shoulders must be carefully designed to provide the desired safety advantages. Shoulder surface types and the width of shoulders are determined by traffic volumes, aesthetics, right-of-way considerations and environmental impacts.

While almost every rural highway will have shoulders, they are more difficult to provide in urban areas. If there is adequate right-of-way, they may be desirable on high-speed, high volume roads as right-turn lanes, and to provide space for disabled vehicles. In urban situations it is especially difficult to prevent improper use of shoulders as travel and parking lanes. At intersections, usable shoulders may be eliminated in order to better provide for turning movements.

An additional 0.5 meters of graded shoulder must be added to the usable shoulder dimension to allow for an offset to vertical roadway elements over 200 mm in height, such as guardrail, bridge rail, concrete barrier, walls, trees, utility poles, etc. The required width of usable shoulder is provided in Table 5.1.

Safety considerations may warrant shoulder rumble strips at appropriate locations.

5.1.3 Auxiliary, Parking and Bicycle Lanes

An auxiliary lane is a lane provided for special purposes to provide for more continuous traffic flow in the travel lanes. Auxiliary lanes include:

1. Right and left-turning and storage lanes at at-grade intersections, (See Section 7.3);
2. Two-way left-turning lanes (2WLTLs), (See Section 7.3.3);
3. Speed change lanes at freeway interchanges, (See Section 6.5);
4. Weaving lanes within interchanges (See Section 6.4.3);
5. Truck climbing lanes. (See Section 4.2);
6. Bicycle lanes (See Section 12.1).

Parking lanes are provided on urban streets and in built-up areas where there is insufficient off-street parking to support adjacent residential and commercial development. Parallel on-street parking is the desirable arrangement. On-street parking reduces through traffic capacity and increases accident potential, especially on higher speed streets and highways. Parking regulations vary between State highways and those regulated by municipalities. The designer should contact the MHD Traffic Regulations Section to coordinate traffic agreements. Signs and pavement markings should be provided in accordance with the *MUTCD*.

Where needed in residential areas, a parking lane should be provided 2 to 3 meters in width. In commercial and industrial areas, parking lane widths should range from 2.5 to 3 meters. The preferred width for parking lanes in all cases is 3.0 meters.

For greater detail on the effects of and proper design for on-street parking, refer to *HRB Special Report 125 and FHWA-RD-79-75/76*.

5.1.4 High Occupancy Vehicle Lanes

High Occupancy Vehicle Lanes may be provided on freeway and other roadways for the exclusive use of buses and other high occupancy vehicles so that they can bypass peak period congestion on the remaining lanes. High occupancy vehicle lanes are required to be considered in certain air quality "non-attainment" zones and are also required to be considered in any major highway widening project.

Implementation of these facilities have the following benefits:

1. Maximum person moving capacity by providing improved operating levels of service for the high occupancy vehicle.
2. Conservation of fuel and minimal consumption of other transportation resources.
3. Improved air quality.
4. Increased overall accessibility while reducing vehicular congestion.

The designer is directed to the *AASHTO Guide for the Design of High Occupancy Vehicle Facilities* 1992 for design guidance. Because these facilities are often constructed within the restricted right of way of highly developed areas, design

waivers for lane and shoulder widths are usually required. Consult Chapter 8 for design waiver procedures.

5.1.5 Cross Slopes and Crowns

Surface cross slopes are necessary on travel lanes to facilitate drainage. This reduces the hazard of wet pavements and standing water. On flexible pavements travel lanes should be designed for a cross slope of 0.020 meter/meter. Concrete pavements should be designed for 0.016 meter/meter for lanes adjacent to the crown, and 0.020 meter/meter for all other lanes. For lower classes of pavement, higher cross slopes may be desirable to achieve the design drainage.

5.1.6 Curbs, Berms and Edging

Curbs are used extensively on urban streets and highways. Generally, they are not used in rural areas, except in conjunction with sidewalks where vertical barrier curb is required. Curbs serve to control drainage, restrict vehicles to the pavement area and to define points of access to abutting properties.

Barrier curbs are vertical and are usually portland cement concrete, bituminous, or granite. Barrier curbs range in height from 150 to 200 millimeters with a batter of 15:1 or steeper. Berm or sloped edging are 100 millimeters or less in height and have rounded or plane sloping faces. The MHD standard details are illustrated in the Construction Standards. (See Appendix, this chapter, for reveals)

The Type A Berm is used on rural and urban highways which do not have continuous curb and require control of drainage. It directs water to closed drainage systems, prevents sloughing of the pavement edge and provides additional lateral support. The Type A berm should be used only:

1. where the longitudinal grade exceeds 5% for an extended length, or
2. where control and collection of drainage is otherwise required.

Pavement milling mulch, or other suitable material, shall be used in lieu of berm under guard rails and in other areas where control of erosion from roadway runoff ("Country Drainage") is a concern. See Construction Standards for Details.

Curbs are not adequate to prevent a vehicle from leaving the roadway. Where positive protection is required, a suitable traffic barrier should be provided. Vertical curbs should not be used on highways with design speeds of more than 70 kilometers per hour. Sloped edging should be used on raised traffic islands, and raised medians without barriers, for edge of road delineation.

5.1.7 Borders, Buffer Strips and Sidewalks

The border is the area between the roadway and the right-of-way line. Border areas separate the traffic from properties abutting the road or highway. On roads with sidewalks a minimum 500 millimeter buffer strip separating the sidewalk from the curb is desirable, provided sufficient right of way is available.

Buffer strips provide room for snow storage, storm drainage, traffic control devices, roadside appurtenances, utilities and landscaping features. Buffer strips should be free of any obstacles which may be a hazard to errant vehicular traffic or which interfere with pedestrian traffic. When traffic control devices, and other appurtenances are located on the buffer strip they should not project into the sidewalk area.

Sidewalks are provided where they are justified by pedestrian activity. Sidewalk width varies according to projected use and available right of way, with 2 meters preferred. In commercially developed areas, the entire area between the curb and buildings is often used as a paved sidewalk. If roadside appurtenances are placed within the sidewalk, they reduce the useable sidewalk width. A 1.0 meter minimum clearance must be maintained for wheel chairs with sufficient 1.6 meter zones for passing as required by the Americans with Disability Act (ADA). The preferred location for these appurtenances (utility poles, fire hydrants, lighting and traffic control boxes) is beyond the back of the sidewalk, especially when a travel lane is immediately adjacent to the curb. Where buildings are located at the back of sidewalk and/or where a parking lane is provided, the appurtenances should all be located in a line near the curb.

Additional handicapped access issues including proper design of walks and wheelchair ramps must be addressed. Refer to the MHD Construction Standards and Department Directives and consult with the Department's Handicapped Access Coordinator for more information.

5.2 MEDIANS

A median is defined as the portion of a highway separating the traveled ways of opposing traffic. The width of the median is defined as the distance between the edges of the two inside travel lanes. A median will provide many or all of the following benefits:

1. Separation from opposing traffic reducing the likelihood of accidents and improving the traffic flow characteristics.
2. Refuge for emergency stops.

3. Area for control of errant vehicles.
4. Reduction in headlight glare.
5. Area for deceleration and storage of mainline left-turning and U-turning vehicles.
6. Enforcement and traffic management areas.
7. Area for storage of vehicles crossing the mainline at intersections.
8. Space for snow storage.
9. Open green space.
10. Increased drainage collection area.
11. Area for placement of luminaire supports, traffic signs, traffic signals, guardrail, landscaping, and bridge piers.
12. Refuge area for pedestrians, bicyclists, and people with disabilities.
13. Area for future additional lanes.

5.2.1 Median Types and Median Width

The type of median selected will depend upon many factors, including:

- drainage
- availability of right of way
- design speed
- traffic volumes
- clear zone (recovery area) requirements
- landscaping and aesthetic considerations
- snow and ice impacts
- maintenance considerations
- superelevation impacts
- urban or rural location

In general, the median should be as wide as can be provided advantageously. The design width will depend on the functional class, type of median, availability of right-of-way,

construction costs, maintenance, traffic operations at crossing intersections, and safety. Based on these considerations, medians may be 2 meters to 30 meters or more in width. A median must be at least 12 meters or wider to attain a true sense of separation from opposing traffic. Widths of 18 meters or more can be pleasingly landscaped in a park-like manner. Several considerations will determine the appropriate median width:

1. The need for left-turn storage lanes affect the width.
2. Need for emergency parking and clear zones.
3. A median must be at least 8 meters wide to allow a crossing passenger vehicle to stop safely between the two roadways.
4. At signalized intersections, wide medians can lead to inefficient traffic operations.
5. Sufficient median width should be available to allow for snow storage.
6. The warrants for a median barrier are partially dependent upon the median width. If feasible, the median should be wide enough to eliminate the need for a barrier. (See Chapter 9).
7. In general, a uniform median width is desirable. However, variable width medians may be advantageous where right of way is restricted, at-grade intersections are widely spaced, or an independent alignment is practical or desirable to minimize cut/fill or for aesthetic purposes, such as establishing views.

5.2.1.1 Flush Medians

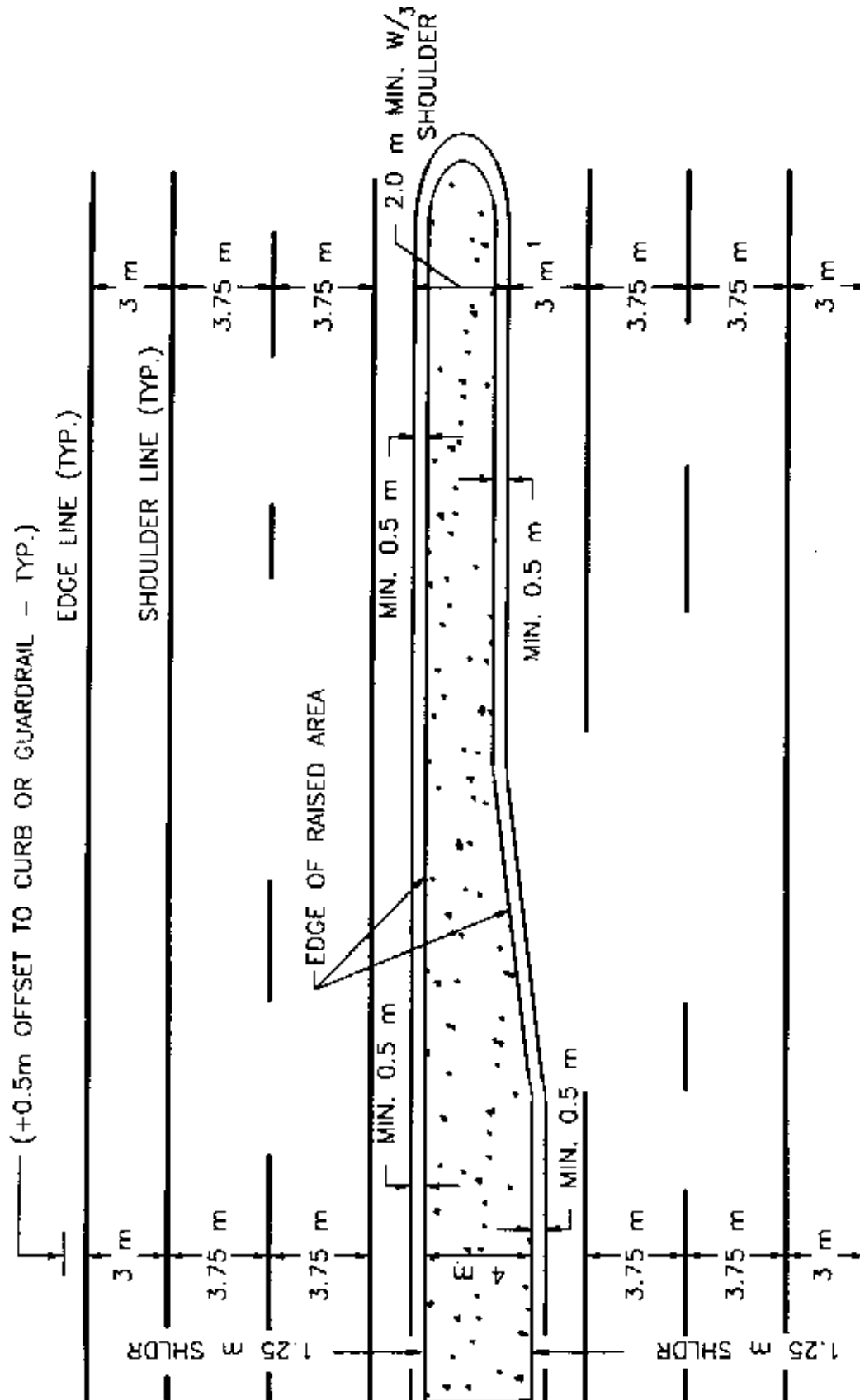
Although raised medians are preferred for directing traffic, flush medians may be used. Suitable width is to be determined on a project-by-project basis, depending upon the available right of way. Although painted medians are acceptable, a contrasting surface material such as scored white concrete is preferred to define the flush median.

A flush median is generally paved and may or may not have a barrier depending on traffic conditions. It is normally crowned to prevent parking. The median must be at least 3.0 meters wide to allow for a left-turn lane; desirably, it will be 5.0 meters wide to allow for a minimum 1.0 meter separation from the opposing traffic. If there is a continuous demand for left turns on both sides of the arterial, the designer may consider a continuous 2-way left-turn lane. Section 7.3.3 discusses this design in greater detail. All flush medians should be marked according to the criteria in the MUTCD. Where inside usable shoulders are provided, the dimension required for usable shoulder shall be in addition to the above median widths.

5.2.1.2 Raised Medians

Raised medians may be used on urban highways with a design speed of 60 kilometers per hour or less, and on other facilities where engineering judgement dictates. The minimum width of median should be 2.0 meters which allows for a 1.0 meter raised area with a 0.5 meter offset between the outside edge of the raised area and the travel lane. Raised areas should have sloped edging. Where refuge is required for pedestrians, bicycles, and disabled persons, vertical curb should be used and the minimum offset to the travel lane shall be 0.5 meter.

If left turns are provided at intersections, the median should be at least 5.0 meters wide (see Figure 5-2).



- Notes:**
1. VARIES TO 3.75 m
 2. SEE SECTION 7.3.2 AND FIGURE 7.22 TO DETERMINE THE PROPER LENGTH AND ENTERING TAPER OF LEFT-TURN LANE
 4. WITHOUT SHOULDER, 1.0 m MIN.

Figure 5-2. LEFT-TURN LANE ON URBAN ARTERIAL WITH RAISED MEDIAN

When compared to flush medians, raised medians offer some advantages including:

1. Mid-block left turns are eliminated.
2. Left-turn channelization can be more effectively delineated.
3. A distinct location is available for traffic signs, signals, refuge, and snow storage.
4. The median edges are much more discernible.
5. Drainage collection may be improved.
6. Limited physical separation is available.

Some disadvantages of raised medians when compared to flush medians include:

1. They are more expensive to construct.
2. They require greater widths to serve the same function (e.g., left-turn lanes at intersections).
3. Curbs result in adverse vehicle behavior upon impact.
4. Prohibiting mid-block left turns may overload street intersections and may increase the number of U-turns.

5.2.1.3 Depressed Medians

A depressed median is usually unpaved and wide enough to provide for a drainage ditch below the roadway gravel subbase and is usually used on rural freeways, expressways and multi-lane arterials. It should also be used in urban areas if right of way is sufficient. Generally, depressed medians provide better drainage and snow storage than flush or raised medians.

A depressed median would normally be a minimum of 18 meters wide, which allows for two 1.25 meter left shoulders, 1v:6h or flatter slopes, a one meter wide ditch bottom and a 1 meter ditch depth. Greater median widths, within the constraints of additional right of way and environmental impacts, and construction costs, are desirable. When selecting a width for a depressed median, these additional factors should be considered:

1. The appropriate roadside recovery area for the section involved should be considered as outlined in Section 9.2.

2. Provisions for future additions of traffic lanes should be considered.

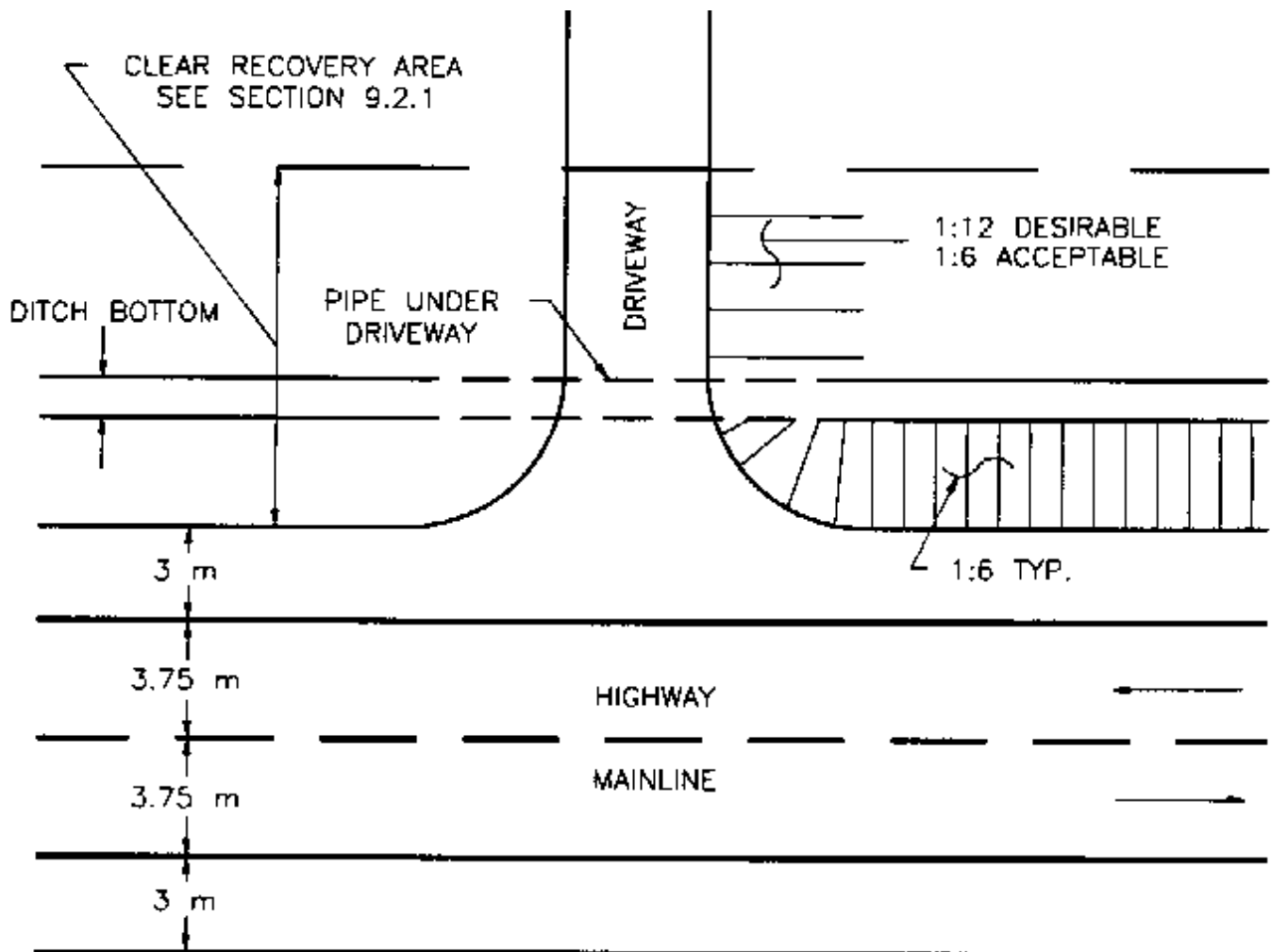
5.3 ROADSIDE ELEMENTS

Roadside features will significantly affect safety, construction and maintenance costs, right of way requirements, drainage and erosion, environment, and aesthetics. Chapter 10 discusses in detail the hydraulics of highway drainage. Chapter 9 discusses the safety aspects of the highway roadside, such as the criteria for roadside recovery areas.

5.3.1 Side Slopes and Cuts

Cut and fill slopes should be designed to ensure the stability of the roadway and be as flat as possible to enhance the safety of the roadside. Much of the necessary information will be provided in the Soils Report prepared by the Research and Materials Section, although not every project will require a Soils Report. The designer should consider the following when selecting a cut or fill slope design:

1. It is desirable for fill slopes on high speed roadways to be 1v:6h or flatter. All soils (except possibly wetland or muck material) are stable at this rate. Maintenance efforts are greatly reduced, the erosion potential is reduced, and the slopes are safely traversable at 1v:6h. The designer should obtain clear zones where feasible. For fills greater than 5 meters high in wetlands and in other sensitive areas, 1v:2h slopes (with guardrail) are typical. Site conditions may require a slopes up to 1v:1h. Slope retaining treatments such as geo-textiles shall be considered for these situations.
2. Erosion possibilities must be minimized. To the extent possible, the natural and existing drainage patterns should be preserved. Severely rutted side slopes can cause vehicle rollover even on relatively flat slopes. In good soil, turf can be established on slopes as steep as 1v:1h. However, flatter slopes obviously reduce the erosion potential and should be used where feasible. All slopes shall be planted with sufficient vegetation to stabilize the slope.
3. Cut-to-fill transition slopes are particularly susceptible to erosion. The problem is most acute along the bottom of the fill embankment. Special protective measures should be considered here.
4. Where the highway mainline intersects a driveway, side road, or median crossing, the intersecting slopes need careful consideration (see Figure 5-3). These should be as flat as possible, preferably 1v:12h or flatter; 1v:6h slopes are acceptable.



Note: THIS DESIGN ALSO APPLIES TO INTERSECTING HIGHWAYS AND CROSSOVERS IN THE MEDIANS OF DIVIDED HIGHWAYS.

Figure 5-3. SIDE SLOPE OF INTERSECTING DRIVEWAY

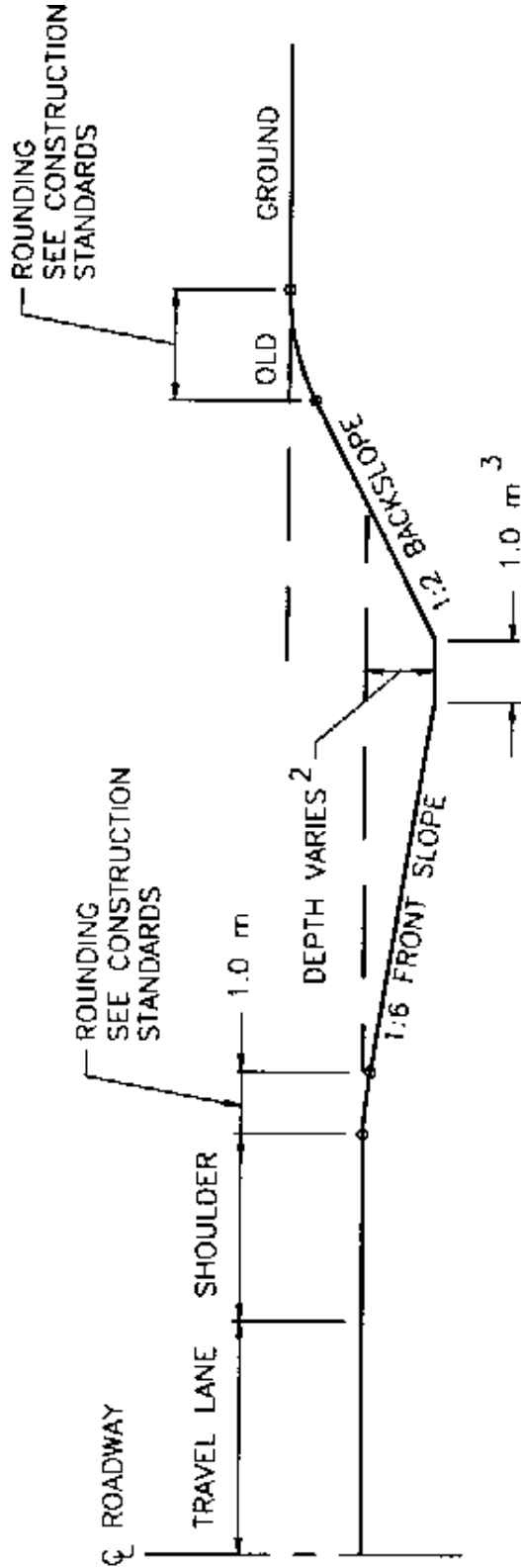
5. Slopes up to vertical are possible in rock cuts using pre-splitting methods. The typical rock slope is 4v:1h, depending upon the material stability. When feasible, the bottom of the rock-cut slope should be outside of the calculated clear zone. Jagged rock outcroppings exposed to possible vehicle impacts should be avoided. A typical rock cut is shown in the Construction Standards.
6. High earth cuts may warrant terracing. Terracing reduces erosion and enhances soil stability. As a general rule, a terrace should be provided at approximately 6 meter intervals. The Geotechnical Unit shall be consulted for these designs.
7. For cut or fill sections, it may be necessary to reduce the required recovery widths for environmental, cost, right of way or aesthetic considerations. Recent requirements for clear zones frequently increase the cut and fill requirements substantially. Guardrail should be used on fill slope where recovery area is not available. A concrete barrier may be appropriate at cut locations as a retaining wall. A 0.5 meter offset must be added to the shoulder dimension as is done for guardrail. In cut sections a ditch of sufficient width must be provided behind the barrier to maintain drainage flow from the hillside and to retain rocks and debris which may fall from the hillside.

5.3.2 Ditch Sections

Roadside ditches divert and remove water from the surface and subsurface of the roadway. Chapter 10 discusses the types, hydraulic characteristics, and protective linings for ditches.

Roadside ditches can have several shapes: V, radial, trapezoidal or parabolic. The trapezoidal ditch is the preferred shape when considering safety and ease of design, construction and maintenance. Figure 5-4 provides the design information for a typical trapezoidal roadside ditch. Parabolic and circular ditch sections are used in special circumstances. Examples of these are provided in the *Construction Standards*.

Roadway ditch foreslopes steeper than 1v:6h are not desirable for safety reasons. In addition, 1v:6h or flatter foreslopes reduce the potential for snow drifts.



- Notes:**
1. FOR TYPICAL DITCH SECTION IN ROCK CUT, SEE CONSTRUCTION STANDARD 102.1.0.
 2. THE BOTTOM OF THE DITCH SHOULD BE BELOW THE BOTTOM OF THE GRAVEL SUBBASE.
 3. OR WIDER TO MEET HYDRAULIC REQUIREMENTS.

Figure 6-4. TYPICAL DITCH SECTION IN EARTH CUT

5.4 BRIDGE AND UNDERPASS CROSS SECTION

The bridge or underpass cross section will depend upon the cross section of the approaching roadway, its functional classification, and whether the project entails new construction, reconstruction, restoration, or major bridge deck rehabilitation. The MHD *Bridge Manual* should be referred to for details related to design. All bridge designs are the responsibility of the Bridge Engineer.

5.4.1 Freeways and Expressways

Freeways and expressways which pass over a highway, railroad, or waterway must carry the full roadway cross section including usable shoulders plus a 0.5 meter offset on each side. Figure 5-5 and the *Bridge Manual* illustrate the typical section. The pavement cross slopes on the approaching roadway are carried through the bridge section. Long bridges of overall lengths of 60 meters or more may be designed without shoulders. A minimum 1.5 meter offset from the travel lanes to vertical elements of the bridge must be provided.

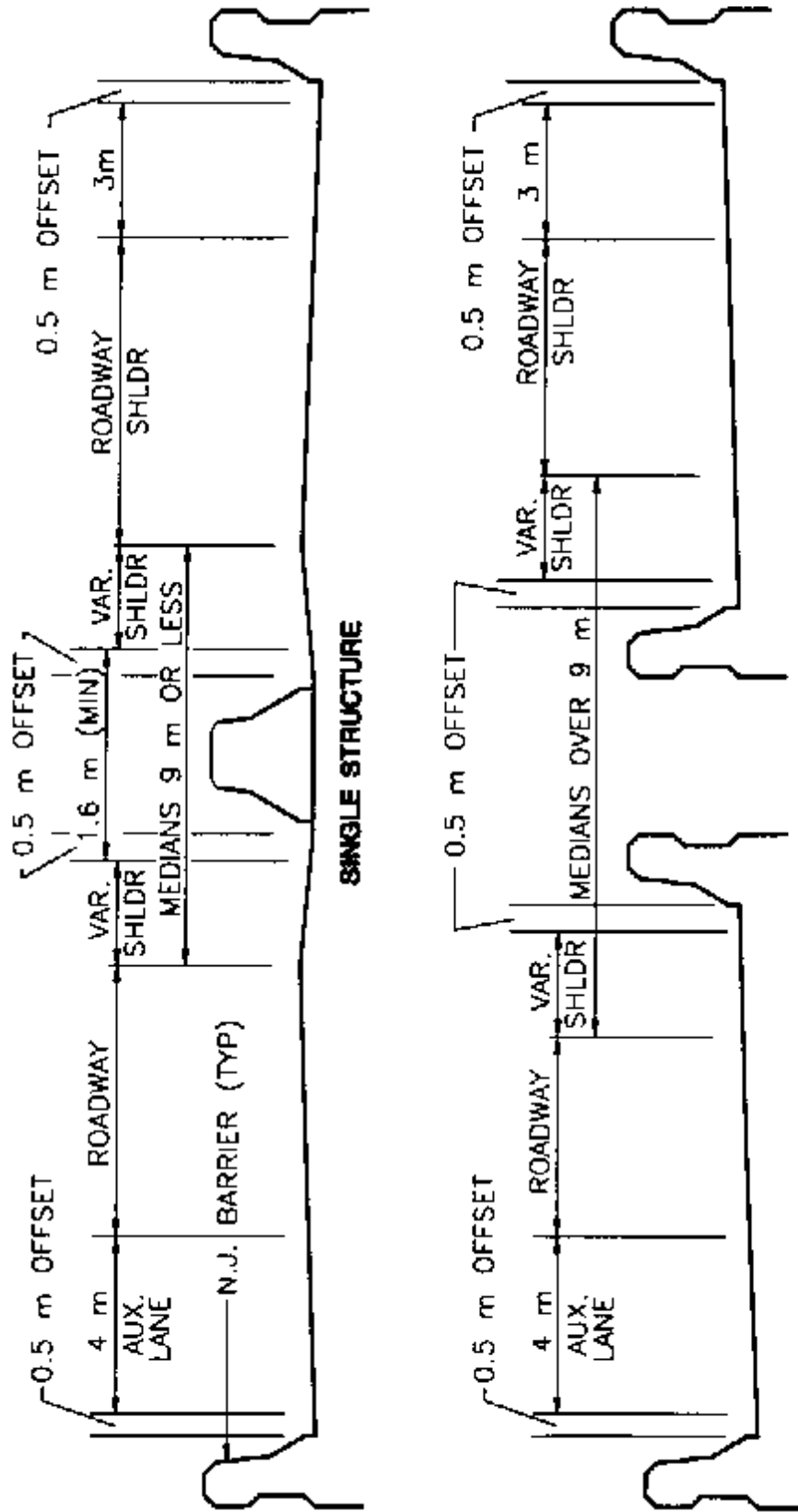


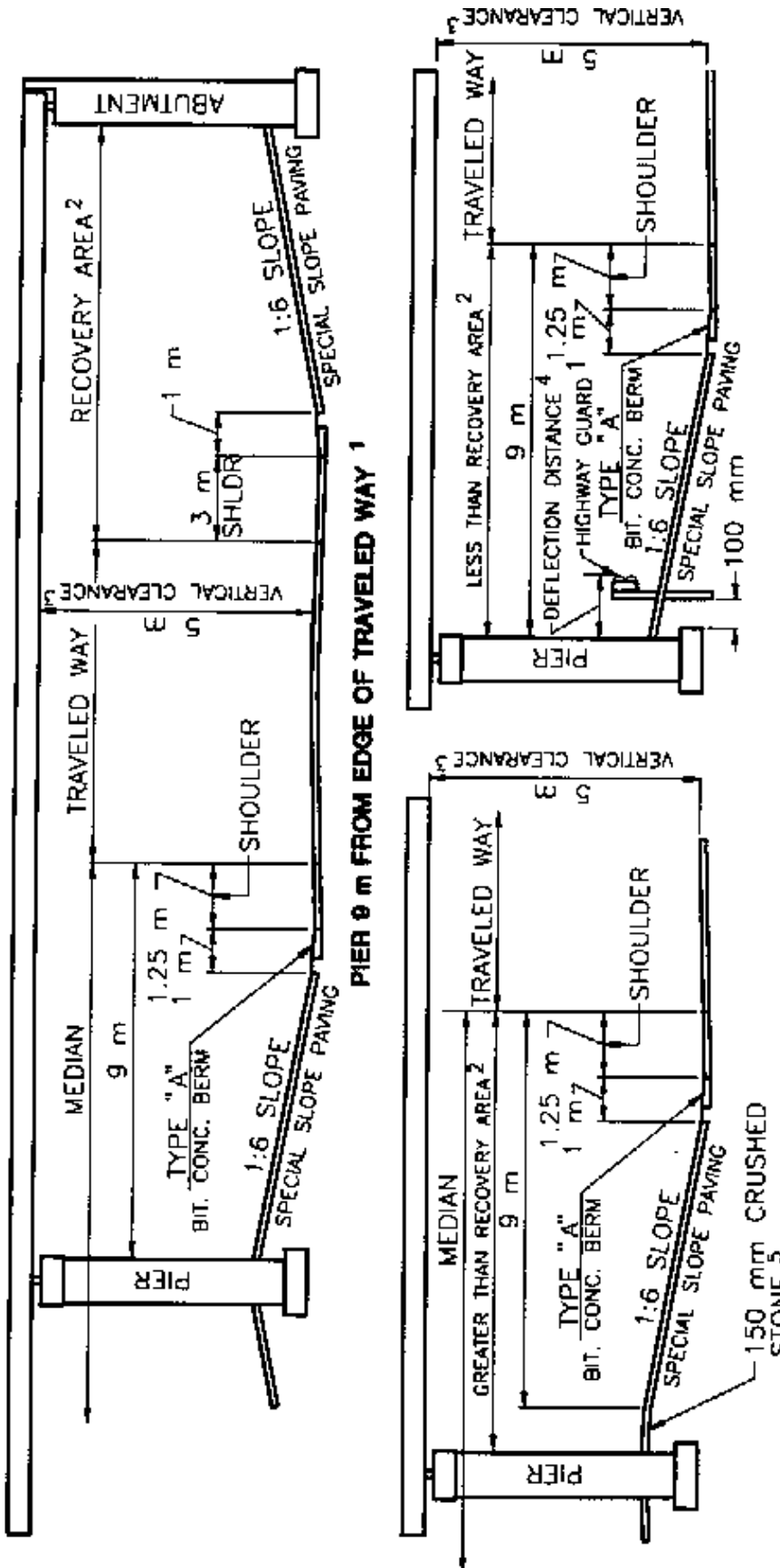
Figure 5-5. TYPICAL FREEWAY BRIDGE SECTION

For freeway and expressway underpasses, the approaching highway cross section, preferably including roadside recovery areas, should be carried through. The recovery areas are functions of design speed, traffic volumes and side slopes (see Section 9.2.1). If these distances cannot be provided through the underpass, then guardrail, concrete barrier or an impact attenuator will likely be necessary. Chapter 9 discusses barriers and guardrail in detail.

If the highway approaching the bridge underpass warrants a median barrier, the median barrier should be carried through the underpass. However, if bridge piers must be located in the median, it is necessary to split the barrier to pass on either side of the piers or to encase the pier as part of the barrier. The distance between the barrier and pier must meet the deflection characteristics of the barrier system as discussed in Chapter 9. The designer must also provide an acceptable barrier taper as the barrier passes to either side of the bridge piers. Every reasonable effort must be made to carry the full usable shoulder width plus offsets through the underpass. This may involve using a barrier system through the underpass or possibly widening the approach median width.

If an auxiliary lane passes through the undercrossing, the recovery area distance will still be measured from the edge of the outermost through lane. The lateral clearances for collector distributor roads should be treated separately from the mainline with its recovery area based on its own design speed, side slope, and traffic characteristics.

Figure 5-6 and the *Bridge Manual* provide the typical design for a freeway or expressway bridge underpass cross section.



PIER OUTSIDE OF RECOVERY AREA DISTANCE 2 **PIER LESS THAN RECOVERY AREA DISTANCE 2**

- Notes:**
1. GUARDRAIL MAY BE WARRANTED IF THE ROADSIDE RECOVERY AREA IS GREATER THAN 9 m.
 2. SEE SECTION 9.2.1 TO DETERMINE ROADSIDE RECOVERY AREA.
 3. SEE THE DEPARTMENT BRIDGE MANUAL FOR METHOD OF DETERMINING CLEARANCES.
 4. DEFLECTION DISTANCE IS 1.2 m FOR POST SPACING OF 1.905 m; IT IS 610 mm FOR POST SPACING OF 0.952 m.
 5. 100 mm CEMENT CONC. OVER 150 mm GRAVEL SHOULD BE USED IN URBAN AREAS.

Figure 5-6. FREEWAY UNDERPASS CROSS SECTION

5.4.2 Arterials

The bridge cross section for arterial highways must provide the full approach roadway width including usable shoulders and sidewalks, plus an additional 0.5 meter offset to vertical elements of the bridge. At least one sidewalk shall be provided. Long bridges of overall length in excess of 60 meters may have lesser width by eliminating the outside shoulder. A minimum 1.5 meter offset from the travel lanes must be provided to any parapet, rail or barrier.

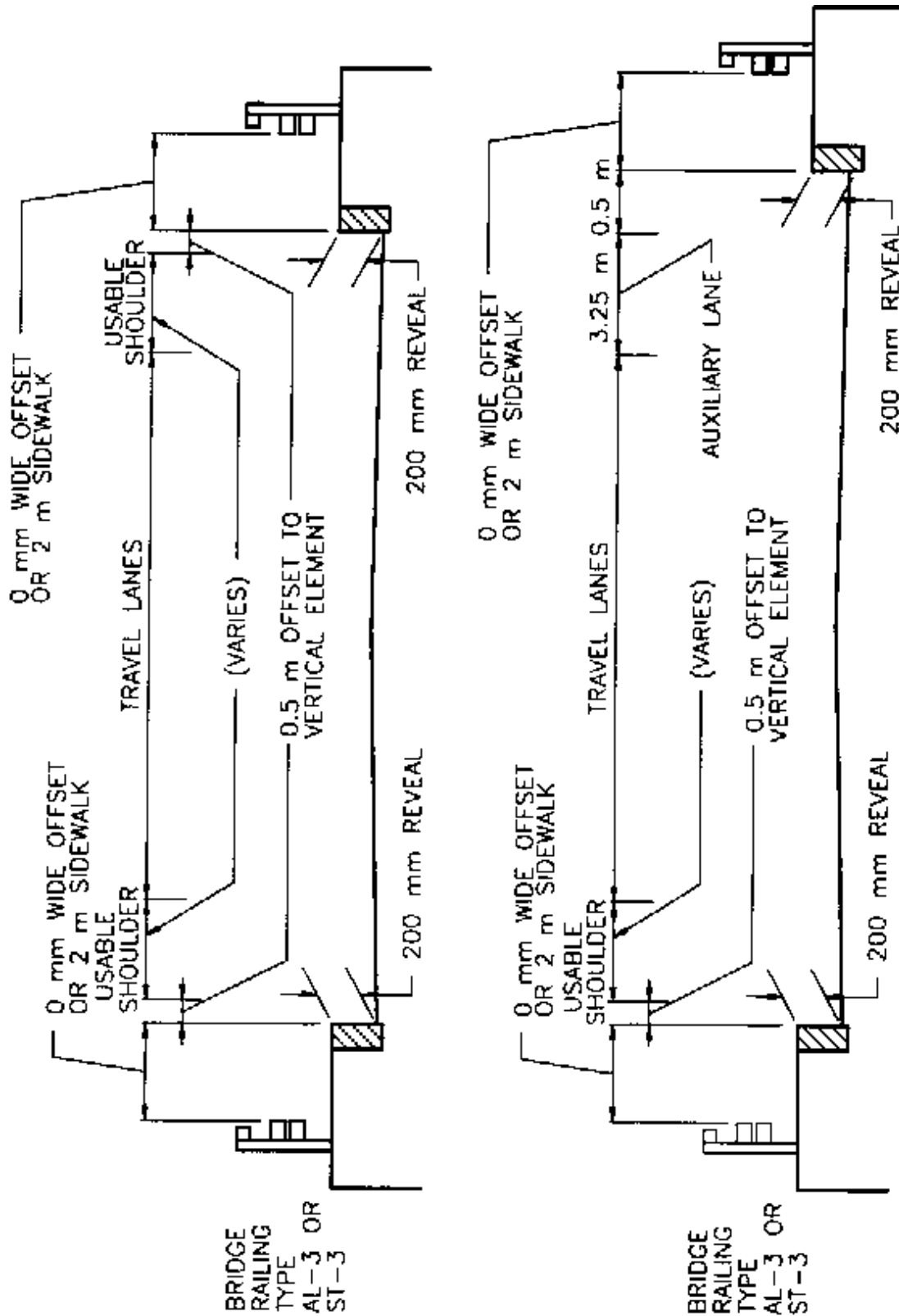
The arterial cross section for underpasses should be the same as that approaching the underpass, preferably including the roadside recovery area. If the recovery area cannot reasonably be provided, then guardrail, concrete barrier, or an impact attenuator will likely be necessary. On divided, multi-lane arterials with a median barrier, the barrier must divide to pass around any bridge piers in the median. The designer must consider the barrier deflection distance and acceptable barrier flare rate. Chapter 9 discusses the design details for barriers.

For additional information on designing bridge widths, the MHD's Bridge R&R Program for Non-NHS Roadways should be referred to for arterials that are not on the National Highway System.

5.4.3 Collectors and Local Roads

The bridge cross section for collectors and local roads should provide the full approach roadway width, including usable shoulders and sidewalks plus an additional 0.5 meter offset to vertical elements of the bridge. All bridges shall have at least one sidewalk. Minimum travel and shoulder lane widths as described in Section 5.1 should be provided. MHD's Bridge R&R Program for Non-NHS Roadways should be referred to for design criteria where conditions are constrained.

Figure 5-7 and the *Bridge Manual* provide typical examples for collector or local bridge cross sections.



Note: 1. AT LEAST ONE SIDEWALK IS TO BE PROVIDED ON ALL STRUCTURES.

Figure 5-7. TYPICAL COLLECTOR AND LOCAL ROAD BRIDGE SECTION

Underpasses for collector and local roads should provide the same cross section as the approaches to the underpass, preferably including the roadside recovery area. If the recovery area cannot reasonably be provided, then guardrail, concrete barrier or an impact attenuator will likely be necessary.

Figure 5-8 and the *Bridge Manual* provide a typical example of an underpass for a collector or local road.

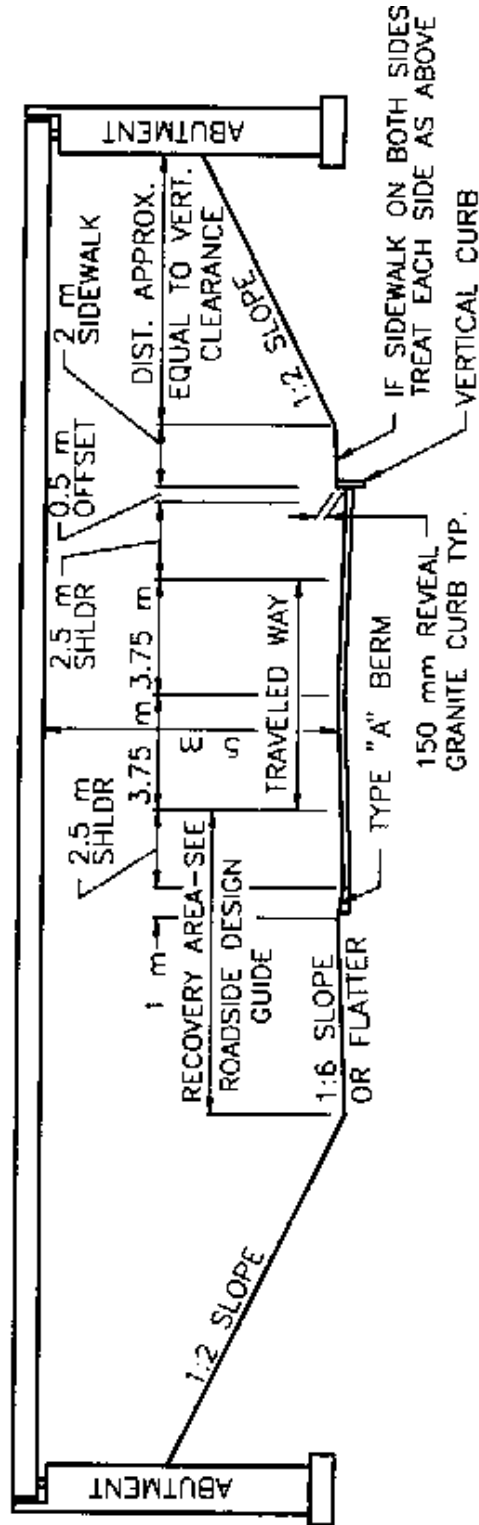


Figure 5-8. TYPICAL COLLECTOR AND LOCAL ROAD UNDERPASS

5.5 FRONTAGE ROADS

Frontage roads are often advantageous on expressways, arterials and freeways in both rural and urban areas. They control access to abutting properties, and in urban areas they remove the roadside friction and parking from the main arterial. Frontage roads can be continuous or intermittent, can be on one or both sides, and can be one-way or two-way. Where used along an arterial with frequent at-grade intersections, intermittent frontage roads help alleviate the operational problems at the intersections.

The principal disadvantages of frontage roads are the large amounts of space they require and the complex operational problems at intersections and interchanges. Two-way frontage roads present more complications than one-way facilities at intersections and at points of access with the mainline. They should be avoided if possible.

The normal design elements of pavement width, cross slope, horizontal and vertical alignment, etc. should be provided in accordance with the functional operation of the frontage road. That is, the same considerations related to functional classification, design speed, traffic volumes, etc. apply to frontage roads as they would to any other highway. However, frontage roads introduce special design elements which must be addressed:

1. The width, or outer separation, between the mainline and frontage road warrants special attention. Physical separation between the two flows of traffic improve operation and driver comfort, particularly for two-way frontage roads. An area is provided for pedestrian refuge, landscaping, and signing. Proper operation at intersections, as discussed in Item 2 below, requires a desirable width of 50 meters. This may be achieved by maintaining a narrower separation along most of the facility and widening out at intersections.
2. The number of conflicting movements at intersections is greatly increased, and the confusing pattern of roadways can lead to wrong-way entries. A distance of 50 meters between the throughway and frontage road is considered the desirable separation to allow full operation of the intersections with all possible movements accommodated. Narrower separations are acceptable for low volumes, but certain turning maneuvers may have to be prohibited and the likelihood of wrong-way entry is increased.
3. Access between the frontage road and arterials must be provided. This can be achieved at at-grade intersections if their frequency is often and the outer separation is sufficiently wide. Otherwise, slip ramps are necessary to provide the access. However, slip ramps to and from two-way frontage roads are unacceptable because of their likelihood of wrong-way entry.

5.6 RIGHT-OF-WAY

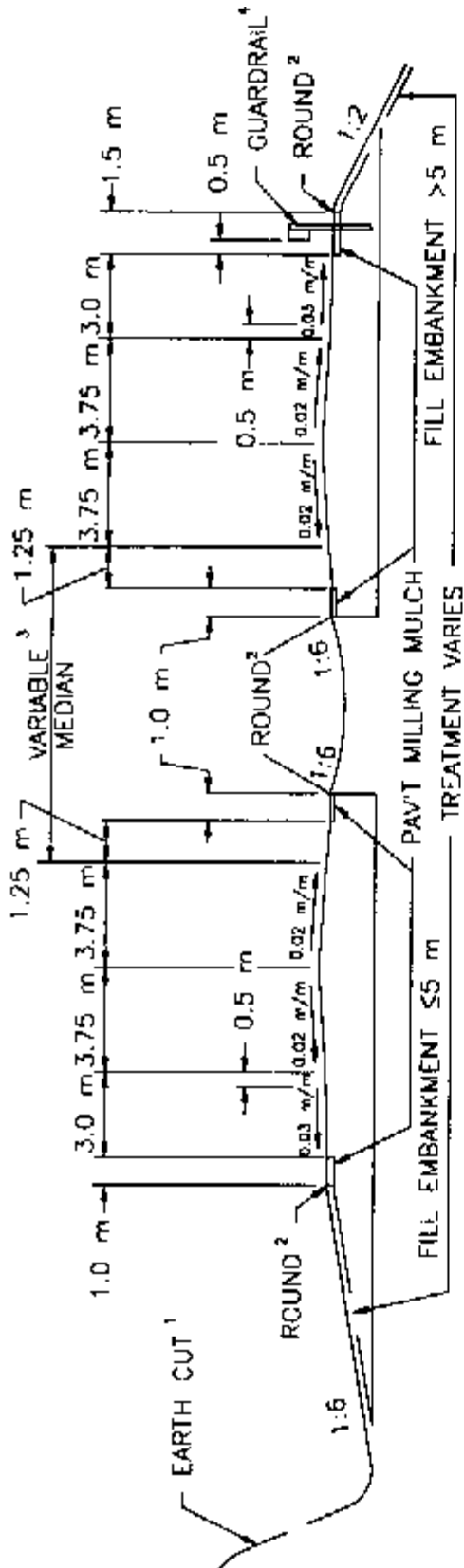
The necessary right-of-way (ROW) width is the summation of all cross section elements: lanes, shoulders, berms, medians, sidewalks, buffer strips, clear zones, drainage ditches, utility accommodations and frontage roads. Consideration should also be given to the possibility of adding travel lanes in the future. However, land use patterns, availability and cost of right-of-way may dictate the type and width of cross section elements that are provided. Typically, an undivided, two-lane rural major collector or arterial has a ROW width of 20 meters. Lower classes of roadway or low volume facilities might have narrower ROW's while more major highways require more ROW. In most cases, urban streets and highways have less available ROW than rural highways.

ROW width should be uniform. In urban areas variable widths may be necessary due to the existing development; varying side slopes and embankment heights may make it desirable to vary ROW width; and ROW limits will likely have to be adjusted at intersections and freeway interchanges. Other special ROW controls should also be considered:

1. At horizontal curves and intersections additional ROW acquisition may be warranted to ensure that the necessary sight distance is always available in the future.
2. In areas where the necessary ROW widths cannot be reasonably obtained, the designer will have to consider the advisability of using steeper slopes, revising grades, or using slope retaining treatments.
3. Right of way should be acquired and reserved for future improvements such as roadway widening and interchange completion.
4. On sections of highway adjacent to railroads, any encroachment on railroad ROW should be avoided, whenever possible.
5. Temporary slope easements should be considered to minimize public ownership of land.
6. Because a road is an inherent part of a community, the engineer needs to pay special attention to ROW impact on cultural and commercial features.
7. Additional right of way is often required for wetland mitigation.

5.7 CROSS SECTION EXAMPLES

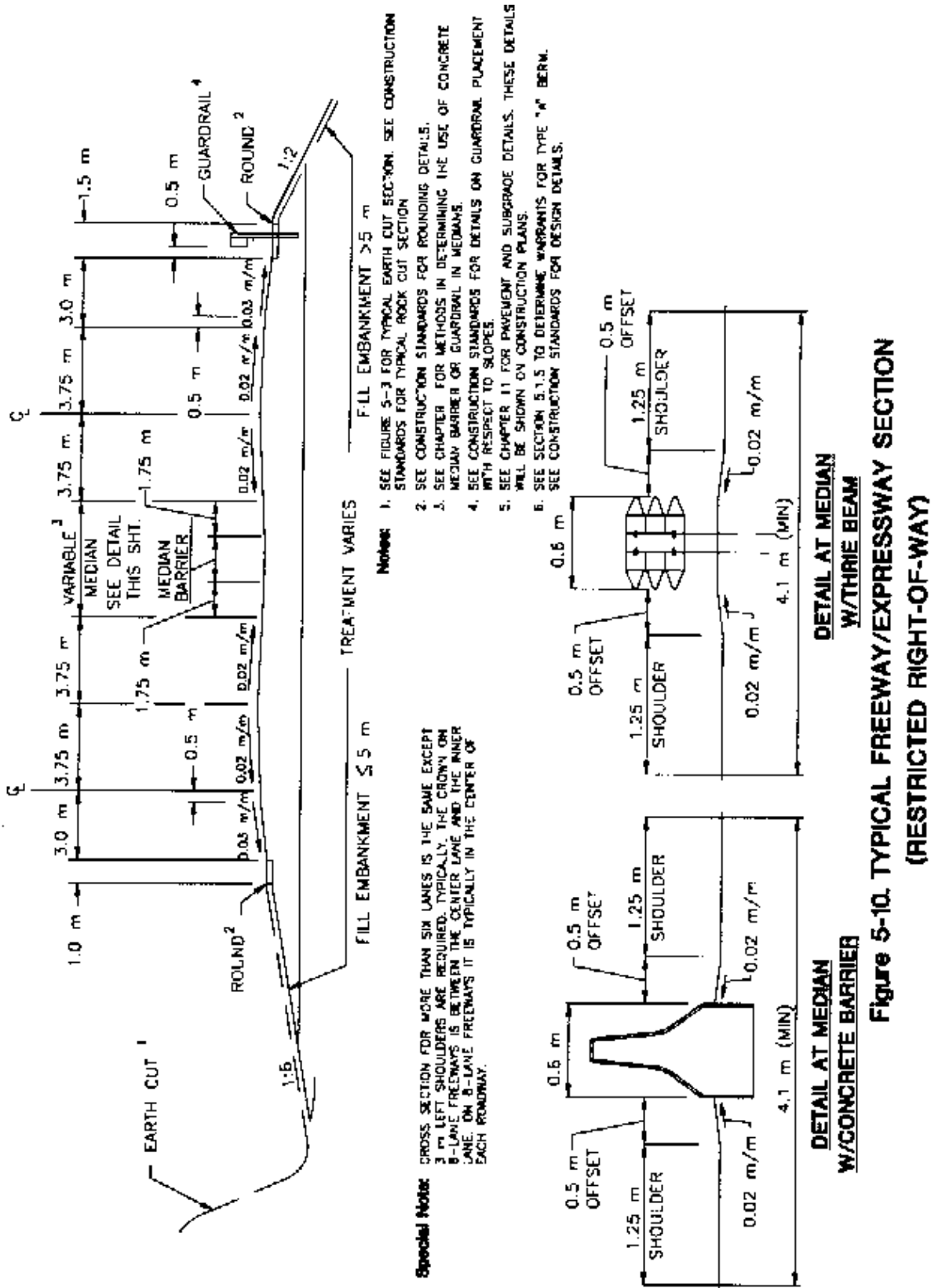
Figures 5-9 to 5-14 provide typical cross sections for roadways in developed and underdeveloped areas for each functional class. When the construction plans are prepared, the typical sections should also provide the details for the pavement and subgrade sections. This information is determined by the criteria and procedures found in Chapter 11.

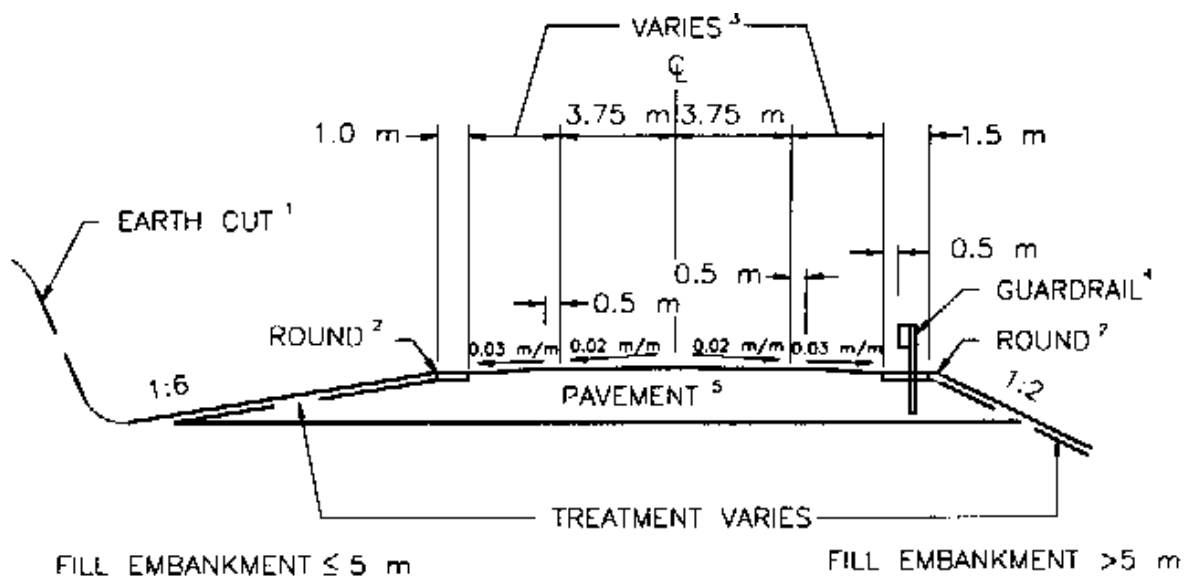


- Notes:**
1. SEE FIGURE 5-3 FOR TYPICAL EARTH CUT SECTION. SEE CONSTRUCTION STANDARDS FOR TYPICAL ROCK CUT SECTION.
 2. SEE CONSTRUCTION STANDARDS FOR ROUNDING DETAILS.
 3. DESIRABLY, MEDIAN WIDTH WILL BE TWICE THE RECOVERY ZONE AND WIDE ENOUGH NOT TO WARRANT A MEDIAN BARRIER.
 4. SEE CONSTRUCTION STANDARDS FOR DETAILS ON GUARDRAIL PLACEMENT WITH RESPECT TO SLOPES.
 5. SEE CHAPTER 11 FOR PAVEMENT AND SUBGRADE DETAILS. THESE DETAILS WILL BE SHOWN ON CONSTRUCTION PLANS.
 6. SEE SECTION 5.1.5 TO DETERMINE WARRANTS FOR TYPE "A" BERM. SEE CONSTRUCTION STANDARDS FOR DESIGN DETAILS.

Special Note: CROSS SECTION FOR MORE THAN SIX LANES IS THE SAME EXCEPT 3 m LEFT SHOULDERS ARE REQUIRED. TYPICALLY, THE CROWN ON 6-LANE FREEWAYS IS BETWEEN THE CENTER LANE AND THE INNER LANE. ON 8-LANE FREEWAYS IT IS TYPICALLY IN THE CENTER OF EACH ROADWAY.

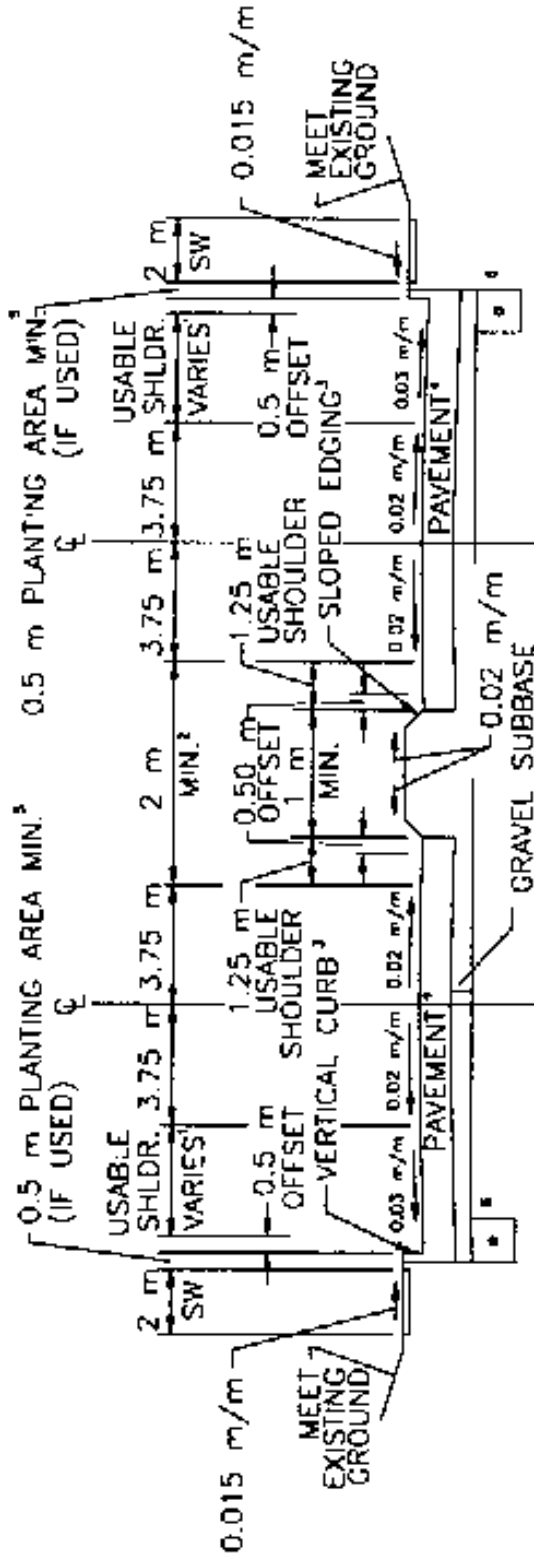
**Figure 5-9. TYPICAL FREEWAY/EXPRESSWAY SECTION
(UNRESTRICTED RIGHT-OF-WAY)**





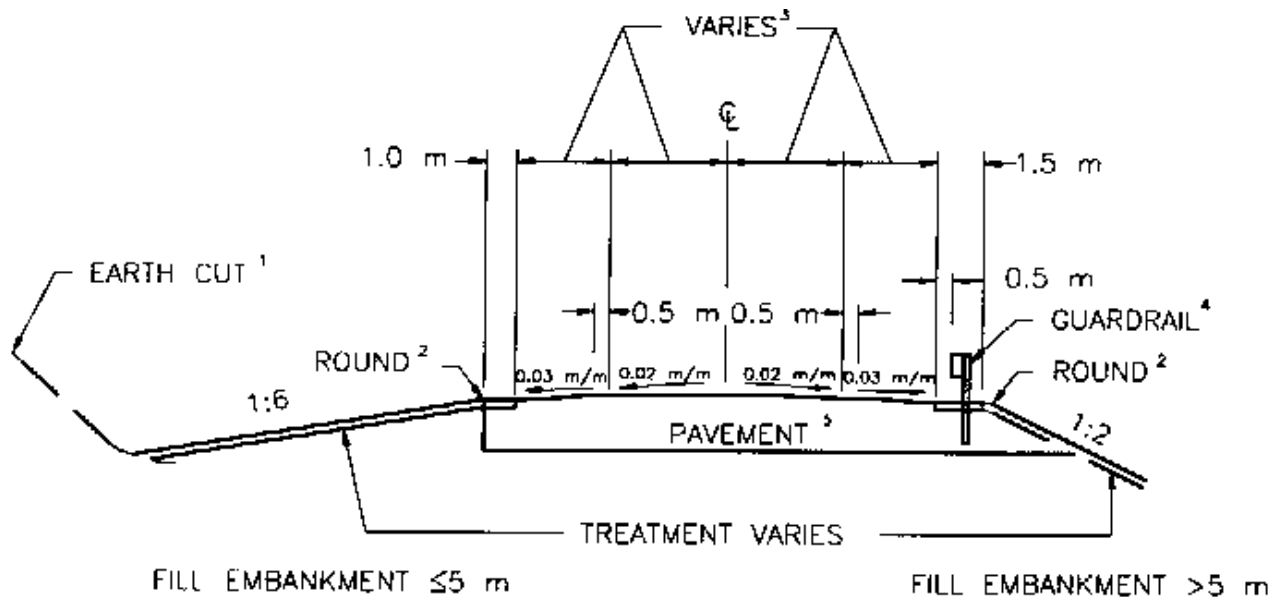
- Notes:**
1. SEE FIGURE 5-3 FOR TYPICAL EARTH CUT SECTION. SEE CONSTRUCTION STANDARDS FOR TYPICAL ROCK CUT SECTION.
 2. SEE CONSTRUCTION STANDARDS FOR ROUNDING DETAILS.
 3. USABLE SHOULDER WIDTH VARIES. SEE TABLE 5.1.
 4. SEE CONSTRUCTION STANDARDS FOR DETAILS ON GUARDRAIL PLACEMENT WITH RESPECT TO SLOPES.
 5. SEE CHAPTER 11 FOR PAVEMENT AND SUBGRADE DETAILS. THESE DETAILS WILL BE SHOWN ON CONSTRUCTION PLANS.
 6. SEE SECTION 5.1.5 TO DETERMINE WARRANTS FOR TYPE "A" BERM. SEE CONSTRUCTION STANDARDS FOR DESIGN DETAILS.

**Figure 5-11. TYPICAL ARTERIAL SECTION
(UNDERDEVELOPED AREAS)**



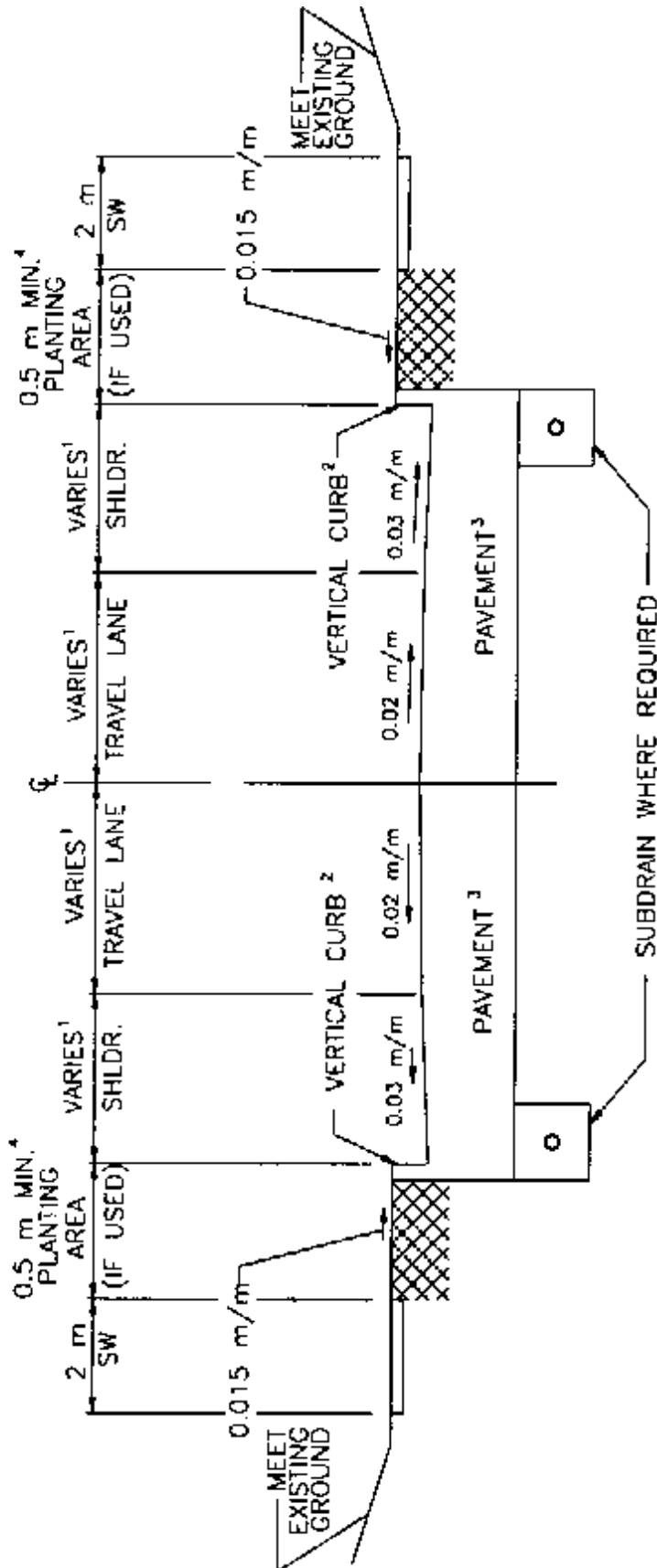
- Notes:**
1. USABLE SHOULDER WIDTH VARIES - SEE TABLE 5.1
 2. GREATER WIDTHS ARE REQUIRED IF LEFT-TURN LANES ARE PROVIDED AT INTERSECTIONS. FLUSH MEDIANS MAY ALSO BE USED. SEE DISCUSSION IN SECTION 5.2.
 3. DETAILS IN CONSTRUCTION STANDARDS
 4. SEE CHAPTER 11 FOR PAVEMENT AND SUBGRADE DETAILS. THESE DETAILS WILL BE SHOWN ON CONSTRUCTION PLANS.
 5. SEE SECTION 12.8 FOR PLANTING REQUIREMENTS.
 6. SUBDRAIN WHERE REQUIRED. SEE CHAPTER 11.

**Figure 5-12. TYPICAL ARTERIAL SECTION
(DEVELOPED AREA)**



- Notes:**
1. SEE FIGURE 5-3 FOR TYPICAL EARTH CUT SECTION. SEE CONSTRUCTION STANDARDS FOR TYPICAL ROCK CUT SECTION.
 2. SEE CONSTRUCTION STANDARDS FOR ROUNDING DETAILS.
 3. TRAVEL LANE AND SHOULDER WIDTH VARY. SEE TABLE 5.1.
 4. SEE CONSTRUCTION STANDARDS FOR DETAILS ON GUARDRAIL PLACEMENT WITH RESPECT TO SLOPES.
 5. SEE CHAPTER 11 FOR PAVEMENT AND SUBGRADE DETAILS. THESE DETAILS WILL BE SHOWN ON CONSTRUCTION PLANS.
 6. SEE SECTION 5.1.5 TO DETERMINE WARRANTS FOR TYPE "A" BERM. SEE CONSTRUCTION STANDARDS FOR DESIGN DETAILS.

**Figure 5-13. TYPICAL COLLECTOR AND LOCAL ROAD
(UNDEVELOPED AREAS)**



- Notes:**
1. TRAVEL LANE AND SHOULDER WIDTH VARY, SEE TABLE 5.1
 2. DETAILS IN CONSTRUCTION STANDARDS.
 3. SEE CHAPTER 11 FOR PAVEMENT AND SUBGRADE DETAILS. THESE DETAILS WILL BE SHOWN ON CONSTRUCTION PLANS.
 4. SEE CHAPTER 12 FOR PLANTING REQUIREMENTS.

**Figure 5-14. TYPICAL COLLECTOR AND LOCAL ROAD
(DEVELOPED AREAS)**

5.8 REFERENCES

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 1994.
- *Highway Capacity Manual*, Special Report No. 209, Transportation Research Board 1995.
- *Roadside Design Guide*, AASHTO, 1994.
- *A Guide for Transportation Landscape and Environmental Design*, AASHTO, 1991.
- *Guide for the Design of High Occupancy Vehicle Facilities*, AASHTO, 1992.
- *Compendium of the Safety Effectiveness of Highway Design Features*, Publication FHWA-RD-91-044 through 049 (6 volumes).
- *MHD Design Policy for Bridge R&R Program for Non-NHS Roadways*, October 1992.
- *Americans with Disabilities Act Handbook*, December 1991
- *Architectural Access Board, Rules and Regulations*, 521 CMR 1.00 et seq.
- *MHD Engineering Directive, Bicycle and Pedestrian Accomodation*, December 1996

5.9 APPENDIX

Curbs

Curb Type	Vertical Height (mm)
Bridge curb	200
Barrier curb	150
Sloped edging	100
Type A berm	75

CHAPTER 6

GRADE SEPARATIONS AND INTERCHANGES

Interchanges and grade separations physically separate the through traffic movements of two intersecting highways. Interchanges, unlike grade separations, provide access between the two highways by ramps.

6.1 DEFINITION AND WARRANTS

A grade separation is a crossing of two highways or a highway and railroad at different levels; it eliminates dangerous crossings and may be used to bypass busy urban areas. A grade separation where the subject highway passes over an intersecting highway or railroad is called an overpass or overcrossing. A grade separation where the subject highway passes under an intersecting highway is called an underpass or undercrossing.

The general warrants for interchange and grade separations include:

1. *Design Designation* - once it has been decided to provide a fully access-controlled facility, each intersecting highway must be terminated, rerouted, provided a grade separation, or provided an interchange. The importance of the continuity of the crossing road or the feasibility of an alternate route will determine the warrant for a grade separation or interchange. An interchange should be provided on the basis of the anticipated demand for access to the minor road. Interchange spacing is also a factor. In urban areas, a general rule is a 1.5 kilometer minimum spacing between interchanges to allow the entrance and exit maneuvers. Closer spacing may require collector-distributor roads to remove the merging and existing traffic from the mainline. In rural, undeveloped areas, interchanges should be spaced no closer than 5.0 kilometers apart. Interchange spacing is the measured distance between the center line of intersecting streets with ramps.
2. *Congestion* - An interchange may be warranted where the level of service of an at-grade intersection is unacceptable, and the intersection cannot be redesigned to operate at an acceptable level.
3. *Safety* - The accident reduction benefits of an interchange may warrant its selection at a particularly dangerous at-grade intersection.
4. *Site Topography* - At some sites the topography may allow an interchange i.e., separation at less than or equal to the cost of an at-grade intersection.

5. *Road-User Benefits* - Interchanges significantly reduce the travel time and costs when compared to at-grade intersections. Therefore, if an analysis reveals that road-user benefits over the service life of the interchange will exceed the costs, then the interchange will be warranted.
6. *Traffic Volume* - Interchanges are desirable at cross streets with heavy traffic volumes. The elimination of conflicts due to high crossing volume greatly improves the movement of traffic.

Additional reasons for grade separations include providing access to areas not served by frontage roads or other means of access; physically separating railroad grade crossings, providing access to HOV facilities, providing access for unusual concentrations of pedestrian traffic (for instance, a city park developed on both sides of a major arterial), and allowing the passage of bicycles.

There are many situations where grade separations are provided without ramps. Major arterials often intersect existing highways that must be kept open for service but on which traffic is minor. Lacking a suitable relocation plan for the crossroad, a highway grade separation without ramps may be provided. All drivers desiring to turn to or from that road are required to use other existing routes and enter or leave the throughway at other locations. In some instances these vehicles may have to travel a considerable extra distance, particularly in rural areas.

Ramps may be omitted, even though a considerable number of vehicles would use them if provided. Omitting ramps is done to avoid having interchanges so close to each other that signing and operation would be difficult, to eliminate interference with large major road volumes, and to increase safety and mobility by concentrating turning traffic at a few points where it is feasible to provide adequate ramp systems. On the other hand, undue concentration of turning movements at one location should be avoided where it would be better to have several interchanges.

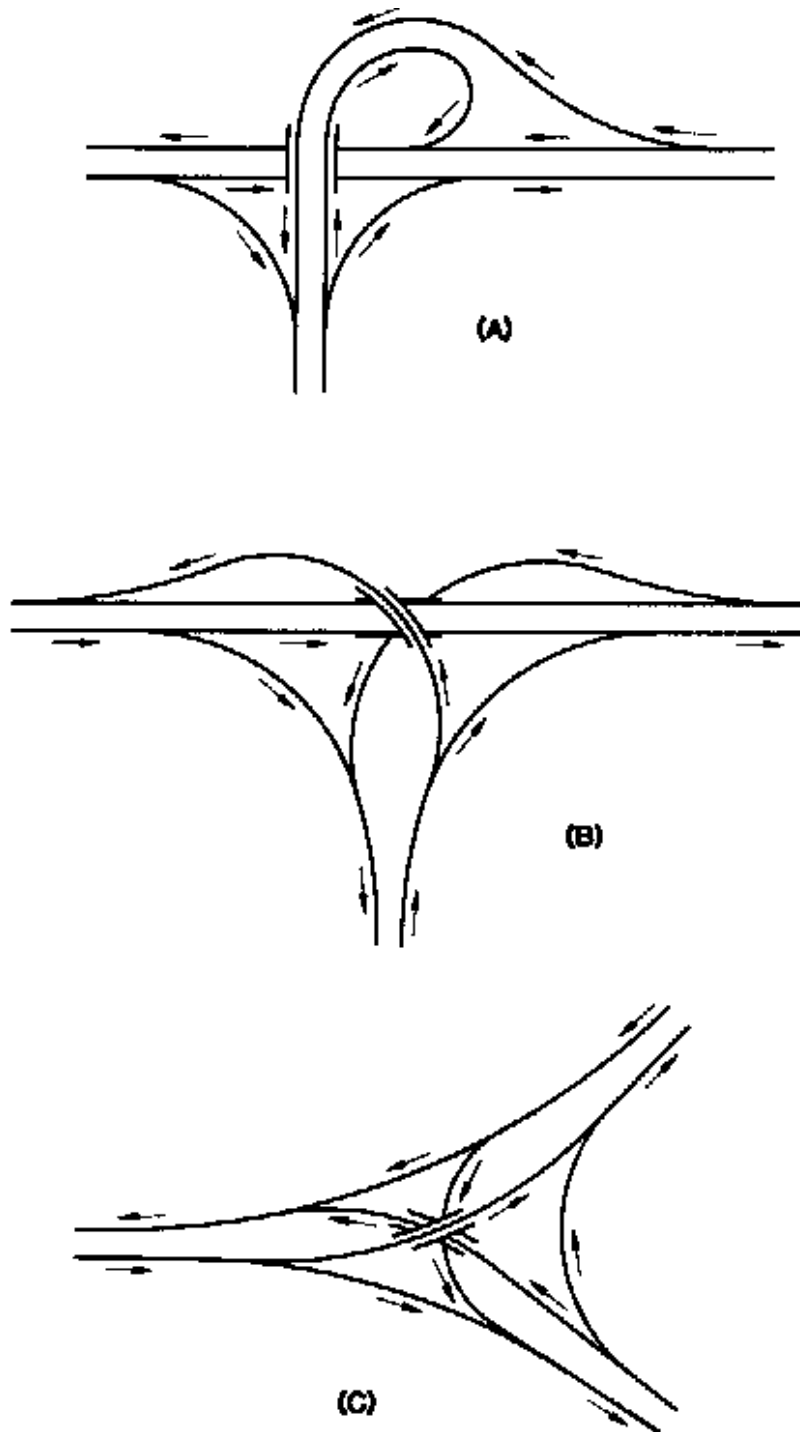
In rugged topography the site conditions at an intersection may be more favorable for provision of a grade separation than an at-grade intersection. If ramp connections are difficult or costly, it may be practical to omit them at the structure site and accommodate turning movements elsewhere by way of other intersecting roads.

6.2 INTERCHANGE TYPES

Each interchange must be designed to fit individual site conditions. The final design may be a minor or major modification of one of the basic types, or it may be a combination of the basic types. For further discussion and examples of interchange types see *A Policy on Geometric Design of Highway and Streets*, AASHTO.

6.2.1 Three-Leg

Three-leg interchanges, also known as T-or Y-interchanges, are provided where major highways begin or end. Figure 6-1 illustrates examples of three-leg interchanges with several methods of providing the turning movements. The trumpet type is shown in Figure 6-1(a) where three of the turning movements are accommodated with direct or semi-direct ramps and one movement by a loop ramp. In general, the semi-direct ramp should favor the heavier left-turn movement and the loop the lighter volume. Where both left-turning movements are fairly heavy, the design in Figure 6-(b) should be used. A fully directional interchange Figure 6-1(c) is appropriate when all turning volumes are heavy or the intersection is between two access controlled highways. This would be the most costly type because of the necessary multiple structures.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

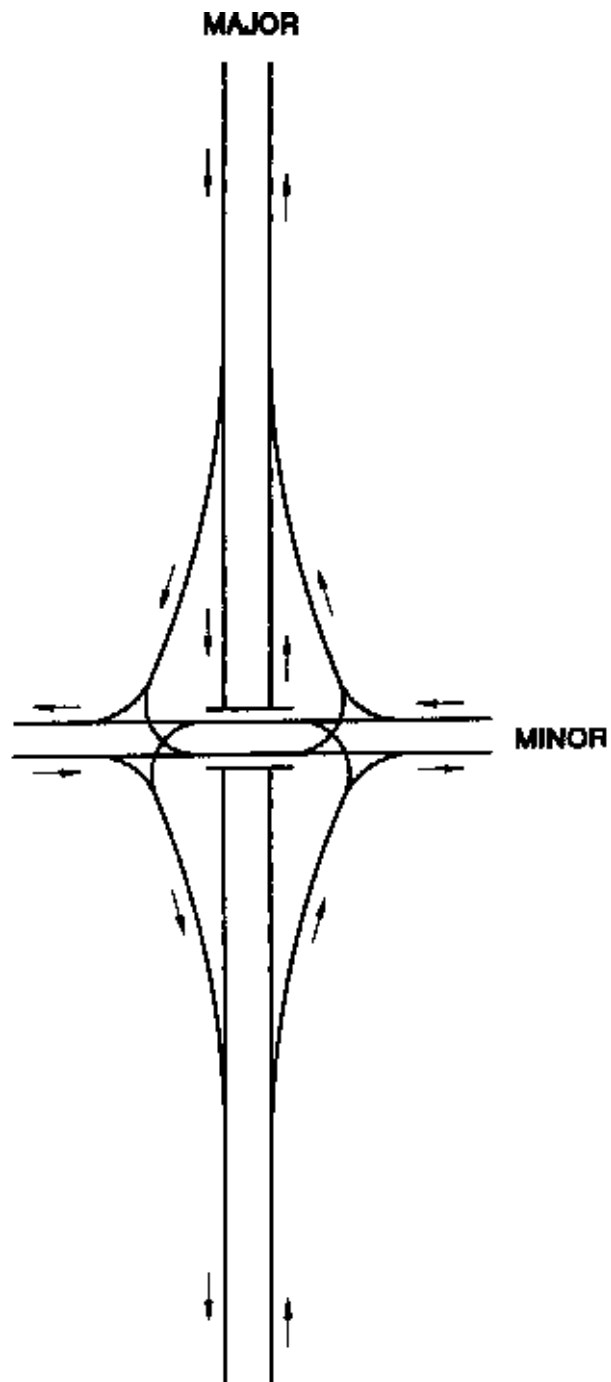
Figure 6-1. THREE-LEG INTERCHANGES

6.2.2 Diamond

Diamond interchanges use one-way diagonal ramps in each quadrant with two at-grade intersections provided on the minor road. If these two intersections can be properly designed, the diamond is usually the best choice of interchange where the intersection road is not access controlled. Where topography permits, the preferred design is to carry the minor road over the major roadway. This aids in deceleration to the lower speed roadway and in acceleration to the higher speed roadway. The advantages of diamond interchanges include:

1. All traffic can enter and exit the mainline at relatively high speeds. Adequate sight distance can usually be provided and the operational maneuvers are normally uncomplicated.
2. Relatively little right-of-way is required.
3. All exits from the mainline are made before reaching the structure.
4. Left-turning maneuvers require little extra travel distance.
5. The diamond interchange allows modifications to provide greater ramp capacity, if needed in the future.
6. Their common usage has resulted in a high degree of driver familiarity.

The primary disadvantage of a diamond interchange are potential operational problems with the two at-grade intersections at the minor road, and the potential for wrong-way entry onto the ramps. Figure 6-2 illustrates a schematic of a typical diamond interchange. Turning movements at the minor road are critical. Sufficient sight distance must be provided (see Section 7.2).

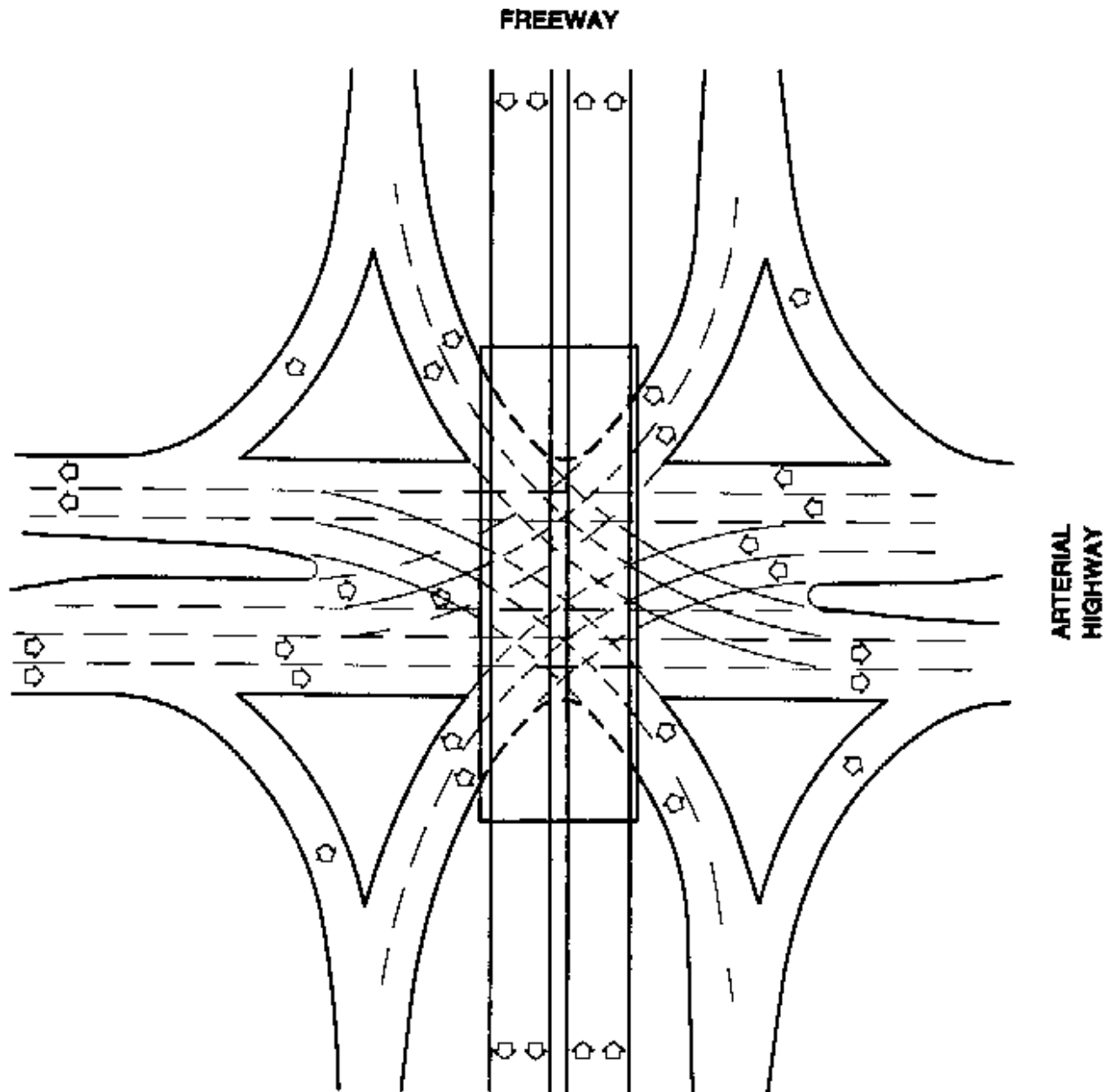


Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 6-2. TYPICAL DIAMOND INTERCHANGE (SCHEMATIC)

Compressed diamond interchanges, i.e. diamond interchanges where the nearest ramp terminal is less than 60 meters from the bridge, may be used where right of way is restricted. Adequate sight distance based on unsignalized intersection criteria must be provided even if signals are installed.

Figure 6-3 illustrates a special type of diamond interchange, called an "urban" interchange, which significantly increases the interchange capacity. This arrangement can alleviate the operational problems of having two closely spaced at-grade intersections on the minor road. In particular, it overcomes the left-turning lane storage problem for drivers trying to enter the freeway. Opposing left turns can occur during the same signal phase. U-turns can be easily provided for the major roadway within the ramp system. The "urban" interchange requires a multi-phase traffic signal system. The primary disadvantages are its higher costs because of the need for a larger structure and the need for a careful design of channelization to minimize driver confusion and the likelihood of wrong-way maneuvers.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

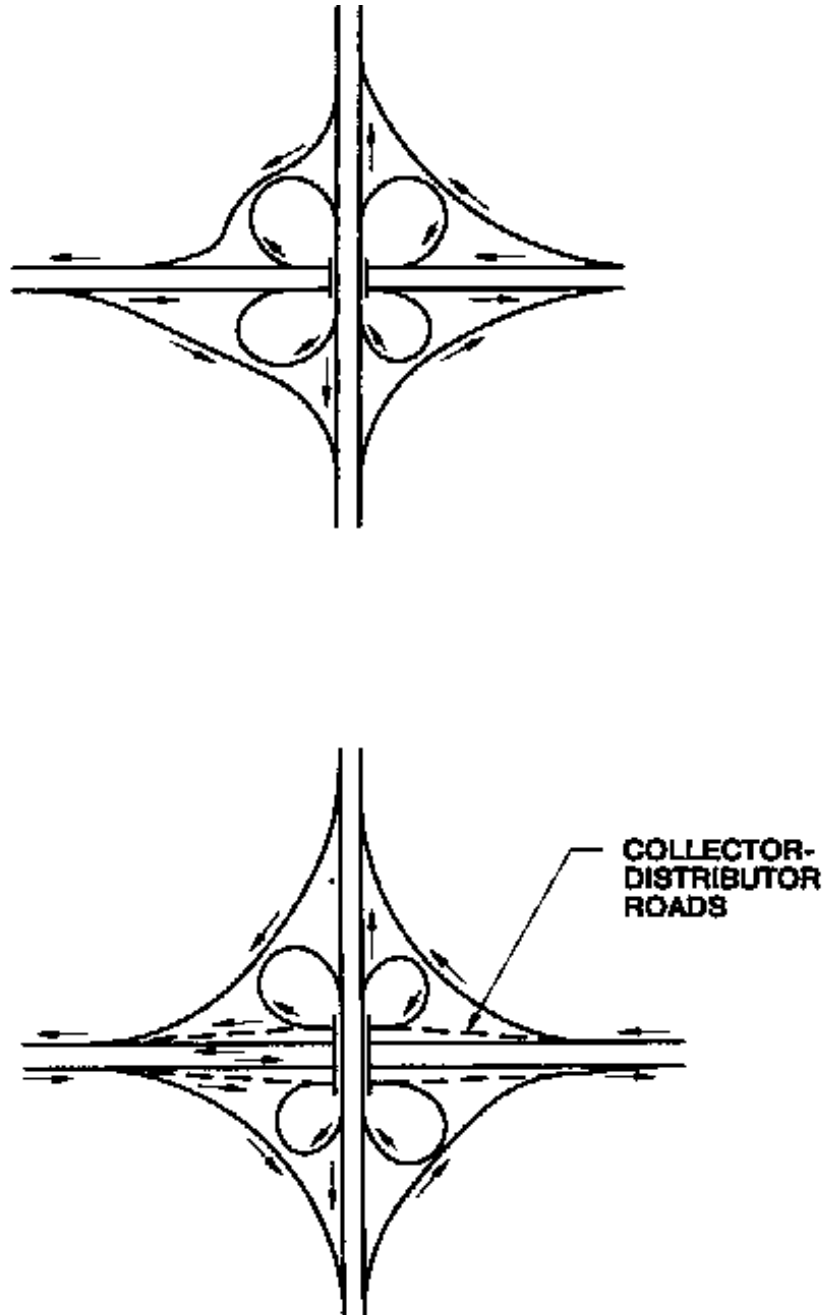
Figure 6-3. URBAN INTERCHANGE

6.2.3 Cloverleaves

Cloverleaf interchanges are used at four-leg intersections with loop ramps to accommodate left turn movements. Full cloverleaf interchange are those with loops in all four quadrants; all other are partial cloverleaves.

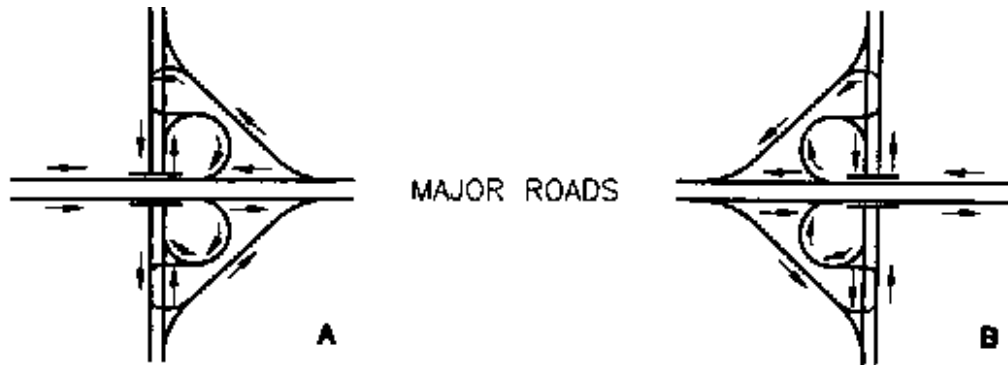
Where two access controlled highways intersect, a full cloverleaf is the minimum type design interchange that will suffice. However, these interchanges introduce several undesirable operational features such as the double exits and entrances from the mainline, the weaving between entering and exiting vehicles with the mainline traffic, and the lengthy travel time and distance for left-turning vehicles. Therefore, at freeway-to-freeway interchanges, a collector distributor (C-D) road should be used. Figure 6-4 provides typical examples of full cloverleaves with and without C-D roads.

Partial cloverleaves are appropriate where right-of-way restrictions preclude ramps in one or more quadrants. Figure 6-5 illustrates six examples of partial cloverleaves. In "A" and "B", both left turn movements onto the major road are provided by loops, which is desirable. The other examples (C-F) illustrate two loops in opposite quadrants and loops in three quadrants. In these examples, the desirable feature is that no left-turn movements are made onto the major road.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 6-4. FULL CLOVERLEAFS



MAJOR ROADS

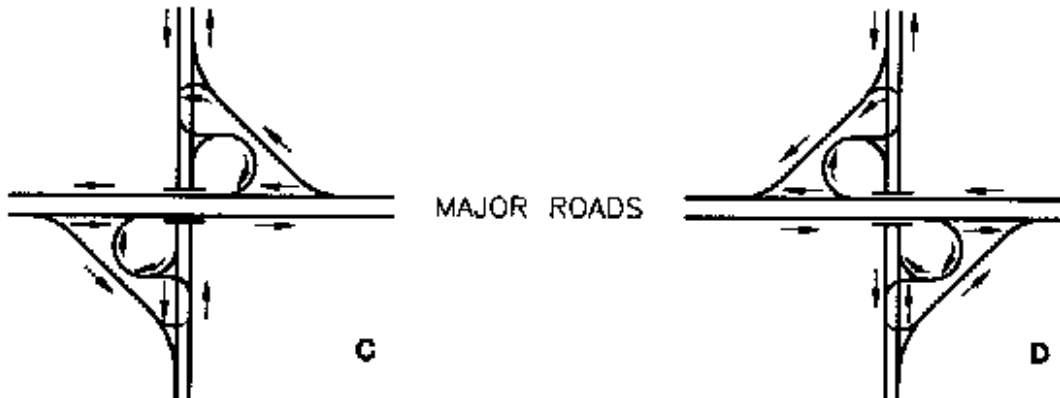
A

B

ON BOTH SIDES OF MAJOR ROAD
LEFT TURNS: NONE ON MAJOR ROAD
FOUR ON MINOR ROAD

ON BOTH SIDES OF MAJOR ROAD
LEFT TURNS: NONE ON MAJOR ROAD
FOUR ON MINOR ROAD

TWO QUADRANTS ADJACENT



MAJOR ROADS

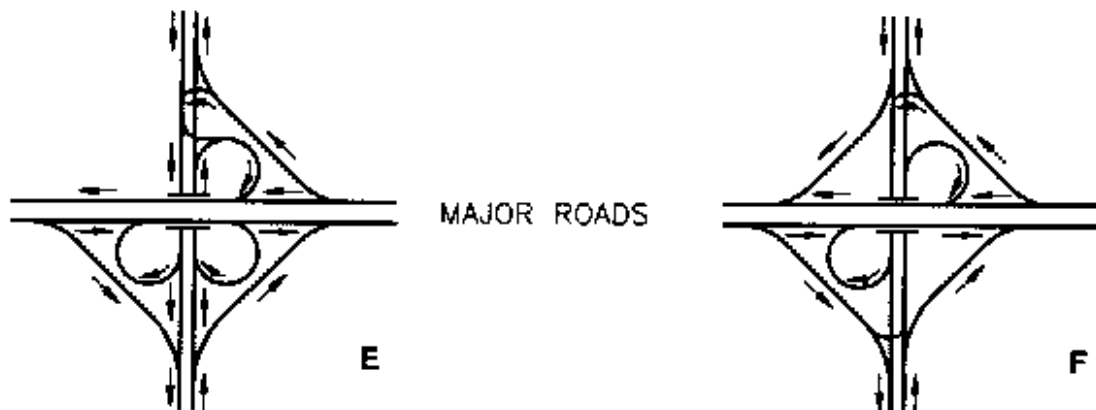
C

D

MAJOR ROAD EXITS ON NEAR SIDE
LEFT TURNS: NONE ON MAJOR ROAD
FOUR ON MINOR ROAD

MAJOR ROAD EXITS ON FAR SIDE
LEFT TURNS: NONE ON MAJOR ROAD
FOUR ON MINOR ROAD

TWO QUADRANTS DIAGONALLY OPPOSITE



MAJOR ROADS

E

F

**TWO MAJOR ROAD EXITS ON NEAR SIDE
ONE ON FAR SIDE**
LEFT TURNS: NONE ON MAJOR ROAD
TWO ON MINOR ROAD

MAJOR ROAD EXITS ON NEAR SIDE
LEFT TURNS: NONE ON MAJOR ROAD
TWO ON MINOR ROAD

THREE QUADRANTS

FOUR QUADRANTS

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 6-5. PARTIAL CLOVERLEAF ARRANGEMENTS

At other than a freeway-to-freeway intersection, the choice of interchange is between a full or partial cloverleaf and a diamond. The following should be considered when making the selection:

1. Cloverleafs require more right-of-way and are more expensive than diamonds.
2. Full cloverleafs result in a no 90-degree intersections as do partial cloverleafs and diamonds.
3. Weaving on the mainline should be avoided. This can be accomplished with C-D roads, a partial cloverleaf or a diamond design.
4. The loops in cloverleafs result in a greater travel distance for left-turning vehicles than do diamonds, and the loops operate at lower speeds.
5. All exit and entrance maneuvers at diamonds are executed before reaching the structure, which conforms to driver expectancy. This is not true of cloverleafs and the double exits cause signing problems.
6. Ramps at diamond interchanges can be widened to increase capacity. Loop ramps, regardless of width, almost always operate in a single line, thereby limiting capacity.
7. Pedestrian movements along cross streets are more difficult to accommodate safely at cloverleaf interchanges.
8. Full cloverleafs are often considered more appropriate than diamonds when traffic volumes are high. However, considering the general advantages of diamonds, the designer should investigate measures to increase the capacity of diamond interchanges such as advanced signal phasing, signal coordination on the minor road, or an urban diamond arrangement.

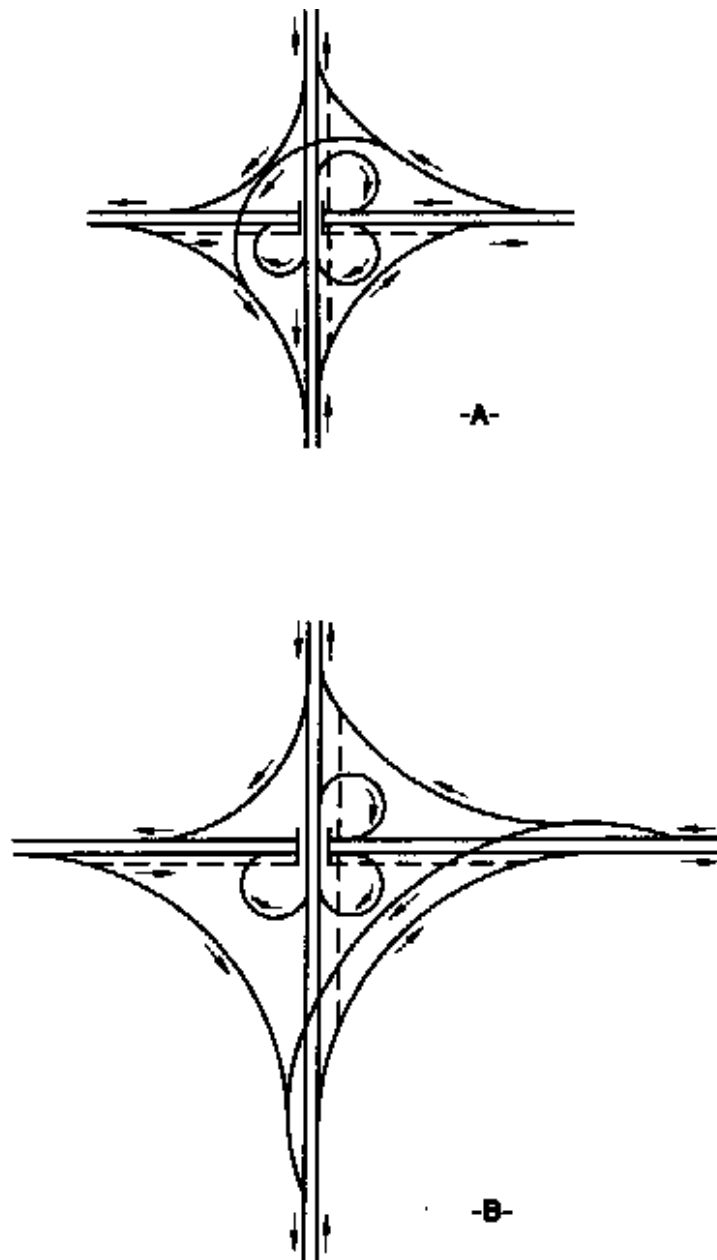
6.2.4 Directional and Semi-Directional

The following definitions apply to directional and semi-directional interchanges:

1. *Direct Ramp Connection* - A ramp that does not deviate greatly from the intended direction of travel (as does a loop, for example).
2. *Semi-Direct Ramp Connection* - A ramp that is indirect in alignment yet more direct than loops.

3. *Directional Interchange* - An interchange where one or more left-turning movements are provided by direct connection, even if the minor left-turn movements are accommodated on loops.
4. *Semi-Directional Interchange* - An interchange where one or more left-turning movements are provided by semi-direct connections, even if the minor left-turn movements are accommodated on loops.
5. *Fully Directional Interchange* - An interchange where all left-turning movements are provided by direct connections.

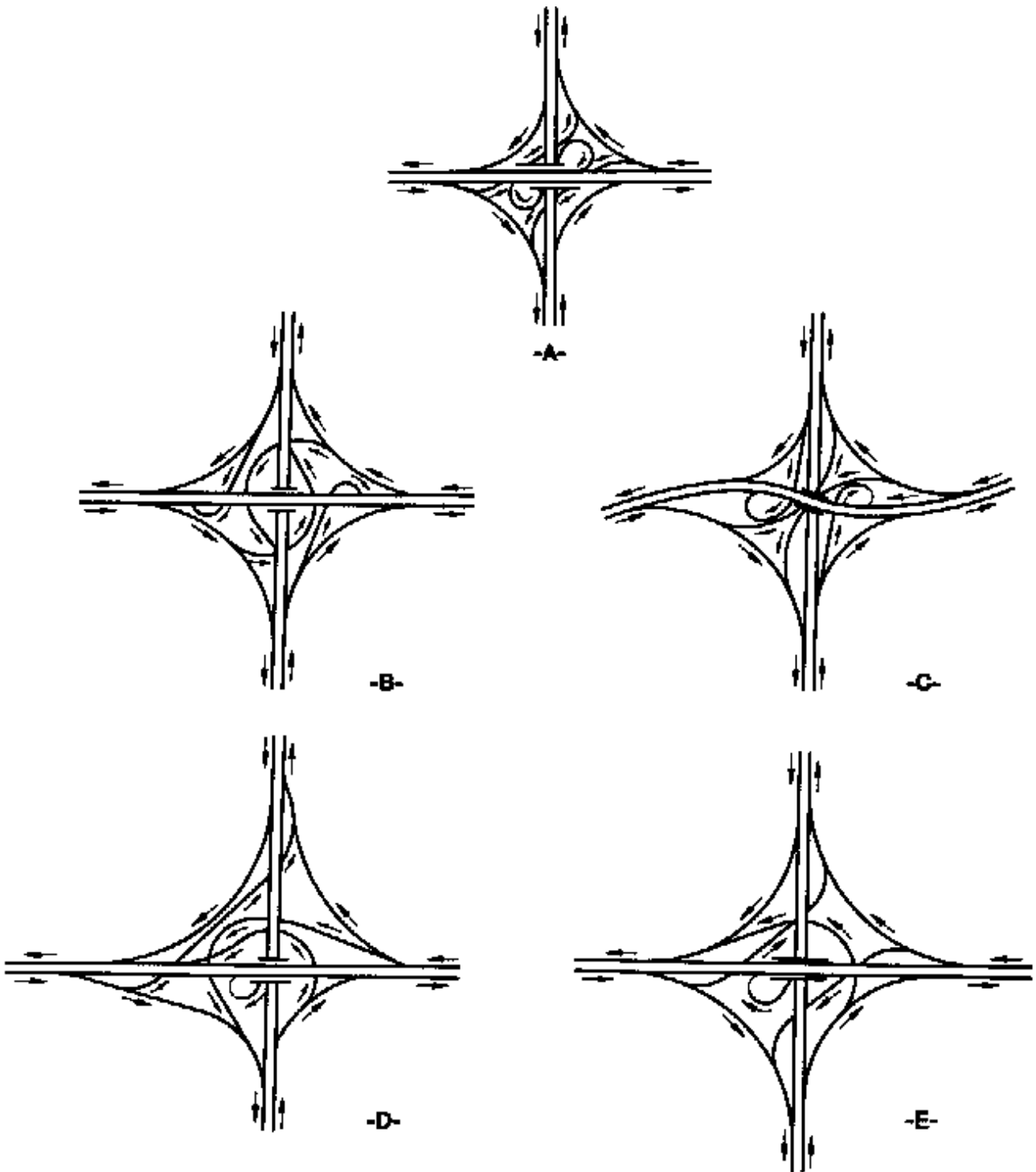
Direct or semi-direct connections are used for heavy left-turn movements to reduce travel distance, increase speed and capacity, and eliminate weaving. This should be strongly considered for use as freeway-to-freeway interchanges. Examples of direct and semi-direct interchanges are shown in Figures 6-6, 6-7, and 6-8.



Note: WEAVING ADJACENT TO THE THROUGH LANES IS ELIMINATED BY PROVIDING COLLECTOR-DISTRIBUTOR ROADS AS SHOWN BY DOTTED LINES.

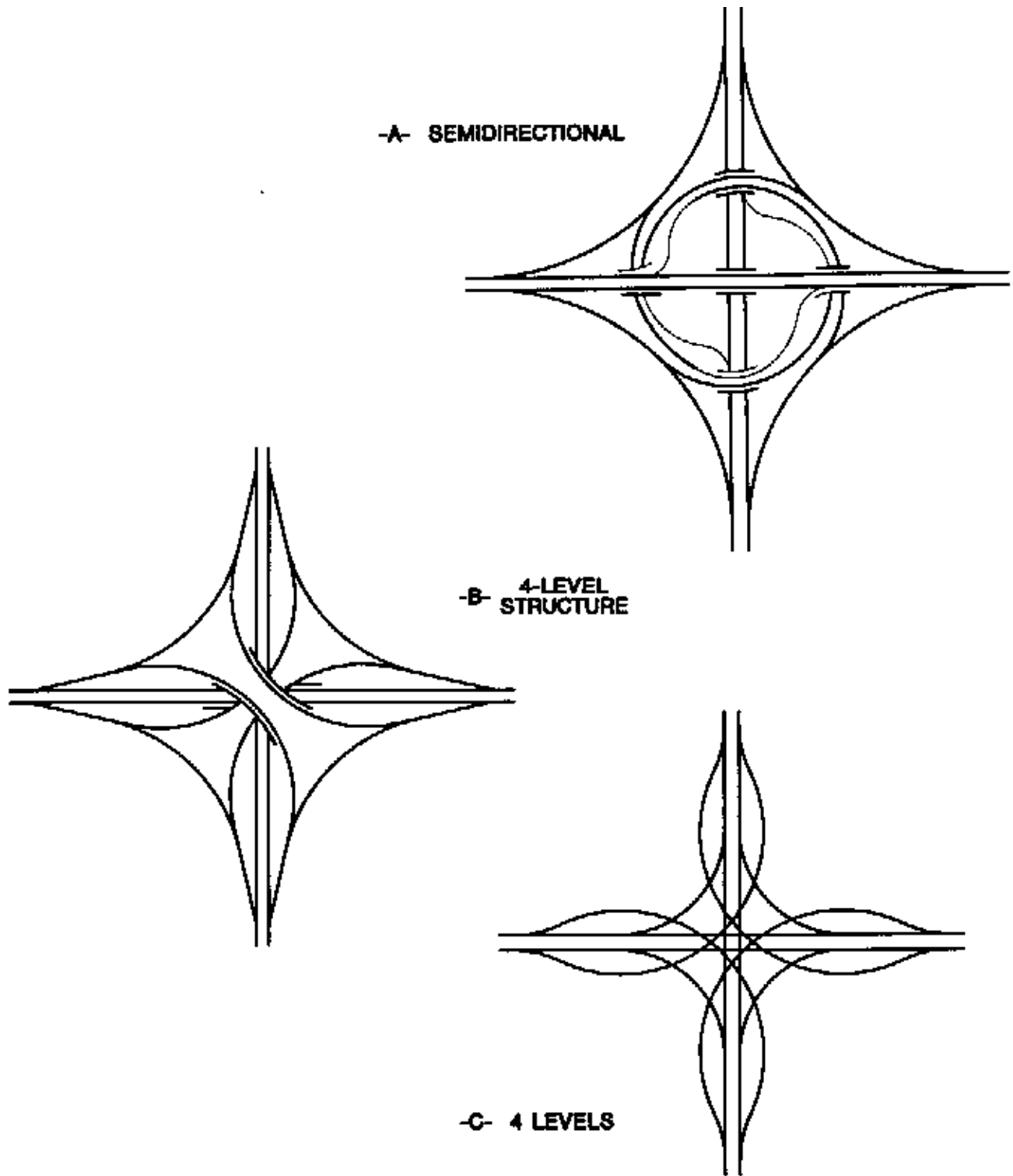
Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 6-6. SEMIDIRECT INTERCHANGES WITH WEAVING



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 6-7. SEMIDIRECT INTERCHANGES WITHOUT WEAVING



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 6-8. SEMIDIRECTIONAL AND DIRECTIONAL INTERCHANGES - MULTILEVEL STRUCTURES.

6.3 INTERCHANGE ANALYSIS

Interchanges are expensive, and it is therefore often necessary to develop and study several alternatives in depth. Each alternative should be evaluated on the basis of its cost, safety, capacity, operation, and compatibility with the surrounding highway system. The design must accommodate present and probable adjacent land uses and should attempt to minimize ownership and maintenance responsibilities.

6.3.1 Capacity and Level of Service

An interchange must accommodate the anticipated traffic volumes. The capacity and level of service for an interchange will depend upon the operation of its individual elements along with the interaction and coordination of each of these elements in the overall design.

1. basic freeway section where interchanges are not present (Section 3.5.2).
2. freeway-ramp junctions or terminals (Section 6.5.4).
3. weaving areas (Section 6.5.3).
4. ramp proper (Section 6.6.2).
5. ramp/minor road intersection (Section 6.7).

The basic capacity reference for freeways is the *Highway Capacity Manual*. The interchange should operate at an acceptable level of service. It is desirable for the level of service of each interchange element to be as good as the level of service provided on the basic freeway section. Interchange elements should not operate at more than one level of service below that of the basic freeway section. In addition, the designer should ensure that the operation of the ramp/minor road intersection will not impair the operation of the mainline. This will likely involve a consideration of the operation characteristics on the minor road for some distance in either direction from the interchange.

6.3.2 Safety Considerations

Typical design problems at existing interchanges include:

1. *Exit Points* - Many interchanges have been built with exit points which could not clearly be seen by approaching drivers. When feasible, decision sight distance should

be provided at freeway exits, and the pavement surface should be used for the height of object (0.0 meter) (see Section 3.6.2). Proper advance signing of exits is also essential.

2. *Exit Speed Changes* - Many freeway exits do not provide sufficient distance for safe deceleration. The design should provide enough distance to allow safe deceleration from the freeway design speed to the design speed of the first exit curve.
3. *Merges* - The most frequent type of accident at interchanges is the rear-end collision at entrances onto the freeway. This problem can be lessened by providing an acceleration lane of sufficient length to allow a merging vehicle to attain speed and find a sufficient gap into which to merge.
4. *Left Hand Entrances and Exits* - Left-hand entrances and exits are contrary to driver expectations and have been associated with higher accident rates and should be avoided.
5. *Fixed-Object Accidents* - A number of fixed objects may be located within interchanges, such as signs at exit gores or bridge piers and rails. These should be removed where possible, made breakaway, or shielded with barriers or impact attenuators.
6. *Wrong-Way Entrances* - In almost all cases, wrong-way maneuvers originate at interchanges. Some cannot be avoided, but may result from driver confusion due to poor visibility, deceiving ramp arrangement, or inadequate signing. The interchange design must attempt to minimize wrong-way possibilities. This includes staggering ramp terminals and controlling access in the vicinity of the ramps.
7. *Excessive Speed on Minor Roadways* - Ramp and merge designs should slow down drivers leaving the high-speed roadway so that they will not exceed the design speed on the secondary road. The reconstructed section of the secondary road should have a design speed similar to (not faster than) the design of adjoining sections of that road.

6.3.3 Selection of Interchange Type

Freeway interchanges are of two general types. A "systems" interchange will connect freeway to freeway; a "service" interchange will connect a freeway to a lesser facility. Once several alternative interchange designs have been developed, they can be evaluated considering:

1. compatibility with the surrounding highway system.
2. uniformity of exit and entrance patterns.
3. capacity and level of service.
4. operational characteristics (single versus double exits, weaving, signing).
5. road user impacts (travel distance and time, safety, convenience and comfort).
6. construction and maintenance costs.
7. right-of-way impacts and availability, and
8. environmental impacts.

In addition, two other general factors influence the selection of an interchange type:

1. The setting is a factor (urban or rural). In rural areas where interchanges are relatively infrequent, the design can be selected primarily on the basis of service demand. In urban areas, where restricted right-of-way and close spacing of interchanges are common, the type and design of the interchange may be severely limited. A collector distributor road may be necessary between closely spaced interchanges. The operational characteristics of the intersecting road and nearby interchanges will also be major influences on the design of an interchange.
2. All interchanges should provide for all movements, even when the anticipated turning volume is low. An omitted maneuver causes extreme confusion to those drivers searching for the exit or entrance. Particular attention to signing must be made to minimize confusion. In addition, unanticipated future developments may increase the demand for a given maneuver. Even when ramps are not constructed, sufficient right-of-way should be purchased for completing the interchange at a later date.

Figure 6-9 depicts interchanges that are adaptable on freeways as related to classifications of intersecting facilities in rural, suburban, and urban environments.

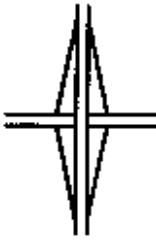

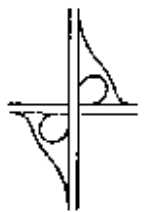
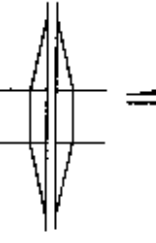
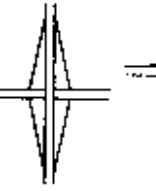



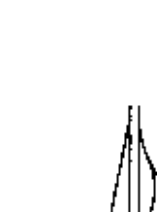
	URBAN	SUBURBAN	RURAL	
				<p>TYPE OF INTERSECTING FACILITY</p> <p>LOCAL ROAD OR STREET</p>
<p>SERVICE INTERCHANGES</p>				<p>COLLECTORS AND ARTERIALS</p>
<p>SYSTEMS INTERCHANGES</p>				<p>FREEWAYS</p>

Figure 8-8. ADAPTABILITY OF INTERCHANGES ON FREEWAYS AS RELATED TO TYPES OF INTERSECTING FACILITIES.

6.4 TRAFFIC LANE PRINCIPLES

Certain traffic lane principles are important in the design of an interchange. These principles minimize confusion, operational problems, and the number of accidents.

6.4.1 Basic Number of Lanes and Freeway Lane Drops

The basic number of lanes is the minimum number of lanes needed over a significant length of a highway based on the overall capacity needs of that section. The number of lanes should remain constant over short distances. For example, a lane should not be dropped at the exit of a diamond interchange and then added at the downstream entrance simply because the traffic volumes between the exit and entrance drops significantly. Similarly, a basic lane should not be dropped between closely spaced interchanges because the estimated traffic volume in that short section of highway does not warrant the higher number of lanes.

Freeway lane drops, where the basic number of lanes is decreased, must be fully designed. They should occur on the freeway mainline away from any other activity, such as interchange exits and entrances. The following recommendations are important when designing a freeway lane drop:

1. *Location* - The lane drop should occur approximately 600-1000 meters beyond the previous interchange. This distance allows adequate signing and adjustments from the interchange, but yet is not so far downstream that drivers become accustomed to the number of lanes and are surprised by the lane drop. In addition, a lane should not be dropped on a horizontal curve or where other signing is required, such as for an upcoming exit.
2. *Sight Distance* - The lane drop should be located so that the surface of the roadway within the transition remains visible for its entire distance. This favors, the example, placing a lane drop within a sag vertical curve rather than just beyond a crest. Decision sight distance to the roadway surface is desirable. See Section 3.6.2.
3. *Transition* - The desirable taper rate is 100:1 for the transition at the lane drop. The minimum is 70:1.
4. *Right-Side Versus Left-Side Drop* - All freeway lane drops must be on the right side, unless specific site conditions greatly favor a left-side lane reeducation.
5. *Signing* - Motorists must be warned and guided into the lane reduction. Advance

signing and pavement markings must conform to the requirements of the *Manual of Uniform Traffic Control Devices*.

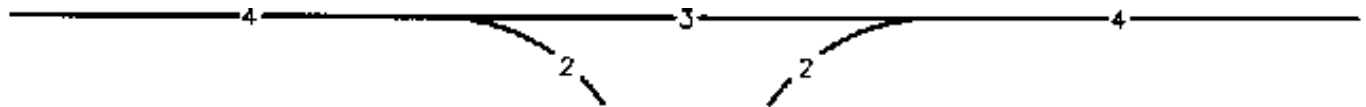
6.4.2 Lane Balance

To realize efficient traffic operation through and beyond an interchange, there should be a balance in the number of traffic lanes on the freeway and ramps. Design traffic volumes and a capacity analysis determine the basic number of lanes to be used on the highway and the minimum number of lanes on the ramps. The basic number of lanes should be established for a substantial length of freeway and should not be changed, through pairs of interchanges, simply because there are substantial volumes of traffic entering and leaving. Variations in traffic demand should be accommodated by means of auxiliary lanes where needed.

After the basic number of lanes is determined for each roadway, the balance in the number of lanes should be checked on the basis of the following principles:

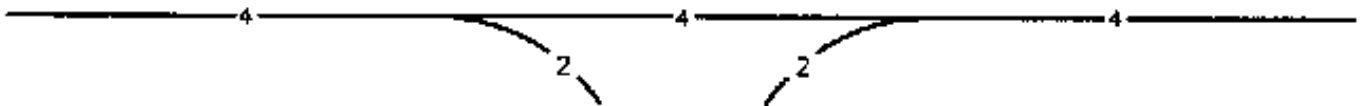
1. At entrances the number of lanes beyond the merging of two traffic streams should not be less than the sum of all traffic lanes on the merging roadways, minus one.
2. At exits the number of approach lanes on the highway must be equal to the number of lanes on the highway beyond the exit plus the number of lanes on the exit, less one. An exception to this principle would be at cloverleaf loop ramp exits which follow the loop ramp entrance or at exits between closely spaced interchanges; i.e., interchanges where the distance between the end of the taper of the entrance terminal and the beginning of the taper of the exit terminal is less than 450 meters and a continuous auxiliary lane between the terminals is being used. In these cases, the auxiliary lane may be dropped in a single-lane exit with the number of lanes on the approach roadway being equal to the number of through lanes beyond the exit plus the lane on the exit.
3. The traveled way of the highway should be reduced by not more than one traffic lane at a time.

Figure 6-10 illustrates the typical treatment of the four-lane freeway with a two lane exit followed by a two lane entrance.



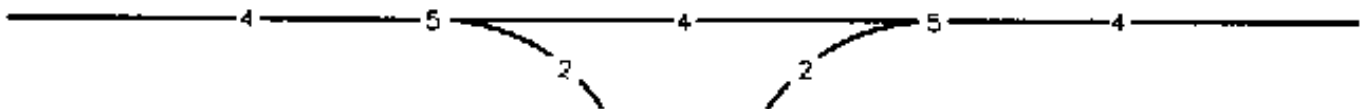
LANE BALANCE BUT NO COMPLIANCE WITH BASIC NUMBER OF LANES

-A-



NO LANF. BALANCE BUT COMPLIANCE WITH BASIC NUMBER OF LANES

-B-



COMPLIANCE WITH BOTH LANE BALANCE AND BASIC NUMBER OF LANES

-C-

Figure 6-10. COORDINATION OF LANE BALANCE AND BASIC NUMBER OF LANES.

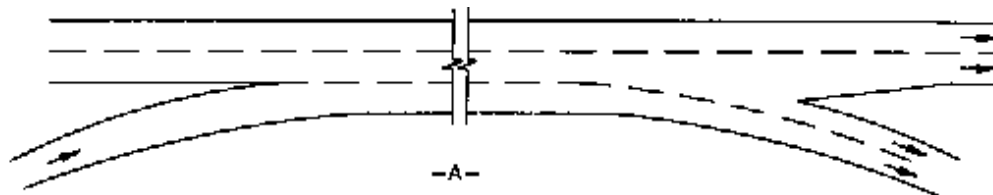
6.4.3 Auxiliary Lanes

An auxiliary lane is defined as the portion of the roadway adjoining the traveled way for parking, speed change, turning, storage for turning, weaving, truck climbing, and other purposes supplementary to through-traffic movement. The width of an auxiliary lane should equal that of the through lanes. An auxiliary lane may be provided to comply with the concept of lane balance, to comply with capacity requirements in the case of adverse grades, or to accommodate speed changes, weaving, and maneuvering of entering and leaving traffic. Where auxiliary lanes are provided along freeway main lanes, the adjacent shoulder would desirably be 2.5 to 3.75 meters in width, with a minimum 2.0-meters-wide shoulder considered.

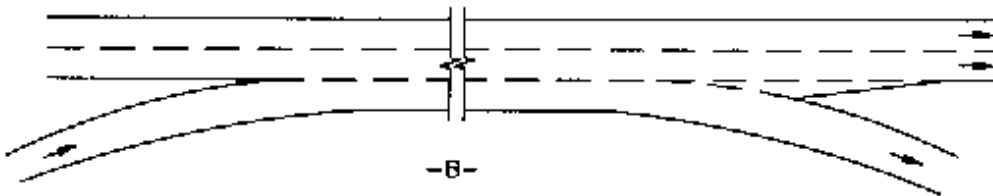
Auxiliary lanes may be added to satisfy capacity and weaving requirements between interchanges, to accommodate traffic patterns variations at interchanges, and for simplification of operations (as reducing lane changing). The principles of lane balance must always be applied in the use of auxiliary lanes. In this manner the necessary balance between traffic load and capacity is provided, and lane balance and needed operational flexibility are realized.

Where interchanges are closely spaced in urban areas, the acceleration lane from an entrance ramp should be extended to the deceleration lane of a downstream exit ramp.

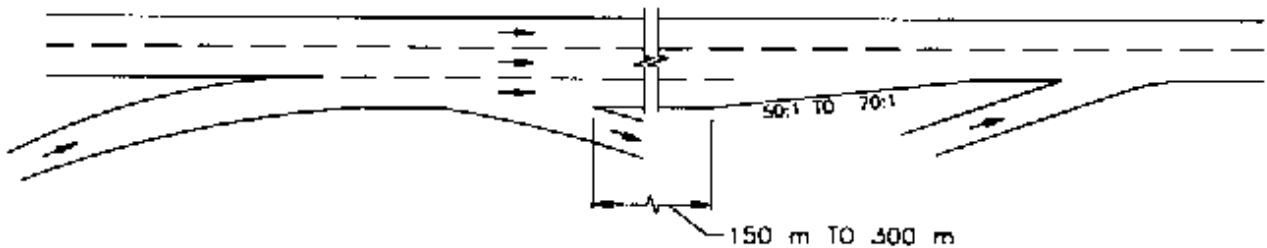
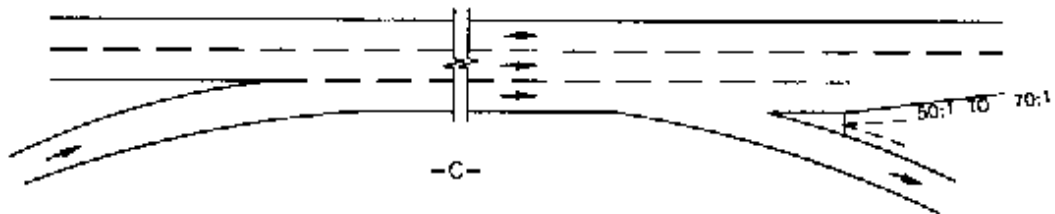
Figure 6-11 shows alternatives in dropping auxiliary lanes.



AUXILIARY LANE DROPPED ON EXIT RAMP



AUXILIARY LANE BETWEEN CLOVERLEAF LOOPS OR CLOSELY SPACED INTERCHANGES DROPPED ON SINGLE EXIT LANE.



AUXILIARY LANE DROPPED WITHIN AN INTERCHANGE

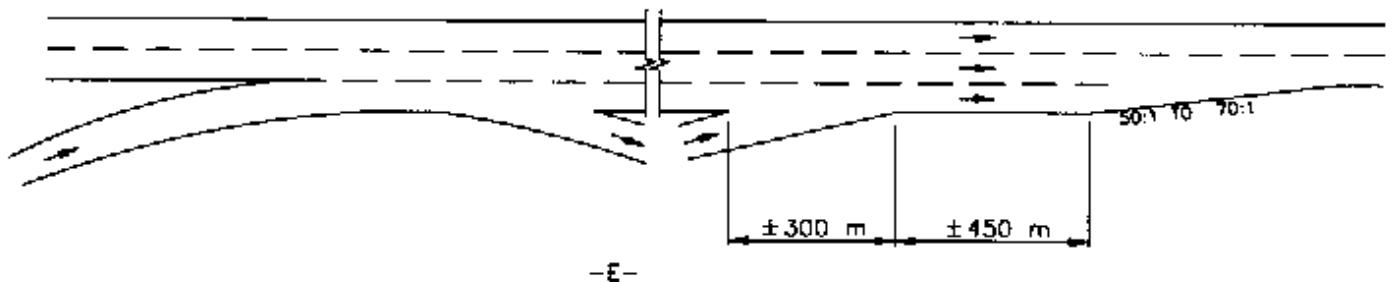


Figure 6-11. ALTERNATIVES IN DROPPING AUXILIARY LANES.

6.4.4 Distance Between Successive Ramp Terminals.

On freeways there are frequently two or more ramp terminals in close succession along the through lanes. To provide sufficient maneuvering length and adequate space for signing, a reasonable distance is required between terminals.

Spacing between successive outer ramp terminals is dependent on the classification of the interchanges involved, the function of the ramp pairs (entrance or exit), and weaving potential, when applicable.

The term "systems interchange" is used to identify an interchange that transfers traffic freeway to freeway. A "service interchange" is the designation for an interchange between a freeway and a local arterial.

The ramp-pair combinations are entrance followed by entrance (EN-EN), exit followed by exit (EX-EX), exit followed by entrance (EX-EN), entrance followed by exit (EN-EX) (weaving), and turning roadways.

Figure 6-12 shows the minimum values for spacing of ramp terminals for the various ramp-pair combinations as they are applicable to the interchange classifications.

EN-EN OR EX-EX	EX-EN	TURNING ROADWAYS	EN-EX (WEAVING)											
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">FULL FREEWAY</div> <div style="text-align: center;">CDR OR FDR</div> </div>	<div style="text-align: center;">FULL FREEWAY</div>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">SYSTEM INTER- CHANGE</div> <div style="text-align: center;">SERVICE INTER- CHANGE</div> </div>	<div style="text-align: center;">* NOT APPLICABLE TO CLOVERLEAF LOOP RAMPS</div>											
MINIMUM LENGTHS MEASURED BETWEEN SUCCESSIVE RAMP TERMINALS (meters)														
300	240	150	120	240	180	600	480	480	300					
				FULL FWY.			CDR OR FDR			SERVICE INTER- CHANGE	CDR OR FDR	FULL FWY.	CDR OR FDR	CDR OR FDR

NOTE: FDR - FREEWAY DISTRIBUTOR ROAD EN - ENTRANCE
 CDR - COLLECTOR DISTRIBUTOR ROAD EX - EXIT

THE RECOMMENDATIONS ARE BASED ON OPERATIONAL EXPERIENCE AND NEED FOR FLEXIBILITY AND ADEQUATE SIGNING. THEY SHOULD BE CHECKED IN ACCORDANCE WITH THE PROCEDURE OUTLINED IN THE HIGHWAY CAPACITY MANUAL (3) AND THE LARGER OF THE VALUES IS SUGGESTED FOR USE. ALSO, A PROCEDURE FOR MEASURING THE LENGTH OF THE WEAVING SECTION IS GIVEN IN THE CHAPTER 4 OF THE HIGHWAY CAPACITY MANUAL (3).

Figure 6-12. RECOMMENDED MINIMUM RAMP TERMINAL SPACING.

Where an entrance ramp is followed by an exit ramp, the absolute minimum distance between the successive noses is governed by weaving requirements. A notable exception to this length policy for EN-EX ramp combinations is the distance between loop ramps of cloverleaf interchanges. For these interchanges the distance between EN-EX ramp noses is primarily dependent on loop ramp radii and roadway and median widths. A recovery lane beyond the nose of the loop ramp exit is desirable.

When the distance between the successive noses is less than 450 meters, the speed-change lanes should be connected to provide an auxiliary lane. This auxiliary lane is provided for improved traffic operation over relatively short sections of the freeway route and is not considered as an addition to the basic number of lanes.

See *A Policy on Geometric Design of Highways and Streets* by AASHTO for additional information on auxiliary lane design and lane balance criteria at interchanges.

6.5 FREEWAY/RAMP JUNCTIONS

6.5.1 Exit Ramps

Exit ramps are one-way roadways which allow traffic to exit from the freeway to provide access to other crossing highways. They are provided for all highways which intersect a freeway where the warrants for an interchange are satisfied.

6.5.1.1 Sight Distance

Decision sight distance should be provided for drivers approaching an exit. Sufficient sight distance is particularly important for exit loops immediately beyond a structure. Vertical curvature or bridge piers can obstruct the exit point if not carefully designed. When measuring for adequate sight distance, the designer should use the pavement surface at the gore nose as a 0.0 meter height of object. Section 3.6.2 discusses decision sight distance in detail.

6.5.1.2 Deceleration Lanes

Sufficient deceleration distance is needed to allow an exiting vehicle to leave the freeway mainline safely and comfortably. All deceleration should occur within the full width of the deceleration lane. The length of the deceleration lane will depend upon the design speed of the mainline and the design speed of the first (or controlling) curve on the exit ramp. In

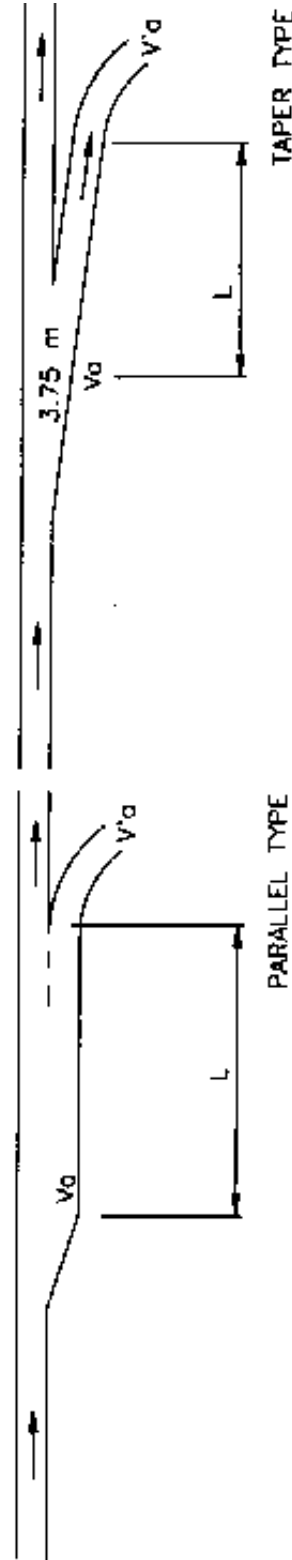
addition, if compound curvature is used, there should be sufficient deceleration in advance of each successively sharper curve. Table 6.1 provides the deceleration distance for various combinations of highway design speeds and exit curve design speeds. Deceleration lanes are measured from the point where the lane reaches 3.75 meters wide to the painted nose for parallel types and the first controlling curve for taper types. Greater distances should be provided if practical. If the deceleration lane is on a grade of 3% or more, the length of the lane should be adjusted according to the criteria in Table 6.2.

Deceleration lanes can be the taper type or the parallel lane type, with the parallel type preferred. It is necessary for a full deceleration lane to be developed and visibly marked well ahead of the gore area.

Figures 6-21 to 6-29 in the Chapter 6 Appendix illustrate the standard MHD designs for freeway exits at interchanges.

Table 6.1 MINIMUM DECELERATION LENGTHS FOR EXIT TERMINALS WITH FLAT GRADES OF 2 PERCENT OR LESS.

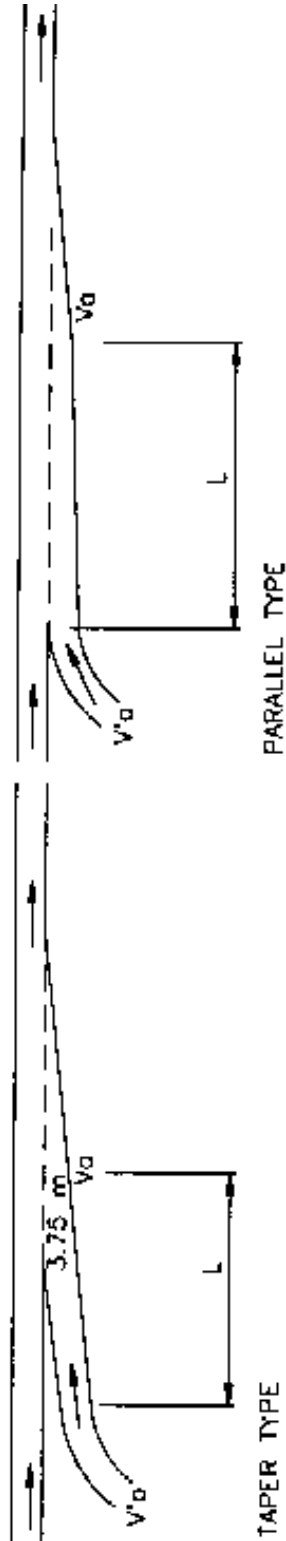
		DECELERATION LENGTH, L (m) FOR DESIGN SPEED OF EXIT CURVE V' (km/h)							
		20	30	40	50	60	70	80	
		FOR AVERAGE RUNNING SPEED ON EXIT CURVE, V _a (km/h)							
HIGHWAY DESIGN SPEED, V (km/h)	SPEED REACHED, V _a (km/h)	0	20	28	35	42	51	63	70
50	47	75	70	60	45	-	-	-	-
60	55	95	90	80	65	55	-	-	-
70	63	110	105	95	85	70	55	-	-
80	70	130	125	115	100	90	80	55	-
90	77	145	140	135	120	110	100	75	60
100	85	170	165	155	145	135	120	100	85
110	91	180	180	170	160	150	140	120	105
120	98	200	195	185	175	170	155	140	120



- V = DESIGN SPEED OF HIGHWAY
- V_a = AVERAGE RUNNING SPEED OF HIGHWAY
- V' = DESIGN SPEED OF EXIT CURVE
- V'a = AVERAGE RUNNING SPEED OF EXIT CURVE

**Table 62. MINIMUM ACCELERATION LENGTHS FOR ENRTNANCE
 TERMINALS WITH FLAT GRADES OF 2 PERCENT OR LESS.**

		ACCELERATION LENGTH, L (m)												
		FOR ENTRANCE CURVE DESIGN SPEED (km/h)												
		STOP	20	30	40	50	60	70	80					
		CONDITION												
HIGHWAY DESIGN SPEED, V (km/h)	SPEED REACHED, V _a (km/h)	AND INITIAL SPEED, V' _a (km/h)												
		0	20	28	35	42	51	63	70	80				
50	37	60	-	-	-	-	-	-	-	-	-	-	-	-
60	45	100	85	70	-	-	-	-	-	-	-	-	-	-
70	53	145	125	110	85	50	-	-	-	-	-	-	-	-
80	60	195	180	165	135	100	55	-	-	-	-	-	-	-
90	67	275	260	240	210	175	130	50	-	-	-	-	-	-
100	75	370	345	330	300	265	220	145	55	-	-	-	-	-
110	81	430	405	390	360	330	285	210	120	-	-	-	-	-
120	88	520	505	500	470	445	400	335	245	-	-	-	-	-



Note: Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 400 m.

V = DESIGN SPEED OF HIGHWAY

V_a = AVERAGE RUNNING SPEED OF HIGHWAY

V' = DESIGN SPEED OF EXIT CURVE

V'_a = AVERAGE RUNNING SPEED OF EXIT CURVE

6.5.1.3 Superelevation

The superelevation at an exit ramp must be developed to transition the driver properly from the mainline to the curvature at the exit. The principles of superelevation for open highways, as discussed in Chapter 4, should be applied to the exit design. The following criteria apply:

1. The maximum superelevation rate is 0.06 meter/meter.
2. Preferably, full superelevation (0.06 meter/meter) is achieved at the PCC at the gore nose. However, this is subject to the minimum longitudinal slopes in Table 4.3 in Chapter 4.
3. The paved part of the gore is normally sloped at a 0.03 meter/meter rate.

6.5.1.4 Gore Area

The gore area is normally considered to be both the paved triangular area between the through lane and the exit lane and the graded area which extends downstream beyond the gore nose. The following should be considered when designing the gore:

1. Signing in advance of the exit and at the divergence should be in accordance with the *MUTCD*. This also applies to the pavement markings in the triangular area upstream from the gore nose.
2. If possible, the area beyond the gore nose should be free of signs and luminaire supports. If they must be present, they must be yielding or breakaway, or shielded by guardrail or impact attenuators.
3. The graded area beyond the gore nose should be as flat as possible. If the difference in elevation between the exit ramp or loop and the mainline increases rapidly, this may not be possible. These areas will likely be non-traversable and the gore design must shield these areas from the motorist. Often, the vertical divergence of the ramp and mainline will warrant protection for both roadways beyond the gore.

6.5.2 Entrance Ramps

Entrance ramps are one-way roadways which allow traffic from crossing highways to enter a freeway. They are provided for all highways which intersect a freeway where the warrants for an interchange are satisfied.

6.5.2.1 Sight Distance

Decision sight distance should be provided for drivers on the mainline approaching an entrance terminal. They need sufficient distance to see the merging traffic so they can adjust their speed or change lanes to allow the merging traffic to enter the freeway. Likewise, drivers on the entrance ramp need to see a sufficient distance upstream from the entrance to locate the gaps in the traffic stream within which to merge. When measuring sight distance use 1300 millimeters as the height of objects.

6.5.2.2 Acceleration Lanes

A properly-designed acceleration lane will facilitate driver comfort, traffic operations, and safety. The length of the acceleration lane will primarily depend upon the design speed of the last (or controlling) curve on the entrance ramp and the design speed of the mainline. Table 6.2 provides the data for minimum lengths of acceleration lanes. These lengths are for the full width of the acceleration lane, and are measured from the end of the painted nose for parallel types, and from the end of the last controlling curve on taper types, to a point where the full 3.75 meter lane width is achieved. Taper lengths, typically 100 meters, are in addition to the table lengths. Where grades of 3% or more occur on the acceleration lane, adjustments should be made in its length according to Table 6.3. Figures 6-21 to 6-29 in the Chapter 6 Appendix illustrate the MHD standard designs for entrance ramps.

The values in Table 6.3 provide sufficient distance for vehicle acceleration; they may not safely allow a vehicle to merge into the mainline if traffic volumes are high. Where the mainline and ramp will carry traffic volumes approaching the design capacity of the merging area, the acceleration lane length should be extended by 60 meters or more.

**Table 6.3 SPEED CHANGE LANE ADJUSTMENT FACTORS
AS A FUNCTION OF GRADE.**

DESIGN SPEED OF HIGHWAY (km/h)	DECELERATION LANES						
	RATIO OF LENGTH ON GRADE TO LENGTH FOR DESIGN SPEED OF TURNING CURVE (km/h)*						
ALL SPEEDS	3 TO 4 % UPGRADE			3 TO 4 % DOWNGRADE			
	0.9			1.2			
ALL SPEEDS	5 TO 6 % UPGRADE			5 TO 6 % DOWNGRADE			
	0.8			1.35			
DESIGN SPEED OF HIGHWAY (km/h)	ACCELERATION LANES						
	RATIO OF LENGTH ON GRADE TO LENGTH FOR DESIGN SPEED OF TURNING CURVE (km/h)*						
	40	50	60	70	80	ALL SPEEDS	
	3 TO 4 % UPGRADE					3 TO 4 % DOWNGRADE	
60	1.3	1.4	1.4	--	--	0.7	
70	1.3	1.4	1.4	1.5	--	0.65	
80	1.4	1.5	1.5	1.5	1.6	0.65	
90	1.4	1.5	1.5	1.5	1.6	0.6	
100	1.5	1.6	1.7	1.7	1.8	0.6	
110	1.5	1.6	1.7	1.7	1.8	0.6	
120	1.5	1.6	1.7	1.7	1.8	0.6	
	5 TO 6 % UPGRADE					5 TO 6 % DOWNGRADE	
60	1.5	1.5	--	--	--	0.6	
70	1.5	1.6	1.7	--	--	0.6	
80	1.5	1.7	1.9	1.8	--	0.55	
90	1.6	1.8	2.0	2.1	2.2	0.55	
100	1.7	1.9	2.2	2.4	2.5	0.5	
110	2.0	2.2	2.6	2.8	3.0	0.5	
120	2.3	2.5	3.0	3.2	3.5	0.5	

* RATIO FROM THIS TABLE MULTIPLIED BY THE LENGTH IN TABLE 6.1 OR TABLE 6.2 GIVES LENGTH OF SPEED CHANGE LANE ON GRADE.

6.5.2.3 Superelevation

The ramp superelevation should be gradually transitioned to meet the normal cross slope of the mainline. The principles of superelevation for open highways, as discussed in Chapter 4, should be applied to the entrance design. The following criteria should be used:

1. The maximum superelevation rate is 0.06.
2. Preferably, the cross slope of the acceleration lane will equal the cross slope of the through land (0.02 meter/meter) at the PT of the flat horizontal curve near the entrance gore.
3. The superelevation transition should not exceed the minimum longitudinal slopes in Table 4.3.

6.5.3 Weaving Areas

Weaving occurs where one-way traffic streams cross by merging and diverging maneuvers. This frequently occurs within an interchange or between two closely-spaced interchanges. Figure 6-13 illustrates a simple weave diagram and the length over which a weaving distance is measured.

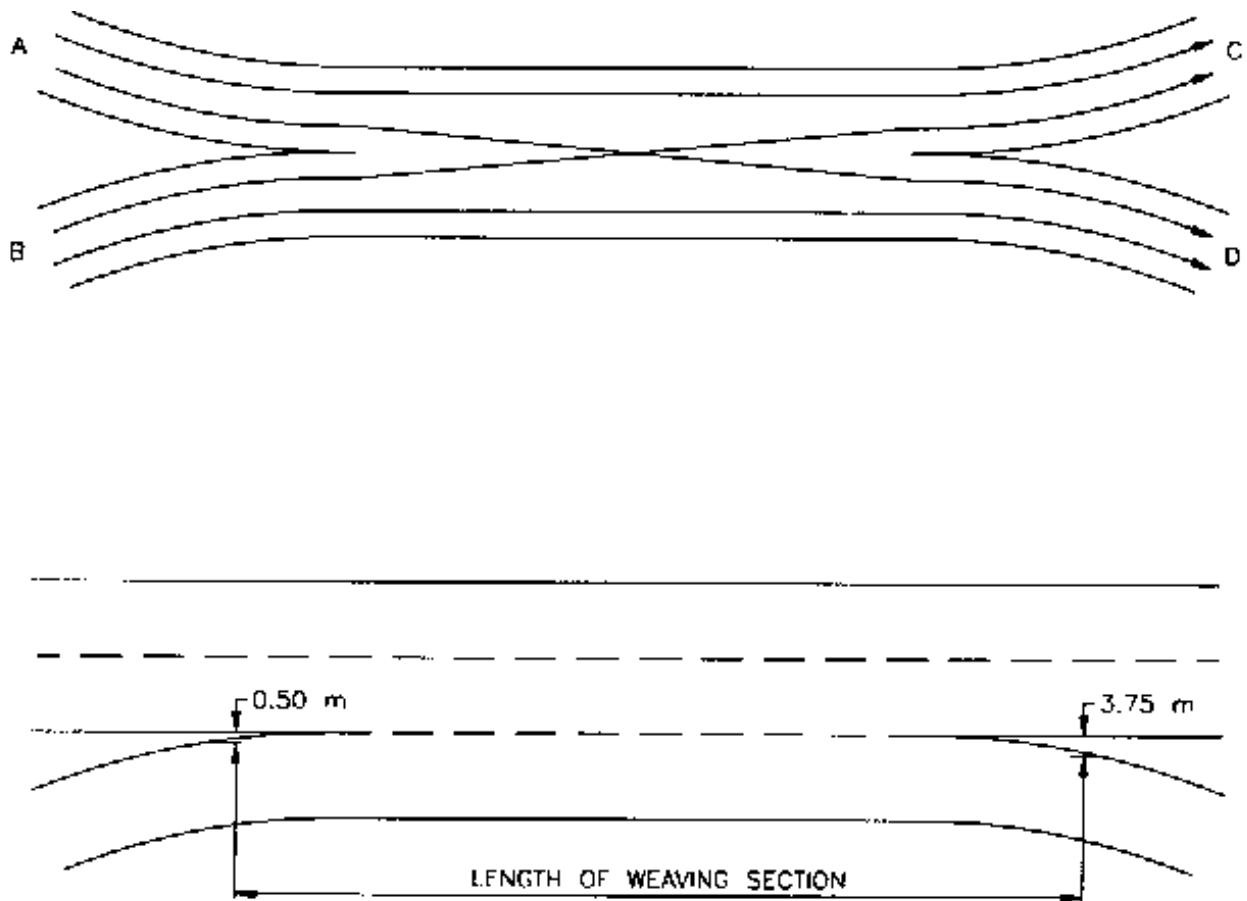


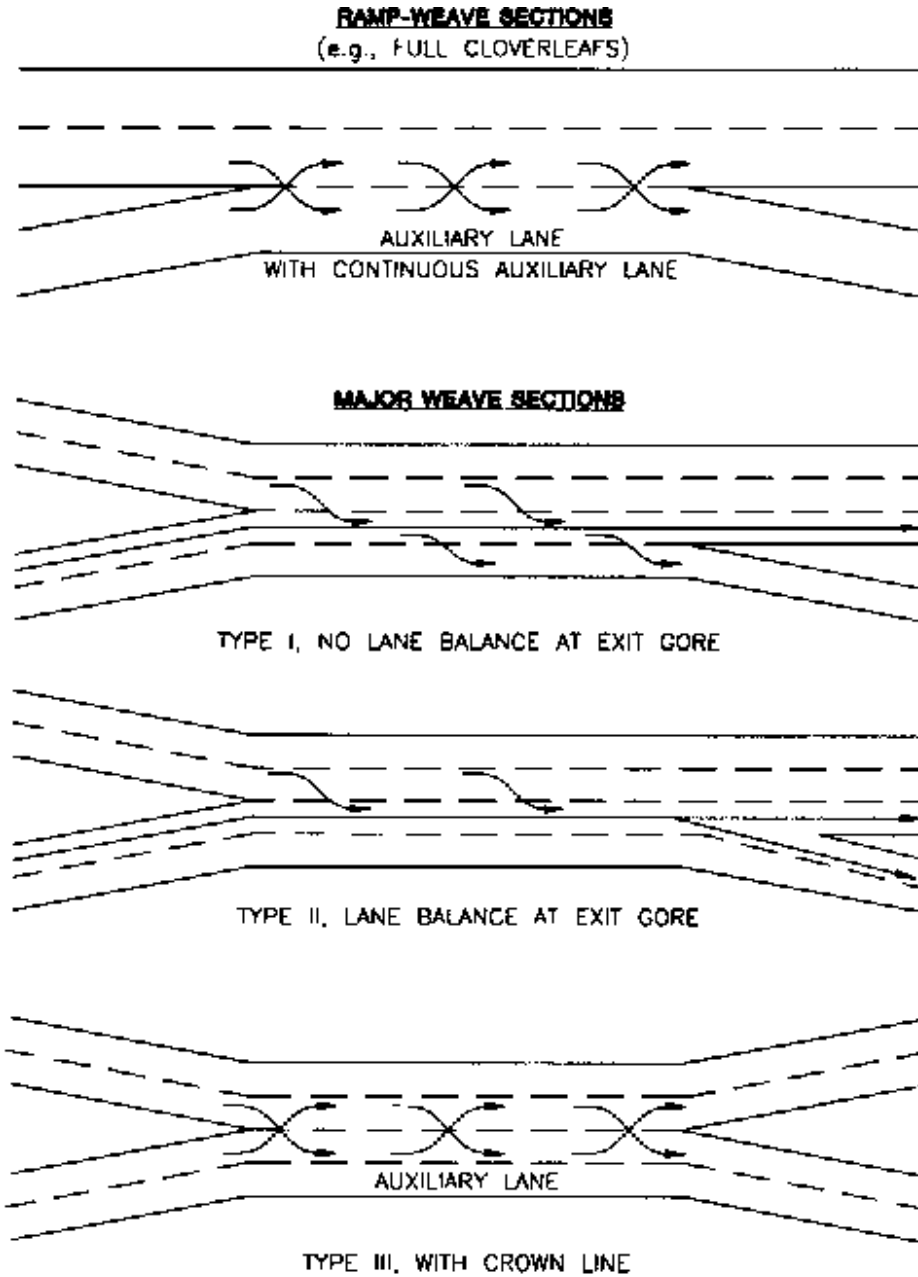
Figure 6-13. WEAVING SECTIONS

The capacity and level of service calculations are made from the methodology presented in the *Highway Capacity Manual*. The methodology determines the needed length on the weaving section to accommodate the predicted traffic conditions, including the weaving and non-weaving volumes and the average running speed of those volumes. Important design elements which must be considered are:

1. the number of lanes in the weaving areas,
2. the configuration of the section in terms of lane balance (i.e., the adding and dropping of auxiliary lanes),
3. the level of service (preferably, it will be the same as the mainline; it should not be more than one level below the mainline), and
4. the speed of weaving vehicles which should be within 8 kilometers/hour of non-weaving vehicles to provide acceptable operation.

Figure 6-14 illustrates a ramp-weave section and three major-weave sections. The ramp-weave section occurs in cloverleaf interchanges where a freeway entrance from an inner loop is immediately followed by an exit onto an inner loop. The entrance and exit are joined by a continuous auxiliary lane. This weaving configuration is complicated because all weaving vehicles are involved in a ramp movement which usually requires reduced speeds due to restrictive geometry. Therefore, three vehicle operations are occurring simultaneously - weaving, acceleration, and deceleration. The methodology in the *Highway Capacity Manual* should be used to determine the needed length for this section. Figure 6-27 (see Chapter 6 Appendix) illustrates the design details for the interior of a clover leaf interchange and provides the minimum distance between the entrance and exit loops within the interchange area. If the weave area is on a freeway, or if the site conditions will not allow the necessary distance, a collector-distributor road should be provided.

Major-weave sections differ from the ramp-weave in that multiple lanes are involved and the geometry allows weaving speeds approximately equal to the speed on the open freeway. The Type 1 weave shown in Figure 6-14 is undesirable because of the lack of lane balance. The *Highway Capacity Manual* provides the methodologies for computing the length, capacity and level of service for weaving sections. Regardless of the calculations from the *HCM*, the minimum desirable length of major-weave section is 350 meters.



NOTE: THE TYPE I MAJOR WEAVE SHOULD NOT BE USED BECAUSE OF ITS LACK OF LANE BALANCE AT THE EXIT GORE.

Figure 6-14. WEAVING CONFIGURATIONS

6.5.4 Capacity and Level of Service

The capacity and level of service for freeway exits and entrances should be computed using the procedures in the *Highway Capacity Manual*. Those factors which will affect the traffic operation conditions at freeway/ramp junctions are:

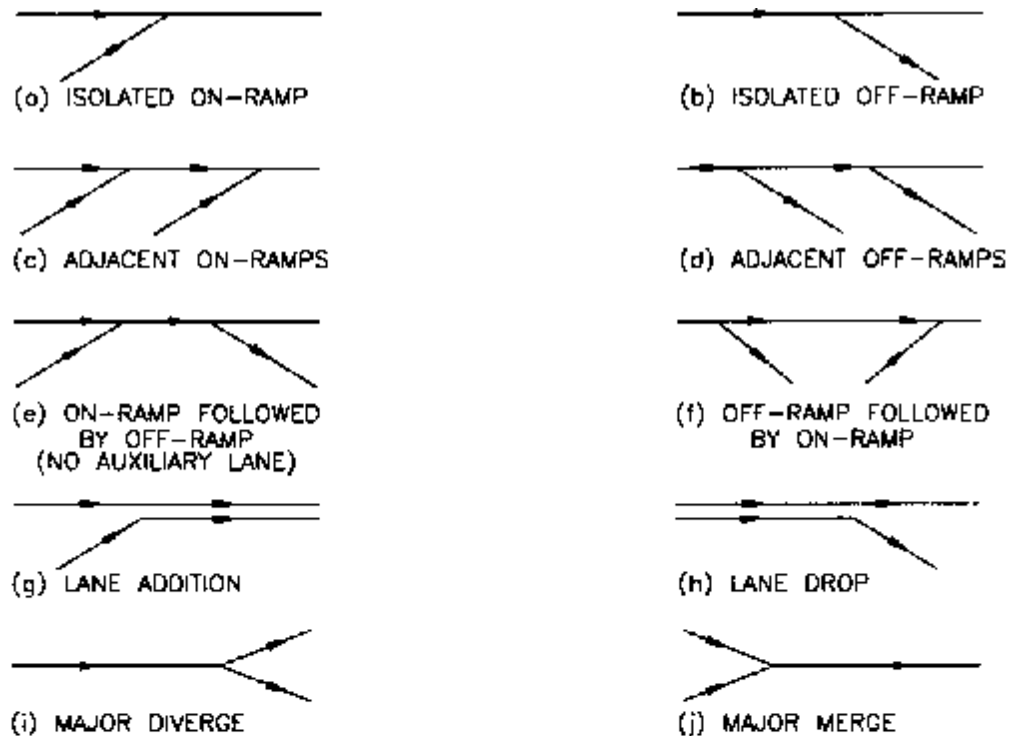
1. acceleration and deceleration distances,
2. sight distance,
3. horizontal and vertical curvature at the junction,
4. merge and diverge volumes, and
5. freeway volumes.

The methodology in the *Highway Capacity Manual* will allow the analysis of isolated ramps, or of ramps in association with another one upstream or downstream. Figure 6-15 illustrates several of the configurations which can be analyzed using the HCM. The table in the figure shows the volumes which can be accommodated at a ramp junction for a given level of service.

6.5.5 Major Forks and Branch Connections

Major forks are where a freeway separates into two freeways. Figure 6-16 illustrates three schematics for a major fork. It is important that one interior lane has an option to go in either direction. This interior lane should be widened over a distance of about 300-550 meters.

Branch connections are where two freeways converge into one freeway. Figure 6-17 illustrates two schematics for a branch connection. When a lane is dropped, as in "B", this should be designed as a freeway lane drop (see Figure 6-11).



LEVEL-OF-SERVICE CRITERIA FOR CHECKPOINT FLOW RATES AT RAMP-FREEWAY TERMINALS

LEVEL OF SERVICE	MERGE FLOW RATE (PCPH) ^a V_m	DIVERGE FLOW RATE (PCPH) ^b V_d	FREEWAY FLOW RATES (PCPH) ^c V_f								
			110 km/h DESIGN SPEED			100 km/h DESIGN SPEED			80 km/h DESIGN SPEED		
			4-LANE	6-LANE	8-LANE	4-LANE	6-LANE	8-LANE	4-LANE	6-LANE	8-LANE
A	≤ 600	≤ 650	≤ 1,400	≤ 2,100	≤ 2,800	d	d	d	d	d	d
B	≤ 1,000	≤ 1,050	≤ 2,200	≤ 3,300	≤ 4,400	≤ 2,000	≤ 3,000	≤ 4,000	d	d	d
C	≤ 1,450	≤ 1,500	≤ 3,100	≤ 4,650	≤ 6,200	≤ 2,800	≤ 4,200	≤ 5,600	≤ 2,600	≤ 3,900	≤ 5,200
D	≤ 1,750	≤ 1,800	≤ 3,700	≤ 5,550	≤ 7,400	≤ 3,400	≤ 5,100	≤ 6,800	≤ 3,200	≤ 4,800	≤ 6,400
E	≤ 2,000	≤ 2,000	≤ 4,000	≤ 6,000	≤ 8,000	≤ 4,000	≤ 6,000	≤ 8,000	≤ 3,800	≤ 5,700	≤ 7,600
F	WIDELY VARIABLE										

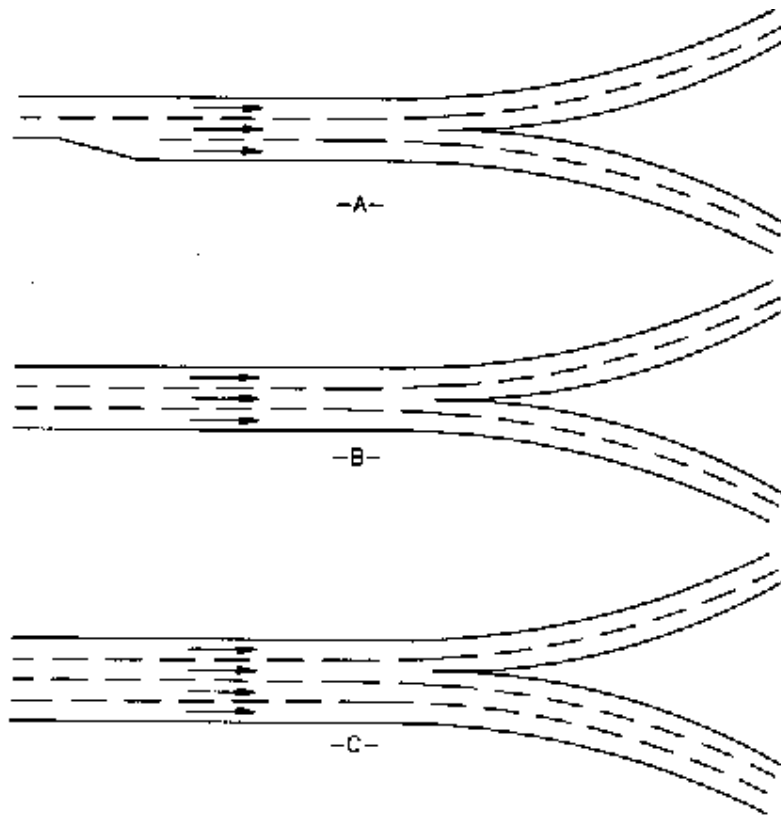
^a LANE 1 FLOW RATE PLUS RAMP FLOW RATE FOR ONE-LANE, RIGHT-SIDE ON-RAMPS.

^b LANE 1 FLOW RATE IMMEDIATELY UPSTREAM OF OFF-RAMP FOR ONE-LANE, RIGHT-SIDE RAMPS.

^c TOTAL FREEWAY FLOW RATE IN ONE DIRECTION UPSTREAM OF OFF-RAMP AND/OR DOWNSTREAM OF ON-RAMP.

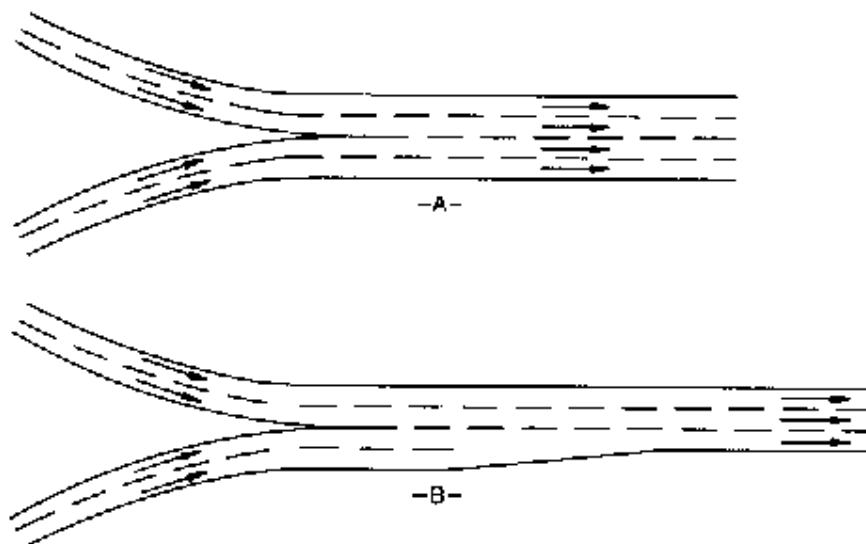
^d LEVEL OF SERVICE NOT ATTAINABLE DUE TO DESIGN SPEED RESTRICTIONS.

Figure 6-15. CAPACITY OF RAMP CONFIGURATIONS



Reference: A POLICY ON THE GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, AASHTO.

Figure 6-16. MAJOR FORKS



Reference: A POLICY ON THE GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, AASHTO.

Figure 6-17. BRANCH CONNECTIONS

6.6 RAMP DESIGN

The term "ramp" includes all types, arrangement, and sizes of turning roadways that connect two or more legs at an interchange. Ramp design shall be compatible with safe operations on both the main highway and minor roadway and shall accommodate the full transition in driving behavior. Location of ramp and intersections must consider adjacent intersections, existing and future development.

6.6.1 Geometric Design

6.6.1.1 Design Speed

Ideally, the ramp design speed will approximate the low-volume running speed on the intersecting highways. Where this is not practical, the values in Table 6.4 should be used as the minimum design speed. These design speeds apply to the ramp proper and not to the freeway/ ramp junction, which is discussed in Section 6.5. If the two intersecting mainlines have different design speeds, the higher of the two should control at the entrance to the ramp. However the ramp design speed should vary, the portion of the ramp nearer the lower-speed highway is designed for the lower speed.

In general, the higher range of design speeds should apply to diagonal ramps for right turns, such as at diamond and cloverleaf interchanges. The low end of the range should apply to loop ramps. Loop ramps with design speeds above 50 kilometers/hour require extremely large areas and greatly increase the travel distance for vehicles.

If a ramp will be terminating at an at-grade intersection with stop or signal control, the design speeds in the Table 6.4 will not apply to the ramp portion near the intersection.

**Table 6.4 GUIDE VALUES FOR DESIGN SPEED AS RELATED TO
HIGHWAY DESIGN SPEED**

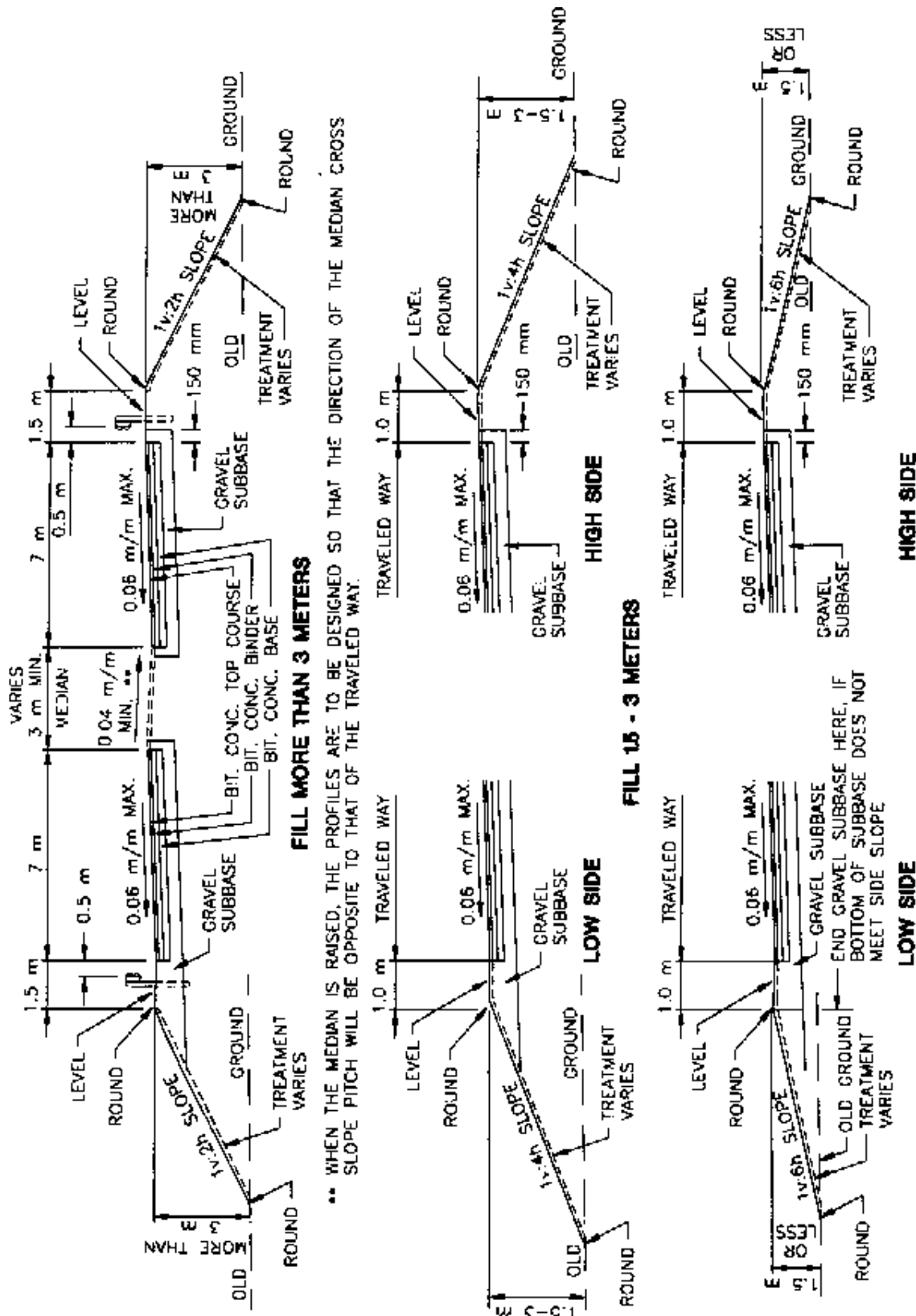
HIGHWAY DESIGN SPEED (km/h)	50	60	70	80	90	100	110	120
RAMP DESIGN SPEED (km/h)	40	50	60	70	80	90	100	110
UPPER RANGE (85%)	30	40	50	60	60	70	80	90
MIDDLE RANGE (70%)	20	30	40	40	50	50	60	70
LOWER RANGE (50%)								
CORRESPONDING MINIMUM RADIUS (m)	SEE TABLE 6.5							

6.6.1.2 Cross Section

The following will apply to the ramp cross section:

1. *Ramp Width* - The typical width is 7 meters for one lane ramps and 9 meters for two lane ramps.
2. *Cross Slope* - Tangent sections of ramps should be uniformly sloped at 0.02 meter/meter from the median edge to the opposite edge. The maximum superelevation is 0.06 meter/meter.
3. *Side Slopes* - Fill and cut slopes should be as flat as possible. If feasible, they should be 1:6 or flatter thus eliminating the need for guardrail.
4. *Bridges and Underpasses* - The full width of the ramp or loop should be carried over a bridge or beneath an underpass.
5. *Lateral Clearances to Obstructions* - Best practice calls for the lateral clearance from the edge of the travel lane to be equal to its clear zone as determined from the criteria in Section 9.2.
6. *Exit Ramps* - Where the through lane and exit ramp diverge, the typical width will be 7.75 meters. This will be maintained until the gore nose is reached and transitioned to the standard 7 meter width at approximately a 12:1 rate.
7. *Entrance Ramps* - The standard 7 meter width will be transitioned to 5 meter width at the convergence with the through lane as shown in the standard MHD figures.

Figures 6-18 and 6-19 illustrate typical ramp sections.

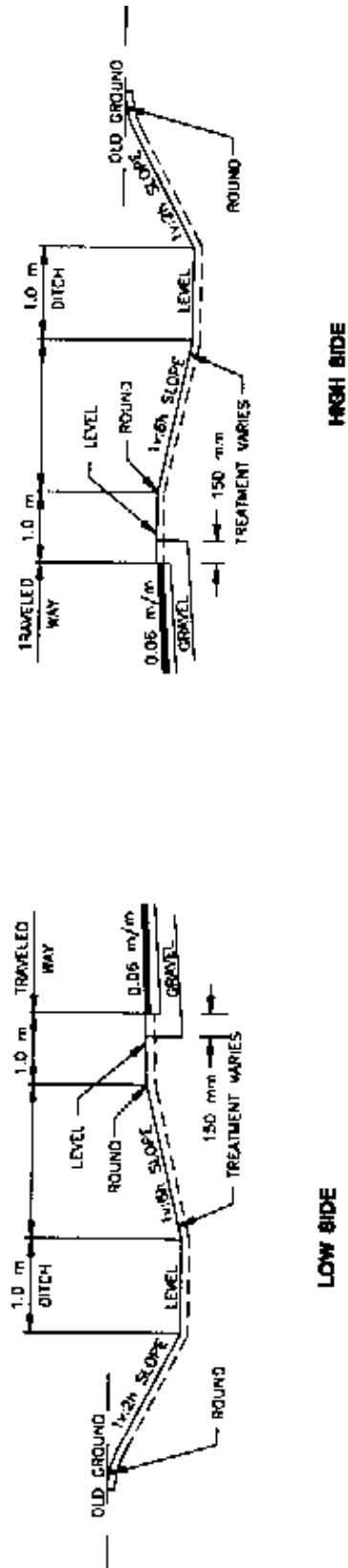


** WHEN THE MEDIAN IS RAISED, THE PROFILES ARE TO BE DESIGNED SO THAT THE DIRECTION OF THE MEDIAN CROSS SLOPE PITCH WILL BE OPPOSITE TO THAT OF THE TRAVELED WAY.

- Notes:**
1. THE RAMP PAVEMENT STRUCTURE WILL BE SIMILAR TO THE MAINLINE UNLESS OTHERWISE NOTED.
 2. SEE CONSTRUCTION STANDARDS FOR ROUNDING DETAILS.
 3. USE BIT. CONC. BERM IF OTHERWISE REQUIRED FOR DRAINAGE

Reference: MASSACHUSETTS HIGHWAY DEPARTMENT

Figure 6-18. TYPICAL SECTIONS FOR RAMPS IN FILL AREAS



EARTH CUT

NOTES:

1. THE RAMP PAVEMENT STRUCTURE WILL BE SIMILAR TO THE MAINLINE UNLESS OTHERWISE NOTED.
2. SEE CONSTRUCTION STANDARDS FOR ROUNDING DETAILS.
3. USE BIT. CONC. BERM IF OTHERWISE REQUIRED FOR DRAINAGE.
4. SEE CONSTRUCTION STANDARDS FOR TYPICAL ROCK CUT SECTION.
5. BOTTOM OF DITCH TO BE BELOW BOTTOM OF SUB-BASE, OR PROVIDE SUBDRAIN.

Figure 6-19. RAMP SECTION IN CUT AREAS

6.6.1.3 Horizontal Alignment

Horizontal alignment will largely be determined by the design speed and type of ramp. The following should be considered:

1. Table 6.5 shows the minimum ramp radii required for the ramp design speed. Ramps should be designed for 50 kilometer/hour or greater unless restricted by site conditions.

Table 6.5 MINIMUM RADII FOR INTERSECTION CURVES.

DESIGN (TURNING) SPEED V (km/h)	15	20	30	40	50	60
SIDE FRICTION FACTOR, f	0.40	0.35	0.28	0.23	0.19	0.17
ASSUMED MINIMUM SUPERELEVATION, e/100	0.00	0.00	0.02	0.04	0.06	0.08
TOTAL e/100 + f	0.40	0.35	0.30	0.27	0.25	0.25
CALCULATED MINIMUM RADIUS R, (m)	5	9	24	47	79	113
SUGGESTED MINIMUM RADIUS CURVE FOR DESIGN (m)	7	10	25	50	80	115
AVERAGE RUNNING SPEED (km/h)	15	20	28	35	42	51

NOTE: FOR DESIGN SPEEDS OF MORE THAN 60 km/h, USE VALUES FOR OPEN HIGHWAY CONDITIONS

2. *Outer Connection* - The outer connection at cloverleaf interchanges should be as directional as possible. However, if site conditions are restrictive, it may be allowed to follow a reverse path alignment around the inner loop.
3. *Loops* - Loop ramps should be on a continuously curved alignment in a spiral or compound curve arrangement.
4. *Superelevation* - The maximum superelevation rate is 0.06 meter/meter. It is preferred that the open highway conditions discussed in Chapter 4 should apply for transitioning to and from the needed superelevation. However, because of the restrictive nature of some ramps, this may not be possible. The minimum longitudinal slope should not exceed 1% which corresponds to a "P" of 100. (See Table 4.3 to determine the length of the transition for p=100). In addition, if the ramp will be terminated at an at-grade intersection with stop or signal control, it is not appropriate to superelevate curves fully near the terminus. The axis of rotation will be the profile edge.

5. *Sight Distance* - Desirable stopping sight distance (Table 3.11) should be the minimum design for horizontal curves. An object height of 0.0 meter should be used to calculate the stopping sight distance at exit areas.
6. *Two-Lane Ramps* - The minimum radius is 100 meters. See Figure 6-20 for typical two-lane exit treatments.

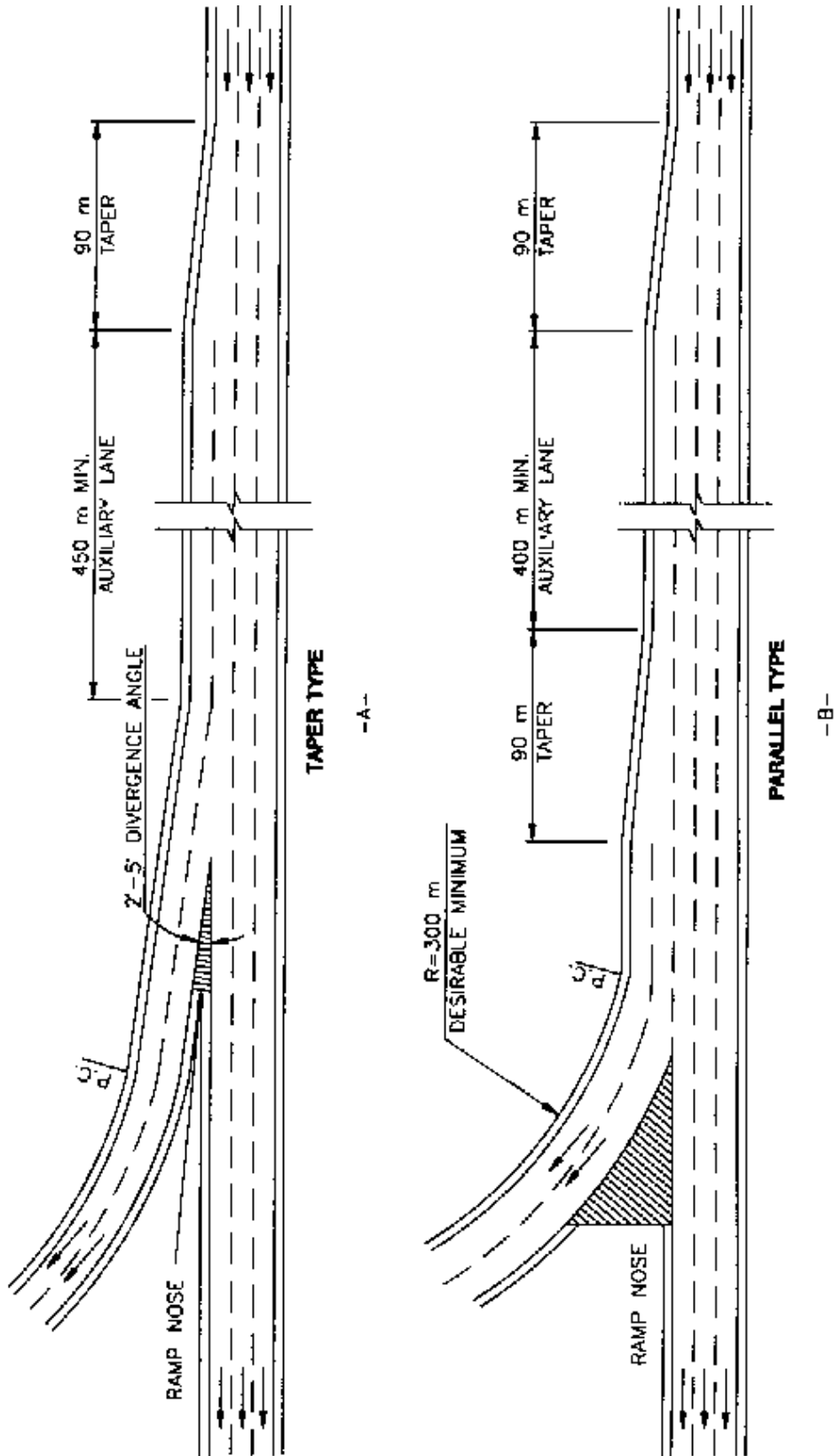


Figure 6-20. TWO-LANE EXIT TERMINALS.

6.6.1.4 Vertical Alignment

Maximum grades for vertical alignment cannot be as definitively expressed as for highway mainline. The minimum grade is 0.50%. General values of limiting gradient for upgrades are shown in Table 6.6, but for any one ramp the selected gradient is dependent upon a number of factors.

These factors include the following:

1. The flatter the gradient on the ramp, the longer it will be.
2. The steepest gradients should be designed for the center part of the ramp. Landing areas or storage platforms at at-grade intersections with ramps should be as flat as possible.
3. Downgrades on ramps should follow the same guidelines as upgrades. They may, however, safely exceed these values by 2%, with 8% considered the desired maximum grade.
4. Ramp gradients and lengths can be significantly impacted by the angle of intersection between the two highways and the direction and amount of gradient on the two mainlines.
5. K values and desirable stopping sight distance should be the minimum design for vertical curves.

Table 6.6 RAMP GRADIENT GUIDELINES

	RAMP DESIGN SPEED (km/h)			
	30 to 40	40 to 50	60	70 to 80
MAXIMUM DESIRABLE GRADE RANGE (%)	6-8	5-7	4-6	3-5

6.6.2 Capacity

Table 6.7 provides the volumes for a given ramp design speed and level of service. Although the table indicates that up to 1700 passenger cars equivalents per hour (PCPH) can be accommodated on a single lane ramp, freeway/ramp junctions are not capable of handling this volume. *Therefore, 1500 pcph should be used as a threshold to warrant a two-lane ramp.* The minimum radius of a two-lane ramp should be 100 meters. The capacity of a loop ramp is about 1250 pcph; however, two-lane loop ramps are very undesirable because of their

restrictive geometry. Therefore, if a left-turn movement will exceed 1250, a directional or semi-directional connection may be needed. Ramps must be designed with sufficient capacity to avoid backups on the main line. The *Highway Capacity Manual* further discusses the capacity of the ramp proper.

Table 6.7
APPROXIMATE SERVICE VOLUMES FOR SINGLE-LANE RAMPS
(PEAK HOUR FACTOR =1.00; VALUES IN PASSENGER CARS PER HOUR)

LEVEL OF SERVICE	RAMP DESIGN SPEED (km/h)				
	≤30	30 - 50	50-70	70- 80	≥80
A	**	**	**	**	700
B	**	**	**	1000	1050
C	**	**	1125	1250	1300
D	**	1025	1200	1325	1500
E	1250	1450	1600*	1650*	1700*
F	--WIDELY VARIABLE --				

* FOR 2-LANE RAMPS, MULTIPLY ABOVE VALUES BY 1.7 FOR ≤30 km/h
1.8 FOR 30-50, 70-80 km/h
1.9 FOR 50-70 km/h
2.0 FOR ≥80 km/h

** LEVEL OF SERVICE NOT ACHIEVABLE DUE TO RESTRICTED DESIGN SPEED

6.7 RAMP/MINOR ROAD INTERSECTIONS

At service interchanges the ramp or loop normally intersects the minor road at-grade at approximately a 90-degree angle. This intersection should be treated as described in Chapter 7. This will involve a consideration of the necessary traffic control devices, capacity, and the physical geometric design elements such as sight distance, angle of intersection, grade, channelization, and turning lanes. However, the following points warrant special attention in the design of the ramp/minor road intersection:

1. *Capacity* - In urban areas where traffic volumes may be high, inadequate capacity of the ramp/minor road intersection can adversely affect the operation of the ramp/freeway junction. In a worst case situation the safety and operation of the mainline itself may be impaired by a back-up onto the freeway. Therefore, special attention should be given to providing sufficient capacity and storage for an at-grade intersection or merge with the minor road. This could lead to the addition of lanes

at the intersection or on the ramp proper, or it could involve traffic signalization where the ramp traffic will be given priority. The analysis must also consider the operational impacts of the traffic characteristics in either direction on the intersecting road. The *Highway Capacity Manual* should be used to calculate capacity and level of service for the ramp/minor road intersection.

2. *Wrong-Way Movements* - Most wrong-way movements originate at the ramp/minor road intersection. This intersection must be properly signed and designed to minimize the potential for a wrong-way movement.
3. *Access Restrictions* - Access to abutting properties or to other local road systems will interfere with the operation and safety of the interchange. Therefore, access must not be permitted from ramps or from the through roadways within the entire limits of the interchange. The no-access layout line should be extend a minimum distance of 70 meters from all ramp terminals.
4. *Sight Distance* - Chapter 7 discusses the procedure for addressing sight distance at at-grade intersections. This procedure should be used for the ramp/minor road intersection. However, special attention must be given to the location of the bridge pier or abutment because these will present major sight distance obstacles. The Case IIIB and IIIC methodologies for left turning and right-turning vehicles presented in Chapter 7 should be used to determine if adequate sight distance is available. The combination of the bridge obstruction and the needed sight distance may result in relocating the ramp/ minor road intersection to provide the needed sight distance.
5. *Transition* - The transition between high-speed driving on the mainline and safe operating speed on the minor road should take place on the ramps.

Ramp and intersection design should require the driver to adopt a safe speed before entering the minor road. Consider roadside development to reinforce awareness of speed. Free right-turn and merge is appropriate only when an acceleration taper can be provided; otherwise provide a full stop. Minor road design shall be consistent with adjacent sections where possible. Provide right-of-way for upgrading and consider pedestrian movements.

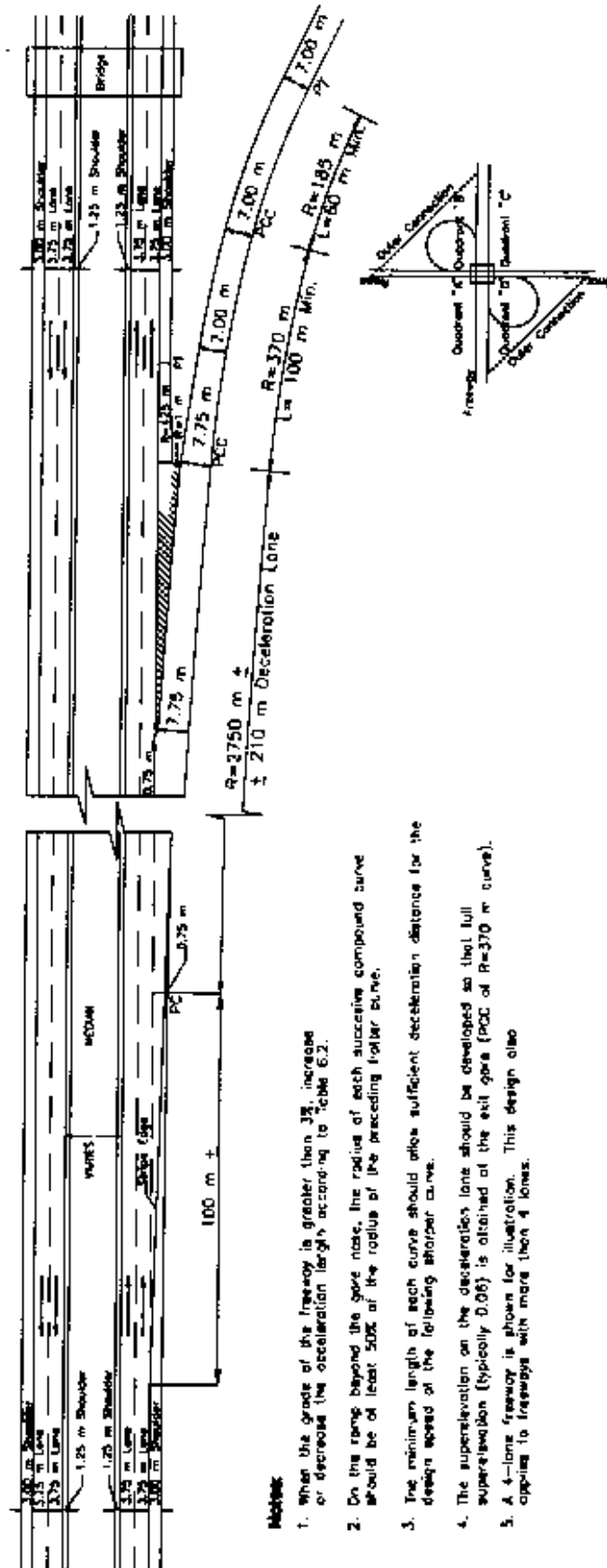
Figures 6-28 and 6-29 (see Chapter 6 Appendix) provide typical designs for the at-grade intersections of partial cloverleaves and diamond interchanges.

6.8 REFERENCES

- *A Policy on Geometric Design of Highways and Streets*, AASHTO,
- *Highway Capacity Manual*, Special Report No. 209, Transportation Research Board

6.9 APPENDIX

- Standard Designs for Freeway/Minor Road Interchanges (Cloverleaf and Diamond), Figures 6-21 through 6-29.

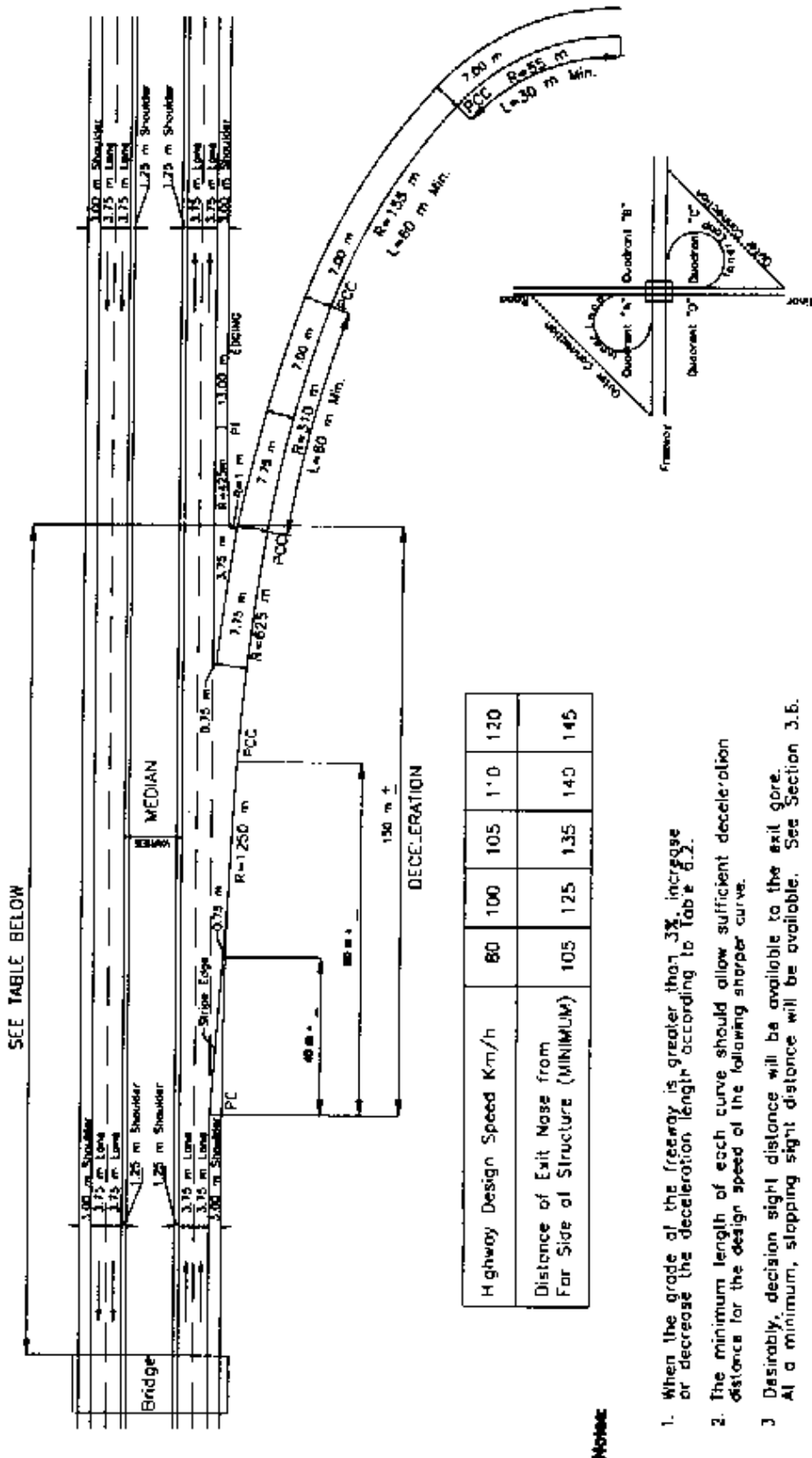


The exit above is applicable to the outer connection in Quadrant "B" and "D".

**Figure 6-21. FREEWAY EXIT AT INTERCHANGE
(VIA OUTER CONNECTION OF CLOVERLEAF TYPE RAMP)**

Notes:

1. When the grade of the freeway is greater than 3%, increase or decrease the deceleration length according to Table 6.2.
2. On the ramp beyond the gore nose, the radius of each successive compound curve should be at least 50% of the radius of the preceding outer curve.
3. The minimum length of each curve should allow sufficient deceleration distance for the design speed of the following sharper curve.
4. The superslevation on the deceleration lane should be developed so that full superslevation (typically 0.06) is obtained at the exit gore (POC of $R=370\text{ m}$ curve).
5. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.



The exit details above are applicable to a ramp in Quadrant "A" when there is no ramp in Quadrant "B", and to a ramp in Quadrant "C" when there is no ramp in Quadrant "B".

Figure 6-22. FREEWAY EXIT AT INTERCHANGE (FROM INNER LOOP CLOVERLEAF TYPE RAMP)

NOTES

1. When the grade of the freeway is greater than 3%, increase or decrease the deceleration length according to Table 6.2.
2. The minimum length of each curve should allow sufficient deceleration distance for the design speed of the following sharper curve.
3. Desirably, decision sight distance will be available to the exit gore. At a minimum, stopping sight distance will be available. See Section 3.5.
4. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is attained at the exit gore nose (PCC of R=310 m curve).
5. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

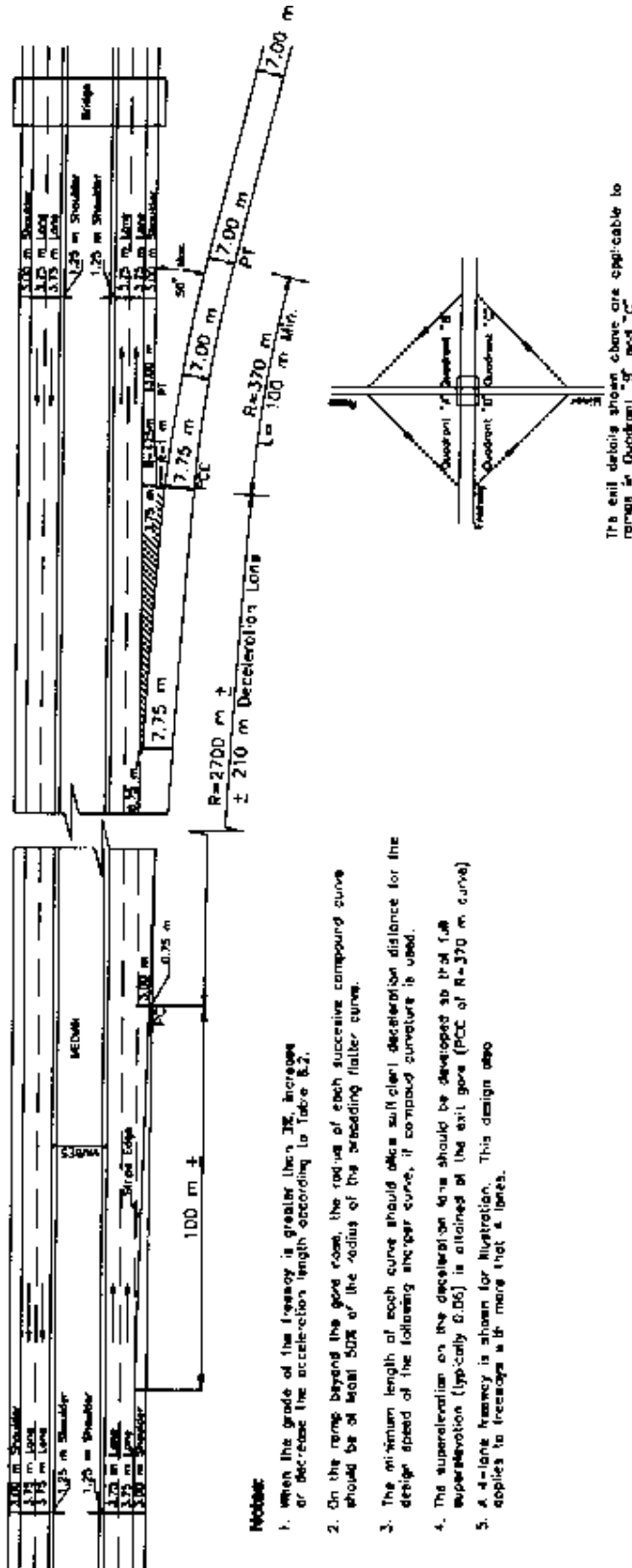


Figure 6-23. FREEWAY EXIT AT DIAMOND INTERCHANGE

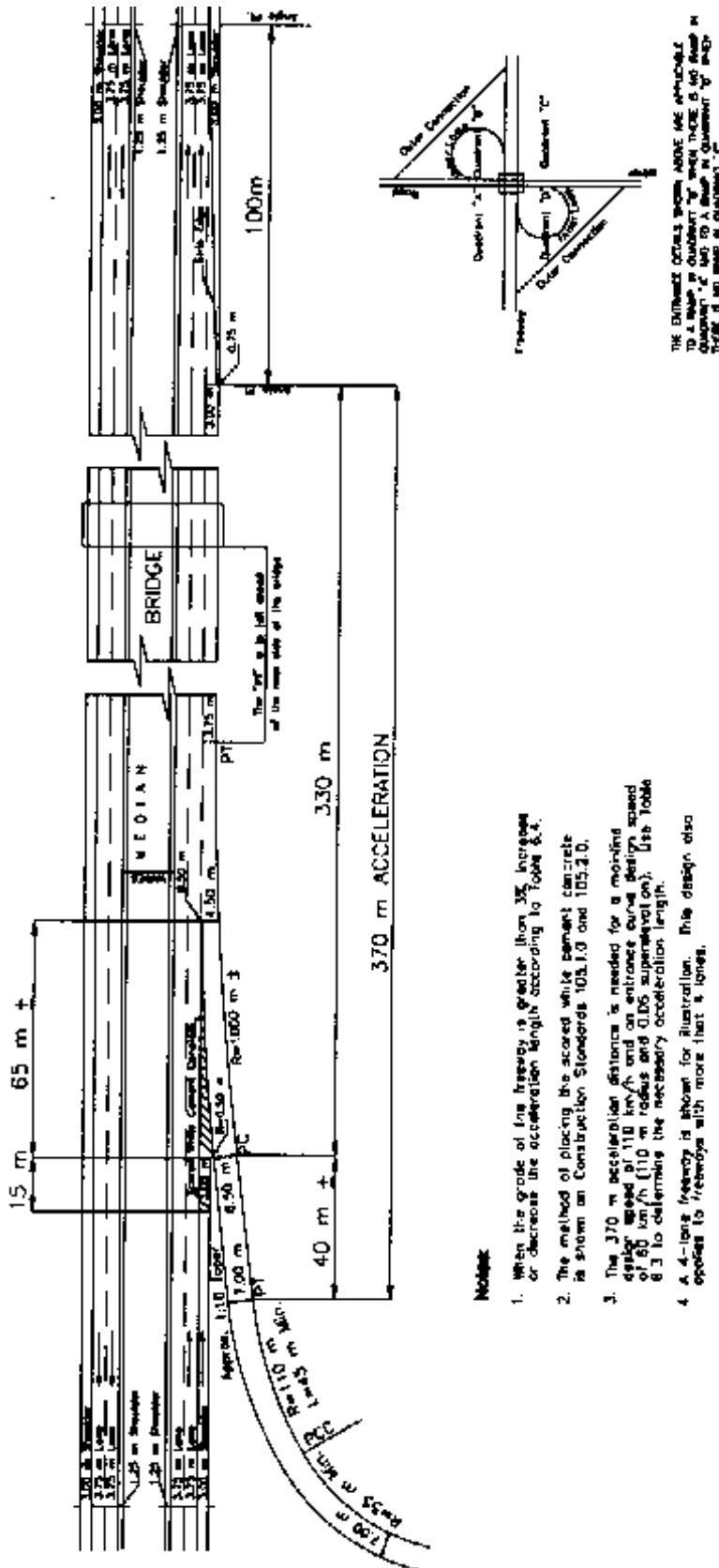
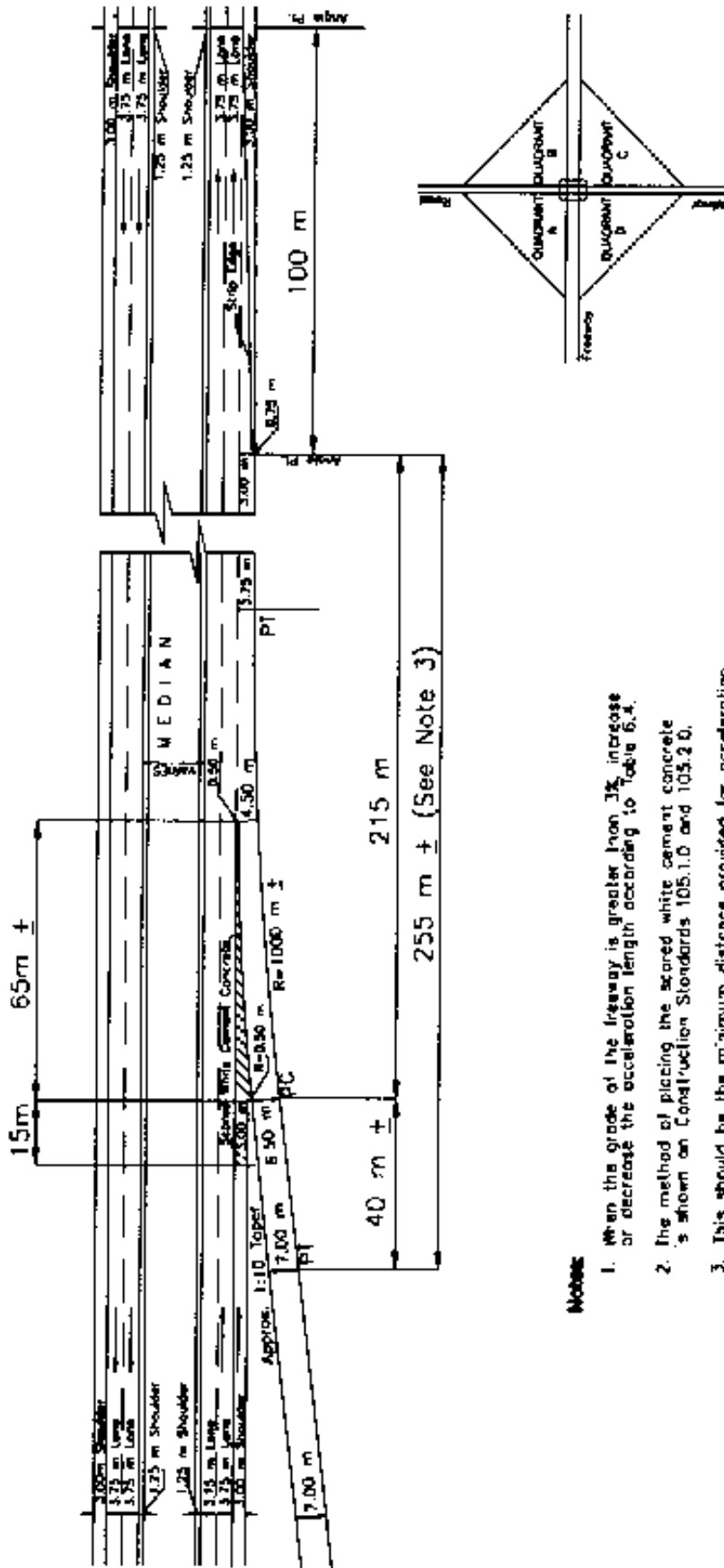


Figure 6-25. FREEWAY ENTRANCE AT INTERCHANGE (FROM INNER LOOP CLOVERLEAF TYPE RAMP)

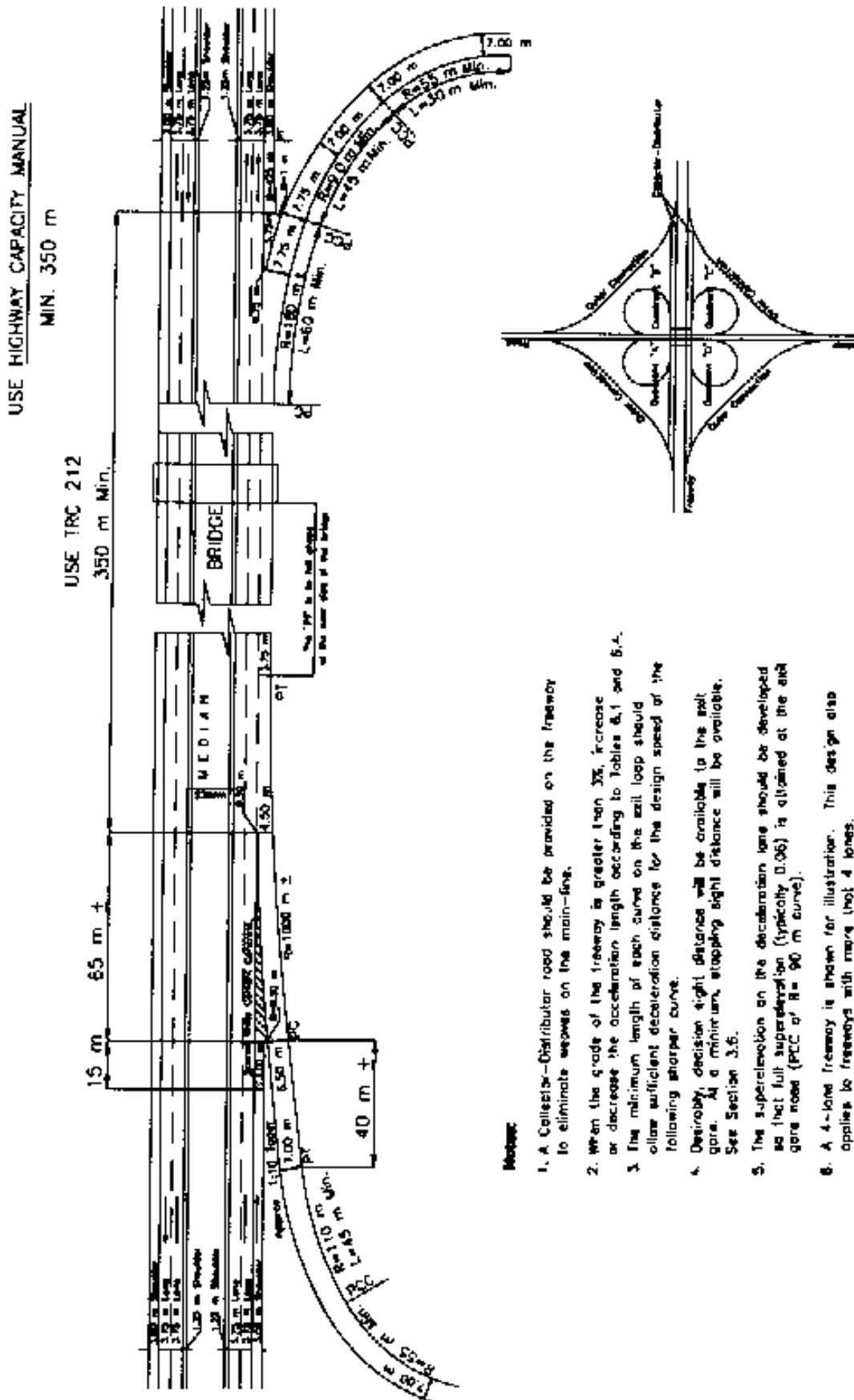


Notes

1. When the grade of the freeway is greater than 3%, increase or decrease the acceleration length according to Table 6.4.
2. The method of placing the scored white cement concrete is shown on Construction Standards 105.1.0 and 105.2.0.
3. This should be the minimum distance provided for acceleration regardless of the criteria from Table 6.3.
4. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

THE ENTRANCE DETAILS SHOWN ABOVE ARE APPLICABLE TO RAMP IN DIRECTION "A" AND "C".

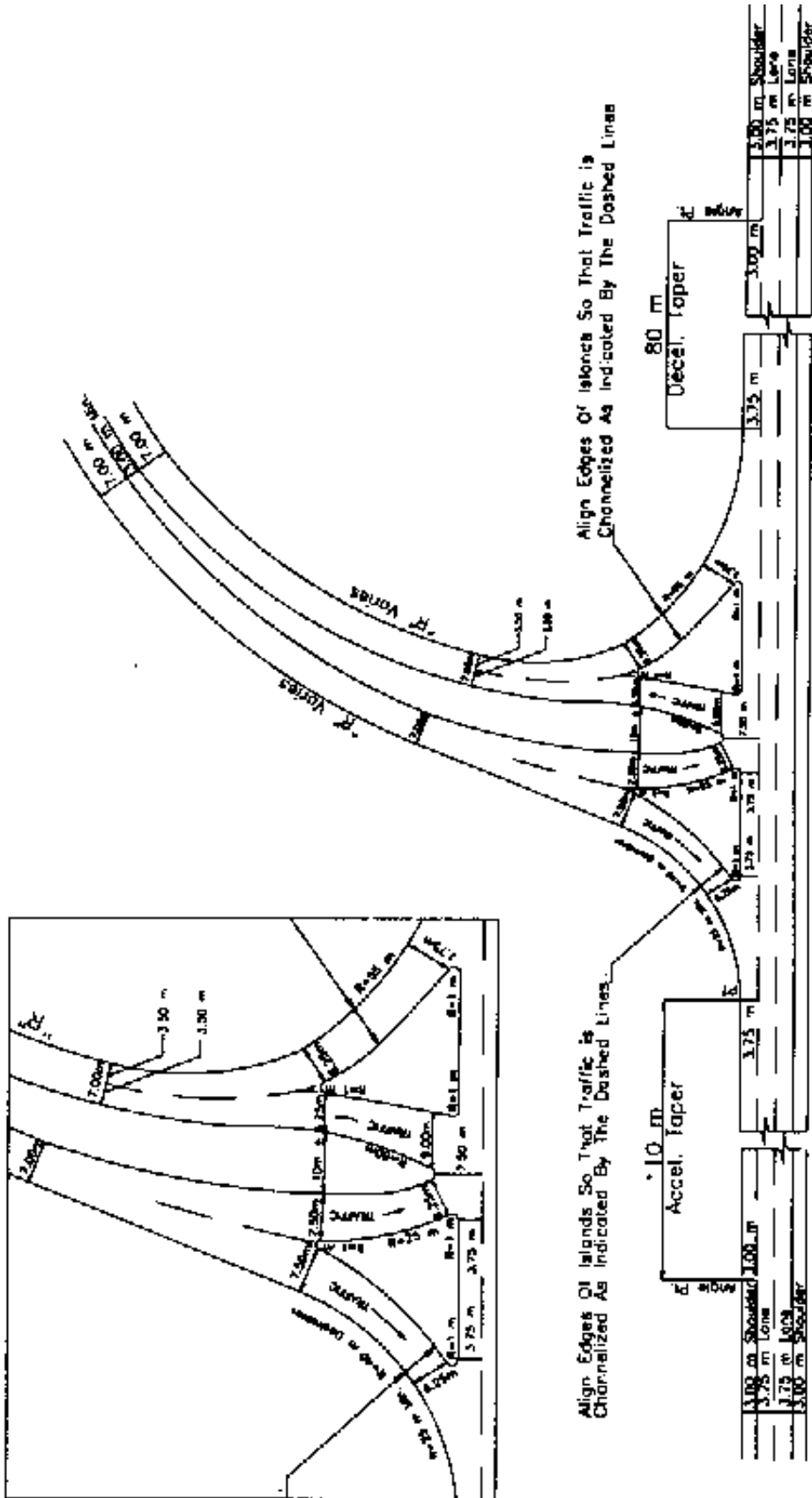
Figure 6-28. FREEWAY ENTRANCE AT INTERCHANGE (DIAMOND TYPE RAMP)



Notes:

1. A Collector-Distributor road should be provided on the freeway to eliminate weaves on the main-line.
2. When the grade of the freeway is greater than 3%, increase or decrease the acceleration length according to Tables 6.1 and 6.4.
3. The minimum length of each curve on the exit loop should allow sufficient deceleration distance for the design speed of the following sharper curve.
4. Desirably, decision sight distances will be available in the exit lane. At a minimum, stopping sight distance will be available. See Section 3.6.
5. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is obtained at the exit lane nose (PCC of R=90 m curve).
6. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

**Figure 6-27. FREEWAY ENTRANCE - EXIT AT INTERCHANGE
(INNER LOOP ENTRANCE - INNER LOOP EXIT OF CLOVERLEAF TYPE RAMP)**



- Notes**
1. All islands to be edged.
 2. See Chapter 7 for additional details on the design of at-grade interchanges.
- THESE RADII MAY BE COMPLICATED

**Figure 6-28. EXIT AT INTERCHANGE
(PARTIAL CLOVERLEAF TYPE RAMP)**

CHAPTER 7

AT-GRADE INTERSECTIONS

7.1 GENERAL DESIGN CONSIDERATIONS

7.1.1 Capacity and Level of Service

A capacity analysis must be performed during the design of any at-grade intersection. A future design year, typically 20 years from the date the facility is completed, should be used. Often, the analysis will dictate several geometric design features such as approach width, channelization, exit width, and number of approach and exit lanes. The designer will use the methodologies in the *Highway Capacity Manual* for both signalized and unsignalized intersections. The interaction of adjacent roadways and intersections must be considered in the analysis.

The intersection should be designed to accommodate an acceptable level of service. The values in Table 3.8 should be met, when feasible, so that the highway facility will operate at a consistent level of service. At a minimum, the at-grade intersection should operate at no more than one level below the values in the table. Levels of service are discussed in Section 3.5.

7.1.2 Vehicle Considerations

Vehicle turning paths yield minimum turning radii which are used in the design of intersections. Figures 7-1 to 7-7 illustrate the turning paths for the P, SU, BUS, A-BUS, WB-12, WB-15, and WB-18 vehicles. Computer programs are available for this analysis. The vehicle dimensions in the figures are used to determine the turning radii design as discussed in Section 7.3.1. One of the semi-trailer combinations should typically be used as the design vehicle where truck traffic is anticipated. The WB-18 vehicle is restricted by law to Interstate highways, access roads to the Interstate, and selected non-Interstate highways and should normally not be used for intersection design. The SU vehicle should be the minimum size used. Turning paths for other design vehicles may be found in *A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, AASHTO, 1994*.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

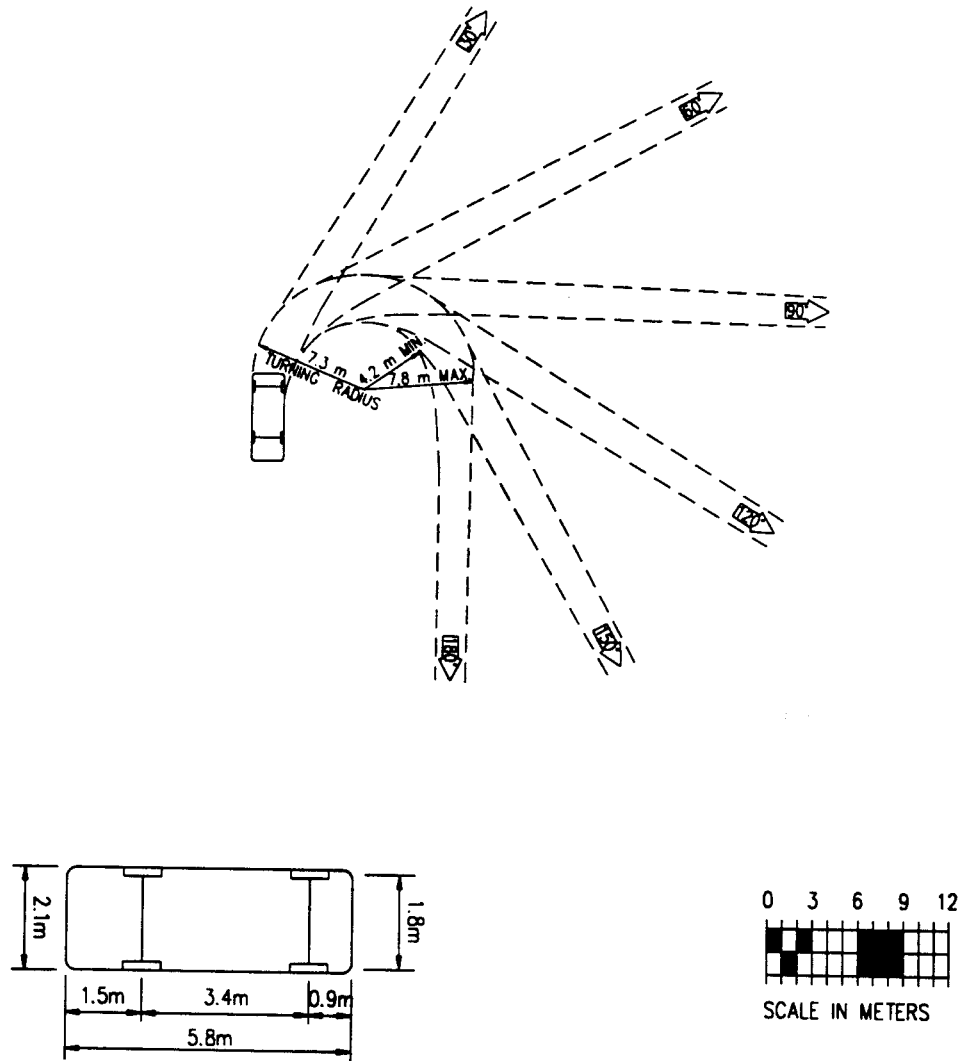


Figure 7-1. (T1) MINIMUM TURNING PATH FOR P DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

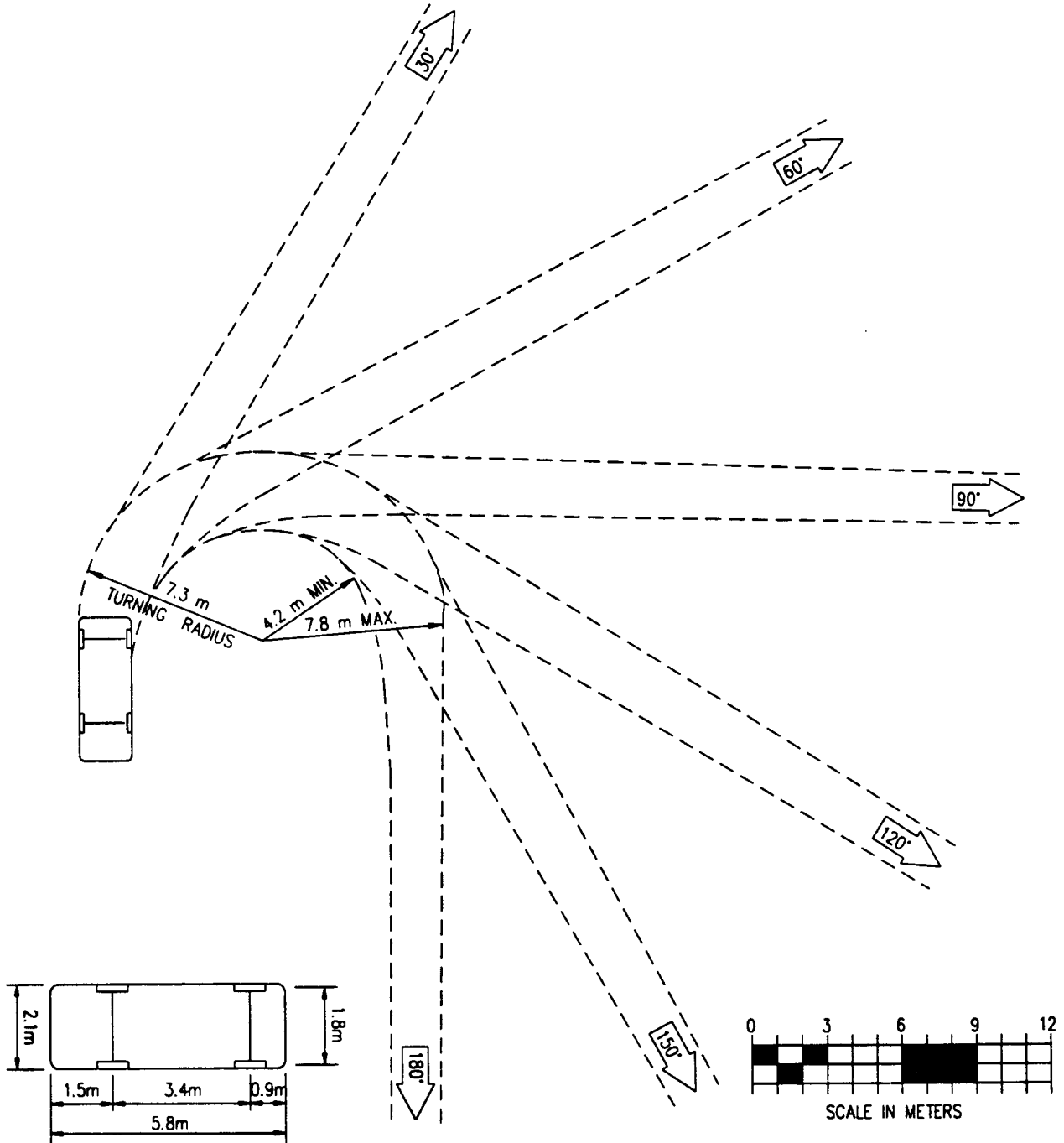


Figure 7-1. (T2) MINIMUM TURNING PATH FOR P DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

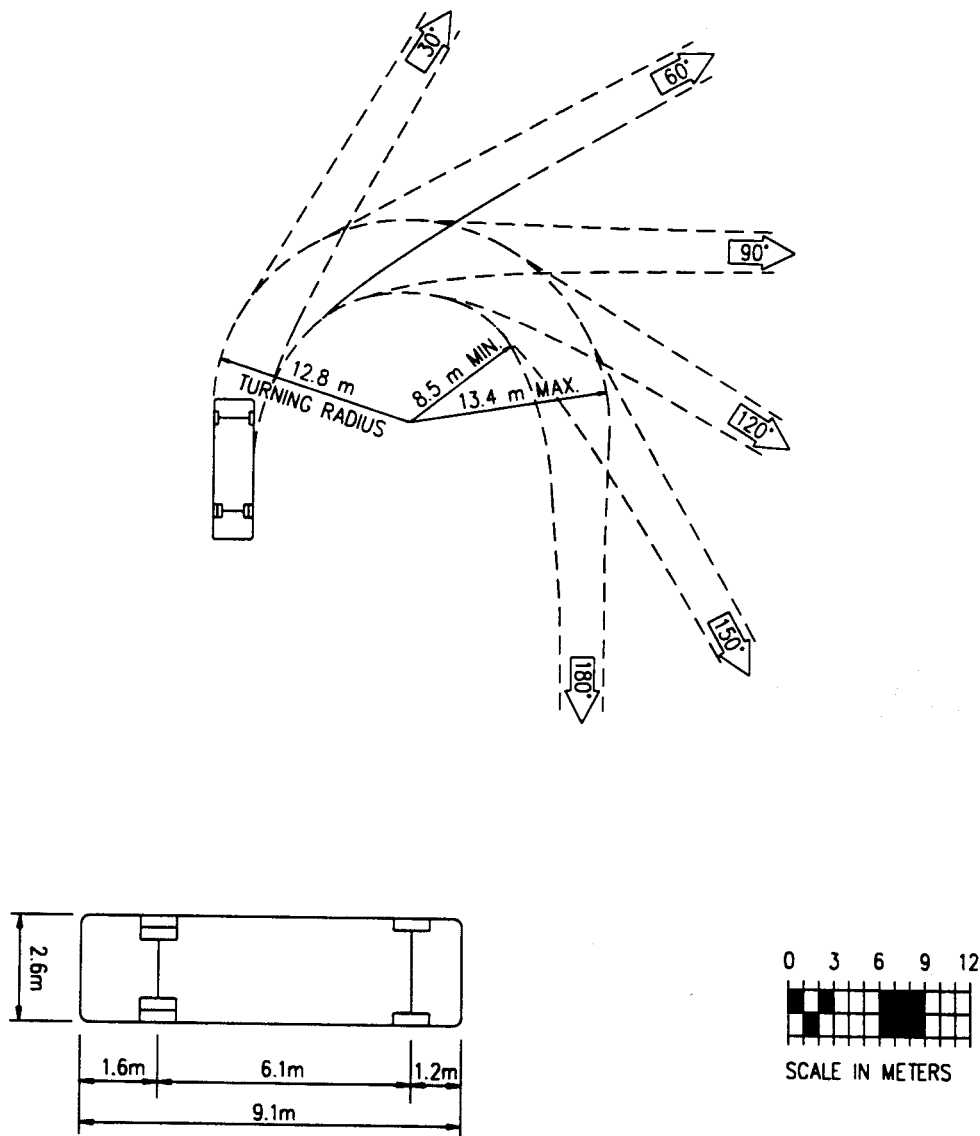


Figure 7-2. (T1) MINIMUM TURNING PATH FOR SU DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

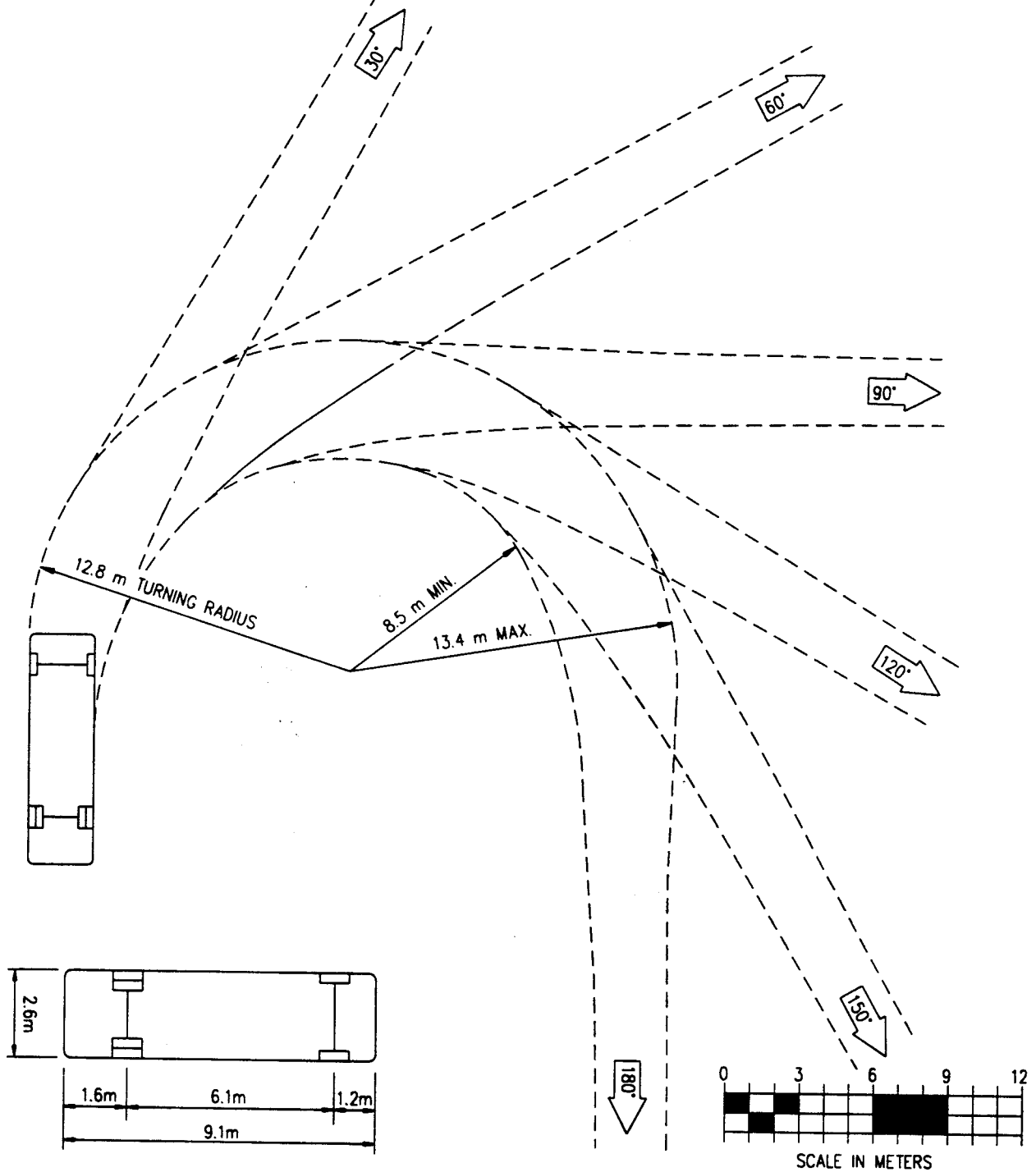


Figure 7-2. (T2) MINIMUM TURNING PATH FOR SU DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

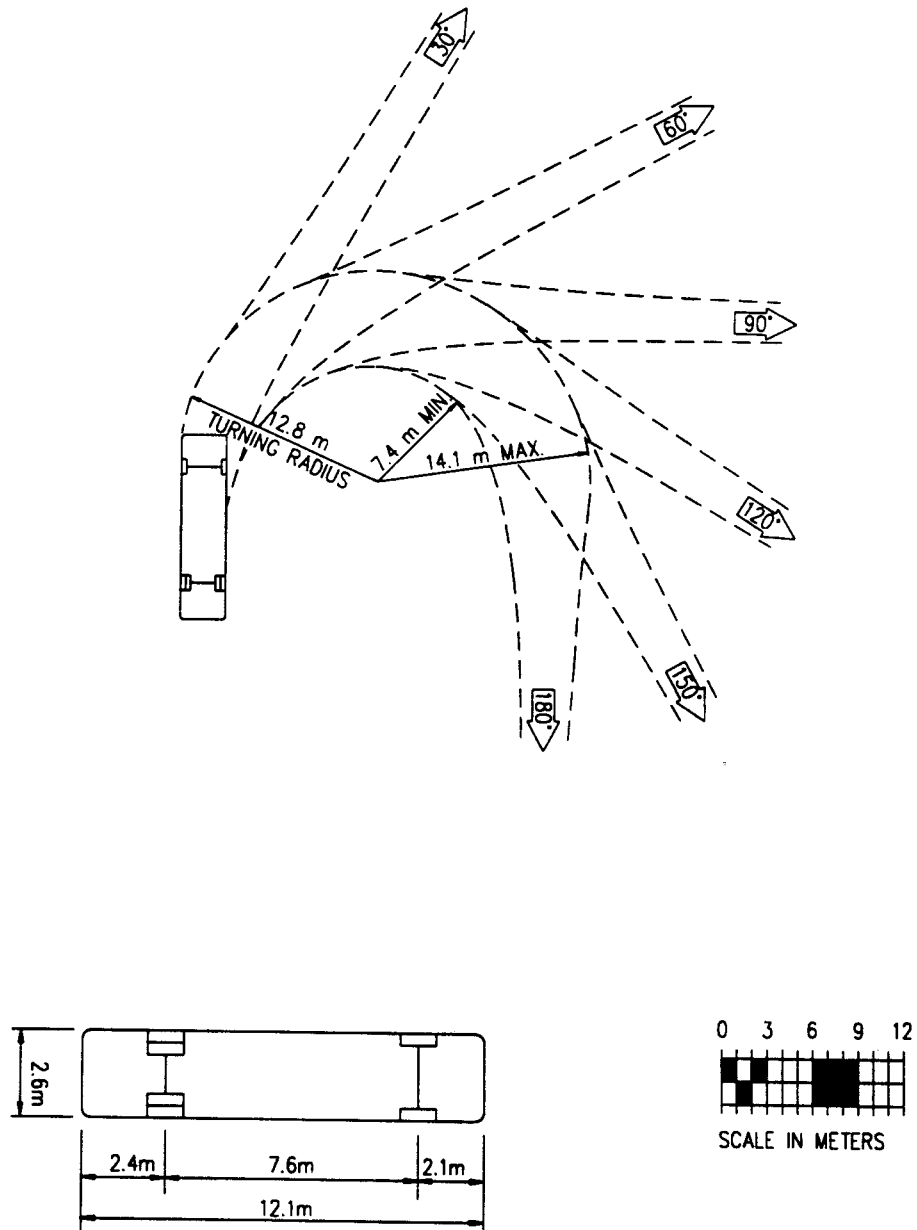


Figure 7-3. (T1) MINIMUM TURNING PATH FOR BUS DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

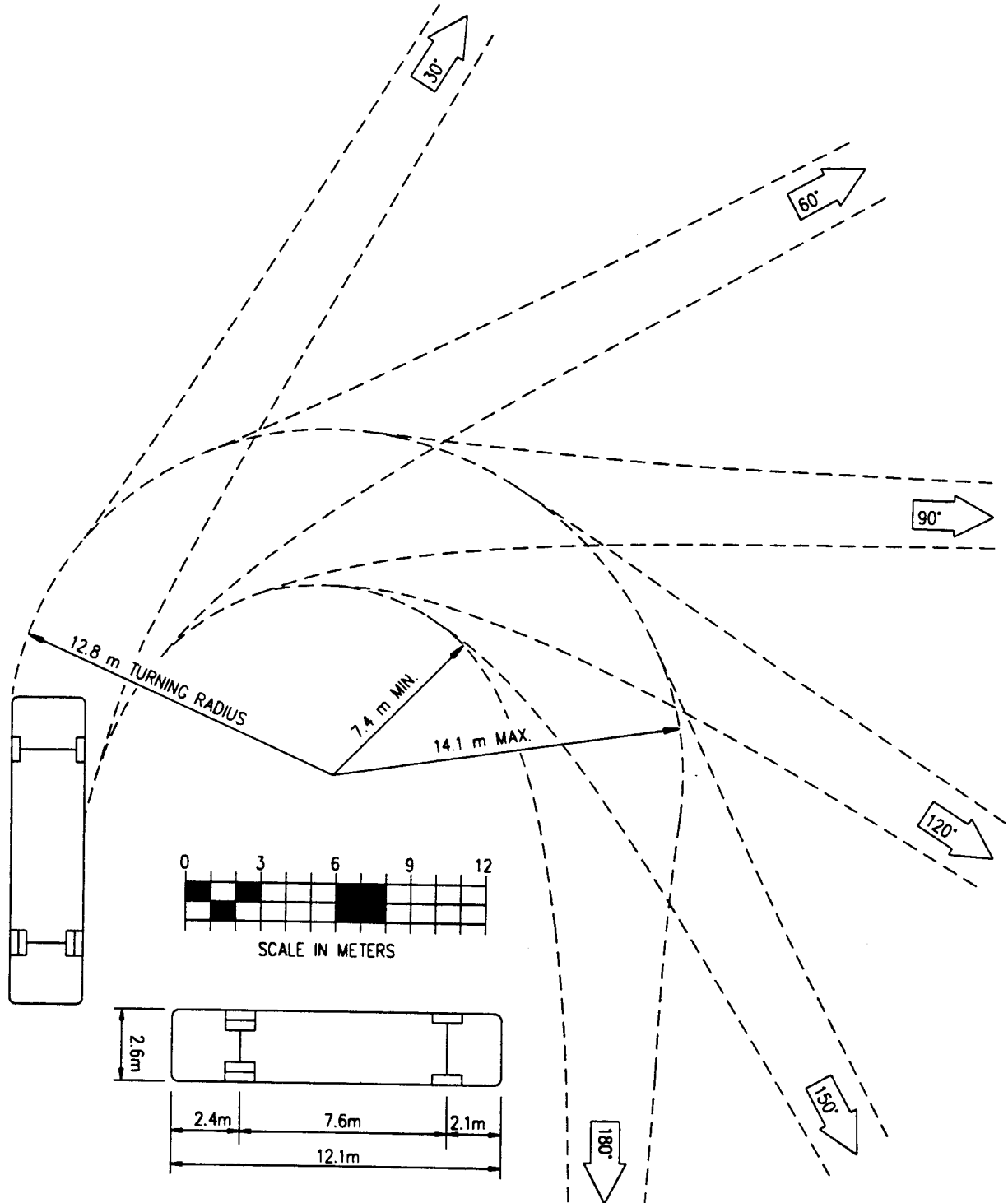


Figure 7-3. (T2) MINIMUM TURNING PATH FOR BUS DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

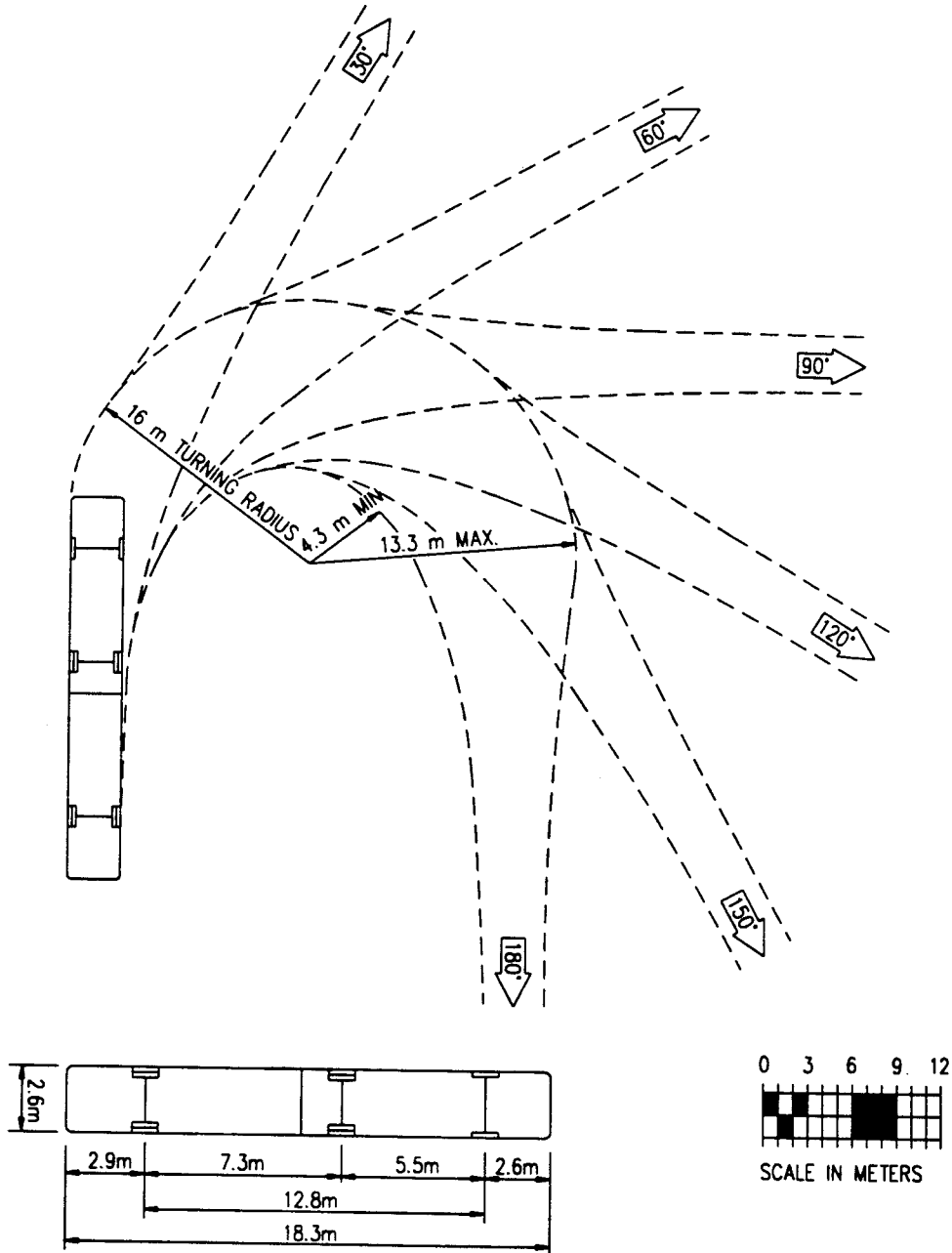


Figure 7-4. MINIMUM TURNING PATH FOR A-BUS DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

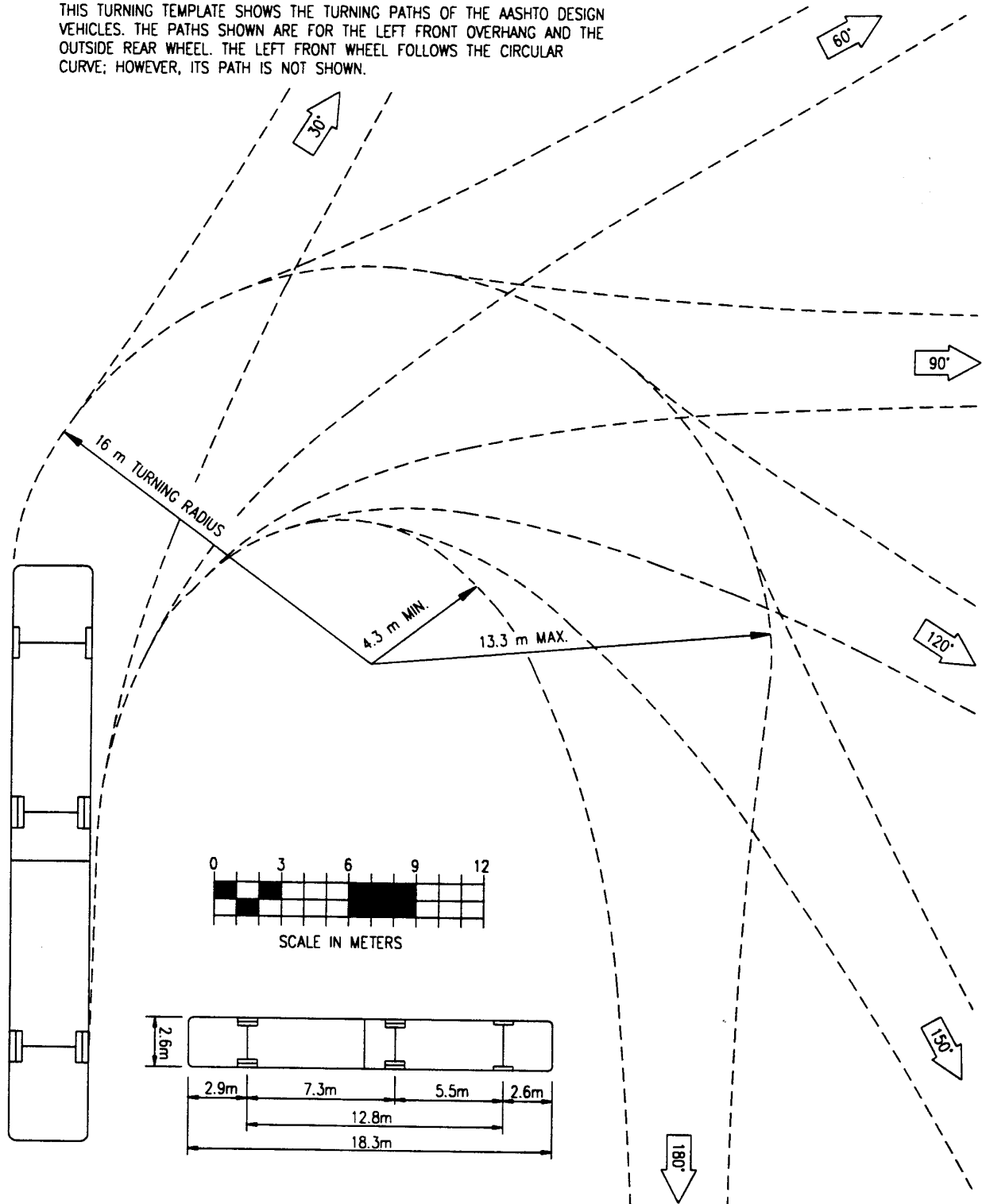


Figure 7-4. (T2) MINIMUM TURNING PATH FOR A-BUS DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

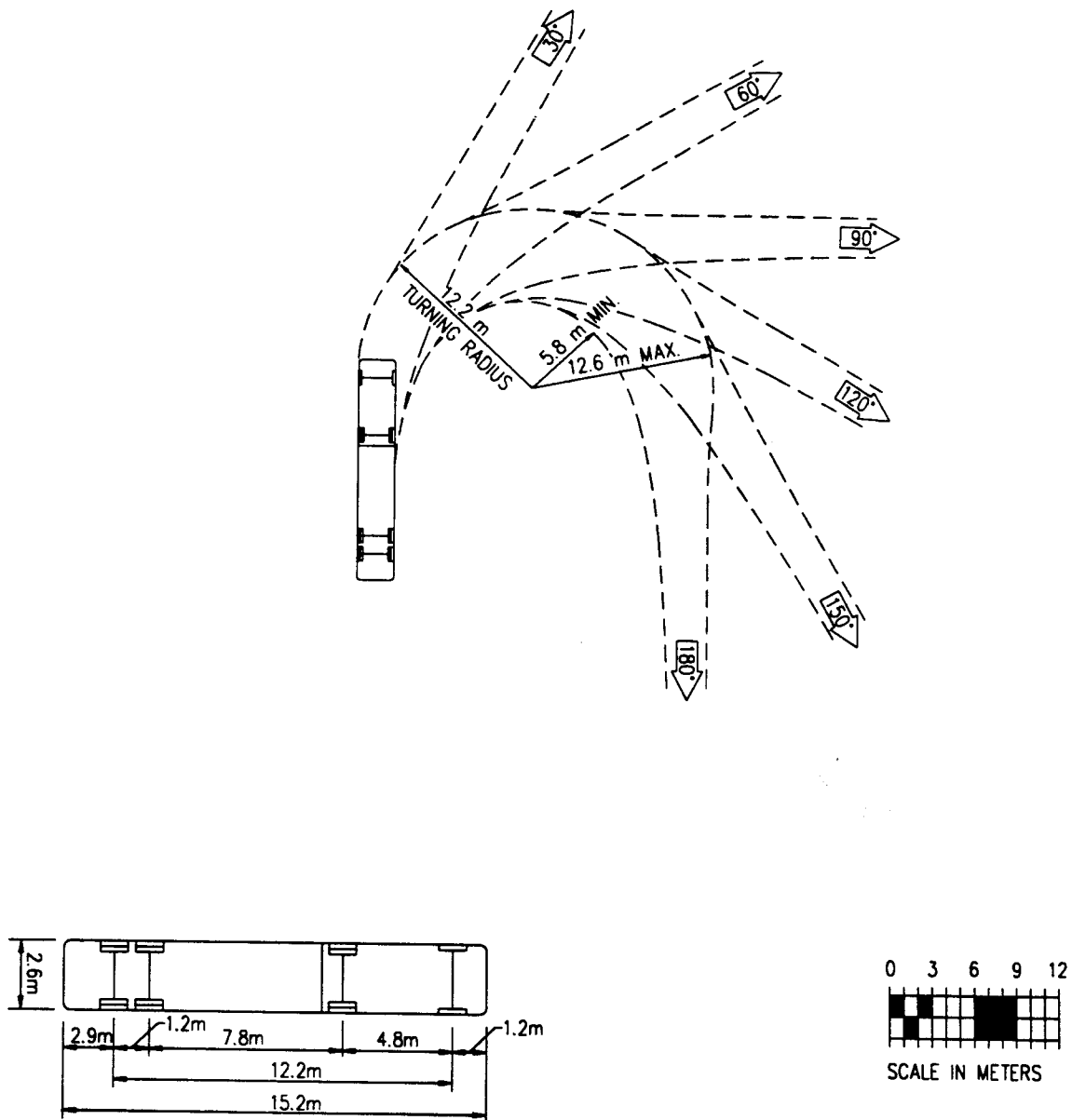


Figure 7-5. (T1) MINIMUM TURNING PATH FOR WB-12 DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

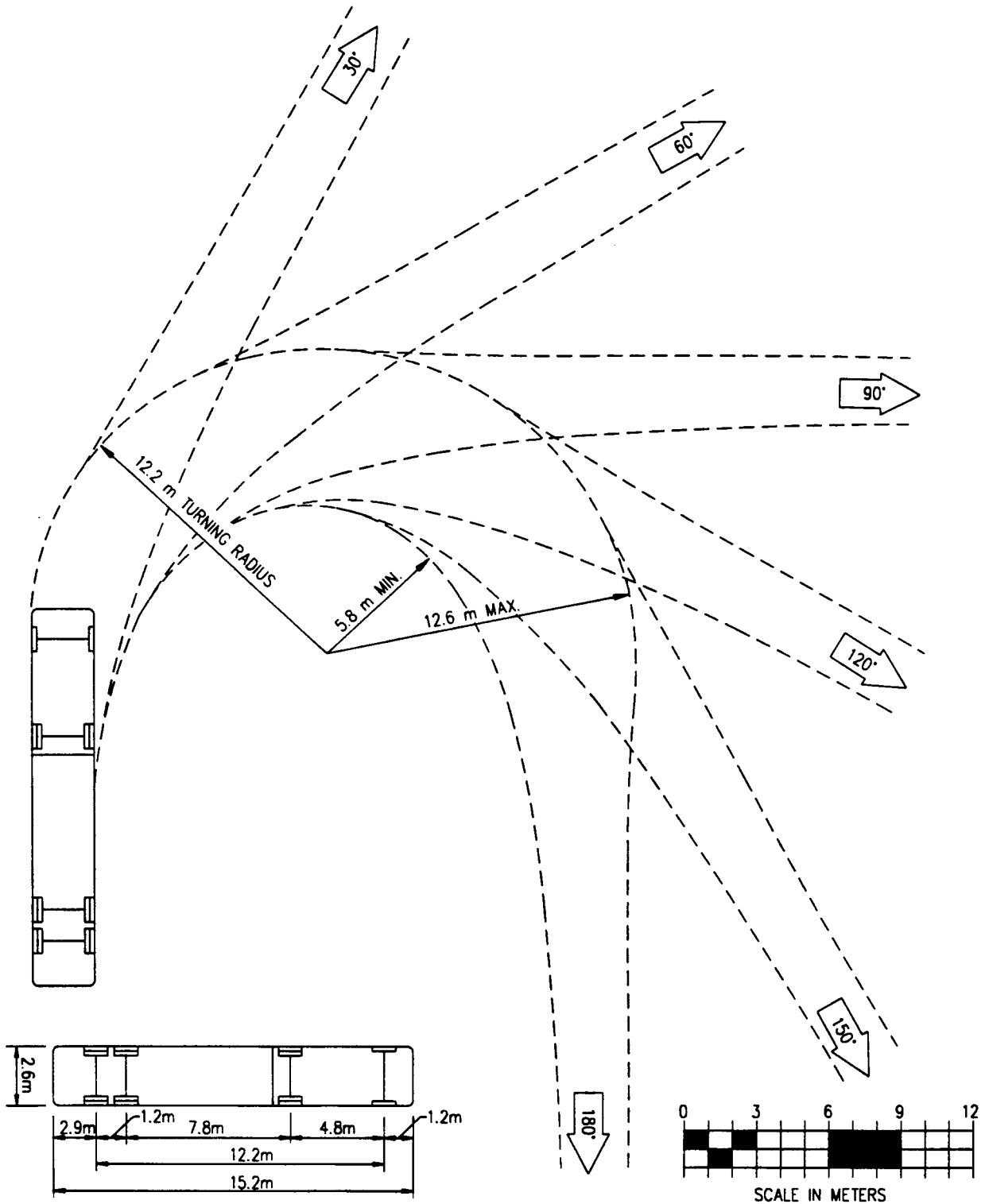


Figure 7-5. (T2) MINIMUM TURNING PATH FOR WB-12 DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

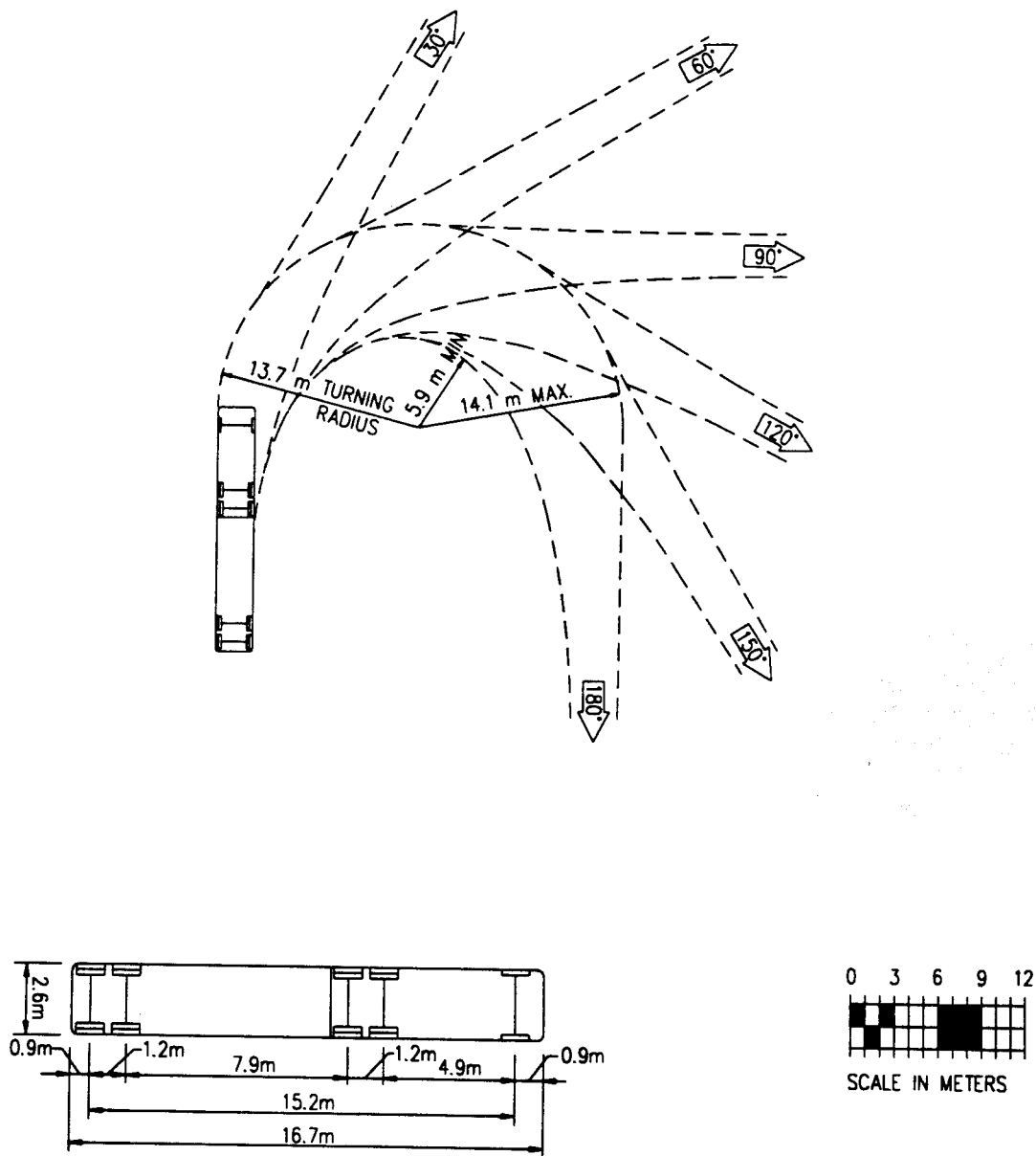


Figure 7-6. (T1) MINIMUM TURNING PATH FOR WB-15 DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

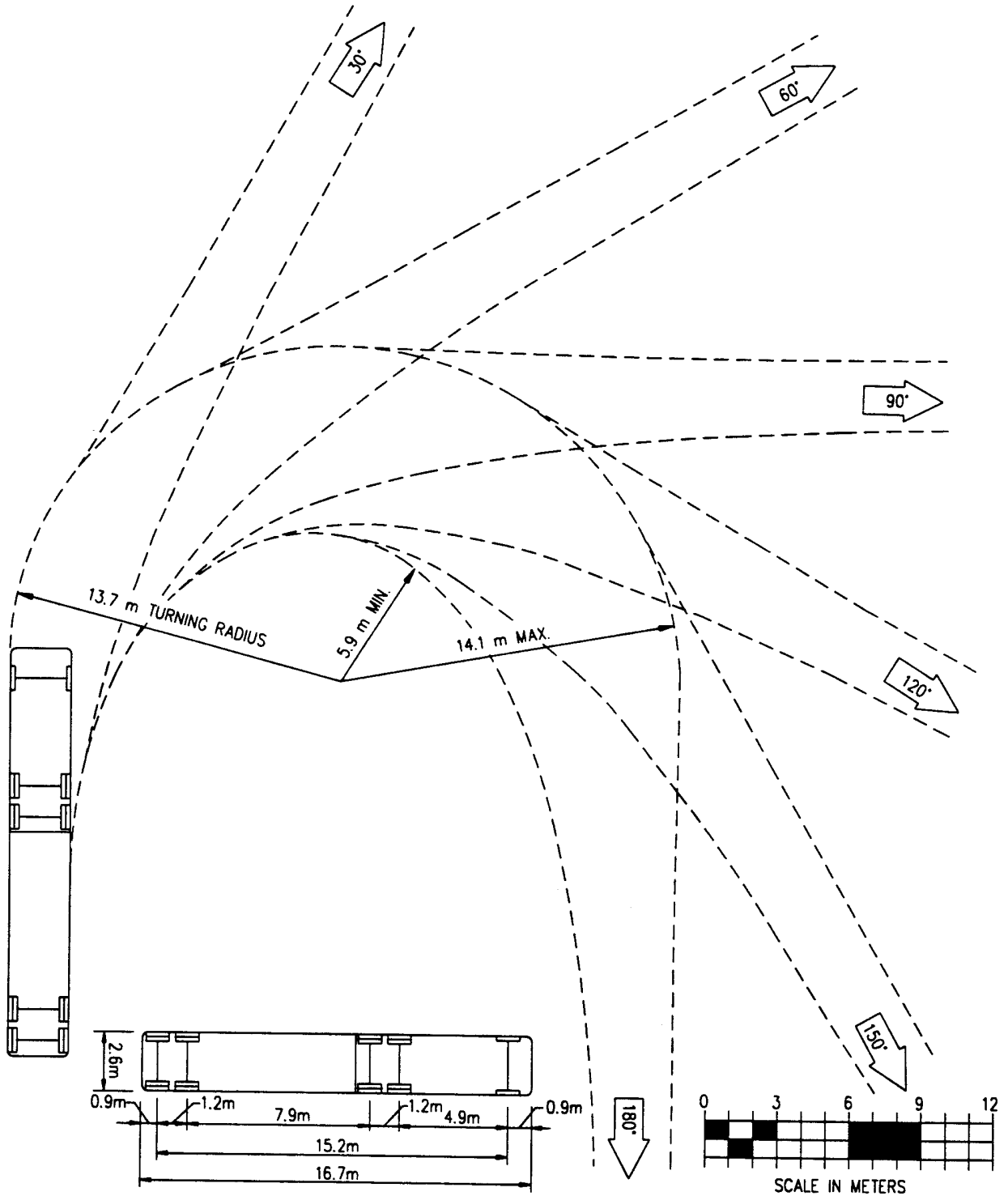


Figure 7-6. (T2) MINIMUM TURNING PATH FOR WB-15 DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

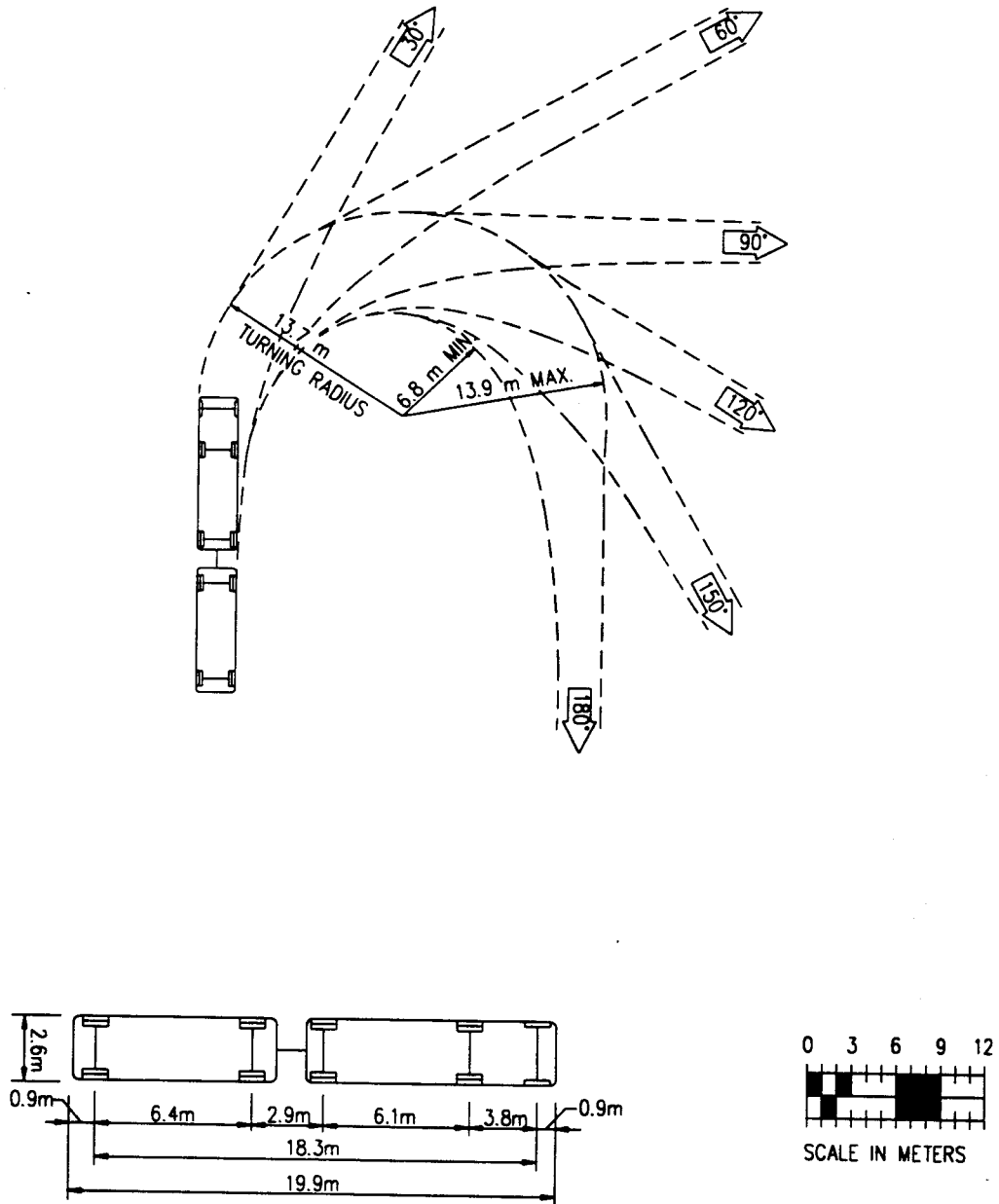


Figure 7-7. (T1) MINIMUM TURNING PATH FOR WB-18 DESIGN VEHICLE.

THIS TURNING TEMPLATE SHOWS THE TURNING PATHS OF THE AASHTO DESIGN VEHICLES. THE PATHS SHOWN ARE FOR THE LEFT FRONT OVERHANG AND THE OUTSIDE REAR WHEEL. THE LEFT FRONT WHEEL FOLLOWS THE CIRCULAR CURVE; HOWEVER, ITS PATH IS NOT SHOWN.

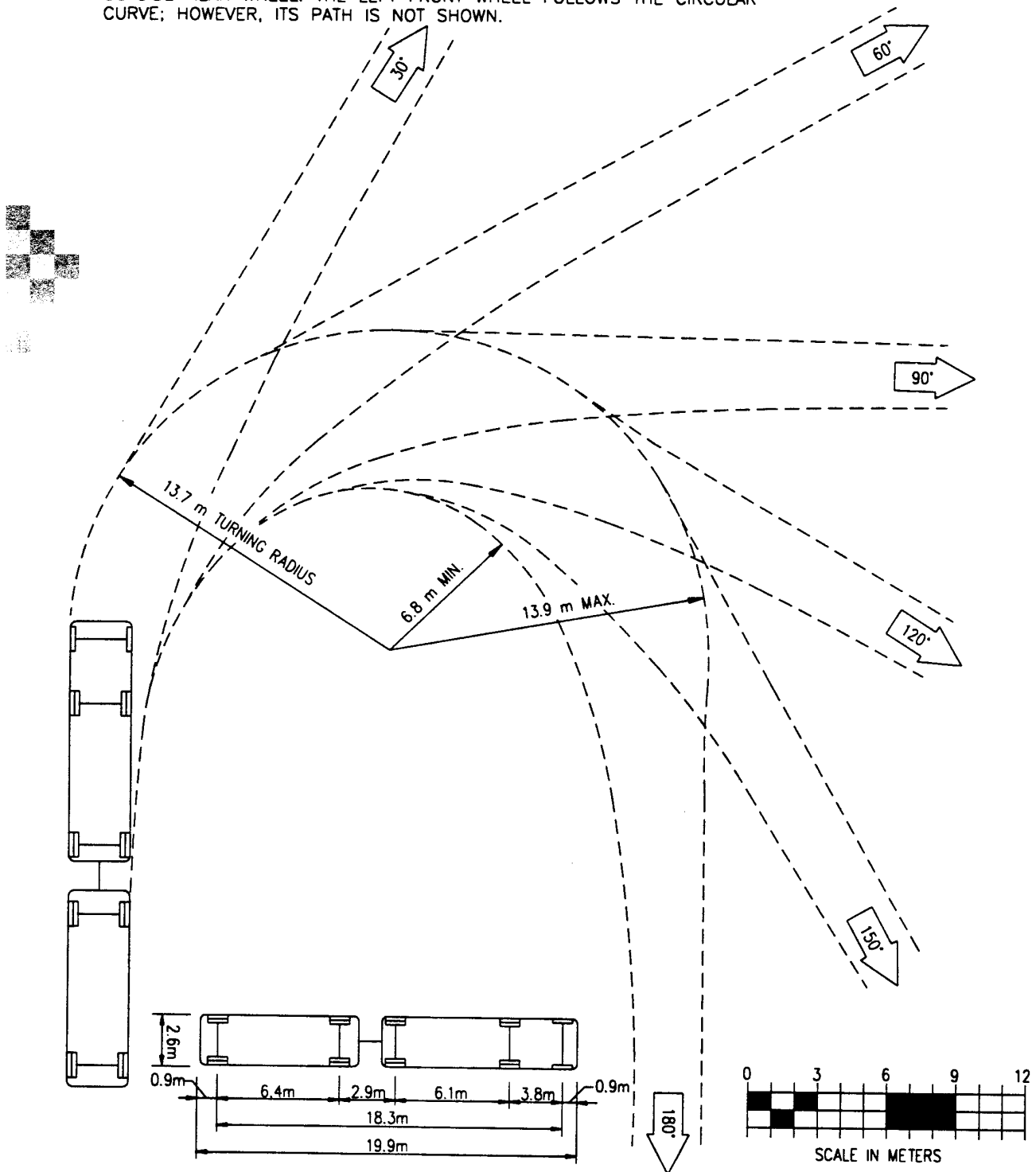


Figure 7-7. (T2) MINIMUM TURNING PATH FOR WB-18 DESIGN VEHICLE.

A vehicle must be able to negotiate the vertical profile at an intersection without dragging its underside or front and rear edges. This vehicle characteristic most often presents problems at driveway entrances and exits. A complete discussion of driveways and the design criteria for driveway vertical profile is provided in Section 7.4. The vehicle dimensions of new passenger vehicles are published annually by the Motor Vehicle Manufacturing Association in *Parking Dimension, (Year) Model Cars*.

7.1.3 Alignment

At-grade intersections should occur on tangent sections of highway. Where a minor road intersects a major road on a horizontal curve, this complicates the geometric design of the intersection particularly sight distance, channelization, and superelevation. Preferably, the intersection should be relocated to a tangent section of the major road. Another possibility is to realign the minor road to intersect the major road perpendicular to a tangent at a point on the horizontal curve. However, this arrangement would still result in difficult turning movements if the superelevation is high.

At-grade intersections should be as close to 90 degrees as possible. Skewed intersections increase the travel distance across the major highway, adversely affect sight distance, and complicate the design for turning movements. Intersection angles of more than 30 degrees from the perpendicular cause particular problems. Skewed intersections should be realigned to 90 degrees, if possible, particularly for those which deviate by more than 30 degrees. See *A Policy on Geometric Design of Highways and Streets* AASHTO, for a discussion and criteria on methods of realigning skewed intersections.

Realignment shall be considered when accident data or traffic volumes indicate a need to do so.

7.1.4 Profile

The vertical profile of an at-grade intersection should be as level as possible, subject to drainage requirements. This also applies to the distance along any intersection leg, called the storage platform, where vehicles stop and wait to pass through the intersection. The storage platform typically should accommodate 3 vehicles with a gradient of 2%.

Grades approaching or leaving the intersection will affect vehicle deceleration distances (and therefore stopping sight distance) and vehicle acceleration distances. Where the grades exceed 3%, the stopping sight distance must be adjusted according to the criteria in Table 3.10 in Chapter 3.

In general, the profile and cross section of the major road will be carried through the

intersection, and the minor road will be adjusted to fit the major road. This will require transitioning the crown of the minor road to an inclined section sloped to fit the longitudinal gradient of the major highway. The transition should be gradual and comparable to the transition rates for superelevation as discussed in Section 4.3. Intersections of two major roadways should be graded to meet drainage and comfort considerations.

7.1.5 Vehicular Safety

At-grade intersections contribute significantly to the number of highway accidents. Many pedestrian accidents occur at urban intersections. In rural areas there is normally a large speed differential between through vehicles and turning or entering vehicles. All at-grade intersection safety problems can be minimized by proper design of its geometric elements: sight distance, roadway width, turning lanes, alignment and profile, channelization, and turning radii.

When redesigning an existing at-grade intersection, the designer should review the accident history and prepare a collision diagram of the intersection. Figure 7-8 illustrates a typical collision diagram. The collision analysis may identify any accident patterns. The designer should then include countermeasures to correct the problem. For example, several angle or rear-end accidents involving left-turning vehicles at an unsignalized intersection may indicate the need for an exclusive left-turn lane.

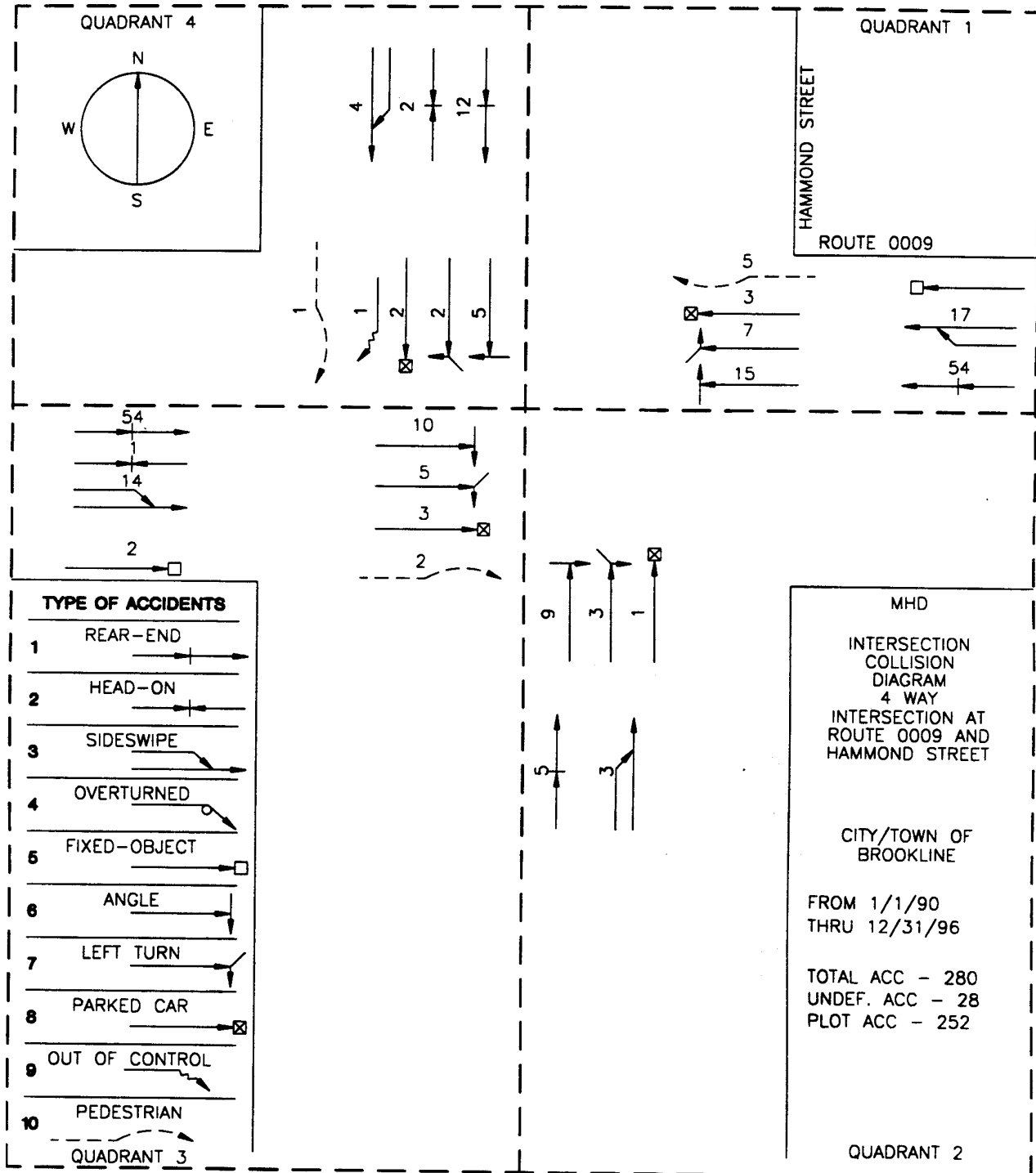


Figure 7-8. COLLISION DIAGRAM

The type and level of sophistication of traffic control will affect the safety and geometric design of the intersection. Following are examples of how geometric design and traffic control are related at an intersection:

1. At intersections with no signal control, the full pavement widths, including lane alignments, should be continued through.
2. Stop control may sufficiently reduce capacity to warrant additional approach lanes.
3. Stop and signalization control require the consideration of stopping or decision sight distance for the approaching vehicles.
4. Signalization will impact the length and width of storage areas, location and position of turning roadways, and channelization. The number and type of lanes for signalized intersections will be significantly different than for unsignalized intersections.
5. The intersection must be designed to allow for physical placement of the traffic control devices in the safest location. Traffic control devices are discussed in detail in the *Manual on Uniform Traffic Control Devices (MUTCD)*. The MHD Traffic Engineer will approve the type of traffic control devices at all intersections.

7.1.6 Control

Signs and signals are employed to convey control information to the driver. Traffic signals have definite disadvantages and advantages and should be installed only after other less restrictive means of control, such as STOP and YIELD signs, have been employed without success.

Traffic control signals control vehicular and pedestrian traffic by assigning the right of way to various movements for certain pretimed or traffic-actuated intervals of time. They are one of the key elements in the function of many intersections. Careful consideration should be given in plan development to intersection and access locations, horizontal and vertical curvature with respect to signal visibility, pedestrian requirements, and geometric schematics to ensure the best possible signal operation (individual signal phasing and traffic coordination between signals).

The design of traffic signal devices and warrants for their use are covered in Part IV of the MUTCD. Signal timing, phasing and level of service are developed using *Highway Capacity*

Manual methodology. Certain computer programs have been approved to perform this analysis.

Traffic control signals should not be installed unless one or more of the signal warrants are met. Information should be obtained by means of engineering studies and compared with the requirements set forth in the warrants. If these requirements are not met, a traffic signal should neither be put into operation nor continued in operation (if already installed).

When a traffic control signal is indicated as being warranted, it is presumed that the signal and all related traffic control devices and markings are installed according to the standards set forth in *MUTCD*.

An investigation of the need for traffic signal control should include where applicable, at least an analysis of the factors contained in the following warrants:

Warrant 1 - Minimum vehicular volume.

Warrant 2 - Interruption of continuous traffic.

Warrant 3 - Minimum pedestrian volume.

Warrant 4 - School crossings.

Warrant 5 - Progressive movement.

Warrant 6 - Accident experience.

Warrant 7 - Systems.

Warrant 8 - Combination of warrants.

Warrant 9 - Four Hour Volumes.

Warrant 10 - Peak Hour Delay.

Warrant 11 - Peak Hour Volume.

When traffic control signals are not warranted but some control of the intersection is required, consideration may be given to the installation of STOP or YIELD signs. Warrants for their installation are described in Section II of the *MUTCD*.

A number of techniques are available for evaluating the operation of a signalized

intersection, determining an appropriate signal timing, and considering design alternatives. Among these techniques, the most important are:

- The "critical movement" based technique of the 1995 *Highway Capacity Manual* (HCM), latest edition.
- Computer software packages based on the HCM including; Highway Capacity Software (HCS), SIDRA (Signalized and unsignalized Intersection Design and Research Aid), 94' CINCH, and EzSignals.
- The signal-optimization techniques incorporated in the latest versions of the following software packages, Synchro, 94' CINCH and SIG/Cinema.
- Vehicle queue lengths based on MHD standard analysis. The following software packages have built-in queue length analysis; SIDRA, 94' CINCH, and EzSignals, or a separate spreadsheet format is available from the MHD - Traffic Operations Unit.

The latest version of any of the above programs is acceptable for signal design and evaluation at isolated intersections.

For problems involving signal progression or coordination, the use of one of the following programs is encouraged:

- The latest version of PASSER, Transyt, or Synchro are useful for designing or evaluating signal systems along an arterial or in a network.
- For simulation of signal operations on an arterial or in a network, the latest version CORSIM (Traf-NETSIM) is recommended.

7.1.7 Other Considerations

1. *Expectancy.* Intersections are points of conflict between vehicles, pedestrians, bicycles, and other users. Intersection design should permit users to discern and perform readily the maneuvers necessary to pass through the intersection safely and with a minimum of interference.
2. *Pedestrians.* Intersections are the most significant point where vehicles and pedestrians share roadways. When pedestrians approach an intersection, there is a major interruption. The sidewalk should provide sufficient storage area for those

wanting to cross plus area for cross traffic to pass. The storage area (SA) necessary for pedestrians at a signalized intersection can be computed by the following formula:

$$SA = R(C - G_W) A_P$$

Where: R = rate of flow of pedestrians for design period, number/sec;

C = cycle length of signal, sec;

G_W = length of walk indication on the pedestrian signal, sec; and

A_P = storage area per person in queue (generally 0.5 square meter per person).

The designer should provide for the critical design period such as that containing the peak pedestrian flow, a period of heavy pedestrian cross-traffic, or frequent interference from turning motor vehicles.

Once pedestrians are given the walk indication, the crosswalk width becomes important. The crosswalk must be wide enough to accommodate the pedestrian flow in both directions within the duration of pedestrian signal phase. The necessary crosswalk width X_W can be estimated by the following equation:

$$X_W = (RC/P) (C/G_W)$$

Or the level of service at which an existing crosswalk is operating can be computed from:

$$P = (RC/X_W) (C/G_W)$$

When: R = Rate of flow of pedestrians for design period, number/sec;

C = cycle length of signal, seconds;

G_W = length of walk indication on the pedestrian signal, seconds;

X_W = crosswalk width, meters; and

P = pedestrian-crossing volume in number/meter/minute.

From a pedestrian perspective, short crosswalks are desirable. If the intersection is not signalized or if stop signs do not prohibit conflict with vehicular traffic, pedestrians must wait

for sufficient gaps in the traffic to cross. Because of the numerous variables, no

minimum gap size can be given and each site must be evaluated separately. It is desirable for the pedestrian to cross the entire roadway in a single cycle and not be caught in the median. The clear area on the sidewalk free of obstructions should have a minimum 1.5 meter clearance between objects (poles, control boxes etc.). See the *MUTCD* for a more detailed discussion.

3. *The Handicapped.* Design considerations for the handicapped are discussed in Section 9.6 and in the *Rules and Regulation of the Architectural Barrier Board*. Each intersection will differ with respect to the intersection angles, turning roadway widths, size of islands, drainage inlets, traffic control devices, and other variables previously described. An appropriate plan should be prepared (e.g. 1:250) that indicates all of the desired geometrics, including vertical profiles at the curb flow line. The plan could then be evaluated for the convenient and safe locations of the ramps for the handicapped. Drainage inlets should be located on the upstream side of all crosswalks and sidewalk ramps. This design operation will govern the pedestrian crosswalk patterns, stop bar locations, regulatory signs, and in the case of new construction, establish the most desirable location of signal supports.
4. *Bus Stops and Turnouts.* The location of bus stops and turnouts can have a considerable impact on traffic flow, turning movements, sight distance, and pedestrian safety. Bus stops and turnouts are discussed in Section 12.2.
5. *Bicycles.* Intersections frequently present hazards for bicyclists. Intersection design elements to accommodate bicycles are discussed in Section 12.1.
6. *Access to Abutting Property.* Intersection design elements, such as channelization, can eliminate access to abutting property. While such access control contributes to safety, it may upset the desired balance between access and mobility. Each intersection must be evaluated independently to assure that design features are consistent with safety and the functional class of the roadways.

7.2 INTERSECTION SIGHT DISTANCE

Two sight distance criteria must be met at intersections. First, the driver must be able to see the intersection itself. At a minimum, stopping sight distance must be provided to the intersection. However, decision sight distance (see Section 3.6.2) is often the desirable treatment at inter-sections because:

1. Many at-grade intersections present roadway conditions that are too complex for

the 2.5 second perception/reaction time factored into the stopping sight distances.

2. Decision sight distance allows time to conduct an evasive maneuver, which is desirable at intersections where slower moving, stopped, or crossing vehicles may be in the through lane.
3. Intersections often have high numbers of accidents. Therefore, the additional visibility provided by decision sight distance may be warranted.

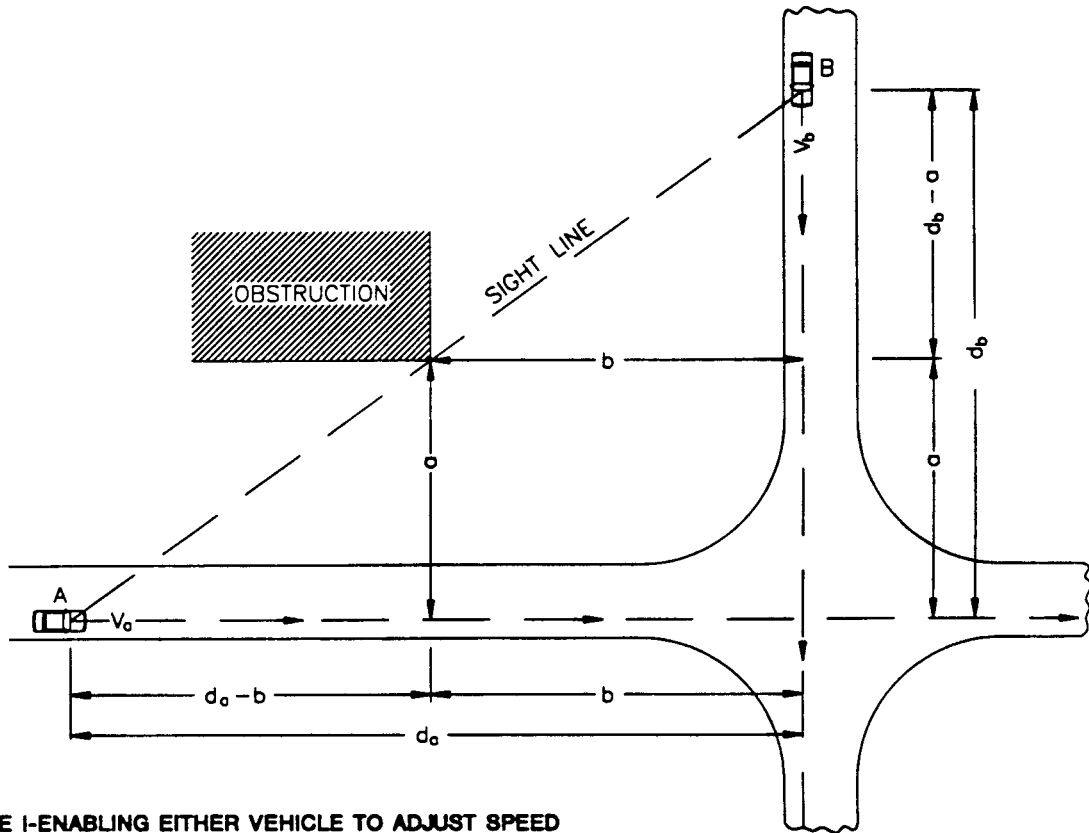
When measuring for sight distance, the intersection surface should be used as a 0.0 meter height of object. Decision sight distance and its values are discussed in Section 3.6.2.

The second sight distance criterion which must be met is the corner sight distance along the legs of the intersecting highway. One of five sight distance conditions (or a combination) may apply at the intersection; these cases are discussed in the following sections. For each case, the criteria will determine what minimum sight triangle must be free of obstructions to allow the intended maneuver. In addition, for Case IIIA the applicable design vehicle must be selected based on the type and frequency of vehicles using the intersection.

No rigid criteria can be established for case selection. The designer must decide which of the five cases will be the design control based on an assessment of the functional classes of the intersecting highways, traffic control, traffic volumes, traffic composition, and highway design speed. Accident patterns may indicate where a critical problem exists and therefore which sight distance case should be selected.

7.2.1 Case I - No Control: Enabling Either Vehicle to Adjust Speed

At intersections without traffic control, drivers should at a minimum be able to adjust their speed to avoid a collision. Figure 7-9 provides the minimum sight distances along each intersecting leg assuming 3 seconds of perception/reaction time. Distances d_a and d_b can be extracted from the table for the sight triangle.



A. CASE I-ENABLING EITHER VEHICLE TO ADJUST SPEED

SPEED (km/h)	DISTANCE (m)
20	20
30	25
40	35
50	40
60	50
70	60
80	65
90	75
100	85
110	90
120	100

$$d_b = \frac{ad_o}{d_o - b}$$

B. CASE II-DISTANCES TRAVELED BY VEHICLES IN 3.0 s

DESIGN SPEED (km/h)	15	20	30	40	50	60	70
STOPPING SIGHT DISTANCE (m)	20	20	30	50	60-70	80-90	100-120

Reference: A POLICY ON THE GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, AASHTO

**Figure 7-9. SIGHT DISTANCE AT INTERSECTIONS
MINIMUM SIGHT TRIANGLE
NO CONTROL OR YIELD CONTROL ON MINOR ROAD**

The Case I distances are considerably less than the lower stopping sight distances. Therefore, the use of the Case I criteria should be limited to low-volume, low-speed intersections where attaining greater sight distance would be too costly. They typically apply to intersections in residential areas and between minor rural roads.

7.2.2 Case II - No Control: Enabling Either Vehicle to Stop

At intersections without traffic controls, it is desirable to provide enough sight distance along the intersecting legs to allow either vehicle to stop. The Case II sight distances are provided in Figure 7-9, which are the greater stopping sight distances. At restricted sites, the lower stopping sight distances may be used.

Where it is too costly to remove an obstruction which blocks the needed sight triangle, the Case II criteria can be used to determine the safe speed through the intersection. Advance warning signs should then be used to notify approaching drivers of the hazard.

7.2.3 Case IIIA - Stop Control: Enabling Vehicles to Cross a Major Highway

At an intersection with stop control on the minor road, the driver of a stopped vehicle must have sufficient sight distance in both directions to cross a major road without interfering with oncoming vehicles. Figure 7-10 provides an illustration of the Case IIIA layout and the necessary equations for computation of "d", the sight distance needed in either direction. The following steps are necessary in the calculation:

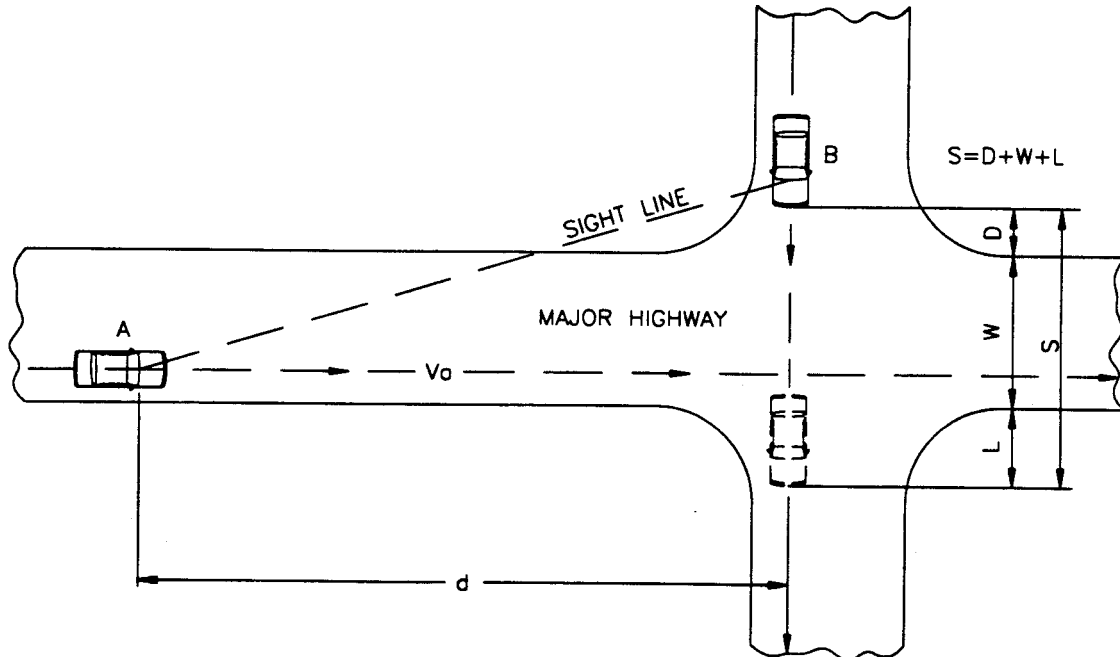
1. Select the design vehicle. This should be the vehicle which will be making the crossing maneuver with considerable frequency to justify the sight distance provided.
2. Calculate the distance "S" the crossing vehicle must traverse. As shown in Figure 7-10, this will depend upon the length of the vehicle and the width of the major highway, and the typical setback distance (usually 3 meters).
3. Find t_a the time needed to travel distance "S", from Figure 7-11. This will depend upon the selected design vehicle. The values from the figure are valid for relatively flat conditions.
3. Select a value "J", the perception/reaction time for a driver to begin moving the vehicle. Normally, J is assumed to be 2.0 seconds. However, a somewhat lower

value may be justified in urban and suburban areas where drivers use many intersections with stop control.

5. Calculate "d", the minimum sight distance along the major highway, from the equation in Figure 7-10:

$$d = 0.28 V (J + t_a)$$

When testing for adequate sight distance, use a height of eye of 1070 mm and height of object of 1300 mm.



CASE IIIA - ENABLING STOPPED VEHICLES TO CROSS A MAJOR HIGHWAY

$$S = D + W + L$$

- WHERE S = TOTAL DISTANCE VEHICLE MUST TRAVEL TO CLEAR INTERSECTION.
 D = DISTANCE FROM THE NEAR EDGE OF THE PAVEMENT TO THE FRONT OF THE STOPPED VEHICLE, USE 3 m.
 W = WIDTH OF THE PAVEMENT ALONG THE PATH OF THE CROSSING VEHICLE.
 L = OVERALL LENGTH OF THE VEHICLE. 6 m FOR P, 9 m FOR SU, AND 17 m FOR WB-35.

$$d = 0.28V(J + t_o)$$

- WHERE d = MINIMUM SIGHT DISTANCE ALONG THE MAJOR HIGHWAY FROM THE INTERSECTION (m).
 V = DESIGN SPEED ON THE MAJOR HIGHWAY (kph).
 J = SUM OF THE PERCEPTION TIME AND THE TIME REQUIRED TO SHIFT TO FIRST GEAR OR ACTUATE AN AUTOMATIC SHIFT (SEC.).
 t_o = TIME REQUIRED TO ACCELERATE AND TRAVERSE THE DISTANCE S TO CLEAR THE MAJOR HIGHWAY PAVEMENT (SEC.).

REFERENCE: A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS & STREETS, AASHTO, 1994

**Figure 7-10. SIGHT DISTANCE AT INTERSECTIONS
(VEHICLE CROSSING MAJOR HIGHWAY FROM STOP-CASE IIIA)**

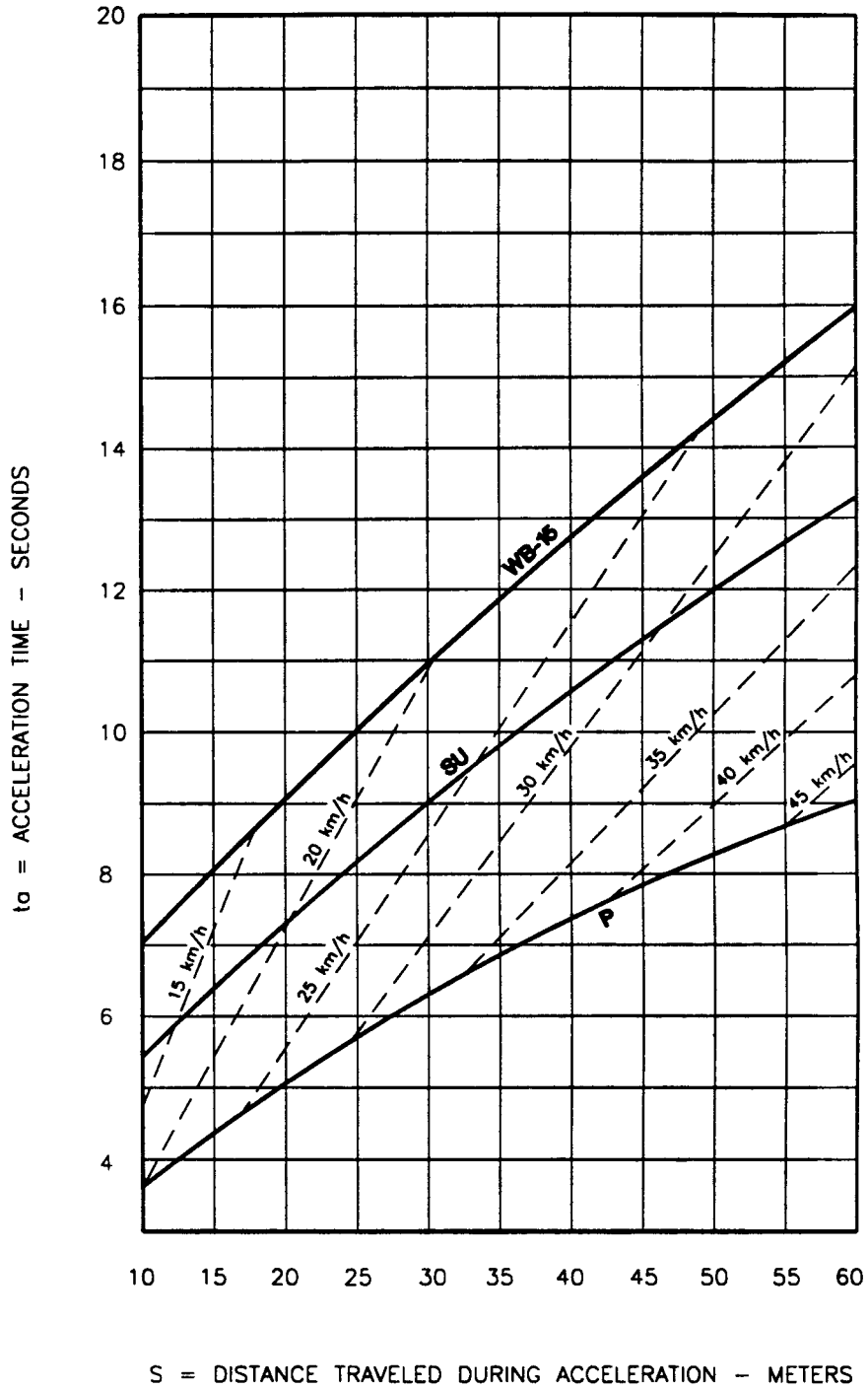


Figure 7-11. SIGHT DISTANCE AT INTERSECTIONS (CASE III, ACCELERATION FROM STOP)

Example (Case IIIA)

Given: Design speed of major highway - 100 km/hr

$$W = 13 \text{ m}$$

Problem: Determine required distance "d" for a passenger vehicle to cross the highway safely.

Solution: Step 1: Use a passenger vehicle.

$$\begin{aligned} \text{Step 2: } D &= 3 \text{ m; } W = 13 \text{ m; and } L = 6 \text{ m; Therefore:} \\ S &= 3 + 13 + 6 = 22 \text{ m} \end{aligned}$$

Step 3: From Figure 7-11 for "assumed P" $t_a = 5.7$ sec,

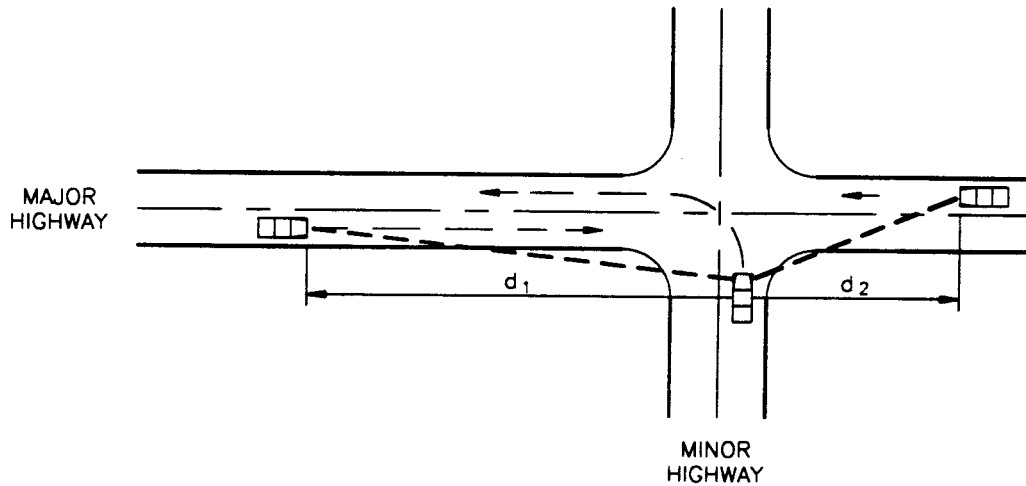
$$\text{Step 4: } J = 2.0 \text{ sec.}$$

$$\begin{aligned} \text{Step 5: } d &= 0.28 \times 100 (2.0 + 5.7) \\ d &= 216 \text{ meters} \end{aligned}$$

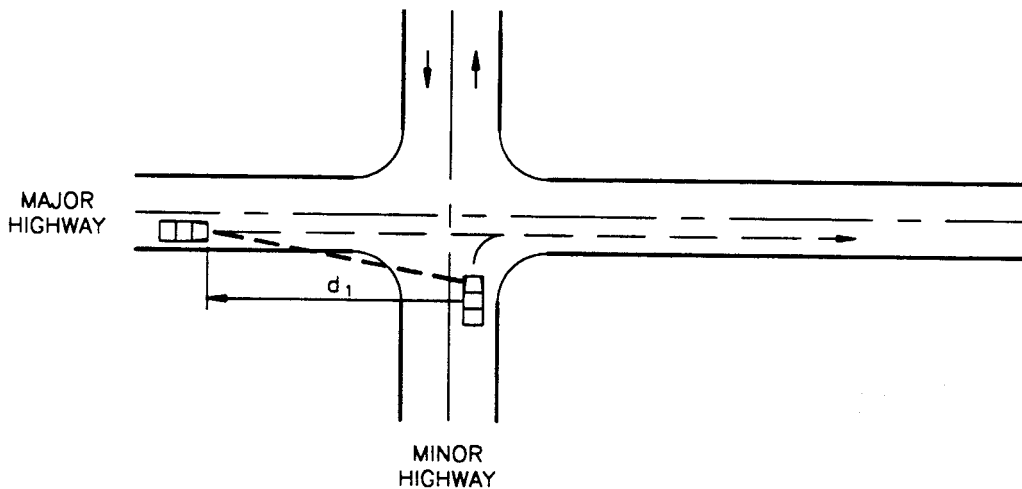
7.2.4 Case IIIB (Left Turn) and IIIC (Right Turn) - Stop Control

If a vehicle operator intends to turn left or right onto a highway from a stopped position, additional sight distance is needed. Figure 7-12 illustrates Case IIIB and Case IIIC. Figure 7-13 provides the design criteria for the sight distance needed along the major highway. Preferably, the criteria for design speed should be used; the criteria for average running speed is acceptable as a minimum. Normally, sight distances for Case IIIB and IIIC should be satisfied. (Note: Criteria for buses and trucks have not been established. The corner sight distances for these vehicles would obviously be much greater.)

Cases IIIB and IIIC should be used at an intersection where the frequency of left-turning and/or right-turning vehicles justifies the additional costs of providing the sight distance. A review of the intersection accident history may indicate the extent of any sight distance problems.



CASE III B - STOPPED VEHICLE TURNING LEFT INTO TWO-LANE MAJOR HIGHWAY



CASE III C - STOPPED VEHICLE TURNING RIGHT INTO TWO-LANE MAJOR HIGHWAY OR RIGHT TURN ON A RED SIGNAL

Figure 7-12. INTERSECTION SIGHT DISTANCE AT AT-GRADE INTERSECTIONS.

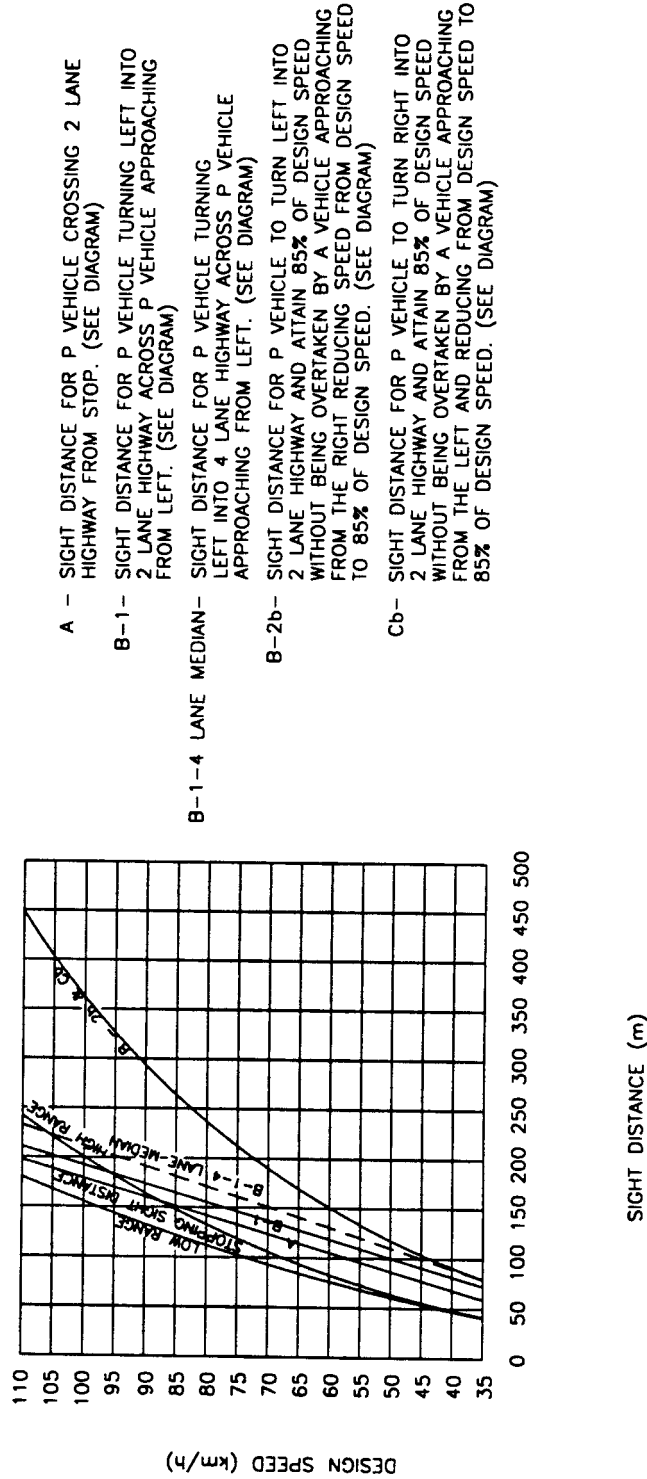


Figure 7-13. INTERSECTION SIGHT DISTANCES AT AT-GRADE INTERSECTION (CASE IIIB AND CASE IIIC)

7.2.5 Case IV - Signal Control

Due to a variety of operational characteristics associated with all intersections, sight distance based on the Case III procedures must be available to the driver. This principle is based on the increased driver workload at intersections and the problems involved when vehicles turn onto or cross the major highway. The problems associated with unanticipated vehicle conflicts at signalized intersections, such as, violation of the signal, right turns on red, malfunction of the signal, or use of flashing red/yellow mode, further substantiate the need for incorporation of Case III sight distance even at signal-controlled intersections.

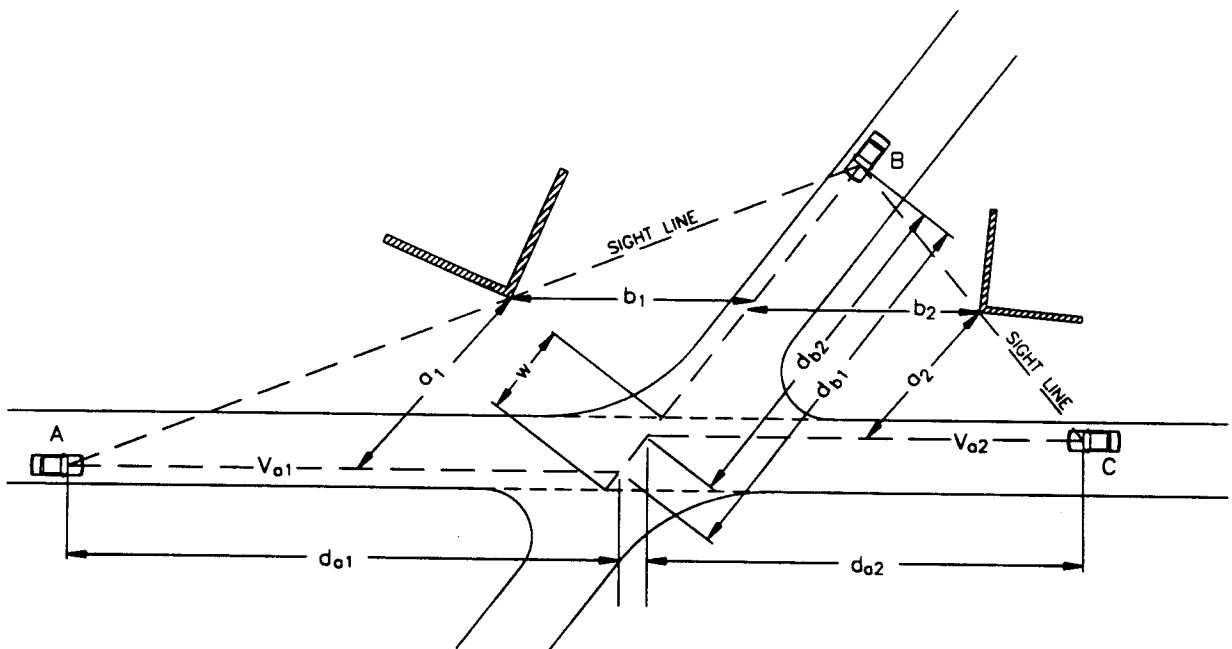
A basic requirement for all controlled intersections is that drivers must be able to see the control device soon enough to perform the action it indicates. At intersections where right turns on red are permitted, the departure sight line for right turning vehicles should be determined by the methods discussed in "Case IIIC, Turning Right into a Major Highway."

In addition, when determining sight lines for the design maneuver, the designer should consider the effects of roadside appurtenances, parked cars, snow accumulation or any other restriction to the sight line.

7.2.6 Effects of Skew

Sight distance calculations must be adjusted when the angle of intersection is less than 60 degrees. Figure 7-14 shows the adjusted sight triangles of oblique angle intersections. The following alterations are necessary in the analysis:

1. Because of the difficulty of looking for approaching traffic, the intersection should never be treated as Case I, even where traffic is light.
2. Treatments by Case II or Case III, whichever is larger, should be used at oblique angle intersections.
3. The d distance along the highway can be computed from the equation $d = 0.28v(J - t_a)$ by reading t_a from Table 7.1.



Reference: A POLICY ON THE GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, AASHTO

Figure 7-14. SIGHT DISTANCE AT SKEWED INTERSECTIONS

Table 7.1 ACCELERATION RATES FOR PASSENGER VEHICLES

SPEED (km/h)	DISTANCE (m)	ta. (s)
30	25	5.7
40	40	7.3
50	70	9.8
60	110	12.3
70	160	15.2
80	235	18.8
90	325	22.4
100	455	27.4
110	650	33.9

7.2.7 Effect of Vertical Profile

A vehicle descending a grade requires a somewhat greater distance to stop than does one on level grade: also, a vehicle ascending a grade requires less distance in which to stop. The effect of grade on acceleration can be expressed as a multiplicand to be applied to t_a as determined for level conditions for a given distance. See Table 7.2.

**Table 7.2 EFFECT OF GRADIENT ON ACCELERATING TIME (t_a)
AT INTERSECTIONS**

RATIO, ACCELERATING TIME ON GRADE TO ACCELERATING TIME ON LEVEL SECTION

DESIGN VEHICLE	CROSSROAD GRADE (%)				
	-4	-2	0	+2	+4
P	0.7	0.9	1.0	1.1	1.3
SU	0.8	0.9	1.0	1.1	1.3
WB-15	0.8	0.9	1.0	1.2	1.7

7.3 INTERSECTION TURNS

7.3.1 Design for Right Turns

The following steps apply when designing an at-grade intersection to accommodate right-turning vehicles.

1. Select the design vehicle based on the largest vehicle likely to make the turn, unless this would be a relatively infrequent occurrence. (Typically use the Semi-tractor combination or SU design vehicle where applicable).
2. Select the design speed at which the vehicle should be allowed to make the turn. The turning radii designs discussed in Section 7.3.1.1 are negotiable at speeds of 15 km/h or less. If higher turning speeds are desired, then a turning roadway should be used (Section 7.3.1.2).
3. Determine the tolerable encroachment onto other lanes. This will vary with traffic volumes, lane width, and one-way or two-way operation.
4. Determine the need for auxiliary turn lanes.
5. Determine the availability of right of way.
6. Consider the effects of parking on turning movements.
7. Evaluate the need to accommodate pedestrian movements.
8. Select the appropriate channelization treatment.

7.3.1.1 Turning Radii

Turning radii allow vehicles to negotiate a right turn. A curve radius with or without modification is used. The edge of pavement or curb line for a right turn can be designed by these methods.

1. simple radius,
2. simple radius with taper offsets,
3. 3-centered symmetric compound curve,

4. 3-centered asymmetric compound curve, or
5. spiral curve

The 3-centered compound curve and spiral curve arrangements are rarely used. They complicate design and construction and should be considered in special cases only.

The simple radius is the easiest to design and construct; however, it has several disadvantages when compared to the taper offset design:

1. To accommodate a specific vehicle with no encroachment, a simple radius requires greater amounts of right of way.
2. A simple radius results in greater distance for pedestrians to cross.
3. Simple curves cannot reasonably be used to accommodate large vehicles with no encroachment; too much open area results in the intersection. A channelized island would be necessary.
4. Likewise, a simple radius is less than ideal for turns greater than 90 degrees. Again, a channelized island would be needed.

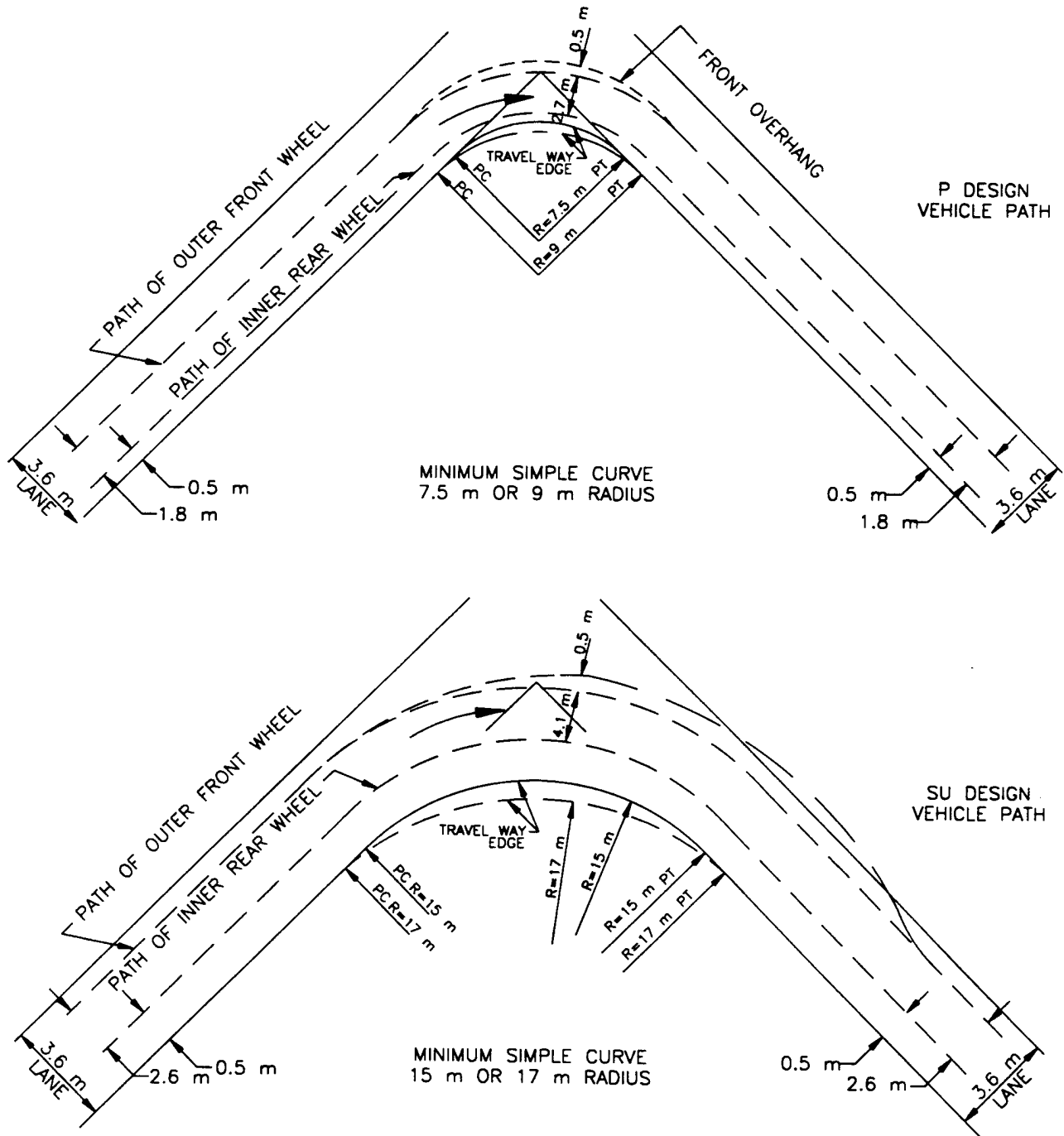
The simple radius with taper offset provides a good transition for the turning vehicle. Therefore, a simple radius with a taper offset should be used where practical. Tables 7.3 & 7.4 provide the data for the two methods for various design vehicles and turning angles. These designs will allow the design vehicle to turn at speeds up to 15 km/h. Figure 7-15 illustrates minimum designs for simple curves for passenger and single-unit vehicles. Figures 7-16 to 7-18 provide the design details and examples for simple curve radii with taper offsets for 90 degrees, less than 90 degrees, and greater than 90 degrees angle of turns.

Table 7.3 MINIMUM EDGE-OF-TRAVELED WAY DESIGNS FOR TURNS AT INTERSECTIONS.

Angle of Turn (degrees)	Design Vehicle	Simple Curve Radius (m)	Simple Curve Radius with Taper		
			Radius (m)	Offset (m)	Taper (m:m)
30	P	18	-	-	-
	SU	30	-	-	-
	WB-12	45	-	-	-
	WB-15	60	-	-	-
	WB-19	110	67	1.0	15:1
	WB-20	116	67	1.0	15:1
	WB-29	77	37	1.0	15:1
	WB-35	145	77	1.1	20:1
45	P	15	-	-	-
	SU	23	-	-	-
	WB-12	36	-	-	-
	WB-15	53	36	0.6	15:1
	WB-19	70	43	1.2	15:1
	WB-20	76	43	1.3	15:1
	WB-29	61	35	0.8	15:1
	WB-35	-	61	1.3	20:1
60	P	12	-	-	-
	SU	18	-	-	-
	WB-12	28	-	-	-
	WB-15	45	29	1.0	15:1
	WB-19	50	43	1.2	15:1
	WB-20	60	43	1.3	15:1
	WB-29	46	29	0.8	15:1
	WB-35	-	54	1.3	20:1
75	P	11	8	0.6	10:1
	SU	17	14	0.6	10:1
	WB-12	-	18	0.6	15:1
	WB-15	-	20	1.0	15:1
	WB-19	-	43	1.2	20:1
	WB-20	-	43	1.3	20:1
	WB-29	-	26	1.0	15:1
	WB-35	-	42	1.7	20:1
90	P	9	6	0.8	10:1
	SU	15	12	0.6	10:1
	WB-12	-	14	1.2	10:1
	WB-15	-	18	1.2	15:1
	WB-19	-	36	1.2	30:1
	WB-20	-	37	1.3	30:1
	WB-29	-	25	0.8	15:1
	WB-35	-	35	0.9	15:1

Simple Curve with Taper

Angle of Turn (degrees)	Design Vehicle	Simple Curve Radius (m)	Radius (m)	Offset (m)	Taper (m:m)
105	P	-	6	0.8	8:1
	SU	-	11	1.0	10:1
	WB-12	-	12	1.2	10:1
	WB-15	-	17	1.2	15:1
	WB-19	-	35	1.0	30:1
	WB-20	-	35	1.0	30:1
	WB-29	-	22	1.0	15:1
	WB-35	-	28	2.8	15:1
120	P	-	6	0.6	10:1
	SU	-	9	1.0	10:1
	WB-12	-	11	1.5	8:1
	WB-15	-	14	1.2	15:1
	WB-19	-	30	1.5	25:1
	WB-20	-	31	1.6	25:1
	WB-29	-	20	1.1	15:1
	WB-35	-	26	2.8	15:1
135	P	-	6	0.5	15:1
	SU	-	9	1.2	8:1
	WB-12	-	9	2.5	6:1
	WB-15	-	12	2.0	10:1
	WB-19	-	24	1.5	20:1
	WB-20	-	25	1.6	20:1
	WB-29	-	19	1.7	15:1
	WB-35	-	25	2.6	15:1
150	P	-	6	0.6	10:1
	SU	-	9	1.2	8:1
	WB-12	-	9	2.0	8:1
	WB-15	-	11	2.1	6:1
	WB-19	-	18	3.0	10:1
	WB-20	-	19	3.1	10:1
	WB-29	-	19	2.2	10:1
	WB-35	-	20	4.6	10:1
180	P	-	5	0.2	20:1
	SU	-	9	0.5	10:1
	WB-12	-	6	3.0	5:1
	WB-15	-	8	3.0	5:1
	WB-19	-	17	3.0	15:1
	WB-20	-	16	4.2	10:1
	WB-29	-	17	3.1	10:1
	WB-35	-	17	6.1	10:1



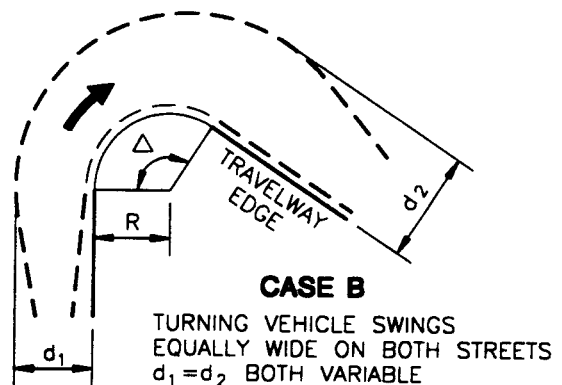
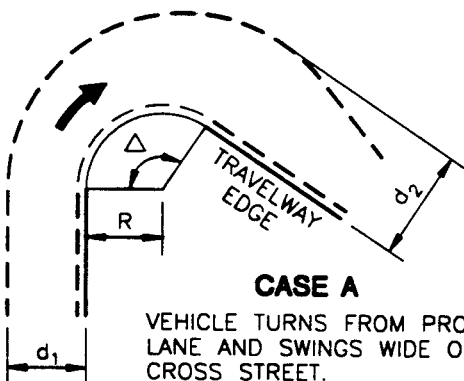
REFERENCE: A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS & STREETS, AASHTO, 1994

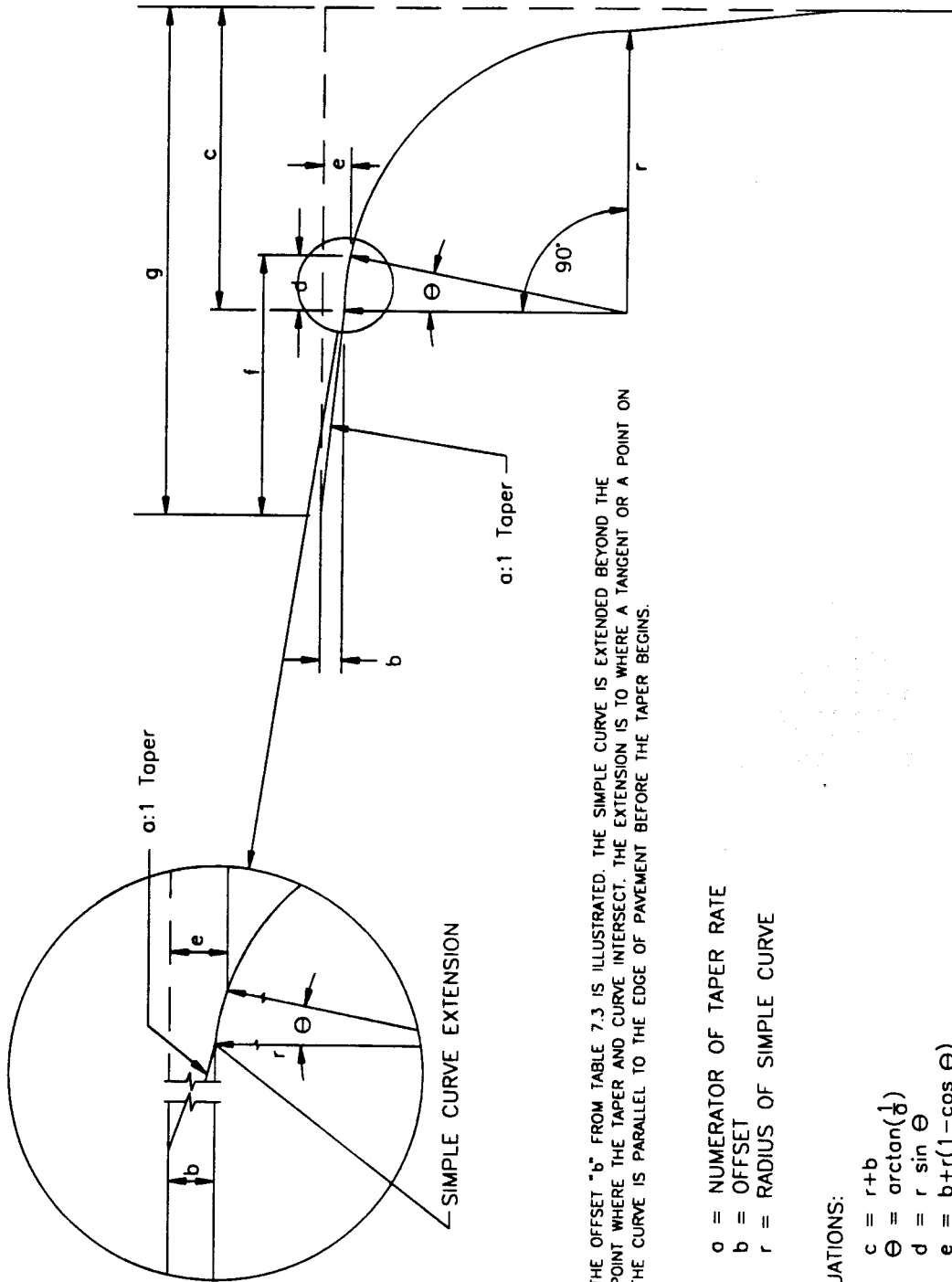
Figure 7-15. MINIMUM DESIGNS FOR SIMPLE CURVES

Table 7.4
CROSS STREET WIDTH OCCUPIED BY TURNING VEHICLE FOR
VARIOUS ANGLES OF INTERSECTION AND CURB RADII.

d_2 (m) FOR CASES A AND B WHERE:											
Δ (degrees)	DESIGN	R = 4.5 m		R = 6 m		R = 7.5 m		R = 9 m		R = 12 m	
		A	B	A	B	A	B	A	B	A	B
30	SU	4.3	4.0	4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	BUS	6.7	5.2	5.8	5.2	5.8	5.2	5.8	5.2	5.5	5.2
	WB-12	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
	WB-15	6.1	5.2	6.1	5.2	6.1	5.2	5.8	4.9	5.5	4.9
	WB-19	-	-	-	-	-	-	-	-	8.2	5.2
	WB-20	-	-	-	-	-	-	-	-	8.5	5.5
60	SU	5.8	4.9	5.8	4.9	5.2	4.6	4.9	4.6	4.3	4.3
	BUS	8.5	6.4	7.9	6.1	7.3	6.1	7.0	5.8	6.7	5.5
	WB-12	7.3	5.8	6.7	5.8	6.4	5.8	5.8	5.5	5.2	4.9
	WB-15	9.4	6.7	8.2	6.4	8.5	6.1	7.6	5.8	6.7	5.5
	WB-19	-	-	-	-	-	-	-	-	9.1	6.7
	WB-20	-	-	-	-	-	-	-	-	11.3	7.3
90	SU	7.9	6.1	7.0	5.5	5.8	4.9	5.2	4.6	4.0	4.0
	BUS	11.6	7.0	10.0	6.7	9.1	6.7	7.6	6.4	6.7	5.5
	WB-12	9.4	6.7	8.2	6.4	7.0	6.4	5.8	5.5	5.2	4.9
	WB-15	12.8	6.7	11.3	7.3	9.8	6.7	8.8	6.4	6.7	5.5
	WB-19	-	-	-	-	-	-	-	-	11.9	7.0
	WB-20	-	-	-	-	-	-	-	-	11.9	7.6
120	SU	10.4	6.7	8.2	5.8	6.4	5.5	5.2	4.9	4.0	4.0
	BUS	14.0	8.5	12.2	7.6	9.8	7.0	7.9	5.8	5.8	5.5
	WB-12	11.3	7.0	8.8	6.7	7.3	6.7	5.8	5.5	5.2	4.9
	WB-15	15.2	8.8	13.1	8.5	11.0	8.2	9.1	7.9	6.7	5.5
	WB-19	-	-	-	-	-	-	-	-	7.9	6.7
	WB-20	-	-	-	-	-	-	-	-	9.1	7.0
150	SU	12.2	7.6	9.8	6.4	6.7	5.8	5.2	4.9	3.6	3.6
	BUS	14.6	8.5	12.2	7.6	9.8	7.0	6.7	5.5	5.2	4.9
	WB-12	11.9	7.3	8.8	6.7	7.0	6.7	5.8	5.5	5.2	4.9
	WB-15	16.2	9.4	14.0	8.5	11.0	8.2	8.5	7.9	6.7	5.5
	WB-19	-	-	-	-	-	-	-	-	6.1	5.5
	WB-20	-	-	-	-	-	-	-	-	8.2	5.5

Note: P DESIGN VEHICLE TURNS WITHIN 3.6 m WIDTH WHERE $R = 4.5$ m OR MORE.
NO PARKING ON EITHER STREET.





THE OFFSET "b" FROM TABLE 7.3 IS ILLUSTRATED. THE SIMPLE CURVE IS EXTENDED BEYOND THE POINT WHERE THE TAPER AND CURVE INTERSECT. THE EXTENSION IS TO WHERE A TANGENT OR A POINT ON THE CURVE IS PARALLEL TO THE EDGE OF PAVEMENT BEFORE THE TAPER BEGINS.

- a = NUMERATOR OF TAPER RATE
- b = OFFSET
- r = RADIUS OF SIMPLE CURVE

EQUATIONS:

$$c = r + b$$

$$\theta = \arctan\left(\frac{b}{d}\right)$$

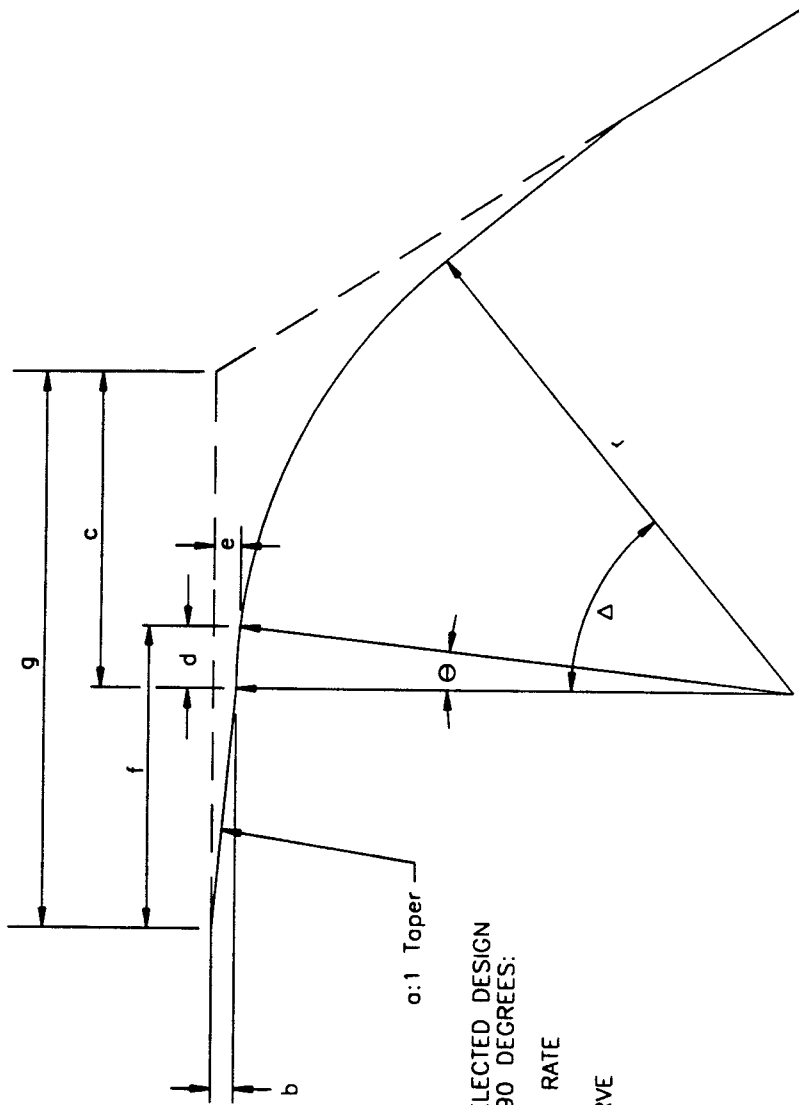
$$d = r \sin \theta$$

$$e = b + r(1 - \cos \theta)$$

$$f = e \times \frac{a}{d}$$

$$g = c + f - d$$

Figure 7-16. DETAILED LAYOUT OF SIMPLE CURVE RADIUS WITH TAPER OFFSET (90 DEGREE TURN)



DATA FROM TABLE 7.3 FOR A SELECTED DESIGN VEHICLE AND ANGLE OF TURN OF <90 DEGREES:

- a = NUMERATOR OF TAPER RATE
- b = OFFSET
- r = SPACE OF SIMPLE CURVE
- Δ = ANGLE OF TURN

EQUATIONS:

$$c = (r+b)\tan\left(\frac{\Delta}{2}\right)$$

$$\Theta = \arctan\left(\frac{1}{d}\right)$$

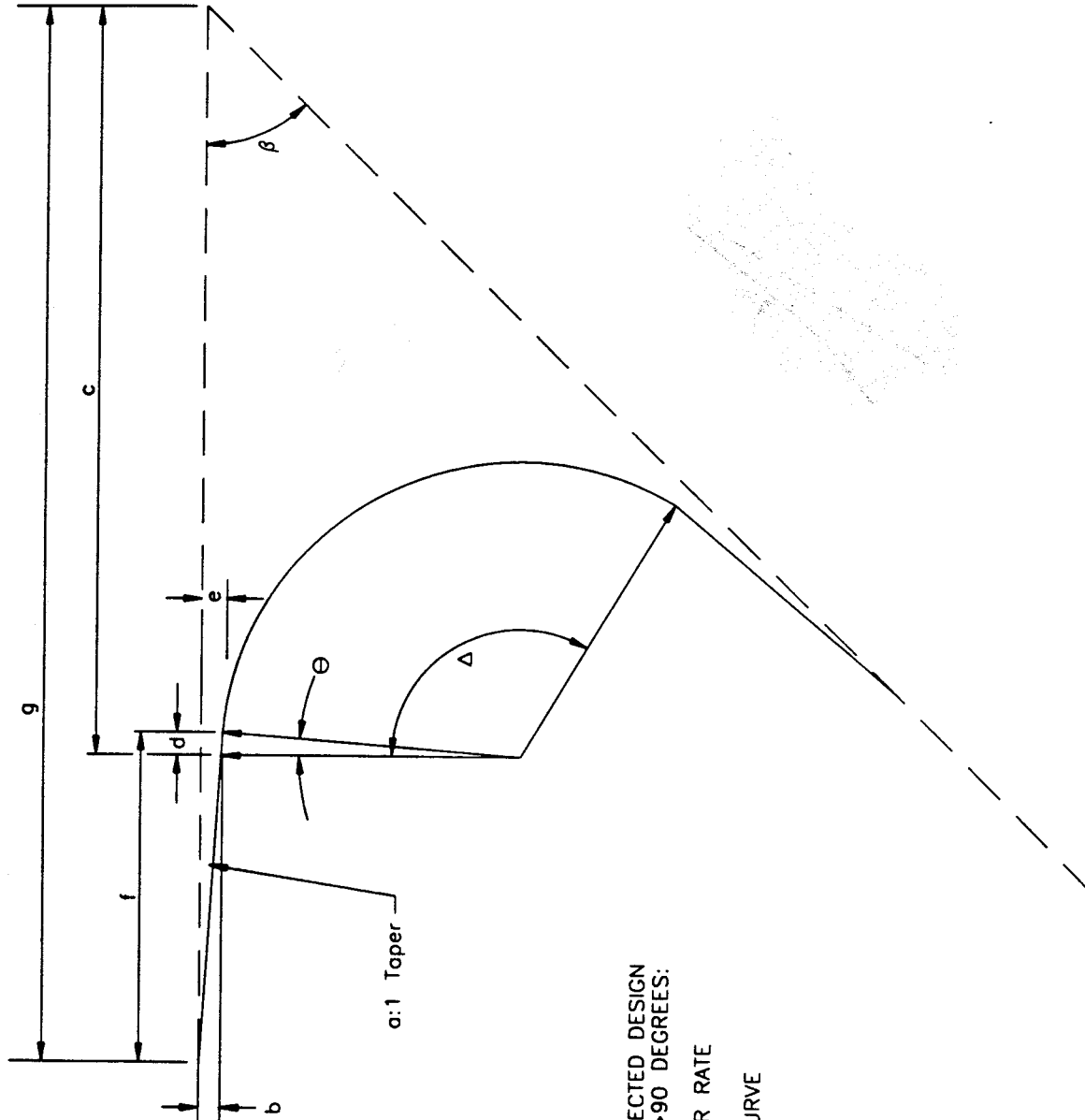
$$d = r \sin \Theta$$

$$e = b+r(1-\cos \Theta)$$

$$f = e \times a$$

$$g = c+f-d$$

**Figure 7-17. DETAILED LAYOUT OF SIMPLE CURVE RADIUS WITH TAPER OFFSET
(ANGLE OF TURN <90 DEGREES)**



DATA FROM TABLE 7.3 FOR SELECTED DESIGN VEHICLE AND ANGLE OF TURN >90 DEGREES:

- a = NUMERATOR OF TAPER RATE
- b = OFFSET
- r = RADIUS OF SIMPLE CURVE
- Δ = ANGLE OF TURN

EQUATIONS:

$$\beta = 180^\circ - \Delta$$

$$c = (r+b) \left(\frac{1+\cos\beta}{\cos\beta \tan\beta} \right)$$

$$\Theta = \arctan\left(\frac{d}{r}\right)$$

$$d = r \sin \Theta$$

$$e = b+r(1-\cos \Theta)$$

$$f = e \times a$$

$$g = c+f-d$$

**Figure 7-18. DETAILED LAYOUT OF SIMPLE CURVE RADIUS WITH TAPER OFFSET
(ANGLE OF TURN >90 DEGREES)**

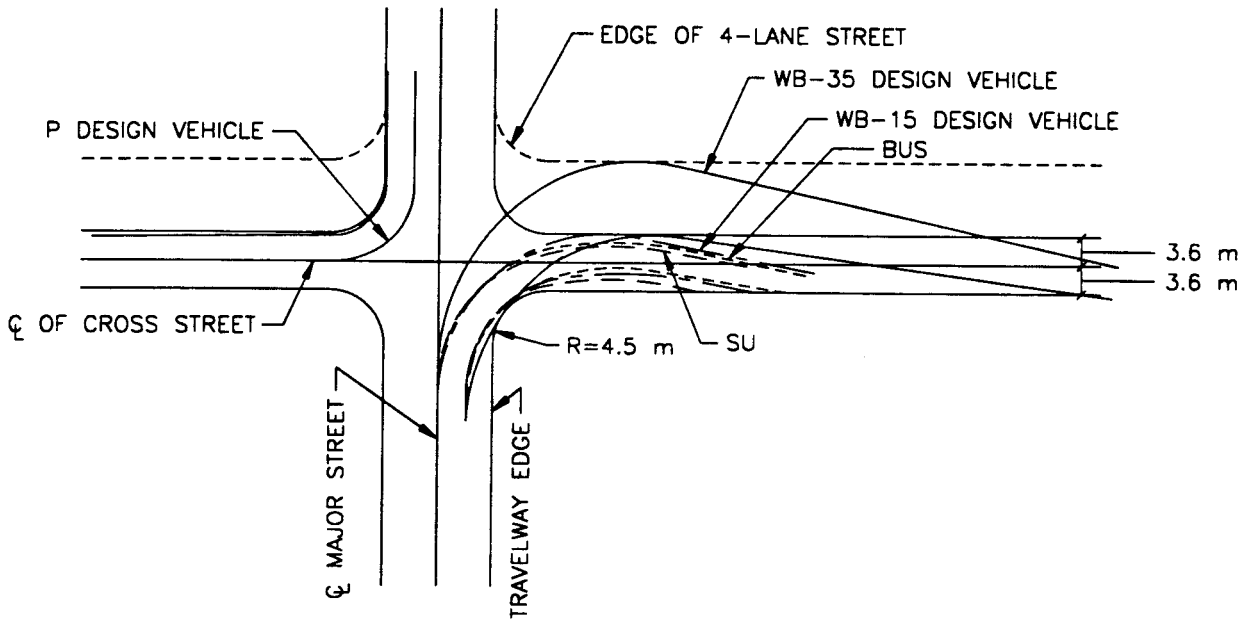


Figure 7-18A. EFFECT OF CURB RADII ON TURNING PATHS OF VARIOUS DESIGN VEHICLES.

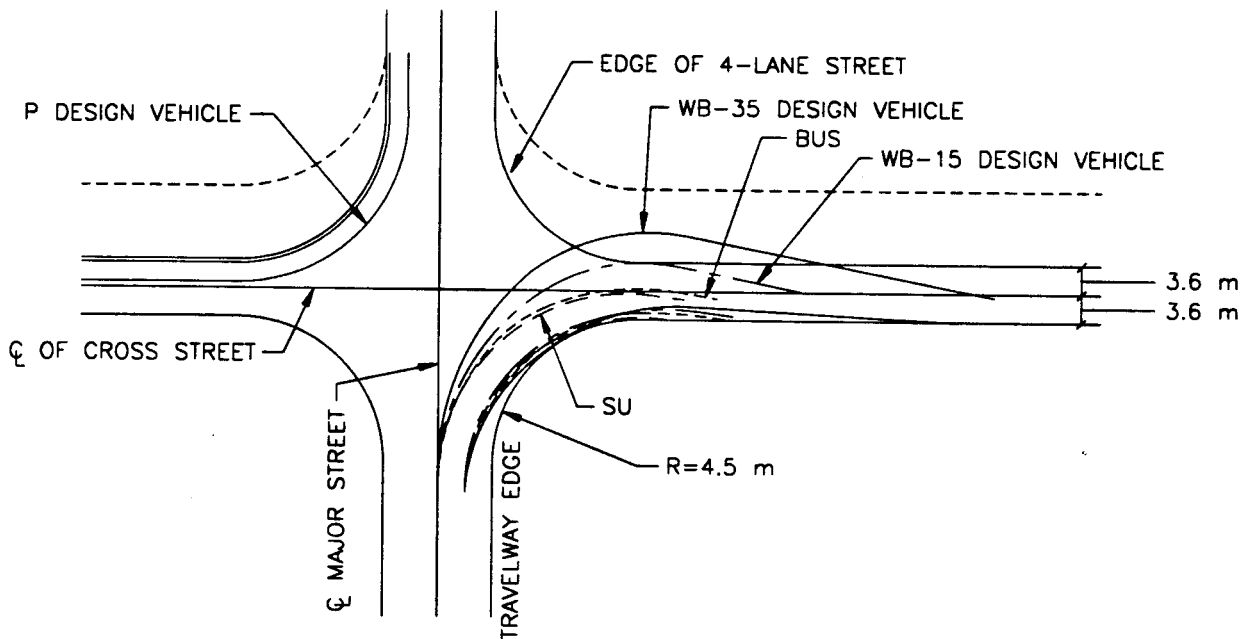


Figure 7-18B. EFFECT OF CURB RADII ON TURNING PATHS OF VARIOUS DESIGN VEHICLES.

7.3.1.2 Turning Roadways

Turning roadways are channelized areas which allow a right turn to be made away from the intersection area. They should be considered where:

1. it is desirable to allow right turns at 25 km/h or more.
2. intersections are skewed; or
3. buses or semitrailers must be accommodated.

Table 7.5 provides the design data for the horizontal alignment, width, and superelevation for various design speeds. Figure 7-19 illustrates a typical design for a turning roadway. These criteria apply to the design of a turning roadway.

1. *Curvature* - 3 centered compound curves should be used. Table 7.6 and Figure 7-20 show the minimum design criteria.
2. *Spirals* - May also be used for smoother transitions. See Table 7.7 for minimum spiral lengths.
3. *Superelevation* - Superelevation on turning roadways does not need to be developed to the strict criteria of open highways. A flexible approach may be used where superelevation is provided as site conditions allow. The maximum superelevation is 0.04 m/m. If possible, the superelevation should be developed in the same manner as described in Section 6.5 for deceleration lanes at freeway exits.
4. *Speed-Change Lanes* - For large differences between the design speeds of mainline and turning roadway, the designer should consider deceleration and acceleration lanes. The decision to use a speed-change lane will depend upon the functional classification of the two highways, traffic volumes, accident history, design speed, and the speed differential between the mainline and turning roadway. Speed-change lanes should be provided from high-volume, high-speed urban and rural arterials. Acceleration lanes are normally provided when the turning roadway is merging with these facilities. A 15:1 taper is sufficient for deceleration lanes, and a 25:1 taper is preferred for the acceleration lane. Preferably, the length of the speed change lane should be determined from the criteria in Chapter 6 for interchanges (Tables 6.1. and 6.3).

Table 7.5

DESIGNS FOR TURNING ROADWAYS

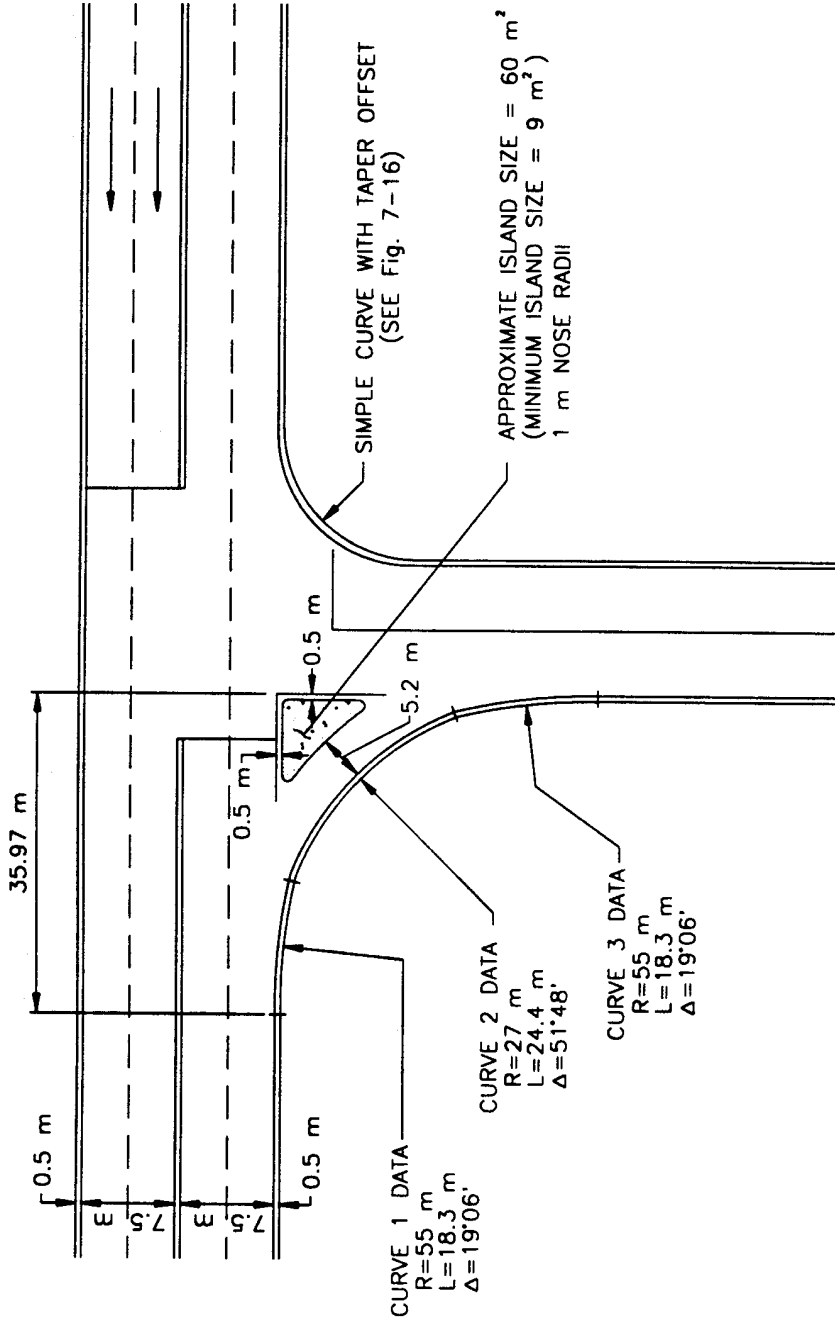
Design ¹ Speed (km/h)	Side Friction (f)	Assumed ² Superelevation (e)	e + f	Minimum ³ Radius (m)	Width (m) ⁴		
					A	B	C
30	.27	.02	.29	28	4.50	5.0	5.5
40	.23	.04	.27	46	4.25	5.0	5.25
50	.20	.04	.26	70	4.0	5.0	5.0

- Notes:**
1. For design speeds greater than 50 km/h use open highway conditions.
 2. Superelevation is typically between .02 and .04
 3. A flatter curve, no more than twice the minimum radius, should be used to transition into and out of the sharper radius. The minimum length of the flatter transition curve will be:

Radius (m)	30	45	60	75	90	120	150 ⁺
Minimum Length (m)	12	15	18	24	30	36	43
Desirable Length (m)	18	20	27	36	42	41	60

4. Add a minimum of 0.5 m and desirably 1.25m on each side of a barrier curb.
Traffic conditions are:

- A - Predominantly P vehicles, but some consideration for SU trucks;
- B - Predominantly SU vehicles, but some considerations for semitrailers;
- C - Sufficient bus and semitrailer vehicles to govern design (>10%)



TURNING ROADWAY DESIGN CRITERIA:
30 km/h
TRAFFIC CONDITION "B"
0.5 m EXTRA FOR CURB OFFSET

Figure 7-19. TYPICAL DESIGN FOR TURNING ROADWAY

Table 7.6 MINIMUM DESIGNS FOR TURNING ROADWAYS.

ANGLE OF TURN (degree)	DESIGN CLASSIFICATION	3-CENTERED COMPOUND CURVE		WIDTH OF LANE (m)	APPROX. ISLAND SIZE (m ²)
		RADII (m)	OFFSET (m)		
75	A	45-23-45	1.0	4.2	5.5
	B	45-23-45	1.5	5.4	5.0
	C	55-28-55	1.0	6.0	5.0
90°	A	45-15-45	1.0	4.2	5.0
	B	45-15-45	1.5	5.4	7.5
	C	55-20-55	2.0	6.0	11.5
105	A	36-12-36	0.6	4.5	6.5
	B	30-11-30	1.5	6.6	5.0
	C	55-14-55	2.4	9.0	5.5
120	A	30-9-30	0.8	4.8	11.0
	B	30-9-30	1.5	7.2	8.5
	C	55-12-55	2.5	10.2	20.0
135	A	30-9-30	0.8	4.8	43.0
	B	30-9-30	1.5	7.8	35.0
	C	48-11-48	2.7	10.5	60.0
150	A	30-9-30	0.8	4.8	130.0
	B	30-9-30	2.0	9.0	110.0
	C	48-11-48	2.1	11.4	160.0

*ILLUSTRATED IN FIGURE 7-19

NOTES: ASYMMETRIC THREE-CENTERED COMPOUND CURVE AND STRAIGHT TAPERS WITH A SIMPLE CURVE CAN ALSO BE USED WITHOUT SIGNIFICANTLY ALTERING THE WIDTH OF ROADWAY OR CORNER ISLAND SIZE.

PAINTED ISLAND DELINEATION IS RECOMMENDED FOR ISLANDS LESS THAN 7 m² IN SIZE

DESIGN CLASSIFICATION:

A-PRIMARILY PASSENGER VEHICLES; PERMITS OCCASIONAL DESIGN SINGLE-UNIT TRUCK TO TURN WITH RESTRICTED CLEARANCES.

B-PROVIDES ADEQUATELY FOR SU; PERMITS OCCASIONAL WB-15 TO TURN WITH SLIGHT ENCROACHMENT ON ADJACENT TRAFFIC LANES.

C-PROVIDES FULLY FOR WB-15.

Table 7.7 MINIMUM LENGTHS OF SPIRAL FOR INTERSECTION CURVES.

DESIGN (TURNING) SPEED (km/h)	30	40	50	60	70
MINIMUM RADIUS (m)	25	50	80	125	160
ASSUMED C	1.2	1.1	1.0	0.9	0.8
CALCULATED LENGTH OF SPIRAL (m)	19	25	33	41	57
SUGGESTED MINIMUM LENGTH OF SPIRAL (m)	20	25	35	45	60
CORRESPONDING CIRCULAR CURVE OFFSET FROM TANGENT (m)	0.7	0.7	0.7	0.8	0.9

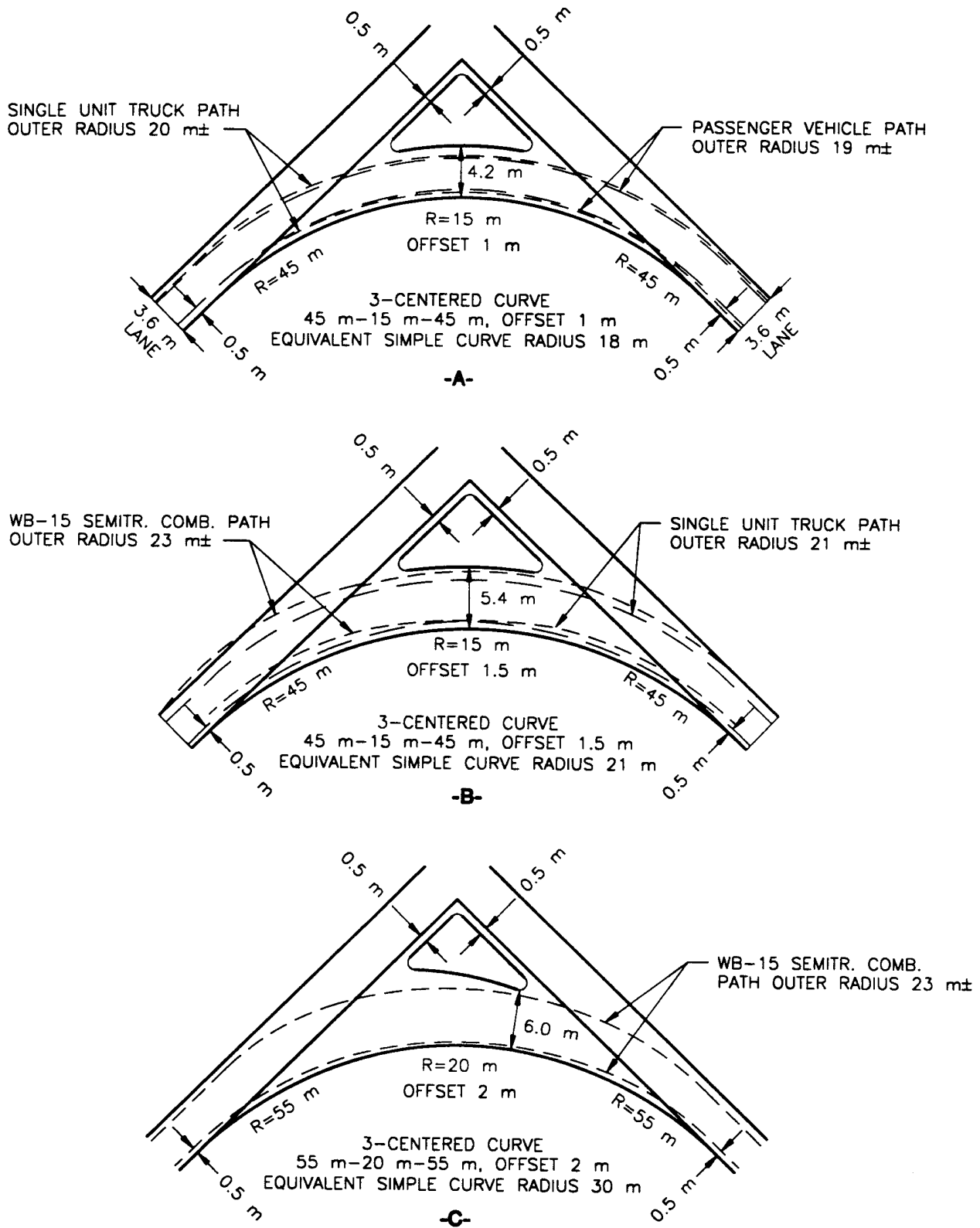


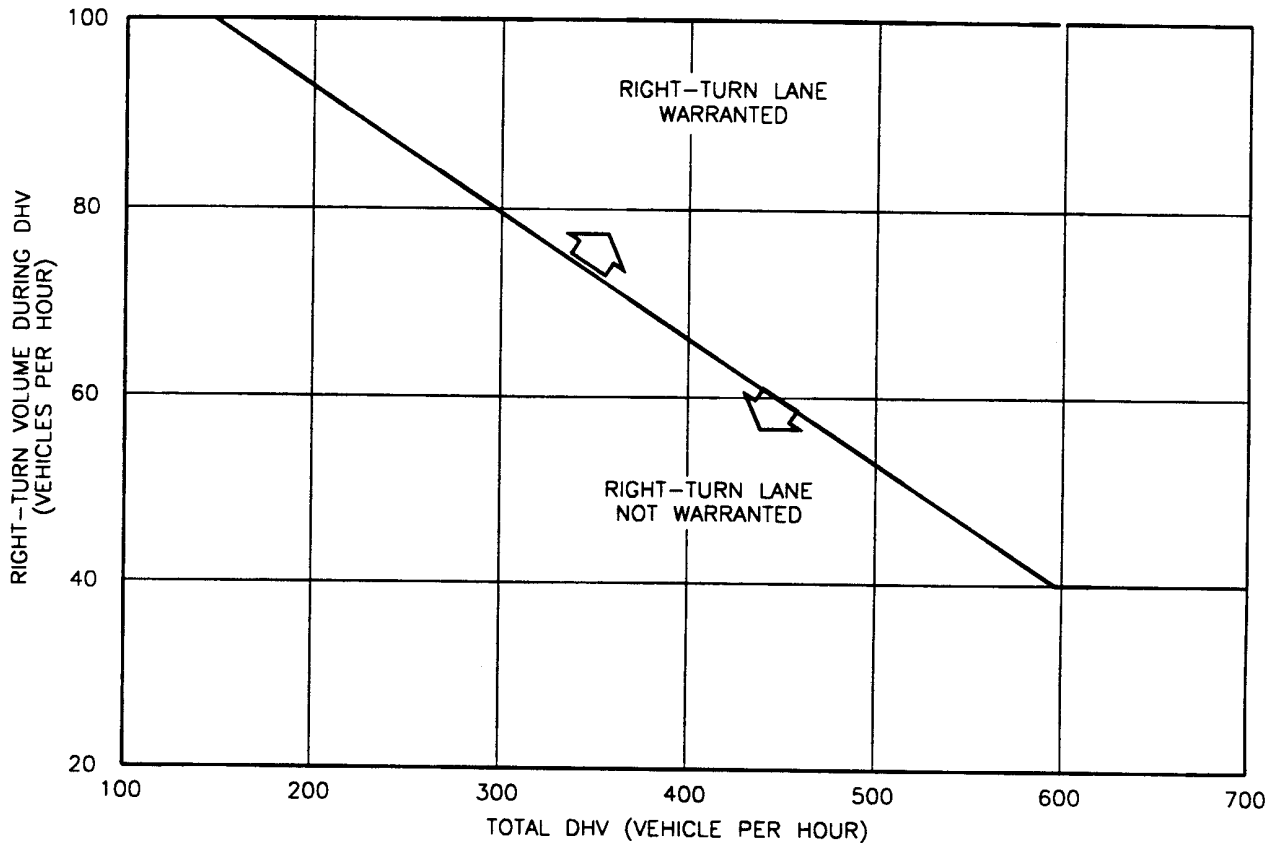
Figure 7-20. DESIGNS FOR TURNING ROADWAYS WITH MINIMUM CORNER ISLANDS.

7.3.2 Auxiliary Turning and Storage Lanes

7.3.2.1 Warrants for Right-Turn Lanes

Exclusive right-turn lanes should be considered for at-grade intersections, as follows:

1. at intersections with high-speed and/or high-volume turning movements;
2. at unsignalized intersections on two-lane urban or rural highways which satisfy the criteria in Figure 7-21;
3. at intersections where the accident experience, existing traffic operation, or engineering judgment indicate a significant hazard or capacity problem related to right turning vehicles.



REFERENCE: "GUIDELINES FOR TREATMENT OF RIGHT-TURN MOVEMENTS ON RURAL ROADS," TRANSPORTATION RESEARCH RECORD 855, 1982.

NOTE: FOR HIGHWAYS WITH A DESIGN SPEED BELOW 70 km/h AND DHV <300 AND RIGHT TURNS >40, AN ADJUSTMENT SHOULD BE USED. TO READ THE VERTICAL AXIS OF THE CHART, SUBTRACT 20 FROM THE ACTUAL NUMBER OF RIGHT TURNS.

EXAMPLE

GIVEN: DESIGN SPEED = 70 km/h
DHV = 250 VPH
RIGHT TURNS = 100 VPH

PROBLEM: DETERMINE IF A RIGHT-TURN LANE IS WARRANTED.

SOLUTION: TO READ THE VERTICAL AXIS, USE $100 - 20 = 80$ VPH. THE FIGURE INDICATES THAT A RIGHT-TURN LANE IS NOT WARRANTED, UNLESS OTHER FACTORS (e.g., HIGH ACCIDENT RATE) INDICATE A LANE IS NEEDED.

Figure 7-21. RIGHT-TURN WARRANTS AT UNSIGNALIZED INTERSECTIONS ON 2-LANE HIGHWAYS

7.3.2.2 Warrants for Left-Turn Lanes

Exclusive left-turn lanes should be considered for at-grade intersections, as follows:

1. at intersections with major roads on urban and rural arterials;
2. at unsignalized intersections on two-lane urban or rural highways which meet the criteria in the *Highway Capacity Manual*. Refer to Table 7.7.
3. at intersections where the accident experience, existing traffic operations, or engineering judgment indicate a significant hazard or capacity problem related to left-turning vehicles.

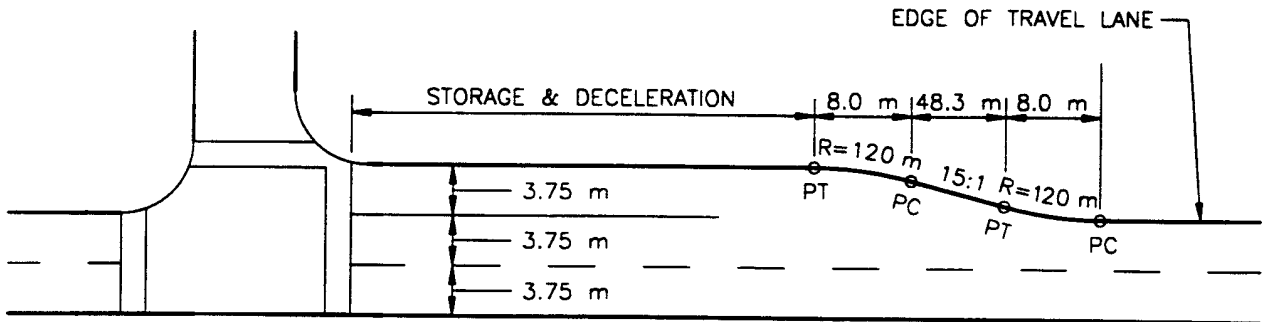
7.3.2.3 Length of Auxiliary Turn and Storage Lanes

The length of the turning lane is the sum of its taper, deceleration, and storage lengths:

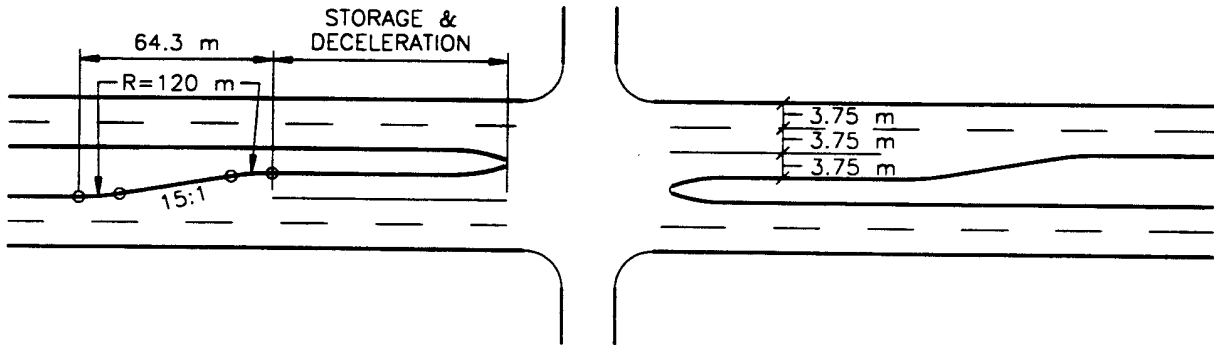
1. *Taper* - A taper of 15:1 should be used. Short curves should be used at the beginning and end of the taper.
2. *Deceleration* - It is desirable for the lengths for deceleration to be the same as those given for deceleration lanes at freeway exits in Chapter 6 (Table 6.1), and for all deceleration to occur within the full width of the turn lane. Figure 7-22 provides the minimum criteria for the length of turn lanes.

Table 7-8. GUIDE FOR LEFT-TURN LANES ON TWO-LANE HIGHWAYS.

ADVANCING VOLUME/HOUR				
OPPOSING VOLUME/HOUR	5% LEFT TURNS	10% LEFT TURNS	20% LEFT TURNS	30% LEFT TURNS
60 km/h OPERATING SPEED				
800	330	240	180	160
600	410	305	225	200
400	510	380	275	245
200	640	470	350	305
100	720	515	390	340
80 km/h OPERATING SPEED				
800	280	210	165	135
600	350	260	195	170
400	430	320	240	210
200	550	400	300	270
100	615	445	335	295
100 km/h OPERATING SPEED				
800	230	170	125	115
600	290	210	160	140
400	365	270	200	175
200	450	330	250	215
100	505	370	275	240



TYPICAL RIGHT-TURN LANE



TYPICAL LEFT-TURN LANE ON DIVIDED HIGHWAY

- Notes:**
1. WIDTHS MUST BE INCREASED FOR CURB OFFSETS OR SHOULDERS, WHERE APPLICABLE.
 2. AS SHOWN IN THE FIGURE, ALL DECELERATION WILL DESIRABLY OCCUR AFTER THE FULL WIDTH OF THE TURNING LANE BEGINS. IF POSSIBLE, THE CRITERIA IN Table 7-8 SHOULD BE USED. HOWEVER, IN AREAS OF RESTRICTED RIGHT-OF-WAY, THIS MAY NOT BE PRACTICAL. USE THE FOLLOWING MINIMUM DISTANCES FOR DECELERATION:
 3. SEE ALSO FIGURE 5-2

DESIGN SPEED (km/h)	LENGTH (m) (DECELERATION AND TAPER - GRADES 2% OR LESS)
50	70 m
60	100 m
80	130 m

Figure 7-22. TYPICAL RIGHT AND LEFT TURN LANES ON DIVIDED HIGHWAY

3. *Storage Length* - The storage length should be long enough to store the number of vehicles likely to accumulate in the design period. The following minimum criteria will apply:
 - a. At unsignalized intersections the storage length should accommodate the number of turning vehicles likely to arrive in an average two-minute period within the peak hour. As a minimum, 15 meters should be allowed; if the turning traffic is over 10% trucks, a minimum of 25 meters should be provided.
 - b. At signalized intersections, the storage length should be based on 1.5 or 2.0 times the average number of vehicles that would store per cycle.

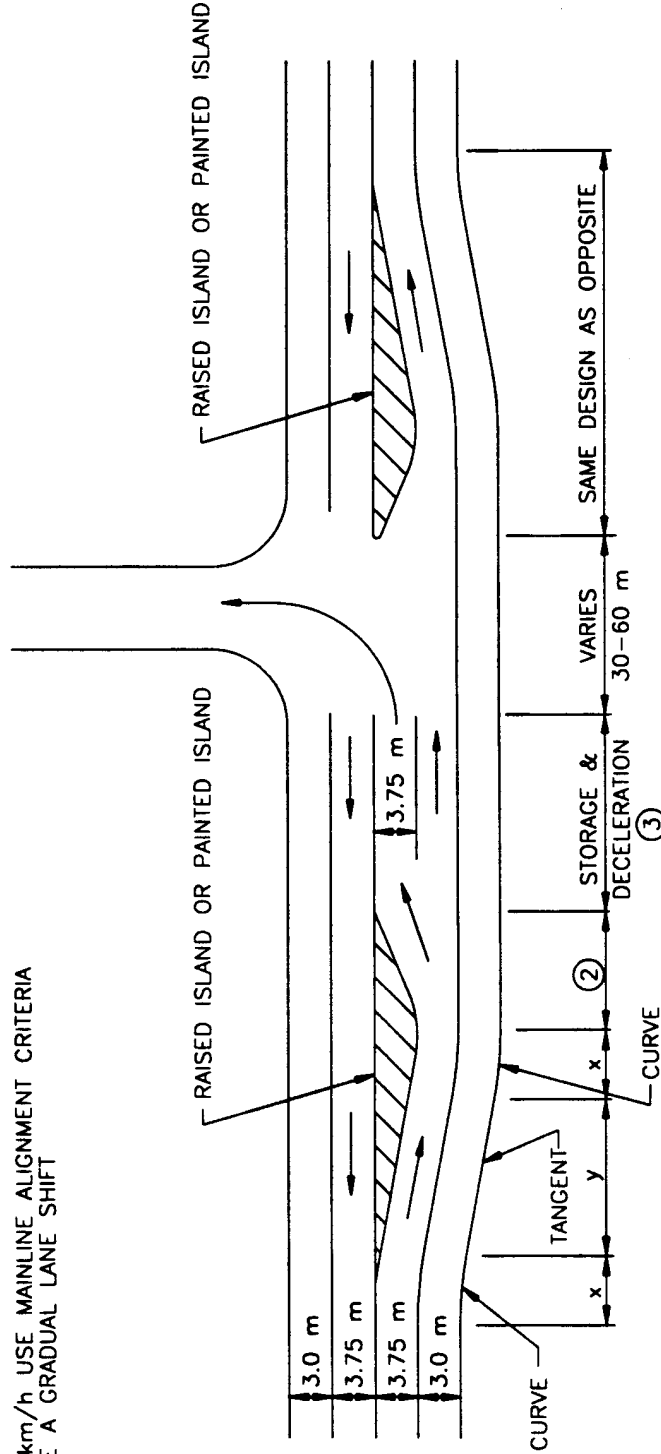
Right-and left-turn lanes should be designed as follows:

1. Figure 7-22 illustrates a typical right-turn lane and a typical left-turn lane (on a divided highway). Minimum distances for deceleration are provided.
2. Figure 7-23 illustrates the typical treatment for developing a left-turn lane on a undivided highway.
3. Figure 7-24 illustrates the typical design for a by-pass lane on low speed facilities in developed areas. This is a relatively inexpensive design to provide for through and left-turn movements at unsignalized intersections. It is appropriate for T-intersections where left-turning volumes are light to moderate, where right of way is restricted, and accident history is negligible.

TABLE ①

SPEED* (km/h)	R curve (m)	x (m)	y (m)
50	700	46.63	8.17
60	930	45.02	30.93

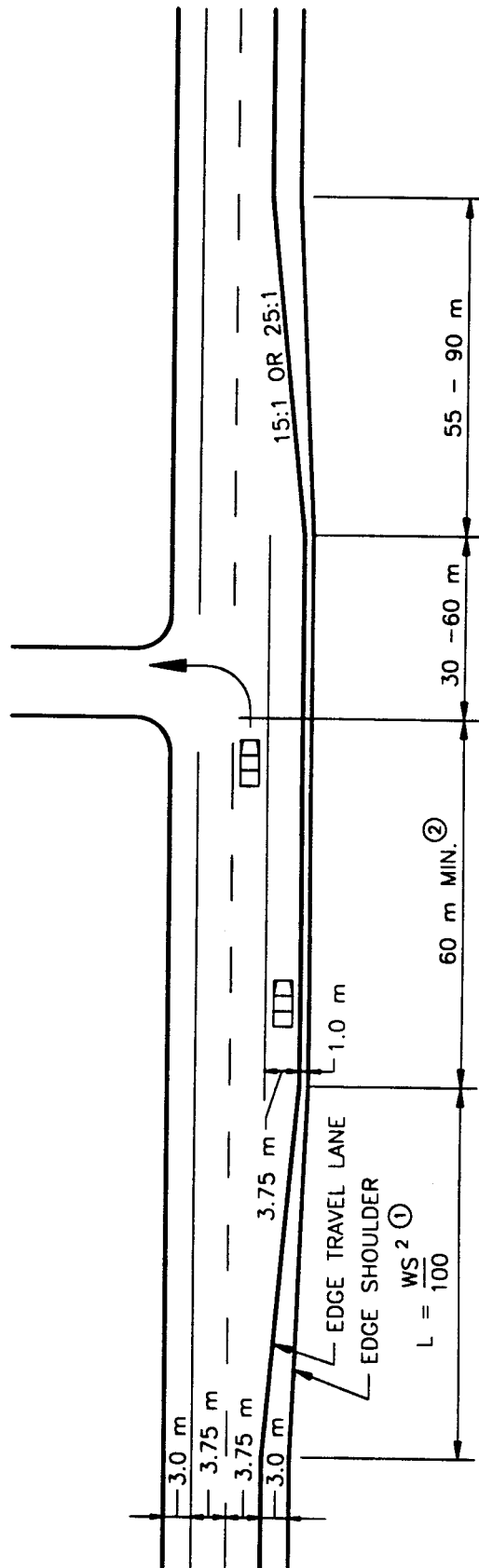
* ABOVE 60 km/h USE MAINLINE ALIGNMENT CRITERIA TO PROVIDE A GRADUAL LANE SHIFT



NOTES:

- TABLE VALUES ARE BASED ON:
 - CURVE RADIUS ARE MINIMUM RADIUS FOR OPEN HIGHWAY CONDITIONS FOR GIVEN DESIGN SPEED AND A NORMAL CROWN OF 0.02 m/m, WHICH IS THE TYPICAL CROSS SLOPE.
 - TANGENT DISTANCE ASSUMES A TAPER OF: $L = \frac{ws^2}{100}$
- SEE FIGURE 7-22 FOR DETAILS OF TURNING LANE TAPER.
- SEE FIGURE 7-22 FOR DETAILS OF TURNING LANE LENGTH.
- ISLAND MAY BE RAISED, PAINTED, OR SCORED CONCRETE.

Figure 7-23. TYPICAL LEFT-TURN LANE ON A UNDIVIDED HIGHWAY



- Notes:**
1. L = LENGTH, m
W = BY-PASS LANE WIDTH, m
S = DESIGN SPEED, km/h
 2. INCREASE LENGTH IF STORAGE REQUIREMENTS EXCEED 30 m.
 3. MAY BE USED AS AN ALTERNATIVE TO FIGURE 7-23 IN HIGHLY DEVELOPED AREAS, WHERE RIGHT-OF-WAY IS RESTRICTED.

Figure 7-24. BY-PASS LANE IN HIGHLY DEVELOPED AREAS ON AN UNDIVIDED HIGHWAY AT LESS THAN 60 km/h

7.3.2.4 Other Considerations

When designing an auxiliary turning and storage lane, these factors should also be considered:

1. Where the proper length of a turn lane cannot be provided or becomes prohibitive, the designer may consider a dual-turn lane. Generally, a dual-turn lane approximately 60% as long as a single-turn lane will operate comparably. However, double left turns require a protected turn phase to operate properly.
2. A right-turn lane in an urban area will often require parking restrictions beyond the usual restricted distances from the intersection. Also, it may require relocating near-side bus stops to the far side of the intersection.
3. With sufficiently wide medians, a left-turn lane may be offset 0.5 meters or more from the inside through lane to provide a striped island between the two.
4. Medians must be designed to accommodate the turning radii of the design vehicle.
5. Pavement markings for lane demarkation must line up from one side of the intersection to the other.
6. The width of the turn lane should be according to Figure 5-2.
7. Median openings should be designed according to the criteria in Section 7.3.5.

7.3.3 Two-Way Left-Turn Lanes

A continuous or two-way left-turn lane (2WLTL) is a paved, flush, traversable median which can be used for left-turn storage in either direction. A 2WLTL may be considered in developed areas with frequent commercial roadside access and with no more than two through lanes in each direction.

Although the 2WLTL offers many advantages, they are hazardous unless there is sufficient sight distance and adequate delineation. The following should be used as guidance in selecting and designing a 2WLTL:

1. A 2WLTL is limited to arterials with operating speeds of 70 km/hr or less.
2. The preferred lane width is 4.5 meters with a minimum lane width of 3.75 meters.

3. At minor intersections, the 2WLTL should be extended up to the intersection. At major and/or signalized intersections, the 2WLTL should be terminated in advance of the intersection. An exclusive left-turn lane of the proper length should be provided. This should be accomplished according to the methods in the *MUTCD*.
4. Any 2WLTL must be clearly marked and adequately delineated to prevent possible use as a passing lane. Overhead signing should be used. Pavement markings and signing for the 2WLTL are described in the *MUTCD*.
5. A 2WLTL may be used where average daily traffic through volumes are 10,000 to 20,000 (4 lane) and 5,000 to 12,000 (2 lane) and left turns consist of at least 70 midblock turns per 300 meters during peak hour and/or 20% or more of the total volume. High left-turning volumes combined with high ADT's could possibly lead to operational and safety problems. Restricting all left turns except at public road intersections and indirect (jug handle) U-turns, or providing a raised median, with left turn and/or U-turn lanes should also be considered. Each site requires careful evaluation of the suitability of the 2WLTL.

7.3.4 Channelization

At-grade intersections with large paved areas permit undesirable vehicle movements, encourage vehicle wandering from intended paths, result in larger unused pavement areas, and require long pedestrian crossings. This often occurs at oblique angle intersections and where turning radii are designed to accommodate large vehicles. Channelization with islands can be used effectively to eliminate these problems.

Channelized islands can be used to control and direct traffic movements, protect and store turning and crossing vehicles, divide opposing traffic flows, or provide an area for pedestrian refuge and traffic control devices. They may be triangular or elongated and may be raised, painted, or scored concrete. Raised islands are preferable. Following are general criteria for channelization and islands:

1. The minimum size of a triangular island should be 9 square meters. Elongated islands should be at least 0.5 meters wide and preferably 1.0 meters. They should be 2.0 meters wide if signs are used. Their minimum length is 8 meters.
2. Islands used for channelization should not interfere with or obstruct bicycle lanes at intersection.

3. Approach ends of islands should be offset from the edges of the traveled way to funnel drivers smoothly into the desired path. Tapers should be smooth and extended to provide a natural transition from the offset back to the controlling edge of the island.
4. Islands for pedestrian use must be designed to be handicapped-accessible by incorporating ramps, lateral clearances, and surface treatments in accordance with the Americans with Disabilities Act Requirements and Architectural Access Board.

Additional guidance for channelization design may be found in the *Intersection Channelization Design Guide* NCHRP 279.

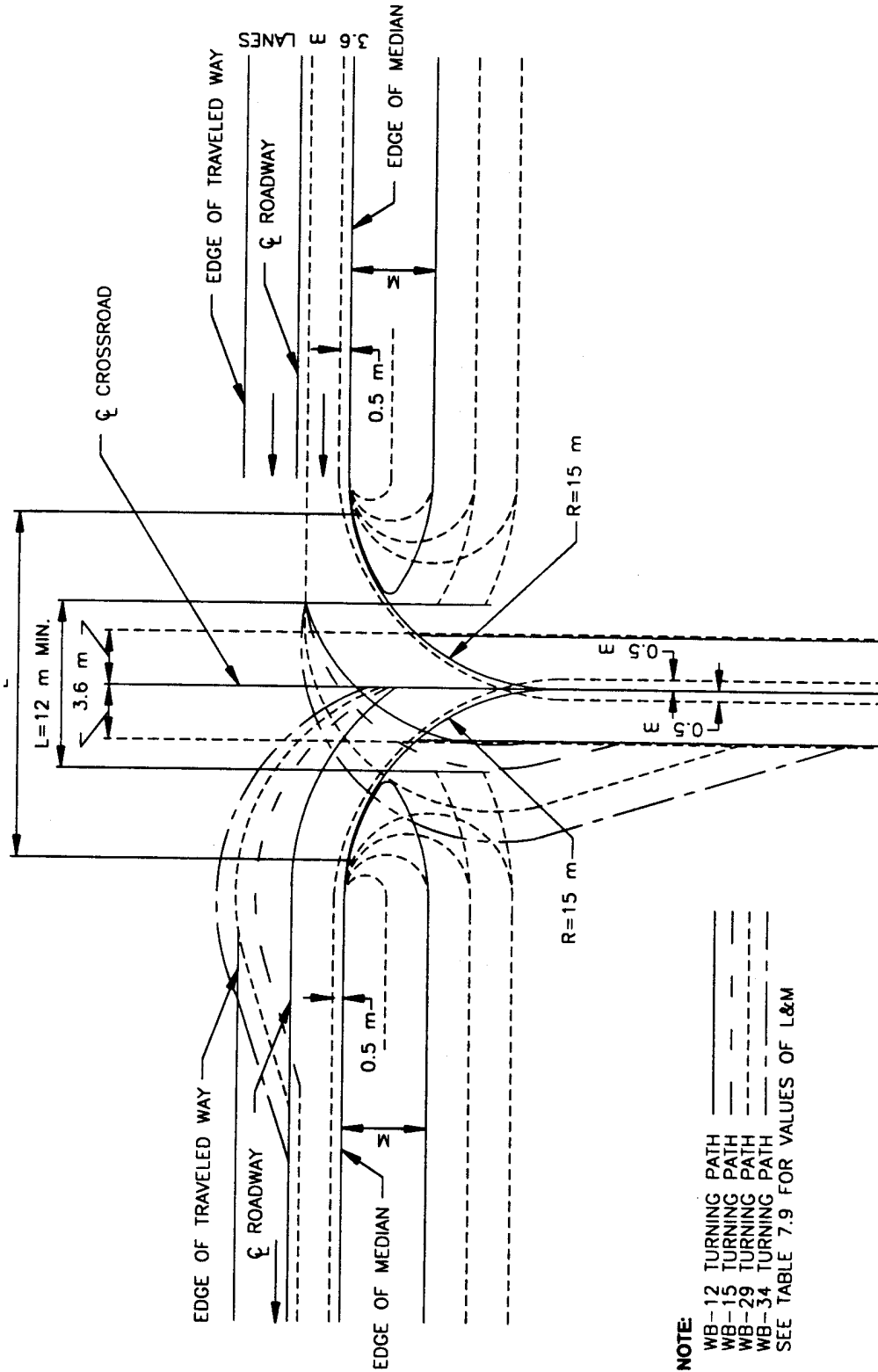
7.3.5 Median Openings

Median openings should be provided primarily at public road intersections and to allow left turns to and from the main highway.

In order to provide coordinated signal progression for mainline traffic, median openings should not be closely spaced. On major arterials, signalized intersections with median openings should be spaced no closer together than 500 meters to 600 meters. On minor arterials, signalized intersections with median openings should be spaced no closer together than 400 meters to 500 meters.

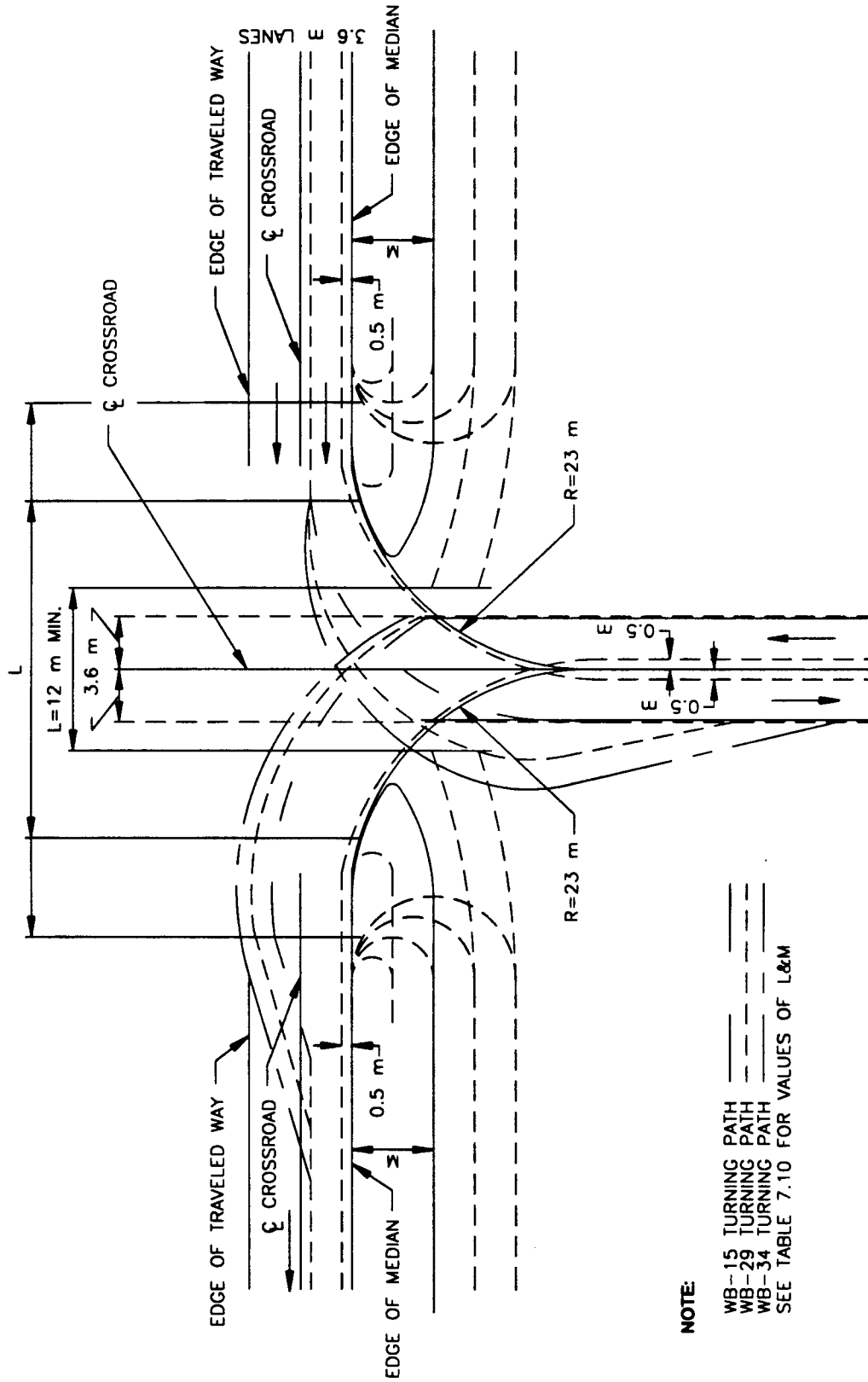
Median openings must be designed to accommodate left-turning vehicles properly. Left-turning vehicles trace essentially the same path as right-turning vehicles. Figure 7-25 and 7-26 illustrate the design vehicle paths and provide the criteria for intersections with control radii 15 meters and 23 meters. The following criteria apply:

1. The nose should be designed to accommodate the traffic movement at the intersection.
2. The minimum lengths of median openings are 12 meters and are shown on Tables 7.9.to 7.12. Intersections on a skew may require larger openings.
3. The acceptable encroachment is the primary factor in selecting the design vehicle. The median opening figures illustrate how much the larger vehicles encroach on the adjacent lanes for a given design. The decision to use the SU, or WB-15 design is based on truck volumes, through traffic volumes, design speed, accident history, costs, signalization and judgment.



NOTE:
 WB-12 TURNING PATH
 WB-15 TURNING PATH
 WB-29 TURNING PATH
 WB-34 TURNING PATH
 SEE TABLE 7.9 FOR VALUES OF L&M

**Figure 7-25. MINIMUM DESIGN OF MEDIAN OPENINGS
(SU DESIGN VEHICLE, CONTROL RADIUS OF 15 m).**



**Figure 7-26. MINIMUM DESIGN OF MEDIAN OPENINGS
(WB-12 DESIGN VEHICLE, CONTROL RADIUS OF 23 m).**

Table 7.9
MINIMUM DESIGN OF MEDIAN OPENINGS
(SU DESIGN VEHICLE, CONTROL RADIUS OF 15 m).

WIDTH MEDIAN (M)	L=MINIMUM LENGTH OF MEDIAN OPENING (m)	
	SEMICIRCULAR	BULLET NOSE
1.2	28.8	28.8
1.8	28.2	22.8
2.4	27.6	20.4
3.0	27.0	18.6
3.6	26.4	17.4
4.2	25.8	15.9
4.8	25.2	15.0
6.0	24.0	13.2
7.2	22.8	12.0 MIN
8.4	21.6	12.0 MIN
9.6	20.4	12.0 MIN
10.8	19.2	12.0 MIN
12.0	18.0	12.0 MIN
15.0	15.0	12.0 MIN
18.0	12.0 MIN	12.0 MIN
21.0	12.0 MIN	12.0 MIN

Table 7.10
MINIMUM DESIGN OF MEDIAN OPENINGS
(WB-12 DESIGN VEHICLE, CONTROL RADIUS OF 23 m).

WIDTH MEDIAN (M)	L=MINIMUM LENGTH OF MEDIAN OPENING (m)	
	SEMICIRCULAR	BULLET NOSE
1.2	43.8	36.6
1.8	43.2	34.5
2.4	42.6	33.0
3.0	42.0	31.5
3.6	41.4	30.0
4.2	40.8	28.8
4.8	40.2	27.6
6.0	39.0	25.5
7.2	37.8	23.4
8.4	36.6	21.9
9.6	35.4	20.1
10.8	34.2	18.6
12.0	30.0	17.1
18.0	27.0	12.0 MIN
24.0	21.0	12.0 MIN
30.0	15.0	12.0 MIN
33.0	12.0 MIN	12.0 MIN
36.0	12.0 MIN	12.0 MIN

Table 7.11
EFFECT OF SKEW ON MINIMUM DESIGN FOR MEDIAN OPENINGS
(TYPICAL VALUES BASED ON CONTROL RADIUS OF 15 m)

SKEW ANGLE (degrees)	WIDTH OF MEDIAN (m)	LENGTH OF MEDIAN OPENING MEASURED NORMAL TO THE CROSSROAD (m)			
		SEMI-CIRCULAR A	BULLET NOSE		R FOR DESIGN C (m)
			SYMMETRICAL B	ASYMMETRICAL C	
0	3	27	19	--	--
	6	24	13	--	--
	9	21	12 MIN.	--	--
	12	18	12 MIN.	--	--
	15	15	12 MIN.	--	--
	18	13	12 MIN.	--	--
10	3	32	24	23	21
	6	28	17	16	20
	9	25	14	12 MIN.	20
	15	21	12 MIN.	12 MIN.	19
	15	18	12 MIN.	12 MIN.	18
	18	14	12 MIN.	12 MIN.	18
20	3	36	29	27	29
	6	32	22	20	28
	9	28	18	14	26
	12	24	14	12 MIN.	25
	15	20	12 MIN.	12 MIN.	23
	18	16	12 MIN.	12 MIN.	21
30	3	41	34	32	42
	6	36	27	23	39
	9	31	23	17	36
	12	27	19	13	33
	15	23	15	12 MIN.	30
	18	18	12	12 MIN.	27
40	3	44	38	35	63
	6	39	32	27	58
	9	35	27	20	53
	12	29	23	15	47
	15	24	19	12 MIN.	42
	18	19	15	12 MIN.	36

Table 7.12
DESIGN CONTROLS FOR MINIMUM MEDIAN OPENINGS

DESIGN VEHICLES ACCOMMODATED	CONTROL RADIUS (m)		
	12	15	23
PREDOMINANT	P	SU	WB-12
OCCASIONAL	SU	WB-12	WB-15

On access controlled freeways, median crossings are prohibited, and on rural expressways the openings may be infrequent. However, occasional median openings for emergency crossovers are needed to accommodate maintenance and emergency vehicles. The following should be considered:

1. Emergency crossovers should be placed well away from any mainline conflicts, such as interchanges.
2. Because of the unexpected U-turn maneuver, sight distance must be great when vehicles make U-turns on access controlled highways. At a minimum, decision sight distance in the upper ranges, as described in Section 3.6.2 must be provided.
3. To discourage use by unauthorized vehicles, the crossover should be unpaved, but a stabilized gravel treatment should be used.
4. Emergency crossovers should be avoided when a median barrier is present. If a crossover must be provided, the barrier should be terminated as described in Section 9.4.3.4. The width of the opening should be about 8 to 10 meters. A sliding median barrier gate may be considered at these locations.

7.4 Driveways

Several factors should be addressed in the geometric design of driveways:

1. *Width/Turning radii* - Figure 7-27 to 7-29 provide the criteria for driveway spacing, frequency, width, and turning radii for various types of highways.
2. *Sight distance* - The criteria from Section 7.2 also apply to driveways. Normally, Cases IIIB and IIIC for turning vehicles will govern. Drivers on the mainline should, when feasible, have decision sight distance to the driveway entrance (0.0 meter height of object). At a minimum, stopping sight distance (1300 mm height of object) must be provided.
3. *Vertical profile* - To allow entrance and exit speeds of at least 15 km/hr, the vertical profile cannot exceed certain limits without causing vehicle underride and edge clearance problems. Maximum grades for residential driveways are 10%-15% and for commercial 5% to 8%. Vertical curves at least 3.0 meters in length may be used to connect the tangent slopes.
4. *Auxiliary lanes* - Turning and storage lanes should be considered on high-speed,

high-volume roadways. Section 7.3.2. further discusses the design and warrants for these lanes.

5. *Side slopes* - Where an open channel is used for roadside drainage, the channel will intercept the driveway at approximately a 90-degree angle. The driveway side slope, including the pipe end section for the channel, should not exceed 1:6. Preferably, it will be 1:12.

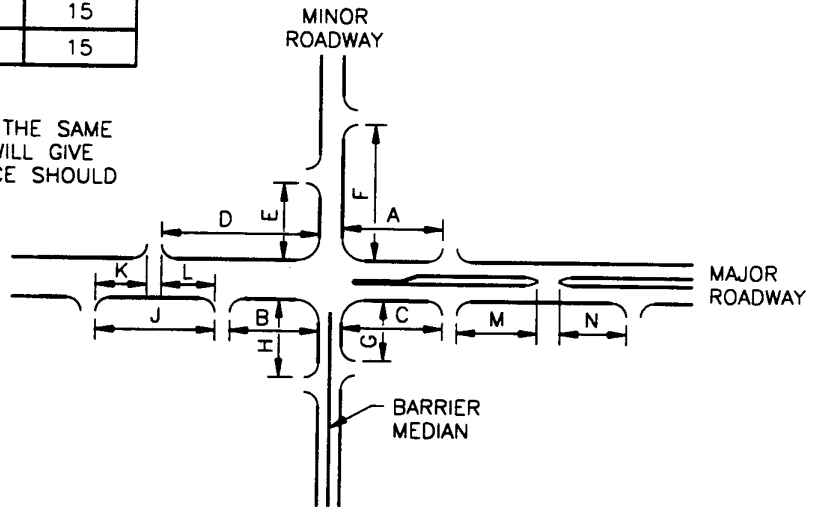
6. *Sidewalks, Bikeways and Parking lanes* - These roadside elements need to be considered in the geometric design of driveways. A minimum 1.0 meter wide wheelchair path of no more than 2% cross slope must be provided where a driveway crosses a sidewalk.

In addition to the geometric design, the designer should consider replacing the driveway surface with the same type of material existing before construction. However, if construction will make radical changes on unpaved driveways, it may be necessary to pave the surface for proper drainage and erosion prevention. In all cases, the driveway should be paved to the roadway layout.

MINIMUM CORNER CLEARANCES (m)			
ITEM	CLASS OF MAJOR ROADWAY		
	ARTERIAL	COLLECTOR	LOCAL
A	35	23	15
B	26	26	15
C	35	23	15
D	35	23	15
E	70	35	15
F	70	53	15
G	15	15	15
H	70	53	15

MAXIMUM DRIVEWAY SPACINGS (m)			
ITEM	ROADWAY CLASS		
	ARTERIAL	COLLECTOR	LOCAL
J	23	15	10
K	23	0	0
L	23	15	10
M	23	0	0
N	23	15	10

Note: WHERE BOTH ROADWAYS ARE OF THE SAME CLASS, THE DIMENSIONS WHICH WILL GIVE THE GREATEST CORNER CLEARANCE SHOULD BE USED.



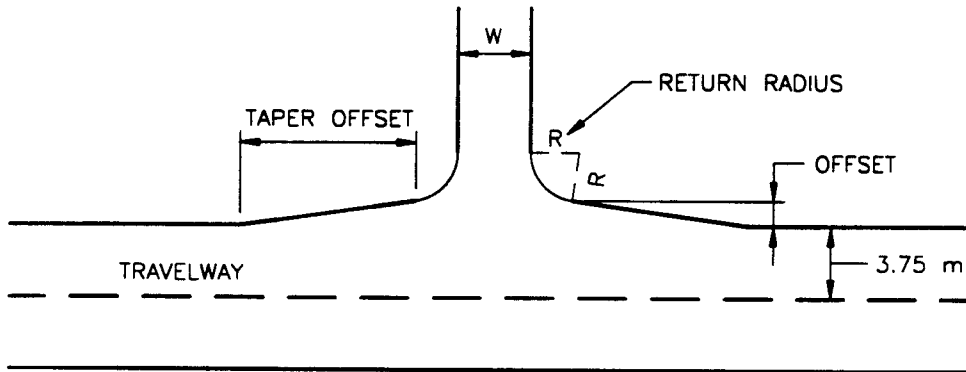
CORNER CLEARANCES AND DRIVEWAY SPACINGS

Note: THESE DIMENSIONS RECOMMENDED FOR 50 km/h. DISTANCES SHOULD BE PROPORTIONATELY HIGHER AT HIGHER SPEEDS.

FUNCTIONAL CLASS	URBAN	RURAL
MAJOR ARTERIAL	MAJOR TRAFFIC GENERATORS	3 PER KILOMETER PER SIDE
MINOR ARTERIAL	1 PER 60 m OF FRONTAGE	8 PER KILOMETER PER SIDE
COLLECTOR	1 PER 15 m OF FRONTAGE	NO CONTROL
LOCAL	NO CONTROL	NO CONTROL

DRIVEWAY FREQUENCY

Figure 7-27. DRIVEWAY SPACING AND FREQUENCY GUIDELINES



Note: PREFERABLY, THE RADIUS SHOULD NOT EXTEND BEYOND THE PROPERTY LINE

PASSENGER VEHICLE @ 0+ km/h							
OFFSET (m)	0	0.5	1.0	2.0	3.0	4.0	
RETURN RADIUS (m)	1.5	15.8	13.1	10.4	9.1	7.3	5.8
	3	14.3	11.9	9.4	7.9	6.0	4.9
	4.5	14.0	11.6	7.9	6.7	5.2	4.5
	6	11.0	8.8	6.7	5.8	4.5	4.5
	7.5	9.7	7.6	5.5	4.5	4.5	4.5
	9	7.6	6.0	4.5	4.5	4.5	4.5
	12	4.5	4.5	4.5	4.5	4.5	4.5

Notes:

1. THESE WIDTHS WILL ALLOW THE DESIGN VEHICLE TO NEGOTIATE THE TURN AT THE INDICATED SPEED WITHOUT ENCRANCHING ON ADJACENT THROUGH LANES AND WITHIN THE DRIVEWAY WIDTH.
2. THE OFFSET SHOULD BE ACHIEVED BY A STRAIGHT TAPER, USUALLY 10:1 OR 15:1. THE TABLE VALUES ASSUME AN OFFSET IS ONLY PROVIDED ON THE MAINLINE. NARROWER DRIVEWAY WIDTHS MAY BE USED IF THE OFFSET IS PROVIDED ON BOTH DRIVEWAY AND MAINLINE.
3. DRIVEWAYS IN RESIDENTIAL AREAS MAY HAVE A MORE RESTRICTED DESIGN. THE SHARPER RADIUS AND SMALLER OFFSETS MAY BE USED WITH A WIDTH OF 5 m.
4. THE TABLE WIDTHS ARE FOR 1-WAY OPERATION. FOR 2-WAY OPERATION, THE TOTAL WIDTH WOULD BE THE SUM OF THE WIDTH BASED ON THE ENTRANCE DESIGN CONDITIONS PLUS THE WIDTH BASED ON EXIT DESIGN CONDITIONS. THE MINIMUM 2-WAY WIDTH SHOULD BE 9m. FOR LARGE TRAFFIC GENERATORS, THE DESIGN SHOULD PROVIDE AN ISLAND.
5. ABOVE 60 km/h USE ACCELERATION/DECELERATION CRITERIA FOR DRIVEWAY ENTRANCES AND EXITS.

Figure 7-28. RECOMMENDED RESIDENTIAL DRIVEWAY WIDTHS (W) FOR 90° INTERSECTIONS

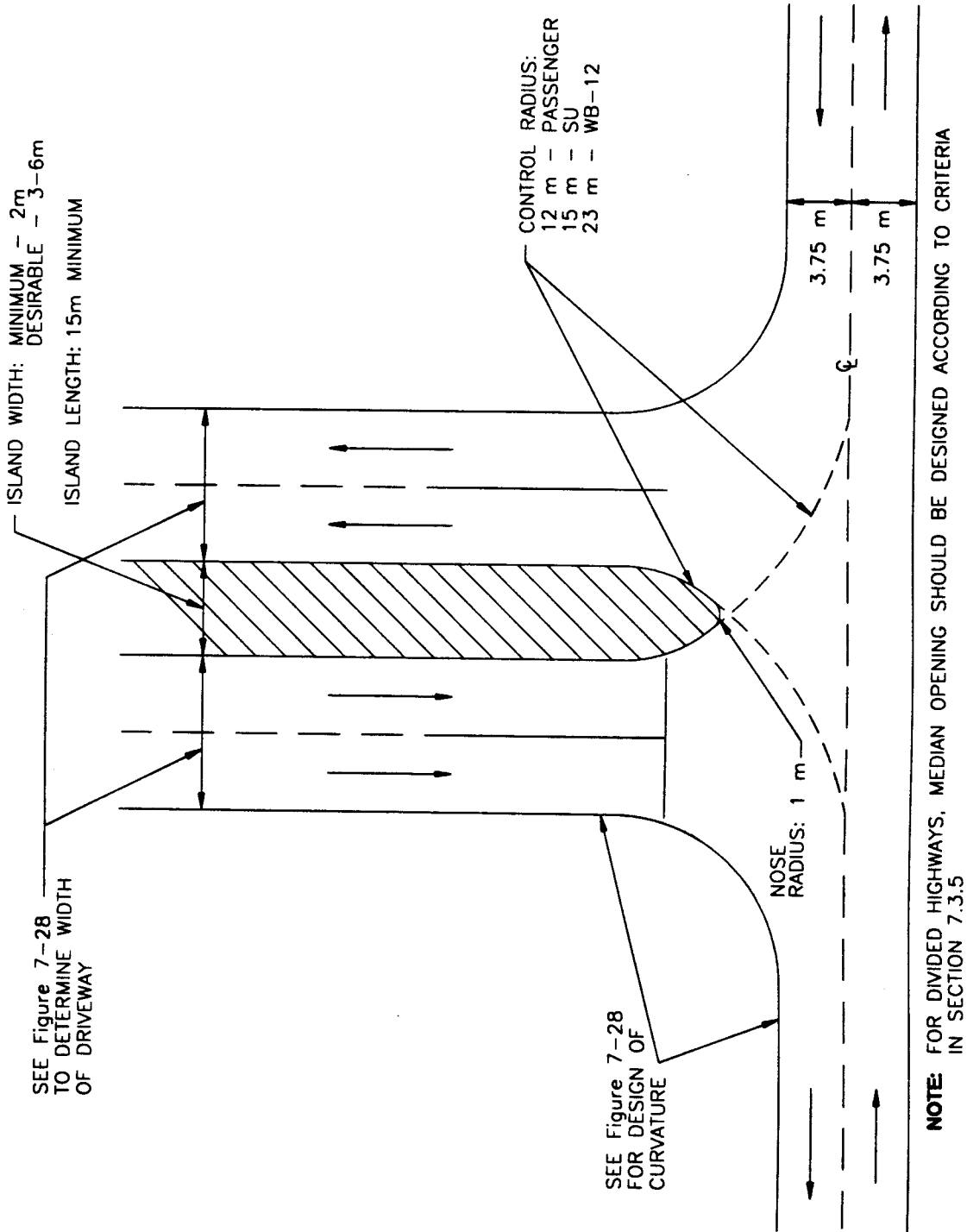


Figure 7-29. DRIVEWAY DESIGN-MAJOR TRAFFIC GENERATORS

7.5 REFERENCES

- *A Policy on Geometric Design of Highways and Streets*, AASHTO 1994.
- *Highway Capacity Manual*, Special Report No. 209, Transportation Research Board.
- *Manual on Uniform Traffic Control Devices*, FHWA.
- *Institute of Traffic Engineers Recommended Practice*, "Guidelines for Driveway Design and Location," 1986.
- *Technical Council Information Report*, "Design and Use of Two-way Left-Turn Lanes," Institute of Traffic Engineers, ITE Journal, February, 1981.
- *Guidelines for Treatment of Right-Turn Movements on Rural Roads*," Transportation Research Record 855, 1982.

CHAPTER 8

DESIGN EXCEPTIONS

8.1 DESIGN EXCEPTIONS

The Massachusetts Highway Department has adopted the American Association of State Highway Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets 1994* (the "Green Book") for design criteria. The Federal Highway Administration (FHWA) has also adopted the Green Book, supplemented with *A Policy on the Interstate System*, AASHTO as standard design criteria. This Highway Design Manual has incorporated AASHTO criteria for Massachusetts' roadway and bridge design. This is for the most part because AASHTO criteria is based on years of research and empirical data for the safe and efficient movement of vehicular traffic. As the result of recent ISTEA Federal Legislation, MHD has the option of developing its own standards for non-NHS roadways. Section 8.2, Low/Speed/Low Volume Roads are types of projects which are categorically exempt from AASHTO standards. All other projects must be reviewed and approved on a project by project basis.

The FHWA and MHD recognize 13 controlling criteria from AASHTO policy which, if not met, require formal approval of design exceptions. These criteria are:

Roadway and Bridge Criteria;

- design speed
- lane width
- shoulder width
- horizontal alignment
- vertical alignment
- grades
- stopping sight distance
- cross slope
- superelevation
- horizontal clearance (other than "clear zone")

Bridge only Criteria;

- width
- structural capacity
- vertical clearance

Desirable and minimum standards for most of these controlling criteria are found in various parts of this manual and the AASHTO Green Book. Structural capacity criteria is in the MHD Bridge Manual. Guidance for horizontal clear zone, although not a controlling criteria requiring a Design Exception, is found in the AASHTO Roadside Design Guide. Every reasonable effort should be made to use the desirable standards. Use of less than desirable values should be justified within Functional Design Report. Although minimum standards are acceptable, when the minimum standards can not be achieved, documentation and approval of these as Design Exceptions are required. Use of less than minimum standards must be based on sound engineering judgement weighing relevant factors. Some criteria, such as Design Speed, affects other criteria, and any interrelated criteria must also be addressed. Safety and traffic operations must not be reduced on the facility as a result of using lower standards.

For resurfacing, rehabilitation and minor reconstruction projects, the values in Table 8.1 may be substituted for the values in Table 5.1. Reasons for not using the Table 5.1 values should be documented in a design exception request, however, use of the lower values will generally require minimal justification.

Table 8.1
Widths - Resurfacing, Rehabilitation, and minor Reconstruction Projects

TRAVEL LANES	
Width In Table 5.1(m)	Substitution Width (m)
3.75	3.6
3.5	3.3
3.25	3.0
3.0	3.0
2.75	2.7
USABLE SHOULDER	
Width In Table 5.1(m)	Substitution Width (m)
3.5	3.3
3.0	3.0
2.5	2.4
1.25	1.2
0.75	0.6

Consideration should first be given to using the Table 5.1 travel lane dimensions and, if necessary, reducing the shoulder dimension to fit existing conditions.

8.1.1 Design Exception Process

If minimum controlling criteria can not be met, documentation of design exceptions is required for all projects, regardless of functional classification or funding. Documentation is required for using less than minimum standards to demonstrate that sound engineering judgement was used to design the improvements. Such documentation may be required at a later date to prove that the roadway was designed prudently. This documentation may even be required in a court of law if an accident occurs on the facility to demonstrate that sound engineering judgement was used and that the design element was not arbitrary. Documentation for all MHD Design Exceptions should follow the guidelines included in this manual, FHWA procedures from the *Federal-Aid Program Guide (FAPG) Transmittal 9 and 23 CFR, Part 625* as revised, and relevant FHWA and MHD Policy and Engineering Directives. Because of its relevance to all roadway and bridge projects, and the need for consistent applicability of design exception issues, the FHWA guidance should be followed regardless of project funding.

All Design Exceptions must be forwarded to and approved by the Chief Engineer. Projects which normally require Federal Highway Administration review must also be forwarded to FHWA for review and approval of the Design Exception.

8.1.1.1 Design Exception Documentation

Documentation of the Design Exception should be in report format. This report should include but not be limited to:

- * Executive Summary:
 - A brief description of the proposed project
 - A listing of the controlling criteria for which a design exception is requested

- * Proposed Improvement
 - Description of proposed project
 - Type of project; reconstruction, rehabilitation, etc.
 - Purpose of improvements; safety?, capacity?
 - Other existing deficiencies to be improved by the project

- * Description of the Existing Conditions, include:
 - Functional Classification of the roadway(s)
 - Traffic character and volumes
 - Description of Surrounding Area
 - Developed or Undeveloped
 - Scenic?
 - Speeds
 - Posted
 - 85 percentile
 - Observed?
 - Design Speed?
 - Existing lane and shoulder width (usable shoulder?)
 - Right of Way layout
 - Accident data
 - Environmental Factors
 - Wetlands?
 - Trees?
 - Parklands?
 - Cultural Resources
 - Historic or Archaeological Areas

- * Discussion of Design Exceptions, include:
 - A separate discussion of each controlling criteria (Sec. 8.1)
 - MHD and AASHTO Desirable and Minimum Standards
 - Project proposed values and degree of reduction
 - Typical section (s) or other graphical description of the existing and proposed improvement along with other roadway elements
 - An analysis of the accident data as it relates to the controlling criteria
 - Discussion of compatibility with adjacent roadway sections and future expectations for corridor improvements
 - If a Design Speed exception is requested, a discussion of effects on other controlling criteria
 - Discussion of right of way constraints
 - Discussion of environmental, cultural resource, or other constraints
 - Any features that might be used to mitigate the substandard feature such as signing and striping
 - A rough cost estimate of the incremental cost to comply with MHD/AASHTO minimum standards. A benefit/cost analysis and/or a Value Engineering assessment may also be included when appropriate data is available.

- * Recommendation/Summary
The designer must document that reasonable engineering judgement was used to justify the proposed design by drawing from the above information

8.1.1.2 Approval Process

The Design Exception documentation is normally prepared by the design engineer and forwarded to the project manager for review. The project manager then forwards the document under the signature of the appropriate Deputy Chief Engineer, along with any recommendations, to the Chief Engineer for approval. Design Exceptions on all projects which otherwise require FHWA review are then forwarded to FHWA for approval. Upon receipt of all approvals, the documentation and the approval letters must be kept in a permanent project file for future reference. The project submittal to the Capital Expenditures Program Office (CEPO) for construction advertising should include a statement such as "design exceptions have been approved for this project and are on file".

8.2 Low Speed/Low Volume Roads

The following are the design standards for **resurfacing, rehabilitation and reconstruction of existing low speed/ low volume roadways**. New roadway construction of low speed/ low volume roadways should adhere to the design standards found elsewhere in this manual.

As in conventional roadway design, design standards are based on the functional classification of the roadway. Because of the transportation significance of the National Highway System and the rest of the arterial system and the fact that most arterials (including minor arterials) are high speed/high volume facilities, arterials and freeways are not included in this low speed/low volume criteria. Therefore, only roadways functionally classified as **Collectors and Local Roads** are subject to low speed/low volume roadway criteria discussed in this section.

For the purpose of these standards the following definitions apply:

Speed is defined as the 85th percentile running speed. This is usually, but not always, the posted speed. (Often, the posted speed may be set artificially lower than the 85th percentile speed for safety or local reasons.) Low speed is defined as less than **70 km/h**.

Volume is defined as Average Annual Daily Traffic (AADT). Low volume is defined as **2000 AADT** or less.

Design Year (for estimating future AADT)

Resurfacing projects	5 years
Rehabilitation projects	10 years
Reconstruction projects	20 years

8.2.1 Design Criteria for Low Speed/Low Volume Roadways

The following criteria may be used for existing low speed / low volume road designs.

Travel Lane and Shoulder Width

Table 8.2 defines the required travel lane and shoulder (usable and/or graded) dimensions for low speed/low volume roads based on the 85th percentile running speed.

Horizontal Curvature / Sight distance

Stopping Sight Distance should be in accordance with at least the minimum sight distances on Table 3.9 based on the 85th percentile running speed.

Vertical Curvature / K values

The K values should be in accordance with the at least the minimum K values on Tables 4.4 and 4.5, based on the 85th percentile running speed.

TABLE 8.2
MINIMUM ROADWAY WIDTHS FOR
LOW SPEED / LOW VOLUME ROADWAYS

DESIGN YEAR ADT	RUNNING (OPERATING SPEED) (85TH PERCENTILE)																
	50 KM/H		50 - 60 KM/H		65 KM/H												
	TRAVEL LANE METERS	USABLE SHOULDER METERS	OFF-SET METERS	TRAVEL LANE METERS	USABLE SHOULDER METERS	OFF-SET METERS	TRAVEL LANE METERS	USABLE SHOULDER METERS	OFF-SET METERS	TRAVEL LANE METERS	USABLE SHOULDER METERS	OFF-SET METERS					
< = 100		2.75	0.00	0.50	RDWY	IN	2.75	0.00	0.50	RDWY	IN	2.75	0.50**	0.50	SHLD	ON	
		1.50	REQ'D CLEAR BEYOND LANE EDGE				1.50	REQ'D CLEAR BEYOND LANE EDGE				6.50	PAVED	7.50	RAIL TO RAIL		
		8.50	TOTAL CLEAR WIDTH REQ'D				8.50	TOTAL CLEAR WIDTH REQ'D				10.50	TOTAL CLEAR WIDTH REQ'D				
101 - 250		2.75	0.00	0.50	RDWY	IN	2.75	0.00	0.50	RDWY	IN	3.00	0.50**	0.50	SHLD	ON	
		1.50	REQ'D CLEAR BEYOND LANE EDGE				2.50	REQ'D CLEAR BEYOND LANE EDGE				2.50	REQ'D CLEAR BEYOND LANE EDGE				
		8.50	TOTAL CLEAR WIDTH REQ'D				10.50	TOTAL CLEAR WIDTH REQ'D				11.00	TOTAL CLEAR WIDTH REQ'D				
251 - 400		3.00	0.00	0.50	RDWY	IN	3.00	0.50*	0.50	SHLD	ON	3.00	0.50*	0.50	SHLD	ON	
		1.50	REQ'D CLEAR BEYOND LANE EDGE				2.50	REQ'D CLEAR BEYOND LANE EDGE				2.50	REQ'D CLEAR BEYOND LANE EDGE				
		9.00	TOTAL CLEAR WIDTH REQ'D				11.00	TOTAL CLEAR WIDTH REQ'D				11.00	TOTAL CLEAR WIDTH REQ'D				
401 - 1500		3.00	0.50*	0.50	SHLD	ON	3.25	0.50*	0.50	SHLD	ON	3.25	0.50*	0.50	SHLD	ON	
		2.00	REQ'D CLEAR BEYOND LANE EDGE				2.50	REQ'D CLEAR BEYOND LANE EDGE				2.50	REQ'D CLEAR BEYOND LANE EDGE				
		10.00	TOTAL CLEAR WIDTH REQ'D				11.50	TOTAL CLEAR WIDTH REQ'D				11.50	TOTAL CLEAR WIDTH REQ'D				
1501 - 2000		3.00	1.00	0.50	SHLD	ON	3.25	1.00	0.50	SHLD	ON	3.25	1.00	0.50	SHLD	ON	
		2.50	REQ'D CLEAR BEYOND LANE EDGE				2.75	REQ'D CLEAR BEYOND LANE EDGE				2.75	REQ'D CLEAR BEYOND LANE EDGE				
		11.00	TOTAL CLEAR WIDTH REQ'D				12.00	TOTAL CLEAR WIDTH REQ'D				12.00	TOTAL CLEAR WIDTH REQ'D				

* 1.0m PAVED SHOULDER IN CURBED / DEVELOPED AREAS TO ACCOMMODATE BICYCLES. (TOTAL PAVED WIDTH IN THESE AREAS WILL BE 0.5M GREATER THAN PAVED WIDTH SHOWN IN CHART FOR UNDEVELOPED AREAS.) OFFSETS WILL BE WITHIN THE SIDEWALK IN CURBED AREAS.

** PAVED SHOULDER IS PROVIDED ONLY FOR ACCOMMODATION OF BICYCLES. (USABLE SHOULDER NOT REQUIRED EXCEPT FOR BICYCLE ACCOMMODATION.)

NOTES:
ALL SHOULDERS DESIGNATED FOR BICYCLE ACCOMMODATION MUST BE PAVED.
NO PARKING IS PERMITTED WITHIN 1.0m OF THE RAIL TO RAIL CLEARANCE. ANY PARKING WHERE VEHICLE DOORS MAY ENCROACH ON THE RAIL TO RAIL DISTANCE WILL REQUIRE ADDITIONAL ROADWAY WIDTH FOR BICYCLE ACCOMMODATION.

CHAPTER 9

HIGHWAY SAFETY

9.1 ACCIDENT DATA AND APPLICATIONS

9.1.1 MHD Accident Data System

Historical accident data should be reviewed during the design of any reconstruction project. The latest 3 years of accident data available is required for calculation of accident rates, analysis of trends, and documentation of probable causes, including geometric shortfalls, safety hazards and stopping sight distances if applicable. Discussion of potential remedial action is appropriate and the project design can then include mitigative measures to correct the identified hazards.

Accident rates should be calculated for roadway segments based on Hundred Million Vehicle kiloMeters of travel (HMVM), and for intersections based on Million Entering Vehicles (MEV). The equations for calculating these rates are as follows:

$$\text{HMVM} = \frac{A \times 1,000,000,000}{\text{VMT}} \qquad \text{MEV} = \frac{A \times 1,000,000}{V}$$

Where;

- A = number of total accidents or number of accidents by type at the study location, during a given time period (usually 1 year = 365 days)
- VMT = total vehicles of travel during a given period
= ADT x (number of days in the study period) X (length of road section)
- ADT = average daily traffic from automatic traffic recorder (ATR) counts

Accident data is available for all state-maintained highways and local roads from the MHD Traffic Design and Operations Section. The following accident reports can be obtained:

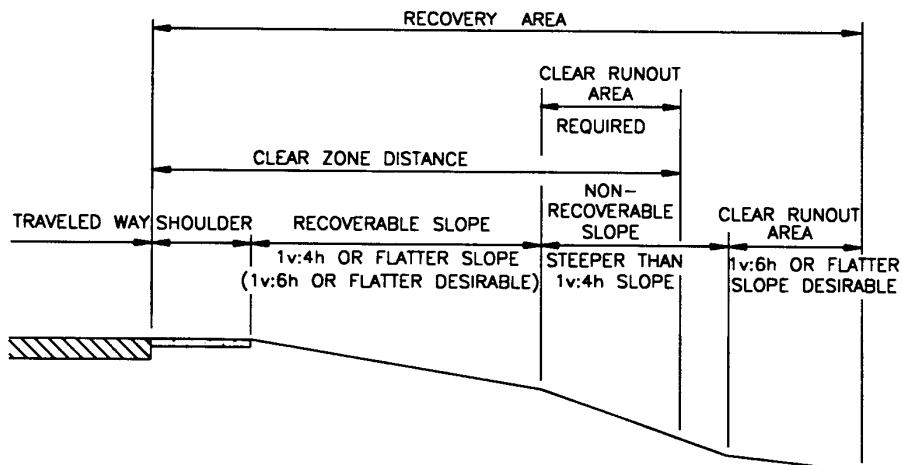
1. At-Grade intersections -- The MHD accident data system can provide a summary of all vehicular and pedestrian accidents that have occurred at any intersection. The "High Accident Intersections -- All Roadways" report(s) can provide: 1) the top 1,000 highway intersection accident locations statewide; and 2) the top 25 highway intersection accident locations by MHD Districts. Whenever an intersection is being redesigned, this listing should be checked to determine if the intersection is a high-accident location. This requirement also applies to intersections within the project limits of a reconstruction project.

2. Route, Street, or individual intersection (by city/town) for the entire state-- The MHD accident system can provide a Highway Analysis report for any roadway in a city/town or for the entire state. This report briefly summarizes each accident within the roadway and provides information such as accident location, type, severity, day/night and roadway surface.

The Traffic Design and Operations Section is in the process of upgrading the accident record system. This system will have many new features when completed. As the features come on line, inserts to this section will be distributed. These inserts will describe the added feature(s).

9.2 RECOVERY AREA (Clear Zone)

The recovery area is the total roadside border area, starting from the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. It should be free and clear of any non-traversable hazards or fixed objects. The desired width is dependent upon the traffic volumes and speeds, and on the roadside geometry. Roadside recovery area may be greater than the clear zone. Figure 9.1 shows clear zone application between recovery area and clear zone for typical fill section. Table 9.1 can be used to determine the required roadside clear zone distance.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 9-1. CLEAR ZONE APPLICATION FOR TYPICAL FILL SECTION

**Table 9.1
 CLEAR ZONE DISTANCES
 (IN METERS FROM EDGE OF DRIVING LANE)**

DESIGN SPEEDS	DESIGN ADT	FILL SLOPES			CUT SLOPES		
		1v:6h OR FLATTER	1v:5h TO 1v:4h	1v:3h	1v:3h	1v:5h TO 1v:4h	1v:6h OR FLATTER
60 km/h OR LESS	UNDER 750	2.0 - 3.0	2.0 - 3.0	* *	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
	750-1000	3.0 - 3.5	3.5 - 4.5	* *	3.0 - 3.5	3.0 - 3.5	3.0 - 3.5
	1500-6000	3.5 - 4.5	4.5 - 5.0	* *	3.5 - 4.5	3.5 - 4.5	3.5 - 4.5
	OVER 6000	4.5 - 5.0	5.0 - 5.5	* *	4.5 - 5.0	4.5 - 5.0	4.5 - 5.0
70-80 km/h	UNDER 750	3.0 - 3.5	3.5 - 4.5	* *	2.5 - 3.0	2.5 - 3.0	3.0 - 3.5
	750-1000	4.5 - 5.0	5.0 - 6.0	* *	3.0 - 3.5	3.5 - 4.5	4.5 - 5.0
	1500-6000	5.0 - 5.5	6.0 - 8.0	* *	3.5 - 4.5	4.5 - 5.0	5.0 - 5.5
	OVER 6000	6.0 - 6.5	7.5 - 8.5	* *	4.5 - 5.0	5.5 - 6.0	6.0 - 6.5
90 km/h	UNDER 750	3.5 - 4.5	4.5 - 5.5	* *	2.5 - 3.0	3.0 - 3.5	3.0 - 3.5
	750-1000	5.0 - 5.5	6.0 - 7.5	* *	3.0 - 3.5	4.5 - 5.0	5.0 - 5.5
	1500-6000	6.0 - 6.5	7.5 - 9.0	* *	4.5 - 5.0	5.0 - 5.5	6.0 - 6.5
	OVER 6000	6.5 - 7.5	8.0 - 10.0*	* *	5.0 - 5.5	6.0 - 6.5	6.5 - 7.5
100 km/h	UNDER 750	5.0 - 5.5	6.0 - 7.5	* *	3.0 - 3.5	3.5 - 4.5	4.5 - 5.0
	750-1000	6.0 - 7.5	8.0 - 10.0*	* *	3.5 - 4.5	5.0 - 5.5	6.0 - 6.5
	1500-6000	8.0 - 9.0	10.0 - 12.0*	* *	4.5 - 5.5	5.5 - 6.5	7.5 - 8.0
	OVER 6000	9.0 - 10.0*	11.0 - 13.5*	* *	6.0 - 6.5	7.5 - 8.0	8.0 - 8.5
110 km/h	UNDER 750	5.5 - 6.0	6.0 - 8.0	* *	3.0 - 3.5	4.5 - 5.0	4.5 - 4.9
	750-1000	7.5 - 8.0	8.5 - 11.0*	* *	3.5 - 5.0	5.5 - 6.0	6.0 - 6.5
	1500-6000	8.0 - 10.0*	10.5 - 13.0*	* *	5.0 - 6.0	6.5 - 7.5	8.0 - 8.5
	OVER 6000	9.0 - 10.5*	11.5 - 14.0*	* *	6.5 - 7.5	8.0 - 9.0	8.5 - 9.0

* WHERE A SITE SPECIFIC INVESTIGATION INDICATES A HIGH-PROBABILITY OF CONTINUING ACCIDENTS OR SUCH OCCURANCES ARE INDICATED BY ACCIDENT HISTORY, THE DESIGNER MAY PROVIDE CLEAR ZONE-DISTANCES GREATER THAN 9 METERS AS INDICATED. CLEAR ZONES MAY BE LIMITED TO 9 METERS FOR PRACTICALITY AND TO PROVIDE A CONSISTANT ROADWAY TEMPLATE IF PREVIOUS EXPERIENCE WITH SIMILAR PROJECTS OR DESIGNS INDICATES SATISFACTORY PERFORMANCES.

** SINCE RECOVERY IS LESS LIKELY ON THE UNSHIELDED, TRAVERSABLE 1v:3h SLOPES, FIXED OBJECTS SHOULD NOT BE PRESENT IN THE VICINITY OF THE TOE OF THESE SLOPES. RECOVERY OF HIGH SPEED VEHICLES THAT ENCROACH BEYOND THE EDGE OF THE SHOULDER MAY BE EXPECTED TO OCCUR BEYOND THE TOE OF SLOPE. DETERMINATION OF THE WIDTH OF THE RECOVERY AREA AT THE TOE OF SLOPE SHOULD TAKE INTO CONSIDERATION RIGHT-OF-WAY AVAILABILITY, ENVIRONMENTAL CONCERNS, ECONOMIC FACTORS, SAFETY NEEDS AND ACCIDENT HISTORIES. ALSO, THE DISTANCE BETWEEN THE EDGE OF THE TRAVEL LANE AND THE BEGINNING OF THE 1v:3h SLOPE SHOULD INFLUENCE THE RECOVERY AREA PROVIDED AT THE TOE OF SLOPE. WHILE THE APPLICATION MAY BE LIMITED BY SEVERAL FACTORS, THE FILL SLOPE PARAMETERS WHICH MAY ENTER INTO A MAXIMUM DESIRABLE RECOVERY AREA ARE ILLUSTRATED IN FIGURE 9-1.

9.2.1 Definitions

CLEAR ZONE: The distance required to recover control of, or stop, an errant vehicle leaving the traveled way. This distance is measured from the edge of the travel lane nearest the recovery area, and is based on the traffic volume, the speed of the vehicle and the steepness of the recoverable slopes within the recovery area. Often the clear zone will be the same as the recovery area.

RECOVERABLE SLOPES: A roadway side slope of 1v:4h or flatter.

TRAVERSABLE

NON-RECOVERABLE SLOPES: A roadway side slope steeper than 1v:4h but flatter than 1v:4h.

NON-TRAVERSABLE SLOPES: A roadway side slope 1v:3h or steeper. On these slopes the errant vehicle is likely to overturn. These slopes are by definition non-traversable and non-recoverable.

The Designer should use engineering judgement in applying the recommended clear zone distances. Obstacles located within the recovery area should be removed, relocated, redesigned or shielded by traffic barriers or crash cushions. If signs, lighting and/or traffic signals are required within the recovery area, breakaway posts should be used or safety treatments must be provided.

The designer should consult the *Roadside Design Guide* for further information on recovery areas.

9.3 ROADSIDE BARRIERS

A roadside barrier is a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a roadway. It may occasionally be used to protect pedestrians and bicyclists from vehicular traffic. Single-faced longitudinal barrier installed either in the median or on the outside of the roadway is a "Roadside Barrier". Double-faced longitudinal barrier which is designed to redirect vehicles striking either side of the barrier is "Median Barrier". See Section 9.4 for Median Barrier criteria.

The primary purpose of all roadside barriers is to prevent a vehicle from leaving the roadway and striking a fixed object or terrain feature that is considered more objectionable

than the barrier itself. This is accomplished by containing and redirecting the impacting vehicle.

Roadside recovery areas as discussed in Section 9.2 should be provided wherever possible. Where this is not feasible or practical, roadside barriers must be considered.

Roadside barriers are usually categorized as flexible, semi-rigid, or rigid, depending on their deflection characteristics on impact. Flexible systems are generally more forgiving than the other categories since much of the impact energy is dissipated by the deflection of the barrier and lower impact forces are imposed upon the vehicle.

Rigid systems are generally more effective in performance and relatively low in cost when considering their maintenance-free characteristics.

9.3.1 Roadside Barrier Systems

Once it has been decided that a roadside barrier is warranted, the designer must choose the appropriate type of barrier. This choice is based on a number of factors including performance criteria, cost (construction and maintenance), and aesthetics. Table 9.2 summarizes the factors that should be considered. The Roadside Design Guide should be consulted for more information.

Table 9.2
SELECTION CRITERIA FOR ROADSIDE BARRIERS

CRITERIA	COMMENTS
1. PERFORMANCE CAPABILITY	BARRIER MUST BE STRUCTURALLY ABLE TO CONTAIN AND REDIRECT DESIGN VEHICLE.
2. DEFLECTION	EXPECTED DEFLECTION OF BARRIER SHOULD NOT EXCEED AVAILABLE ROOM TO DEFLECT
3. SITE CONDITIONS	SLOPE APPROACHING THE BARRIER, AND DISTANCE FROM TRAVELED WAY, MAY PRECLUDE USE OF SOME BARRIER TYPES.
4. COMPATABILITY	BARRIER MUST BE COMPATIBLE WITH PLANNED END ANCHOR AND CAPABLE OF TRANSITION TO OTHER BARRIER SYSTEMS (SUCH AS BRIDGE RAILING).
5. COST	STANDARD BARRIER SYSTEMS ARE RELATIVELY CONSISTENT IN COST, BUT HIGH-PERFORMANCE RAILINGS CAN COST SIGNIFICANTLY MORE.
6. MAINTENANCE ----- a. ROUTINE ----- b. COLLISION ----- c. MATERIALS STORAGE ----- d. SIMPLICITY	----- FEW SYSTEMS REQUIRE A SIGNIFICANT AMOUNT OF ROUTINE MAINTENANCE ----- GENERALLY, FLEXIBLE OR SEMI-RIGID SYSTEMS REQUIRE SIGNIFICANTLY MORE MAINTENANCE AFTER A COLLISION THAN RIGID OR HIGH PERFORMANCE RAILINGS. ----- THE FEWER DIFFERENT SYSTEMS USED, THE FEWER INVENTORY ITEMS/STORAGE SPACE REQUIRED. ----- SIMPLER DESIGNS, BESIDES COSTING LESS, ARE MORE LIKELY TO BE RECONSTRUCTED PROPERLY BY FIELD PERSONNEL
7. AESTHETICS	OCCASIONALLY, BARRIER AESTHETICS IS AN IMPORTANT CONSIDERATION IN ITS SELECTION.
8. FIELD EXPERIENCE	THE PERFORMANCE AND MAINTENANCE REQUIREMENTS OF EXISTING SYSTEMS SHOULD BE MONITORED TO IDENTIFY PROBLEMS THAT COULD BE LESSENERED OF ELIMINATED BY USING A DIFFERENT BARRIER TYPE.

9.3.1.1 Semi-Rigid Systems

1. Steel Beam Highway Guard-Type SS Single- Faced - This system uses a heavy post with a block out and corrugated steel face (W-beam). Typical post spacing is 1.905 meters. Posts may be either steel or wood. The details for this system are shown in the Construction Standards.

2. Steel Thrie Beam Highway Guard-Type SS Single-Faced - This system is similar to the normal steel beam guardrail, except a deeper corrugated metal face is used. The deeper beam will minimize the possibility of underride or vaulting by impacting vehicles. The details for this system are shown in the Construction Standards.
3. Steel Backed Timber Rail - This system consists of heavy wood rail backed with a steel plate and installed on heavy wood posts. Its rustic appearance is sometimes compatible with the surrounding area. It may be used only on low volume facilities with design speeds under 60 km/h. Because only the full height straight sections have been crash tested, this system must transition to other approved systems at termini and on sharp curves. See the MHD Construction Standards for design details.

9.3.1.2 Rigid Systems

Concrete Safety Shape Barrier - The most commonly used concrete safety shape barriers are the New Jersey shape and F-shape barriers. F-shape barrier is preferred because of its better performance with small vehicle impact with respect to vertical roll and redirection. The details for this system are shown in the Construction Standards.

9.3.2 Roadside Barrier Requirements

Once a potential roadside hazard (fixed objects or non-traversable slopes) has been identified, determining barrier warrants involves these steps:

1. Is the hazard within the recovery zone?
2. Can the hazard be removed, relocated, or made breakaway?
3. Can the slope be flattened to provide recovery area?
4. Is the barrier less of an obstacle than the hazard it will shield?
5. Is a barrier installation practical, based on engineering judgment?

Barrier guidelines are presented below:

1. Embankments - Generally, barrier is required to protect slopes steeper than 1:4. Barrier may also be warranted based on the speed, traffic volumes, and accident history.
2. Fixed Object and Non-Traversable Hazards - The barrier warrants for hazards within

the roadside recovery zone are to be found in the most recent AASHTO *Roadside Design Guide*.

3. Bridge Rails or Parapets (overpass) - These will require an approach section which will securely attach to the rail or parapet. Roadside barrier should also be installed on the trailing end of the bridge, if its end is within the recovery area for opposing traffic. The Construction Standards provide the details for the transition and attachment to the bridge.
4. Ditches - See *ROADSIDE DESIGN GUIDE*.
5. Traffic Signal Support - Isolated traffic signals within recovery area on high speed rural facilities may require shielding.

9.3.3 Roadside Barrier Design

9.3.3.1 Deflection Distance

The distance between the barrier and the obstacle should not be less than the dynamic deflection of the barrier system. This distance is based on crash tests with a full-size car at 46.6 km/h and a 25-degree angle of impact. The distance is measured from the face of the barrier to the front of the obstacle. Table 9.3 provides the offset distance for the barrier systems used in Massachusetts. There is room for the exercise of engineering judgment under low-speed conditions. Concrete barrier is assumed to have 0.0 meter deflection.

Table 9.3
GUARDRAIL OFFSET DISTANCE

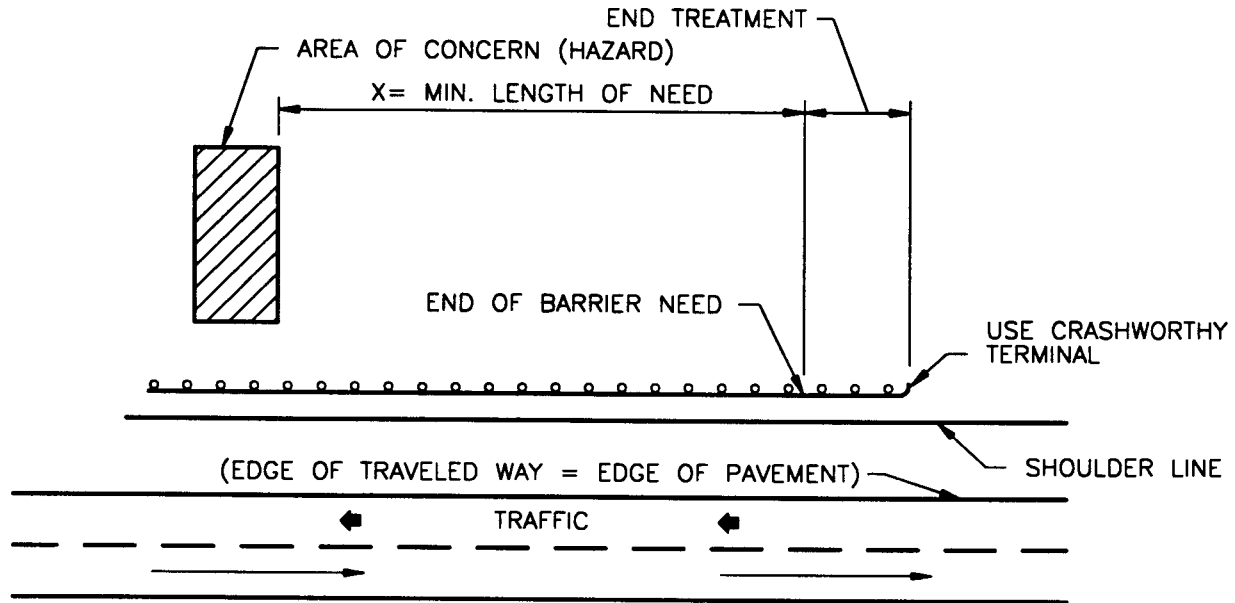
POST SPACING	BEAM DESCRIPTION	MINIMUM OFFSET (m)
SINGLE	SINGLE W - BEAM	1.25
SINGLE	SINGLE THRIE - BEAM	1.10
DOUBLE	SINGLE W - BEAM	0.95
DOUBLE	DOUBLE W - BEAM	0.85
DOUBLE	SINGLE THRIE - BEAM	0.90
DOUBLE	DOUBLE THRIE - BEAM	0.80
QUADRUPLE	DOUBLE W - BEAM	0.70
QUADRUPLE	SINGLE THRIE - BEAM	0.75
QUADRUPLE	DOUBLE THRIE - BEAM	0.70

Note 1. MEASURED FROM THE FACE OF THE RAIL TO THE FRONT OF THE OBSTACLE

9.3.3.2 Length of Need

The barrier must be long enough to sufficiently shield the hazard from errant vehicles. Figure 9-2 illustrates the typical guardrail layout for protection of a hazard. The minimum length of need for full height guardrail for 60 km/h, 100 km/h, and 110 km/h is 60 meters, 90 meters, and 100 meters respectively. Barrier end treatment is in addition to the length of need. See Construction Standards for typical installation details of guardrail and concrete barrier.

On a undivided highway, the minimum guardrail length on the downstream end of the run to protect the opposing traffic from the hazard for 60 km/h, 80 km/h, 100 km/h and 110 km/h is 50 meters, 60 meters , 70 meters and 70 meters respectively.



DESIGN SPEED km/h	X IN (m)
60	60
80	80
100	90
110	100

Note:

THE DISTANCE BEYOND THE HAZARD SHOULD BE DETERMINED BY A LENGTH-OF-NEED CALCULATION FOR OPPOSING TRAFFIC, IF APPLICABLE. THE MINIMUM DISTANCES FOR DESIGN SPEEDS 60 km/h, 80 km/h, 100 km/h, AND 110 km/h ARE 50 m, 60 m, 70 m, AND 70 m, RESPECTIVELY

Figure 9-2. BARRIER LENGTH OF NEED

9.3.3.3 End Treatments

The barrier end terminals are used to reduce severity of impacts by gradually slowing and bringing vehicle to a stop or by redirecting it around the object of concern. Generally, the vehicle must remain upright during and after the collision and not be redirected into adjacent traffic lanes.

Improper roadside barrier end treatment is extremely hazardous to vehicles if hit. Preferably, the roadside barrier should be flared away from the travel lane and, if feasible, should be terminated outside the recovery area. A crashworthy end treatment is considered essential if the barrier terminates within the clear zone or is in an area where it is likely to be hit head-on by an errant motorist. To be crashworthy, the end treatment should not spear, vault or roll a vehicle for head-on or angled impacts. For impacts within the length of need, the end treatment should have the some redirectional characteristics as standard roadside barrier.

The Construction Standards illustrate the standard MHD end treatment for roadside barriers. Intersecting streets and driveways may cause special problems for providing the proper roadside barrier end treatment. These must be considered on a case-by-case basis. The following end treatments are most commonly used by MHD.

1. Anchored in Back Slope or Earth Berm

A back slope or an earth berm can be used to eliminate the hazard posed by the ends of traffic barriers. Where conditions permit this is the MHD preferred barrier end treatment. The berm must be constructed beyond the length of need for a particular barrier installation.

Anchorage in back slope should be used wherever a back slope is conveniently near the end of the length of need of the barrier. The earth berm treatment may be used in the center of wide medians and may also have applications on the outside of the roadway.

Full height barrier must be flared a minimum rate of 5:1 to a point in the back slope beyond the recovery area. A 1v:12h or flatter ground slope must be provided in front of the barrier. Consult the MHD Construction Standards for details on earth berm design and guardrail installation.

2. Buried End Guardrail Terminals

W-beam or thrie beam rail is reduced from full height to ground level typically over a distance of 11.43 meters for W-beam and 15.24 meters for thrie beam. A clear, traversable runout path behind the guardrail is required. Buried ends are the preferred

end treatments for facilities with design speeds of less than 80 km/h where back slopes or earth berms cannot be utilized. Consult the MHD Construction Standards for details.

3. Special End Treatments

Where it is not appropriate for either (1) anchoring in back slope or earth berm, or (2) buried end barrier end treatments, special end treatments may be used. These must meet NHCRP 350 testing requirements and be approved by FHWA for general use for the intended application (see Section 9.5).

For more details about roadside barrier end treatments, consult the *Roadside Design Guide*.

9.3.3.4 Minimum Functional Length and Guardrail Gaps

Short runs of guardrail have little value. Likewise, short gaps between runs of guardrail are undesirable. Therefore, these criteria will apply in general:

1. The minimum length guardrail is 50 meters of full height guardrail plus the end treatment.
2. Gaps of less than 100 meters between guardrail termini should be avoided. The two barrier runs should be connected into a single run. However, this may not be possible at intersecting streets and driveways.

9.3.3.5 Placement on Slopes and Behind Curbs

If guardrail is improperly located on slopes or behind curbs, an errant vehicle could impact the barrier too high or too low, with undesirable results. Therefore, these criteria apply:

1. Guardrail height is measured from the ground or pavement surface at the guardrail face. For W-beam and thrie beam this dimension is typically 550 mm from the surface to the center post bolt.
2. Berm and curb must be located to minimize vaulting potential. See the Construction Standards for details.

3. Where guardrail is required to be offset from the edge of pavement, it should not be placed on a slope steeper than 1v:12h.

9.3.3.6 Transitioning

Once a type of barrier is selected for a particular longitudinal application, the selected type should be used throughout the run. Transitions from concrete to guardrail or guardrail to concrete systems should be avoided where possible. Where stiffer sections are required for runs of guardrail, extra posts and rails should be considered before transitioning to concrete barrier. If a guardrail run crosses over a retaining wall or culvert, it should be secured to the top of the wall rather than transition to a concrete section. If a concrete run crosses drainage structures, the concrete barrier should be specially designed to accommodate the drainage structure and may be formed in steel in the same shape as the adjacent concrete barrier.

Transition sections are necessary to provide continuity of protection when two different roadside barriers join, when a roadside barrier joins another barrier system such as a bridge rail, or when a roadside barrier is attached to a rigid object. The transition design should produce a gradual transition in the stiffness of the overall protection system so that vehicular pocketing, snagging, or penetration can be reduced or avoided at any position along the transition. For transition details consult the MHD Construction Standards and the *Roadside Design Guide*.

9.4 MEDIAN BARRIERS

Median Barriers are double faced longitudinal systems. Median barriers are normally used in narrow medians for separating opposing traffic or for separating traffic flowing in the same direction, i.e. collector-distributor roadways and High-Occupancy Vehicle lanes. Single-faced barriers used in the median are Roadside Barriers. See Section 9.3 for Roadside Barrier criteria.

9.4.1 TYPES

MHD uses the following types of median barrier systems:

1. **Steel Beam Highway Guard-Type SS Double-Faced**
This W-Beam system may be used as median barrier on roadways with design speeds of 60 km/h or less. The MHD Construction Standards present the design details.
2. **Thrie Beam Highway Guard-Type SS Double-Faced**
Thrie beam must be used for median barrier system on highway facilities with design speeds over 60 km/h.
3. **Concrete Median Barrier Double-Faced**
This barrier is reinforced concrete in which the sloped shape of the face is designed to minimize vehicle damage and the possibility of rollover. Two types, the F-shape and Jersey shape are used for barrier systems. The F-shape is preferred because it better redirects passenger vehicles.

In areas with heavy truck volume, poor roadway geometry, and a history of truck accidents, tall concrete barriers with heights of 1.070 meters or higher may be used. See MHD Construction Standards for details.

Once it has been decided that a median barrier is warranted, the designer must choose the appropriate type of barrier. This choice is based on a number of factors including performance criteria, cost (construction and maintenance), and aesthetics. The most desirable system is usually one that offers the required degree of shielding at the lowest cost. Table 9.2 summarizes the factors that should be considered. The *Roadside Design Guide* should be consulted for more information.

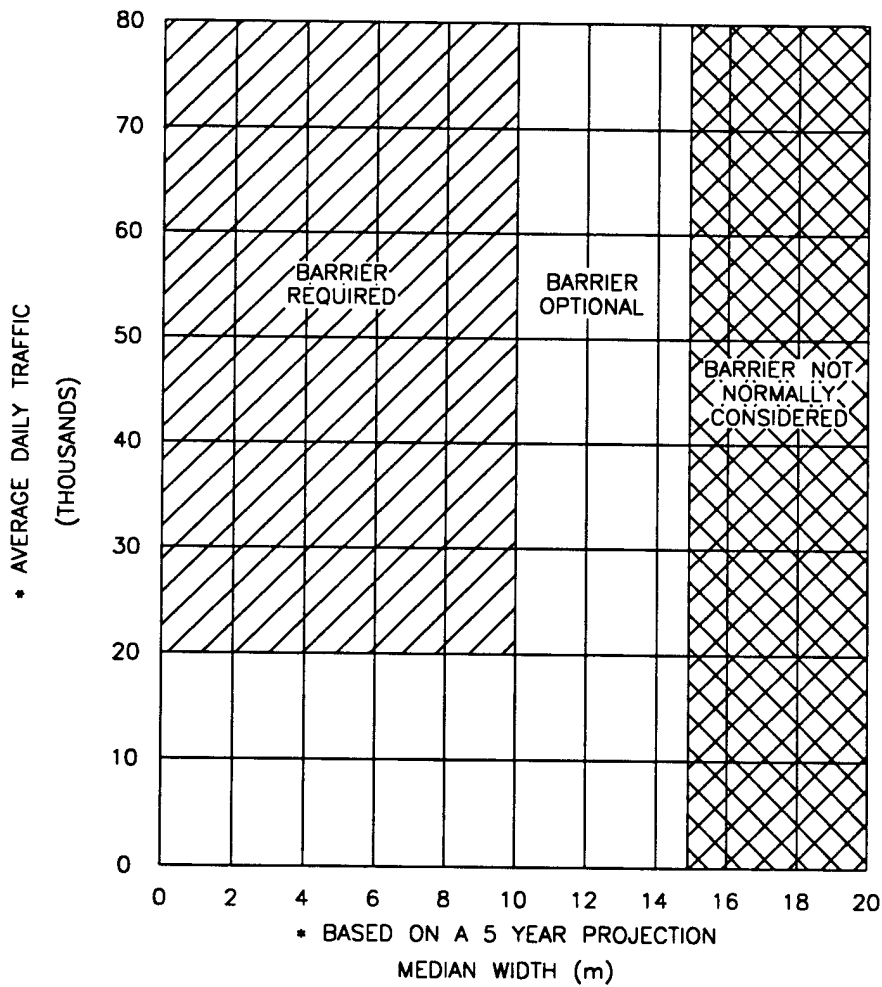
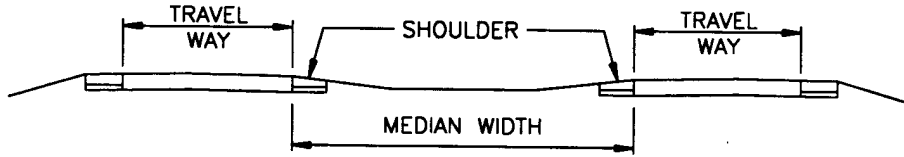
In general the designer must choose between Thrie Beam Double-Faced Guard Rail and a concrete safety shape. The choice between guardrail or concrete should be based on factors such as the width of median, barrier deflection, cost (construction and maintenance), and aesthetics. Guardrail which deflects upon impact is generally preferred due to the lower impact forces on the vehicle and its occupants. On high speed, high volume roadways with significant truck volumes and narrow medians of less than 4 meters, concrete barrier should be strongly considered due to the possibility that if guardrail is used it may deflect into the opposing lanes. Consideration should also be given to the increased likelihood that the barrier may be damaged which could result in higher maintenance costs for guard rail than for concrete. The designer should consider, however, that concrete barrier may not be aesthetically appropriate in undeveloped areas and that the open appearance of guardrail may appear less imposing and may be more acceptable to the public.

Once a type of median barrier is selected for a particular longitudinal application, it should be used throughout the run. Transitions between dissimilar barrier systems should be avoided. For instance, if a concrete median barrier run crosses drainage structures, the concrete barrier should be specially designed to accommodate the structure. This may be accomplished by forming a section of the barrier with steel in the same shape as the adjacent concrete barrier. Median barrier must be installed with no abrupt horizontal transitions. Flare rates should be designed in accordance with the *Roadside Design Guide*.

9.4.2 Median Barrier Requirements

Figure 9-3 presents the requirements for a median barrier based on median width and traffic volumes. In the areas shown as optional, the decision to use a median barrier will be primarily based on costs and accident experience. A barrier should not be used where the criteria do not require it, except where a significant number of crossover accidents have occurred.

Figure 9-3 was developed for freeways and expressways. On lower-speed, lower-class highways, some judgment must be used. Figure 9-3 may be used for guidance. On non-freeway highways, the designer should evaluate the accident history, traffic volumes and speeds, median width, alignment, sight distance, and construction costs to determine the need for a median barrier. On expressways and highways without access control, the median barrier must terminate at each at-grade intersection. Lower speeds will reduce the likelihood of a crossover accident.



Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 9-3. MEDIAN BARRIER WARRANTS FOR FREEWAYS AND EXPRESSWAYS

9.4.3 Median Barrier Design

9.4.3.1 Lateral Placement

The median barrier will normally be placed in the center of the median. Where roadway conditions dictate different grades between two roadway barrels, median barrier should be placed on the high side of the median. Concrete barrier may split vertically to accommodate the two grade lines. See the *Roadside Design Guide* for further guidance. See MHD Construction Standards for details.

9.4.3.2 Cross-Slope

A maximum 1v:12h cross-slope must be used between the roadway gutter line and the median barrier. See MHD Construction Standards for details.

9.4.3.3 Flare Rate

A median barrier may have to be divided at the approach of superelevated curves or because of obstacles in the median, or flared to terminate in the wide median section. Flare rates in accordance with the *Roadside Design Guide* should be used.

9.4.3.4 Median Barrier Openings

Emergency median crossovers are sometimes needed on access-controlled highways. Where a median barrier is warranted, the opening in the barrier should prevent crossover accidents, provide crashworthy end treatments, and provide sufficient width for emergency vehicles to use. An opening between 25 and 30 meters is a reasonable compromise. At this width, the chances of an errant vehicle passing through the opening are negligible; however, the width is sufficient to allow U-turn maneuvers by emergency or maintenance vehicles. Mechanical gate treatments for emergency openings are available.

9.4.3.5 Glare Screens

Headlight glare from opposing vehicles can be both bothersome and distracting. Glare screens might be used to eliminate these problems. Plantings should be considered as an

alternative.

The following criteria present general guidance for glare screen warrants:

1. Glare screens are rarely warranted in rural areas.
2. Narrow medians and high traffic volumes increase the benefits of glare screens. Where the concrete median barrier is warranted (medians 50 meters or less), a glare screen will often be cost-effective.
3. On medians between 50 and 100 meters, a glare screen should be considered where the current traffic volumes exceed 20,000 ADT.
4. Glare screens will not normally be used on medians greater than 100 meters wide.

9.4.3.6 Median Barrier End Treatments

An unprotected median barrier end presents a hazard to errant vehicles. A crashworthy end treatment for a median barrier is essential if the barrier is terminated where it is vulnerable to head-on impacts. To be crashworthy, the end treatment must not spear, snag, or roll the vehicle, and vehicle decelerations should not be excessive. The end must be properly anchored and capable of developing the full tensile strength of the barrier.

Because median barriers are normally used in narrow medians, the options for end treatments are limited. Barrier end treatments which have the potential for vaulting or rolling vehicles cannot be used. Therefore, tapered end treatments such as buried ends or ramped concrete barrier ends, are not acceptable treatments for median barrier unless the ends of the barrier can be flared a sufficient distance laterally from the traveled way so as not to be susceptible to head-on impacts.

Where feasible, the median barrier may be terminated in an earth berm or anchored in a back slope. This treatment should be designed in accordance with Roadside Barrier End Treatments criteria (Section 9.3.3.3). This treatment usually requires that the barrier terminate in a wider portion of the median.

The preferred method for treating median barrier terminals in narrow medians is to use Impact Energy Attenuators. These manufactured treatments have been crash-tested to provide energy absorption and/or redirection capabilities in restricted areas. See Sections 9.5 for more information on Impact Energy Attenuators.

9.5 IMPACT ENERGY ATTENUATORS

9.5.1 Use

Median barrier ends which are located in narrow medians, roadside barrier ends, or other fixed roadside hazards which cannot be relocated must be shielded with appropriate attenuators. Impact energy attenuators have been crash-tested to conform to the redirection and attenuation requirements of NCHRP 350. All attenuators which were previously approved under the requirements of NCHRP 230 must be successfully retested by 1999 to be accepted by the FHWA for use on MHD projects.

The MHD recognizes two basic types of energy attenuators; those that redirect the vehicle into its travel lane when struck at any other than a nose-on impact (redirecting); and those that only absorb vehicle energy and cause a speed reduction as the vehicle continues along its path regardless of where the impact occurs along the attenuator (non-redirecting). Each type of attenuator may be installed in either a shoulder or median application. It is the designer's judgment as to which type of attenuator (redirecting or non-redirecting) is most appropriate for a particular location.

In order to increase market competition and minimize the use of proprietary product, the Department specifies attenuators in a generic format.

9.5.2 Requirements

Once a hazard is identified, the designer should attempt to remove, relocate, or make the hazard breakaway. If this is not feasible, then the hazard must be shielded with an attenuator. Impact attenuators are most often used to shield fixed point hazards or median barrier ends adjacent to bridge piers, sign supports, and median barrier ends. Barriers which terminate within the recovery area, if not buried in a back slope or earth berm or if not protected with a MELBCT or buried end, are also hazards which must be protected with an attenuator.

The requirements for impact attenuators are under ongoing research. AASHTO prioritizes need on the basis of accident history, traffic volume, and operating speeds. For additional information the designer should consult the *Roadside Design Guide*, and the *Policy on Geometric Design of Highways and Streets*.

9.5.3 Design

The designer must follow the following procedures in specifying an attenuator in a project.

Once the designer has determined the need for an attenuator in a particular location, the designer determines the type to be used (redirecting or non-redirecting), and any limiting width or length for attenuator placement, then determines the design speed for the attenuator which must never be less than the design speed of the roadway. The design speed should be greater than the roadway speed to allow controlled safe stopping of a vehicle with excessive speed. The designer calculates the allowable deceleration forces for each location measured in "g"s (9.8 m/sec^2). The deceleration forces are inversely proportional to attenuator length and directly proportional to the square of the speed. The designer must check that deceleration can be accomplished within the required distance while not exceeding critical "g" forces. The average deceleration force should be less than 7 g's but in no case should the deceleration exceed 12 g's.

The designer then provides this information for each attenuator location as part of the PS&E package.

The designer should refer to the current edition of the AASHTO *Roadside Design Guide* and other available literature for further information and a discussion of crash cushions and end treatments.

9.5.4 Side Impacts

The attenuator must be designed to sustain side impacts. Redirecting attenuators normally will not require repair after side impacts. Non-redirecting attenuators, in order to provide some side impact protection, are generally designed at least 0.75 meters wider on each side than the object they protect. Greater widths should be provided where possible.

9.5.5 Site Conditions

Several factors at the attenuator site are important to its proper function:

1. Level Terrain - The attenuator should be placed on a level surface. Most attenuators will not function well on cross slopes exceeding 5%. If the attenuator is likely to be struck by a vehicle traveling on a down grade, this additional energy must be compensated for in the design.
2. Curbs - No curbs, berms or slope edgings are allowed at the attenuator installation. To function properly the vehicle should have a straight, smooth run at the

attenuator.

3. Surface - A paved bituminous or portland cement concrete surface must be installed under permanent attenuator installations where required. Some installations may only require a firmly packed gravel or crushed stone surface.
4. Orientation - Non-redirecting attenuators must be oriented to maximize the chance of an impact being head-on. Where a non-redirecting system is specified, it should be shown on the plans as set at approximately a 10 degree angle with the travel lane. The angle is measured between the longitudinal axis of the attenuator and the centerline of the highway. However, this is not necessary for those attenuators with redirecting capability. Attenuators with redirecting capabilities, such as GREAT systems, should be aligned parallel to the travel way.

9.6 PEDESTRIAN SAFETY AND ACCOMMODATION

Pedestrian safety and accommodation should be addressed in the design of any project. Section 5.1 discusses sidewalk and buffer strip widths.

All pedestrian facilities must be designed to accommodate handicapped pedestrians. Handicapped pedestrians include not only people confined to wheelchairs but individuals who have difficulty walking, blind people and those with limited vision and people with mental impairments. Care must be taken that the inclusion of curb cuts and ramps for wheelchairs, light poles, or poles for pedestrian-actuated signal buttons and other appurtenances do not make pedestrian facilities more hazardous for blind pedestrians or those with mobility impairments. Every effort should be made to accommodate the handicapped within the normal path of travel.

All project must be designed and constructed in conformance with the American Disabilities Act and the Rules and Regulations of the Massachusetts Architectural Access Board (AAB) 521 CMR 1.00 et seq.

If the designer is unable to comply with AAB specifications, a variance must be secured from the AAB.

9.6.1 Pedestrian Safety

Most pedestrian accidents occur in urban areas and most of these occur at at-grade

intersections, but pedestrian safety is a concern in every highway design. During the design of any project, the accident history should be reviewed to identify the location, number, and type of pedestrian accidents. The designer can then develop safety countermeasures. School locations and areas of high pedestrian volumes deserve particular attention. Following are examples of pedestrian safety measures:

1. Crosswalks should be provided at every intersection. The *MUTCD* provides design details.
2. Sidewalks and other walkways which are designed to accommodate projected pedestrian volumes limit use of street, shoulders, or auxiliary lanes as walkways. Sidewalk design is discussed in Section 12.1.
3. In commercial areas or in locations with infrequent intersections, midblock crosswalks should be considered.
4. Signal phases which favor the pedestrian may be desirable. These include pedestrian-actuated signals and an exclusive pedestrian signal phase. Pedestrian-actuated signals are not desirable in areas of high pedestrian volumes where automatically recalled concurrent or exclusive walk signals are preferred. The designer should consult with the Traffic Engineer.
5. On wide streets or streets with auxiliary lanes, channelization provides refuge islands for pedestrians. However, refuge islands create obstacles for pedestrians in wheelchairs and may make the intersection dangerously confusing for pedestrians with vision impairments or mental handicaps. There should be sufficient time in a walk cycle for a pedestrian to completely cross the roadway without having to wait at the island for a second cycle.
6. Where severe pedestrian safety problems exist, a pedestrian overpass may be warranted (see Section 9.6.2).
7. Other pedestrian safety measures include lighting, barriers, and parking restrictions to improve visibility at school crossings and mid-block crosswalks.

9.6.2 Pedestrian Overpasses

Pedestrian overpasses should be considered where a combination of pedestrian volumes, traffic volumes, and pedestrian accidents indicates their use. Following are general

1. Freeways may divide areas where pedestrian crossings would otherwise be high. If highway crossings are spaced relatively far apart, a pedestrian overpass may be justified.
2. Pedestrian overpasses may be warranted where the traffic and pedestrian volumes exceed the criteria presented in Section 4C-5 "Minimum Pedestrian Volume" of the *MUTCD*. This section provides warrants for actuated signals or exclusive pedestrian phases for traffic signals.
3. Pedestrian overpasses may be warranted where a significant safety hazard exists.
4. Pedestrian overpasses must meet the standards established in the *Rules and Regulations of the Architectural Barriers Board*.

Providing a pedestrian overpass will always depend upon the practicality of its accommodation at an individual site. At some locations an overpass may be virtually impossible, while at others favorable topography may lend itself to an overpass. Personal security is a critical issue in overpass design. Design must assure surveillance and maintenance.

9.7 HIGHWAY-RAILROAD GRADE CROSSINGS-HIGH TYPE

There are two high-type railroad crossing surface materials approved for installation as follows:

1. Full-Depth, Heavy Duty, Virgin Rubber, and
2. Full-Depth, Standard Rubberized Railroad Grade Crossing Surface Materials.

After calculating the car equivalent count per lane to make the proper surface type selection, the designer should refer to Figure 9-6 and project upward to the annual rail gross traffic load in million gross tons. The surface type appearing within the boundary curves should be selected.

9.7.1 Project Administration

Most highway-railroad crossing improvement projects are administered as separate and distinct projects by the MHD Traffic Design and Operations Section (TDAOS). This work is normally accomplished under a force account agreement prepared by the TDAO Section. Each

railroad has a separate force account agreement.

Other highway-railroad grade crossing improvements are made as part of regular highway construction projects either by force account with the respective railroad or by a construction contract. In either case, a Utility Agreement prepared by the Railroad-Utilities section is required. Whenever a highway-railroad grade crossing is within the limits of a highway project, the designer should consider improvements approaching and at the crossing. The designer should coordinate his/her effort with the Railroad-Utilities Engineer, who will coordinate with the involved railroad company and the Department of Public Utilities (DPU).

The designer should coordinate his/her efforts with the TDAOS. Before beginning the design, the designer should obtain a copy of the document entitled: "General Specifications and Guideline for Site Preparation and Installation of Specific Types of Railroad Crossing Surfaces" from the TDAOS.

9.7.2 Improvement Alternatives

Railroad/highway crossings within project limits should always be evaluated for improvements. Any proposed improvements or crossing eliminations must be coordinated with the Traffic Engineer, who will establish priorities and select the project design.

Factors which will impact the design at the crossing include accident history, train and vehicular volumes, design speed, existing geometrics, and estimated construction costs. These improvement (individually or in combination) should be considered:

Elimination

1. Remove Crossing - Many railroad/highway crossings have been abandoned. Removing these crossings will eliminate the precautionary action a typical driver will take at a crossing and will improve safety and the highway rideability. To remove a crossing, the designer must comply with the relevant provisions of the MGL statutes. These statutes are administered by the Massachusetts Department of Public Utilities (MDPU); therefore, all efforts in this regard must be coordinated with the MDPU.
2. Grade Separation - The maximum crossing improvement would be to separate the railroad and highway. However, this usually involves a large expenditure of funds and should be selected only after an analysis indicates it would be worthwhile. Grade separations are required on fully-access-controlled highways and are often warranted on high-speed urban and rural arterials.
3. Relocation - The highway or railroad can sometimes be relocated to eliminate the

crossing.

Improvement

1. Traffic Control Devices - The *MUTCD* discusses which traffic control devices are appropriate for any railroad/highway crossing. Improvements include cross bucks, advance warning signs, pavement markings, flashing lights, automatic gates, illumination, circuit improvements, and coordination with highway traffic signals. Automatic gates are typically used for the following:
 - Multiple main line railroad tracks;
 - Multiple tracks where a train on or near the crossing can obscure the movement of another train approaching the crossing;
 - High speed train operation combined with limited sight distance;
 - A combination of high speed and moderately high volume highway and railroad traffic;
 - Presence of school buses, transit buses, or farm vehicles in the traffic flow;
 - Presence of trucks carrying hazardous materials, particularly when the view down the track from a stopped vehicle is obstructed;
 - Continuance of accidents after installation of flashing lights;
 - Presence of passenger or commuter trains;
2. Crossing Surface - The type and condition of the crossing surface should be examined for every proposed railroad/highway crossing project to determine if any improvements are warranted.
3. Geometric Improvements - Every proposed railroad/highway improvement site should be examined to see if any highway geometric improvements are warranted. Possibilities would include sight distance, pavement width, highway realignment at the crossing and approaching the crossing, and nearby highway at-grade intersections.
4. Surface and subsurface drainage should be examined.

9.7.3 Design

The highway design must be compatible with the railroad crossing, both in geometrics and safety. Vehicle and pedestrian safety will be the primary concern. Sight distance at the crossing is the most critical factor see Figure 9-4. Three criteria must be met:

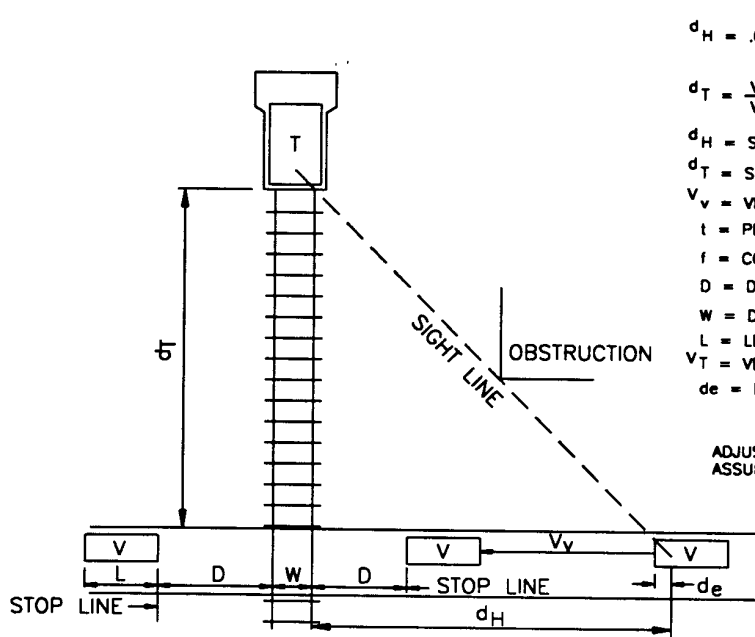
1. d_n - The driver should have sufficient sight distance to stop 20 meters away from the first rail. Preferably, decision sight distance, as discussed in Chapter 3, should be available. At a minimum, stopping sight distance will be available.
2. d_t - The driver needs adequate sight distance in either direction along the tracks to have time to decide if he must stop or if there is sufficient time to cross the track safely (Case A). These distances are a function of vehicle and train speed as defined in the figure.
3. d_r - If a driver is stopped at the track, he needs enough sight distance to make the crossing maneuver before an approaching train reaches the crossing (Case B).

If these sight distance criteria cannot be met, then signals should be installed.

The highway geometrics and drainage must be compatible with the railroad crossing. The following factors should be considered:

1. The railroad and highway should cross at approximately right angles. Skewed crossings interfere with sight distance and can produce poor rideability because of the alternating contact with the rails.
2. The crossing should not occur on a horizontal curve. Attaining proper superelevation may be difficult, and poor rideability may result.
3. Sharp horizontal curves approaching the crossing should be eliminated.
4. At-grade highway intersections near a railroad/highway crossing can present special problems, particularly if signalized. This condition must be addressed in the geometric design of the crossing.
5. The full width of travel lanes and shoulders of the approach roadway must be carried through the crossing.
6. The pavement surface of the approaching highway should be even with the top of the rail at all points. This will require removing the crown and warping the pavement into a plane even with the track. The rate of change of highway cross slope should be the same as that described for superelevation transition in Chapter 4.
7. At a minimum, the approaching highway should be resurfaced or reconstructed to allow proper application of the required pavement markings.

8. Transverse duct required to carry future electrical cables will be installed at all sites. This will prevent any damage from future utility construction.
9. Drainage design at the crossing should include. Where applicable:
 - a. subgrade preparation and proper ballast.
 - b. sideline ditch maintenance and grading.
 - c. fabric filter material installation at the plane of the subgrade.
 - d. installation of transverse perforated subdrain to collect and convey drainage to sideline ditches.
 - e. catch basin installation and other drainage structures as required for severe drainage or grade problems, and
 - f. alteration of the existing highway profile in extreme cases. See Figure 9-5, Highway-Rail Grade Crossing Typical Cross Section.



$$d_H = .028V_v T + \frac{V_v^2}{25ef} \div D = d_e$$

$$d_T = \frac{V_r}{V_v} \left[0.28 V_v t + \frac{V_v^2}{25.4f} 2D + L + W \right]$$

d_H = SIGHT DISTANCE ALONG HIGHWAY

d_T = SIGHT DISTANCE ALONG RAILROAD TRACKS

V_v = VELOCITY OF VEHICLE

t = PERCEPTION-REACTION TIME (ASSUMED 2.5 S)

f = COEFFICIENT OF FRICTION (SEE TABLE 4.4)

D = DISTANCE FROM STOP LINE TO NEAR RAIL (ASSUMED 4.5 m)

W = DISTANCE BETWEEN OUTER RAILS (SINGLE TRACK $W=1.5$ m)

L = LENGTH OF VEHICLE (ASSUMED 20 m)

V = VELOCITY OF TRAIN

d_e = DISTANCE FROM DRIVER TO FRONT OF VEHICLE (ASSUMED 3 m)

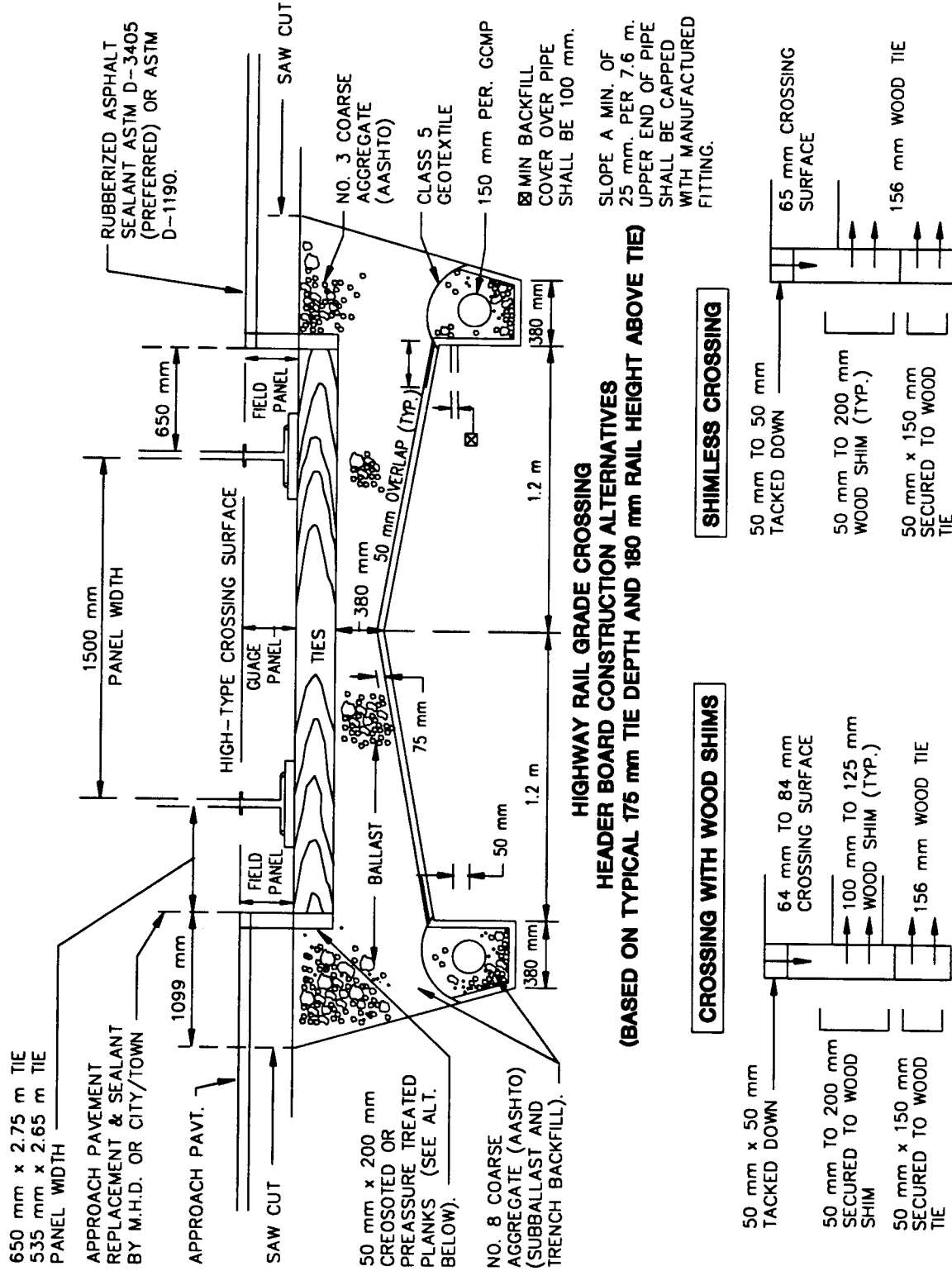
ADJUSTMENTS MUST BE MADE FOR SKEW CROSSINGS.
ASSUMED FLAT HIGHWAY GRADES ADJACENT TO AND AT CROSSINGS

CASE A: MOVING VEHICLE TO SAFELY CROSS OR STOP AT RAILROAD CROSSING.
CASE B: DEPARTURE FROM STOP.

CASE B TRAIN DEPARTURE SPEED FROM STOP (km/h)	CASE A MOVING VEHICLE												
	VEHICLE SPEED (km/h)												
	0	10	20	30	40	50	60	70	80	90	100	110	120
DISTANCE ALONG RAILROAD FROM CROSSING, d_T (m)													
10	45	38	24	20	15	13	18	20	21	22	24	25	26
20	91	77	48	40	37	37	38	40	43	44	47	50	53
30	136	115	72	60	56	56	58	61	64	66	71	76	79
40	181	153	96	80	75	75	77	81	85	89	94	101	105
50	227	192	120	100	94	93	96	101	106	111	118	126	132
60	272	230	144	120	112	112	115	121	128	133	141	151	158
70	317	268	168	140	131	131	134	141	149	155	165	176	185
80	362	307	193	161	150	149	154	162	170	177	189	202	211
90	408	345	217	181	168	168	173	182	191	199	212	227	237
100	453	383	241	201	187	187	192	202	213	221	236	252	264
110	498	422	265	221	206	205	211	222	234	244	259	277	290
120	544	460	289	241	225	224	230	242	255	266	283	302	316
130	589	498	313	261	243	243	249	263	275	288	306	327	343
140	634	537	337	281	262	261	269	283	298	310	330	353	369
DISTANCE ALONG HIGHWAY FROM CROSSING, d_H (m)													
	16	26	38	52	71	93	119	148	177	213	256	294	

Reference: "A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS" AASHTO, 1994

Figure 9-4. REQUIRED SIGHT DISTANCE FOR COMBINATION OF HIGHWAY AND TRAIN VEHICLE SPEEDS; 20 m TRUCK CROSSING A SINGLE SET OF TRACKS AT 90 DEGREES.



**HIGHWAY RAIL GRADE CROSSING
HEADER BOARD CONSTRUCTION ALTERNATIVES
(BASED ON TYPICAL 175 mm TIE DEPTH AND 180 mm RAIL HEIGHT ABOVE TIE)**

**Figure 9-5. HIGHWAY RAIL GRADE CROSSING
TYPICAL CROSS SECTION
NOT TO SCALE**

9.7.4 Crossing Surfaces

The crossing surface must preserve the structure and stability of the crossing and must provide a rideable design. The rideability of the surface is often the most noticeable crossing characteristic to the motorist. If it is in poor condition, it could preoccupy the motorist such that he does not pay proper attention to an approaching train.

Many types of crossing surfaces exist. The type should be commensurate with the traffic and train characteristics and roadway traffic it must accommodate. Railroad/highway crossings are broadly considered to be either high or low type. For a general guide for the threshold between the types of crossing surfaces, the designer is referred to Figure 9-6, "Rational for the Selection of the most effective railroad crossing surface." The key factors to consider when selecting a crossing design are: (1) Annual million gross tons traversing the track and (2) car equivalent count/lane (thousands) traversing the roadway. A 20-year design life should be used. Railroad companies install and maintain the crossing surface; therefore, their input into the selection type is important. Following is a brief discussion of crossing surface type:

LOW TYPE

Bituminous Grade Crossing Surface -- There are two different approved methods for interfacing between the running rail and the bituminous surface as set forth below:

- 1) Nelson chair-rail and
- 2) The rubber-formed flangeways that eliminate contact between the running rail and the bituminous surface.

Either one of these bituminous treatments are approved by the MHD for locations where low annual railroad million gross tons and low car equivalent counts per lane exist. For the thresholds limits for this type of treatment, please view Figure 9-6 "Rational For The Selection Of The Most Effective Railroad Grade Crossing Surface."

HIGH TYPE - Discussed previously

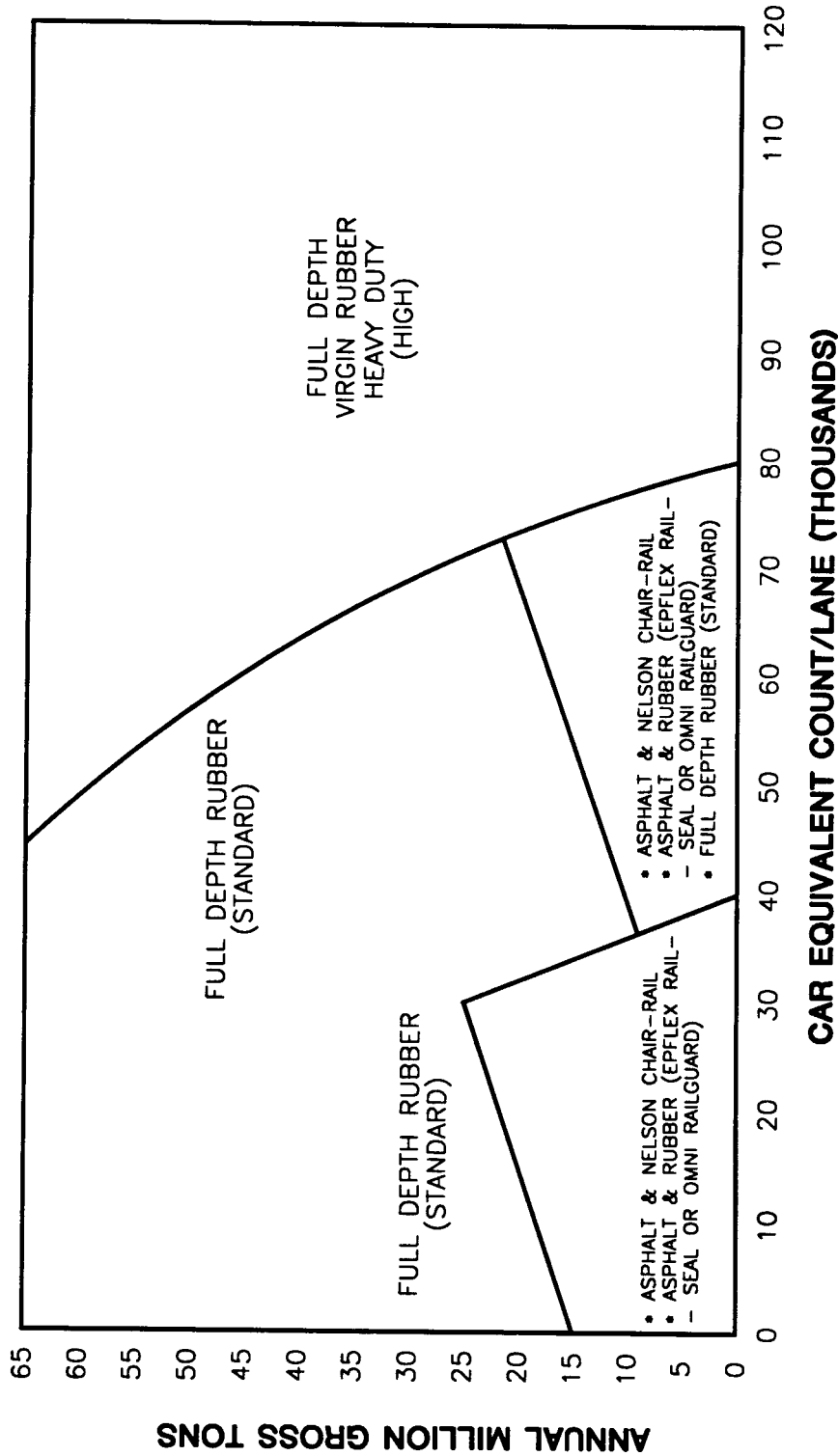


Figure 9-6. RATIONALE FOR THE SELECTION OF THE MOST EFFECTIVE RAILROAD CROSSING SURFACE

9.8 TRAFFIC CONTROL DEVICES AND HIGHWAY LIGHTING

Traffic control devices constitute an integral part of highway design. They include signs, signals and pavement markings. The TDAOS will specify requirement. The designer should therefore contact the TDAOS early on to preclude delay. The 25% review should be decisive as to requirements for traffic control devices. See Chapter I; in particular boxes 25 and 27 of the design flow chart and the 25% Submission Guidelines. See also *MUTCD*.

9.8.1 Highway Lighting

The TDAOS will determine need and specify requirements for highway lighting. Again, designers should contact the Traffic Operations section early on to enable the section to study warrants and define requirements in a timely manner. See *MUTCD* and *AASHTO Lighting Guide*.

When considering any geometric, safety, signal or pavement improvement at a highway railroad grade crossing, the designer should reference FHWA-TS-86-225 *Highway Railroad Grade Crossing Handbook*, September 1986 and the latest edition of the *MUTCD*. This section is intended to supplement these references.

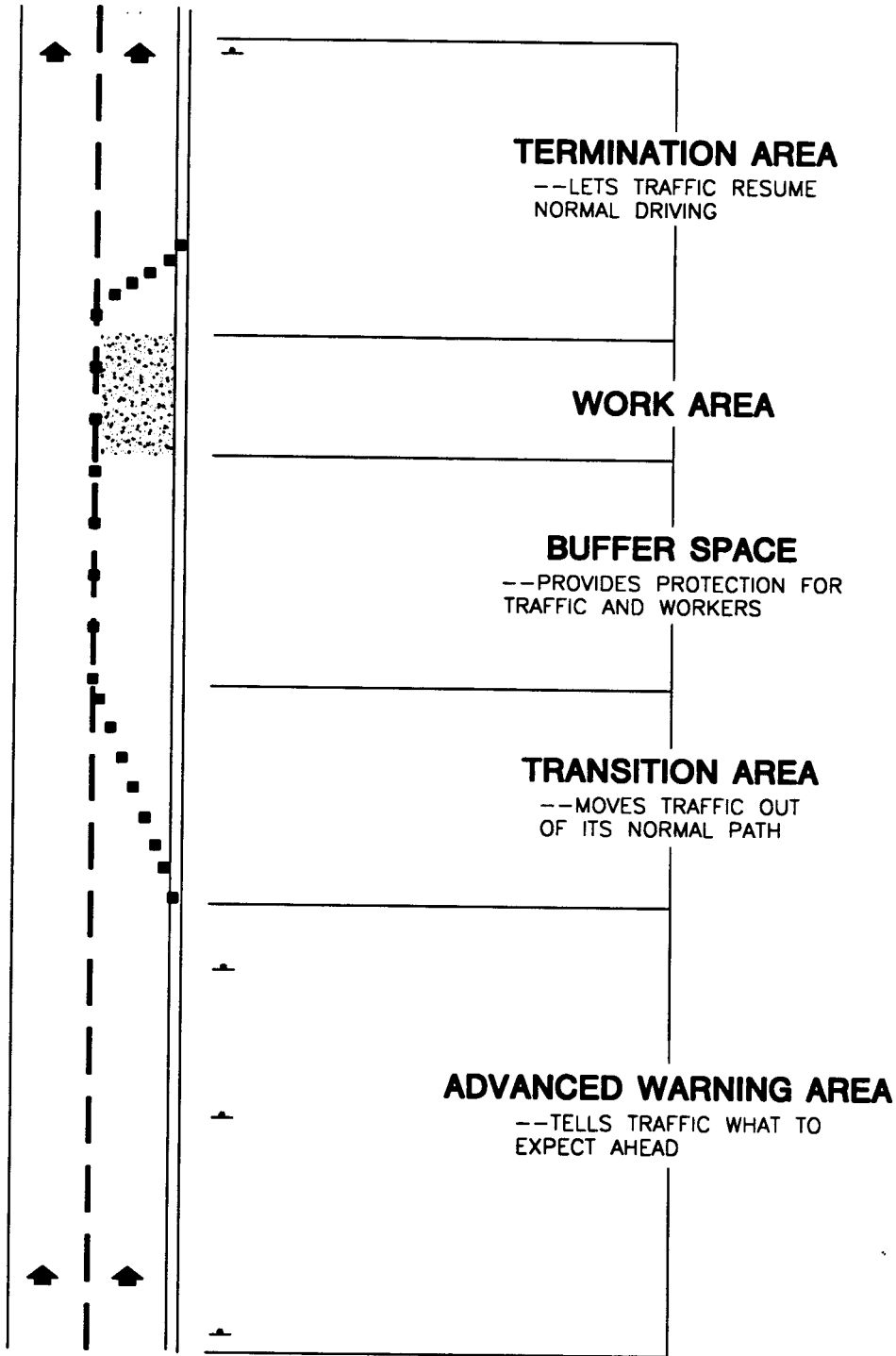
9.9 TRAFFIC CONTROL THROUGH CONSTRUCTION ZONES

Highway construction will disrupt normal traffic operations, thus the designer must give special attention to construction traffic control during the design of every project. A construction traffic control plan must be designed for each project. It should minimize the operational and safety problems through the work zone.

9.9.1 Traffic Control Zones

The FHWA's *Traffic Control Devices Handbook* defines a traffic control zone as the distance between the first advance warning sign and the point beyond the work area where traffic is no longer affected. This traffic control zone can be divided into five parts - advance warning area, transition area, buffer space, work area, and termination area (see Figure 9-7).

This workzone definition applies on all projects, from interstate highways to two lane-two way roadways.



Reference: FEDERAL HIGHWAY ADMINISTRATION, *TRAFFIC CONTROL DEVICES HANDBOOK*. 1985

Figure 9-7. AREAS IN A TRAFFIC CONTROL ZONE

9.9.1.1 Advance Warning Area

The purpose of the advance warning area is to provide the necessary information to motorists on what to expect ahead. Advance warning signs should be used when problems or conflicts with the flow of traffic might occur. The length of the advance warning area should be of sufficient distance to provide adequate motorist information. Some guidelines for this length include:

- 1.6 km to 4.8 km for freeways
- 450 meters for most other roadways
- At least one block for urban streets

9.9.1.2 Transition Area

The purpose of the transition area is to position oncoming vehicles in the lanes not under construction to allow safe and efficient movement through the construction zone. The major means of accomplishing this is through tapers. There are four general types of tapers used in traffic control zones:

- Lane closure tapers are those necessary for closing lanes of moving traffic (sometimes referred to as channelizing tapers).
- Two-way traffic tapers are those needed to control two-way traffic where traffic is required to alternately use a single lane (commonly used when traffic officers are present or temporary traffic signal control is to be installed).
- Shoulder closure tapers are those needed to close shoulder areas.
- Downstream tapers are those installed to direct traffic back into its normal path.

For lane closure tapers, the length of the taper is a function of the speed of traffic and the width of lane to be closed. The formulas for determining this length are as follows:

Posted Speed	Formula
60 km/h or under	$L = \frac{WS^2}{155}$
70 km/h or over	$L = 0.6WS$

Where: L = taper length

W = width of lane or offset

S = posted speed, or off-peak 85 percentile speed

If restricted sight distance is a problem, the taper should begin well in advance of the view obstruction. Table 9.4 shows the taper lengths, the number and spacing of channelizing devices for varying speeds and lane widths.

If a two-lane roadway requires a workzone that alternates traffic over a one-lane section, the two-way traffic tapers should be 15 meters to 30 meters long, with channelizing devices spaced a maximum of 3.0 to 6.0 meters. One-third the length of tapers shown in Table 9.4 is recommended for shoulder closure tapers. Closing tapers are similar in length and spacing to two-way traffic tapers.

The designer should be aware that the transition zone is second only to the work area in the frequency of accidents.

Table 9.4
TAPER LENGTHS FOR LANE CLOSURES - DISTANCE

SPEED LIMIT (km/h)	TAPER LENGTH LANE WIDTH (m)			NUMBER OF CHANNELIZING DEVICES FOR TAPER	SPACING OF DEVICES ALONG TAPER (m)
	3.0	3.5	4.0		
30	22	24	25	5	30
40	32	35	40	6	40
50	46	50	55	7	50
55	60	70	80	8	55
60	85	90	100	9	60
70	140	150	160	13	70
80	150	170	180	13	80
90	170	190	200	13	90

REFERENCE *FEDERAL HIGHWAY ADMINISTRATION, TRAFFIC CONTROL DEVICES HANDBOOK, 1985*

SITUATIONS OCCUR WHERE OPPOSING STREAMS OF TRAFFIC ARE TRANSITIONED SO ONE LANE OF TRAFFIC USES A LANE THAT NORMALLY FLOWS IN THE OPPOSING DIRECTION. IN THESE SITUATIONS, A BUFFER SPACE SHOULD BE USED TO SEPARATE THE TWO TAPERS FOR OPPOSING DIRECTIONS OF TRAFFIC BECAUSE IT COULD HELP PREVENT HEAD-ON COLLISIONS.

9.9.1.3 Buffer Zone

The buffer space is the open space between the transition and work areas. The major purpose of the buffer space is to provide sufficient distance for a driver to stop if he/she is unable to negotiate the transition area safely. The following guidelines should be considered:

- Place channelizing devices along the edge of the buffer space. The suggested spacing in meters is equal to the posted speed limit in km/h divided by 2.5.
- Situations occur where opposing streams of traffic are transitioned so one lane of traffic uses a lane that normally flows in the opposite direction. In these situations, a buffer space should be used to separate the two tapers for opposing directions of traffic in order to help prevent head-on collisions.

9.9.1.4 Work Area

The work area is that portion of the traffic control zone which contains the work activity. The work area is often shielded by barriers to exclude traffic and pedestrians. Effective delineation must be provided through the work area, especially in work areas that remain overnight. *The Traffic Control Devices Handbook* suggests the following actions to minimize conflicts in the work area:

- Use traffic control devices to make the travel path clearly visible to traffic.
- Place channelizing devices between the work area and the traveled way. The *MUTCD* does not specify a spacing for the devices along the closed lane. For high-speed roadways, a range from 0.4 to 0.2 times the posted speed is suggested. For low-speed or urban streets, a closer spacing may be used.
- Provide a safe entrance and exit for work vehicles.
- Protect mobile and moving operations with adequate warning on the work and/or shadow vehicles.
- Flags and flashing lights should be considered on work vehicles exposed to traffic.
- Most work areas will require positive barriers to separate workers from the motorists.
- Special care should be given to this area because most work zone accidents occur here.

9.9.1.5 Termination Area

The termination area is the distance of road which allows traffic to clear the work area and to return to normal traffic lanes. Sometimes, a downstream taper is used to provide a good transition to normal traffic flow. The taper in the termination area is optional.

9.9.2 Traffic Management Plans

A formal Traffic Management Plan (TMP) is required by FHWA to be included in the plans, specifications and estimates for all Federal-aid projects. TMP's should be prepared for all Department projects as well. Each project shall include a plan for the safe and effective movement of traffic through a highway or street work zone. This may range in scope from a TMP which describes every detail of traffic accommodation to a reference to the MUTCD and standard plans, depending upon the complexity and duration of the construction project. It is suggested that traffic management planning be initiated at the 25% level and carried through the entire design process.

The TMP is part of the plans, specifications and estimates (PS&E). It shall include the following:

1. A plan of each construction stage, including:
 - A. signing;
 - B. application and removal of pavement markings;
 - C. delineation and channelization; (modular guidance system, if applicable)
 - D. lane closures;
 - E. detours, crossovers;
 - F. placement of all traffic control devices;
 - G. location and types of safety appurtenances;
 - H. means of maintaining access to and from existing interchange ramps;
2. In addition the following items should be addressed:
 - A. flagging or police location requirements;

- B. work scheduling restrictions, if applicable;
- C. storage of equipment and materials;
- D. traffic regulation, if applicable;

Table 9.5 shows the traffic control devices for various locations of work. FHPM 6-4-2-12 paragraph 6a (2) provides additional detail on Traffic Management Plans.

**Table 9.5
TRAFFIC CONTROL DEVICES FOR VARIOUS LOCATIONS**

	ROAD WORK AHEAD	KEEP RIGHT	ONE LANE ROAD	FLAGGER AHEAD	RIGHT (OR LEFT) LANE CLOSED	RIGHT (OR LEFT) TWO LANES CLOSED	MERGE RIGHT (LEFT)	SIGNS ON BOTH SIDES OF ROADWAY	TAPER IN SHOULDER W/CHANNELIZING DEVICES	TAPER LENGTH L W/CHANNELIZING DEVICES**	FLAGGER	FLASHING ARROW PANEL	DOUBLE TAPER SEPARATED BY 2L	BUFFER SPACE WITH CHANNELIZING DEVICES	WARNING DEVICES IN FRONT OF WORK AREA	BARRIERS IF WORK REQUIRES EXCAVATION***	FLASHING LIGHTS AND FLAGS ON VEHICLES ARE SUGGESTED	CHANNELIZING DEVICES ALONG WORK AREA	END WORK AREA	DOWNSTREAM TAPER
ENTIRELY BEYOND SHOULDER (OR CURB) NO ACCESS FROM SHOULDER NEEDED.																				
ENTIRELY BEYOND SHOULDER (OR CURB) WITH ACCESS FROM SHOULDER.																				
ON OR OVER SHOULDER (OR PARKING LANE)																				
ON SHOULDER (OR PARKING LANE) WITH MINOR ENCROACHMENT INTO TRAVELED LANE.																				
ONE LANE OF A 2-LANE, 2-WAY ROADWAY.																				
RIGHT LANE OF A 4-LANE, 2-WAY ROADWAY.																				
LEFT LANE OF A 4-LANE, 2-WAY ROADWAY.																				
TWO RIGHT LANES OF A 4-LANE, 2-WAY ROADWAY. (LEFT LANES ARE SIMILAR).																				
RIGHT LANE OF A 2-LANE, 1-WAY OR DIVIDED ROADWAY. (LEFT LANE IS SIMILAR.)																				
TWO RIGHT LANES OF A 4-LANE, 1-WAY ROADWAY. (LEFT LANES ARE SIMILAR).																				
WORK LOCATION	ADVANCE WARNING AREA ^a		TRANSITION AREA		BUFFER SPACE		BUFFER AREA		TERMINATION AREA											

• A CONSISTENT PATTERN OF MESSAGES IS SHOWN IN THIS FIGURE. REFER TO MUTCD FOR OTHER ACCEPTABLE MESSAGES OR SYMBOL SIGNS
 ** OLD PAVEMENT MARKINGS SHOULD BE REMOVED AND NEW MARKINGS PLACED IN.
 *** THE USE OF BARRIERS IS DETERMINED BY AN ENGINEERING ANALYSIS OF THE NEED FOR POSITIVE PROTECTION.

Reference: FEDERAL HIGHWAY ADMINISTRATION, *TRAFFIC CONTROL DEVICES HANDBOOK*, 1985

9.9.2.1 MHD Standard Criteria and Procedures

The MHD Traffic Design and Operations Section (TDAOS) will review all TMP's for adequacy for the following projects:

- Projects on the National Highway Systems;
- Projects designed in the Boston Office (design, maintenance or traffic projects);
- Projects being expedited by the TDAOS;
- Also, the TSAOS shall review the preliminary design and traffic analysis portion of all 25% design submission.

The following lists the standard publications adopted by MHD for TMP development.

1. MHD Standard Specifications with supplements:
 - a. Subsection 7.09 Public Safety and Convenience
 - b. Subsection 7.10 Barricades and Warning Signs
 - c. Subsection 7.11 Traffic Officers and Railroad Flagging Services
 - d. Subsection 7.13 Protection and Restoration of Property
 - e. Subsection 7.17 Traffic Accommodations
 - f. Subsection 8.02 Schedule of Operations
 - g. Subsection 8.03 Prosecution of Work
 - h. Subsection 850 Traffic Control for Construction and Maintenance Operations
2. Massachusetts and Federal *MUTCD* (Part VI)
3. *MHD Construction and Traffic Standard Drawings*

The Department uses pre-bid and pre-construction conferences to clarify and resolve traffic management operations, particularly for complex projects.

9.9.2.2 Research Activities and MHD Reference File

The Transportation Research Board, FHWA, various State Highway Agencies, private research firms, and industry associations have conducted studies to improve the safety of the traveling public and workers in construction and maintenance areas. MHD has been involved in such activities as improved impact attenuators, concrete median barriers, pavement marking removal techniques, the use of raised pavement markers for work area delineation, and PVC pipe barriers.

To reflect the current state of the art and to provide an information source of material on traffic control in construction zones, MHD has established a reference file which will be supplied by the FHWA.

9.9.2.3 Local Involvement

On large scale projects, the designer should coordinate the Traffic Management Plan development with all affected local interests. These include, at the community level, the elected responsible authority, public works department, police, fire department, school boards, businesses, and abutters. In addition, the TMP should be fully discussed at public hearings, if held. The MHD will consider contacting the local media (newspapers, radio, television) to notify the public of the upcoming construction and traffic management plans.

9.9.3 Traffic Control Devices

9.9.3.1 MUTCD Devices

All signs, pavement markings, channelization, and barricades must be designed and located according to Part VI of the *MUTCD*.

9.9.3.2 Temporary Pavement Markings

Temporary pavement markings will be required when the work operation occupies the roadway for a period of more than two consecutive days. For periods two days or less, temporary pavement markings shall conform with Section 850.64 of the Standard Specifications.

Existing pavement markings in conflict with the temporary pavement markings shall be

removed or obliterated. Painting over the lines is not a substitute for removal or obliteration. Removal of the pavement markings may be by grinding, sand-or-water-blasting, or any method that does not materially damage the pavement surface, or cause a drastic change in texture so as to be construed as delineation at night. Non-removable temporary pavement markings shall not be used on finished or final surfaces.

Transition Area

The transition area of a work zone must clearly delineate the intended vehicle path during the day and night under both wet and dry conditions. Temporary solid lines and temporary raised reflectorized pavement markers shall be required for the following three transition area conditions.

- A. Crossovers - Where traffic is diverted from one roadway to another.
- B. Lane Shifts - Where traffic is diverted from one or more lanes to other lanes.
- C Lane drops - Where the number of active traffic lanes are reduced.

Advance, Buffer, Work and Termination Areas

Pavement markings (lines) and temporary raised reflectorized markers shall be used throughout the work zone. The minimum length of broken lines shall be 1.25 meter with 11.0 meter gap, in addition to temporary raised reflectorized pavement markers located every 6.0 meters. However for long term work operations, the length of broken lines shall be 3.0 meters with 9.0 meters gap.

Solid lines shall be used for roadway edge lines where required, and center lines on undivided roadways.

9.9.3.3 Temporary Raised Reflectorized Pavement Markers

Temporary raised reflectorized pavement markers (TRRPM) shall be installed throughout the work zones for night time reflectivity when the work operation occupies the roadway for a period more than two consecutive days.

TRRPM's are not to be located on lines unless recommended by the manufacturer. The near edge of the marker shall be 50 mm millimeters from the traffic side edge of the line.

The recommended spacing for the TRRPM's is as follows:

- A. Transition Areas
Solid Lines - TRRPM's on a minimum of 1.5 meter centers.

- B. Advance, Buffer, Work and Termination Areas
Solid Lines - TRRPM's on 6 meter centers
Broken Lines - TRRPM's on 6.0 meter centers, in line with pavement lines, with a TRRPM located immediately beyond the end of each line.

9.9.3.4 Flashing Arrowboards

Flashing arrowboards provide excellent advance warning of lane closures to drivers. If properly located, field studies have indicated that drivers exit the closed lane well in advance of the closure. These criteria will apply to their use:

1. Flashing arrowboards should be used for all closures on freeways. They should be used if possible on all other major highways.
2. The arrowboard should be placed in the closed lane at the beginning of the taper.
3. Where the sight distance to the arrowboard is less than 450 meters, a supplemental arrowboard (warning mode) should be used. The supplemental arrowboard should be placed on the shoulder approximately 770 meters before the beginning of the taper.
4. A supplemental arrowboard (warning mode) is recommended on freeways and expressways, regardless of sight distance availability.
5. Arrowboards must automatically dim at night.

9.9.3.5 Changeable Message Signs

Changeable Message Signs (CMS) may be considered as a supplement to the standard traffic control scheme. Situations where they may be used include:

1. short-term lane closures where driver expectancy may be reduced.
2. limited sight distance to the closure where flashing arrowboards may not be fully effective.

If a CMS is used, the following criteria will apply:

1. The CMS should be placed at an appropriate location to inform the motorist, who may wish to seek an alternate route of the upcoming conditions.
2. The CMS message may include detour, queuing, merge, and/or lane closure information.
3. The CMS message must be readable at a glance. Therefore, the maximum format should be a three-line presentation with a two-message phase.
4. The Traffic Operations Section shall be consulted for approved standard CMS messages and proper format.

9.9.4 Design Considerations

The design of the traffic control plan should minimize operational and safety problems. This will require careful consideration of many elements.

9.9.4.1 Capacity

The expected capacity of the proposed traffic control corridor should be estimated, particularly on freeways. The design should avoid lengthy backups and delays. The lateral distance from the travel lane to obstacles will be a significant capacity adjustment. Preferably, the level of service through the construction zone should be the same as the approaching highway. It should not be more than one service level below. A capacity analysis could lead to significant modifications in the traffic management scheme. For example, lane closures may be prohibited during peak traffic hours; or the sequence of construction could be altered to improve traffic operations.

9.9.4.2 Speed

Significant speed reductions through construction zones are undesirable and can lead to accidents. With the exception of restricted horizontal alignment, regulatory or warning speed signs are generally ineffective. Therefore, the design speed through the work zone should be as close as possible to that of the approaching highway.

9.9.4.3 Sight Distance - Freeways

Traffic control devices are not a desirable substitute for sight distance. The upper sight distance to the construction zone should be 450 meters. The lower distance should be 300 meters. This should be considered when selecting a lane closure location. As discussed in Section 9.9.3.4, a supplemental flashing arrowboard should be used when the sight distance to a lane closure is less than 450 meters. At sites with restricted sight distance and high traffic volumes, the designer may use a changeable message sign.

9.9.4.4 Safety Appurtenances

Barriers and crash cushions may be warranted in construction zones. Where positive protection is warranted for lengthy sections of highway, temporary concrete median barrier (TCMB) is effective. General conditions which favor its use are:

1. long-term construction activity.
2. high traffic volumes.
3. steep edge of travel lane drop-offs (greater than 100 mm).
4. close proximity between traffic and construction workers and construction equipment.
5. adverse geometrics which increase the likelihood of run-off-the-road vehicles.
6. two-way traffic on one barrel of a divided highway (see Section 9.9.3.5) and.
7. to shield the entire lane of any lane closures when designed as part of the taper and channelization.

Where a point obstacle will be present, an impact attenuator may be warranted. The most common use of an attenuator is at the exposed end of a TCMB. Three criteria will determine the warrants:

1. If the exposed end is 3.8 meter or less from the edge of the travel lane, an impact attenuator should be used.
2. If the end is between 3.8 meter and 6.3 meter, the need for an impact attenuator will be determined by a case-by-case assessment, including costs, traffic volumes, geometric alignment, and duration of exposure.

3. If the end is 6.3 meter or more, an impact attenuator will not normally be used.

Normally, the impact attenuator will be either the inertial system (sand barrels) or an energy impact attenuator capable of redirection, which is a special adaption for Construction zones. The normal sand barrel design provides a 750 mm offset between the corner of the obstacle and the outside barrels. For temporary construction zone installation only, this may be reduced to 380 mm. This is acceptable only where a greater offset will cause unacceptable interference to traffic.

9.9.4.5 Two-Way Traffic on Divided Highways

Often, the most efficient construction scheme on divided highways is to close one barrel of the highway to traffic and provide two-way operation on the other barrel. However, this is a severe violation of driver expectancy and can lead to head-on collisions. Therefore, this scheme should not be used until other methods of traffic management have been considered. All signing and pavement markings must conform to the *MUTCD*.

Some means of separation between the two traffic flows is necessary, except where:

1. drivers can see the transition back to the normal one-way operation, or
2. unusual conditions exist such as very narrow bridges.

The separation can be provided by drums, cones, or the TCMB. To determine which type of separation will be used, a project-by-project analysis will be necessary. The analysis should consider traffic volumes, duration of separation, vehicle speeds, length of two-way operation, geometrics (sight distance, lane widths, horizontal alignment, etc.), and construction costs.

9.9.4.6 Detours

Detours around a construction site effectively remove the traffic from the work area. Detours may be constructed exclusively for the project or may use existing roads to reroute the traffic. Because they have obvious safety and operational advantages, detours should be used if possible. However, detours through local streets can often be controversial. These factors should be considered:

1. All signing must conform to the *MUTCD*.
2. The design speed of the detour should preferably be the same as that of the highway or not less than 10 km/h below the highway design speed. However, this is frequently

not possible when local roads are used for the detour.

3. All detour plans which use local roads must be approved in writing by the municipality as part of the Traffic Management Plan.

9.10 REFERENCES

- *Roadside Design Guide*, AASHTO, 1996
- *Safety Design and Operational Practices for Streets and Highways*, FHWA, March 1980.
- *Manual on Uniform Traffic Control Devices*, National Advisory Committee on Uniform Traffic Control Devices.
- *Work Zone Traffic Control, Standards, and Guidelines*, FHWA, April 1980.
- *Crash Cushions, Safety Systems, Technical Notebook*, Energy Absorption Systems, Inc.
- *"Economics and Physical Consequences of Operating Respective Car Weights Over Truck Structure"*, Illinois Central Gulf Railroad, 1955
- *"Highway-Railroad Grade Crossing Materials Selection-Handbook"*, 1984 Florida Department of Transportation
- *"Railroad-Highway Grade Crossing Handbook"* U.S. D.O.T., FHWA, Section Edition, September 1986
- *"Selecting the Most Cost Effective Grade Crossing Surface:",* proceeding: 1989 National Conference on Rail-Highway Safety, pages 175 through 215
- *"Grade Crossing Renovation - "What Does It Cost",* 1989 Railroad Track & Structures



CHAPTER 10

DRAINAGE & EROSION CONTROL

**NOTE: THIS CHAPTER IS BEING REVISED IN
METRIC UNITS**

**USE 1988 HIGHWAY DESIGN MANUAL AND
CONVERT TO METRIC UNITS AS REQUIRED
FOR DESIGN**

CHAPTER 11

PAVEMENT DESIGN

11.1 PAVEMENT DESIGN PROCESS

This chapter on Pavement Design is based on the 1972 AASHTO *Interim Guide* as revised in 1981. Since then, research has continued into the cost-effective design of highway pavements, resulting in the publication of the 1993 AASHTO *Guide for Design of Pavement Structures*. Features of this new design procedure include:

- Use of statistical reliability instead of the current factor of safe design.
- Use of resilient modulus tests for soil support (a dynamic test) vs. CBR (a static test).
- Introduction of environmental factors to evaluate the effects of spring thaw and frost heave.

While these new design concepts appear very promising, the foundation needed to adopt them is not in place at this time. Until these new methods can be phased in, the Department will continue to design pavements based on a modification of the *Interim Guide*, which has provided satisfactory pavement structures since its introduction.

Effective pavement design is one of the more important aspects of project design. The pavement is the portion of the highway which is most obvious to the motorist. The condition and adequacy of the highway is often judged by the smoothness or roughness of the pavement. From a project design perspective, pavement and related items comprise from 10% of 90% of highway construction costs. Among the costs associated with underdesigned pavements are:

1. increased user costs (fuel consumption, ties, repair, etc.)
2. increased accident costs;
3. increased maintenance costs;
4. cost of user delays due to reconstruction and maintenance;
5. cost of early reconstruction.

Because pavement life is substantially affected by the number of heavy load repetitions applied, a poorly-designed pavement will not be evident until several years after construction. To design a pavement structure properly, the designer must rely on his/her own expertise as well as that of soils and planning engineers. (Pavement design for 3R roadways is covered in Chapter 8). Considerations include:

1. *Evaluate existing pavement* to determine appropriate strategy, value of existing materials or structure for new pavement, and the reasons for its present condition. Check with maintenance forces for history of roadway performance, groundwater problems and other background information;
2. *Evaluate subgrade* for drainage characteristics and bearing capacity;
3. *Make structural calculations.* After selecting the appropriate preliminary rehabilitation strategy, the traffic, soils, and pavement materials data must be used to calculate specific pavement layer requirements;
4. *Compare feasible alternatives* (new pavement, recycling ,overlay, etc.) and select the most economically-sound method for construction;
5. *Set specifications.* The pavement materials, construction methods, and finished project requirements must be both practical to attain and clearly defined. The designer must ensure that the plans, standard specifications, supplemental specifications, and special provisions clearly and unambiguously define the requirements.

11.1.1 Pavement Types

Massachusetts uses a pavement design method based on the method shown in the AASHTO *Interim Guide for the Design of Pavement Structures*. This chapter outlines the design methods for flexible pavement (bituminous concrete). Because Massachusetts highways are primary bituminous concrete, the design for rigid pavements (portland cement concrete) is omitted. Rigid pavement design methods are presented in the AASHTO *Interim Guide* and are available from the Portland Cement Association.

In addition to the major pavement types (rigid and flexible), a combination of bituminous concrete over the portland cement concrete is occasionally used. Combination types are called composite pavements.

A flexible pavement consists of three layers - subbase (foundation), base and surface. The subbase consists of granular material - gravel, crushed stone, or a combination. The base

consists of a coarse bituminous concrete mixture ("black base"). The surface consists of two

courses of bituminous concrete, each with a different consistency - binder material and surface material.

A rigid pavement is portland cement concrete placed on a granular subbase. Portland cement pavements are either plain and jointed or reinforced. Pavement design is discussed in Section 11.3.

11.1.2 Definitions and Abbreviations

Equivalent 80 kN Load - The conversion of mixed vehicular traffic into its equivalent single-axle, 80 kN Load. The equivalence is based on the relative amount of pavement damage.

Daily Equivalent 80 kN Load (T_{80}) - The average number of equivalent 80 kN loads which will be applied to the pavement structure in one day. Normally, a 20-year design period is used to determine the daily load. (See Table 11.1).

Table 11.1
EQUIVALENT 80 kN AXLE APPLICATIONS PER 1000 TRUCKS
FLEXIBLE PAVEMENTS

Highway Class	
Freeways / Expressways	1000
Major Arterial	800
Minor Arterial (Urban)	800
Minor Arterial (Rural)	600
Collector (Urban)	800
Collector (Rural)	600
Local Roads, Urban (City Roads)	600
Local Roads, Rural (Town Roads)	600

1. This table was effective September 1, 1982. It will periodically updated to reflect the MHD loadmeter readings.

Reference: *Massachusetts Highway Department*

Equivalent 80 kN Axle Applications per 1000 Trucks and Combinations - A factor which reflects the relative mix of sizes and weights of trucks on various classes of highways (e.g., interstate, major primary, and city streets.) Truck percentages provided by Planning exclude two-axle, four-tire pickup trucks, the effect of which may be ignored.

Serviceability Index - A measure of a pavement's ability to serve high-speed, high volume automobile and truck traffic on a scale of 0 to 5. It reflects the extent of pavement distress.

Terminal Serviceability Index (Pt) - A pavement design factor which indicates the acceptable pavement serviceability index at the end of the selected design period (usually 20 years). The Department designs for a terminal serviceability (Pt) equal to 2.5.

Bearing Ratio - The load required to produce a certain penetration using a standard piston in a soil, expressed as a percentage of the load required to force the piston the same depth in a selected crushed stone. The test procedures for the California Bearing Ratio (CBR) are used.

Design Bearing Ratio (DBR) - The selected bearing ratio used to design the pavement. It is based on an evaluation of the CBR test results on the soil samples.

Soil Support Value (SSV) - An index of the relative ability of a soil or stone to support the applied traffic loads. It is specifically used for the pavement design method in the AASHTO *Interim Guide for Design of Pavement Structures*. The soil support value of the subgrade is related to its CBR (DBR).

Structural Number (SN) - A measure of the structural strength of the pavement section based on the type and thickness of each layer within the pavement structure.

Layer Coefficient - The relative structural value of each pavement layer per millimeter of thickness. It is multiplied by the layer thickness to provide the contributing SN for each pavement layer.

Pavement Design Engineer - PDE

Design Engineer - The consultant under contract to the Department or municipality or the designer within the Department.

11.2 PROCEDURES

Figure 11-1 describes the MHD pavement design process. All pavement designs are determined by the project design engineer with the MHD Pavement Design Engineer (PDE) reviewing and approving all pavement designs. The major tasks in the design process are:

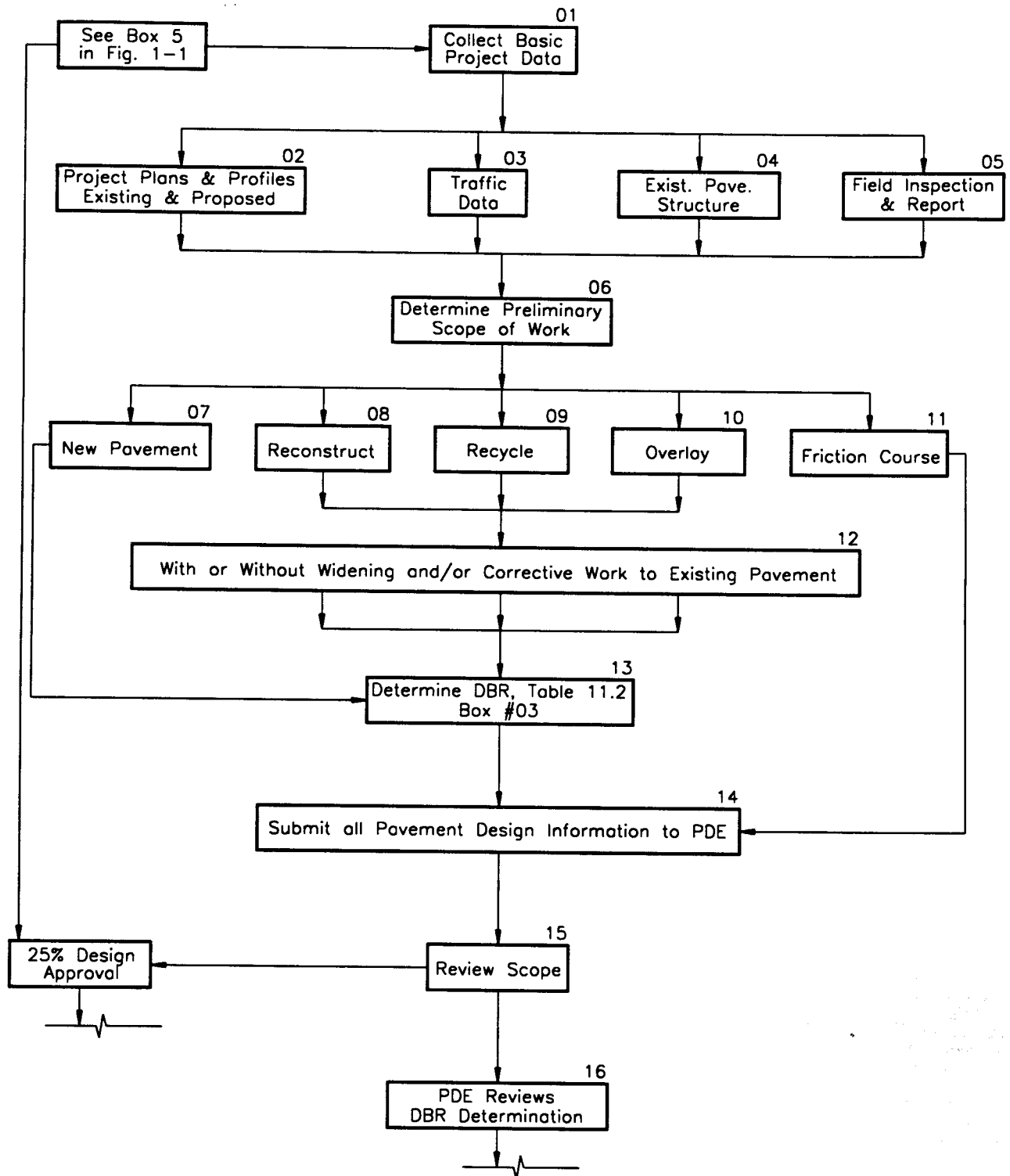


Figure 11-1. PAVEMENT DESIGN PROCESS

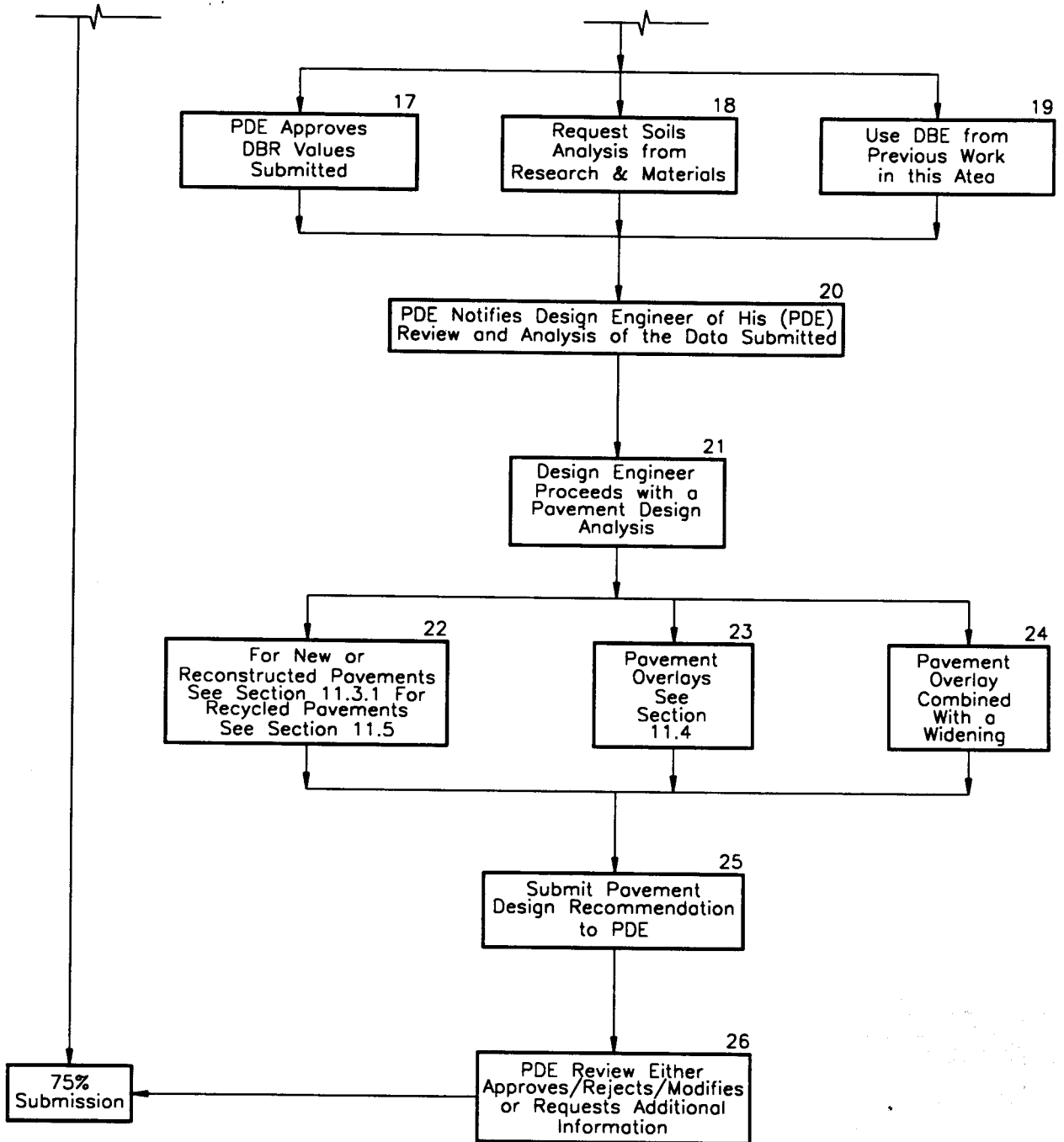


Figure 11-1. (CONTINUED)

BOX 01 COLLECT BASIC PROJECT DATA

The designer must collect the basic project data as discussed in Boxes 02, 03, 04, 05.

BOX 02 PROJECT PLANS AND PROFILES (Existing & Proposed)

These shall be submitted to the Pavement Design Engineer

BOX 03 TRAFFIC DATA

The traffic data includes:

1. Current ADT, (ADT for year of proposed opening to traffic)
2. Projected ADT (20 years)
3. ADT truck percentage
4. Number of lanes
5. Divided/undivided, and
6. Source of traffic data

Enter these data on the pavement design checklist.

BOX 04 EXISTING PAVEMENT STRUCTURE

The thickness and type of each pavement layer (i.e., surface, binder, base and subbase) shall be recorded; it is especially necessary for overlay and recycling projects.

BOX 05 FIELD INSPECTION REPORT

The report shall include the general condition of the roadway such as cracking (type, amount) rutting, rideability, and any other characteristic that may be pertinent to the

selection of pavement type and scope of work. This should include specific discussions with Department and/or municipal maintenance and engineering forces.

BOX 06 DETERMINE THE PRELIMINARY SCOPE OF WORK

The design engineer will determine the scope of work for the pavement design. This can be a new pavement, reconstructed pavement, pavement overlay, or a combination of any two. All or part of an existing pavement may be recycled as part of the pavement design. The designer should use the pavement design checklist to document the reasons for the decision.

BOX 07 NEW PAVEMENT

A new pavement is a pavement structure which is placed on a previously undisturbed subgrade. It applies to a highway on new location, to a relocated highway, or to the new part of a widened highway.

BOX 08 RECONSTRUCTED PAVEMENT

A reconstructed pavement is one which results when an existing pavement structure is completely removed to the subgrade and replaced with a new pavement structure. This type of work is needed when the existing pavement has deteriorated to such a weakened condition that it cannot be salvaged with corrective action. The type and extent of pavement distress will determine when pavement reconstruction is necessary.

BOX 09 RECYCLED PAVEMENT

A recycled pavement results when an existing pavement structure (from which all or part of the pavement is removed on or off site), is combined with new materials and replaced. Recycling is performed in conjunction with a pavement overlay or reconstructed pavement. All proposed recycling projects must be economically justified. Section 11.5 further discusses recycling.

BOX 10 PAVEMENT OVERLAY

A pavement overlay consists of placing the needed thickness of bituminous concrete on an existing pavement. The overlay will return the pavement to a high level of serviceability and provide the necessary structural strength for the pavement design period.

BOX 11 FRICTION

A pavement may not require any corrective work other than the application of a friction course because of low skid resistance. In some instances a friction course may be placed on new or reconstructed pavements. Research and Materials makes periodic skid measurements of all highways and will check the skid resistance of any facility upon request. Research and Materials submits all skid data to Maintenance and Highway Design. The friction course does not add to the structural integrity of the pavement. It is 25 mm thick and in many cases it is placed on a dense graded binder course about 45 mm in thickness. This ensures a better adhesion between the binder and friction courses.

BOX 12 WITH/WITHOUT WIDENING &/OR CORRECTIVE WORK TO THE EXISTING PAVEMENT

- A) A pavement may be reconstructed without any additional work or the reconstruction may include widenings, shoulders, extra lanes, etc., in addition to the new pavement structure.
- B) A recycling project may consist simply in improving the pavement structure by one of the many methods of recycling (See Section 11.5), Other recycling projects may include the addition of shoulders, widenings, etc. The type of work required is to be considered when selecting the methods or type of recycling.
- C) An overlay may be placed on the existing surface without any other work except that related to the overlay. An overall pavement rehabilitation project (widenings, additional lanes, improved geometry etc.) usually includes an overlay. In many cases a certain amount of corrective work may be required prior to the placing of an overlay. This work may consist of strengthening weakened subgrade where indicated, removing and replacing badly-deteriorated surface areas, placing a leveling course filling ruts and depressions. Include also any operations that will minimize reflective cracking.

BOX 13 DETERMINE DBR

Section 11.3 and Table 11.2 discuss the procedure for determining the course of action for selecting a DBR value.

BOX 14 SUBMIT ALL PAVEMENT DESIGN INFORMATION TO PDE

The designer will submit all applicable information for the pavement design to the PDE. This will include:

1. The pavement design checklist documenting the reasons for selecting the scope of work (see Figure 11-2).
2. The DBR value.
3. A set of project plans and profiles
4. Traffic data.

BOX 15 PDE REVIEWS SCOPE OF WORK

The PDE will review the designer's recommendation for scope of pavement work and the pavement design checklist documenting the reasons.

BOX 16 PDE REVIEWS DBR DETERMINATION

The PDE will review the designer's determination of the subgrade DBR. If necessary, he will submit a request to Research and Materials for a DBR determination (Box 18)

BOX 17 PDE APPROVES DBR VALUES SUBMITTAL

Under certain conditions, (see Table 11.2) the PDE will approve the value of the DBR submitted. Otherwise, Research and Materials will determine the DBR in accordance with Box 18.

**Table 11.2
DESIGN BEARING RATIO (DBR) DETERMINATION**

VALUE FROM LINE (h) OF DATA SHEET 1 (T 80)	ACTION
T 80 < 15	USE MINIMUM DESIGN (SEE TABLE 11.3)
15 < T 80 < 120	ASSUME DBR BASED ON SOILS CLASSIFICATIONS (AS DETERMINED BY DISTRICT LAB) FROM TABLE 11.3
T 80 > 120	RESEARCH AND MATERIALS WILL DETERMINE DBR

Reference: *Massachusetts Highway Department*

**Table 11.3
DBR BASED ON AASHTO SOILS CLASSIFICATION**

GENERAL CLASSIFICATION SUBGRADE RATING	AASHTO GROUP CLASSIFICATION	DBR	SSV
GRANULAR MATERIALS / EXCELLENT TO GOOD	A1 - a	30	7.1
	A1 - b	20	6.2
	A2 - 4	15	5.4
	A2 - 5*		
	A2 - 6*		
	A2 - 7*		
	A - 3	10	4.4
SILT -CLAY MATERIALS / FAIR TO POOR	A2 - 4	8	3.9
	A2 - 5**	5	2.8
	A2 - 6**	3	1.6
	A2 - 7**	2	0.6
VIRGIN GRAVEL FOR RECONSTRUCTION		40	7.8
IN - SITE GRAVEL SUBBASE FOR OVERLAY		8.5	6.6

Reference: *Massachusetts Highway Department*

* CONSULT PAVEMENT DESIGN ENGINEER

** CONSIDER ECONOMICS OF REPLACING POOR MATERIAL



I. Project Identification

City/Town _____
 Street / Rte. No. _____
 From Station _____
 From (Landmark) _____
 Date _____

Project Number _____
 Functional Class _____
 To Station _____
 To (Landmark) _____
 Design Engineer _____

II. Traffic Data

Current ADT (year) _____
 T (ADT) _____
 No. of Lanes _____

Future ADT (Year)* _____
 T (PEAK HR.) _____
 Divided / Undivided _____

III Existing Pavement Information

Year Initially Constructed _____ Overlaid _____

Existing Pavement Structure:

<u>Layer</u>	<u>Depth</u>	<u>Type</u>
Surface	_____	_____
Base	_____	_____
Subbase	_____	_____

IV. Document Existing Pavement Distress

<u>Type</u>	<u>Extent (percentages)</u>	<u>Severity</u>			<u>Depth Inches</u>
		<u>High</u>	<u>Medimum</u>	<u>Low</u>	
<input type="checkbox"/> AlligatorCracking					
<input type="checkbox"/> Block Cracking					
<input type="checkbox"/> Other Cracking (transverse, longitudinal, reflective)					
<input type="checkbox"/> Lane / Shoulder Dropoff					
<input type="checkbox"/> Potholes					
<input type="checkbox"/> Rutting (wheelpaths)					
<input type="checkbox"/> Alligator Cracking					
<input type="checkbox"/> Other _____					
<input type="checkbox"/> Other _____					

- Notes:
1. If existing pavement is PCC, provide a separate description of pavement condition.
 2. Provide photographs as needed to demonstrate pavement distress

* Minimum 20 yr. protection

Figure 11-2 Pavement Design Checklist



V. Proposed Corrective Work to Existing Pavement (if any)

- | | |
|---|--|
| <input type="checkbox"/> Leveling Course | <input type="checkbox"/> Subdrainage Pipes |
| <input type="checkbox"/> Crackfilling* | <input type="checkbox"/> Deep Patching/Pothole Filling |
| <input type="checkbox"/> Prime | <input type="checkbox"/> Other _____ |
| <input type="checkbox"/> Cold Planning | <input type="checkbox"/> Other _____ |
| <input type="checkbox"/> Heater/Scarifier | <input type="checkbox"/> Other _____ |

Discussion (if needed): _____
any special site conditions which may limit the practical choices.

VI. Proposed Scope of Work

- | | |
|---|---|
| <input type="checkbox"/> New Pavement | <input type="checkbox"/> Pavement Overlay |
| <input type="checkbox"/> Reconstructed Pavement | <input type="checkbox"/> With widening |
| <input type="checkbox"/> Recycling | <input type="checkbox"/> Without widening |
| <input type="checkbox"/> Surface (in place) | <input type="checkbox"/> With corrective work to existing pavement |
| <input type="checkbox"/> Cold-Mix | <input type="checkbox"/> Without corrective work to existing pavement |
| <input type="checkbox"/> Hot-Mix | |

Discussion (if needed): _____

VII. Briefly discuss reasons for proposed work, including estimated costs and any special site conditions which may limit the practical choices.

Discussion (if needed): _____

* Only done under certain circumstance and with the approval of PDE

Figure 11-2 Pavement Design Checklist

BOX 18 REQUEST LAB ANALYSIS FROM RESEARCH AND MATERIALS (if needed)

If the designer has recommended a lab analysis to determine the DBR and the PDE have concurred, the PDE will submit a request to Research and Materials. The procedure is:

1. Research and Materials determines the required number of test pits, their locations, and the highest bottom pit elevations. This information is shown on the project plans and forwarded to the District.
2. The District stakes the test pit locations and makes arrangement for sampling.
3. Normally, the District is responsible for test pit excavations on state and Interstate highways. Under certain conditions however, if directed by Research and Materials, it may be more expeditious to have a boring contractor or the Department boring crew do the sampling.
4. The Town or City is responsible for test excavations on all other roadways. An engineer from the District must direct the sampling operation, supervise the excavations, and review the test pit logs.
5. The test pit samples must weigh at least 22 kg. When the sample is graded in the District laboratory, the lab must follow the procedures prescribed by Research and Materials. The District forwards all samples, gradations, tabulations, and test pit logs to Research and Materials.
6. Research and Materials will determine the DBR. The report will be sent to the PDE.

BOX 19 USE DBR FROM PREVIOUS WORK

If it is available and still applicable, the PDE will use the DBR used for the original pavement design or any previous pavement overlays.

BOX 20 PDE NOTIFIES DESIGN ENGINEER OF THE (PDE) REVIEW AND ANALYSIS OF THE DATA SUBMITTED

The PDE will notify the design engineer of the results of his/her review. This step applies

to both new/reconstructed pavement and pavement overlays. He/she may approve, disapprove, request modifications, or request additional information from the design engineer. If applicable, he/she will also provide the DBR determined by Research and Materials.

BOX 21 DESIGN ENGINEER CONDUCTS PAVEMENT DESIGN ANALYSIS

The design engineer will conduct the detailed analysis to determine the type and thickness of each layer in the pavement structures. The types of analysis are discussed further in Boxes 22, 23, 24.

BOX 22 NEW/RECONSTRUCTED PAVEMENT

On new and reconstructed pavements, the designer will determine the detailed full-depth design of the pavement. The detailed procedure is discussed in Section 11.3. Recycling may be considered.

BOX 23 PAVEMENT OVERLAYS

On pavement overlays, the designer will specify the depth of the bituminous concrete overlay. The detailed procedure is discussed in Section 11.4. In addition, the designer will determine the corrective work needed on the existing pavement.

BOX 24 COMBINATION (PAVEMENT OVERLAY WITH WIDENING)

This type of work will require a combination analysis. Section 11.3 will determine the full-depth design of the widened section. Section 11.4 will determine the needed depth of overlay.

BOX 25 SUBMIT PAVEMENT DESIGN RECOMMENDATION TO PDE

The design engineer will submit the recommended detailed pavement design with completed data sheets to the PDE.

BOX 26 PDE REVIEWS AND APPROVES/DISAPPROVES/MODIFIES/ REQUESTS ADDITIONAL INFORMATION

The PDE will review the pavement design recommendation from the design engineer. He/she may approve, disapprove, modify, or request additional information from the design engineer. The PDE will notify the design engineer of his/her action.

11.3 NEW AND RECONSTRUCTED PAVEMENT

MHD uses the AASHTO *Interim Guide for Design of Pavement Structures* as the basic design methodology. However, MHD has incorporated several modifications to the *Guide's* procedures to reflect specific conditions in Massachusetts and to simplify the procedure. This section specifies the MHD procedure for determining the detailed design of a new or reconstructed pavement. This procedure applies to bituminous concrete pavements only.

The MHD procedure follows:

PAVEMENTS DESIGN COVER SHEET

The following must be recorded:

1. Enter the project identification data at the top of the cover sheet.
2. Summarize the recommended pavement design by documenting the surface, base, and subbase data. List the depths, type of layer and recommended lifts.
3. Describe the special borrow, if required for the project. Special borrow may be necessary where the existing subgrade is susceptible to frost penetration, and it is within the typical frost penetration depth. The laboratory analysis by Research and Materials will provide the typical frost penetration depth for the project area. The designer will recommend the type and depth of special borrow to be used for frost control. Special Borrow is generally placed on Interstate and Major Primary Routes. Consideration for placement on other roads will depend on functional classification, traffic volumes, presence of utilities, construction methods, etc.

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

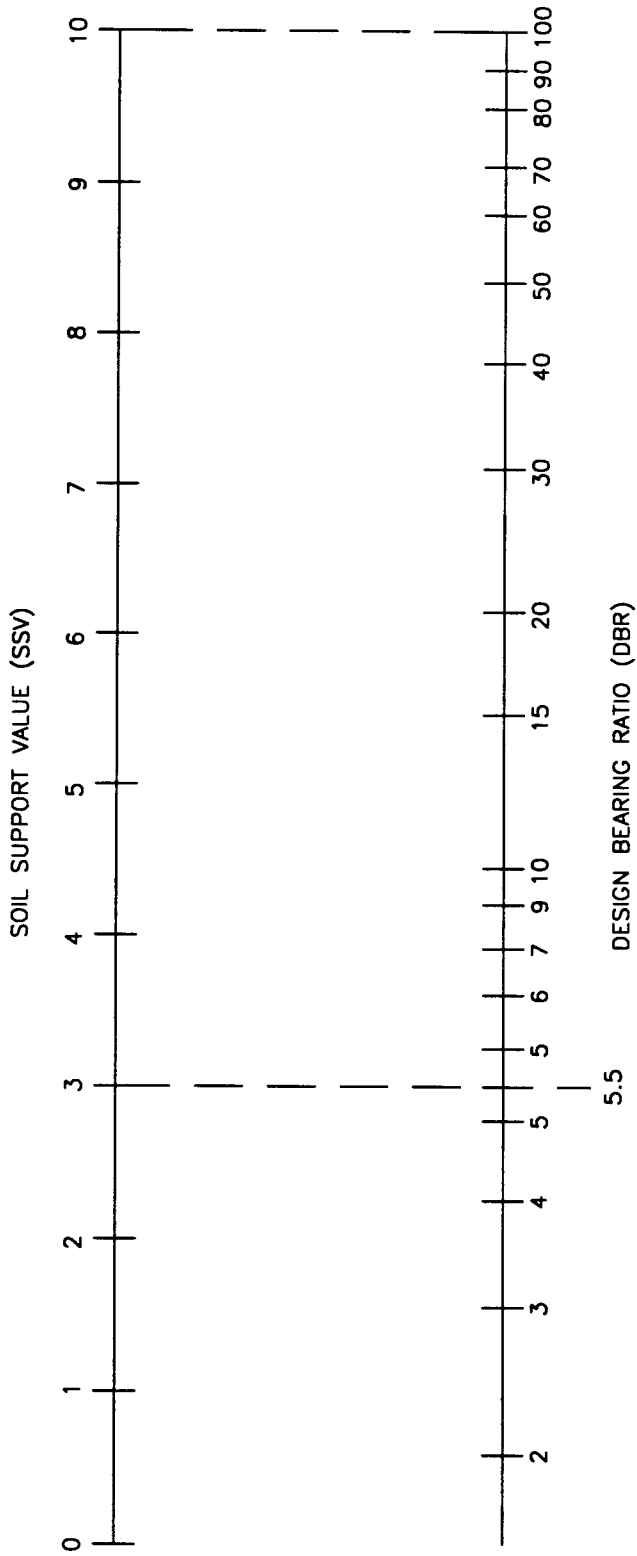
- Line (a): Enter the anticipated (current) ADT for date of opening.
- Line (b): Enter the future ADT, usually for 20 years beyond the projected opening date. Generally the design period for pavements is 20 years; however there may be occasions when the traffic submitted does not cover the design period. In these cases the future ADT is to be estimated by approved methods. Under certain circumstances, pavements may be designed for periods of less than 20 years. 3R projects may be designed for periods of 5 to 10 years.
- Line (c): Calculate the average ADT during the design period.
- Line (d): Calculate the average ADT in one direction.
- Line (e): Enter the truck percentage for the ADT.
- Line (f): Calculate the average daily truck volume in one direction.
- Line (g): Enter the equivalent 80 kN axle application per 1000 trucks and combinations. See Table 11.1.
- Line (h): Calculate the number of 80 kN axle loads per day in one direction (T_{80}).

DESIGN BEARING RATIO (DBR) DETERMINATION

Use the value on Line (j)(T_{80}) and Table 11.2 to determine the subgrade DBR. As noted in Table 11.2, Research and Materials may be required to provide the DBR. In all cases, designers make a general computation of the subgrade DBR for reviews by the Pavement Design Engineer. See Box 16 above.

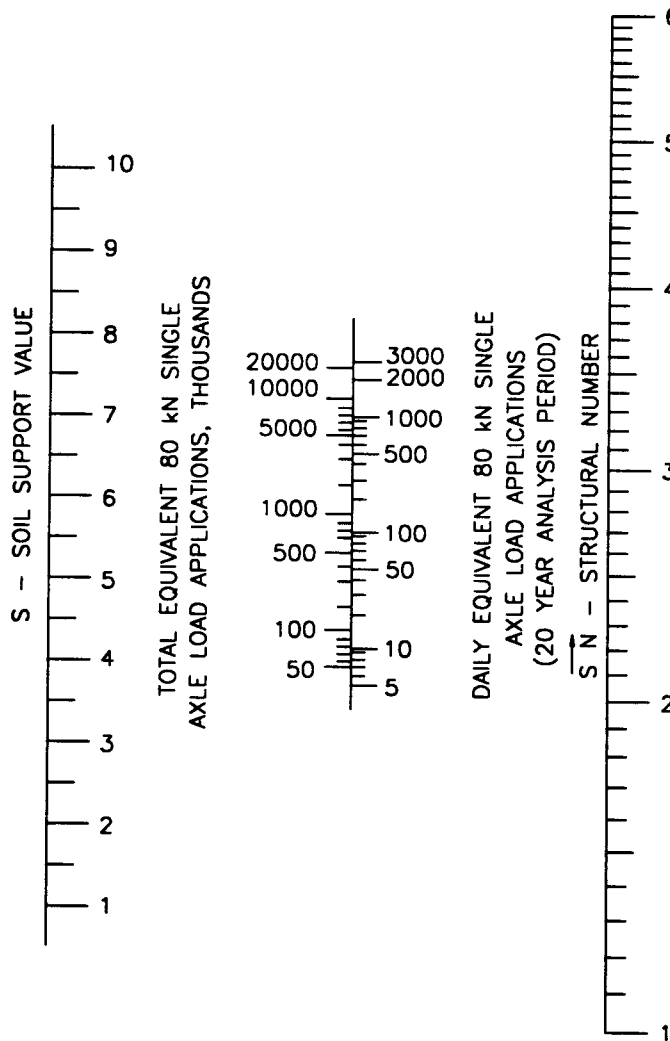
DATA SHEET 2: DETERMINING STRUCTURAL NUMBER (SN)

- Step 1: Determine the design lane equivalent daily 80 kN applications based on the number of lanes.
- Step 2: Determine the DBR for the subgrade from Tables 11.2 and 11.3. The subbase DBR is 40 for the typical MHD subbase on new or reconstructed pavements (gravel).
- Step 3: Determine the soil support value (SSV). Figure 11-3 illustrates the relationship between the DBR and SSV.



REFERENCE: MASSACHUSETTS HIGHWAY DEPARTMENT

Figure 11-3. DBR vs. SSV



Note: THE RIGHT SIDE OF THE VERTICLE LINE IN THE CENTER PROVIDES THE DAILY EQUIVALENT 80 kN SINGLE-AXLE LOAD. IT IS ONLY GOOD FOR A 20-YR ANALYSIS PERIOD. THE LEFT SIDE PROVIDES THE TOTAL LOAD APPLICATION, AND IT CAN BE USED FOR ANY DESIGN ANALYSIS PERIOD.

REFERENCE: INTERIM GUIDE FOR DESIGN OF PAVEMENT STRUCTURES, AASHTO, 1972.

**Figure 11-4. STRUCTURAL NUMBER (SN) NOMOGRAPH
(FOR FLEXIBLE PAVEMENT P = 2.5)**

- Step 4: Determine the required structural number (SN) above the subbase and above the subgrade. Figure 11-4 should be used. Use the design-lane T80 from Step 1 for the daily equivalent 80 kN single axle load. Use the SSV from Step 3 for the soil support value.
- Step 5: Increase the SN by 15% to determine the design SN to adjust for climatic and other environmental conditions.

DATA SHEET 3: PAVEMENTS STRUCTURAL NUMBER (SN)

By trial and error, the designer will select the most cost-effective design that provides the required SN for the highway conditions. The designer should also consider minimum and maximum lift thicknesses and the logistics of construction procedures when designing the pavement design combinations using this procedure.

- Step 1: Select each pavement layer component and the thickness of each layer.
- Step 2: From Table 11.4 select the layer coefficient for each pavement layer.
- Step 3: Determine the contributing SN for each pavement layer by multiplying the layer coefficient by its thickness.
- Step 4: The minimum thicknesses of each layer are noted on Table 11.5.
- Step 5: Check to ensure that the required SN is provided above the subbase and the subgrade. If not, increase the layer thickness as necessary. If the trial design exceeds the required SN, reduce the layer thicknesses.

Table 11.4
LAYER COEFFICIENTS FOR NEW AND RECONSTRUCTED PAVEMENTS

Placement Component	Layer Coefficient per mm
Surface Course: Bituminous Concrete Riding Surface and Binder	1.73×10^{-2}
Base Course: Bituminous Concrete	1.34×10^{-2}
Subbase: Crushed Stone (Dense Graded) Gravel	0.55×10^{-2} 0.43×10^{-2}

Reference: *Massachusetts Highway Department*

Step 6: Determine several alternate pavement designs which satisfy the SN requirements. The selected design will be based on economics.

Step 7: Regardless of the calculations from the pavement design analysis, the minimum design thickness should not be less than those shown in Table 11.5.

Figure 11-5 presents the pavement design cover sheet and data sheets 1 to 3.

* * * * *

Table 11.5
MINIMUM PAVEMENT THICKNESS
(NEW AND RECONSTRUCTED PAVEMENTS)
FLEXIBLE PAVEMENT

HIGHWAY TYPE	BITUMINOUS CONCRETE TOP COURSE										TOTAL SN						
	RIDING SURFACE			BINDER			BITUMINOUS CONCRETE BASE			SUBBASE, STONE-GRAVEL							
	THICKNESS (mm)	LAYER COEFFICIENT	SN	THICKNESS (mm)	LAYER COEFFICIENT	SN	THICKNESS (mm)	LAYER COEFFICIENT	SN	THICKNESS (mm)		LAYER COEFFICIENT	SN				
FREEWAY/ EXPRESSWAY	45	0.017	3	0.78	50	0.017	3	0.87	115	0.013	4	1.54	100 STONE 200 GRAVEL	0.005 0.004	5 3	1.41	4.60
ARTERIALS	45	0.017	3	0.78	45	0.017	3	0.79	90	0.013	4	1.21	100 STONE 200 GRAVEL	0.005 0.004	5 3	1.41	4.19
COLLECTOR LOCAL	45	0.017	3	0.78	45	0.017	3	0.79	80	0.013	4	1.07	300 GRAVEL	0.004	3	1.29	3.93

THE ABOVE TABLE IS ONLY VALID WHEN THE CONVENTIONAL DESIGN CALCULATIONS INDICATE A REQUIRED PAVEMENT STRUCTURE LESS THAN THE ABOVE. ALL PAVEMENT THICKNESSES SHALL BE DESIGNED AS DETAILED HERE. THE USE OF CRUSHED STONE AS PART OF THE BASE COURSE SERVES TWO PURPOSES: IT MAKES A FIRMER BASE FOR THE PAVING MACHINES AND IT REDUCES THE AMOUNT OF GRAVEL REQUIRED, (GRAVEL IS IN SHORT SUPPLY IN SOME AREAS OF THE STATE). GRAVEL ALSO SERVES TWO PURPOSES: STRUCTURAL SUPPORT (THOUGH IT IS WEAKER THAN CRUSHED STONE), AND DRAINAGE. CRUSHED STONE IS INCOMPATIBLE WITH DRAINAGE AND THEREFORE, CANNOT FULLY REPLACE GRAVEL.



MASSACHUSETTS HIGHWAY DEPARTMENT

PAVEMENT DESIGN NEW AND RECONSTRUCTED PAVEMENTS

City/Town _____

Route No. _____ Highway System _____

From Station _____ To Station _____

No. of Lanes _____

Date Pavement Designed _____ Project Designer _____

RECOMMENDED PAVEMENT STRUCTURE

Surface: _____

Base: _____

Subbase: _____

Special Borrow: _____

Figure 11-5



NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

City/Town _____ Route No. _____

From Station _____ To Station _____

No. of Lanes _____ Highway System _____ Date _____

Current ADT _____

Terminal Serviceability Index (T.S.I) = 2.5

(a) Day of Opening A.D.T (Date _____)* _____

(b) Future A.D.T (Date(a) + 20 years)** _____

(c) Mean A.D.T = $\frac{(a) + (b)}{2}$ _____

(d) Mean A.D.T In One Direction = $\frac{(c)}{2}$ _____

(e) A.D.T. Truck Percentage ("T" A.D.T.) _____

(f) Mean Truck A.D.T. In One Direction (d) X (e) _____

(g) Equivalent 80 kN Axle Application per 1000 Trucks and Combinations (See Table 11.1) _____

(h) Number of 80 kN Axle Loads Per Day In One Direction
 $\frac{(f) \times (g)}{1000}$ (T₈₀) _____

Comments: _____

*Anticipated traffic when facility is opened to travel.

**Under certain conditions this may change to a layer or shorter period.

Figure 11-5 (Continued)

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 2: DETERMINATION OF STRUCTURAL NUMBER (SN)

Design Lane Equivalent Daily 80 kN Applications (T80)

For 2-Lane Undivided Highway

Design Lane T80 = 1.00 X Total T80* = 1.00 X = _____

For 4 (Total Lanes) Lane divided Highway

Design Lane T80 = 0.90 X Total T80* = 0.90 X = _____

Design 6 or More (Total Lanes) Divided Highway

Design Lane T80 = 0.80 X Total T80* = 0.80 X = _____

Design DBR Table 11.2 & 11.3, Boxes 17,18,19 & SSV Table 11.1

Subbase.....DBR = _____, SSV = _____

Subgrade.....DBR = _____, SSV = _____

Design Structural Number (SN)

Apply Design SSV and Design Lane T80 from above to Design Nomograph (Figure 11-4)

	From	
	<u>Fig. 11-4</u>	<u>+15%</u>
Above Subbase.....	= _____	_____
Above Subgrade.....	= _____	_____

*From Line (h) of Data Sheet 1.

Figure 11-5 (Continued)

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 3: DETERMINATION OF STRUCTURAL NUMBER (SN)

$$SN = D_1 a_1 + D_2 a_2 + D_3 a_3$$

Surface

Material: $D_2 a_2 =$ = _____

Base Course

Material: $D_2 a_2 =$ = _____

Total SN Above Subbase = _____

Subbase (Foundation)

Material: $D_3 a_3 =$ = _____

..... $D_3 a_3 =$ = _____

Total SN Above Subbase = _____

- Where:
- D_1 = Surface Thickness, mm
 - D_2 = Base Thickness, mm
 - D_3 = Subbase Thickness, mm

- a_1 = Coefficient of Relative Strength, Surface
- a_2 = Coefficient of Relative Strength, Base
- a_3 = Coefficient of Relative Strength, Subbase

Comments: _____

Figure 11-5 (Continued)



MASSACHUSETTS HIGHWAY DEPARTMENT

PAVEMENT DESIGN
NEW AND RECONSTRUCTED PAVEMENTS

City/Town Revere
Route No. Broadway (Rte. 107) Highway System Urban Collector
From Station 4791 To Station 5391
No. of Lanes 2 travel lanes
Date Pavement Designed 2-24-95 Project Designer J. R. Huber

RECOMMENDED PAVEMENT STRUCTURE

Surface: 90 mm Class I Bituminous Concrete Pavement Type T-1 placed in 2 layers: 45 mm Top Course Material over 45 mm Binder Course Material

Base: 115 mm Class I Bituminous Concrete Pavement Type I-1 Base Course Material placed in one layer

Subbase: 100 mm Crushed Stone Dense Graded over 255 mm Gravel Borrow

Special Borrow: _____



NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

City/Town Revere Route No. 107
From Station 4791 To Station 5391
No. of Lanes 2 Highway System Urban Coll. Date 2-24-95
Current ADT 1995

Terminal Serviceability Index (T.S.I) = 2.5

- (a) Day of Opening A.D.T (Date 1995) * 21640
(b) Future A.D.T (Date(a) + 20 years)** 22480
(c) Mean A.D.T = $\frac{(a) + (b)}{2}$ 22060
(d) Mean A.D.T In One Direction = $\frac{(c)}{2}$ 11030
(e) A.D.T. Truck Percentage ("T" A.D.T.) 5
(f) Mean Truck A.D.T. In One Direction (d) X (e) 550
(g) Equivalent 80 kN Axle Application per 1000 Trucks and Combinations (See Table 11.1) 800
(h) Number of 80 kN Axle Loads Per Day In One Direction $\frac{(f) \times (g)}{1000}$ (T₈₀) 440

Comments: _____

*Anticipated traffic when facility is opened to travel.
**Under certain conditions this may change to a longer or shorter period.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 2: DETERMINATION OF STRUCTURAL NUMBER (SN)

Design Lane Equivalent Daily 80 kN Applications (T80)

For 2-Lane Undivided Highway

$$\text{Design Lane T80} = 1.00 \times \text{Total T80}^* = 1.00 \times \underline{440} = \underline{440}$$

For 4 (Total Lanes) Lane divided Highway

$$\text{Design Lane T80} = 0.90 \times \text{Total T80}^* = 0.90 \times \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

Design 6 or More (Total Lanes) Divided Highway

$$\text{Design Lane T80} = 0.80 \times \text{Total T80}^* = 0.80 \times \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

Design DBR Table 11.2 & 11.3, Boxes 17,18,19 & SSV Table 11.1

Subbase...Gravel...DBR = 40 , SSV = 7.8

Subgrade.....DBR = 9 , SSV = 4.2

Design Structural Number (SN)

Apply Design SSV and Design Lane T80 from above to Design Nomograph (Figure 11-4)

	From	
	Fig. 11-4	+15%
Above Subbase..... =	<u>26</u>	<u>2.99</u>
Above Subgrade..... =	<u>4.15</u>	<u>4.77</u>

*From Line (h) of Data Sheet 1.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 3: DETERMINATION OF STRUCTURAL NUMBER (SN)

$$SN = D_1 a_1 + D_2 a_2 + D_3 a_3$$

Surface

Material: 90 mm Bit. Conc. $D_2 a_2 = 90 \times 0.0173 = 1.56$

Base Course

Material: 115 mm Bit. Conc. $D_2 a_2 = 115 \times 0.0134 = 1.54$

Total SN Above Subbase $= 3.10 \approx 2.99$

Subbase (Foundation)

Material: 100 mm Crushed Stone $D_3 a_3 = 100 \times 0.0055 = 0.55$

255 mm Gravel $D_3 a_3 = 255 \times 0.0043 = 1.10$

Total SN Above Subbase $= 4.75 \approx 4.77$

Where: D_1 = Surface Thickness, mm
 D_2 = Base Thickness, mm
 D_3 = Subbase Thickness, mm

a_1 = Coefficient of Relative Strength, Surface
 a_2 = Coefficient of Relative Strength, Base
 a_3 = Coefficient of Relative Strength, Subbase

Comments: _____

Example

Given: Approximately 1 800 meters of Broadway Street (Route 107) is being reconstructed in Revere. Broadway is a two-lane urban facility. The following data is given.

1995 ADT = 2 1640

2015 ADT = 2 2480

T (ADT) = 5%

Problem: Determine the pavement structural design for a 20-year design period.

Solution:

Data Sheet 1

Lines (a) to (g) on Data Sheet 1 are completed as instructed. Table 11.1 is used to select the equivalent 80 kN axle applications per 1000 trucks and combinations. The urban roads value of 800 is used and entered on Line (h). Therefore, Line (j) is 440.

DBR Determination

Line (j) (T80) exceeds 120. Therefore, according to Table 11.2, Research and Materials must determine the DBR for the subgrade. This will be processed by the Pavement Design Engineer as described in Section 11.2.

Data Sheet 2

- Step 1: The design lane equivalent for a two-lane undivided highway is $1.00 \times$ Line (j) which, in this case, is 440.
- Step 2: Research and Materials determines that the subgrade DBR is 9.
- Step 3: Using Figure 11-3, the subgrade SSV = 4.2; the subbase SSV = 7.8.
- Step 4: Using Figure 11-4, the required SN above the subbase is 2.6; above the subgrade it is 4.15.
- Step 5: Increasing these values by 15% yields SN design values of 2.99 and 4.77.

Data Sheet 3

Use the trial-and-error procedure to determine the most economical design which satisfies the SN requirements for the subbase and subgrade. The following design is selected:

- 90 mm bituminous concrete surface
- 115 mm bituminous concrete base
- 100 mm dense graded crushed stone
- 255 mm gravel

A completed summary sheet and completed data sheets follow.

* * * * *

11.4 PAVEMENT OVERLAYS

A pavement overlay can be used if the designer determines that an existing pavement is in reasonably good condition. As discussed in Section 11.2, a pavement overlay may be in conjunction with roadway widening and/or corrective work to the existing pavement. The depth of bituminous concrete overlay will be determined by the following procedure:

Pavement Overlay Design Cover Sheet

The following must be recorded:

1. Enter the project identification data at the top of the cover sheet.
2. Document the existing pavement structure before overlay.
3. Record the recommended pavement overlay thickness.

Data Sheet 1: Pavement Structural Design Data

Line (a): Enter the current ADT

Line (b): Enter the future ADT, usually for 20 years beyond the current. (Note: The traffic data for the Bureau of Transportation Planning and Development may not correspond to the dates in Lines (a) and (b). If not, the designer should assume a uniform straight-line increase between the data from Planning and

Development. This assumption can then be used to determine the traffic volumes in Lines (a) and (b).)

Line (c): Calculate the average ADT during the design period.

Line (d): Calculate the average ADT in one direction.

Line (e): Enter the truck percentage for the ADT.

Line (f): Calculate the average daily truck volume in one direction.

Line (g): Enter the equivalent 80 kN axle applications per 1000 trucks and combinations. See Table 11.1.

Line (h): Calculate the number of 80 kN axle loads per day in one direction.

Line (j): Calculate the design lane equivalent daily 80 kN applications based on number of lanes.

Line (k): Enter the subgrade DBR and SSV. These will be provided by the Pavement Design Engineer as discussed in Section 11.2 and Tables 11.2 and 11.3.

Line (l): Determine the required SN above the subgrade from Figure 11-4.

Line (m): Determine the design SN by increasing the SN by 15%.

Data Sheet 2: Actual SN of Existing Pavement

Line (a): Enter the SSV of the existing pavement elements. The SSV for the penetrated crushed stone base, the sand bound crushed stone base, and the gravel subbase are usually assumed as shown. However, if laboratory-determined DBR results are available, these values should be used. Enter the SSV for the subgrade from Line (k) of Data Sheet 1.

Line (b): Determine the SN of the existing pavement. Follow these steps:

1. Table 11.6 provides the layer coefficient for each layer component for a *new* pavement.
2. The coefficients in Table 11.6 should be multiplied by a reduction factor (RF) from Table 11.7. The RF will be

based on a visual survey of the type and extent of distress in the existing pavement. The RF will apply even if corrective work is performed on the existing pavement.

3. The contributing SN for each layer is calculated by multiplying its depth by the layer coefficient and RF.
4. The total SN is found by summing the SN of each pavement layer.

(Note: If Portland Cement concrete is part of the existing pavement, the PDE will determine its contributing SN.)

Line (c): Determine the actual SN above each layer of the existing pavement. The SN for each layer is entered in the appropriate column. The "Total SN" reflects the cumulative SN above each pavement layer.

Data Sheet 3: Determination of Overlay Thickness

Line (a): Determine the required SN above each layer of the existing pavement using Figure 11-4. The values from Line (j) on Data Sheet 1 and from Line (a) of Data Sheet 2 are used in the figure. The SN values from Figure 11-4 are increased by 15% to determine the design SN.

Line (b): Determine the SN deficiency for each layer for the existing pavement. The required SN from Line (a) of Data Sheet 3 is entered in the first column. Enter the value from Line (c) of Data Sheet 2 in the second column. The first column SN minus the second column SN yields the SN difference, which is entered in the third column. (Note: A negative value indicates there is no SN deficiency for that pavement layer.)

Line (c): The *largest* SN deficiency from the table in Line (b) is used to determine the thickness of the pavement overlay. The 1.73×10^{-2} is in the SN value per mm for bituminous concrete surface course. Regardless of the calculation, the minimum overlay thickness is 45 mm.

Figure 11-6 presents the pavement overlay design cover sheet and data sheets 1 to 3.

* * * * *

Table 11.6
LAYER COEFFICIENTS FOR EXISTING PAVEMENTS

Pavement Component	Layer Coefficient Per mm
Surface Course: Bituminous Concrete Sand Asphalt	.0173 .0157
Base Course: Bituminous Concrete Bituminous Treated Penetrated Crushed Stone / Macadam Sand Bound Crushed Stone Sandy Gravel	.0134 .0095 .0055 .0028
Subbase: Crushed Stone (Dense Graded) Gravel Sand / Sandy Clay	.0055 .0043 .0020 - .0029

1. These are the layer coefficient values for when the pavement was new. They must be reduced according to the Reduction Factors in Table 11.7

Table 11.7
REDUCTION FACTORS FOR EXISTING PAVEMENT

Description of Existing Pavement ¹	Reduction Factor (RF)
BC surface exhibits appreciable cracking and crack patterns, little or no spalling along the cracks, some wheel path deformation, and essentially stable.	0.5 - 0.7
BC surface exhibits some fine cracking, small intermittent cracking patterns, and slight deformation in the wheel paths, and obviously stable.	0.7 - 0.9
BC surface generally uncracked, little or no deformation in the wheel paths, and stable	0.9 - 1.0

1. This is based on a visual survey of the type and extend of distress. If the pavement distress and deterioration is worse than described in the table, consideration should be made for the removal and reconstruction of the pavement.



MASSACHUSETTS HIGHWAY DEPARTMENT

PAVEMENT OVERLAY DESIGN

City/Town _____

Route No. _____ Highway System _____

From Station _____ To Station _____

No. of Lanes _____

Date of Overlay Design _____ Project Engineer _____

EXISTING PAVEMENT ELEMENTS BEFORE OVERLAY

- _____ Bituminous Concrete Surface
- _____ Penetrated Crushed Stone Base
- _____ Sand bound Crushed Stone Base
- _____ Gravel Subbase

RECOMMENDED OVERLAY THICKNESS

.....

Figure 11-6

PAVEMENT OVERLAY DESIGN

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

Terminal Serviceability Index Nomograph = 2.5

- (a) Current A.D.T. (Date _____) _____
- (b) Future A.D.T. (Date _____) _____
- (c) Mean A.D.T. = $\frac{(a) + (b)}{2}$ _____
- (d) Mean A.D.T. In One Direction $\frac{(c)}{2}$ _____
- (e) A.D.T. Truck Percentage _____
- (f) Mean Truck A.D.T. In one Direction (d) X (e) _____
- (g) Equivalent Daily 80 kN Axle Application per 100 trucks and Cominations (See Table 11.1) _____
- (h) Number of 80 kN Axle Loads Per Day in One Direction $\frac{(f) \times (g)}{1000}$ (T80) _____
- (i) 80 kN Load on Design Lane: (h) Z 1.00 for 2 lanes;
(h) X 0.90 for 4 lanes; (h) X0.80 for 6 or more lanes _____
- (j) Subgrade Design Bearing Ration and Soil Support Value _____
- * (k) Structural Number (SN) Required Above the Subgrade _____
- * (l) Increase SN by 15% for Design SN _____

* These values are developed on Data Sheet #3

Figure 11-6. (Continued)

DATA SHEET 2: ACTUAL SN OF EXISTING PAVEMENT

(a) Soil Support Values of Existing Granular Pavement Elements

Penetrated Crushed Stone Base = 90
 Sand Bound Crushed Stone Base = _____
 Gravel Subbase = 66
 Subgrade = _____

(b) Actual Structural Number (SN) of Each Layer of Existing Pavement

(1) Depth		(2) Coefficient <u>Table 11.6</u>	(3) RF <u>Table 11.7</u>	(2) Coefficient <u>(1)X(2)X(3)</u>
_____	Bituminous Concrete Surface	_____	_____	_____
_____	Penetrated Crushed Stone Base	_____	_____	_____
_____	Sand Bound Crushed Stone Base	_____	_____	_____
_____	Gravel Subbase	_____	_____	_____
Total SN =				_____

(c) Actual Structural Number (SN) Above Each Layer of Existing Pavement

Above Top Of:	SN* Bitum. Concrete	SN* Pentrat. Stone	SN* Sand-Bd. Stone	SN* Gravel	Total SN**
Penetrated Crushed Stone Base					
Sand Bound Crushed Stone Base					
Gravel Subbase					
Subgrade					

* From Table (b) Above

** Accumulated SN Values from Layers Above

Figure 11-6. (Continued)

PAVEMENT OVERLAY DESIGN

DATA SHEET 3: DETERMINATION OF OVERLAY THICKNESS

(a) Required Structural Number (SN) Above Each Layer of Existing Pavement

	<u>SN</u>	<u>+15%</u>
Above Top of Penetrated Crushed Stone Base	= _____	_____
Above Top of Sand Bound Stone Base	= _____	_____
Above Top of Gravel Subbase	= _____	_____
Above Top of Subgrade	= _____	_____

(b) SN Deficiency to be Corrected With an Overlay

Above Top Of:	Required SN*	Actual SN**	SN Difference
Penetrated Crushed Stone Base			
Sand Bound Crushed Stone Base			
Gravel Subbase			
Subgrade			

*From (a) Data Sheet #3

**From (c) Data Sheet #2

(c) Thickness of Bituminous Concrete Overlay

$$\text{Depth} = \frac{\text{Largest SN Difference}}{0.0173} = \underline{\hspace{10em}}$$

Figure 11-6. (Continued)

Example

Given: Approximately 750 meters of Route 3 in Hingham is being overlaid. Route 3 is a four-lane urban facility. The existing pavement exhibits some fine cracking with little deformation in the wheel paths. The following data is given:

1995 ADT = 54 100

2015 ADT = 89 300

T(ADT) = 12%

Existing Pavement:

115 mm bituminous concrete surface

115 mm penetrated crushed stone base

300 mm gravel subbase

Problem: Determine the depth of a bituminous concrete overlay for a 20-year design period.

Solution:

Data Sheet 1

Line (a)-

Line (f): Lines (a) to (f) are completed as instructed.

Line (g): Table 11.1 yields a value of 800.

Line (h): This calculation yields a $T_{80} = 3\,442$.

Line (j): For a four-lane facility, the design lane load is $0.9 \times T_{80}$, or 3 098.

Line (k): The PDE provides a subgrade DBR of 11, which yields $SSV = 4.5$.

Line (l): Figure 11-4 yields an SN - 5.35 above the subgrade.

Line (m): Increasing by 15% yields a design SN of 6.15.

Data Sheet 2

Line (a): The subgrade $SSV = 4.5$ is entered.

Line (b): Table 11.6 is used to select the layer coefficients for the existing pavement. The existing pavement is in generally good condition. Therefore, a reduction factor of 0.9 is selected from Table 11.7. The calculations are shown on the completed data sheet.

Line (c): The actual SN above each pavement layer is entered as shown on the completed data sheet.

Data Sheet 3

Line (a): Figure 11-4 is used to determine the required SN above each layer of the existing pavement. These are increased by 15% as shown.

Line (b): The SN deficiency for each layer of the existing pavement is shown on the completed data sheet.

Line (c): The largest SN deficiency is 2.33 for the subgrade. This is used to determine that a 135 mm overlay is needed to provide acceptable pavement performance over the 20 year period.

A completed summary sheet and completed data sheets follow.

* * * * *

11.5 RECYCLING

"Recycling" means reusing existing paving materials for the rehabilitation and maintenance of pavements. It conserves energy, aggregates and asphalt. It is important to understand that recycling is not the answer to all paving problems. In order to use the recycling concept to its best advantage, certain criteria relative to the condition and function at the facility must be considered. The Pavement Design Engineer will review and must approve all proposed recycling projects. Research and Materials and the PDE will develop the specifications and structural design for the recycled pavements.

There are three general methods of recycling pavements; these methods are in turn subdivided into sub-methods. The three general types are described below.

1. **SURFACE RECYCLING:** This is a process in which the bituminous concrete pavement is reworked by a heater planer, hot milling, heater scarifier, etc. The depth of reworked material is usually about 25 mm; it is done in a continuous operation. The operation may involve the additions of virgin hot mix material and modifiers.



MASSACHUSETTS HIGHWAY DEPARTMENT

PAVEMENT OVERLAY DESIGN

City/Town Hingham
Route No. 3 Highway System Freeway
From Station 85 To Station 110
No. of Lanes 4
Date of Overlay Design 6-15-95 Project Engineer J.R. Huber

EXISTING PAVEMENT ELEMENTS BEFORE OVERLAY

115 mm Bituminous Concrete Surface
115 mm Penetrated Crushed Stone Base
115 mm Gravel Subbase

RECOMMENDED OVERLAY THICKNESS

135 mm Class I Bituminous Concrete Type I-1
45 mm Top Course Material over
90 mm Binder Course Material

PAVEMENT OVERLAY DESIGN

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

Terminal Serviceability Index Nomograph = 2.5

(a)	Current A.D.T. (Date <u>1995</u>)	<u>54 100</u>
(b)	Future A.D.T. (Date <u>2015</u>)	<u>89 300</u>
(c)	Mean A.D.T. = $\frac{(a) + (b)}{2}$	<u>71 700</u>
(d)	Mean A.D.T. In One Direction $\frac{(c)}{2}$	<u>35 850</u>
(e)	A.D.T. Truck Percentage	<u>12%</u>
(f)	Mean Truck A.D.T. In one Direction (d) X (e)	<u>4 302</u>
(g)	Equivalent Daily 80 kN Axle Application per 100 trucks and Cominations (See Table 11.1)	<u>1 000</u>
(h)	Number of 80 kN Axle Loads Per Day in One Direction $\frac{(f) \times (g)}{1000}$ (T80)	<u>4 302</u>
(i)	80 kN Load on Design Lane: (h) Z 1.00 for 2 lanes; (h) X 0.90 for 4 lanes; (h) X0.80 for 6 or more lanes	<u>3 872</u>
(j)	Subgrade Design Bearing Ration and Soil Support Value	<u>DBR = ; SSV = 45</u>
* (k)	Structural Number (SN) Required Above the Subgrade	<u>5.45</u>
* (l)	Increase SN by 15% for Design SN	<u>6.27</u>

* These values are developed on Data Sheet #3

PAVEMENT OVERLAY DESIGN

DATA SHEET 2: ACTUAL SN OF EXISTING PAVEMENT

(a) Soil Support Values of Existing Granular Pavement Elements

Penetrated Crushed Stone Base = 9.0
 Gravel Subbase = 6.6
 Subgrade = 4.5

(b) Actual Structural Number (SN) of Each Layer of Existing Pavement

(1) Depth		(2) Coefficient Table 11.6	(3) RF Table 11.7	(2) Coefficient (1)X(2)X(3)
<u>115 mm</u>	Bituminous Concrete Surface	<u>0.0175</u>	<u>0.9</u>	<u>1.79</u>
<u>115 mm</u>	Penetrated Crushed Stone Base	<u>0.0095</u>	<u>0.9</u>	<u>0.98</u>
<u>300 mm</u>	Gravel Subbase	<u>0.0045</u>	<u>0.9</u>	<u>1.16</u>
Total SN =				<u>3.95</u>

(c) Actual Structural Number (SN) Above Each Layer of Existing Pavement

Above Top Of:	SN* Bitum. Concrete	SN* Pentrat. Stone	SN* Sand-Bd. Stone	SN* Gravel	Total SN**
Penetrated Crushed Stone Base	1.79				1.79
Gravel Subbase	1.79	0.98			2.77
Subgrade	1.79	0.98		1.16	3.95

* From Table (b) Above

** Accumulated SN Values from Layers Above

PAVEMENT OVERLAY DESIGN

DATA SHEET 3: DETERMINATION OF OVERLAY THICKNESS

(a) Required Structural Number (SN) Above Each Layer of Existing Pavement

	<u>SN</u>	<u>+15%</u>
Above Top of Penetrated Crushed Stone Base =	<u>3.07</u>	<u>3.53</u>
Above Top of Sand Bound Stone Base =	<u> </u>	<u> </u>
Above Top of Gravel Subbase =	<u>4.21</u>	<u>4.84</u>
Above Top of Subgrade =	<u>5.45</u>	<u>6.27</u>

(b) SN Deficiency to be Corrected With an Overlay

Above Top Of:	Required SN*	Actual SN**	SN Difference
Penetrated Crushed Stone Base	<u>3.53</u>	<u>1.79</u>	<u>1.74</u>
Sand Bound Crushed Stone Base			
Gravel Subbase	<u>4.84</u>	<u>2.77</u>	<u>2.07</u>
Subgrade	<u>6.27</u>	<u>3.93</u>	<u>2.34</u>

*From (a) Data Sheet #3

**From (c) Data Sheet #2

(c) Thickness of Bituminous Concrete Overlay

$$\text{Depth} = \frac{\text{Largest SN Difference}}{0.0173} = \frac{2.34}{0.0173} = 135.26 \text{ mm}$$

Use 135 mm

It is effective in reducing some reflective cracking, eliminates some ravelling, rutting corrugations etc. The structural improvement is minimal, the heater planer has certain limitations relative to depth of penetration. The "Surface Recycling" method is used infrequently.

2. *"IN PLACE SURFACE AND BASE RECYCLING"* The existing surface and base are scarified and pulverized, mixed with some gravel subbase material, reshaped and compacted to form a base. Additives or other agents may be added to this blend. The pulverizing and blending is usually done on the site; however, there is the option of doing the pulverizing and cold blending at a central plant. A top course mix is placed on the compacted material.

The structural capacity is improved, and reflective cracking is eliminated. However, quality control is difficult to maintain. Traffic is disrupted, and the pulverizing equipment breaks down frequently. This is a less expensive operation than a "Central Plant" (hot) reclamation project.

3. *CENTRAL-PLANT RECYCLING* This is a process where the reclaimed pavement is combined with new asphalt and aggregate and in some instances the addition of a modifier may be specified. The pavement surface is usually removed with a cold planer or similar type machine to a predetermined depth. The pavement fragments are transported to a "Central Plant" where they are seized and mixed hot as noted above. The finished product, depending on the sizing specification, may be used as a riding surface or binder.

This method of reclamation increases the structural capacity, improves quality control, reduces and, in most cases, eliminates reflective cracking. Traffic disruption and pollution are significant disadvantages of this type of operation.

11.6 SKID RESISTANCE

All pavement designs will include a surface course that provides the necessary skid resistant qualities. It should also retain these qualities during the pavement design period. MHD standard pavement mix design provides the required skid resistance in most instances.

Skid resistance is a function of the pavement surface texture. Surface texture is a combination of fine (or micro-) texture and coarse (or macro-) texture. Microtexture is determined by the surface roughness of aggregate particles. The roughness penetrates the water film on the road surface to provide direct contact with the tire. A surface that has good microtexture ensures skid resistance at low speed. Macrottexture is a function of aggregate gradation. It provides passages for water to escape from the tire-pavement interface, thereby

reducing hydroplaning. Macrotexture becomes more important as speed increases. At higher speeds skid resistance is provided by combined effects of microtexture and macrotexture.

The skid number is a measure of skid resistance. The skid number is the coefficient of friction times 100. Thus a pavement with a skid number of 35 has a coefficient of friction of 0.35. The skid number is measured on a wet pavement at a skid tester speed of 64 kph. The skid properties of all highways are monitored by Research and Materials.

As noted above, the Department mix design is such that adequate skid resistance is provided. However, after years of service the skid resistance characteristics may be greatly reduced. When the skid number falls below a certain number, corrective measures must be taken to restore the skid resistance to an adequate level. This is accomplished by placing a friction course on the questionable bituminous concrete surface. The friction course (sometimes called pop corn) is an open-graded bituminous concrete mix placed at a depth of about 25 mm. This layer does not contribute to the structural strength of the pavement. It can be subject to ravelling at intersections where start and stop activity is frequent; application may not be practical at certain intersections.

Skid resistance may be built into a Portland Cement concrete pavement by grooving with metal tines while the concrete is in a plastic state. The skid resistance of cement concrete in service can be increased by mechanical grooving. The grooves may be placed longitudinally or transversely; each method has its advantages and disadvantages. The consensus is that longitudinal grooving is preferable for highways, and transverse grooving is preferable for airports.

The designer should inform the Pavement Design Engineer if the skid resistance of a highway is suspect. The Pavement Design Engineer will request Research and Materials for a skid test of the section in question.

11.7 REFERENCES

- *Interim Guide for Design of Pavement Structures*, AASHTO, 1972 (Revised 1981).
- *Layered Pavement Design Method for Massachusetts*, Massachusetts Department of Public Works and Massachusetts Institute of Technology, January, 1965.
- *Guidelines for Skid Resistant Pavement Design*, AASHTO, 1976
- *Asphalt Overlays and Pavement Rehabilitation*, MS-17, The Asphalt Institute, November, 1969.
- *Alternatives in Pavement Maintenance, Rehabilitation and Reconstruction*, IS-178, The Asphalt Institute, May, 1981.

CHAPTER 12

SPECIAL DESIGN ELEMENTS

12.1 BIKEWAYS

Bicyclist safety and accommodation should be addressed in the design process of any project. *A Guide for Development of New Bicycle Facilities* (AASHTO, 1991) is the primary design reference for designing bikeways. The "Guide" provides design guidance which must be supplemented with the designer's judgment and consideration of the particular site conditions.

Part IX of the *MUTCD* is devoted to "Bicycle Facilities" and should be used in conjunction with the "Guide".

The MHD manual *Building Better Bicycling*, 1994, should also be consulted when considering bicycle facilities.

Bicycle-use related signs on highways and bikeways serve three basic purposes -- regulating bicycle usage, directing bicyclists along pre-established routes, and warning of unexpected conditions. Care should be taken not to install too many signs, especially regulatory warning signs, as excess usage tends to become ineffective.

Where signs are for the exclusive use of bicyclists, care should be taken in locating them so that motorists are not confused by them. In addition, the smaller sizes as shown in Chapter IX of the *MUTCD* should be used. Signs may not be appropriate in urban locations. Pavement markings are normally preferable to signs.

12.1.1 Bike Paths

Bike paths are facilities on exclusive rights-of-way and with minimal cross flow with motor vehicles. They may be considered where bicycle volumes will be high; costs and ROW are reasonable; and/or it is impractical, unsafe, or illegal to allow bicycles on nearby public roads. At-grade intersections can be provided where vehicular traffic is infrequent and sufficient sight distance is available.

Bike paths may be located in areas entirely separated from the highway and street

network. When their path follows closely a nearby highway, the bike path and highway should be separated so that it is obvious the two are for different purposes. When the separation is less than 1.5 meters, a physical divider should be used which is consistent with MHD safety criteria.

The minimum width of a one-way bike path is 1.5 meters; 2.5 meters for two-way. 3.0 meters is preferred if the path will be used by maintenance and security vehicles. The recommended cross slope is 0.02 m/m. A minimum 0.75 meter graded shoulder should be provided on either side.

A Guide for Development of New Bicycle Facilities contains additional information on the geometric design of bike paths. This includes design speed, horizontal alignment, vertical alignment, superelevation, sight distance, and at-grade intersections. The design criteria are basically developed from the same considerations as highway design, but reflective of bicycle characteristics.

12.1.2 Bicycle Lanes

Bicycle lanes are portions of the roadway cross section which have been designated for the exclusive or preferential use of bicyclists. The lanes are designated by signs and pavement markings. Bicycle lanes are always one-way facilities on either side of the roadway. They should be considered on highways where bicyclists frequently use the existing highway.

Pavement markings are important on roadways that have a designated bicycle lane. Markings indicate the separation of lanes for motor vehicles and bicycles, assist the bicyclist by indicating assigned travel paths and can provide advance information for turning and crossing maneuvers.

Because the number and severity of conflicts between motorists, bicyclists and pedestrians are greatest at intersections and crossings, utmost care must be taken in designing intersections which are to accommodate bicycle traffic. Whenever a bicycle lane is carried across an at-grade intersection, some form of channelization with specific routings for bicycles should be provided to minimize the number of possible conflict points between bicyclists, motor vehicles and pedestrians within the intersection.

Bicycle lanes can be included in roadway cross sections with or without parking. The minimum width is 1.25 meters; greater widths are appropriate where vehicle speeds typically exceed 60 km/h.

If a closed drainage system is used, an inlet grate will likely be in the path of bicyclists. These grates must be safely traversable by bicyclists. Therefore, on all highways without

access control, a bicycle-safe grate as shown in the *Construction Standards* must be used.

12.1.3 Shared Roadways

Shared roadways are highways where a bicycle lane is not designated, but bicycles are legally allowed to use the highway. The designer must make every effort to provide for the accommodation of bicycles on all of these facilities. Normally the minimum paved roadway widths found in Tables 5.1 and 8.2 are sufficient. When the standard roadway width cannot be provided, at least 5.0 meters of combined outside travel lane plus usable shoulder (curb lane) is required for bicycle accommodation. When this is not feasible a 4.5 meter paved curb lane should be provided. A 0.5 meter offset to vertical objects, such as guardrail, is required beyond the paved usable shoulder. Bicycle-safe drainage grates must be used.

Bicycle accommodation waivers are required for curb lane widths below 5.0 meters, 4.5 meters, or Table 8.2 values (if applicable).

12.1.4 Shared Sidewalks

Bicyclists and pedestrians may be allowed to use the same sidewalks in some locations. The first consideration, however, should be to safely accommodate bicyclists in the roadway. Bike paths designed and built to serve multiple uses (bicycling, walking, etc.) should be considered when substantial numbers of bicyclists will be present, and as conditions allow (see 12.1.1). The designer should consider widening the sidewalk when substantial numbers of both pedestrians and bicyclists will be present. 3.0 meters is a desirable width for bi-walks to accommodate maintenance and emergency vehicles.

12.2 BUS STOPS

If local bus routes are located on an urban or suburban highway, the designer should consider their impact on normal traffic operations. The MHD will coordinate efforts with transit authorities to determine bus stop locations. The stop-and-go pattern of local buses will disrupt the traffic flow, but certain measures can minimize the disruption. The following should be considered:

1. *Far-Side Stops* -- The far side of an at-grade intersection is generally superior to the near-side or mid-block for a bus stop. Far-side stops produce less impediment to through traffic and right-turning traffic; they do not interfere with corner sight distance; and they lend themselves better to bus turnouts.
2. *Near-Side Stops* -- Near-side stops allow easier vehicle re-entry into the traffic stream where curb parking is allowed. They may be necessary where a bus will turn onto a major

highway on which bus stops cannot safely be permitted. Near-side stops should be considered where right turns onto a bus route are frequent.

3. *Mid-Block Stops* -- Mid-block stops may be advantageous where the distance between intersections is large or where there is a fairly heavy and continuous transit demand throughout the block. They may be desirable if a large generator is located in mid-block. Mid-block bus stops may also be considered when right turns at an intersection are high (250 in peak hour) and far-side stops are not possible. If curb parking is allowed, this may complicate mid-block stops.

Where right-of-way is sufficient, bus turnouts should be considered, especially where traffic speeds and volumes are high. These remove the stopped bus from the through lanes and provide a well-defined area for bus stops. The following should be considered in the location and design of bus turnouts.

1. The far side of the intersection is preferable to the near side.
2. The desirable width is 3.0 meters, measured from the edge of the travel lane.
3. The full width of the turnout should be at least 16.0 meters long. If there is a reasonable likelihood of more than one bus occupying the turnout at the same time, the turnout should be 15 meters longer for each additional bus.
4. An entering taper no steeper than 5:1 and re-entry taper no steeper than 3:1 should be provided. Short horizontal curves (30 meters radius) may be located at either end of the tapers. Only one taper may be necessary if the bus turnout is at the near or far side of an intersection, depending upon pedestrian requirements.

Any proposed work related to bus stop location or design must be coordinated with the local transit authority. For additional information on bus stop location and design, the designer should refer to *Design of Urban Streets*, TSR-80-204, FHWA, January, 1980.

12.3 PARK-AND-RIDE FACILITIES

Park-and-ride facilities are constructed to provide a convenient area for commuters to park and carpool or take public transportation.

12.3.1 Location

The designer should consider the following when locating a park-and-ride lot:

1. The lot should be convenient to residential areas, bus routes, and/or the major highway used for commuting.
2. The location should precede any points of congestion on the major commuting highway to maximize its benefits.
3. If carpoolers will use the lot, there should be sufficient highway capacity on the highway(s) between the lot and the major commuting highway.
4. The location should be consistent with the present and future adjacent land use. The cost of land is also a factor in lot location.
5. The site location must be compatible with the design and construction of the lot. The designer must consider terrain, drainage, subgrade soils, and the available space compared to the required lot size.
6. The location should be compatible with the practicalities of signing for the lot on the surrounding highways and streets.
7. The impact on the environment, town/city land use and abutters.

12.3.2 Design

12.3.2.1 Layout

Figure 12-1 illustrates a typical layout for a park-and-ride lot. The designer should consider the following:

1. The bus, drop-off/pickup, and parking areas should be clearly separated from each other.
2. The designer should consider the pedestrian routes to the transit area. The parking spaces should be 90 degrees aligned to the direction of pedestrian travel. Figure 12-1 illustrates this arrangement.

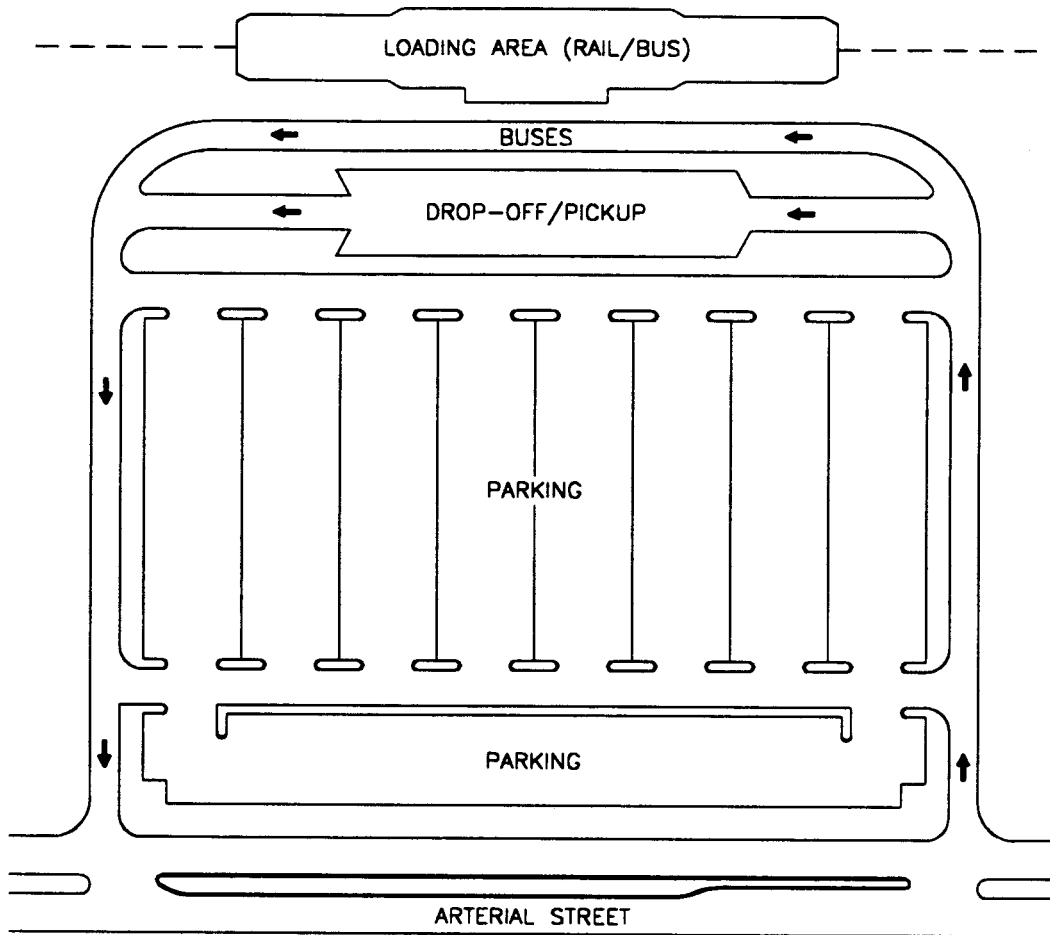


Figure 12-1. TYPICAL LAYOUT FOR PARK AND RIDE LOT

3. If bicyclists will commute to the lot, a bicycle area with racks should be provided.
4. Separate exits and entrances should be provided, desirably on different streets. The entrance should be on the upstream side of the traffic flow nearest the lot, and the exit on the downstream side.
5. Best practice calls for right-angle parking with sufficient aisle width for two-way travel. However, where space is limited, angle parking with one-way travel is acceptable. See Section 12.3.2.2 for a more detailed discussion.

12.3.2.2 Geometric Design and Drainage

The designer should consider the following:

1. The size of the new or expanded park-and-ride facility will be determined by the MHD from information generated by the Bureau of Transportation, Planning and Development.
2. Refer to *AASHTO Guide for Design of High Occupancy Vehicle and Public Transfer Facilities and the AASHTO Guide for the Design of Park-and-Ride Facilities* for parking stall dimensions based upon angle of parking.
3. The area for buses should be at least 7.5 meters wide and 30 meters long (for two buses). Add 15 meters to the length for each additional bus anticipated beyond two.
4. The drop-off/pickup area should provide space according to demand.
5. It is recommended that any sidewalks be at least 2.0 meters wide. Loading areas should be at least 3.75 meters wide. Wheelchair ramps are required for access onto sidewalks and loading areas.
6. There should be at least one exit and one entrance for every 500 parking spaces provided.
7. All exits and entrances should be designed according to the criteria in Chapter 7. This includes capacity, corner sight distance, turning radii, and exclusive left- and right-turn lanes on the intersecting highway or street. An exit or entrance for a park-and-ride lot should desirably be at least 90 meters from any other intersection.
8. All required turns within the parking lot (e.g., to and from bus loading area and around islands) should be designed to accommodate the applicable vehicle. Chapter 7 provides minimum turning radii designs.

9. Where buses will use the park-and-ride lot, the grade should not exceed 7%. It may be steeper where only cars will use the lot. To provide proper drainage, the minimum gradient should be 1%.
10. Chapter 10 should be used for the detailed drainage design of the parking lot. This includes design frequency, pavement discharge, and capacity of drainage inlets. The drainage design should not allow ponding on pedestrian routes, bicycle routes, or any standing areas.

12.3.2.3 Other Design Elements

The designer should consider the following:

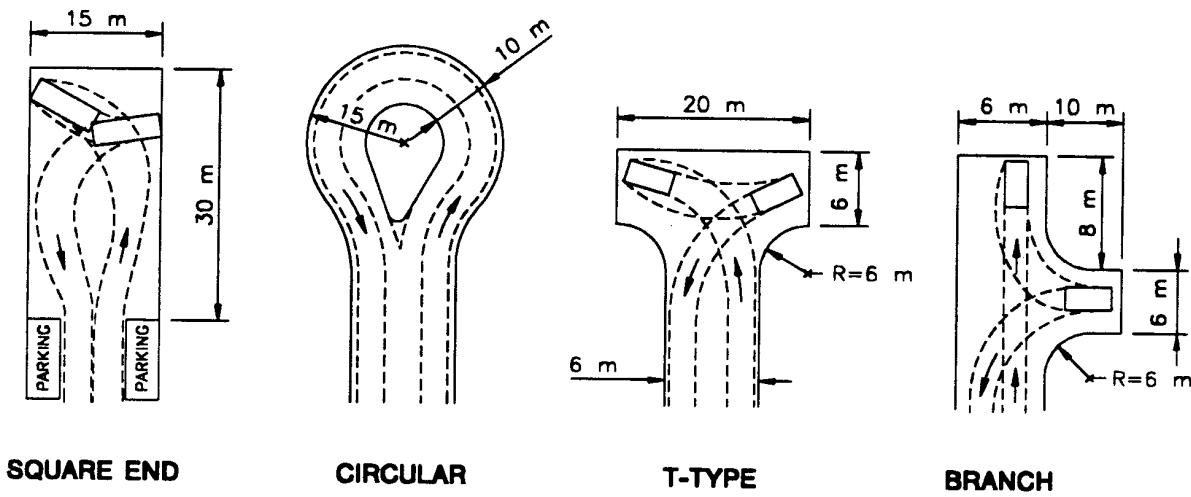
1. Where a loading area for buses or trains will be provided, a shelter should be included in the design. The size of the shelter should be approximately 0.3-0.5 square meters per person.
2. It is desirable to include lighting, benches, trash receptacles, telephones, and route information in loading areas.
3. The entire parking lot should be lighted. The uniformity ratio should not exceed 6:1. The Department's Traffic Division will provide the criteria for the lighting design.
4. The designer shall landscape the park-and-ride lot. If islands are used in the design, these can be convenient locations for trees. Safety, lighting and plowing should also be considered in the placement of trees.

12.4 CUL-DE-SACS

If a street or highway dead ends, the design should provide a turnaround area. Figure 12-2 illustrates several possible designs. Desirably, the turnaround will be circular; however, a square end, T-type, or branch design may be used if space is limited. If a street is under local jurisdiction, local standards will govern.

The cul-de-sac terminal should be large enough to allow the design vehicle to turnaround. The design vehicle should be selected based on the vehicle which will use the street with some frequency. Normally, the SU design vehicle will be used. When feasible, the turnaround will allow the design vehicle to make the turn in a continuous circular path. However, requiring one backing maneuver is acceptable.

The designs in Figure 12-2 will have to be adjusted if parking is allowed in the turnaround area.



Note: ALL OF THESE DESIGNS WILL ACCOMODATE A SU DESIGN VEHICLE.

Figure 12-2. CUL-DE-SACS

12.5 REST AREAS

Rest areas are roadside spaces provided for the safety and convenience of highway travelers. Many have been constructed on freeways and other major arterials in Massachusetts. The location and design of rest areas is considered on an individual highway facility and site basis.

12.5.1 Location

Rest areas may be located on freeways or other major arterials. The following considerations will impact the number and location of rest areas:

1. *Demand* -- The total demand for rest areas is a function of truck and passenger vehicle volumes and the availability of other services along the highway facility.
2. *Frequency* -- The frequency of rest areas will depend on the location of the highway within the state. On highways which are major state entry points, a single large facility may be located just within the state border. A rest area of this type will also be an information center. On internal highways, the strategy may be to provide a series of smaller facilities to accommodate the total demand.
3. *Scenic qualities* -- Desirably, rest areas will be located in naturally scenic areas.

4. *Topography* -- To keep construction costs reasonable, rest areas should be located where the natural topography is favorable to their development, i.e., where earthwork will be minimal.
5. *Operations* -- Rest areas should be located away from any other interference, such as interchanges, along the highway.
6. *Abutting Land Use* -- Avoid locations near areas zoned residential.

12.5.2 Design

Once a site has been selected, the rest area must be designed in detail. The following will be considered during the design:

1. Exits and Entrances -- The rest area junctions should be designed the same as the standards for the adjacent highway. These are described in Section 6.4.0.
2. Parking -- The number of parking spaces should be commensurate with the expected usage of the rest area. The usage, in turn, will be a function of the size and type of facility provided (e.g., a large information facility will generate a greater percent stopping than a smaller one). Separate parking areas should be provided for passenger vehicles and for trucks and buses. Large facilities should be designed to accommodate the traffic expected to stop during a "rest area design hour." Technical Advisory T-5140.8 (August, 1979) contains additional information. Because of the one-way operation of rest areas, angle parking is normally used. Refer to Section 12.3.2.2.
3. Facilities -- Rest areas may provide a building with rest rooms and public information services, picnic tables and shelters, benches, sidewalks, drinking fountains, and trash collectors.
4. Utilities -- Where permanent sanitary facilities are provided, an adequate water supply, sewage disposal system, and power supply will be required. These considerations may dictate the size of the rest area. Other utilities may include lighting and telephones.
5. Landscaping -- The rest area should be landscaped to take advantage of existing natural features and vegetation. Paths, sidewalks, and architectural style should fit naturally into the existing surroundings. If extensive regrading is required, architectural mounds or undulations should be considered both for aesthetics and other functions (safety, noise, and visual barrier).
6. Handicap Considerations -- All rest areas must be designed to properly accommodate

physically-handicapped individuals. Special parking spaces, curb cuts, ramps, and special rest room features should be provided. All buildings must be accessible.

7. Information Center -- If an information center is considered, the designer shall cooperate with appropriate State agencies or other organizations to coordinate the design for operational requirements.

12.6 LANDSCAPE DESIGN

The design of the highway roadside--whether urban, suburban, or rural--must be responsive to the needs of the highway user and the cultural, social and physical environment of the corridor. Transportation landscape architecture concentrates on the analysis, synthesis, and design of natural and engineered elements which affect the perception and use of the highway environment. The successful landscape design will address issues regarding the cultural, social and physical aspects of the landscape and focus on blending highway engineering elements into the environment.

Transportation project designers should seek input from landscape architects at various points in the project development process, beginning at the pre-25% stage. Comprehensive landscape designs including plans, construction details, special provisions and estimates, should be submitted at the 75% stage. If architectural elements are incorporated in the design such as fountains, walls, structures, or stairways, they should be sufficiently detailed in order to facilitate a thorough review by MHD sections. Revisions from comments received at the 75% review should be included in the 100% submission.

In large transportation corridors, planting and earthwork grading are among the most effective ways to blend the highway with its surrounding landscape and to mitigate noise from vehicles. To be successful, the landscape design must be developed concurrently with the overall design of the roadway, including horizontal and vertical geometry, grading, drainage, and layout of structures such as walls and barriers. Through careful analysis of the interaction of highway elements, landscape architects can provide design input to mitigate or enhance the visual perception of engineered structures such as slopes, abutments, walls and noise barriers.

In urban transportation corridors, landscape architects should provide designs to meet the needs of a wide variety of users, including cyclists, pedestrians, and handicapped users. Projects should concentrate on the interaction of design elements such as shade trees, design and location of lighting, sidewalk widths and ramp locations, bicycle racks, pavement patterns and textures, and other site design features.

MHD landscape architects should be consulted early in the project development process to assist in determining the appropriate level of landscape architecture for the following project types:

- * Large or complex projects, including those projects requiring extensive cuts and fills, clearing, large detention/retention facilities, or mitigation and restoration of natural systems.
- * Bicycle paths and lanes, both on and off-road.
- * Projects requiring mitigation under Section 106 of the 1966 National Historic Preservation Act.
- * Projects requiring mitigation under Section 4(f) of the 1966 U.S. D.O.T. Act
- * Projects requiring mitigation under Sections 401 and 404 of the 1972 Clean Water Act.
- * Projects requiring mitigation under Chapter 91 of the Massachusetts Wetlands Protection Act.
- * Rest area/information centers.
- * Park and Ride facilities.
- * Noise mitigation/visual buffer projects
- * Intermodal projects.
- * Transportation enhancements projects under Section 1007(c) of the ISTEA.
- * Scenic byway projects.
- * Any other project where landscaping is being considered.

12.6.1 Landscape Design Considerations

Analysis of Existing Conditions. The existing conditions of a project must be analyzed and understood prior to design. At a minimum, an understanding of the following existing conditions is important to the formation of a suitable landscape design:

- * Ecology--interaction of vegetation, wildlife, climate, hydrology, surficial geology
- * Vegetation--types and patterns, density of canopy, heights of understory and overstory, trees to protect
- * Soils--structure, fertility, pH, susceptibility to erosion and compaction, drainage characteristics
- * Hydrology--surface water, drainage patterns, depth to water table, seasonal fluctuations
- * Topography--elevation, orientation, slope
- * Existing land use--commercial, industrial, residential, open space, parkland
- * Climate--microclimate, regional climate, prevailing winds, salt spray, highway generated winds
- * Physiography--floodplains, ACEC's, aquifer recharge areas, ledge and rock outcrops
- * Aesthetics--scenic vistas, noise, landmarks, major spatial determinants
- * Historic--trails, buildings, structures, sites, other cultural information

It is imperative that the designer visit the site, experience the range of conditions within and outside the project limits, and record observations through video, photography, drawings, notes, or any other suitable method. Aerial photographs are helpful when used in conjunction with conventional photographs of the corridor or site. When designing a project with a large

land area or many complex variables, use of a Geographic Information System is recommended to highlight conflicts contained in design alternatives.

Special attention must be given to the constraints and opportunities which arise from the proposed transportation design. The landscape architect needs to understand the reasons for and implications of the engineering design in order to effectively integrate a landscape design into the project.

Safety. Safety is the first consideration of all landscape design projects. Sight lines must be kept clear around curves and at intersections. Clear zones, as determined using tables in Chapter 9, should be preserved. Trees with 100 mm. or greater caliper size should not be planted in the clear zone. Where there are guardrails, trees may be planted closer to the edge of road, depending on the deflection of the barrier used. Typically there is no minimum setback distance behind rigid obstructions, such as walls, concrete barriers, nontraversable backslopes, banks or curbs. However tree branching and tree maintenance must be considered in plant selection and location. For central business districts and local streets with vertical curbs, a minimum distance of 500 mm should be provided beyond the face of the curb to the mature trunk. On urban arterials and collectors with similar curbs, the offset distance should be increased.

Under some circumstances, plant material can provide safety benefits. In areas of complex roadway geometry, carefully designed planting can aid the driver by providing visual clues to approaching curves. Planting shrubs in the recovery area helps to decelerate encroaching vehicles. Where adequate plantable cross-section is available, shrub plantings in medians can also provide an effective screen to reduce oncoming headlight glare.

Environmental Restoration and Enhancement. Landscape design is a major component of most environmental mitigation and restoration. For areas damaged by new construction, restoration should seek to renew or re-establish self-sustaining ecosystems that bear close relationship to the surrounding ecosystems. To the extent possible, restoration plans should restore the visual and cultural character of the land affected by construction projects.

Plantings can provide a number of climatic benefits. Where adequate right-of way is available, hedgerows of mixed shrubs and trees can dramatically reduce crosswinds and snowdrifts on the highway. Typically, the wind shadow of such hedgerows is 15-20 times the height of the hedge. In addition, plant material adjacent to the road provides a filter for airborne particulates generated by traffic, thereby improving air quality. Shade trees help reduce elevated heat loads associated with pavement in urban areas or large parking areas.

Careful selection of plant materials can enhance wildlife habitat. While wetland areas provide a major source of food and energy in the ecosystem, uplands also support numerous wildlife functions of nesting, food and cover. Plantings are also effectively used to reduce the amount and velocity of stormwater runoff, and when properly designed, can provide filtration of sediments and pollutant uptake functions yielding cleaner discharge into resource areas.

Visual Quality. The public nature and visual importance of our highways require that visual impacts be adequately assessed and considered during the design process. Community acceptance of the highway project may be strongly influenced by its visual effects. Refer to FHWA *Visual Impact Assessment for Highway Projects*. Visual quality is a key issue in determining the use of landscape architectural elements on highways or in urban areas. Types of roadway lighting and their associated illumination toward residential areas need to be considered. Locations and types of signage, both regulatory and informational, have important visual implications in a roadway corridor. Plantings provide many important visual quality benefits. They define scenic views, and improve definition of the roadside edge by providing drivers with an indication of travel speed. Plantings can screen unpleasant views, and can help alleviate driver fatigue induced by long stretches of road without changes in eye focus.

Maintenance. Landscapes should be designed to be self-sustaining, with a minimum of maintenance. Refer to National Park Service, *Guiding Principles of Sustainable Design*. Selection and location of plant materials should not require irrigation, fertilizer, pesticide treatment, pruning, or other amendments beyond those required in the installation contract. Typically MHD contracts require a minimum of one year to ensure establishment of plantings. In some cases, however, certain projects will require maintenance over a two or three year period. Refer to Code of Federal Regulations 23 CFR, Part 752.4(b). In addition, placement and selection of materials must take into account on-road maintenance, including consideration of adequate roadside storage of snow, and the impact of spray from road salts.

12.6.2 Landscape Design Guidelines

Plant Material. Where appropriate, proposed plant species will be native to the glaciated northeastern United States. Refer to Jorgensen, *Sierra Club Guide to Southern New England*. Unless otherwise directed, plants shall only be specified from the latest edition of the *MHD Standard Nomenclature and Designation of Items*. Every highway construction project using landscape materials must have low maintenance herbaceous perennials and/or ornamental grasses specified on the proposed plant list. Plant lists should indicate which proposed trees are subject to fall planting hazard, and alternate plants should be listed on the plans and in the special provisions. The MHD Landscape Design Section should be contacted regarding proposed plant lists prior to review and project completion.

Roadsides. In general, roadside design should preserve or restore as much of the existing natural landscape as possible. Where plant material has been removed, restoration is appropriate. However, maintaining cleared areas may be appropriate in order to establish views of attractive natural landscapes, and to promote new tree growth. Where possible, the clear line should be uneven and undulating, providing a natural appearance and effectively

widening the edge zone between forest and cleared area. Understory trees and shrubs should be planted at edges, combined with low maintenance flowers and grasses.

Slopes flatter than 1:3 are ideal for tree planting. For steeper slopes, selected plant materials should be tolerant of hillside conditions. All slopes steeper than 1:2 should be designed using an erosion control fabric. Slopes steeper than 1:1 may be constructed using soil reinforcing grids and fabrics or by using bioengineered systems. Refer to USDA, *National Engineering Field Handbook* for information on bioengineering for upland slope protection and erosion control. Designs of earth retaining systems should be reviewed by the MHD Geotechnical and Landscape Design Sections.

Drainage. Open drainage swales are frequently planted with a variety of grasses. Grasses must be selected appropriate to climate and soil conditions, and capable of accepting proposed hydraulic flow rates. Typically such swales are mowed at least once a year to prevent the incursion of woody plant material. In such cases, mowing limits should be incorporated into the planting plans. See Chapter 10 for further discussion of drainage design. Vegetated swale designs should be reviewed by MHD Landscape Design Section where the swale profile is steeper than 3%.

Street Trees The maximum allowable caliper size for a proposed deciduous street tree is 100 mm. In developed areas, planting is designed in conjunction with development of sidewalks. Any design for sidewalk planting must take into account ADA guidelines and AAB requirements for lateral clearance and surface treatment. In general, plant materials thrive better in the better planting conditions outside the sidewalk. However, in addition to the environmental benefits of cooling and particulate adsorption, street trees on the traffic side of the walk provide a sense of enclosure and separation between pedestrians and vehicular traffic.

Where possible, street trees should be planted in a continuous planter strip, either grassed, or paved with permeable materials. Such strips should be a minimum of 1 meter wide, measured from back of curb to the sidewalk pavement. Where trees are planted in separate pits, such pits should be no less than one meter each direction. A minimum of 500 mm must be maintained between the face of curb and mature trunk. For urban arterials and collectors, this offset should be increased.

All street tree plantings must take into account location of utilities, directional signs, and sidewalk furnishings (mailboxes, newspaper racks, trash receptacles, benches, etc.). In addition, measures must be taken to ensure that plant soils will not be compacted and will be adequately drained. Use of tree grates is recommended in urban areas.

An assortment of tree species should be specified when designing streetscapes in order to reduce the possibility of damage due to disease.

Medians. New tree planting in medians less than 20 meters is generally discouraged unless protected by safety barriers, such as guardrail. Where such barriers exist, tree planting should be limited to medians with a plantable cross-section (back of barrier to back of barrier) of at least 3 meters. Shrubs require minimum of 1.5 meters plantable cross-section. Medians with plantable cross-sections less than 1.5 meters should be limited to turf, and then only if they can be maintained.

12.6.3 Landscape Design Plans

Item names and numbers shown on the plans, must be consistent with information contained in the special provisions and estimates.

Planting plans should be presented on drawings separate from the highway construction plans, and should be clear, concise and easily understood. Symbols used to represent trees and shrubs should accurately reflect the size of the plant when mature. Refer to Harris and Dines, *Time Saver Standards for Landscape Architecture* for graphic samples representative of the standard of practice. Plans should show pertinent existing and proposed construction features, including but not limited to the following: limits of work, slope limits, earthwork, utility locations, areas of existing vegetation including resource areas, trees to be protected, state, county or municipal layout lines, and all other base information necessary to produce a responsible design.

The planting design should include plant locations, species and quantities. Each sheet of the landscape design in the construction documents shall show a plant list summarizing the plants used on that sheet. A summary plant list showing all plants used on the project shall be included in the construction documents. The summary plant list shall list plants by item number, symbol, common and botanical name, and show quantities, size, and other essential information such as condition of the plants or plant spacing if not graphically represented. Plants should be of excellent quality and readily available from nurseries within the regional plant hardiness zones of southern New England (refer to *USDA Plant Hardiness Zone Map*).

A plan sheet showing landscape construction details specified in the design must be included in the construction documents. Landscape construction details must be reflective of the current technology in the profession, and must be presented in a graphically clear format. Special provisions for nursery stock, planting and landscape construction should be clear, concise and representative of the standard of practice.

12.7 FENCING

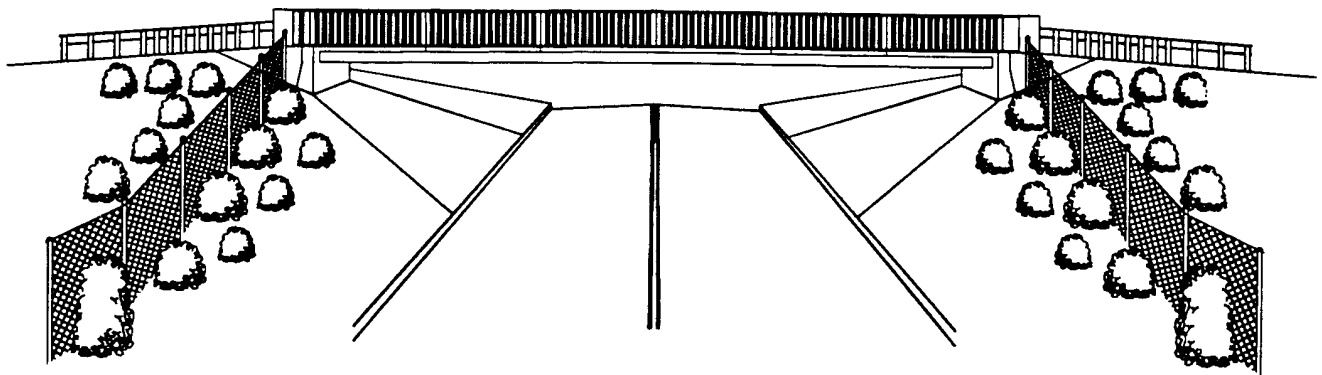
Fences - Fences are placed along the location lines of all "No Access Highways" except when the location line is in a wetland area, at bodies of water and precipitous slopes (see Figure 12-3). In general, omit the fence at locations where the natural ground features obstruct access to the highway.

Stock fence is used in rural areas where there is a possibility of livestock crossing the highway.

Woven wire fence and chain link fence are usually placed in suburban and urban areas as a deterrent to the trespassing of children and adults.

The designer is to exercise judgement when choosing a particular type of fence; population density, land use and practicality should be considered.

The Right of Way Section may occasionally recommend fence replacements and new fence locations.



PROPOSED FENCING LAYOUTS

1. LOCATE THE FENCE MIDWAY DOWN THE SLOPE (SEE DIAGRAM).
2. END AGAINST THE ABUTMENT OR ENDPOST (DEPENDING UPON THE TOPOGRAPHY) AND RUN THE FENCE PERPENDICULAR TO THE UPPER ROADWAY; OR PARALLEL TO THE LOWER ROADWAY.
3. MASK THE FENCE WITH PLANTING ON BOTH SIDES.

Figure 12.3 FENCING AT BRIDGES

12.8 REFERENCES

- *Guide for Development of New Bicycle Facilities*, AASHTO, 1991.
- *Building Better Bicycling*, MHD, 1994.
- *Selecting Roadway Design Treatments to Accommodate Bicycles*, FHWA, 1994.
- *TS-80-204, Design of Urban Streets*, FHWA, January, 1980.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 1994.
- *Guide for the Design of Park-and-Ride Facilities*, AASHTO, 1992.
- *FHWA-IP-81-1 Safety Rest Areas: Planning, Location and Design*, FHWA, 1981.
- *A Guide For Highway Landscape and Environmental Design*, AASHTO, 1990.
- *American National Standard for Nursery Stock*, American Association of Nurserymen, Latest Edition.
- Code of Federal Regulations, 23CFR, Part 752, *Landscape and Roadside Development*, 1993.
- Harris and Dines, *Time Saver Standards for Landscape Architecture*, 1988.
- Smith and Hellmunds, *Ecology of Greenways*, 1993.
- UDDOI, National Park Service, *Guiding Principles of Sustainable Design*, 1993.
- USDA, *National Engineering Field Handbook*, Ch. 18, Bioengineering for Upland Slope Protection and Erosion Control, 1992.
- *Visual Impact Assessment for Highway Projects*, FHWA, 1981.
- *Americans with Disabilities Act Handbook*, December 1991
- *Architectural Access Board, Rules and Regulations*, 521 CMR 1.00 et seq.
- *MHD Engineering Directive, Bicycle and Pedestrian Accommodations*, December 1996

CHAPTER 13

ESTIMATING PROCEDURES

All projects require a final estimate of the quantity and unit bid price for each construction item. The following apply:

1. The method of payment and units of measurement must conform to the latest editions of the *Standard Specifications for Highways and Bridges* and the *Standard Nomenclature and Designation of Items*.
2. Any item of work not covered in the Standard Specifications must be submitted to the Specifications Engineer as a special provision.
3. Earth quantities are calculated by computer or by planimentering the cross sections.
4. At the 25% and 75% stages, project cost estimates are prepared using up-to-date information. A further discussion is included in Chapter 1 "Submission Guidelines."

13.1 TYPES OF PROJECT ESTIMATES

13.1.1 Federal-Aid Projects

Separate estimates are required for Federal-Aid projects.

1. Non-Participating Estimate - This is required for items which will be paid for with other than state and federal funds:
 - A. Non-Participating State only; i.e., cleaning pipes and drainage structures.
 - B. Non-Participating Municipal; i.e., "gas lanterns", "ashfield stone" paved sidewalks.
2. Federal-Aid Roadway Estimate - This is required for roadway construction items, exclusive of bridge items.
3. Federal-Aid Bridge Estimate - This is required for each bridge and for walls which are assigned a structure number by the Bridge Section.
4. Contract Estimate - This is an estimate for the project showing the total project cost, including total contract items, construction engineering, contingencies, force

accounts, non-participating costs, and a summary of project costs which include the requested federal funds.

Table 13.1 provides the shrinkage and swell percentages for excavation and embankment quantities. Table 13.2 provides the weights and measures used for estimating.

**Table 13.1
SHRINKAGE AND SWELL CRITERIA**

ITEM	FACTOR IN PERCENT TO BE APPLIED
ESTIMATE OF EARTH EXCAVATION AVAILABLE FOR EMBANKMENT: EARTH EXCAVATION QUANTITY (EXCLUDING ROCK AND UNSUITABLE MATERIALS) MEASURED AND/OR COMPUTED	-5% (SHRINKAGE)
ESTIMATE OF EMBANKMENT REQUIRED: EMBANKMENT QUANTITY MEASURED AND/OR COMPUTED	+15% (SWELL)
ESTIMATE OF ROCK EXCAVATION AVAILABLE FOR EMBANKMENT: ROCK EXCAVATING QUANTITY MEASURED AND/OR COMPUTED	+37.5% (SWELL)
ESTIMATE OF MUCK EXCAVATION: MUCK EXCAVATING QUANTITY MEASURED AND/OR COMPUTED	0%
ESTIMATE OF SPECIAL BORROW REQUIRED: BORROW QUANTITY MEASURED AND/OR COMPUTED	+15% (SWELL)
ESTIMATE OF GRAVEL BORROW REQUIRED: BORROW QUANTITY MEASURED AND/OR COMPUTED	+25% (SWELL)
ESTIMATE OF LOAM REQUIRED: LOAM QUANTITY MEASURED AND/OR COMPUTED	+25% (SWELL)
ESTIMATE OF TOPSOIL REQUIRED: TOP SOIL QUANTITY MEASURED AND/OR COMPUTED	+25% (SWELL)
PLANTABLE SOIL BORROW	+25% (SWELL)

NOTE: THESE PERCENTAGES ARE FOR ESTIMATING PURPOSES ONLY.

Quantity and detail sheets are part of the contract documents and are required to advertise a project. The amounts match those in the Contract Estimate, but without the estimated costs. Pages 13.07.0 to 13.21.0 illustrate examples for a Federal-Aid project. All estimates will be similar to this example. All quantities and prices in the example are hypothetical.

Table 13.2
WEIGHTS AND MEASUREMENTS FOR ESTIMATING PURPOSES

Material	Use	Weight -metric ton per m ²	Remarks
Bituminous Concrete	For surface, binder or base	0.0024	Per mm of depth
Bitumen	Prime coat	-	Estimate 0.23 L per m ² of surface area
Calcium Chloride	Dust layer	-	Estimate 0.54 kg per m ² of surface area
Crushed Stone	For base course	0.0021	Per mm of depth
	Dense packed mass	0.0026	Per mm of depth
Peastone	For driveways	0.0021	Per mm of depth, to be included in the item: "Crushed stone for wearing surface," use when a small quantity is required.
	For driveways	-	1,9060 kg per m ³ , use when a large quantity is required. Item designation is "peastone for driveways"
Stone dust	Walks, drives, etc.	-	Estimate 1,600 kg per m ³
Water	Dust layer	-	Estimate 4.5 L per m ² of surface area

13.1.2 Non Federal-Aid Projects

Only one contract estimate is required for non Federal-Aid projects. This estimate is similar to the final Contract Estimate for Federal-Aid projects.

13.1.3 Utility Force Accounts

On many highway projects, utility adjustments or relocations will be necessary. The costs of labor and materials may be reimbursable by the State on a force account basis. A separate estimate should be prepared for any force account work for a highway project. The utility company usually prepares this estimate.

Municipal utilities are those operated by a municipality such as fire alarm systems, water, sewer, or electric power and light systems. Private utilities refer to utility companies such

as Boston Edison, New England Power, NYNEX Corporation, or Western Union.

The following criteria apply in determining the eligibility for State reimbursement for utility force account work:

1. MHD will replace in-kind or adjust all municipally-owned utilities on state highways which are disturbed by construction. If any betterments are to be made to a utility, the municipality must pay for the additional cost. MHD will also reimburse the municipality for the required relocation of municipally-owned monuments, flagpoles, etc.
2. Private companies may be reimbursed for adjustments made to facilities only when they occupy the way by legal title or easement. A company incurs the cost of making the adjustments at its own expense when the facilities are within a public way by permit, license, or sufferance. The only exception is on the Interstate Highway System where the Department will reimburse for all adjustments.
3. MHD will pay a railroad under a force account agreement for any work done by the railroad as a result of highway construction. Special provisions submitted by the Railroad will become part of the proposal to bidders.

The designer must prepare utility plans for the Utilities Section which in turn will distribute them to each municipality or utility company. The plan must show all utility changes required by the highway construction. The MHD Utility and Railroad Engineer will request the municipality or utility company to submit its force account plans, estimates, and special provisions for reimbursable items. The utility owner must also include special insurance requirements in the special provisions. The MHD Utility and Railroad Engineer will prepare all agreements with the utility owner covering costs, scope of work, etc. The MHD utility policy is fully discussed in the "*Utility Accommodation Policy.*" Note: Special reimbursement to utilities for bridge reconstruction work may apply.

13.2 PROCEDURES FOR SUBMITTING ESTIMATES FOR COMPUTER PROCESSING

The following steps outline the general procedure for submitting a project estimate for computer processing. Detailed instructions are provided in the *MHD Standard Nomenclature and Designation of Items*.

1. The estimator submits to the computer section a list of all items (item numbers only) that are expected to be used on the project. If the exact item description is not

found in the MHD *Standard Nomenclature and Designation of Items*, the estimator requests item number from the Specifications Section, after which the estimator resubmits to the computer section the non-standard items and nomenclature with the listing.

2. From the above list, a "Work Sheet" is developed by the computer and given to the estimator. The work sheet contains item numbers, item descriptions, and columns for inserting quantities and unit prices. Columns are provided for dividing the quantities of items into different categories to generate individual estimates for roadway and bridge. These columns provide the breakdown of quantities conforming to Department procedures.
3. When an estimator receives the work sheet, the estimator enters the quantities and unit prices in the proper columns and returns the Work Sheet to the computer section. Items may be added or deleted at this time.
4. A "proof sheet" is generated using the data entered on the work sheet. The estimator reviews the proof sheet and makes final changes. The estimator also informs the Computer Section of the type of output desired (i.e., estimates with or without prices).
5. The proof sheet is then returned to the Computer Section for final processing (i.e., paper copies).

The cost estimate cover sheets are prepared on standard MHD forms. Estimates for bridges, non-participating items, or work paid by a municipality directly to the contractor appear on the cover sheets and all contract items appear on the computer generated estimate sheets.

13.3 OFFICE CALCULATION BOOK

The Office Calculation Book (OCB) is to contain all calculations together with locations of the contract quantities as listed in the Proposal. Prior to binding, the OCB pages are to be numbered and two additional sets copied for submission with the PS&E (Copies are to be used in construction). The OCB (original) is to be assembled with a cardboard cover and back, and labeled with an assigned OCB number for the specified project issued by the Plans and Records Section.

The format of the office calculation book should meet these criteria:

1. Place index in the beginning.
2. Illustrate by stations calculated surface areas, including sketches of street approaches and driveways.
3. Quantities should be entered in the calculation book in the order in which they are estimated; i.e., chronologically.
4. Quantities must be checked and initialled by the checker.
5. Include an earthwork summary with the earthwork calculations.
6. All work is to be neat, legible, and suitable for reproduction.
7. Do not make erasures; strike out with a single line.
8. Provide a 25 mm border around each page.
9. Handwritten entries are acceptable.
10. Enter all project calculations in the office calculation book.

Excerpts from an office calculation book are provided on pages 13.22.0 to 13.32.0 and illustrate the recommended format.



SAMPLE PROJECT ESTIMATE

EWO No. 000-000-000		Page 1 of 2			
Office Calc. Book 2065					
Project File No. 000000					
<p>CONTRACT ESTIMATE THE COMMONWEALTH OF MASSACHUSETTS HIGHWAY DEPARTMENT 10 PARK PLAZA, BOSTON, MASSACHUSETTS — PRELIMINARY ESTIMATE —</p>					
		Includes Br. #D-7-11			
Sta. 40+85.672 to Sta. 45+92.994	City/Town [Name]	Road Reloc. Rte. 99			
Sta. _____ to Sta. _____	Road	Class (Federal Aid No. or N.F.A.)			
Sta. _____ to Sta. _____	City/Town	Type (Bridge Replacement)			
Allotment \$ _____	Contract 0.507 km	Date _____			
Length = (To .001)	Fed. Aid 0.507 km				
Item No.	Qty.	Unit	Item	UNIT PRICE	Amount
			Brought forward (from Page 2 of Contract Estimate)		3,787,957.20
999.001	5 000	HRS	Traffic Police	26.00	130,000.00
999.080	2	EA	Journeyman Trainee (When Required)	800.00	1,600.00
999.143	50	CM	Test Pit Excavation*	26.00	1,300.00
999.740	15	MO	Telephone Charges	100.00	1,500.00
			Subtotal		3,922,357.20
			Construction Engineering**		392,222.80
			Subtotal		4,314,580.00
			10 % Contingencies**		378,780.00
			Subtotal		4,693,360.00
			Less Non-Participating Estimate		22,950.00
			Total Participating Construction Cost		4,670,410.00
			Work By S.E. Power Co.		5,500.00
			Work By S.B.A. Railroad Co.		11,700.00
			(Force Account with Federal Aid Participation Name Each Agency and Cost)		
			Total Participating Cost		4,687,610.00
			Non Participating Estimate		22,950.00
			Total Cost		4,710,560.00
			* Use 2x Class A Trench Price		
			** Must equal sum of Construction Engineering/Contingencies amounts from Roadway, Bridge, and Non-Participating Estimates		
			Summary Of Project Cost (If Federal Aid)		
			Total		(80%) Federal Funds Requested
Federal Aid Participating Roadway Construction Cost				3,830,490.00	3,064,392.00
Bridge No. D-7-11				839,920.00	671,936.00
			Sub Total	4,670,410.00	3,736,328.00
Work By S.E. Power Co. (Force Account)				5,500.00	4,400.00
Work By S.B.A. Railroad Co. (Force Account)				11,700.00	9,360.00
			Sub Total	4,687,610.00	3,750,088.00
Non Participating Estimate				22,950.00	
			Total	4,710,560.00	
Made by _____	Checked by _____	Submitted by _____		Section Head or Dist. Hwy Director	

COMPUTER PRINTOUT (CONTRACT)

Item No.	Qty.	Unit	Item	UNIT PRICE	Amount
101.	4	H	CLEARING AND GRUBBING	11,000.00	44,000.00
112.01	1	LS	DEMOLITION OF BUILDING NO. R 1-5-12 (1)	6,000.00	6,000.00
112.02	1	LS	DEMOLITION OF BUILDING NO. R 1-5-14 (1)	9,000.00	9,000.00
120.	12 600	CM	EARTH EXCAVATION	8.50	107,100.00
121	90	CM	CLASS A ROCK EXCAVATION	18.00	1,620.00
123.	500	CM	MUCK EXCAVATION	7.45	3,725.00
140.	980	CM	BRIDGE EXCAVATION	16.00	15,680.00
141	150	CM	CLASS A TRENCH EXCAVATION	13.00	1,950.00
143.	80	CM	CHANNEL EXCAVATION	19.50	1,560.00
144.	270	CM	CLASS B ROCK EXCAVATION	34.00	9,180.00
150	4 000	CM	ORDINARY BORROW	9.00	36,000.00
151.	8 000	CM	GRAVEL BORROW	13.00	104,000.00
151.1	100	CM	GRAVEL BORROW FOR BRIDGE FOUNDATION	23.00	2,300.00
170.	130 000	SM	FINE GRADING AND COMPACTING - SUBGRADE AREAS	1.00	130,000.00
201	90	EA	CATCH BASIN	700.00	63,000.00
202.2	1	EA	MANHOLE (3 METERS TO 4 METERS DEPTH)	1,500.00	1,500.00
226	1	EA	CLEANING DRAINAGE STRUCTURES	60.00	60.00
226.3	100	M	CLEANING DRAINAGE PIPES	12.00	1,200.00
238.200	120	M	200 MM DUCTILE IRON PIPE	134.00	16,080.00
241.300	3 000	M	300 MM REINF CONCRETE PIPE	64.00	192,000.00
363	2	EA	CORPORATION COCK	100.00	200.00
384.	2	EA	CURB STOP	954.00	190.00
420	21 200	T	CLASS 1 BIT CONC BASE COURSE TYPE 1-1	36.00	736,200.00
460	27 400	T	CLASS 1 BIT CONC PAVEMENT TYPE 1-1	36.00	986,400.00
462	80	T	CLASS 1 DENSE PROTECTIVE (BOTTOM) COURSE FOR BRIDGES	68.00	5,440.00
485	350	SM	GRANITE RUBBLE BLOCK PAVEMENT	77.00	26,950.00
503	600	M	GRANITE CURB TYPE VA3 - STRAIGHT	77.00	46,200.00
511.1	2 000	M	GRANITE EDGING TYPE SB, STRAIGHT (RADIUS 3M OR LESS)	31.00	62,000.00
514	90	EA	GRANITE CURB INLET - STRAIGHT	175.00	15,750.00
570.1	6 000	M	BIT CONC CURB TYPE 1	6.50	39,000.00
580.	150	M	CURB REMOVED AND RESET	21.00	3,150.00
620.1	5 000	M	STEEL BEAM HWY GUARD TYPE SS (SINGLE FACED)	34.00	170,000.00
621.1	700	M	STEEL BEAM HWY GUARD TYPE SS (DOUBLE FACED)	54.00	37,800.00
627.2	6	EA	STEEL BEAM TERMINAL SECTION (DOUBLE FACED)	72.00	432.00
678	2	EA	PORTABLE BARRIER FENCE-ILLUMINATED	2,000.00	4,000.00
702	280	T	BITUMINOUS CONCRETE WALK SURFACE	70.00	215,600.00
710.3	6.000	EA	BOUND LETTERED - GRANITE	154.00	924.00
740	6	MO	ENGINEERS FIELD OFFICE AND EQUIPMENT - TYPE A	950.00	5,700.00
744	6	MO	MATERIALS LABORATORY AND EQUIPMENT	800.00	4,800.00
765.2	1 820	KG	SEED FOR EROSION CONTROL	13.58	24,715.60
866.100	12 210	M	100 MM REFLECTORIZED WHITE LINE (THERMOPLASTIC)	0.86	10,500.60
941.	3 000	M	TREATED TIMBER PILES	49.00	147,000.00
955.	3.6	CM	TREATED TIMBER	2,000.00	7,200.00
983.1	300	T	RIPRIAP	19.50	5,850.00
995.01	1	LS	BRIDGE STRUCTURE NO D-7-11	486,000.00	486,000.00

TOTAL 3,787,957.20

COMPUTER PRINTOUT (ROADWAY)

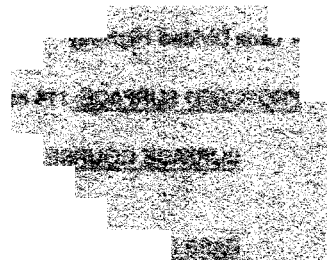
Item No.	Qty.	Unit	Item	UNIT PRICE	Amount
101.	4	H	CLEARING AND GRUBBING	11,000.00	44,000.00
112.01	1	LS	DEMOLITION OF BUILDING NO. R 1-5-12 (1)	6,000.00	6,000.00
112.02	1	LS	DEMOLITION OF BUILDING NO. R 1-5-14 (1)	9,000.00	9,000.00
120.	12 600	CM	EARTH EXCAVATION	8.50	107,100.00
123.	500	CM	MUCK EXCAVATION	7.45	3,725.00
141.	150	CM	CLASS A TRENCH EXCAVATION	13.00	1,950.00
144.	260	CM	CLASS B ROCK EXCAVATION	34.00	8,840.00
150.	4 000	CM	ORDINARY BORROW	9.00	36,000.00
151.	8 000	CM	GRAVEL BORROW	13.00	104,000.00
170.	130 000	SM	FINE GRADING AND COMPACTING--SUBGRADE AREAS	1.00	130,000.00
201	90	EA	CATCH BASIN	700.00	63,000.00
202.2	1	EA	MANHOLE (3 METERS TO 4 METERS DEPTH)	1,500.00	1,500.00
238.200	120	M	200 MM DUCTILE IRON PIPE	134.00	16,080.00
241.300	3 000	M	300 MM REINF. CONCRETE PIPE	64.00	192,000.00
363.	2	EA	CORPORATION COCK	100.00	200.00
384	2	EA	CURB STOP	95.00	190.00
420.	21 200	T	CLASS I BIT. CONC. BASE COURSE TYPE I-1	36.00	736,200.00
460.	27 400	T	CLASS I BIT. CONC. PAVEMENT TYPE I-1	36.00	986,400.00
503.	600	M	GRANITE CURB TYPE VA,3 STRAIGHT	77.00	46,200.00
511.1	2 000	M	GRANITE EDGING TYPE SB, STRAIGHT (RADIUS 3M OR LESS)	31.00	62,000.00
514.	90	EA	GRANITE CURB INLET - STRAIGHT	175.00	15,750.00
570.1	6 000	M	BIT. CONC. CURB TYPE 1	6.50	39,000.00
580.	150	M	CURB REMOVED AND RESET	21.00	3,150.00
620.1	5 000	M	STEEL BEAM HWY GUARD TYPE SS (SINGLE FACED)	34.00	170,000.00
621.1	700	M	STEEL BEAM HWY GUARD TYPE SS (DOUBLE FACED)	54.00	37,800.00
627.2	6	EA	STEEL BEAM TERMINAL SECTION (DOUBLE FACED)	72.00	432.00
678.	2	EA	PORTABLE BARRIER FENCE-ILLUMINATED	2,000.00	4,000.00
702	280	T	BITUMINOUS CONCRETE WALK SURFACE	70.00	215,600.00
710.3	6	EA	BOUND - LETTERED GRANITE	154.00	924.00
740.	6	MO	ENGINEERS FIELD OFFICE AND EQUIPMENT - TYPE A	950.00	5,700.00
744	6	MO	MATERIALS LABORATORY AND EQUIPMENT	800.00	4,800.00
765.2	1 820	KG	SEED FOR EROSION CONTROL	13.58	24,715.60
866.100	12 210	M	100 MM REFLECTORIZED WHITE LINE (THERMOPLASTIC)	0.86	10,500.60
TOTAL					3,086,757.20

COMPUTER PRINTOUT (BRIDGE)

Item No.	Qty.	Unit	Item	UNIT PRICE	Amount
121.	20	CM	CLASS A ROCK EXCAVATION	18.00	360.00
140.	980	CM	BRIDGE EXCAVATION	16.00	15,680.00
143.	80	CM	CHANNEL EXCAVATION	19.50	1,560.00
144.	10	CM	CLASS B ROCK EXCAVATION	34.00	340.00
151.1	100	CM	GRAVEL BORROW FOR BRIDGE FOUNDATION	23.00	2,300.00
462.	80	T	CLASS I DENSE PROTECTIVE (BOTTOM) COURSE FOR BRIDGES	68.00	5,440.00
485.	350	SM	GRANITE RUBBLE BLOCK PAVEMENT	77.00	26,950.00
941.	3,000	M	TREATED TIMBER FILES	49.00	147,000.00
955.	3.6	CM	TREATED TIMBER	2,000.00	7,200.00
983.1	300	T	RIPRAP	19.50	5,850.00
995.01	1	LS	BRIDGE STRUCTURE NO. D-7-11	286,000.00	286,000.00
				TOTAL	498,680.00

COMPUTER PRINTOUT (NON-PARTICIPATING)

Item No.	Qty.	Unit	Item	UNIT PRICE	Amount
226	1	EA	CLEANING DRAINAGE STRUCTURE	60.00	60.00
226.3	100	M	CLEANING DRAINAGE PIPES	12.00	1,200.00
				TOTAL	1,260.00





EWO No. <u>000-000-000</u>		Page <u>1</u> of <u>3</u>			
Project File No. <u>000000</u>					
THE COMMONWEALTH OF MASSACHUSETTS HIGHWAY DEPARTMENT INCLUDES BRIDGE 10 PARK PLAZA, BOSTON, MASSACHUSETTS NO. D-7-11 -PRELIMINARY ESTIMATE OF QUANTITIES - DETAIL SHEET-					
City/Town <u> </u> (Name)		Road Reloc. Rte. <u>99</u> Year <u> </u>			
STA. <u>40 + 85.672</u>	TO STA. <u>45 + 92.994</u>	CLASS <u> </u>	(F.A. NO. or N.F.A.) <u> </u>		
TYPE OF PROJECT (i.e., Construction)		Date <u>19</u>			
Muck Excavation	<u>500</u>	CM	Gravel Sub-base	<u>8 000</u>	CM
Earth Excavation	<u>2 600</u>	CM	Gravel for Bridges	<u>100</u>	CM
Loam Excav. & Stacked	<u>---</u>	CM	Gravel Sidewalks	<u>---</u>	CM
Class "A" Rock Excav.	<u>90</u>	CM	Gravel (Misc.)	<u>---</u>	CM
Bridge Excav.	<u>980</u>	CM			
Channel Excav.	<u>80</u>	CM			
Ordinary Borrow	<u>14 000</u>	CM	Embankment +15%	<u>14 780</u>	CM
Special Borrow	<u>---</u>	CM	(Includes Backfill for Loam Stripping)		
<p>RTE. I-99 4 Lane Divided Highway</p> <p><u>PROPOSED SURFACE:</u> 114 mm Class I. Bit. Conc. Pave. Type I-1 Area= 66 000 S.M.</p> <p><u>SURFACE COURSE:</u> 114 mm Class I Bit. Conc. Pavement Type I-1 Placed in 3 Layers, 38 mm Top Course Material over 2 Layers of Binder Course Material Each 38 mm.</p> <p><u>BASE COURSE</u> 152 mm Class I Bit. Con. Pave. Type I-1 Base Coure Material Placed in 2 Layers each 76 mm.</p> <p><u>SUBBASE</u> 305 mm Gravel</p> <p><u>SHOULDERS:</u> 114 mm Class I Bit. Conc. Pave. Type I-1 Area = 13 300 S.M.</p> <p><u>SURFACE COURSE:</u> Same as I-99 Traveled Way</p> <p><u>BASE COURSE</u> Same as I-99 Traveled Way</p> <p><u>SUBBASE</u> Same as I-99 Traveled Way</p> <p>SEE BRIDGE PLANS FOR BRIDGES WATER FOR DUST CONTROL</p> <p>NOTE TO DESIGNER: ALL AFFECTED ROADWAYS, RAMPS, DRIVES, REST AREAS, ETC. ARE SIMILARLY DESCRIBED. PAVEMENT THICKNESSES ARE USED FOR ILLUSTRATION: THEY VARY FOR EACH PROJECT.</p>					
Plan Nos.	<u>Y-75 S, Y-75 N</u>	Estimated By	<u> </u>	(Name)	
Profile Nos.	<u>668-F, 673-H</u>	Checked By	<u> </u>	(Name)	
Calc. Book Nos.	<u>2065</u>	Submitted By	<u> </u>	(Name)	
		Section Head or District Hwy. Director			

COMPUTER PRINTOUT (CONTRACT W/O PRICES)

Item No.	Qty.	Unit	Item	UNIT PRICE	Amount
101.	4	H	CLEARING AND GRUBBING		
112.01	1	LS	DEMOLITION OF BUILDING NO. R 1-5-12 (1)		
112.02	1	LS	DEMOLITION OF BUILDING NO. R 1-5-14 (1)		
120.	12 600	CM	EARTH EXCAVATION		
121.	90	CM	CLASS A ROCK EXCAVATION		
123.	500	CM	MUCK EXCAVATION		
140.	980	CM	BRIDGE EXCAVATION		
141.	150	CM	CLASS A TRENCH EXCAVATION		
143.	80	CM	CHANNEL EXCAVATION		
144.	270	CM	CLASS B ROCK EXCAVATION		
150.	4 000	CM	ORDINARY BORROW		
151.	8 000	CM	GRAVEL BORROW		
151.1	100	CM	GRAVEL BORROW FOR BRIDGE FOUNDATION		
170.	130 000	SM	FINE GRADING AND COMPACTING - SUBGRADE AREAS		
201.	90	EA	CATCH BASIN		
202.2	1	EA	MANHOLE (3 METERS TO 4 METERS DEPTH)		
226.	1	EA	CLEANING DRAINAGE STRUCTURES		
226.3	100	M	CLEANING DRAINAGE PIPES		
238.200	120	M	200 MM DUCTILE IRON PIPE		
241.300	3 000	M	300 MM REINF CONCRETE PIPE		
363.	2	EA	CORPORATION COCK		
384.	2	EA	CURB STOP		
420.	21 200	T	CLASS 1 BIT CONC BASE COURSE TYPE I-1		
460.	27 400	T	CLASS 1 BIT CONC PAVEMENT TYPE I-1		
462.	80	T	CLASS 1 DENSE PROTECTIVE (BOTTOM) COURSE FOR BRIDGES		
485.	350	SM	GRANITE RUBBLE BLOCK PAVEMENT		
503.	600	M	GRANITE CURB TYPE VA3 - STRAIGHT		
511.1	2 000	M	GRANITE EDGING TYPE SB, STRAIGHT (RADIUS 3M OR LESS)		
514.	90	EA	GRANITE CURB INLET - STRAIGHT		
570.1	6 000	M	BIT CONC CURB TYPE 1		
580.	150	M	CURB REMOVED AND RESET		
620.1	5 000	M	STEEL BEAM HWY GUARD TYPE SS (SINGLE FACED)		
621.1	700	M	STEEL BEAM HWY GUARD TYPE SS (DOUBLE FACED)		
627.2	6	EA	STEEL BEAM TERMINAL SECTION (DOUBLE FACED)		
678.	2	EA	PORTABLE BARRIER FENCE-ILLUMINATED		
702.	280	T	BITUMINOUS CONCRETE WALK SURFACE		
710.3	6.000	EA	BOUND LETTERED - GRANITE		
740.	6	MO	ENGINEERS FIELD OFFICE AND EQUIPMENT - TYPE A		
744.	6	MO	MATERIALS LABORATORY AND EQUIPMENT		
765.2	1 820	KG	SEED FOR EROSION CONTROL		
866.100	12 210	M	100 MM REFLECTORIZED WHITE LINE (THERMOPLASTIC)		
941.	3 000	M	TREATED TIMBER PILES		
955.	3.6	CM	TREATED TIMBER		
983.1	300	T	RIPRAP		
995.01	1	LS	BRIDGE STRUCTURE NO D-7-11		

NOTE: Numbers & quantities are for illustration only. See latest MHD "Standard Nomenclatures and Designation of items"



EWO No. 000-000-000

Page 3 of 3

Project File No. 000000

-PRELIMINARY ESTIMATE OF QUANTITIES-DETAIL SHEET-

City-Town (Name)

Road RELOC. RTE. 99

DATE 19

ALL ITEMS NOT COMPLETELY DESCRIBED AND LOCATED ON THE PLANS ARE TO BE DETAILED AS SHOWN BY THE BELOW

101. CLEARING AND GRUBBING

TOTAL GRADING AREA (EXCLUDING PAVED AREAS, WATER AREAS AND CELLAR HOLES) PLUS 5 M OUTSIDE OF SLOPE LIMITS, PLUS 10 M WIDE STRIP FOR FENCES AND DITCHES WHERE NECESSARY

112.01 DEMOLITION OF BUILDING NO. RI-5-12 (1)
2-STY WD FR HSE STA 41+20 SB-40 M RT

112.02 DEMOLITION OF BUILDING N10 R1-5-14 (1)
2-STY WD FR BARN STA 43+60 NB 65 M LT

580. CURB REMOVED AND RESET
SO. BD.

STA. 42+50 RT. TO STA. 44+10 RT
STA. 43+50 RT. TO STA. 45+50 RT
STA. 42+00 LT. TO STA. 44+00 LT
STA. 44+10 LT. TO STA. 45+80 LT

678. PORTABLE BARRIER FENCE ILLUMINATED
STA. 41+00 NB
STA. 46+00 NB

710.3 BOUND - LETTERED GRANITE
SO. BD.

STA. 42+45 LT
STA. 43+20 RT COUNTY LINE
STA. 45+30 RT

NO. BD.
STA. 41+80 RT STATE LINE
STA. 42+00 LT
STA. 45+00 LT

751.2 PLANTABLE SOIL BORROW
AS SHOWN ON TYPICAL SECTIONS-180 MM DEPTH

765.2 SEED FOR EROSION CONTROL
ALL LOAMED AREAS

780.1 MULCH-OPTION
AS SHOWN ON TYPICAL SECTIONS

988.1 RIPRAP
FOR SPECIAL END STA. 42+50 RT. NB. RDWY



EWO No. 000-000-000
Project File No. 000000

SUMMARY QUANTITY SHEET

City-Town of (NAME) _____

PREPARED BY (Name) _____ (Date) _____
CHECKED BY (Name) _____ (Date) _____

<u>EXCAVATION</u>		<u>EMBANKMENT</u>	
	CM		CM
Total from Cross-Sections _____	12 023.10	_____	12 791.30
Misc. Drives, Walks etc. _____	+ 68.00	_____	+ 61.20
Estimated Excavation _____	12 091.10	_____	12 852.50
Estimate --- % Boulders* _____	- 22.00	Plus 15% _____	+1 927.88
Earth Excavation _____	12 069.10	Required _____	14 780.38
Deduct 5% _____	- 603.46	Available _____	-11 579.94
Rock Plus 37 1/2 % See Below _____	+ 114.30	Borrow _____	3 200.44
Available for Embankment _____	11 579.94		

120. Earth Excavation

From Above _____ 12 069.10 CM Call 12 600 CM

121. Class A Rock Excavation

From Cross-Sections _____ 61.13 CM
Estimate --- % Boulders* _____ + 22.0
Total Excavation _____ 83.13
Plus 37 1/2 % _____ + 31.17
Available _____ 114.30 CM Call 90 CM

123. Muck Excavation

From Cross-Sectons _____ 497.31 CM Call 500 CM

150. Ordinary Borrow

From Above _____ 3 200.44 CM Call 4 000 CM

* This value varies for every project



PROJECT FILE NO. 000000				EARTH QUANTITY SHEET				Page _____ of _____			
CITY-TOWN OF _____ (NAME)				PREPARED BY (NAME) (DATE)							
CALCULATION BOOK 2065 PAGE 35				CHECKED BY (NAME) (DATE)							
STATION	CUT	FILL		STATION	CUT	FILL		STATION	CUT	FILL	
THE QUANTITIES NOTED ON THE QUANTITY SHEETS ARE TRANSCRIBED FROM THE OFFICE CALCULATION BOOK											
ROUTE 1 99				N.E. RAMP-SEA ST.				SEA ST.			
41 00				141 00				3 00			
+ 20	561 00	317 06		+ 20	342 05	118 03		+ 20	213 01	35 00	
+ 40	525 03	311 04		+ 40	322 02	120 08		+ 40	108 08	33 01	
+ 60	502 07	316 02		+ 60	314 09	122 04		+ 60	101 03	31 05	
+ 80	466 02	818 01		+ 80	310 04	119 09		+ 80	91 04	29 00	
42 00	415 01	811 04		142 00	302 00	115 04		+ 80	85 08	25 05	
+ 20	334 02	825 04		+ 20	292 07	112 08		4 00	178 01	21 02	
+ 40	310 07	822 00		+ 40	0 00	0 00		+ 20	162 08	24 03	
+ 60	301 01	821 05		+ 60	274 02	110 05		+ 40	155 03	23 07	
+ 80	298 03	319 01		+ 80	268 04	109 07		+ 60	33 07	21 06	
43 00	291 09	415 07		+ 80	253 02	111 01		+ 80	24 00	19 01	
+ 20	287 06	523 01		143 00	244 08	118 09		5 00	18 02	24 05	
+ 40	255 01	618 03		+ 20	222 04	115 03		+ 20	23 06	23 07	
+ 60	234 02	416 05		+ 40	201 06	121 02		+ 40	121 06	26 08	
+ 80	215 08	513 01		+ 60	195 04	118 01		+ 60	17 02	23 01	
44 00	202 06	618 07		+ 80	166 02	119 06		+ 80	6 07	18 01	
+ 20	195 02	322 06		144 00	155 07	118 02		6 00	98 01	12 09	
+ 40	199 05	417 06		+ 20	141 06	114 07		+ 20	84 00	14 03	
+ 60	205 06	316 05		+ 40	126 04	112 02		+ 40	75 03	10 08	
+ 80	0 00	472 19		+ 60	114 06	110 03		+ 60	68 07	12 04	
	210 01	176 82		+ 80	103 01	109 00		+ 80	111 78	09 01	
TOTAL 6 005 72 10 167 69				TOTAL 4 344 83 2 190 84				TOTAL 1 672 55 432 77			



6826

FRANKLIN - MEDWAY

POND STREET - FRANKLIN STREET

PROJECT FILE NO.....

6826

The Commonwealth of Massachusetts

HIGHWAY DEPARTMENT
TEN PARK PLAZA - BOSTON, MA

CONTENTS

***POND ST., FRANKLIN - FRANKLIN ST., MEDWAY
STA.214490 TO STA.227 + 50
PAGES 1- 49 & 61***



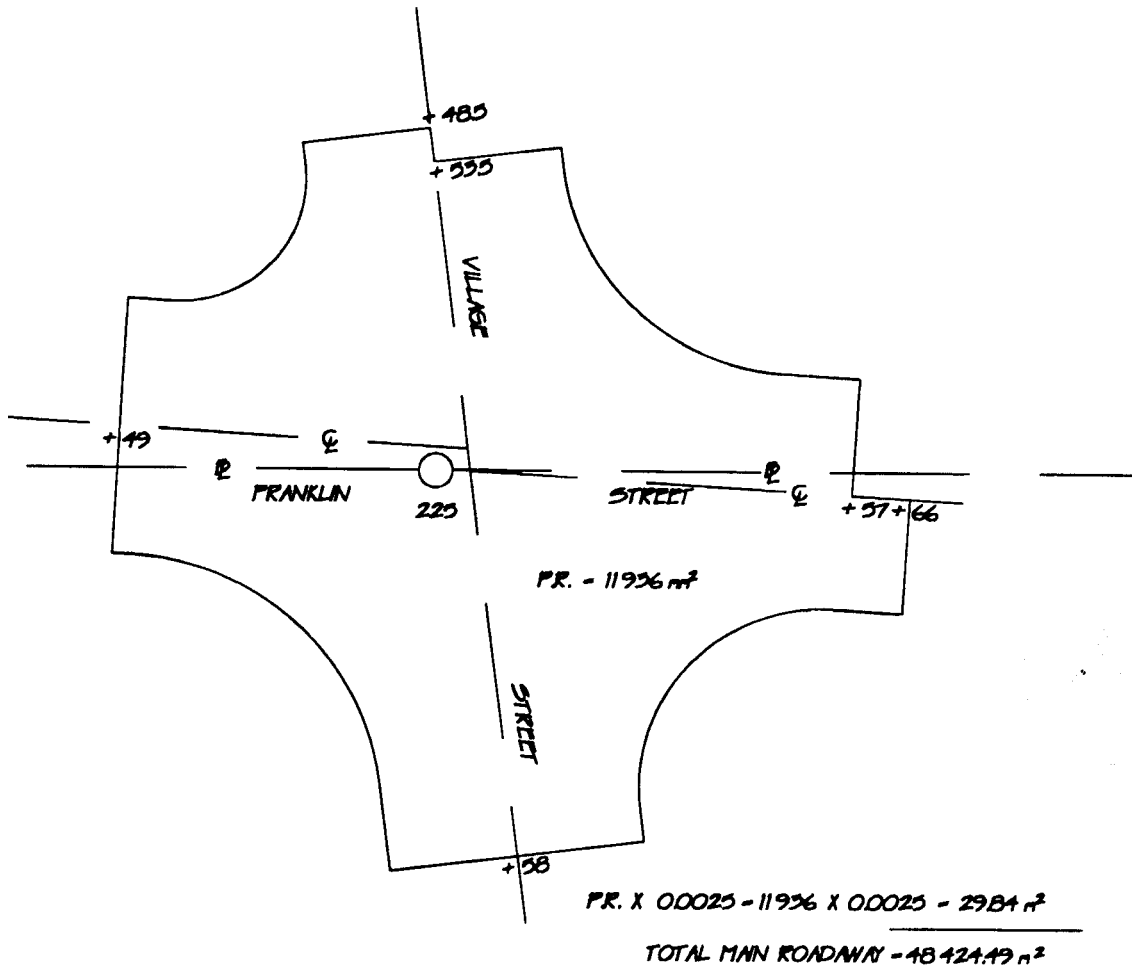
CITY/TOWN FRANKLIN & MEDWAY RD. POND ST. - FRANKLIN ST. STA. 214 + 90 TO STA. 227 + 50
 CLASS _____ ORDER NO. 000 - 802 - 340 (1)
 PLAN NOS. _____ PROFILE NOS. _____ EST. BY J. R. SHEARSTONE
 CROSS SECTIONS _____ TRACINGS _____ CHK'D R. XAVIER

ITEM NO.	QUANTITIES			UNIT	NOMENCLATURES	PG #
	ROADWAY	BRIDGE	COMP'D			
101.	010		010	HA	CLEARING & GRUBBING	9
103.	70		70	EA	TREE REMOVED - DIA UNDER 600 mm	9
104.	30		30	EA	TREE REMOVED - DIA 600 mm AND OVER	9
115J		10	10	LS.	DEMOLITION OF BRIDGE STRUCTURE P - 8 - 10 M - 15 - 4	49
120.	47000		47000	CM	EARTH EXCAVATION	10
121.	2000		2000	CM	CLASS A ROCK EXCAVATION	10
140.		14000	14000	CM	BRIDGE EXCAVATION	49
141.	1000		1000	CM	CLASS A TRENCH EXCAVATION	10
142.	1000		1000	CM	CLASS B TRENCH EXCAVATION	12
143.	1250	3000	4250	CM	CHANNEL EXCAVATION	12 & 49
144	300	100	600	CM	CLASS B ROCK EXCAVATION	12 & 49
145.	30		30	EA	DRAINAGE STRUCTURE ABANDONED	15
146.	10		10	EA	DRAINAGE STRUCTURE REMOVED	15
150.	1500		1500	CM	ORDINARY BORROW	15
151.	31500	7500	39000	CM	GRAVEL BORROW	16 & 49
156.	300		300	MT	CRUSHED STONE FOR DRAINAGE REVET. AND W.W. FOUNDATIONS	17
170.	93000		93000	CM	FINE GRADING AND COMPACTING - SUBGRADE AREAS	17
201.	190		190	EA	CATCH BASIN	18
202.	160		160	EA	MANHOLE	18
204.	10		10	EA	GUTTER INLET	18
220.	150		150	EA	DRAINAGE STRUCTURE ADJUSTED	18
2205	20		20	EA	DRAINAGE STRUCTURE REMODELED	19
2207	10		10	EA	SANITARY STRUCTURE ADJUSTED	19
2208	10		10	EA	SANITARY STRUCTURE REMODELED	19
222.	160		160	EA	FRAME AND GRATE	19
222J	200		200	EA	FRAME AND GRATE MHD CASCADE TYPE	19
238.0	500		500	M	DUCTILE IRON PIPE	19
241300	4300		4300	M	300 mm REINFORCED CONC. PIPE	20
241300	10		10	EA	300 mm REINFORCED CONC. PIPE FLARED END	20
241375	1200		1200	M	375 mm REINFORCED CONC. PIPE	20
241450	4200		4200	M	450 mm REINFORCED CONC. PIPE	20
241600	6000		6000	M	600 mm REINFORCED CONC. PIPE	20
241600	20		20	EA	600 mm REINFORCED CONC. PIPE FLARED END	20

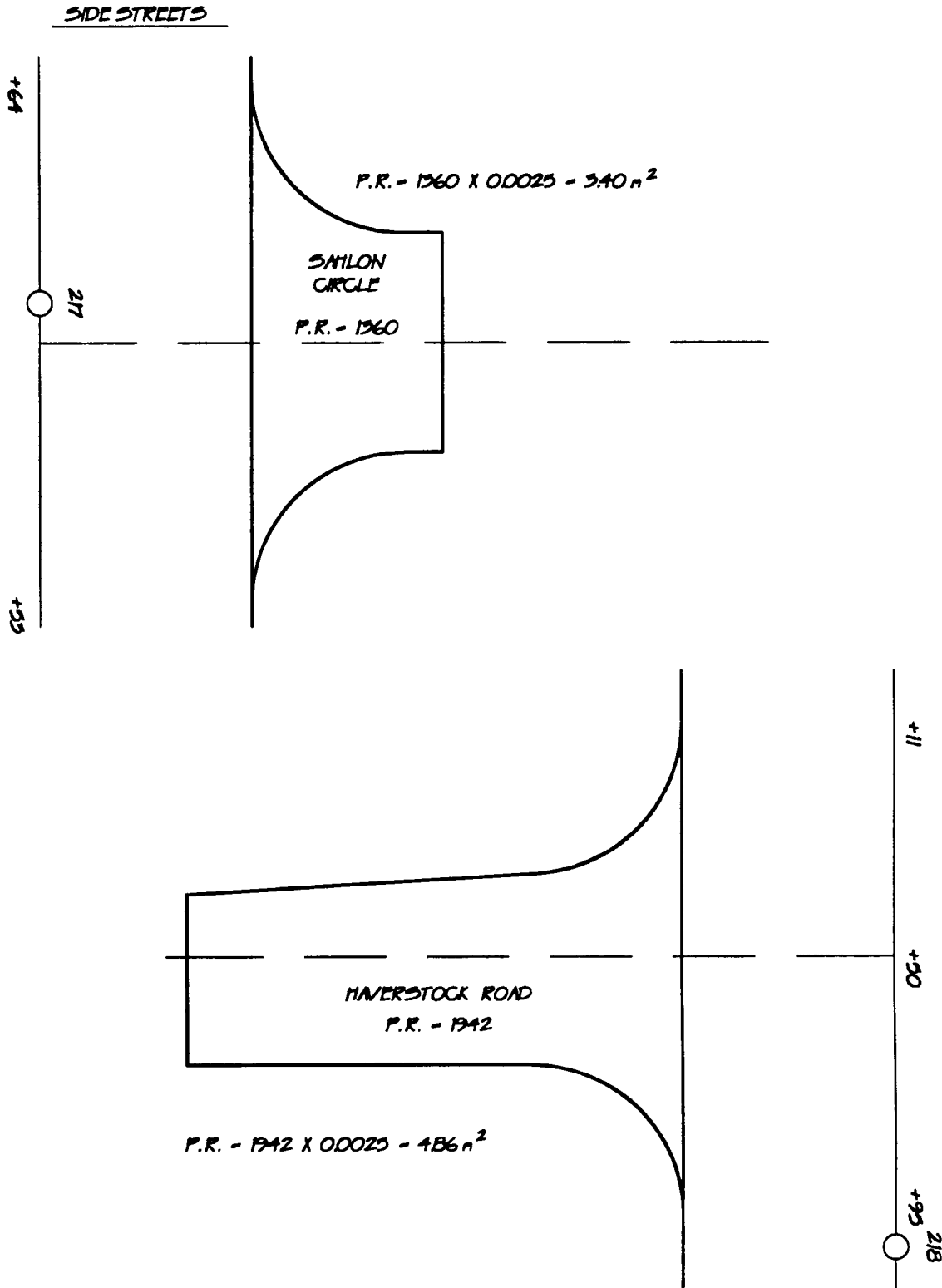
COMPUTER GENERATED OR PLANIMETERED

-- SURFACE AREAS --

STA 214 + 90 LT TO STA 216 + 64 LT	$-\frac{110 + 200}{2}$	(174.00)	= 2697.00 m ²
STA 214 + 90 RT TO STA 217 + 11 RT	$-\frac{125 + 200}{2}$	(221.00)	= 3701.75 m ²
STA 216 + 64 LT TO STA 218 + 54 LT	200	(190.00)	= 3900.00 m ²
STA 217 + 11 RT TO STA 218 + 54 RT	200	(145.00)	= 2860.00 m ²
STA 218 + 88 LT TO STA 219 + 25 LT	200	(37.00)	= 740.00 m ²
STA 218 + 88 RT TO STA 219 + 25 RT	200	(37.00)	= 740.00 m ²
STA 219 + 25 TO STA 220 + 14	$-\frac{100 + 380}{2}$	(89.00)	= 3471.00 m ²
STA 220 + 14 TO STA 224 + 49	380	(435.56)	= 16545.68 m ²
STA 225 + 66 RT TO STA 227 + 50 RT	$-\frac{165 + 106}{2}$	(184.00)	= 4011.26 m ²
STA 225 + 57 LT TO STA 227 + 50 LT	$-\frac{130 + 108}{2}$	(193.00)	= 2489.70 m ²



-- SURFACE AREAS --



-- SURFACE AREAS --

0+00 - 6.40 WIDE	6.25 X 100 - 625 m ²
1+00 - 6.10 WIDE	6.10 X 100 - 610 m ²
2+00 - 6.10 WIDE	6.10 X 100 - 610 m ²
3+00 - 6.10 WIDE	6.10 X 100 - 610 m ²
4+00 - 6.10 WIDE	5.95 X 100 - 595 m ²
5+00 - 5.79 WIDE	5.95 X 100 - 595 m ²
6+00 - 6.10 WIDE	6.10 X 100 - 610 m ²
7+00 - 6.10 WIDE	6.10 X 90 - 549 m ²
+ 90 - 6.10 WIDE	

4804 m²

0+00 - 6.10 WIDE	5.95 X 100 - 595 m ²
1+00 - 5.79 WIDE	5.95 X 100 - 595 m ²
2+00 - 6.10 WIDE	6.10 X 100 - 610 m ²
3+00 - 6.10 WIDE	5.80 X 100 - 580 m ²
4+00 - 5.49 WIDE	5.49 X 100 - 549 m ²
5+00 - 5.49 WIDE	5.80 X 100 - 580 m ²
6+00 - 6.10 WIDE	6.25 X 100 - 625 m ²
7+00 - 6.40 WIDE	6.86 X 100 - 686 m ²
8+00 - 7.32 WIDE	7.78 X 100 - 778 m ²
9+00 - 8.25 WIDE	8.69 X 100 - 869 m ²
10+00 - 9.14 WIDE	8.25 X 100 - 825 m ²
11+00 - 7.32 WIDE	7.62 X 100 - 762 m ²
12+00 - 7.92 WIDE	7.92 X 100 - 792 m ²
13+00 - 7.92 WIDE	7.62 X 100 - 762 m ²
14+00 - 7.32 WIDE	7.17 X 100 - 717 m ²
15+00 - 7.01 WIDE	7.47 X 100 - 747 m ²
16+00 - 7.92 WIDE	8.08 X 100 - 808 m ²
17+00 - 8.25 WIDE	8.25 X 100 - 825 m ²
18+00 - 8.25 WIDE	8.38 X 100 - 838 m ²
19+00 - 8.55 WIDE	8.38 X 100 - 838 m ²
20+00 - 8.25 WIDE	8.38 X 100 - 838 m ²
20+50 - 15.24 WIDE	11.74 X 100 - 1174 m ²

15551 m²

ITEM 101.	CLEARING AND GRUBBING	HECTARE
STA. 219 + 00 LT TO STA. 219 + 50 LT	$\frac{30 + 20}{2}$ (50)	- 1,250.0 S.M.
STA. 219 + 50 LT TO STA. 219 + 70 LT	$\frac{7 + 10}{2}$ (20)	- 170.0 S.M.
STA. 221 + 75 LT TO STA. 222 + 05 LT	$\frac{28 + 0}{2}$ (50)	- 420.0 S.M.
STA. 222 + 05 LT TO STA. 222 + 36 LT	$\frac{28 + 30}{2}$ (54)	- 899.0 S.M.
STA. 225 + 80 LT TO STA. 226 + 70 LT	$\frac{5 + 3}{2}$ (90)	- 360.0 S.M.
VILLAGE ST. VILLAGE ST.		
STA. 48 + 00 LT TO STA. 48 + 85 LT	$\frac{6 + 4}{2}$ (85)	- 425.0 S.M.
TOTAL		- 425.0 S.M.
3524 S.M. ÷ 10,000 = 0.35 HECTARE		
		<u>SAY 1.00 HECTARE</u>

ITEM 103.	TREE REMOVED - DIA UNDER 600 mm	EACH
STA. 216 + 78 RT 460 mm MAPLE	- 1 EA	
STA. 217 + 26 RT 305 mm MAPLE	- 1 EA	
STA. 225 + 53 RT 305 mm APPLE	- 1 EA	
STA. 225 + 88 RT 380 mm SPRUCE	- 1 EA	
STA. 224 + 02 RT 254 mm SPRUCE	- 1 EA	
STA. 224 + 17 RT 356 mm SPRUCE	- 1 EA	
STA. 227 + 02 RT 508 mm ASH	- 1 EA	
TOTAL		- 7 EA
		<u>SAY 7 EACH</u>

ITEM 104.	TREE REMOVED - DIA 600 mm AND OVER	EACH
STA. 216 + 50 RT 600 mm MAPLE	- 1 EA	
STA. 226 + 30 RT 600 mm MAPLE	- 1 EA	
STA. 224 + 29 LT 600 mm APPLE	- 1 EA	
TOTAL		- 3 EA
		<u>SAY 3 EACH</u>

ITEM 145 DRAINAGE STRUCTURE ABANDONED

EACH

STA. 215 + 70 LT TO CB ABANDONED - 1 EA.

STA. 215 + 78 RT TO CB ABANDONED - 1 EA.

STA. 217 + 99 RT TO CB ABANDONED - 1 EA.

TOTAL - 3 EA.

SAY 3 EACH

ITEM 146 DRAINAGE STRUCTURE REMOVED

EACH

STA. 224 + 74 LT REMOVED DI - 1 EA.

SAY 1 EACH

ITEM 150. ORDINARY BORROW

CM.

THIS ITEM SHALL BE USED FOR FORMING AND DRESSING
EMBANKMENTS ACCORDING TO THE PROVISIONS OF SECTION
150 WHEN THE MATERIAL FROM EXCAVATION DOES NOT MEET
THE REQUIREMENTS OF SUBSECTION M101.0.

SAY 150 CM.

— EARTH SUMMARY —

— EXCAVATION —

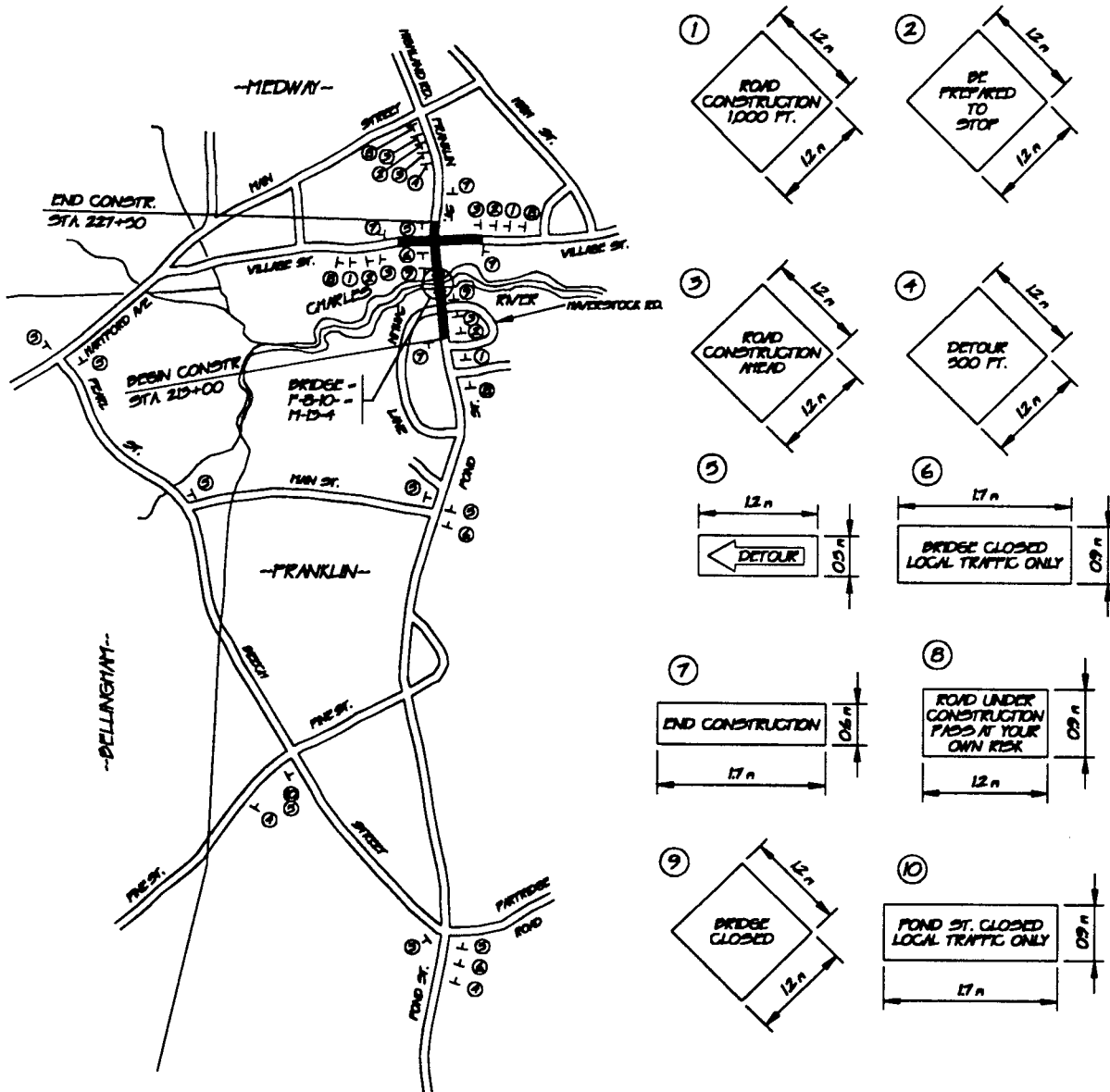
MAIN ROADWAY - ITEM 120. -	4875 CM
LESS CLASS A ROCK EXCAVATION -	200 CM
<hr style="width: 100%;"/>	
EARTH EXCAVATION -	4675 CM
LESS 10% UNSUITABLE -	467 CM
<hr style="width: 100%;"/>	
	4206 CM
CLASS A ROCK EXCAVATION + 37.5% -	275 CM
<hr style="width: 100%;"/>	
AVAILABLE FOR EMBANKMENT -	4481 CM

— EMBANKMENT —

FROM X - SECTIONS B # 61 -	778.8 CM
PLUS 15% -	116.8 CM
<hr style="width: 100%;"/>	
REQUIRED FOR EMBANKMENT -	895.6 CM
AVAILABLE FOR EMBANKMENT -	4481.0 CM
SUITABLE WASTE -	3585.4 CM
UNSUITABLE WASTE -	467.0 CM
<hr style="width: 100%;"/>	
TOTAL WASTE -	4052.4 CM

ITEM 852. SAFETY SIGNING FOR CONSTRUCTION OPERATIONS

31



Note:
EXACT LOCATIONS TO BE DETERMINED IN THE FIELD.



ITEM 82450 FLASHING WARNING BEACON R&R

LUMP SUM

MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS				TRAFFIC ENGINEERING SEC.						
COST ESTIMATE				INSTALLING TRAFFIC SIGNALS OR FLASHING BEACONS						
CITY TOWN <u>MEDWAY</u>				LOCATION <u>FRANKLIN ST. & VILLAGE ST.</u>						
TYPE OF INSTALLATION _____										
Quantity	Unit	Item	Unit Cost	Total Cost	Quantity	Unit	Item	Unit Cost	Total Cost	
POSTS					PULL BOXES					
ea.		Type m					203 mm X 584 mm			
ea.		Type m					305 mm X 305 mm			
ea.		Mast Arm								
					CONDUIT					
CONTROLLERS					20	M	76 mm NM Type OPTION	15	3075	
ea.		TCT-					mm Type			
ea.		Circuit Flasher Mech.								
					FOUNDATIONS					
DETECTORS					2	EA	Signal Post	975	1950	
ea.		Pressure m					Mast Arm			
ea.		Magnetic Type					"M" Box			
ea.		Magnetic Lane Type								
ea.		Magnetic Detector Relay			SERVICE CONNECTION					
ea.		Wire Loop					Equipment & Cable			
ea.		Sonic					Utility Co. Charges			
ea.		Radar								
ea.		Pedestrian Push Button			CABLE					
MISC. EQUIPMENT					70	M	/c No. 12 AWG	90	6300	
		Neon Sign					/c No. 12 AWG			
		Illuminated Barrier					/c No. 12 AWG			
					70	M	/c No. 8 AWG Bare Str.	15	920	
HOUSINGS					70	M	PULL CABLE	250	17500	
ea.		Way Lens			2	EA	SIGNAL POSTS (R&R)	75	150	
ea.		Way Lens			1	EA	SERVICE CONNECTION (R&R)	100.	100.	
ea.		Way Lens								
ea.		Way Lens								
ea.		Way Lens								
ea.		Pedestrian Neon								
ea.		Pedestrian Incan.								
					Materials <u>ITEM 82450</u>			1270	—	
					Equipment					
					<u>CONTINGENCIES</u>			180	—	
					OFFICE ESTIMATE			1450	—	
				Approved _____						
Date: <u>4/11/95</u> Estimated By <u>T. Tronelle</u>				Traffic Engineer						



THE COMMONWEALTH OF MASSACHUSETTS
HIGHWAY DEPARTMENT
BRIDGE ESTIMATE

Bridge No.
F-8-10=M-13-4

TOWN	Franklin - Medway	CLASS	
STATION	218+71.06	ROAD	Pond St. - Franklin St.
TYPE	Prestressed Deck Beam	ROADWAY	12 M
SPANS	1 @ 10.62 M	TOTAL LENGTH	11.62 M
		OVER	Charles River
		WALKS	2 @ 2 M

PRELIMINARY ESTIMATE OF QUANTITIES

ITEM NUMBER	QUANTITY	UNITS	ITEM	UNIT PRICE	AMOUNT	UNIT BID	AMOUNT BID
115.1	1	L.S.	Demolition of Bridge Structure F-8-10=M-13-4	\$7,500 -	\$7,500 -		
140.	1,400	C.M.	Bridge Excavation	\$10 -	\$14,000 -		
143.	300	C.M.	Channel Excavation	\$10 -	\$3,000 -		
144.	10	C.M.	Class B Rock Excavation	\$25 -	\$250 -		
151.	750	C.M.	Gravel Borrow	\$5.50	\$4,125 -		
460.	11	T	Class I Bituminous Concrete Pavement Type I-1	\$30 -	\$330 -		
462.	11	T	Class I Dense Protective (Bottom) Course for Bridges	\$60 -	\$660 -		
983.	565	T	Dumped Riprap	\$20 -	\$11,300 -		
991.1	1	L.S.	Control of Water Structure No. F-8-10=M-13-4	\$70,000 -	\$70,000 -		
993.51	1	L.S.	Remove & Stack Temporary Bridge	\$10,000 -	\$10,000 -		
995.01	1	L.S.	Bridge Structure No. F-8-10=M-13-4	\$189,000 -	\$189,000 -		
			Total		\$310,165 -		

Estimated By J.R.H. Checked By M.W.R. Approved By _____