

CHAPTER 1

BRIDGE SITE EXPLORATION

1.1 SURVEY FOR BRIDGES

1.1.1 General

The following are the minimum survey requirements for bridge projects and the reasons for them. Additional survey beyond these requirements may be needed depending on the complexity of either the proposed bridge structure or the site. The MassDOT Survey Manual shall be used for any additional information on survey theory and methods as practiced by the MassDOT.

1.1.2 Bridge Grid Survey

The bridge grid is taken in order that the proposed bridge may be fitted to the topography and an accurate calculation can be made of excavation quantities. It shall be plotted to either $\frac{1}{8}'' = 1' - 0''$ or $\frac{1}{4}'' = 1' - 0''$. The frequency of shots and extent must be a matter of judgment of the survey party. In general, shots should be taken on a 10-foot grid with additional shots as necessary for abrupt changes in contour. They should extend at least 50 feet beyond the edges of the highway or 25 feet beyond the anticipated end of splayed wingwalls, whichever is furthest, and should cover enough ground for any type of structure. The grid should be extended to reflect topography under existing structures.

1.1.3 Bridge Detail Survey

The following survey information shall be requested when: a new superstructure is to be built on existing substructures; an existing bridge is to be replaced in stages; an existing bridge is to be widened, repaired, or rehabilitated; or when the underclearances for the existing bridge are important to the underclearances to be provided at the replacement, such as for replacement bridges over water or railroads. The accuracy of surveys on bridge locations shall be greater than on general highway work. A copy of all field notes shall be provided to the Designer.

1. The angles of the abutments with the baseline, the location of tops and bottoms of batters, the widths of bridge seats and backwalls, the location of the angles of the wingwalls with abutments, the length of wingwalls and widths of copings shall be measured and the footings located if possible. The type of masonry in the substructure and its condition should be noted.
2. Detail shall be provided for all main superstructure elements, including beam lines, girder lines, truss lines, floorbeam lines, curb lines, sidewalks, fascia lines, utilities, copings, ends of bridge, etc. The stations of the centerlines of bearings and the skew angle between them and the survey baseline shall be established or verified at each abutment and at piers.
3. Bottom of beam elevations shall be taken on every beam at: the face of each abutment, both sides of each pier and span quarter points for spans less than 50 feet, span eighth points for spans over 50 feet. These elevations are needed for calculating the depth of haunches and top of form elevations.

4. Elevations shall be taken of all parts of the substructure and superstructure, such as the bridge seats, tops and ends of wingwalls, gutters, top of curb at intermediate points and at the ends of curbs, tops of slab and footings, if possible. All elevations shall be referred to the North American Vertical Datum (NAVD) of 1988. If only the National Geodetic Vertical Datum (NGVD) of 1929 is available at the site, the Designer shall contact the MassDOT Survey Engineer and obtain the relationship between NAVD and NGVD at the site.
5. Locate and establish the minimum horizontal and vertical underclearances of the existing structure.

1.1.4 Additional Survey for Bridges over Railroads

Whenever a railroad is crossed, the railroad baseline should be reproduced and sections taken a minimum of 50 feet perpendicular to and on both sides of the exterior rails for a distance of about 300 feet left and right of the survey baseline.

1.1.5 Survey for Stream

The stream shall be surveyed for a distance up and downstream of at least 500 feet either side of the baseline. Sections shall be taken at the following locations:

- Upstream: 500 feet, 400 feet, 300 feet, 200 feet, at a distance equal to the total span of the bridge (abutment to abutment) from the upstream face of the bridge, and at 10 feet from the upstream face of the bridge.
- Downstream: 5 feet from the downstream face of the bridge, at a distance equal to two times the total span of the bridge (abutment to abutment) from the downstream face of the bridge, 200 feet, 300 feet, 400 feet and 500 feet.

Any tributary entering the stream near the bridge site, either above or below, shall be surveyed for a distance of at least 500 feet from its junction with sections taken in increments of 100 feet. Locations and size of visually accessible drainpipes should be noted. Where there is any possibility of a relocation of the existing stream, adequate survey shall be taken to encompass the relocation.

The cross sections specified above shall be taken perpendicular to the stream baseline and shall extend laterally from the stream out beyond any known flood height. Elevations of the flood plane and soundings of the stream bottom along the cross section line shall be taken every 10 feet from the stream baseline. In the case of very wide flood planes or in locations with challenging site conditions, the MassDOT Hydraulic Unit should be consulted in order to establish reasonable requirements and limits for the survey.

If there is a dam or other water flow control device within the 500 foot limits of the survey, either up or down stream, the survey shall include: its distance from the bridge; elevations of the spillway, the top of the dam, water and riverbed soundings both upstream and downstream of the dam.

1.2 BORINGS FOR BRIDGES

1.2.1 General

No structure can be stronger than the founding of its substructure elements. Borings are taken for these elements and the study of the results and samples aids in the determination as to the type of foundation support.

In general, all design borings are typically made at one time. On major projects involving the construction of multiple bridges, pilot borings may be required.

1.2.2 Boring Plan

Boring plans for bridges shall be prepared as outlined in Section 1.3 of Part II of this Bridge Manual. They will be drawn on a single sheet of paper no smaller than 8½" x 11" and shall contain the following information:

1. The standard Title Block (Drawing No. 1.3.1 of Part II of this Bridge Manual).
2. A 1" = 40' plan view of the proposed structure, with the boring locations indicated by the standard symbol and a table specifying the following: boring's number, station and offset from baseline, Northing and Easting coordinates, approximate surface elevation, and specified highest bottom elevation (Drawing No. 1.3.2 of Part II of this Bridge Manual).
3. Boring Request Notes, from Drawing No. 1.3.3 of Part II of this Bridge Manual, and modified as indicated on the drawing.

An Adobe Acrobat format (PDF) copy of the proposed boring plan shall be submitted to the MassDOT Project Manager who will transmit hard copies of the boring plan, along with a cover letter requesting that borings be taken, to the Geotechnical Section and to the Bridge Section for review. The Geotechnical Section shall review the proposed boring plan in the office and in the field, shall accept the Bridge Section's comments, and shall transmit all comments to the Designer for boring plan modification and resolution. The Designer shall then forward the revised (if applicable) boring plan to the Geotechnical Section for acceptance. Upon acceptance, the Geotechnical Section shall initiate and conduct the subsurface investigation through its drilling contractor.

1.2.3 Definitions

1.2.3.1 Pilot Borings. Major projects involving the construction of multiple bridges may require pilot borings, which are those made during the preliminary stage of a project. These borings shall be located by the Designer to yield only sufficient soil information to enable the Designer to:

1. Prepare a preliminary foundation assessment.
2. Fix the profile, alignment of the highway, and position of the structures.
3. Prepare a preliminary cost of the project.

1.2.3.2 Design Borings. Design borings are made to furnish all subsurface data and soil samples required by the Designer to complete the design of the project. Depending on the situation, design borings may either be taken all at once or they may consist of control and complementary borings.

Design borings are typically taken after the profile and alignment of the road have been set and the structure type has been advanced sufficiently to identify the number, alignment and location of all substructure units. Borings in the pilot set that fit into the pattern of the design borings shall not be duplicated.

1.2.3.3 Control Borings. Control borings are the initial design borings. The results obtained from control borings are reported immediately to the Designer so that, at each area and location, the depth to which all remaining complementary borings should be taken can be determined.

1.2.3.4 Complementary Borings. Complementary borings are the remaining design borings required for design and construction purposes. They are made after an analysis of the results obtained from the control borings, to the depth specified by the Engineer. Usually, the Designer and the MassDOT's Geotechnical Section and/or Bridge Section jointly review the results of the control borings to determine the depths of the structural complementary borings. Complementary borings are not used for a pilot boring program.

1.2.4 Depth and Location

1.2.4.1 Pilot Borings.

Depth: For structures, the specified highest bottom elevation shall be set 10 feet below the preliminary footing elevation at the boring location. Each boring shall be made to the specified highest bottom elevation or to refusal, whichever is deeper. Refusal is defined as 120 blows for 12 inches (or fraction of 12 inches) of penetration by using the Standard Penetration Test (SPT). If rock is encountered above highest bottom elevation, a 10-foot long rock core is taken and the borehole is terminated.

Location: One boring per bridge site. Consideration of a rock core should be made at this time if rock would influence the foundation design.

1.2.4.2 Design Borings.

Depth: For structures, the specified highest bottom elevation shall be set at the depth equal to two footing widths below the preliminary footing elevation at the boring location. For perched abutments, the specified highest bottom elevation shall be set 15 feet below existing ground. At least one boring shall be made to bedrock and a 10-foot long core taken at each bridge location. Where a viaduct of considerable length is to be designed, every other pier may have one boring made to bedrock, if deemed necessary by the Engineer. Where structure foundations may be pile or drilled shaft supported, one boring shall be made to bedrock under each substructure unit.

Location: Borings shall be taken for every bridge, metal arch, box culvert with a span greater than 8 feet, retaining wall, and "highmast lighting foundation". Borings may be required for sign supports. For smaller structures, engineering judgment should govern.

One boring shall be made at each end of each pier or abutment and at the outer end of each wingwall more than 30 feet long. Where piers and/or abutments are more than 100 feet long, additional borings may be required. This additional borings could consist of both control and complementary borings, as specified by the Designer.

For retaining walls up to 100 feet in length, at least one boring shall be taken at each end of the wall. For walls longer than 100 feet, borings shall be spaced no more than 100 feet apart. Wall borings shall be alternately control and complementary.

For culverts up to 50 feet in length, two borings will be required. For culverts longer than 50 feet, three borings will be required.

The preceding description is given as a guide and should not pre-empt sound engineering judgment. Likewise, the depth to which borings are carried may vary, depending on design requirements. Where utilities are present, the borings shall be accurately located no closer than 5 feet from the nearest edge of the utility.

1.2.5 Other Subsurface Exploratory Requirements

1.2.5.1 The additional subsurface explorations outlined below will be included as part of the boring program. Any laboratory test program on the recovered boring samples required by the Designer which is to be done at an outside testing laboratory shall be approved by MassDOT before any work is done. Upon completion of all boring operations, the samples shall be delivered to the MassDOT storage facilities or as directed by the Geotechnical Engineer. No soils and/or rock samples shall be removed from the referenced facilities without formal approval of the Geotechnical Engineer.

1.2.5.2 Under certain conditions, test pits may be needed to disclose certain features of existing structures that may be retained. Test pits shall be dug to establish the elevations of the top and bottom of the footing toe as well as the projection of the toe from the face of the abutment or wall. A minimum of two test pits shall be dug at each abutment, one approximately at each end of the abutment.

1.2.5.3 Exploratory probes will be taken, in conjunction with coring through concrete decks/abutments and horizontal cores, if required, for all abutments and walls which may be retained and for which accurate plans do not exist. These exploratory procedures are needed to determine the cross sectional geometry of the wall, such as width, batter and footing thickness, from which the re-use potential of the structure can be evaluated. Provisions for this type of investigation will be included as part of the boring program.

1.2.5.4 If a clay stratum or other compressive material is encountered, in-situ tests and/or undisturbed samples may be required for laboratory tests and analysis. Generally, this type of work is accomplished in the complementary boring program after the results of the control borings are reviewed.

1.2.6 Ground Water Observation Wellpoint

Ground water level as reported during a soil-test boring operation may not be accurate, since the water level in a test boring may not have had sufficient time to stabilize or may be affected by the use of water in the drilling process. When a study of the pilot or control borings indicates that an excavation in granular soil must be made below ground-water-level, observation wellpoints should be installed. Not more than one (1) observation wellpoint should be installed at a bridge except with prior approval of the Engineer. Unless otherwise directed, the bottom of the point shall be located approximately 10 feet below the proposed bottom of footing.

District personnel will measure and report water levels weekly for the first month and monthly thereafter, to the Engineer, unless more frequent readings are required. This information is to be

tabulated on the Sketch Plans and Construction Drawings (see Paragraph 2.7.3.3 for Sketch Plans and Paragraph 4.2.2.3 for Construction Drawings).

1.2.7 Inaccessible Boring Locations

Because of certain physical conditions, such as existing buildings, overhead wires, underground utilities, or because of problems with abutters, boring crews may have no access and certain borings specified for the structure cannot be taken. In such cases, the additional required borings may be included in the construction contract. This allows the successful bidder for the contract to take these additional borings without interference, since the project site must be cleared of all structures prior to commencing construction.

The additional borings shall be examined in the Bridge Section to determine if any changes will be required in the design of the foundations. The estimated linear footage of the borings and their cost shall be included in the Designer's estimate. The location of these additional borings shall be shown on the contract plans. It should be noted, however, that every possible effort should be made to obtain the required substructure information during the design stage.

1.2.8 Presentation of Sub-Surface Exploration Data

All borings, test pits, or seismic information that have been taken must appear on the plans, even though some of the borings may be exploratory. This is true even though some of the borings are taken for one site and later the line is changed so that new borings are required. It is mandatory that borings for both lines be shown on the plans.

The exact logs, as specified in the boring contract, must be shown on the plans. If the logs are transcribed on plan sheets, the transcriptions must copy all information exactly as it appears on the logs, including any abbreviations and misspellings. It is not necessary to show the blow count for driving the casing. Data relative to core recovery shall be shown on the boring log. It is the responsibility of the boring contractor to accurately describe the soils obtained with the sampler. In printing the description of soils, abbreviations shall be avoided.

The elevations of ground water level at the completion of the boring, unless otherwise specified on the log, shall be shown on the boring log. This elevation may be of great importance in order to determine water control measures for constructing the footing in the dry.

The bottom (top if on rock) of the proposed footing of each element of the substructure shall be plotted adjacent to the appropriate boring log. Borings shall be plotted in groups as they apply to substructure units for ready reference. In the case of a trestle, the bottom of each pile cap shall be shown on the boring logs.

The estimated tip or length of rock socket of piles or drilled shafts shall be plotted adjacent to the appropriate boring log.

Boring results shall be plotted to true relative elevation to a scale of not less than $\frac{1}{8}'' = 1' - 0''$. Deep borings may offset or show discontinuity only in the event that they cannot be completed in one column.

When posting boring logs on the plans the Designer shall post both depth and elevation at each change in strata.

1.3 HYDROLOGY AND HYDRAULICS

1.3.1 Introduction

The purpose of this section is to provide guidance regarding the performance of hydraulic studies for MassDOT bridges. These studies are required under the Federal Highway Administrations (FHWA) Federal Aid Policy Guide, 23 CFR 650A and the latest edition of *the AASHTO LRFD Bridge Design Specifications*, Article 2.6. The detail of hydraulic studies should be commensurate with the significance of the structure to the transportation network and with the risks associated with its failure. The guidelines contained herein are not intended to address all contingencies associated with the hydraulic design of bridge structures. In atypical situations, early consultation with the MassDOT Hydraulic Engineer is recommended.

1.3.2 Hydraulic Design Criteria

Hydraulic design criteria to be used for MassDOT bridges are enumerated below. These criteria are consistent with the content of Article 2.6 of the *AASHTO LRFD Bridge Design Specifications* and are subject to change when conditions so dictate as approved by MassDOT.

1. To the extent practicable, proposed bridges shall not cause any significant change in the affected waterway's existing flooding regime over the range of discharges considered.
2. Proposed bridges crossing waterway's which have established National Flood Insurance Program (NFIP) Special Flood Hazard Area (SFHA) Zone delineations, shall conform to applicable NFIP SFHA development performance standards as listed in Title 44 Code of Federal Regulations, Section 60, Part 3 [44 CFR 60 (3)]. In particular, proposed bridges crossing waterways with existing NFIP regulatory floodway delineations shall be designed to convey the waterway's base (100-year) flood discharge without causing any increase in waterway's base flood elevation (BFE) profile – or result in any unapproved increases to the width of the waterway's effective delineation- anywhere in the affected community. If a proposed bridge, when constructed, will not meet applicable NFIP SFHA development performance standards, the Designer shall file a Conditional Letter of Map Revision (CLOMR) and, if warranted, a Letter of Map Revision (LOMR) with the Federal Emergency Management Agency (FEMA) as specified in 44 CFR 60 (3).
3. The “No-Rise” Floodway Encroachment Review procedure outlined in Subsection 1.3.5 shall be used determine the degree to which proposed bridges crossing Regulatory Floodways meet applicable NFIP base floodplain development performance standards.
4. Proposed bridges crossing or located in close proximity to municipal or state owned dams under the jurisdiction of the Massachusetts Department of Conservation and Recreation (MassDCR) Office of Dam Safety or an NFIP-certified flood control levee under the jurisdiction of the US Army Corps of Engineers, New England District (USACOE NED) Office of Levee Safety shall be designed so as to avoid or minimize any adverse impact on structural integrity of the affected flood control system.
5. Preferably, piers and abutments shall be placed and oriented such as to minimize flow disruption and potential scour.

6. Bridge foundations shall be evaluated for scour vulnerability considering flood return frequencies up to 500 years. Pertinent scour evaluation guidelines are presented in Subsections 1.3.3, 1.3.4 and 1.3.6.
7. Optimally, new and replacement bridge superstructures should be configured so as to provide 2 feet of freeboard between the hydraulic design flood water surface elevation and the proposed superstructure low chord to allow for the passage of debris and ice. Where this is not feasible, the clearance should be established by the Designer based on a level of bridge flood damage protection approved by MassDOT. Proposed bridges spanning navigational channels regulated by the US Coast Guard (USCG) shall provide a navigational channel opening with vertical and horizontal clearances conforming to the effective USCG Section 10 Permit requirements.
8. Construction of proposed bridges shall have minimal impact to local and regional ecosystems and preserve the natural and beneficial values served by adjacent floodplains.
9. To the extent practicable, the design of new and replacement bridge waterway openings shall conform to applicable sections of 2011 Massachusetts Stream Crossing Standards. The Designer is referred to MassDOT Design of Bridges and Culverts for Wildlife Passage at Freshwater Streams (Reference 16) and FHWA Hydraulic Engineering Circular Number 26, "Culvert Design for Aquatic Organism Passage" (Reference 15), for more definitive design guidance.
10. Design choices should support costs for construction, maintenance and operation, including probable repair and reconstruction and potential liability that are affordable.
11. To address present uncertainties regarding the rate of sea level rise (SLR) along the New England coastline, Designers should apply a safety factor (in feet) equal to the proposed structure's expected service life (in years) times 0.012 feet/year to all tidal flood peak elevations used as bridge design parameters. This factor represents the average expected yearly rate of sea level rise (feet/year) determined for National Oceanographic and Atmospheric Administration (NOAA) Tide Gage Station Nos. 8443970 (Boston), 8447930 (Woods Hole) and 8449130 (Nantucket Island) (for pertinent background information, consult <http://tidesandcurrents.noaa.gov/gmap3/>).

1.3.3 Hydraulic Study Procedure

Although each individual crossing site is unique, the following procedure should be applied to MassDOT bridges unless indicated otherwise by MassDOT.

1.3.3.1 Data Collection. The purpose of this phase is to accumulate and refine the technical database required to support the hydrologic/hydraulic analysis to be performed within the project hydraulic study. The effort expended should be commensurate with the significance and complexity of the project. Pertinent data categories and sources are listed in Table 1.3.3-1 below.

1.3.3.2 Hydrologic Analysis

- A. Recommended hydrologic computational methods* include the following:

- USGS National Streamflow Statistics (NSS) Program (References 30, 31, and 32)
- NRCS Technical Releases 20 and 55 (References 18 and 20).
- USACOE HEC-HMS (Reference 24)

Other standard engineering methods may be used subject to approval by the MassDOT Hydraulic Engineer.

**Designers should use the USGS StreamStats in Massachusetts web application to develop required computational parameters*

B. In general, results from several methods should be compared (not averaged) so as to identify the discharges that best reflect local project conditions with the reasons documented.

C. At a minimum, the Designer should estimate the crossed waterway's 10-, 50-, 100-, and 500-year return frequency discharge peaks.

D. Hydraulic Design Flood Frequency. The hydraulic design flood frequency is the return frequency (in years) of the peak flood discharge (in cubic feet per second) the bridge waterway opening must safely convey. The overtopping flood and the hydraulic design frequency flood may vary widely depending on the grade, alignment and classification of the road and the characteristics of the water course and floodplain (see Section 1.3.4, Hydraulic and Scour Design Flood Selection Guidelines).

E. Designers performing hydraulic studies for proposed bridges at existing NFIP Regulatory Floodway crossings must use the crossed waterway's base (100-year) flood discharge established for the bridge location in the applicable NFIP Flood Insurance Study (FIS) to perform the required "No Rise" Floodway Encroachment Review (see Subsection 1.3.5)

F. The influence of the tide should be considered in all hydraulic adequacy/scour safety assessments performed for MassDOT bridges crossing tidal waterways. The Designer should note that flooding at tidal bridge locations could be the result of the concurrent occurrence of a riverine flood and a tidal flood surge generated by a single metrological event, such as a tropical hurricane or a "Northeaster" type coastal storm.

Accordingly, prior to employing such as "mixed population" tidal flood as a hydraulic or scour design flood event, the Designer should estimate the flood's joint annual exceedance probability to assure the flood's return frequency is appropriate for its intended use.

G. Presently, MassDOT employs the NOAA National Weather Service's Technical Paper 40 (TP-40), Rainfall Frequency Atlas for the United States (Reference 17) as the sole source of precipitation frequency data for rainfall-runoff simulation hydrologic computer applications such as NRCS TR-55 and TR-20. Use of TP-40 in this regard has become problematic in that the rain gage station record database from which regional TP-40 precipitation frequency mapping was formulated is over 52 years old, and clearly does not account for regional climatic changes that have evolved in the interim. To address this concern, NOAA's Hydrometeorological Design Studies Center (HDSC) is presently engaged in developing an interactive web application, Hydrologic Atlas 14, which will serve as TP-40's functional regional replacement. NOAA Atlas 14 NE is currently scheduled for release in September 2015. As an interim adaptation measure, Designers should use regional extreme precipitation frequency mapping recently developed by the NRCS-funded Northeast Regional Climate Center (NRCC) in 1993 (Reference 5) in place of TP-40 products currently in

use. The NRCS NRCC precipitation frequency database for Massachusetts is currently available as an interactive web application at: <http://precip.eas.cornell.edu/>

Table 1.3.3-1 Hydraulic Study - Potential Data Categories and Sources

<i>Data Category</i>	<i>Consideration Items</i>	<i>Data Sources</i>
<i>Regional Climatic</i>		
	Storm-related precipitation intensity, duration, and areal distribution	National Oceanographic and Atmospheric Administration (NOAA) National Weather Service (NWS) (http://www.nws.noaa.gov/) NOAA, Hydrometeorological Design Studies Center (HDSC) Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html). Northeast Regional Climate Center (NRCC), Extreme Precipitation Data Server (http://precip.eas.cornell.edu/)
<i>Service Watershed</i>		
	Recorded riverine or tidal flood data	United States Geologic Survey (USGS) StreamStats in Massachusetts (http://water.usgs.gov/osw/streamstats/massachusetts.html) NOAA http://tidesandcurrents.noaa.gov/ US Army Corps of Engineers, New England Division (USACOE NED) <u>Tidal Flood Profiles, New England Coastline</u> (Reference 28)
	Drainage Area, Main Channel Slope, mean basin elevation	Massachusetts Department of Geographic Information Systems (MassGIS) http://www.mass.gov/mgis/dtm.htm USGS http://water.usgs.gov/osw/streamstats/massachusetts.html
	Surficial soil types and distribution, subsurface soil profiles	Natural Resources Conservation Service (NRCS) http://www.ma.nrcs.usda.gov/technical/soils/index.html MassGIS http://www.mass.gov/mgis/sg24kstat.htm MassDOT Geotechnical Section
	Natural vegetative cover types, distribution, density	MassGIS http://www.mass.gov/mgis/ US Fish and Wildlife Service (USFWS) http://www.fws.gov/wetlands/
	Built land use types and density	MassGIS http://www.mass.gov/mgis/lus.htm
	Natural and built flood controls	MassGIS http://www.mass.gov/mgis/ USFWS http://www.fws.gov/wetlands/ USACOE NED http://www.nae.usace.army.mil/water/civilworks2.asp?mystate=MA USGS http://water.usgs.gov/osw/streamstats/massachusetts.html NFIP Community FIS
	Special Aquatic Resources- Wild and Scenic Rivers, endangered species habitat, cold water fisheries	US National Park Service, http://www.rivers.gov/rivers/ Massachusetts Department of Fish and Game (MassDFG) Natural Heritage & Endangered Species Program (NHESP) http://www.mass.gov/dfwele/dfw/nhesp/land_protection/biomap/biomap_home.htm

<i>Data Category</i>	<i>Consideration Items</i>	<i>Data Sources</i>
<i>Existing Site Conditions</i>		
Approach Waterway	Channel bed slope, sediment distribution, bed forms and stability	NRCS http://www.ma.nrcs.usda.gov/technical/soils/index.html USGS Stream Stability Assessments http://pubs.usgs.gov/of/1997/ofr97-558/ MassDOT project boring logs
	Channel bank sinuosity, horizontal and vertical stability	USGS StreamStats http://water.usgs.gov/osw/streamstats/massachusetts.html USGS Stream Stability Assessments http://pubs.usgs.gov/of/1997/ofr97-558/ NOAA http://www.nauticalcharts.noaa.gov/mcd/OnLineViewer.html
	Overbank floodplain width, topographic relief, surficial soil types and vegetative cover types and density	NRCS http://www.ma.nrcs.usda.gov/technical/soils/index.html MassGIS http://www.mass.gov/mgis/database.htm USFWS http://www.fws.gov/wetlands/ MassDOT Base Plan Survey
	Recreational/commercial vessel waterway usage	US Coast Guard (USCG) http://www.uscg.mil/d1/ Local Harbor Master
	Debris/ice floe conveyance issues	USACOE Cold Regions Research and Engineering Laboratory (CRREL) http://www.crrel.usace.army.mil USGS Stream Stability Assessments http://pubs.usgs.gov/of/1997/ofr97-558/ MassDOT NBIS 4D Database NFIP Community FIS
	Observed high water marks.	NOAA http://tidesandcurrents.noaa.gov/ USGS StreamStats http://water.usgs.gov/osw/streamstats/massachusetts.html MassDOT Base Plan Survey MassDOT NBIS Inspection 4D Data
Existing Structure	Observed/recorded tidal or riverine flood related damage	USGS Stream Stability Assessments http://pubs.usgs.gov/of/1997/ofr97-558/ MassDOT NBIS Inspection 4D Data Base MassDOT Scour Critical Coding Compliance Program (SCCCP) Databases NFIP Community FIS Community Highway Maintenance officials
	Superstructure geometry and condition	MassDOT NBIS Inspection 4D Data Base MassDOT Office of Plans and Records
	Substructure geometry and condition	MassDOT NBIS Inspection 4D Data Base MassDOT Office of Plans and Records

<i>Data Category</i>	<i>Consideration Items</i>	<i>Data Sources</i>
<i>Existing Site Conditions</i>		
Existing Structure	Roadway approach embankment geometry and condition	MassDOT NBIS Inspection 4D Data Base MassDOT Office of Plans and Records
	Existing scour countermeasure installation location and condition	USGS Stream Stability Assessments http://pubs.usgs.gov/of/1997/ofr97-558/ MassDOT NBIS Inspection 4D Data Base MassDOT SCCCPC Databases
<i>Site Environmental Regulatory Issues</i>		
	Local Hazardous Material Releases	Massachusetts Department of Environmental Protection (MassDEP) http://db.state.ma.us/dep/cleanup/sites/search.asp
	Ecosystem restoration	MassDFG, Division of Ecological Restoration (DER) http://www.mass.gov/dfwele/der/index.htm US EPA, National Estuaries Program, http://www.epa.gov/owow/estuaries/nep_home.html MassDOT Environmental Division
	Wildlife/Fish Migratory Accommodation	UMass Amherst, River and Stream continuity Project, http://www.streamcontinuity.org/index.htm MassDOT Environmental Division
	National Flood Insurance Program (NFIP) Special Flood Hazard Area (SFHA) Zone and Regulatory Floodway Delineations	Federal Emergency Management Agency (FEMA), http://www.fema.gov/national-flood-insurance-program MassDOT Hydraulic Section

1.3.3.3 Hydraulic Analysis

A. Computer Modeling. Water surface profile computer programs such as USACOE HEC-RAS (Reference 25) should be used to perform required bridge hydraulic design and scour safety computations, unless indicated otherwise by MassDOT.

B. Hydraulic performance for existing and proposed conditions under at least the 10-, 50-, 100-, and 500-year discharge peaks should be evaluated for all project alternatives considered in the bridge type selection process.

C. A “No Rise” Floodway Encroachment Review- performed in accordance with the guidelines presented in Subsection 1.3.5- is required for all proposed bridge replacement projects encroaching on effective NFIP Regulatory Floodway delineations.

D. At tidal crossing sites, the time dependent correlation between tide stage, discharge, and velocity must be evaluated. The detail of this hydrodynamic analysis should be commensurate with the functional significance of the structure, the capital risks associated with its failure, and the complexity of site hydrodynamics. In most cases, the use of the one dimensional hydrodynamic computer application UNET (Reference 29) nested within the USACOE HEC-RAS computer program (Reference 25) is recommended. However, complex, multi-span structures (esp. Interstate or numbered State Highway bridges) crossing major tidal waterways may warrant assembly and calibration of a two-dimensional finite element hydrodynamic model (References 8 and 26). Early consultation with the MassDOT Hydraulic Engineer to determine an appropriate level of project specific hydrodynamic analysis is recommended.

E. The Designer should use the crossed waterway’s 2-year flood as the design flood event for temporary construction-related structures that will be in place for one year or less. The Designer should use the waterway’s 5- year flood as the design flood event for temporary structures that will be in place for not more than two years- and the 10-year flood for temporary structures that will in place for more than two years.

1.3.3.4 Scour/Stability Analysis

A. Scour Safety assessments must be performed as part of all MassDOT bridge hydraulic studies. With the exception of estimating local abutment scour, these assessments should be performed in a manner consistent with the general guidelines set forth in the FHWA's Hydraulic Engineering Circular Nos. 18 (HEC-18), "Evaluating Scour at Bridges" (Reference 10), HEC-20, "Stream Stability at Highway Structures" (Reference 11), HEC-23, “Bridge Scour and Stream Instability Countermeasures (Reference 12), and HEC-25, “Highways in the Coastal Environment” (Reference 14). The Designer should use the “MassDOT Modified Froehlich Equation” presented in Subsection 1.3.6 to estimate local abutment scour depths.

B. There are many sources of uncertainty involved in the process of estimating potential scour depths along bridge foundations (see Reference 10, Sections 2.1 and 2.3.3). Accordingly, it is the responsibility of the Designer to use sound engineering judgment to evaluate the reasonableness of any computed scour depth with due consideration to build and natural armoring of the local streambed, the location and condition of existing scour countermeasures, the flood conveyance capacity and geometry of the existing waterway opening and upstream approach channel, the topographic relief and vegetated cover of the upstream overbank floodplain, present evidence of

scour (or lack thereof) along the existing structure’s foundation, and the scour resilience demonstrated by the existing structure’s foundation during major flood events that have occurred over the structure’s service life. If a scour estimate is determined to be unreasonable, the Designer should modify the original scour estimate to more closely correspond to observed or recorded site scour conditions. The basis for modifying a computed scour depth should be clearly documented within the project administrative record.

C. Pursuant to Part 3.2.9, Chapter 3 of this Bridge Manual, the Designer should use the guidelines set forth in Subsection 1.3.4 to determine appropriate return frequencies for the project scour design and scour check flood discharges. Nonetheless, the waterway’s incipient overtopping flood discharge should be used in the project scour safety analysis, if less than the scour design flood and/or the scour check flood discharges.

1.3.4 Hydraulic and Scour Design Flood Selection Guidelines

Table 1.3.4-1 below correlates the desired minimum design levels of flood discharge conveyance capacity and foundation scour safety to be provided a particular MassDOT highway bridge to the structure’s functional significance and the capital risk associated with its failure. The Designer shall note that FHWA regulations require the use of at least a 50-year return frequency flood as the hydraulic design flood event for all interstate highways.

Table 1.3.4-1: Hydraulic and Scour Design Flood Selection Guidelines

Highway Functional Classification	Hydraulic Design Flood Return Frequency (Years)	Scour Design Flood Return Frequency (Years)	Scour Check Flood Return Frequency (Years)
Interstate, or Limited Access Highways	100	200	500
Rural Principal Arterial	50	100	200
Rural Minor Arterial	50	100	200
Rural Collector, Major	25	50	100
Rural Collector, Minor	10	25	50
Rural Local Road	10	25	50
Urban Principal Arterial	50	100	200
Urban Minor Arterial Street	25	50	100
Urban Collector Street	10	25	50
Urban Local Street	10	25	50

1.3.5 Guidelines for "No-Rise" Encroachment Reviews For Proposed MassDOT Bridges Crossing NFIP Regulatory Floodway Delineations

The essential NFIP Regulatory Floodway development performance standard, as described in 44 CFR, Section 60.3(d)(3), is presented below.

“A community shall prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in any increase in flood levels within the community during the occurrence of the base flood discharge.”

Bridge Designers should use the following procedure to determine project encroachment impact on existing NFIP Regulatory Floodway delineations.

1. Obtain a copy of input files for the waterway's currently effective NFIP hydraulic model from FEMA archives. Pertinent contact information is presented below. A fee will be assessed for providing this data.

FEMA Project Library
3601 Eisenhower Avenue
Alexandria, VA 22304-6425
Fax: (703) 751-7391

Note: If the input data files for the effective hydraulic model are not available, the Designer must assemble and calibrate an alternate model. Alternate model cross sections should be developed at the waterway locations at which cross sections were acquired for the NFIP effective model. The alternate model's cumulative reach lengths should match those of the effective model as closely as possible. The alternate model calibration runs should be performed using FIS peak discharge and flood elevation data as up and down stream boundary conditions- and with each cross section's effective flow area set at the currently effective floodway delineation's horizontal limits. The calibration process should yield an alternate model that reproduces the "with floodway" elevations provided in the community FIS Floodway Data Table within 0.10 ft.

2. Develop a Duplicate Effective Model by uploading the currently effective model's input data into the most current release of USACOE HEC-RAS. Calibrate the same as required to reproduce the currently effective BFE profile shown in the FIS within 0.10 ft. The reach domain for the Duplicate Effective Model should extend sufficiently upstream and downstream from the project location to assure the upstream and downstream limits of flood profiles generated by this model "tie into" the currently effective NFIP BFE profile without significant elevation discontinuities (+/- 0.25 feet).
3. Develop an Existing Conditions Model by revising the Duplicate Effective Model to correct any legacy computer coding errors and incorporating any relevant cross section data reflecting changes in the floodplain that may have occurred since the original effective model was developed (without the proposed project in place). The Regulatory Floodway limits at any new model cross sections should be determined by interpolation of FIS Floodway Table data and DFIRM mapping. The model's cumulative reach lengths should match those of the currently effective model. The base flood simulations performed with the Existing Conditions Model will provide modified effective model BFE and Regulatory Floodway elevation profiles reflecting current existing base floodplain conditions at the proposed project site.
4. Develop a Proposed Condition Model by modifying the Existing Conditions Model to account for base floodplain feature alterations expected as a result of project implementation. This model must use the currently effective regulatory floodway widths at every model cross section, and have cumulative reach lengths that match those of the currently effective model. BFE and Regulatory Floodway elevation profiles are then generated with the Proposed Conditions Model and compared to those of the Existing Conditions Models. For compliance with 44CFR 60.3(d)(3), the Proposed Conditions BFE

and Regulatory Floodway elevation profiles must indicate a “no-rise” impact on the same Existing Conditions profiles at every model cross section location.

1.3.6 MassDOT Modified Froehlich Local Abutment Scour Equation

FHWA HEC-18 (Reference 10) recommends the use of adapted versions of the HIRE or Froehlich equations to generate estimates of local abutment scour (see Reference 10, Section 8.6). The HEC-18 HIRE equation was developed from scour depth measurements recovered by USACOE personnel at the end of spur dikes along the Mississippi River. This equation is only valid when the ratio of projected abutment length (L') to flow depth (Y_a) is greater than 25. The vast majority of MassDOT bridges does not meet this criterion, and therefore require the use of the HEC-18 Froehlich equation, which is presented below.

$$Y_s/Y_a = 2.27 K_1 K_2 (L' / Y_a)^{0.43} Fr^{0.61} + 1 \quad (\text{Equation 1})$$

where:

K_1 = coefficient for abutment shape

K_2 = coefficient for angle of embankment to flow

L' = the length of abutment projected normal to flow, ft (m)

Y_a = average depth of flow in the floodplain = A_e / a' , ft (m)

A_e = the flow area of the approach cross section obstructed by the embankment, ft² (m²)

Fr = the Froude Number = $V_e / (g Y_a)^{0.5}$

V_e = Q_e / A_e , m/s (ft/s)

Q_e = the flow obstructed by the abutment and approach embankments, ft³/s (m³/s)

Y_s = scour depth, m (ft)

The HEC-18 Froehlich equation differs significantly from the original Froehlich equation form in that it includes the expression “...+1” shown on the right side of Equation 1. The presence of this expression essentially increases the predicted scour depth by the estimated depth of the approach overbank flow. The FHWA authors of HEC-18 elected to insert the same as a factor of safety (F.S.) to “force” the original Froehlich equation to yield computational results that fit a curve that “enveloped” 98% of all the experimental data examined during the equation’s development (See Reference 10, Section 8.6.1).

The original Froehlich equation form itself was derived from dimensional and regression analysis of data generated in a limited number of laboratory simulations conducted in carefully controlled experimental flumes provided with level, uniformly graded fine sand beds (see Reference 10, Section 8.2.1). Each scour simulation involved exposure of small scale rectangular representations of bridge abutments and approach banks projecting from the flume’s side walls to a “flood” flow maintained at a constant discharge rate and depth over the flume’s length throughout the simulation duration. Subsequent analysis of the simulation results indicated that the overbank flow intercepted by an abutment’s approach embankment and returned to the main channel at the abutment’s upstream corner was the governing factor in the local abutment scour process – and that the probable local scour depth associated with a given simulation discharge was directly proportional to the length of the abutment’s approach bank.

These determinations were seriously flawed in that, unlike an experimental laboratory simulation flume, overbank flow rates and depth distributions of natural waterways are highly variable, non-

uniform phenomena. The overbank discharge ultimately returned to the main channel at the abutment can be significantly influenced by the abutment's shape, the discharge conveyed, cross sectional shape and horizontal alignment of the main channel at the abutment, channel and bank sediment characteristics, and the overbank floodplain topography and vegetative cover density. As a consequence, a local abutment scour depth estimated with the original Froehlich equation for a particular bridge should be considered a conservative approximation of the structure's actual potential local abutment scour risk.

Given the inherently conservative predictive nature of the original Froehlich equation form, MassDOT has determined that inclusion of the "...+1" FHWA safety factor (as shown on the right side of Equation 1) in any Froehlich equation solution unacceptably increases the solution's overall uncertainty- and collaterally diminishes the value of the equation as a tool for objectively assessing scour risk along bridge abutment foundations.

Accordingly, MassDOT recommends use the following modified version of Equation 1 to generate estimates of local abutment scour depths at MassDOT bridge and highway structure locations statewide.

$$Y_s/Y_a = 2.27 K_1 K_2 (L' / Y_a)^{0.43} Fr^{0.61} \quad (\text{MassDOT Modified Froehlich Equation})$$

Like all scour depths computed in accordance with HEC-18 guidelines, the Designer should apply sound engineering judgment to evaluate the reasonableness of local scour depths computed with MassDOT Modified Froehlich Equation, giving due consideration to all other relevant factors, as outlined in Paragraph 1.3.3.4 above.

1.3.7 Hydraulic Study References

1. American Association of State Highway and Transportation Officials (AASHTO), LRFD Bridge Design Specifications, Fifth Edition, 2010
2. AASHTO, Model Drainage Manual, March 2005
3. AASHTO, Highway Drainage Guidelines, Fourth Edition, 2007.
4. Chow, V. T. Open-Channel Hydraulics, McGraw-Hill, New York, 1959
5. Cornell University, Northeast Regional Climate Center (NRCC), Atlas of Precipitation Extremes for the Northeastern United States and Southeastern Canada, May 1993.
6. Deliman, P. N., Ruiz, C. E., Manwaring, C. T., and Nelson, E. J., Watershed Modeling System Hydrological Simulation Program; Watershed Model User Documentation And Tutorial, ERDC/EL SR-02-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS., 2002.
7. Federal Emergency Management Agency (FEMA), Guidelines and Specifications for Flood Hazard Mapping Partners, April 2003.
8. Federal Highway Administration (FHWA), FESWMS-2DH, Finite Element Surface Water Modeling System: Two Dimensional Flow in a Horizontal Plane, User's Manual, 1996.

9. FHWA, Hydraulic Engineering Circular Number 11, Design of Rip Rap Revetment, HEC-11, March 1989
10. FHWA, Hydraulic Engineering Circular Number 18, Evaluating Scour at Bridges, HEC-18, April 2012.
11. FHWA, Hydraulic Engineering Circular Number 20, Stream Stability at Highway Structures, HEC-20, April 2012
12. FHWA, Hydraulic Engineering Circular Number 23, Bridge Scour and Stream Instability Countermeasures, Volumes 1 and 2, September 2009
13. FHWA, Hydraulic Design Series Number 7 (HDS-7), Hydraulic Design Of Safe Bridges FHWA-Hif-12-018, April 2012
14. FHWA, Hydraulic Engineering Circular Number 25, Highways In The Coastal Environment Hydraulic Engineering Circular No. 25, June 2008
15. FHWA, Hydraulic Engineering Circular Number 2, Culvert Design for Aquatic Organism Passage, October 2010
16. MassDOT, Design of Bridges and Culverts for Wildlife Passage at Freshwater Streams, 2010
17. National Oceanographic and Atmospheric Administration (NOAA), National Weather Service Weather (NWS), Technical Paper No. 40 (TP-40), Rainfall Frequency Atlas of the United States, May 1961.
18. Natural Resources Conservation Service (NRCS), WinTR-20 Computer Program for Project Formulation Hydrology, Version 1.11, 2009.
19. NRCS, Section 4- Hydrology, National Engineering Handbook, 1972.
20. NRCS, WinTR-55, Urban Hydrology for Small Watersheds, Version 1.00.1, February 2013.
21. Neill, C. R., Guide to Bridge Hydraulics, Roads and Transportation Association of Canada, 2001 Edition.
22. Parker, G.W., Bratton, L., and Armstrong, D.S., Stream stability and scour assessments at bridges in Massachusetts: U.S. Geological Survey Open File Report 97-588, 53 p., 2 CD-ROMs, 1997.
23. Rosgen, David, Applied River Morphology, Wildland Hydrology, Pagosa Springs, Colorado, 1996.
24. US Army Corps of Engineers (USACOE), Hydrologic Research Center, HEC-HMS, Hydrologic Modeling System, Version 3.5, August 2010.

25. USACOE, Hydrologic Research Center, HEC-RAS, River Analysis System, Version 4.1, January 2010.
26. USACOE Research and Development Center, HEC-SMS, "Surface Water Modeling System", Version 10.0.7, 2008.
27. USACOE, Engineer Waterways Experiment Station, Coastal Engineering Research Center Shore Protection Manual, 4th ed., 2 vols., 1984
28. USACOE, New England Division (NED), Tidal Flood Profiles, New England Coastline, September 1988
29. USACOE, UNET, One Dimensional Unsteady Flow through a Full Network of Open Channels, Report CPD-66, Version 3.1, 1996.
30. U.S. Geologic Survey (USGS), The National Streamflow Statistics Program: A Computer Program For Estimating Streamflow Statistics For Ungaged Sites: U.S. Geological Survey Techniques and Methods Report TM Book 4, Chapter A6, 2006.
31. USGS, Estimating Peak Discharges of Small Rural Streams in Massachusetts, Open File Report 80-676, 1982
32. Water Resources Council, Guidelines for Determining Flood Flow Frequency, Bulletin 17B, Washington, D. C., June 1977.