COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF TRANSPORTATION
STANDARD SPECIFICATIONS

for Highways and Bridges

2026 Edition

DIVISION III

massDOT
Massachusetts Department of Transportation
Highway Division

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DIVISION III:
MATERIALS SPECIFICATIONS

SECTION M: MATERIALS

Approval and Acceptance

All materials must be approved prior to incorporation in the work. Approval of materials shall be in accordance with the applicable requirements of Subsection 5.03: Conformity with Plans and Specifications and Section 6.00: Control of Materials. Materials may be approved at the source of manufacture or at the project site. Information regarding the origin, composition and/or manufacture of any material shall be furnished if requested by the Engineer.

Approval and acceptance of any material intended for use in the work of the Department is contingent upon the particular material conforming to a designated specification. All questions relating to materials will be resolved by RMS or its duly authorized representative.

The Department maintains a QCML of commonly used materials that meet these specifications.

Sampling and Testing

Materials will be sampled and tested in accordance with the designated Standards. The applicable edition of the Standard shall be as stipulated in Subsection 1.03: Defined Terms.

Sampling of materials will be performed by Department personnel, personnel authorized by the Department or personnel under Department supervision.

Certification

Materials accepted on certification as stipulated in Subsection 6.01: Source of Supply and Quality fall into two categories:

- Those accepted on a particular certification and sampling frequency.
- Those accepted on certification alone.

A listing of materials falling into one or the other of the above categories will be furnished upon request to RMS.

SECTION M1: SOILS AND BORROW MATERIALS

M1.00.0: General

All Soils and borrow materials shall conform to the requirements of the specifications as designated hereinafter.

M1.01.0: Ordinary Borrow

Ordinary Borrow shall consist of a material satisfactory to the Engineer and not specified as gravel borrow, sand borrow, special borrow material or other particular kind of borrow.

This material shall have the physical characteristics of soils designated as group A-1, A-2-4 or A-3 under AASHTO M 145. It shall have properties such that it may be readily spread and compacted for the formation of embankments.

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate may be homogeneously blended with the borrow material up to an addition rate of 10 % by mass in areas that will not be exposed, providing the AASHTO M 145 physical characteristics are maintained.

M1.02.0: Special Borrow

Special Borrow shall consist of one of the following:

- A native in-situ soil that is classified under AASHTO M 145 as A-3, or that portion of A-1 and A-2 with less than 12% passing the No. 200 sieve as determined by AASHTO T 311.
- A crushed rock, either obtained from ledge excavation on the project or other approved sources, that meets the following requirements:

Type	Percentage
Percent of wear LA abrasion test	50% Maximum
Plasticity Index	6% Maximum

Table M1.02.0-1: Gradation Requirements for Special Borrow

Sieve Designation	Percent Passing
6 in.	100
2 in.	90-100
No. 4 mesh	20-65
No. 200 mesh	0-12

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate may be blended with either special borrow material outlined above. An addition rate of 10% by mass in areas where the borrow will not be exposed will be allowed, providing the physical characteristics are maintained. The PGA will be blended so as to produce a homogeneous borrow material.

M1.03.0: Gravel Borrow

Gravel Borrow shall consist of inert material that is hard, durable stone and coarse sand, free from loam and clay, surface coatings, and deleterious materials.

Gradation requirements for gravel shall be determined by AASHTO T 311 and shall conform to the following:

Table M1.03.0-1: Gradation Requirements for Gravel Borrow

Sieve Designation	Percent Passing
½ in.	50-85
No. 4	40-75
No. 50	8-28
No. 200	0-10

Maximum size of stone in gravel shall be as follows:

Material Type	Size
M1.03.0 Type a	6 in. largest dimension
M1.03.0 Type b	3 in. largest dimension
M1.03.0 Type c	2 in. largest dimension
M1.03.0 Type d	1.5 in. largest dimension

The gradation for Gravel Borrow for Bridge Foundations shall have at least 70% passing the ¾-in. sieve.

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate may be homogeneously blended with the processed gravel up to an addition rate of 10% by mass, providing the subbase material will not be exposed. The resulting blend will meet the physical requirements of gravel borrow types a, b, c and d specified above.

M1.03.1: Processed Gravel for Subbase

This specification covers the quality and gradation for subbase material of crusher run gravel.

Gravel shall consist of inert material that is hard, durable stone and coarse sand, free from loam and clay, surface coatings and deleterious materials.

The coarse aggregate shall have a percentage of wear, by the Los Angeles Abrasion Test, of not more than 50.

The gradation shall meet the following requirements:

Table M1.03.1-1: Gradation Requirements for Processed Gravel for Subbase

Sieve Designation	Percent Passing
3 in.	100
1 ½ in.	70-100
¾ in.	50-85
No. 4	30-60
No. 200	0-10

The approved source of bank-run gravel material shall be processed by mechanical means. The equipment for producing crushed gravel shall be of adequate size and with sufficient adjustments to produce the desired materials. The processed material shall be stockpiled in such a manner to minimize segregation of particle sizes. All processed gravel shall come from approved stockpiles.

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate may be homogeneously blended with the processed gravel up to an addition rate of 10% by mass, providing the subbase material will not be exposed. The resulting blend will meet the physical requirements of processed gravel specified above.

M1.04.0: Sand Borrow

Sand Borrow shall consist of clean inert, hard, durable grains of quartz or other hard durable rock, free from loam or clay, surface coatings and deleterious materials. The allowable amount of material passing a No. 200 sieve as determined by AASHTO T 11 shall not exceed 10% by weight.

The maximum particle size for Sand Borrow shall be as follows:

Material Type	Size
M1.04.0 Type a	¼ in
M1.04.0 Type b	⅜ in.

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate will be allowed at an addition rate of 10% mass to type b sand borrow. This addition is allowed providing the material will not be exposed, that the blended material is homogeneous and that the physical requirements specified for Sand Borrow above are maintained.

M1.04.1: Sand Borrow for Subdrains

Sand for use in subdrain installations shall conform to the requirements of M1.04.0: Sand Borrow with the following grading limitations, as determined by AASHTO T 311:

Table M1.04.1-1: Gradation Limitations for Sand Borrow for Use in Subdrains

Sieve Size	Minimum Percent by Weight Passing Through	Maximum Percent by Weight Passing Through
½ in.	100	
⅜ in.	85	100
No. 4	60	100
No. 16	35	80
No. 50	10	55
No. 100	2	10

M1.05.0: Loam

Loam shall be fertile, friable soil obtained from naturally well-drained areas or shall be the product of a commercial sand and gravel processing facility. It shall be uncontaminated by salt water, foreign matter, or substances harmful to plant growth. Loam shall be free of debris rocks, clods, and any other extraneous matter. Loam for Roadsides shall have no material greater than 1 in. in diameter. Loam for Lawns shall have no material greater than ½ in. in diameter.

Loam shall have the following mechanical analysis:

Table M1.05.0-1: Gradation Requirements for Loam

Sieve Size	Percent Passing
No. 10	85-100
No. 40	35-85
No. 200	10-35
<20 µm	<5

Testing shall be on material that has passed the No. 10 sieve. Loam shall contain 4% to 10% organic matter as determined by the loss on ignition of oven-dried samples. Lawn areas shall have an organic content of at least 4%. Organic content for lawn areas shall be at least 4%; for woody plantings, organic content shall be 7% to 10%. Salinity (electrical conductivity) shall be less than 0.1 S/m as determined by a 1:2 (by volume) soil-to-water mix. Salt test samples shall not be oven-dried. The acidity range of the Loam shall be pH 5.5 to 7.0.

The Contractor shall provide testing submittals as follows:

- One 25-lb representative sample per source of loam
- For sources providing >1,000 yd^3, one additional 25-lb representative sample for each 1,000 yd^3 unit of soil

In addition, five random representative 25-lb samples of on-site stockpiles of delivered loam shall be collected and packaged in the presence of the Engineer.

The Contractor shall deliver samples to testing laboratories and shall have the testing report sent directly to the Engineer.

Testing and analysis will be at the Contractor's expense. Soil samples shall be dry. Tests for particle gradation, organic content, and pH shall be performed by an Agricultural Experiment Station testing laboratory or other testing laboratory approved by the Engineer. Soil analysis tests shall show recommendations for soil additives to correct soils deficiencies, and for additives necessary to accomplish particular planting objectives noted. University of Massachusetts Agricultural Extension Service methods for soil and soil additive analysis shall be used.

No Loam shall be delivered to the site until the review and approval of loam test results by the Engineer.

M1.06.0: Compost

The Contractor shall submit for approval a written list of all vendors of manufactured compost that will be used on the project, including locations of compost facilities and feedstock materials. All vendors shall submit certified results of regular periodic testing by an approved testing facility. Certification shall be per US Composting Council Seal of Testing Assurance (STA) Program.

In addition, the Contractor shall provide representative 1-gallon samples from each proposed source for testing and analysis. The Contractor shall deliver samples to testing laboratories and shall have the testing report sent directly to the Engineer. Compost tests shall be performed by STA-certified laboratory. (https://www.compostingcouncil.org/page/CertifiedLabs)

Compost shall be a well-decomposed humus material derived from the aerobic decomposition of biodegradable matter, free of viable weed seeds and other plant propagules (except airborne weed species), foreign debris such as glass, plastic, etcetera and substances toxic to plants. Compost shall be suitable for use as a soil amendment and shall support the growth of ornamental nursery stock and turf establishment. Compost shall be in a shredded or granular form and free from hard lumps.

Food and agriculture residues, animal manure are acceptable source materials. Biosolids and peat are not acceptable as source materials.

Composted material with an unpleasant odor, such as that of ammonia or fecal material shall be rejected by the Engineer.

Compost shall have the following properties:

Table M1.06.0-1: Compost Properties by Type of Compost

Parameter	Units	Type 1 Organic Amendment to Loam	Type 2 Compost Blanket and Compost for Modified Rock	Type 3 Compost Filter Berm	Type 4 Sediment Barrier Media
pH	pH Scale Range	6.0-8.5	6.0-8.5	6.0-8.5	5.0-8.5
Soluble Salt Concentration (Electrical Conductivity)	dS/m	Max 10	Max 5	Max 5	Max 10
Moisture Content	%, wet weight	30-60	30-60	30-60	< 60
Organic Matter Content	%, dry weight	30-65	25-65	25-65	25-100
Particle Size % passing a selected mesh size, dry weight basis	3 in.	-	100	100	100
	2 in.				99-100
	1 in.	-	90-100	90-100	-
	¾ in.	-	65-100	70-100	
	⅜ in.	95	-	-	0-50
	¼ in.	95	0-75	30-75 (no more than 60% passing in high rainfall/flow rate situations)	-
	Particle length	Max. 6 in.	Max. 6 in.	Max. 6 in.	Max. 2 in.
Stability (Carbon Dioxide Evolution Rate)	mg CO2-C per g OM per day	< 4	< 4	< 4	< 8
Maturity (plant bioassay)	%, germination and vigor	> 80 / 80	> 80 / 80	N/A	N/A
Physical Contaminants (Man-made inert materials)	%, dry weight	< 0.5% (0.25% film plastic)	< 0.5 (0.25 film plastic)	< 0.5 (0.25 film plastic)	< 0.5 (0.25) film plastic)

M1.08.0: Impervious Soil Borrow

Impervious Soil shall have the physical characteristics of one of the following, under AASHTO M 145:

- A-4, A-5, A-6, A-7 soils;
- A-2 soils containing more than 20% by weight passing the No. 200 sieve; or

- Peats and other highly organic soils.

The Impervious Soil shall be reasonably free of stumps, brush, and stones larger than 3 in. in diameter.

Material excavated near salt water to be used as impervious soil will be tested for salt content. The maximum soluble salt index shall be 100.

M1.09.0: Reclaimed Pavement Borrow Material

Reclaimed Pavement Borrow material shall consist of crushed asphalt pavement and/or crushed cement concrete, and gravel borrow meeting M1.03.0: Gravel Borrow. The material shall be free of loam, clay, and deleterious materials such as brick, reinforcing steel, wood, paper, plaster, lathing, and building rubble, etc.

The coarse aggregate shall have a percentage of wear not greater than 50 as measured by the Los Angeles Abrasion Test.

Gradation requirements shall be determined by AASHTO T 311 except the material shall not be oven dried. It shall be air dried, fan dried at low speed, or other low temperature heat so as not to liquefy the asphalt or cause the asphalt to adhere to the sieves. Water used for the No. 200 sieve analysis shall be cold tap water.

The gradation shall meet the following requirements:

Table M1.09.0-1: Gradation Requirements for Reclaimed Pavement Borrow

Sieve Designation	Percent Passing
3 in.	100
1 ½ in.	70-100
¾ in.	50-85
No. 4	30-60
No. 50	8-24
No. 200	0-10

The portion of materials passing the No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6. The reclaimed pavement borrow shall be compacted to a minimum of 95% of AASHTO T 180 proctor density. Liquid limits shall be determined by AASHTO T 90.

Reclaimed pavement borrow material shall be processed by mechanical means and blended to form a homogeneous material. The equipment for producing crushed material shall be of adequate size and have sufficient adjustments to produce the desired materials. Blended materials that are stockpiled for more than 3 months shall be reworked to a uniform material and retested prior to use however, the Engineer may require additional testing any time the materials appear excessively hard, wet and/or segregated. The processed materials shall be stockpiled in such a manner as to minimize segregation of particle sizes. All reclaimed pavement borrow material shall come from approved sources and stockpiles.

The amount of combined crushed asphalt pavement and crushed cement concrete shall not exceed 50% by volume as determined by visual inspection, and/or by laboratory tests required by the Engineer.

M1.10.0: Pavement Milling Mulch

Pavement milling mulch shall consist of recently milled asphalt concrete pavement. The milled material shall meet the following gradation requirements as determined by AASHTO T 311:

Table M1.10.0-1: Gradation Requirements for Pavement Milling Mulch

Square Opening Sieve	Percent Passing by Weight
1 ½ in.	100
1 in.	85-100
½ in.	10-98
No. 4	0-70
No. 200	0-12

SECTION M2: AGGREGATES AND RELATED MATERIALS

M2.01.0: Crushed Stone

Crushed stone shall consist of one or the other of the following materials:

- Durable crushed rock consisting of the angular fragments obtained by breaking and crushing solid or shattered natural rock, and free from a detrimental quantity of thin, flat, elongated* or other objectionable pieces. A detrimental quantity will be considered as any amount in excess of 15% of the total weight.
- Durable crushed gravel stone obtained by artificial crushing of gravel boulders or fieldstone with a minimum diameter before crushing of 8 in.

*Thin or elongated pieces are defined as follows: Thin stones shall be considered to be such stones whose average width exceeds 4 times their average thickness. Elongated stones shall be considered to be such stones whose average length exceeds 4 times their average width.

The crushed stone shall be reasonably free from clay, loam or deleterious material and not more than 1.0% of satisfactory material passing a No. 200 sieve will be allowed to adhere to the crushed stone. Where crushed stone is to be used for surfacing, this requirement shall be not more than 0.5% of satisfactory material passing a No. 200 sieve.

The crushed stone shall have a maximum 45% wear as determined by the Los Angeles Abrasion Test (AASHTO T 96).

The crushed stone shall be uniformly blended according to the grading requirements for the respective stone sizes shown in Table M2.01.0-1.

Table M2.01.0-1: Tabulation of Stone Sizes Percent by Weight Passing Through

Square Opening Sieve	**M2.01.1 & M2.02.2**	**M2.01.3**	**M2.01.4**	**M2.01.5**	**M2.01.6**
	1 ½ in.	**1 ¼ in.**	**¾ in.**	**½ in.**	**⅜ in.**
2 ½ in.					
2 in.	100				
1 ½ in.	95-100	100			
1 ¼ in.		85-100			
1 in.	35-70		100		
¾ in.	0-25	10-40	90-100		
⅝ in.				100	
½ in.		0-8	10-50	85-100	100
⅜ in.			0-20	15-45	85-100
No. 4			0-5	0-15	20-50
No. 8				0-5	0-15
No. 16					0-5

M2.01.7: Dense Graded Crushed Stone for Sub-base

This Specification covers the quality and gradation requirements for a sub-base material combining crusher-run coarse aggregates of crushed stone (trap only, meeting M2.01.0,1), and fine aggregates uniformly premixed with a predetermined quantity of water.

Coarse aggregate shall consist of hard, durable particles of fragments of stone. Materials that break up when alternately frozen and thawed or wetted and dried shall not be used.

Coarse aggregate shall have a percentage of wear, by the Los Angeles test, of not more than 45.

Fine aggregate shall consist of natural or crushed sand.

The composite material shall be free from clay, loam or other plastic material, and shall conform to the following grading requirements:

Table M2.01.7-1, Gradation Requirements for Dense Graded Crushed Stone for Sub-base

Sieve Designation	Percentage by Weight Passing Square Mesh Sieves
2 in.	100
1 ½ in.	70-100
¾ in.	50-85
No. 4	30-55
No. 50	8-24
No. 200	3-10

Testing shall be in accordance with AASHTO T 311.

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate will be allowed at a maximum addition rate of 10% mass, providing the blended material is homogeneous and the physical requirements of dense graded crushed stone are maintained.

M2.01.8: Processed Glass Aggregate

PGA shall be manufactured from an approved supplier of crushed cullet. The material shall consist of recycled glass food or beverage containers free of debris such as paper, metals, fabrics, toxins, clay, loam, or other materials that would be associated with the glass recycling process. A maximum of 5% mass of the material may be produced from china dishes, ceramics, plate glass or other glass products. The material will have a nominal aggregate size of ⅜ in. and meet the following gradation requirements.

Table M2.01.8-1: Gradation Requirements for Processed Glass Aggregate

Sieve Designation	Percent by Mass Passing
⅜ in.	100
No. 4	70-100
No. 8	35-88
No. 16	15-40
No. 50	4-12
No. 200	0-5

The percent wear as determined by the Los Angeles Abrasion Test, Class C or D will be a maximum of 40%.

M2.02.0: Riprap

Riprap shall be sound, durable rock which is angular in shape. Rounded stones, boulders, sandstone or similar soft stone or relatively thin slabs will not be acceptable. Each stone shall weigh not less than 50 lb and at least 75% of the volume shall consist of stones weighing not less than 500 lb each. The remainder of the stones shall be so graded that when placed with the larger stones the entire mass will be compact.

M2.02.1: Rockfill

Stone for rockfill shall be sound, angular in shape, free from structural defects and comparatively free of chemical decay. From 50% to 70% of the stones shall weigh not less than 500 lb each and remainder shall weigh not less than 50 lb each.

M2.02.2: Dumped Riprap

Stone used for dumped riprap shall be hard, durable, angular in shape, resistant to weathering and shall meet the gradation requirement specified. Neither breadth nor thickness of a single stone should be less than one-third its length. Rounded stone or boulders will not be accepted.

Stone shall be free from overburden, spoil, shale, and organic material and shall meet the following gradation requirement specified:

Table M2.02.2-1: Gradation Requirements for Dumped Riprap

Size of Stone (lb)	Maximum Percent of Total Weight Smaller Than Given Size
400	100
300	80
200	50
*25	10

*No more than 5% by weight shall pass a 2 in. sieve.

Each load of riprap shall be reasonably well graded from the smallest to the maximum size specified. Stones smaller than the specified 10% size and spalls will not be permitted in an amount exceeding 10% by weight of each load.

Control of gradation will be by visual inspection. The Contractor shall provide at the locations specified a mass of rock of at least 5 tons meeting the gradation for the class specified. The sample at the construction site may be a part of the finished riprap covering. At the quarry, an additional sample shall be provided. These samples shall be used as a frequent reference for judging the gradation of the riprap supplied. Any difference of opinion between the Engineer and the Contractor shall be resolved by dumping and checking the gradation of two random truckloads of stone. Mechanical equipment, a sorting site and labor needed to assist in checking gradation shall be provided by the Contractor at no additional cost to the Department.

M2.02.3: Stone for Pipe Ends

Stone for pipe ends shall be sound, durable rock which is angular in shape. Rounded stones, boulders, sandstone or similar stone or relatively thin slabs will not be acceptable. Each stone shall weigh not less than 50 lb not more than 125 lb and at least 75% of the volume shall consist of stones weighing not less than 75 lb each. The remainder of the stones shall be so graded that when placed with the larger stones the entire mass will be compact.

M2.02.4: Modified Rockfill

Modified rockfill shall consist of hard, durable angular shaped stones which are the product of the primary crushing of a stone crusher. Rounded stone, boulders, sandstone and similar soft stone or relatively thin slabs will not be acceptable.

Stone shall be free from overburden, spoil, shale, organic material and meet the following gradation requirements:

Table M2.02.4-1: Gradation Requirements for Modified Rockfill

Size of Stone (in.)	Passing Percentages
8	95-100
4	0-25
2 ½	0-5

M2.03.0: Granite Rubble Block

Rubble pavement blocks shall be granite, basically light grey in color, free from seams and other structural imperfections or flaws which would impair its structural integrity, and of a smooth splitting appearance. Natural color variations characteristic of the deposit from which the paving blocks are obtained will be permitted.

Rubble pavement blocks shall be not less than 4 in. nor more than 12 in. in length, not less than 3.5 in. nor more than 4.5 in. in width and depth. Rubble blocks shall be rectangular in shape with one good face.

Opposite faces of rubble blocks shall be approximately parallel and adjoining faces shall be approximately at right angles to each other. Blocks shall be dressed so that they may be laid with 1 in. to 1.5 in. joints.

M2.04.0: Aggregate for Sand Blasting

Aggregate to be used for sand blasting shall be an approved material currently used in the industry. It shall be graded to produce the profile requirements of the material being cleaned and shall meet the applicable requirements of OSHA, EPA, and DEP.

M2.05.0: Stone Screenings

Stone Screenings shall be that product from a stone crusher that completely passes a No. 4 sieve and not less than 40% passes a No. 8 sieve.

M2.06.0: Slope Paving

Stone for slope paving shall be sound, angular in shape and free from structural defects. Each stone shall have one reasonably flat face and a thickness perpendicular to the face of not less than 6 in., which shall be the least dimension of the stone.

Approximately 60% of the stones shall vary from 2 ft^3 to 3 ft^3 each in volume and the remainder of the stones shall each be from 1 ft^3 to 2 ft^3 in volume.

M2.06.1: Slope Paving Under Bridge

Quarry stone shall consist of granite or other similar durable stone. The exposed surface of the stones shall range from roughly square to rectangular shape, with split or quarry face finish and uniform in color. The stones shall be from 12 in. to 28 in. long, 10 in. to 14 in. wide and from 3 in. to 6 in. thick.

M2.06.2: Channel Paving

Stones for Channel Paving and Grouted Channel Paving shall be sound, approved quality angular blocks, as nearly rectangular or cubical as practicable. Rounded stones or relatively thin slabs will not be acceptable. At least 75% of the volume shall consist of stones weighing at least 200 lb each. The remainder of the stones shall be so graded that when placed with the larger stones a compact mass will result.

SECTION M3: ASPHALTIC MATERIALS

M3.00.0: General

Asphaltic materials (also referred to as bituminous materials) include liquid asphalts as well as Hot Mix Asphalt (HMA) mixtures and other related materials. All asphaltic materials shall conform to the requirements of the specifications as designated hereinafter.

The sampling of liquid asphalt materials shall be in accordance with AASHTO R 66.

The following procedure shall be followed in obtaining liquid asphalt samples from pressure distributors or tankers used for the transport of liquid asphalt materials:

- Distributors and tankers shall be equipped with approved sampling valves. The sampling valves on tankers shall be installed in the rear bulkhead approximately ⅓ of the height from the bottom. The sampling valves on pressure distributors may be located in the side of the tank somewhere in the middle third of the tank depth.
- At least 1 gal of material shall be drained off through the sampling valve and discarded before the sample is obtained.
- Sample containers shall be new, clean and sealed with a tight-fitting cap. Washing of sample containers with solvents or water will not be permitted.

M3.01.0: Performance Graded Asphalt Binder

Performance Graded Asphalt Binder (PGAB) delivered to a project or to an HMA plant must be accompanied by a Bill of Lading (BOL) signed by the asphalt binder Supplier's authorized representative in accordance with AASHTO R 26. Shipments of material not accompanied by a BOL will not be accepted for use in the work.

The PGAB Supplier and the Contractor shall perform random Quality Control (QC) sampling and testing of PGAB as specified in 450.65: Quality Control Sampling and Testing Requirements, Part F(1). The Contractor shall furnish, to the Engineer, the PGAB Supplier's BOL for each truckload of asphalt binder shipped to the project or HMA plant. The Contractor shall also submit to the Engineer the Supplier's Certificate of Compliance (COC) along with copies of the Certificate of Analysis (COA) showing the certified AASHTO M 320 test results for each Supplier Lot of PGAB. The COA shall meet the requirements of AASHTO R 26. The Contractor shall maintain a copy of the COA for each Lot of PGAB used, with a copy attached to each sample obtained for testing.

The Contractor shall assist the Engineer in obtaining random Department Acceptance samples of PGAB from the HMA plant in accordance with AASHTO R 66 and as specified in 450.74: Acceptance Sampling & Testing, Part C. Each sample shall be labeled with the PGAB grade, Supplier source and Lot number, sampling location, quantity represented, project name, plant, date, and the sampling inspector. When the PGAB is used for HMA production under Subsection 450: Hot Mix Asphalt Pavement the sample shall be obtained from an in-line sample valve located between the asphalt tanks and mixing chamber at a sampling location downstream of all additive injection ports.

The Engineer will test the Department Acceptance samples for verification of the PGAB grade. The material shall conform to the specification requirements for the applicable performance grade as specified herein. Material not conforming to specification requirements shall be subject to corrective action, production suspension, rejection, or removal as determined by the Engineer.

The blending of binder of different grades or binder from different Suppliers at the HMA plants is strictly prohibited without the Engineer's approval. Contractors may switch to another approved source of binder, upon written notification to the Engineer, and by certifying that the tank to be utilized has been drained to an un-pumpable condition. The binder tanks at the HMA production facility shall be managed in a manner which prevents contamination. The Contractor shall not switch binder suppliers in the middle of a production Lot as defined in 450.20: Quality Assurance, Part B.

Contractors who modify, blend PG binders, or add additives to the PGAB at the HMA production facility will be reclassified as a Supplier and shall be required to certify the binder in accordance with AASHTO R 26.

A copy of the COA for each Lot shall be provided in accordance with AASHTO R 26. The data reported shall meet the requirements of the specific binder specification:

- For AASHTO M 320 – Table 1
- For AASHTO M 332 – Table 1
- For Crumb Rubber Modified Asphalt ASTM D6114 – Table 1

M3.01.1: Standard Asphalt Binder Grade

The asphalt binder for HMA mixtures shall be a PGAB which meets the specification requirements of AASHTO M 320. PGAB shall be provided by an Approved Supplier in accordance with AASHTO R 26. Approved Suppliers shall be listed on the QCML.

The standard PGAB Grade of PG64-28 shall be used.

M3.01.2: Modified Asphalt Binder Grades

When specified by the contract documents, the PGAB shall be modified in accordance with the following:

M3.01.2.A: Polymer Modified Asphalt Binder

The polymer modified asphalt binder shall be a PGAB which meets the specification requirements of AASHTO M 332, however "E" grades will not be subject to the $J_{nr\text{diff}}$ difference requirement. PGAB shall be provided by an approved Supplier in accordance with the AASHTO R 26. The modified PGAB Grade of PG64E-28 shall be used.

M3.01.2.B: Crumb Rubber Modified Asphalt Binder

The modified binder shall be in accordance with ASTM D6114, Type II. Virgin PGAB for the crumb rubber modified asphalt shall be a PG 58-28 or PG 64-28 provided by an approved Supplier in accordance with the AASHTO R 26. The grade selected shall be based on laboratory testing by the asphalt-rubber Manufacturer.

The granulated rubber shall be vulcanized rubber product from the ambient temperature processing of scrap, pneumatic tires. The granulated rubber shall meet the gradation found in Table M3.01.2-1.

Table M3.01.2-1: Crumb Rubber Gradation

Sieve Size	Percent by Weight Passing
No. 10	100
No. 16	90-100
No. 30	25-100
No. 80	0-20

The use of crumb rubber of multiple types from multiple sources is acceptable provided that the overall blend of crumb rubber meets the gradation requirements. The length of the individual rubber particles shall not exceed ⅛ in. The rubber shall be certified by the crumb rubber Manufacturer.

The percent of crumb rubber shall be a minimum of 15% by weight of binder. The temperature of the asphalt shall be between 350°F and 400°F at the time of addition of the granulated crumb rubber. The asphalt and crumb rubber shall be combined and mixed together in a blender unit and reacted in the distributor for a period of time as required by design. The temperature of the asphalt-rubber mixture shall be above 325°F during the reaction for a period of one hour.

M3.01.3: Asphalt Binder Grade for Recycled Asphalt Materials

For any HMA mixture containing recycled asphalt materials, a binder that is softer than the standard asphalt binder shall be utilized in the mixture to account for the amount and stiffness of the recycled binder in accordance with Table M3.01.3-1.

If greater than 25% Reclaimed Asphalt Pavement (RAP) or any quantity of Recycled Asphalt Shingles (RAS) are used in an asphalt mixture, the virgin PGAB grade when blended with the RAP binder shall meet the binder grade specified by the project. The resulting final PGAB grade shall be in accordance with Table M3.01.3-1. Only PGABs meeting the requirements of AASHTO M 320 or M 323 will be used.

The type and amount of virgin asphalt binder to be used in the HMA mixture shall be included as part of the Laboratory Trial Mix Formula (LTMF). The Contractor shall submit certified test results from an AASHTO accredited laboratory showing the testing of the individual binders and the blending.

Table M3.01.3-1: PGAB Grades for HMA Containing RAP/RAS

Amount of RAP in Mixture	Virgin PGAB Grade	Resulting PGAB Grade
≤25% RAP by Weight of Mixture	Project Specified Grade	Project Specified Grade
>25% to 40% RAP by Weight of Mixture	Follow AASHTO M 323 Appendix X1	Project Specified Grade
≤5% RAS by Weight of Mixture	Follow AASHTO PP 78	Project Specified Grade

M3.01.4: Warm Mix Asphalt Additive

All HMA shall be modified using a WMA additive. The WMA additive shall be listed on the QCML. No WMA foaming technology which requires the mechanical injection of steam or water into the liquid asphalt will be permitted.

For HMA placed on bridge decks, the WMA additive shall not be used to lower the mixing and compaction temperatures. The mixing and compaction temperatures specified for the binder prior to addition of the WMA additive shall be used.

The WMA additive must be compatible with polyphosphoric acid modified binders, polymer modified binders, and anti-stripping agents. The WMA additive shall be introduced in accordance with the Manufacturer's dosing rates and approved blending methods.

The HMA mixture design shall incorporate the requirements of AASHTO R 35 Appendix X2: Special Mixture Design Considerations and Practices for Warm Mix Asphalt (WMA). Laboratory mixing and compaction temperatures shall be reduced per the WMA Manufacturer's recommendations, however, the optimum laboratory compaction temperature for unmodified asphalt binders shall be less than 260°F. Target laboratory mixing and compaction temperatures shall be submitted to the RMS for review prior to performing a mix design.

When the asphalt binder is modified with the WMA additive at the HMA plant, all WMA additive equipment shall be fully automated and integrated into the plant controls and shall record actual dosage rates on the plant printouts. The Contractor's QSM shall provide mixture production and placement alterations due to the WMA additive and shall incorporate the modification of asphalt binders when the WMA additive is blended with the asphalt binder at the plant. This plan shall specifically address WMA metering requirements, tolerances and other QC measures.

M3.01.5: Asphalt Anti-Stripping Additive

An anti-stripping additive may be required in a HMA mixture to increase the resistance of the asphalt binder coating to stripping in the presence of water. An anti-stripping additive may be a liquid anti-strip or hydrated lime.

The Engineer may verify the effectiveness of the anti-strip used in a HMA mixture. When added at the dosage rate recommended by the Manufacturer to a HMA mixture showing moisture susceptibility, the anti-strip shall cause an improvement to the mixture's moisture susceptibility. This shall be determined by testing specimens with and without the anti-strip additive in accordance with AASHTO T 324. If the antistrip does not show an improvement in the moisture susceptibility the additive will not be permitted for use.

The Manufacturer shall certify that the material is in accordance with this specification. The Manufacturer shall submit a COC for each Lot in accordance with Division 1 Section 6.0. The COC shall also include the:

- Brand name and designation.
- Composition or description of the anti-strip additive.
- Manner in which the material will be identified on the containers.

M3.01.5.A: Hydrated Lime

The hydrated lime for HMA shall conform to the requirements of AASHTO M 303.

M3.0.5.B: Liquid Anti-Strip

The anti-strip Manufacture shall submit product documentation, including the recommended dosage rate, to RMS for approval. Approved anti-strip additives shall be listed on the QCML.

Anti-stripping additives shall be an organic chemical compound free from inorganic mineral salts or inorganic mineral soaps. The anti-strip additive shall be chemically inert to asphalt binder and shall not appreciably alter the specified characteristics of the asphalt binder. When blended with asphalt binder, it shall be stable and withstand storage at a temperature of 400°F for extended periods without loss of effectiveness.

M3.01.6: Asphalt Release Agents

Approved asphalt release agents shall be tested in accordance with AASHTO T 383 and be listed on the QCML. The asphalt release agent shall not be detrimental to the HMA and shall not dissolve asphalt binder when applied to the truck bed. Dilution by diesel or other petroleum products will not be permitted.

M3.02.0: Cutback Asphalts

These materials shall be blends of asphalt cements and suitable solvents. They shall be homogeneous, free from water and conform to the requirements of AASHTO M 81 for the rapid curing type and AASHTO M 82 for the medium curing type.

M3.03.0: Asphalt Emulsions

Approved asphalt emulsions suppliers will be on the QCML.

M3.03.1: Anionic Emulsified Asphalt

These materials shall conform to the requirements of AASHTO M 140. Anionic emulsion used for tack coat shall be grade RS-1h.

When HMA paving takes place between November 1st and March 31st the use of RS-1 is acceptable.

When supplied in 5-gallon buckets the anionic emulsion used for tack coat shall be grade RS-1.

M3.03.2: Cationic Emulsified Asphalt

This material shall conform to the requirements of AASHTO M 208. Cationic asphalt emulsion used for tack coat shall be grade CRS-1h.

When HMA paving takes place between November 1st and March 31st the use of CRS-1 is acceptable.

When supplied in 5-gallon buckets the cationic emulsion used for tack coat shall be grade CRS-1.

M3.03.3: Polymer Modified Emulsified Asphalt

This material shall conform to the requirements of AASHTO M 316. Polymer modified asphalt emulsion used for tack coat shall be grade CRS-1P.

M3.05.0: Pavement Crack Sealers and Joint Adhesives

The material shall pour readily and penetrate a ¼ inch pavement crack or joint to a depth of at least 1 inch when the application temperature of the fully reacted mixture is 350°F and the air temperature is 35°F or higher.

The material, when placed with conventional field installation equipment, shall readily melt to a pumping consistency after being heated to 400°F for a maximum of 2 hr. The mixture shall remain

in a pumping consistency when the temperature of the field installation equipment is reduced to the normal operating temperature range of 300°F to 350°F.

M3.05.1: Chemically Modified Crumb Rubber Crack Sealer

Chemically modified crumb rubber crack sealer (CMFR) shall be a polymer modified performance graded asphalt binder which also incorporates crumb rubber and fibers.

- The asphalt binder shall consist of a blend of performance graded asphalt binder and crumb rubber that meets the following specifications:
    - The SBS and Rubber modified binder shall meet a grade of PG64E-28 with a JnR3.2 < 0.5.
    - The PGAB utilized in the CMCR shall be a PG58-28 and shall comply with the requirements of M3.01.0: Performance Graded Asphalt Binder.
    - The modified binder shall contain a minimum of 3% SBS polymer.
    - The modified binders shall contain a minimum of 7% 80 mesh crumb rubber.
    - The asphalt binder supplier shall provide testing for the base asphalt binder and modified asphalt binder in accordance with AASHTO M 320 and M 332.
- Fiber reinforcing materials shall be short-length polyester fibers having properties listed in Table M3.05.1-1.
- The asphalt-fiber blend shall consist of 8% fiber by weight of asphalt binder.
- Blending of the fibers with the modified asphalt binder shall be in accordance with the recommendations of the manufacturer of the fibers.

Table M3.05.1-1: Polyester Fiber Requirements

Characteristic	Test Method	Requirement
Length (See Note 1)		0.25 in.+0.02
Elongation at break	ASTM D2256	38%
Melting point	ASTM D3418	> 475°F
Crimps per inch	ASTM D3937	None
Cross Section		Round
Denier	ASTM D1577	4.5 Nominal dpf
Tensile Strength	ASTM D2256	>70,000 psi
Diameter		0.0008 in. (See Note 2)
Specific Gravity	ASTM D792	1.32 to 1.40

Note 1: At temperature ranging from ambient to maximum finished product mix temperature.
Note 2: Subject to normal variations.

M3.05.2: Hot Applied Crack Sealer

This sealer shall meet the requirements of ASTM D6690 Type II. Products shall be listed on the QCML.

M3.05.3: Asphalt-Fiber Crack Sealer

Asphalt-fiber crack sealer shall be a performance graded asphalt binder blended with fibers.

- The PGAB utilized in the asphalt-fiber crack sealer shall be a PG64-28 and shall comply with the requirements of M3.01.0: Performance Graded Asphalt Binder.
- Fiber reinforcing materials shall be short-length polyester fibers having properties listed in Table M3.05.1-1.
- The asphalt-fiber blend shall consist of 7-8% fiber by weight of asphalt binder.

M3.05.4: Hot Applied Pavement Joint Adhesive

This material shall be a hot applied asphaltic product designed to adhere and seal HMA construction joints. The material shall meet the requirements of Table M3.05.4-1.

Table M3.05.4-1 Hot Applied Pavement Joint Adhesive

Property	Test Method	Requirement
Flash Point	AASHTO T 48	> 410°F
Ductility (See Note 1)	AASHTO T 51	> 300 mm
Ductility (See Note 2)	AASHTO T 51	> 300 mm
Softening Point	AASHTO T 53	> 170°F
Viscosity (See Note 3)	ASTM D3236	4,000 – 10,000 cp
Asphalt Compatibility	ASTM D5329	Pass
Cone Penetration (See Note 1)	ASTM D5329	60 – 100 mm
Resilience (See Note 1)	ASTM D5329	> 30 %
Tensile Adhesion (See Note 1)	ASTM D5329	> 500 %

Note 1: Test to be conducted at 77°F.
Note 2: Test to be conducted at 39°F.
Note 3: Test to be conducted at 400°F

The manufacturer must supply all current product literature, including technical data sheets and Safety Data Sheets (SDS). This shall include information relevant to the material's use, its limitations, material properties, instructions for storage, mixing, and application.

As part of the evaluation, the Department will review the submitted laboratory test results. Qualified products will be listed on the QCML.

M3.05.5: Preformed Bituminous Joint Filler for Concrete

This material shall be a non-extruding and resilient bituminous type preformed expansion joint filler. It shall conform to the requirements of AASHTO M 213.

M3.06.0: Hot Mix Asphalt

M3.06.1: General

All HMA mixtures shall meet the requirements of the Superpave volumetric mix design system as well as the following. Asphalt mixtures shall be composed of the following:

- Mineral aggregate
- Mineral filler (if required)

- PGAB

The use of recycled materials shall be at the Contractor's option in accordance with these specifications. And as permitted, recycled materials shall be limited to:

- RAP
- RAS
- PGA

Each HMA pavement course placed shall be compromised of one of the mixture types listed in Table 450.10-1.

Approval of HMA mix designs shall be defined as the Department's prequalification and verification of the mix design to ensure conformance with the materials requirements, design targets, and testing limits specified herein. The Contractor shall be responsible for selecting and placing approved HMA mix designs that meet the desired HMA properties, per the contract's specified application.

M3.06.2: Aggregate for Hot Mix Asphalt

M3.06.2.A: Coarse Aggregate

The coarse mineral aggregate shall be clean, hard, durable, crushed rock consisting of the angular fragments obtained by breaking and crushing shattered natural rock, reasonably free from thin and/or elongated pieces, free from dirt or other objectionable materials. It shall be surface dry and shall have a moisture content of not more than 0.5 percent after drying. Aggregates from multiple sources of supply shall not be mixed or stored in the same stockpile.

M3.06.2.B: Fine Aggregate

The fine aggregate shall consist of one of the following:

- 100% Natural Sand.
- 100% Stone Sand.
- A blend of sand and stone screenings, the proportions of which shall be approved by the Engineer.
- A blend of natural sand and stone sand.

Natural sand shall consist of inert, hard, durable grains of quartz or other hard, durable rock, free from topsoil or clay, surface coatings, organic matter or other deleterious materials.

Stone sand shall be a processed material prepared from stone screenings to produce a consistently graded material conforming to specification requirements.

Stone screenings shall be the product of a secondary crusher and shall be free from dirt, clay, organic matter, excess fines or other deleterious material.

M3.06.2.C: Consensus Properties

Aggregates utilized in HMA mixtures, including RAP if used in the mixture, shall be tested for conformance with the Consensus Property requirements outlined in AASHTO M 323 Sections 6.2 to 6.6 and Table M3.06.2-1.

Table M3.06.2-1: Aggregate Consensus Property Requirements

Traffic Level	Design ESALs (Millions) (See Note 1)	Fractured Faces, Coarse Aggregate % Minimum (See Note 2)		Uncompacted Content of Fine Aggregate % Minimum		Sand Equivalent % Minimum	Flat and Elongated % Maximum (See Note 2)
		All Courses (except Base Course)	Base Course	All Courses (except Base Course)	Base Course		
1	<0.3	55/--	--/--	-- (See Note 4)	--	40	--
2	0.3 to <10	85/80 (See Note 3)	60/--	45	40	45	10
3	≥10	95/90	80/75	45	40	45	10

Note 1: The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
Note 2: This criterion does not apply to #4 nominal maximum size mixtures.
Note 3: 85/80 denotes that 85% of the coarse aggregate has one fractured face and 80% has two or more fractured faces.
Note 4: For #4 nominal maximum size mixtures designed for traffic levels below 0.3 million ESALs, the minimum Uncompacted Void Content is 40.

M3.06.2.D: Source Properties

The coarse aggregate utilized in asphalt mixtures shall be clean, crushed rock consisting of the angular fragments obtained by breaking and crushing shattered natural rock. It shall be free from dirt or other objectionable materials. The coarse aggregate, including RAP if used in the mixture, shall be tested for conformance with the requirements indicated in Table M3.06.2-2. The specific gravity of each aggregate component shall be determined as specified in Table M3.06.2-3 below.

To determine the bulk specific gravity of RAP aggregate the method outlined in FHWA Publication Number FHWA-HRT-11-021 “Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice” shall be used. The following excerpt is the method to be followed:

If the source of RAP is known and original construction records are available, the bulk specific gravity (BSG) value of the virgin aggregate from the construction records may be used as the BSG value of the RAP aggregate. However, if original construction records are not available, the recommended procedure for estimating BSG of the RAP aggregate is a simple three-step process as follows:

1. Determine the maximum theoretical specific gravity of the RAP mixture, G_{mm}^{RAP}, according to AASHTO T 209.
2. Calculate the effective specific gravity of the RAP aggregate, G_{se}^{RAP}, using G_{mm}^{RAP}, the asphalt content of the RAP mixture (P_b) and an assumed asphalt specific gravity (G_b) as follows:

$$G_{se}^{RAP} = \frac{100 - P_b}{{100}/{G_{mm}} - {P_b}/{G_b}}$$

Where: $G_b = 1.030$

3. The asphalt absorption, P_{ba}, shall be assumed to be 0.5%. Use this value to estimate the BSG of the RAP aggregate, G_{sb}^{RAP}, from the calculated G_{se}^{RAP}.

$$G_{sb}^{RAP} = {G_{se}^{RAP}}\Big/{\left(\frac{P_{ba} \times G_{se}^{RAP}}{100 G_B} + 1\right)}$$

Table M3.06.2-2: Aggregate Source Property Requirements

Source Property Test	Test Method	Limit
Toughness	AASHTO T 96	Maximum Loss < 30%
Soundness (See Note 1)	AASHTO T 104	Maximum Loss < 10%
Deleterious Materials	AASHTO T 112	Maximum Permissible < 0.5%

1. 5 cycles using Sodium Sulfate solution.

Table M3.06.2-3: Aggregate Specific Gravity Test Method

Aggregate Type	Test Method
Coarse	AASHTO T 85
Fine	AASHTO T 84 or ASTM D7370
Mineral Filler	AASHTO T 100
RAP	From FHWA-HRT-11-021

M3.06.2.E: Recycled Asphalt Pavement

RAP shall meet the requirements of M3.06.2: Aggregate for Hot Mix Asphalt, Paragraphs C and D as well as the following. RAP shall consist of the material obtained from state highways or streets by crushing or milling existing HMA pavements. This material shall be transported to the HMA production facility yard and processed through an appropriate crusher so that the resulting material will contain no particles larger than the maximum aggregate size of the HMA mixture in which it will be used.

The RAP shall be stockpiled on a free draining base and kept separate from the other aggregates. RAP stockpiles shall be covered by a framed structure which prevents the intrusion of water but also allows the flow of air to promote drying of the stockpile. The structure shall be capable of storing a minimum of 500 tons of RAP. The RAP stockpiles shall have a reasonably uniform gradation from fine to coarse and shall not be contaminated by foreign materials. The RAP used in

the HMA mix production shall have a moisture content such that the final HMA contains no more than 0.5% moisture.

The proportion of RAP to virgin aggregate shall be in accordance with Table M3.06.2-4 and M3.01.3: Asphalt Binder Grade for Recycled Asphalt Materials.

Table M3.06.2-4: Maximum Allowed RAP Content by Mix Type

Mix Type	Maximum Amount of RAP Allowed (%)	Maximum Amount of RAS Allowed (%) (see Note 1)
Friction Course (OGFC)	0	0
Friction Course (ARGG)	10	0
Surface Course	15	0
Leveling Course	15	5
Bridge Surface Course	15	0
Bridge Protective Course	15	0
Intermediate Course	40	5
Base Course	40	5

Note 1: When RAS is used in HMA mixtures containing RAP or other recycled materials, the RAS will be considered as part of the overall allowable weight of recycled materials in the mixture.

M3.06.2.F: Recycled Asphalt Shingles

RAS shall consist of only the by-product materials obtained from the roofing shingle manufacturing process. Post-consumer shingle waste and re-roofing shingle scrap will not be allowed. The Contractor or the plant shall provide certification from the roofing shingle manufacturer that RAS material provided is a by-product of the shingle manufacturing process. This material shall be transported to the HMA production facility yard and processed through an appropriate crusher so that the resulting material will contain no particles larger than 0.5 in. The material shall be stockpiled on a free draining base and kept separate from the other aggregates. The material contained in the processed stockpile shall not be contaminated by foreign materials. RAS stockpiles shall be covered in a manner that prevents the intrusion of water but also allows the flow of air.

RAS may be used in HMA leveling courses, HMA intermediate courses, and HMA base courses at a maximum rate of 5% by weight. When RAS is used in HMA mixtures containing RAP or other recycled materials, the RAS will be considered as part of the overall allowable weight of recycled materials in the mixture.

M3.06.2.G: PGA

The use of PGA meeting the requirements of M2.01.8: Processed Glass Aggregate may be added at a maximum addition rate of 10% by weight. This addition will only be allowed in base and intermediate mixtures. PGA in mixes containing RAP will be considered as part of the overall allowable mass of RAP in the mix. If PGA is used in the mix, a separate aggregate bin shall be used and the use of lime as an anti-stripping agent shall be required.

M3.06.3: Performance Graded Asphalt Binder

The PGAB utilized in the HMA mixture shall be specified by the Contract and shall comply with the requirements of M3.01.0: Performance Graded Asphalt Binder.

M3.06.4: Hot Mix Asphalt Mixture Design

The Contractor shall be responsible for development of all HMA mixture designs. All HMA surface courses, intermediate courses, base courses, leveling courses, bridge surface courses, and bridge protective courses shall be supported by volumetric mixture designs using the Superpave mixture design system. All Superpave HMA designs shall be developed in accordance with the following AASHTO standards, as modified herein:

- AASHTO M 323
- AASHTO R 35
- AASHTO T 312

OGFC and ARGG mixtures shall be designed in accordance with Subsections M3.06.4: Hot Mix Asphalt Mixture Design, Parts G and H, respectively.

M3.06.4.A: Development of LTMF

The Contractor shall develop and submit a LTMF for each HMA mixture type, which is to be proposed as a JMF, a minimum of 60 days prior to HMA production. Each LTMF shall be submitted with supporting documentation and adequate amount of blended aggregate material and PGAB in order to verify the LTMF.

Once verified by the Department, the LTMF may become the JMF for a project. Two or more JMFs per HMA type may be approved for a particular plant, however, only mixture conforming to one JMF is permitted to be produced and placed on any given day.

M3.06.4.B: Estimated Design Traffic

The estimated traffic level to be used for HMA mix designs shall be specified by the contract. The traffic level shall be expressed in Equivalent Single Axle Loads (ESALs) for the design travel lane over a 20-year period in million 18-kip ESALs.

M3.06.4.C: Specific Gravity Requirements

The individual aggregate specific gravities shall be included with the LTMF. The Contractor shall provide samples of each aggregate material a minimum of 60 days prior to production for each LTMF to the Department for verification specific gravity of each stockpile.

M3.06.4.D: Superpave Aggregate Gradation Requirements

The combined aggregate blend for each Superpave HMA mixture shall conform to the Gradation Control Point requirements specified in Table M3.06.4-1. The results of the selected optimum design aggregate structure shall be plotted on a 0.45 power chart and included with the LTMF.

The combined aggregate gradation shall be classified as coarse-graded when it passes below the Primary Control Sieve (PCS) control point as defined in Table M3.06.4-2. All other gradations shall be classified as fine graded.

When a Superpave Surface Course - 19.0 (SSC - 19.0) is specified in the contract, the LTMF aggregate gradation shall provide a fine-graded HMA mixture as defined in Table M3.06.4-2.

M3.06.4.E: Gyratory Compaction Criteria

Each asphalt mixture shall be designed and controlled during production using an approved gyratory compactor which meets the requirements of AASHTO T 312. Compaction shall be in accordance with the requirements of AASHTO T 312. The density of each HMA mixture shall be evaluated at the initial number of gyrations ($N_{initial}$), the design number of gyrations (N_{design}), and the maximum number of gyrations (N_{max}). The gyratory-compacted specimens for each LTMF shall meet the density requirements specified in Table M3.06.4-3 below.

M3.06.4.F: Superpave Volumetric Design Requirements

Each Superpave HMA mixture shall be designed in accordance with the volumetric mixture design specifications contained in AASHTO M 323 and procedures contained in AASHTO R 35, as modified herein. Each HMA mixture LTMF shall be tested for conformance with the following volumetric properties:

- Air Voids at N_{design} (V_a)
- Voids in the Mineral Aggregate at N_{design} (VMA)
- Voids Filled with Asphalt at N_{design} (VFA)
- Fines to Effective Asphalt Ratio ($P_{0.075}$ / P_{be})

The volumetric property test results shall be submitted with the LTMF for each Superpave HMA mixture. The required minimum or maximum criteria for each of the volumetric property tests are specified in Table M3.06.4-3, Table M3.06.4-4, and Table M3.06.4-5.

Table M3.06.4-1: Superpave Aggregate Gradation Control Points

	Nominal Maximum Aggregate Size – Control Points (% Passing)											
Sieve	#4		⅜ in.		½ in.		¾ in.		1 in.		1 ½ in.	
(in.)	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2											100	
1.5									100		90	100
1							100		90	100		90
¾					100		90	100		90		
½	100		100		90	100		90				
⅜	95	100	90	100		90						
#4	90	100		90								
#8			32	67	28	58	23	49	19	45	15	41
#16	30	55										
#30												
#50												
#100												
#200	6	13	2	10	2	10	2	8	1	7	0	6

Table M3.06.4-2: Gradation Classification

PCS Control Point for Mixture Nominal Maximum Aggregate Size (% Passing)					
Nominal maximum aggregate size	⅜ in.	½ in.	¾ in.	1 in.	1 ½ in.
Primary Control Sieve	#8	#8	#4	#4	⅜ in.
PCS control point, % passing	47	39	47	40	47

Table M3.06.4-3: Superpave Asphalt Mixture Design Laboratory Compaction Requirements

Traffic Level	**Design ESALs (millions)**	**Number of Gyrations**			**Percent Density of G_{mm} from Asphalt Mixture Gyratory Specimen**		
		N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
1	<0.3	6	50	74	≤91.5	96.0	≤98.0
2	0.3 to <10	7	75	115	≤90.5	96.0	≤98.0
3	≥10	8	100	160	≤89.0	96.0	≤98.0

Table M3.06.4-4: Superpave Volumetric Requirements

	Nominal Maximum Aggregate Size					
	#4	⅜ in.	½ in.	¾ in.	1 in.	1 ½ in.
P_b	LTMF Value					
G_{mb}						
G_{mm}						
V_a	4.0					
VMA	≥17.0	≥16.0	≥15.0	≥14.0	≥13.0	≥12.0
VFA	See Table M3.06.4-5					
Dust/P_{be} (See Note 1)	0.9 to 2.0	0.6 to 1.2	0.6 to 1.2	0.6 to 1.2	0.6 to 1.2	0.6 to 1.2
Mixture Temp. (See Note 2)	Unmodified PGAB ≤325°F Modified PGAB ≤350°F					

Note 1: If the aggregate gradation passes beneath the PCS Control Point specified in M 323 Table 5, the dust-to-binder ratio range may be increased from 0.6-1.2 to 0.8-1.6 at the Engineer's discretion.

Note 2: Laboratory mixing and compaction temperatures shall be based on the PGAB COA. When additives such as WMA, polymers, and rubber are introduced the mixing and compaction temperatures may be modified from the PGAB COA. Temperature modifications shall be recommended by the binder Supplier and approved at the Engineer's discretion.

Table M3.06.4-5: Superpave Asphalt Mixture VFA Requirements

Traffic Level	**Design ESALs (millions)**	**Voids Filled with Asphalt (VFA) Based on Nominal Maximum Aggregate Size**					
		#4	⅜ in.	½ in.	¾ in.	1 in.	1 ½ in.
1	<0.3	70 to 80	70 to 80	70 to 80	70 to 80	67 to 80	64 to 80
2	0.3 to <10	65 to 78	65 to 78	65 to 78	65 to 78	65 to 78	64 to 78
3	≥10	75 to 78	73 to 76	65 to 75	65 to 75	65 to 75	64 to 75

M3.06.4.G: OGFC Design Requirements

Each OGFC asphalt mixture shall be designed in accordance with AASHTO R 113, as modified herein. The combined aggregate gradation shall conform to Table M3.06.4-6 and the mixture shall conform to Table M3.06.4-7.

- OGFC-P will utilize asphalt binder meeting the requirements of M3.01.2: Modified Asphalt Binder Grades, Part A.
- OGFC-AR will utilize asphalt binder meeting the requirements of M3.01.2: Modified Asphalt Binder Grades, Part B.

Table M3.06.4-6: OGFC Aggregate Gradation Control Points

Sieve	⅜ in. OGFC Control Points (% Passing)	
In.	Min	Max
1	-	-
¾	-	-
½	100	-
⅜	85	100
#4	20	30
#8	5	15
#200	0	4

Table M3.06.4-7: OGFC Mixture Requirements

Property	Requirement
N_{des}, gyrations	50
P_b, % (Polymer)	≥6.5
P_b, % (Asphalt Rubber)	≥7.5
V_a, %	18 to 22
VCA_{mix}, %	$<VCA_{DRC}$
Draindown, % (See Note 1)	≤0.3
Abrasion Loss, % (See Note 2)	≤15
Moisture Susceptibility, % (See Note 3)	≥70
Permeability, in/sec (See Note 4)	≥0.0178

Note 1: Draindown shall be tested in accordance with AASHTO T 305 at the production temperature.
Note 2: Abrasion loss shall be tested in accordance with AASHTO T 401.
Note 3: Moisture susceptibility shall be tested in accordance with AASHTO T 283.
Note 4: Permeability shall be performed in accordance with the procedure outlined by RMS.

M3.06.4.H: ARGG Design Requirements

Each ARGG asphalt mixture shall be designed in accordance with the AASHTO M 323 and procedures contained in AASHTO R 35, as modified herein. The combined aggregate gradation shall conform to Table M3.06.4-8 and the mixture shall conform to Table M3.06.4-9.

ARGG will utilize asphalt binder meeting the requirements of M3.01.2: Modified Asphalt Binder Grades, Part B.

Table M3.06.4-8: ARGG Aggregate Gradation Control Points

Sieve Size	⅜ in. ARGG Control Points (% Passing)		½ in. ARGG Control Points (% Passing)	
	Min	Max	Min	Max
1 inch	-	-	-	-
¾ inch	-	-	100	-
½ inch	100	-	90	100
⅜ inch	90	100	83	87
#4	38	52	28	42
#8	22	30	14	22
#200	0	6	0	6

Table M3.06.4-9: ARGG Mixture Requirements

Property	Requirement ⅜ in.	Requirement ½ in.
N_{des}, gyrations	75	100
P_b, % (Asphalt Rubber)	≥7.6	≥7.6
V_a, %	3 to 5	3 to 5
VMA, %	18 to 23	18 to 23
Draindown % (See note 1)	≤0.3	≤0.3

Note 1: Draindown shall be tested in accordance with AASHTO T 305 at the production temperature.

M3.06.5: Verification of Laboratory Trial Mix Formula

The Contractor shall submit an LTMF in accordance with M3.06.4: Hot Mix Asphalt Mixture Design. The Engineer will perform laboratory verification of each LTMF.

If the Engineer is unable to verify the Contractor's LTMF in accordance with the applicable LTMF Verification Limits in Table M3.06.5-1, Table M3.06.5-2, or Table M3.06.5-3, then the Engineer will work with the Contractor to resolve the verification issue(s). The Contractor shall not proceed with production and placement of a Control Strip under Subsection 450: Hot Mix Asphalt Pavement until the LTMF is verified by the Engineer.

Table M3.06.5-1: Superpave LTMF Verification Limits

Properties	Test Method	LTMF Verification Limit
Asphalt Binder Content (P_b)	AASHTO T 308	Target ± 0.3%
Gradation Passing #4 and Larger Sieves	AASHTO T 30	Target ± 6.0%
Gradation Passing #8 Sieve	AASHTO T 30	Target ± 5.0%
Gradation Passing #16 to #50 Sieve	AASHTO T 30	Target ± 3.0%
Gradation Passing #100 Sieve	AASHTO T 30	Target ± 2.0%
Gradation Passing #200 Sieve	AASHTO T 30	Target ± 1.0%
Bulk Specific Gravity (G_{mb})	AASHTO T 166	Target ± 0.022
Max. Theo. Specific Gravity (G_{mm})	AASHTO T 209	Target ± 0.020
Air Voids (V_a)	AASHTO R 35	Target ± 1.0%
Voids in Mineral Aggregate (VMA)	AASHTO R 35	Target ± 1.0%
Voids Filled with Asphalt (VFA)	AASHTO R 35	Target ± 5.0%
Rutting and Moisture Susceptibility	AASHTO T 324	See Table M3.06.5-4

Table M3.06.5-2: OGFC LTMF Verification Limits

Properties	Test Method	LTMF Verification Limit
Asphalt Binder Content (P_b)	AASHTO T 308	Target ± 0.3%
Gradation Passing #4 and Larger Sieves	AASHTO T 30	Target ± 6.0%
Gradation Passing #8 Sieve	AASHTO T 30	Target ± 4.0%
Gradation Passing #16 to #50 Sieve	AASHTO T 30	Target ± 4.0%
Gradation Passing #100 Sieve	AASHTO T 30	Target ± 2.0%
Gradation Passing #200 Sieve	AASHTO T 30	Target ± 1.0%
Bulk Specific Gravity (G_{mb})	AASHTO T 331	Target ± 0.022
Max. Theo. Specific Gravity (G_{mm})	AASHTO T 209	Target ± 0.020
Air Voids (V_a)	AASHTO R 35	Target ± 2.0%
Voids in Mineral Aggregate (VMA)	AASHTO R 35	Target ± 2.0%
Voids Filled with Asphalt (VFA)	AASHTO R 35	Target ± 5.0%
Draindown	AASHTO T 401	≤0.3%
Abrasion Loss	AASHTO T 283	≤15%
Tensile Strength Ratio		≥70%

Table M3.06.5-3: ARGG LTMF Verification Limits

Properties	Test Method	LTMF Verification Limit
Asphalt Binder Content (P_b)	AASHTO T 308	Target ± 0.3%
Gradation Passing ¾ in. Sieve	AASHTO T 30	Target ± 0.0%
Gradation Passing #4 to ½ in. Sieve	AASHTO T 30	Target ± 6.0%
Gradation Passing #8 Sieve	AASHTO T 30	Target ± 5.0%
Gradation Passing #16 to #50 Sieve	AASHTO T 30	Target ± 3.0%
Gradation Passing #100 Sieve	AASHTO T 30	Target ± 2.0%
Gradation Passing #200 Sieve	AASHTO T 30	Target ± 1.0%
Bulk Specific Gravity (G_{mb})	AASHTO T 166	Target ± 0.022
Max. Theo. Specific Gravity (G_{mm})	AASHTO T 209	Target ± 0.020
Air Voids (V_a)	AASHTO R 35	Target ± 1.0%
Voids in Mineral Aggregate (VMA)	AASHTO R 35	Target ± 1.0%
Voids Filled with Asphalt (VFA)	AASHTO R 35	Target ± 5.0%
Draindown	AASHTO T 305	≤0.3%
Rutting and Moisture Susceptibility	AASHTO T 324	See Table M3.06.5-4

Evaluation of Rutting and Moisture Sensitivity

Each HMA mixture, with the exception of Base Courses and OGFC, shall be tested by RMS for rutting and moisture sensitivity in accordance with the requirements of AASHTO T 324 using the Hamburg Wheel-Tracking Device (HWTD).

The Engineer may also require that mixtures meet the requirements of AASHTO T 283 with a minimum tensile strength ratio of 80%.

Table M3.06.5-4: Hamburg Wheel Tracking Device Requirements

Traffic Level	Maximum Rut Depth (in.)	Minimum number of passes before Stripping Inflection Point is observed
1	½	10,000
2	½	15,000
3	½	15,000

M3.07.0: HMA for Driveways, Sidewalks, Berm, and Curb

HMA mixtures for driveways, sidewalks, berm, and curb shall conform to the master ranges in Table M3.06.6-1. The PGAB shall conform to M3.01.1: Standard Asphalt Binder Grade. The aggregate shall conform to M3.06.2: Aggregate for Hot Mix Asphalt. The Contractor shall submit a JMF prior to production which shows the target aggregate gradation and PG asphalt binder content for each HMA mixture for driveways, sidewalks, berm, and curb.

With the approval of the Engineer, the Contractor may substitute a MassDOT approved 9.5 mm or 12.5 mm Superpave Surface Course mixture (Traffic Level 1 or 2) for Driveways and Sidewalks.

The composition limits in Table M3.07.0-1 are HMA mix design master ranges for aggregate gradation and asphalt binder content. The JMF for each HMA mixture type shall establish a single percentage of aggregate passing each required sieve size, and a single percentage of asphalt binder material to be added to the aggregate.

The JMF shall be submitted in writing by the Contractor to the Engineer at least 30 days prior to the start of paving operations and shall include the following as a minimum:

- Source of materials
- Percent of each aggregate stockpile
- Percent passing each sieve size
- Combined aggregate specific gravity
- Percent of asphalt binder
- Performance grading test results and Certificate of Compliance certifying the PG grade
- Mixing temperature
- Compaction temperature
- Temperature of mix when discharged from the mixer
- Maximum theoretical specific gravity of the mixture

AASHTO T 195 (Ross Count) with a coating factor of 98% will be used when necessary to evaluate proper mixing time.

The use of recycled materials will be permitted at the option of the Contractor and provided that the end product is in conformance with the designated JMF. The proportion of reclaimed materials (including RAP, PGA, and RAS) in the total mix shall be limited to a maximum of 15%.

All HMA JMFs for sidewalks, pedestrian curb ramps, driveways, and berm will be submitted to the Engineer for approval.

The JMF for each mixture shall be in effect until modified in writing by the Contractor and approved by the Engineer. Should a change in sources of materials be made, a new JMF must be approved by the Engineer before the new material is used.

Table M3.07.0-1: Master Ranges for HMA for Driveways, Sidewalks, Berm, and Curb

	Control Points (% Passing)			
Mix Type	Driveways, Sidewalks, and Berm		Berm and Curb Only	
Sieve (in.)	Min	Max	Min	Max
1	-	-	-	-
¾	100	-	-	-
½	95	100	100	-
⅜	87	93	87	93
#4	57	69	62	73
#8	41	45	52	55
#16	30	36	40	45
#30	21	25	28	34
#50	14	17	18	23
#100	9	12	10	14
#200	4	5	6	6
P_b, %	6.0	6.6	7.4	7.6

M3.08.0: Cold Patch for Temporary Patching

When HMA is not available due to seasonal limitations the Contractor shall use stockpiled cold patch mixtures approved by the Research & Materials Section.

M3.10.0: Surface Preservation Treatment

M3.10.2: Stress Absorbing Membrane & Stress Absorbing Membrane Interlayer

All Stress Absorbing Membrane (SAM) and Stress Absorbing Membrane Interlayer (SAMI) mixtures shall meet the requirements as specified below. SAM & SAMI mixtures shall be composed of the following:

- Mineral aggregate
- Performance Graded Asphalt Binder

M3.10.2.A: Aggregate

The aggregate shall conform to M3.06.2: Aggregate for Hot Mix Asphalt. Crushed gravel stone will not be permitted. The aggregate shall be pre-heated to a temperature between 200°F and 300°F, and be pre-coated with 0.4% to 0.8% asphalt binder (by weight of aggregate) prior to application. The aggregate shall meet the requirements in Tables M3.10.2-1 and M3.10.22.

Table M3.10.2-1: SAM & SAMI Aggregate Control Points

	Nominal Maximum Aggregate Size – Control Points (% Passing)					
Type	**⅜ in.**	**⅜ in.**	**½ in.**	**½ in.**	**⅜ in. (SAMI only)**	**⅜ in. (SAMI only)**
Sieve	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
⅝ in.	100	-	100	-	100	-
½ in.	100	-	90	100	100	-
⅜ in.	85	100	25	65	85	100
#4	0	8	0	8	0	30
#8	0	4	0	4	0	5
#200	0	2	0	2	0	2

Table M3.10.2-2: SAM & SAMI Aggregate Source Property Requirements

Source Property Test	**Test Method**	**Limit**
Toughness	AASHTO T 96	<30%
Flakiness Index (for SAM)	TEX-224-F (see note 1)	<20%
Flakiness Index (for SAMI)	TEX-224-F (see note 1)	<30%

Note 1: Determined following TxDOT's Test Procedure for Determining Flakiness Index.

M3.10.2.B: Performance Graded Asphalt Binder

The PGAB binder to be applied to the pavement shall be in conformance with M3.01.2: Modified Asphalt Binder Grades, Part B. Asphalt binder that is pre-coated onto the aggregate shall be in conformance with M3.01.1: Standard Asphalt Binder Grade.

M3.10.5: Ultrathin Bonded Overlay

All Ultrathin Bonded Overlay (UTBO) mixtures shall meet the requirements as specified below. UTBO mixtures shall be composed of the following:

- Mineral aggregate
- Mineral filler (if required)
- PGAB

The use of recycled materials will not be permitted.

M3.10.5.A: Coarse Aggregate

Coarse aggregate shall meet the requirement of M3.06.2: Aggregate for Hot Mix Asphalt, Part A as well as the following. Where coarse aggregates for these mixes are from more than one source or of more than one type of material, they shall be proportioned and blended to provide a uniform mixture.

Table M3.10.5-1: Coarse Aggregate Requirements

Source Property Test	Test Method	Limit
Flat and Elongated, 3:1	ASTM D4791	<25%
Crushed Particles, Two Faced	AASHTO T 335	>90%
Water Absorption	AASHTO T 85	≤3.0%

M3.10.5.B: Fine Aggregate

Fine aggregate shall meet the requirement of M3.06.2: Aggregate for Hot Mix Asphalt, Part B as well as one of the following. Fine aggregate shall be 100% crushed and consist of one of the following:

- 100% stone sand
- A blend of stone sand and stone screenings

Table M3.10.5-2: Fine Aggregate Consensus Property Requirements

Source Property Test	Test Method	Limit
Fine Aggregate Angularity	AASHTO T 304	>40%
Methylene Blue	AASHTO T 330	≤10 mg/g
Water Absorption	AASHTO T 84	≤3.0%

M3.10.5.C: Mineral Filler

Hydrated lime, fly ash, and baghouse fines are acceptable as mineral filler. The material shall conform to the following:

- Lime – AASHTO M 303
- Fly Ash – AASHTO M 295
- Baghouse fines – AASHTO M 17

Typical acceptable gradation:

- #30 - 100% passing
- #200 - 75-100% passing

M3.10.5.D: Performance Graded Asphalt Binder

The PGAB utilized in the HMA mixture shall be specified by the Contract and shall comply with the requirements of M3.01.2: Modified Asphalt Binder Grades.

M3.10.5.E: UTBO Mixture Design

The Contractor shall be responsible for development of all UTBO mixture designs. All UTBO designs shall be developed in accordance with the requirements specified below.

M3.10.5.F: Development of Laboratory Trial Mix Formula

The Contractor shall develop and submit an LTMF for each UTBO mixture type, which is to be proposed as a JMF, a minimum of 60 days prior to UTBO production. Each LTMF shall be submitted

with supporting documentation and adequate amount of blended aggregate material and PGAB in order to verify the LTMF. Once verified by the Department, the LTMF may become JMF for a project.

M3.10.5.G: Specific Gravity Requirements

The individual aggregate, mineral filler, and PGAB specific gravities shall be included with the LTMF. The Contractor shall provide samples of each material a minimum of 60 days prior to production for each LTMF to the Department for verification specific gravity of each stockpile.

M3.10.5.H: UTBO Aggregate Gradation and Binder Requirements

The combined aggregate blend for each UTBO mixture shall conform to the Gradation Control Point requirements specified in Table M3.10.5-3. The results of the selected optimum design aggregate structure shall be plotted on a 0.45 power chart and included with the LTMF.

Table M3.10.5-3: UTBO Aggregate Control Points

	Nominal Maximum Aggregate Size – Control Points (% Passing)					
	Type 1	**Type 1**	**Type 2 (see Note 1)**	**Type 2 (see Note 1)**	**Type 3 (see Note 1)**	**Type 3 (see Note 1)**
Sieve	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
¾ in.	100	-	100	-	100	-
½ in.	100	-	92	100	85	100
⅜ in.	85	100	55	90	45	85
#4	24	40	24	41	24	41
#8	21	32	21	33	21	33
#16	16	26	15	26	15	26
#30	12	20	11	20	11	20
#50	8	16	8	16	8	16
#100	5	10	5	10	5	10
#200	5	7	4	7	4	7
Pb, % (Polymer)	4.8	5.2	4.7	5.2	4.6	5.2
Pb, % (Asphalt Rubber) (See note 2)	-	-	5.7	6.2	5.6	6.2

Note 1: When asphalt rubber is specified the gradation master ranges may be modified with the prior approval from the Research & Materials Section.
Note 2: Type 1 UTBO shall not use asphalt rubber.

M3.10.5.I: UTBO Mixture Requirements

The combined mixture for each UTBO mixture shall conform to the mixture requirements specified in Table M3.10.5-4. The results of the selected optimum design shall be included with the LTMF.

Table M3.10.5-4: UTBO Mixture Requirements

Property	Requirement
Unit Weight	Per LTMF
Draindown, % (see Note 1)	≤0.1
Moisture Susceptibility, % (see Note 2)	≥80

Note 1: Draindown shall be tested in accordance with AASHTO T 305 at the production temperature.
Note 2: The mixture shall be compacted according to AASHTO T 312 and tested in accordance with AASHTO T 283.

The tensile strength ratio, TSR, shall meet or exceed 80% when tested in accordance with AASHTO T 283. Specimens for AASHTO T 283 shall be 6 in. in diameter by 3 ¾ ± ¼ in. in height and compacted in accordance with AASHTO T 312, except the specimens shall be compacted to 100 gyrations and resultant air voids reported for information purposes only. The compaction temperatures shall be 300 ± 10°F or as recommended by the binder supplier.

Follow T 283 with the following exceptions:

- Condition the mixture for 2 hours in accordance with AASHTO R 30, Section 7.1.
- Compact the Superpave Gyratory Compactor, SGC, specimens to 100 gyrations.
- Extrude the samples as soon as possible without damage to the sample.
- Use AASHTO T 269 to determine the air void content.
- Record the air void content of the specimens.
- If less than 55% saturation is achieved, the procedure does not need to be repeated unless the difference in tensile strength between duplicate specimens is greater than 25 lb/in.^{2}.

3.10.5.J: Verification of Laboratory Trial Mix Formula

The Contractor shall submit an LTMF in accordance with Subsections M3.10.5.A: Coarse Aggregate to M3.10.5.I: UTBO Mixture Requirements. The Engineer will perform laboratory verification of each LTMF.

If the Engineer is unable to verify the Contractor's LTMF in accordance with the applicable LTMF Verification Limits in Table M3.10.5-4, then the Engineer will work with the Contractor to resolve the verification issue(s). The Contractor shall not proceed with production and placement of a Control Strip until the LTMF is verified by the Engineer.

Table M3.10.5-4: UTBO LTMF Verification Limits

Properties	Test Method	LTMF Verification Limit
Asphalt Binder Content (P_b)	AASHTO T 308	Target ± 0.3%
Gradation Passing ¾ in. Sieve	AASHTO T 30	Target ± 0.0%
Gradation Passing #4 and Larger Sieves	AASHTO T 30	Target ± 6.0%
Gradation Passing #8 Sieve	AASHTO T 30	Target ± 5.0%
Gradation Passing #16 to #50 Sieve	AASHTO T 30	Target ± 3.0%
Gradation Passing #100 Sieve	AASHTO T 30	Target ± 2.0%
Gradation Passing #200 Sieve	AASHTO T 30	Target ± 1.0%
Draindown	AASHTO T 305	≤0.1%
Moisture Susceptibility	AASHTO T 283	≥80%

M3.12.0: Hot Mix Asphalt Production Facility

All facilities producing HMA must be approved on an annual basis by the Department. All sources of materials used for the production of HMA must be approved by the Department prior to their use. Such materials shall include:

- Coarse aggregate
- Fine aggregate
- Mineral filler
- Performance graded asphalt binder
- Modifiers and/or additives

HMA production operations shall follow industry accepted best management practices including:

- Aggregate handling and stockpile management
- Recycled asphalt pavement handling and stockpile management
- PGAB storage
- Plant process controls
- Silo loading
- Truck loading

The plant shall meet the requirements of AASHTO M 156 as well as the following provisions. HMA plants meeting these requirements and which have been approved by RMS shall be listed on the QCML.

An adequate quantity of each size aggregate, mineral filler and asphalt binder shall be maintained at the HMA plant site at all times while the plant is in operation to ensure that the plant can continuously produce mixtures that meet these specifications. The quantity of such materials shall never be less than one day's production capacity.

M3.12.0.A: Production Facility Quality Control System

The production facility shall provide a Quality Control System (QC System) adequate to ensure that all materials and workmanship meet the required quality levels for each specified Quality Characteristic. The QC System shall be documented in a Quality System Manual (QSM). The Contractor shall provide qualified QC personnel and QC laboratory facilities and perform Quality Control inspection, sampling, testing, data analysis, corrective action (when necessary), and documentation.

The QSM shall conform to the requirements of AASHTO R 38 and the MassDOT Model QSM. The pages of the QSM shall be sequentially numbered and shall address, in sufficient detail, the specific information requested under each section and subsection contained in the MassDOT Model QSM.

M3.12.0.B: Scales

Plant and truck scales shall be certified:

- At the start of each construction season, prior to use for MassDOT projects.
- At intervals of not more than 90 calendar days.
- Whenever the plant changes location.
- At any time as requested by the Engineer.

M3.12.0.C: Calibration of Plant Equipment

The plant's systems shall be calibrated:

- At the start of each construction season, prior to use for MassDOT projects.
- Whenever there is a significant change to the material.
- Whenever a plant component supply system affecting the ingredient proportions has been repaired, replaced, or adjusted.
- At any time as requested by the Engineer.

M3.12.0.D: Automatic Recordation

Recordation equipment shall be provided. Each recorder shall include an automatic printer system. The printer shall be so positioned that the digital display and the printer can be readily observed within the plant's control room by the Engineer and the plant operator, simultaneously. The delivery ticket shall be printed with an original and at least one copy. The original shall be furnished to the Engineer at the paving site and the copy to the Engineer at the plant. The delivery ticket format shall be approved by RMS and will include the following information:

- Company / plant location.
- MassDOT contract number and/or distinct project name.
- MassDOT mix ID number and/or distinct mix description.
- Percentage of RAP in the mixture.
- Percentage of asphalt binder in the mixture.
- Date and time of loading.
- Sequential load number for the contract for a 24-hour period.
- Total weight of mix in truck (pay weight).

The following mixture production information shall also be provided:

For Batch Plants

- Date mixed.
- Time of batching.
- Tare weight of aggregate weigh box.
- Tare weight of PGAB weigh bucket.
- Moisture content of recycled materials.
- Target and actual cumulative or net weights as batched for each bin with a batch total for all net ingredients.
- Target and actual weight of PGAB.
- Total weight of mix in truck (pay weight).

Note: This information shall be included on the delivery ticket when the mix is batched directly into a truck. When the mix is batched and stored in a silo the information may be separate from the delivery ticket however it must be provided to the Engineer at the plant.

For Drum Plants

- Percent of mixture as well as the target and actual production rate for each individual mix component including:
    - Aggregate
    - Mineral Filler
    - PGAB
    - Recycled materials
    - Additives
- Moisture content of aggregates and recycled materials.
- PGAB temperature.
- Target and actual mix temperature.
- Target and actual mix production rate.

Note: This information is not required to be included on the delivery ticket however it must be provided to the Engineer at the plant.

M3.12.0.E: Surge and Storage Silo Holding Time

The mixtures shall not be stored in surge and storage bins longer than the following:

Bin Type	Time
Unheated and not insulated	2 hours
Unheated and insulated with heated gate	15 hours
Insulated and heated	24 hours

Note: In order to prevent excessive draindown, OGFC shall not be stored in a surge or storage bin for longer than 2 hours. ARGG shall not be stored for more than 6 hours.

M3.12.0.F: Asphalt Release Agents

The plant shall have a method of applying MassDOT approved asphalt release agents to the haul units in accordance with the Manufacturer's recommendations. Spray systems may either be

manual or automated but application of the release agent must be at the rate specified by the Manufacturer.

M3.12.0.G: Air Quality

The plant shall be designed and operated to meet all current Federal and State air quality requirements.

M3.12.0.H: Equipment Failure

If at any time the automatic proportioning or recording system becomes inoperative, the plant will cease all HMA production. Work will only be allowed to restart once all automatic controls and recording systems are functional.

M3.12.1: HMA Plant Facility Inspection

The Engineer shall have access at any time to all parts of the plant for:

- Inspections of the conditions and operations of the plant.
- Confirmation of the adequacy of the equipment in use.
- Verification of the character and proportions of the mixture.
- Determination of temperatures being maintained in the preparation of the mixture.
- Inspection of incidental related procedures.

M3.13.0: Hot Mix Asphalt Materials Testing Laboratory and Equipment

M3.13.1: Contractor Quality Control Laboratory

All Contractor QC testing shall be performed in laboratories that are approved by RMS and qualified through the NETTCP LQP or accredited through the AAP. All laboratories shall maintain a QSM in accordance with the outline maintained by RMS.

- Laboratories that perform HMA mix designs or QC testing under Subsection 450: Hot Mix Asphalt Pavement shall at a minimum be qualified as a NETTCP LQP Category 2 laboratory.
- Laboratories performing only QC testing shall be qualified as a NETTCP LQP Category 3 laboratory.

Contractors who do not produce mixtures under Subsection 450: Hot Mix Asphalt Pavement will not be required to have their own laboratory at the production facility but will be required to either test at their central laboratory or hire a consultant testing company to perform the QC testing required in the specification. The Contractor will still be required to maintain a QSM.

The Contractor's QC laboratory shall be qualified to perform all testing required by Table M3.13.2-1 as well as contract specifications.

Laboratories meeting these requirements, and which have been approved by the RMS, shall be listed on the QCML.

The Contractor's QC Manager shall have overall responsibility for ensuring that all laboratories utilized for QC are in compliance with the requirements of the NETTCP LQP. This includes providing required AASHTO, ASTM, and NETTCP reference documents and ensuring that all required equipment and tools are properly functioning and calibrated.

The Engineer shall be permitted unrestricted access to inspect and review the Contractor's laboratory facility.

Along with the required testing capabilities the laboratory facilities shall meet the following:

- Be kept clean and all equipment shall be maintained in proper working condition.
- Provide adequate environmental control to the satisfaction of the Engineer and must be able to maintain an inside temperature of 68°F to 86°F during working hours.
- Adequate ventilation to remove dust and fumes from the laboratory.
- Hot and cold potable water.
- First aid kit and emergency eye wash station.
- Multi-class ABC fire extinguisher.
- A restroom shall also be made available within 500 ft of the laboratory during all work shifts. The restroom facilities shall be enclosed in a separate room with proper ventilation and comply with applicable sanitary codes as well as:
    - A flush toilet.
    - A sink with hot and cold running water.
    - A sewer or septic tank with connections.
    - Adequate rest room supplies.
    - Maintained environmental control and cleanliness.

M3.13.2: Department Acceptance Laboratory at HMA Production Facility

The Engineer shall be provided laboratory working space meeting the requirements of M3.13.1: Contractor Quality Control Laboratory as well as the following. A desk must be located in close proximity to the laboratory but be separated from the ovens, sieve shakers, and anything else that can cause poor air and sound quality. The Engineer's desk and laboratory space will not be shared with any other entity.

Contractors who do not produce mixtures under Subsection 450: Hot Mix Asphalt Pavement will not be required to have a Department Acceptance Laboratory at the production facility, but will be required to allow the Engineer to perform Acceptance testing at their central laboratory or Consultant testing company laboratory. These laboratories are still required to meet M3.13.1: Contractor Quality Control Laboratory.

If the Engineer is unable to perform their duties either due to lack of working space, poor working conditions, or access to equipment it will be considered a laboratory facility deficiency. The Engineer will advise the Contractor in writing of any noted deficiencies concerning the laboratory facility, equipment, supplies, or testing personnel and procedures. Deficiencies shall be grounds for the Engineer to order an immediate stoppage of work until the deficiencies are corrected.

The plant, silos, and sample rack shall be in view of laboratory when performing testing under Subsection 450: Hot Mix Asphalt Pavement.

The Engineer shall be provided with the following:

M3.13.2.A: Computer

For plants producing HMA in accordance with Subsection 450: Hot Mix Asphalt Pavement, the Engineer shall be furnished with a computer with high-speed internet access which conforms to the requirements determined by RMS. The minimum requirements shall include:

- The Engineer is required to have 1 computer at the laboratory.
- Computers shall be required to have the latest MS Office Professional with all security updates, Antivirus software with all current security updates maintained, and any other software required by RMS.
- A laser printer with the capability to also scan and copy. The printer shall be compatible and connected to the laboratory's computer.

M3.13.2.B: Testing Equipment

The Contractor shall supply the Engineer with the following equipment. This equipment shall only be utilized by the Engineer and shall be labeled as such. It shall be the Contractor's responsibility to maintain and replace equipment as needed.

- For T 27 and T 30:
    - 12-in. sieve stack (2 in. to #200) with cover and pan.
    - Mechanical sieve shaker (only for Subsection 450: Hot Mix Asphalt Pavement Category A Lots).
    - Electronic balance (only for Subsection 450: Hot Mix Asphalt Pavement Category A Lots).
- For T 166 and T 209: Complete setup (only for Subsection 450: Hot Mix Asphalt Pavement).
- For T 312: Gyratory mold.
- For T 308:
    - Ignition oven sample basket.
    - Ignition oven and 2 sample baskets (only for Subsection 450: Hot Mix Asphalt Pavement Category A Lots).
- Miscellaneous equipment such as sample buckets, scoops, pans, brushes, thermometers, etc.
- Oven which meets AASHTO R 30 and is capable of storing the sample buckets for 3 samples (only for Subsection 450: Hot Mix Asphalt Pavement Category A Lots).
- Supply of sample boxes.
- Sample rack which is a suitable sampling platform from which the Engineer is able to stand and sample the material in the truck bed adequately and safely. The rack shall:
    - Be of sturdy construction.
    - Be able to safely accommodate at least two people at a time (minimum standing area of 4 ft x 4 ft).
    - Have a safe stairway that is attached to the sampling platform.
    - Be at a height which allows the Technician the ability to reach the HMA in the bed of any size truck safely and efficiently.
    - Have a mounted spotlight to allow for sampling at night.
    - Be within 100 ft of the laboratory and visible from the laboratory.
    - Meet applicable OSHA standards.

Table M3.13.2-1: Required Test Methods by Laboratory

Test Method	Description	Mix Design Laboratory	QC Laboratory	Department Acceptance Laboratory
AASHTO M 323	Superpave Volumetric Mix Design	X		
AASHTO R 30 (See note 1)	Mixture Conditioning of HMA	X		
AASHTO R 35	Superpave Volumetric Design for Asphalt Mixtures	X		
AASHTO R 47	Reducing Samples of HMA to Testing Size	X	X	X
AASHTO R 66	Sampling of Asphalt Materials		X	
AASHTO R 76	Reducing Samples of Aggregate to Testing Size	X	X	
AASHTO R 79 (See note 3)	Vacuum Drying Compacted HMA Specimens		X	
AASHTO R 90	Sampling of Aggregate		X	
AASHTO R 97	Sampling of Bituminous Paving Mixtures		X	X
AASHTO T 11	Material Finer Than #200 Sieve by Washing	X	X	X
AASHTO T 27	Sieve Analysis of Fine and Coarse Aggregates	X	X	X
AASHTO T 30	Sieve Analysis of Extracted Aggregate	X	X	X
AASHTO T 84	Specific Gravity and Absorption of Fine Aggregate	X		
AASHTO T 85	Specific Gravity and Absorption of Coarse Aggregates	X		
AASHTO T 96	Coarse Aggregate L.A. Abrasion	X		
AASHTO T 104	Soundness of Aggregates	X		
AASHTO T 166	Bulk Specific gravity of HMA	X	X	X
AASHTO T 176	Sand Equivalence	X		
AASHTO T 209	Theoretical Maximum Specific Gravity of HMA	X	X	X
AASHTO T 255	Moisture Contents of Aggregates		X	
AASHTO T 283 (See note 4)	Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage	X		
AASHTO T 304	Un-compacted Void Content of Fine Aggregate	X		

Test Method	Description	Mix Design Laboratory	QC Laboratory	Department Acceptance Laboratory
AASHTO T 305 (See note 3)	Draindown in Uncompacted Asphalt Mixtures	X		
AASHTO T 308	Asphalt Binder Content by Ignition Oven		X	X
AASHTO T 312	Density of HMA by Superpave Gyratory	X	X	X
AASHTO T 329	Moisture Control of HMA		X	X
AASHTO T 331 (4)	Bulk Specific Gravity and Density of Compacted Asphalt Mixtures Using Automatic Vacuum Sealing	X	X	X
AASHTO T 335	Determining the Percentage of Fracture in Coarse Aggregate	X		
ASTM D3549	Thickness of Compacted HMA Specimens		X	
ASTM D4791	Flat & Elongated Particles in Coarse Aggregate	X		
ASTM D7370 (See note 2)	Relative Density and Absorption of Aggregate Using Combined Vacuum Saturation and Rapid Submersion	X		

Note 1: Two ovens shall be required; one to heat binder, aggregate, and mixing tools to mixing temperature and one to condition the loose mixture at the compaction or conditioning temperature.
Note 2: Optional test.
Note 3: Required for OGFC and ARGG.
Note 4: Required for OGFC.

SECTION M4: CEMENT CONCRETE AND RELATED MATERIALS

M4.00.0: General

All cement concrete and related materials identified this section shall meet the requirements specified herein.

M4.01.0: Constituent Materials and Mix Design Formulations of Cement Concrete

Constituent materials and mix design formulations of cement concrete shall meet the requirements specified herein.

M4.01.1: Cementitious Materials

Cementitious materials, including hydraulic cement and supplementary cementitious materials (SCM), shall maintain qualification on the QCML and meet the requirements specified herein. Cementitious materials shall exhibit acceptable quality characteristics and material properties, including chemical composition, hydration phase composition, performance, and uniformity. The Manufacturer shall submit cementitious materials mill certification reports to the Department for review upon request.

Table M4.01.1-1: Types of Hydraulic Cement

Specification	Type		Description
AASHTO M 85	Portland Cement	I	General Use
AASHTO M 85	Portland Cement	IA	Type I with Air-Entraining Materials
AASHTO M 85	Portland Cement	II	Moderate Sulfate Resistance
AASHTO M 85	Portland Cement	IIA	Type II with Air-Entraining Materials
AASHTO M 85	Portland Cement	III	High Early Strength
AASHTO M 85	Portland Cement	IIIA	Type III with Air-Entraining Materials
AASHTO M 85	Portland Cement	IV	Low Heat of Hydration
AASHTO M 85	Portland Cement	V	High Sulfate Resistance
AASHTO M 240	Blended Hydraulic Cement	IS(%) [1]	Portland Blast-Furnace Slag Cement
AASHTO M 240	Blended Hydraulic Cement	IFA(%) [1]	Portland-Fly Ash Cement
AASHTO M 240	Blended Hydraulic Cement	ISF(%) [1]	Portland-Silica Fume Cement
AASHTO M 240	Blended Hydraulic Cement	IL(%) [1]	Portland-Limestone Cement
AASHTO M 240	Blended Hydraulic Cement	IT(X%)(Y%) [1]	Ternary Blended Cement
ASTM C1600 [1][2]	Rapid Hardening Hydraulic Cement	GRH	General Rapid Hardening
ASTM C1600 [1][2]	Rapid Hardening Hydraulic Cement	MRH	Medium Rapid Hardening
ASTM C1600 [1][2]	Rapid Hardening Hydraulic Cement	VRH	Very Rapid Hardening

Specification	Type		Description
ASTM C1600 [1][2]	Rapid Hardening Hydraulic Cement	URH	Ultra Rapid Hardening
ASTM C1600 [1][2]	Rapid Hardening Hydraulic Cement	RH-CAC [3]	Rapid Hardening Calcium Aluminate Cement
ASTM C1157 [1][2]	Performance Based Hydraulic Cement	GU	General Use
ASTM C1157 [1][2]	Performance Based Hydraulic Cement	HE	High Early Strength
ASTM C1157 [1][2]	Performance Based Hydraulic Cement	MS	Moderate Sulfate Resistance
ASTM C1157 [1][2]	Performance Based Hydraulic Cement	HS	High Sulfate Resistance
ASTM C1157 [1][2]	Performance Based Hydraulic Cement	MH	Moderate Heat of Hydration
ASTM C1157 [1][2]	Performance Based Hydraulic Cement	LH	Low Heat of Hydration

[1] The percentage of supplementary cementitious materials by total mass shall be identified in parenthesis on the Manufacturer's certified mill test report, as specified herein. For ternary blended cement (IT), "X" and "Y" shall be replaced by the supplementary blended constituents (S, FA, SF, or L) incorporated into the blended hydraulic cement, with their corresponding percentage by mass of total cement. Special property suffixes include MH for moderate heat of hydration, MS for moderate sulfate resistance, HS for high sulfate resistance, and LH for low heat of hydration.

[2] The chemical composition and mineralogical composition shall also be identified on the Manufacturer's certified mill test report.

[3] Mix designs formulated with Type RH-CAC rapid hardening calcium aluminate cement shall be used for Department approved repair applications only and shall be prohibited from use on structural applications, as determined by the Department.

Table M4.01.1-2: Types of Supplementary Cementitious Materials

Specification	Type		Description
AASHTO M 295	Fly Ash	FA-C	> 18% Calcium Oxide Content
AASHTO M 295	Fly Ash	FA-F	≤ 18% Calcium Oxide Content
AASHTO M 302	Slag	S-100	Moderate Activity Index
AASHTO M 302	Slag	S-120	High Activity Index
AASHTO M 307	SF		Silica Fume
ASTM C1945	Natural Pozzolan	NP-MET	Metakaolin
ASTM C1945	Natural Pozzolan	NP-DE	Diatomaceous Earth
ASTM C1945	Natural Pozzolan	NP-VA	Volcanic Ash and Pumicite
AASHTO M 321	HRP		High Reactivity Pozzolans
ASTM C1866	Ground-Glass Pozzolan	GGP-GS	Ground Soda-Lime Glass
ASTM C1866	Ground-Glass Pozzolan	GGP-GE	Low Alkali E-Glass
ASTM C1697	SCMB [1]		Blended Supplementary Cementitious Materials

[1] The naming convention for the type of blended supplementary cementitious material shall meet ASTM C1697.

M4.01.2: Aggregate

Aggregate shall meet the requirements specified herein. Aggregate shall exhibit acceptable quality characteristics and material properties for concrete, including particle size distribution, shape, surface texture, absorption, compressibility, modulus of elasticity, volume stability, coefficient of thermal expansion, and resistance to abrasion, alkali aggregate reaction (ASR), iron sulfide reaction (ISR), wetting and drying cycles, freezing, thawing, and de-icing cycles, d-cracking, popouts, internal sulfate attack, and other deleterious reactions. All required testing and examination shall be conducted by a Department recognized independent laboratory.

Table M4.01.2-1: Types of Aggregate

Specification	Type
AASHTO M 6	Normal Weight Fine Aggregate
AASHTO M 43 and AASHTO M 80	Normal Weight Coarse Aggregate
AASHTO M 195	Lightweight Aggregate
AASHTO M 45	Aggregate for Masonry Mortar

M4.01.2.A: Petrographic Examination

Aggregate shall be sufficiently limited of deleterious materials that negatively affect cement concrete performance, including workability, setting, hardening, aggregate-cement bond, strength, color, long-term durability, and other properties identified in Table M4.01.2-2. Aggregate with suspected deleterious materials or limited historical field and test data shall be examined through ASTM C295. The Manufacturer shall submit the petrographic examination reports to the Department for review.

Table M4.01.2-2: Potentially Deleterious Materials

Aggregate Composition		Potentially Deleterious Effect
Silica	Quartz (Highly Strained / Fractured); Quartz (Microcrystalline); Quartz (Cryptocrystalline); Opal; Chalcedony; Cristobalite; Tridymite; Vein Quartz; Siliceous Glass (Natural); Siliceous Glass (Synthetic)	Alkali Silica Reaction; Substantial Expansion; Map Cracking; Popouts
Igneous Rocks	Volcanic Glass (Obsidian, Pumice, Trachyte, Rhyolite, Scoria, Dacite, Basalt, Andesite, Perlite); Gneissic Granite; Felsite (Microcrystalline or contains Natural Glass, Rhyolite, Dacite, and Andesite)	Alkali Silica Reaction; Substantial Expansion; Map Cracking; Popouts
Sedimentary Rocks	Sandstone (Quartzite, Graywacke); Shale (Siliceous); Shale (Opaline); Argillite (Some); Siltstone (Some); Carbonate (Siliceous Dolomite, Siliceous Limestone, Reactive Quartz, Amorphous Silica); Chert; Chert (Chalcedonic)	Alkali Silica Reaction; Substantial Expansion; Map Cracking; Popouts
Metamorphic Rocks	Phyllite; Slate; Metaquartzite; Metagraywacke; Gneiss; Schist; Mylonite; Others (Containing Low Temperature Silica Minerals and Silicate Minerals and Reactive Quartz)	Alkali Silica Reaction; Substantial Expansion; Map Cracking; Popouts
Iron Sulfide	Pyrrhotite, Pyrite, Marcasite	Substantial Expansion; Internal Sulfate Attack
Zeolite	Heulandite, Natrolite	Increases Alkali Content in Concrete; Increases Alkali-Silica Reactions in Reactive Aggregate
Zeolite	Laumontite, Leonhardite	Substantial Expansion with Wetting and Drying
Silicate	Mica	Decrease in Workability; Increase in Water Demand
Sulfate	Gypsum, Anhydrite	Susceptible to Sulfate Attack
Iron Oxide	Limonite	Adsorption of Water; Impurities Including Silica, Clay, and Organic Matter
Iron Oxide		Discoloration
Clay		Increase in Water Demand; Abrasion During Mixing; Substantial Expansion with Wetting and Drying
Organic Impurities		Setting and Hardening; Deterioration
Material Finer Than No. 200 Sieve		Decrease in Bonding of Cement
Coal, Lignite, or Other Lightweight Materials		Decrease in Durability; Discoloration; Popouts
Soft Particles		Decrease in Durability
Clay lumps and friable particles		Decrease in Workability; Decrease in Durability; Popouts

M4.01.2.B: Aggregate Manufacturer Quality Control.

The Manufacturer shall conduct routine quality control (QC) sampling and testing of the aggregate quality characteristics and properties, to ensure uniformity and consistency of the material, in accordance with the Manufacturer's QC operating documents and the requirements specified herein. The QC test results shall be reported on test report forms (TRFs) and submitted to the Department for review upon request. The QC test results shall meet the limits specified in Table M4.01.2-1.

M4.01.2.C: Aggregate Source Licensing.

The Manufacturer shall meet the requirements specified in 700 CMR 19.00: Aggregate Source Licensing for the Production of Cement Concrete.

M4.01.3: Mixing Water

Mixing water shall meet AASHTO M 157, the potable classification of ASTM C1602, and the requirements specified herein. Mixing water shall include batch water, water added after batching, free moisture on aggregate, water from chemical admixtures, wash water, ice, and other possible sources of water incorporated into the concrete. Mixing water shall not adversely impact the potential properties of concrete. Mixing water shall be sufficiently limited of potentially deleterious amounts of impurities that may negatively affect cement concrete performance, including workability, setting, hardening, aggregate-cement bond, strength, permeability, long-term durability, and other properties.

M4.01.4: Chemical Admixtures

Chemical admixtures shall maintain qualification on the QCML, meet the requirements and performance criteria of the product's technical data sheet (TDS), and meet the requirements specified herein. Chemical admixture types that are not identified herein shall meet the product's applicable AASHTO or ASTM standard specification. Chemical admixture products that do not currently have AASHTO or ASTM standard specifications shall meet the requirements identified on the product's technical data sheet.

Chemical admixtures shall be defined as constituent materials in both liquid or powder form that are incorporated into the material immediately prior or during mixing, to enhance mix properties and maintain consistency during mixing, transporting, placing, finishing, and curing. Chemical admixtures shall be considered any ingredient added to a concrete mixture other than cement, supplementary cementitious materials (SCM), aggregate, water, and fibers. Chemical admixtures shall exhibit acceptable quality characteristics and material properties, including chemical composition, performance, and uniformity. Chemical admixtures containing calcium chloride are prohibited from use in concrete.

Table M4.01.4-1: Types of Conventional Chemical Admixtures

Specification	Type	Description	Properties
AASHTO M 194	A	Water Reducing	Increases workability and air Content; Decreases water demand (5 – 10%, 3 – 6 in. slump)
AASHTO M 194	B	Retarding	Increases initial and final setting time, air content, long-term strength; Stabilizes the hydration during long delivery times; Stabilizes the hydration of wash water and unused or returned concrete; Offsets the accelerating effect of hot conditions; Decreases early-age strength
AASHTO M 194	C	Accelerating	Increases early-age strength; Decreases initial and final setting time
AASHTO M 194	D	Water Reducing and Retarding	Type A and Type B admixture properties
AASHTO M 194	E	Water Reducing and Accelerating	Type A and Type C admixture properties
AASHTO M 194	F	High Range Water Reducing	Increases workability, air content, early-age strength, and ultimate strength; Decreases water demand (12 – 40%, > 6 in. slump) and permeability
AASHTO M 194	G	High Range Water Reducing and Retarding	Type F and Type B admixture properties
AASHTO M 194	AF	Mid-Range Water Reducing	Type A and Type F admixture properties; Increases workability; decreases water demand (6 – 12 %, 5 – 8 in. slump)
AASHTO M 154	AEA	Air-Entraining	Increases cohesion, workability, stabilization of air bubbles, and resistance to freezing, thawing, and de-icing, alkali-reactive environments, and sulfate reaction

Table M4.01.4-2: Types of Specific Performing Chemical Admixtures

Specification	Type	Description	Properties
AASHTO M 194	S-ADA	Air-Detraining	Decreases air content
AASHTO M 194	S-AWA	Anti-Washout	Component of underwater concrete; Increases cohesion for underwater placements
AASHTO M 194	S-CNA	Carbon Nanotube	Component of shotcrete and other types of concrete; Enhances workability, rheology, finishing; Increases compressive, tensile and flexural strength, modulus of elasticity, resistance to shrinkage, cracking, freezing, thawing, and de-icing cycles, scaling, abrasion and shrinkage; Decreases permeability
AASHTO M 194	S-CRA	Crack Reducing	Decreases cracking and crack width

Specification	Type	Description	Properties
AASHTO M 194	S-PRAN	Permeability Reducing (Non-Hydrostatic)	Decreases permeability under non-hydrostatic conditions with the use of long-chain fatty acid derivatives, soaps and oils, petroleum derivatives, silanes, and reactive or inert fine particle fillers (colloidal silica, silicates, silicious powders, clay, lime, bentonite, talc); Increases water repellency; Reduces water absorption
AASHTO M 194	S-PRAH	Permeability Reducing (Hydrostatic)	Decreases permeability under hydrostatic conditions with the use of crystalline hydrophilic polymers; Increases resistance to water penetration under pressure; Reduces corrosion in chemically aggressive environments; Blocks pores and capillaries in concrete
AASHTO M 194	S-RCA	Rheology Controlling	Improves extrusion rate of drycast concrete and other types of concrete
AASHTO M 194	S-SEA	Strength Enhancing	Increases early age strength and late age strength; Enhances cement hydration and workability
AASHTO M 194	S-SCA	Shrinkage Compensating	Contains components (ACI 223) that produce expansive ettringite (Type K, M, or S) or calcium hydroxide platelet crystals (Type G) when mixed with portland cement and water; Compensates for shrinkage caused by constituent materials, mixture proportions, curing, drying environment, and restraint; Offsets tensile stresses and strains caused by restraint to drying shrinkage; Reduces net shrinkage from hydraulic cement; Types of S-SCA: Type K (sulfoaluminate and calcium sulfate), Type M (calcium aluminate cement and calcium sulfate), Type S (tricalcium aluminate cement and calcium sulfate), and Type G (calcium oxide, silicon dioxide, and aluminum oxide)
AASHTO M 194	S-SRA	Shrinkage Reducing	Decreases the surface tension of water and capillary stress in the concrete's pore structure; Decreases drying shrinkage cracking and bleed rate; Increases setting time
AASHTO M 194	S-VMA	Viscosity Modifying	Component of self-consolidating concrete (SCC) and other types of concrete; Decreases segregation
AASHTO M 194	S-WRA	Workability Retaining	Component of self-consolidating concrete (SCC) and other types of concrete; Maintains slump, workability, and consistency of concrete without retarding

Table M4.01.4-3: Types of Miscellaneous Chemical Admixtures

Specification	Type	Description	Properties
ASTM C1582	M-CIA [1]	Corrosion Inhibiting	Creates passive ferric oxide film around steel reinforcement; Decreases chloride ion penetration in steel reinforcement
TDS	M-BA	Bonding	Component of latex modified concrete; Increases bond strength to existing concrete substrate
ASTM C979	M-CA [2]	Coloring	Specialized coloring
ASTM C1622	M-CWA	Cold Weather	Increases hydration rate; Decreases freezing point of mixing water
ASTM C869	M-FA	Foaming	Lightweight, low density, foamed concrete

[1] Type M-CIA corrosion inhibiting admixtures shall contain a minimum of 30% calcium nitrite by weight.
[2] The product color name of Type M-CA coloring admixtures shall be identified on the Manufacturer's color chart.

M4.01.5: Fibers

Fibers shall meet the requirements and performance criteria of the product's technical data sheet (TDS) and the requirements specified herein. Fibers shall be manufactured from steel, synthetic, glass, or natural materials, in a variety of shapes, sizes, and thickness, uniformly dispersed into the cement concrete. Fibers shall exhibit acceptable quality characteristics and material properties, including shape, size, thickness, performance, and uniformity.

Table M4.01.5-1: Types of Fibers

Specification	Type		Description
ASTM A820	Steel Fibers	Type I	Cold-Drawn Wire Fibers
ASTM A820	Steel Fibers	Type II	Cut Sheet Fibers
ASTM A820	Steel Fibers	Type III	Melt-Extracted Fibers
ASTM A820	Steel Fibers	Type IV	Mill Cut Fibers
ASTM A820	Steel Fibers	Type V	Modified Cold-Drawn Fibers
ASTM D7508	Polyolefin Fibers [1]	A	Macro Cut
ASTM D7508	Polyolefin Fibers [1]	B	Micro Cut
ASTM D7508	Polyolefin Fibers [1]	C	Hybrid
ASTM D7508	Polyolefin Fibers [1]	D	Multi-Length
ASTM D7508	Polyolefin Fibers [1]	E	Graded
ASTM C1666	Akali Resistant (AR) Glass Fibers	Type I	Roving
ASTM C1666	Akali Resistant (AR) Glass Fibers	Type II	Chopped Strands
ASTM C1666	Akali Resistant (AR) Glass Fibers	Type II	Textiles
ASTM D7357	Wood Cellulose Fibers	SG	Stone Ground
ASTM D7357	Wood Cellulose Fibers	RMP	Refiner Mechanical Pumping
ASTM D7357	Wood Cellulose Fibers	TMP	Thermo-Mechanical Pumping
ASTM D7357	Wood Cellulose Fibers	CTMP	Chemi-Thermo-Mechanical Pumping

[1] Polyolefin fibers are a category of synthetic fibers and include polyethylene, polypropylene, and other olefin units. Other categories of synthetic fibers, including acrylic, aramid, carbon, nylon, and polyester shall meet the requirements identified on the product's technical data sheet.

M4.01.6: Mix Design Formulation

Producers shall report proposed mix design formulations on a Department issued mix design sheet in its entirety and submit annually to the Department for review and approval. The proportions reported on the mix design sheet shall yield 27.0 ft^3 (1 cubic yard) of material. Proposed mix design formulations shall be approved by the Department prior to construction. Approval signifies Department verification of a mix design formulation's conformance to design targets and limits at the time of review or testing but does not signify Department authorization or endorsement for specific contract work items. The Contractor shall select and place the applicable Department approved mix design formulation for the contract work item, exposure conditions, and application, as specified in contract documents, special provisions, Division II: Construction Details, and herein. Approval of a mix design formulation is subject to its performance at the plant and contract site.

Modifications to approved mix design formulations outside the scope of M4.02.5: Mixing and Delivery or placement of mix design formulations prior to Department approval shall be prohibited. Such modifications shall require a new mix design formulation submission to the Department for review and approval. Mix design formulations not approved by the Department shall be prohibited from use. Mix design formulations shall maintain qualification on the QCML and meet the requirements specified herein.

Table M4.01.6-1: Types of Mix Design Formulations

Specification	Type [1][2]	Description
M4.06.1	CC	Conventional Concrete
M4.06.2	HPC	High Performance Concrete
M4.06.3	HESC	High Early Strength Concrete
M4.06.4	RHC	Rapid Hardening Concrete
M4.04.1	CP	Concrete Products (Extended)[3]
M4.04.2	RHCP	Rapid Hardening Concrete Products (Extended)[3]
M4.06.5	LWC	Lightweight Concrete
M4.06.6	SCC	Self-Consolidating Concrete
M4.06.7	ESC	Exterior Slab Concrete
M4.06.8	PC	Pavement Concrete
M4.06.9	MPC	Mass Placement Concrete
M4.06.10	FRC	Fiber Reinforced Concrete
M4.06.11	UHPC	Ultra-High Performance Concrete
M4.06.12	SHOT	Shotcrete
M4.06.13	UWC	Underwater Concrete
M4.06.14	DC	Drycast Concrete
M4.07.0	EC	Elastomeric Concrete
M4.08.0	CLSM	Controlled Low-Strength Materials

[1] A mix design formulation incorporating multiple types shall meet the quality characteristics and materials properties specified for each type. Each type incorporated into the mix design formulation shall be reported on the Department issued mix design sheet.

[2] A mix design formulation meeting M4.01.6.A: Global Warming Potential shall be reported as low carbon concrete (LCC), in addition to the type(s) of mix design formulation(s) already reported on the Department issued mix design sheet.

[3] Cementitious, grout, mortar, and concrete products (M4.04.0) extended with aggregate not included in the original product packaging shall be reported on the Department issued mix design sheet and be formulated per the product's technical data sheet.

M4.01.6.A: Global Warming Potential

When specified in contract documents and special provisions, the cradle-to-gate (ISO 21930 life cycle modules A1, A2, and A3) global warming potential (GWP) shall be reported on environmental product declarations (EPD) in accordance with the following International Organization for Standardization (ISO) publications:

- ISO 14025 Environmental labels and declarations – Type III environmental declarations – Principles and procedures
- ISO 14040 Environmental management – Life cycle assessment – Principles and framework
- ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines

- ISO 21930 Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services

Environmental product declarations shall be verified by a Department recognized independent third-party. GWP values for constituent materials shall be reported in terms of kilograms of equivalent carbon dioxide emitted per 1000 kilograms of manufactured material (kg CO_2e/1000 kg). GWP values for cement concrete mix design formulations shall be reported in terms of kilograms of equivalent carbon dioxide emitted per cubic yard of concrete (kg CO_2e/yd^3). Low carbon concrete (LCC) shall meet the GWP targets specified in Table M4.01.6-2.

Table M4.01.6-2: Global Warming Potential

28-Day Compressive Strength (psi)	GWP Target (kg CO_2e/yd^3)	
	Normal Weight	Lightweight
2500	≤ 156.91	–
3000	≤ 172.79	≤ 332.24
4000	≤ 206.50	≤ 369.30
5000	≤ 249.07	≤ 406.13
6000	≤ 262.81	–
8000	≤ 310.93	–

M4.01.6.B: Cementitious Materials Content

Cementitious materials content shall be defined as the total quantity (lb/yd^3) of hydraulic cement and supplementary cementitious materials (M4.01.1) incorporated into the mix design formulation. The total cementitious content of the mix design formulation shall be optimized to meet the specified quality characteristics and material properties, while limiting the global warming potential (GWP), as specified herein.

M4.01.6.B.1: Supplementary Cementitious Materials Content

Mix design formulations shall meet Table M4.01.6-3 to enhance durability and sustainability. Incorporation of supplementary cementitious materials (SCM) may affect certain properties of the cement concrete, including workability, bleed rate, setting time, curing duration, and other properties. Sufficient communication between the Producer and Contractor is required so that adequate adjustments in Contractor workmanship practices are made to account for these changes in properties and to prevent premature degradation of the cement concrete.

Table M4.01.6-3: Enhanced Durability and Sustainability [1]

Cementitious Material	Cement Replacement Target (%) [2]
Slag	20 – 50
Silica Fume	5 – 15
Fly Ash (Class F)	15 – 30
Fly Ash (Class C)	20 – 50
Metakaolin (Class N)	10 – 20
Calcined Clay or Shale (Class N)	20 – 35
Ground-Glass Pozzolan	[3]
High Reactivity Pozzolan	[3]
Blended Hydraulic Cement	[4]
Rapid Hardening Hydraulic Cement	[4][5]
Performance Based Hydraulic Cement	[4][5]

[1] Subject to Department review and approval, the maximum limits for cement replacement (%) may be waived for mass placement concrete (M4.06.9) and other Department approved applications.
[2] The cement replacement (%) shall be determined by calculating the cement replaced by mass divided by the total cementitious content by mass. The total cement replacement of supplementary cementitious materials shall not exceed 50%. The total cement replacement of fly ash and silica fume shall not exceed 35%.
[3] Per Manufacturer's recommendations.
[4] Shall meet the cement replacement target requirements specified in the table.
[5] Cement replacement target requirements are not applicable to mix design formulations incorporating hydraulic cement with GWP values (kg CO2e/1000 kg) less than or equal to the GWP values of portland cement blended with the minimum SCM content targets specified in the table, while meeting the specified quality characteristics and material properties specified herein.

M4.01.6.B.2: Equivalent Cement Content

Mix design formulations (for cast-in-place concrete only) shall meet the equivalent cement content design targets for a given concrete member dimension as specified in Table M4.01.6-4, to resist delayed ettringite formation (DEF) and thermal cracking. Cast-in-place cement concrete mix design formulations not meeting Table M4.01.6-4 shall be considered mass placement concrete (M4.06.9).

Table M4.01.6-4: Delayed Ettringite Formation and Thermal Cracking Resistance

Smallest Dimension of Concrete Member (ft)	Equivalent Cement Content Target (lb/yd³) [1]		Cementitious Materials (lb/yd³) and Heat Reduction Factors (F)
> 9.0	[2]	ECC = (F_C*C) + (F_{FAF}*FAF) + (F_{FAC}*FAC) + (F_S*S) + (F_{SF}*SF) + (F_{MET}*MET)	ECC = Equivalent Cement Content C = Type I/II or IL cement FAF = Class F Fly Ash FAC = Class C Fly Ash S = Slag SF = Silica Fume MET = Metakaolin F_C = 1.0; F_{SF} = 1.2; F_{MET} = 1.2; F_S = 1.0 (≤ 45% cement replacement); F_S = 0.9 (> 45% and ≤ 65% cement replacement); F_S = 0.8 (> 65% and ≤ 80% cement replacement); F_{FAC} = 0.8; F_{FAF} = 0.5
> 6.0; ≤ 9.0	≤ 250		
> 4.5; ≤ 6.0	≤ 300		
> 3.5; ≤ 4.5	≤ 350		
3.5	≤ 400		
3.0	≤ 450		
2.5	≤ 500		
2.0	≤ 550		
1.5	≤ 650		
1.0	≤ 700		
0.5	≤ 850		

[1] Equivalent cement content (lb/yd³) estimates the heat of hydration behavior of concrete for the cementitious materials (M4.01.1) identified in the table. Equivalent cement content estimates for cementitious materials not identified in the table shall be subject to Department review and approval.
[2] A heat of hydration analysis and thermal control plan shall be conducted for a concrete member with a thickness > 9.0 ft as specified herein.

M4.01.6.B.3: Sulfate Exposure Content

Mix design formulations shall meet Table M4.01.6-5 to resist sulfate reaction.

Table M4.01.6-5: Sulfate (S) Reaction Resistance

Exposure Class	Severity	Condition		Cementitious Material Type
		Water-soluble sulfate in soil (% by mass) [1]	Dissolved sulfate in water (ppm) [2]	
S0	None	SO_4 < 0.10	SO_4 < 150	–
S1	Moderate	0.10 < SO_4 < 0.20	150 < SO_4 < 1,500	Type II (or MS) [3][4]
S2	Severe	0.20 < SO_4 < 2.00	1500 < SO_4 < 10,000	Type V (or HS) [5]
S3	Very Severe	SO_4 > 2.00	SO_4 > 10,000	Type V (or HS) Cement and SCM

[1] Conducted in accordance with ASTM C1580 Standard Test Method for Water-Soluble Sulfate in Soil.
[2] Conducted in accordance with ASTM D516 Standard Test Method for Sulfate Ion in Water.
[3] Type I or Type III hydraulic cement is permitted if the tricalcium aluminate (C_3A) content is less than 8 percent.
[4] For seawater exposure, Type MS Cement is not required if the tricalcium aluminate (C_3A) content is less than or equal to 10 percent and the w/cm ratio is less than or equal to 0.40.
[5] Type I or Type III hydraulic cement is permitted if the tricalcium aluminate (C_3A) content is less than 5 percent.

M4.01.6.B.4: Chloride Ion Content

Mix design formulations shall meet Table M4.01.6-6 to resist corrosion of steel reinforcement.

Table M4.01.6-6: Corrosion (C) Resistance of Steel Reinforcement [1]

Exposure Class	Severity	Condition	Chloride Ion (Cl-) Content (%) [2]
C0	None	Not exposed to moisture or external sources of chlorides	≤ 1.00
C1	Moderate	Exposed to moisture; Not exposed to external sources of chlorides	≤ 0.30
C2	Severe	Exposed to moisture and external sources of chlorides including de-icing chemicals, salt, brackish water, and seawater	≤ 0.15
C3	Very Severe	All prestressed concrete structures; Exposed to any condition	≤ 0.06

[1] Not applicable to one or more of the following conditions:
- Mix designs formulated with Type M-CIA corrosion inhibiting admixtures (M4.01.4) as specified in Table M4.01.6-8 (C3 exposure class).
- Epoxy coated (M8.01.7), galvanized (M8.01.0), or stainless steel reinforcing bars.

[2] Water-soluble chloride ion (Cl-) content in concrete (percent by mass of total cementitious materials) shall be determined by one of the following methods:
- The sum of the total chloride ion content of the cementitious materials (AASHTO T 105), aggregate (ASTM C1152), mixing water (AASHTO T 105), and chemical admixtures (provided by chemical admixture Manufacturer).
- ASTM C1218 Standard Test Method for Water-Soluble Chloride in Mortar and Concrete at 28 days.

M4.01.6.C: Chemical Admixture Content.

Chemical admixtures (M4.01.4) shall be incorporated into mix design formulations to enhance the properties of cement concrete in accordance with the requirements specified herein. Chemical admixture compatibility shall be verified by the Producer prior to mix design formulation.

M4.01.6.C.1: Air-Entraining Admixtures.

Mix designs shall be formulated with Type AEA air-entraining admixtures (M4.01.4) to stabilize the air bubble distribution and promote quality concrete properties, including enhanced workability, cohesion, strength, and resistance to freezing, thawing, and de-icing, as specified in Table M4.01.6-7.

Table M4.01.6-7: Freezing, Thawing, and De-icing (F) Resistance [1]

Exposure Class	Severity	Condition	Type AEA Target (fl. oz./ yd^3)
F0	None	Not exposed to freezing, thawing, and de-icing cycles	–
F1	Moderate	Exposed to freezing and thawing cycles; Not exposed to accumulation of snow, ice, and de-icing chemicals; Limited exposure to water	[2]
F2	Severe	Exposed to freezing and thawing cycles and accumulation of snow and ice; Not exposed to de-icing chemicals; Frequent exposure to water; Direct contact with soil	[2]
F3	Very Severe	Exposed to freezing and thawing cycles and accumulation of snow, ice, and de-icing chemicals; Frequent exposure to water	[2]

[1] Subject to Department review and approval, freezing, thawing, and de-icing resistance requirements may be waived under one or more of the following conditions:
- Mix designs formulated with hydraulic cement containing air-entraining materials (M4.01.1).
- Mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).

[2] Dosage per Manufacturer's recommendations. Air content (%) shall meet the requirements specified in Table M4.01.6-10.

M4.01.6.C.2: Corrosion Inhibiting Admixtures

When specified in M4.06.0: Cement Concrete, mix designs shall be formulated with Type M-CIA corrosion inhibiting admixtures (M4.01.4) as specified in Table M4.01.6-8.

Table M4.01.6-8: Corrosion (C) Resistance of Steel Reinforcement

Exposure Class	Severity	Condition [1]	Type M-CIA Target (fl. oz./ yd^3)
C0	None	Not exposed to moisture or external sources of chlorides; Non-prestressed concrete internal chloride ion content ≤ 1.00%; Prestressed concrete internal chloride ion content ≤ 0.06%	–
C1	Moderate	Exposed to moisture; Not exposed to external sources of chlorides; Non-prestressed concrete internal chloride ion content ≤ 0.30%; Prestressed concrete internal chloride ion content ≤ 0.06%	–
C2	Severe	Exposed to moisture and external sources of chlorides including de-icing chemicals, salt, brackish water, and seawater; Non-prestressed concrete internal chloride ion content ≤ 0.15%; Prestressed concrete internal chloride ion content ≤ 0.06%	–
C3	Very Severe	Exposed to C0, C1, or C2 conditions with the internal chloride ion content exceeding each specified exposure class limit	384.0
		All prestressed concrete or high performance concrete (M4.06.2) exposed to any condition	

[1] Water-soluble chloride ion (Cl^-) content in concrete (% by mass of cementitious materials) shall be determined by one of the methods identified in Table M4.01.6-6.

M4.01.6.C.3: Shrinkage Inhibiting Admixtures.

When specified in M4.06.0: Cement Concrete, mix designs shall be formulated with shrinkage inhibiting admixtures as specified in Table M4.01.6-9.

Table M4.01.6-9: Shrinkage Resistance [1]

Types of Mix Design Formulations	Type	Description	Target (fl. oz./yd^3)
High Performance Concrete (M4.06.2) High Early Strength Concrete (M4.06.3) Rapid Hardening Concrete (M4.06.4) Exterior Slab Concrete (M4.06.7) Pavement Concrete (M4.06.8)	S-SCA	Shrinkage Compensating	[2]
	S-SRA	Shrinkage Reducing	≥ 128.0 or [2]
	S-CRA	Crack Reducing	[2]

[1] Subject to Department review and approval, the shrinkage resistance requirements may be waived under one or more of the following conditions:
- Mix designs formulated with a paste content meeting the limits specified in Table M4.01.6-16.
- Mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).
- Unrestrained and restrained shrinkage test results meet the limits specified in Table M4.06.3-2.

[2] Dosage per Manufacturer's recommendations.

M4.01.6.D: Air Content

When specified in M4.06.0: Cement Concrete, mix design formulations shall meet Table M4.01.6-10 to resist freezing, thawing, and de-icing.

Table M4.01.6-10: Freezing, Thawing, and De-icing (F) Resistance [1]

Exposure Class	Severity	Condition	NMAS (in.)	Air Content Target (%) [3]	
				Reinforced	Non-Reinforced
F0	None	Not exposed to freezing, thawing, and de-icing cycles	–	–	–
F1[2]	Moderate	Exposed to freezing and thawing cycles; Not exposed to accumulation of snow, ice, and de-icing chemicals; Limited exposure to water	⅜	6.0	7.0
			½	5.5	7.0
			¾	5.0	6.5
			1	4.5	6.5
			1-½	4.5	6.0
F2[2]	Severe	Exposed to freezing and thawing cycles and accumulation of snow and ice; Not exposed to de-icing chemicals; Frequent exposure to water; Direct contact with soil	⅜	7.5	7.5
			½	7.0	7.0
			¾	6.0	7.0
			1	6.0	6.5
			1-½	5.5	6.5
F3[2]	Very Severe	Exposed to freezing and thawing cycles and accumulation of snow, ice, and de-icing chemicals; Frequent exposure to water	⅜	7.5	7.5
			½	7.0	7.0
			¾	6.0	7.0
			1	6.0	6.5
			1-½	5.5	6.5

[1] Subject to Department review and approval, the freezing, thawing, and de-icing resistance requirements may be waived for mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).
[2] Mix design shall be formulated with Type AEA air-entraining admixtures (M4.01.4) as specified in Table M4.01.6-7 or hydraulic cement containing air-entraining materials (M4.01.1).
[3] A 1.0% reduction from the air content target is permitted for 28-day compressive strength ≥ 5000 psi.

M4.01.6.E: Water-Cementitious Ratio

When specified in M4.06.0: Cement Concrete, mix design formulations shall meet Tables M4.01.6-11, M4.01.6-12, and M4.01.6-13 to resist water, freezing, thawing, de-icing, sulfate reaction, and corrosion of steel reinforcement. The water-cementitious ratio shall be determined by calculating the total water content by mass divided by the total cement and SCM content by mass.

Table M4.01.6-11: Water (W), Freezing, Thawing, and De-icing (F) Resistance [1]

Exposure Class	Severity	Condition	w/cm Ratio Target
F0/W0	None	Not exposed to water, freezing, thawing, and de-icing cycles	–
F1	Moderate	Exposed to freezing and thawing cycles; Not exposed to accumulation of snow, ice, and de-icing chemicals; Limited exposure to water	≤ 0.55
W2	Severe	Not exposed to freezing and thawing cycles; Frequent or intermittent exposure to water; Absorption of water from surrounding soil	≤ 0.50
F2	Severe	Exposed to freezing and thawing cycles and accumulation of snow and ice; Not exposed to de-icing chemicals; Frequent exposure to water; Direct contact with soil	≤ 0.45
F3	Very Severe	Exposed to freezing and thawing cycles and accumulation of snow, ice, and de-icing chemicals; Frequent exposure to water	≤ 0.40
			≤ 0.45 [2]

[1] Subject to Department review and approval, the water, freezing, thawing, and de-icing resistance requirements may be waived under one or more of the following conditions:
- Mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).
- Mix designs formulated with lightweight aggregate (M4.01.2).
- Mix designs formulated with Type S-PRAN non-hydrostatic permeability reducing admixtures (M4.01.4).
- Mix designs formulated with Type S-PRAH hydrostatic permeability reducing admixtures (M4.01.4).

[2] For exterior slab concrete (M4.06.7) without steel reinforcement, the w/cm ratio shall be less than or equal to 0.45.

Table M4.01.6-12: Sulfate (S) Reaction Resistance [1]

Exposure Class	Severity	Condition		w/cm Ratio Target
		Water-soluble sulfate in soil (% by mass) [2]	Dissolved sulfate in water (ppm) [3]	
S0	None	$SO_4 < 0.10$	$SO_4 < 150$	–
S1	Moderate	$0.10 < SO_4 < 0.20$	$150 < SO_4 < 1500$	≤ 0.40 [4]
				≤ 0.50
S2 [5]	Severe	$0.20 < SO_4 < 2.00$	$1500 < SO_4 < 10,000$	≤ 0.45
S3 [5]	Very Severe	$SO_4 > 2.00$	$SO_4 > 10,000$	≤ 0.40

[1] Subject to Department review and approval, the sulfate resistance requirements may be waived for mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).
[2] Conducted in accordance with ASTM C1580.
[3] Conducted in accordance with ASTM D516.
[4] For seawater exposure, Type MS Cement is not required if the tricalcium aluminate (C_3A) content is less than or equal to 10 percent and the w/cm ratio is less than or equal to 0.40.
[5] Chemical admixtures containing calcium chloride are prohibited from use.

Table M4.01.6-13: Corrosion (C) Resistance of Steel Reinforcement [1]

Exposure Class	Severity	Condition	w/cm Ratio Target
C0	None	Not exposed to moisture or external sources of chlorides; Non-prestressed concrete internal chloride ion content ≤ 1.00%; Prestressed concrete internal chloride ion content ≤ 0.06%	–
C1	Moderate	Exposed to moisture; Not exposed to external sources of chlorides; Non-prestressed concrete internal chloride ion content ≤ 0.30%; Prestressed concrete internal chloride ion content ≤ 0.06%	–
C2	Severe	Exposed to moisture and external sources of chlorides including de-icing chemicals, salt, brackish water, and seawater; Non-prestressed concrete internal chloride ion content ≤ 0.15%; Prestressed concrete internal chloride ion content ≤ 0.06%	≤ 0.40
C3	Very Severe	Exposed to C0, C1, or C2 conditions with the internal chloride ion content exceeding each specified exposure class limit	≤ 0.40
		All prestressed concrete or high performance concrete (M4.06.2) exposed to any condition	

[1] Subject to Department review and approval, the corrosion resistance of steel reinforcement requirements may be waived under one or more of the following conditions:
- Mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).
- Mix designs formulated with Type M-CIA corrosion inhibiting admixtures (M4.01.4) as specified in Table M4.01.6-8 (C3 exposure class).

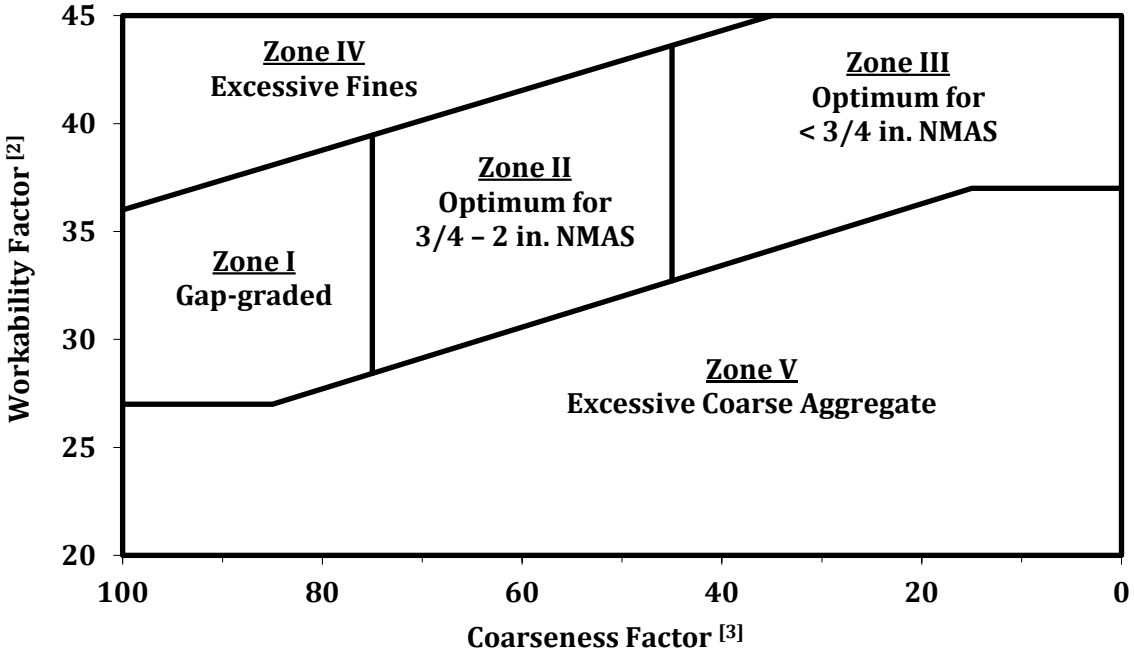
M4.01.6.F: Combined Aggregate System

The combined aggregate system shall be optimized to promote quality concrete properties, including enhanced workability, surface finishing, cohesion, strength, and resistance to segregation, edge slumping, shrinkage, cracking, curling, spalling, and scaling. Nominal maximum aggregate size (NMAS) shall be determined from the combined aggregate system of the proposed mix design formulation and is defined as the sieve size immediately above the first sieve size that cumulatively retains more than 10% by mass.

M4.01.6.F.1: Shilstone Workability-Coarseness

When specified in M4.06.0: Cement Concrete, mix design formulations shall meet Figure M4.01.6-1 and Table M4.01.6-14 to enhance workability.

Figure M4.01.6-1: Shilstone Workability-Coarseness Chart for Enhanced Workability [1]



[1] Subject to Department review and approval, the enhanced workability requirements may be waived under one or more of the following conditions:
- Mix designs formulated with chemical admixtures (M4.01.4) that enhance workability, consolidation, or cohesion.

[2] The workability factor is determined by the equation WF = W + (2.5(C - 564) / 94), where WF = workability factor, W = percent passing No. 8 sieve (%) and C = total cementitious materials content (lb).

[3] The coarseness factor is determined by the equation CF = (Q/R) * 100, where CF = coarseness factor, Q = cumulative percent retained on ⅜ in. sieve (%) and R = cumulative percent retained on No. 8 sieve (%).

Table M4.01.6-14: Shilstone Workability-Coarseness Zones for Enhanced Workability

Zone	Property	Cause
Zone I	Gap-graded; High potential for segregation during placement and consolidation; Cracking, blistering, spalling, and scaling	Deficiency in intermediate particles; Non-cohesive
Zone II	Optimum mixture for nominal maximum aggregate size from 2 in. – ¾ in.	Optimized workability factor and coarseness factor
Zone III	Optimum mixture for nominal maximum aggregate size < ¾ in.	Optimized workability factor and coarseness factor
Zone IV	Sticky; High potential for segregation during consolidation and finishing; Variable strength, high shrinkage, cracking, curling, spalling, and scaling	Excessive fines
Zone V	Rocky; Lacking plasticity	Excessive amount of coarse and intermediate aggregate

M4.01.6.F.2: Tarantula Curve

When specified in M4.06.0: Cement Concrete, mix design formulations shall meet Table M4.01.6-15 to enhance workability.

Table M4.01.6-15: Tarantula Curve Particle Size Distribution for Enhanced Workability [1]

Sieve Opening	Percent by Mass Retained Targets (%) [2]		
2 in.	–	–	–
1-½ in.	–	–	–
1 in.	0 – 16	–	–
¾ in.	0 – 20	–	–
½ in.	4 – 20	–	–
⅜ in.	4 – 20	–	–
No. 4	4 – 20	–	–
No. 8	0 – 12	Coarse Sand: 15 – 44	–
No. 16	0 – 12		–
No. 30	4 – 20		Fine Sand: 24 – 34 [3] 25 – 40 [4]
No. 50	4 – 20	–	
No. 100	0 – 10	–	
No. 200	0 – 1	–	

[1] Subject to Department review and approval, the enhanced workability requirements may be waived under one or more of the following conditions:
- Mix designs formulated with chemical admixtures (M4.01.4) that enhance workability, consolidation, or cohesion.
- Unattainable tarantula curve particle size distribution due to limited coarse aggregate gradation sizes. However, the combined aggregate system shall be designed and optimized as close to the specified particle size distribution as possible.

[3] Total fine sand target for slip formed concrete applications.
[4] Total fine sand target for fixed formed concrete applications.

M4.01.6.F.3: Void Content

When specified in M4.06.0: Cement Concrete, the void content of the combined aggregate system (composite) shall be determined through AASHTO T 19. The void content shall be used to determine the paste content (with air) to mix design void content ratio (M4.01.6.G.2).

M4.01.6.G: Paste Content and Mix Design Void Content

Cement concrete shall be designed with a paste content that decreases the tendency of shrinkage cracking, while also adequately filling the voids of the concrete to provide sufficient separation and effective bonding between the aggregate particles.

M4.01.6.G.1: Paste Content

When specified in M4.06.0: Cement Concrete, mix design formulations shall meet Table M4.01.6-16 to resist shrinkage. The paste content (PC) shall be defined as the sum of the volume of cement, supplementary cementitious materials, chemical admixtures, and water divided by the volume of the mix design.

Table M4.01.6-16: Shrinkage Resistance [1]

Types of Mix Design Formulations		PC Target (%)
High Performance Concrete (M4.06.2)		≤ 30.0
High Early Strength Concrete (M4.06.3)		≤ 30.0
Rapid Hardening Concrete (M4.06.4)		≤ 30.0
Exterior Slab Concrete (M4.06.7)		≤ 30.0
Pavement Concrete (M4.06.8)	Slip Form	≤ 25.0
	Fixed Form	≤ 28.0

[1] Subject to Department review and approval, the shrinkage resistance requirements may be waived under one or more of the following conditions:
- Mix designs formulated with shrinkage inhibiting chemical admixtures identified in Table M4.01.6-9.
- Mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).
- Unrestrained and restrained shrinkage test results meet the specified limits identified in Table M4.06.3-2.

M4.01.6.G.2: Paste Content (with air) to Mix Design Void Content Ratio.

When specified in M4.06.0: Cement Concrete, mix design formulations shall meet Table M4.01.6-17 to enhance workability.

Table M4.01.6-17: Enhanced Workability [1]

Types of Mix Design Formulations	PC_{AIR}/VC_{MIX} Ratio Target [2]
High Performance Concrete (M4.06.2) Exterior Slab Concrete (M4.06.7) Pavement Concrete (M4.06.8)	1.25 – 1.75 [3]

[1] Subject to Department review and approval, the enhanced workability requirements may be waived under one or more of the following conditions:
- Mix designs formulated with chemical admixtures (M4.01.4) that enhance workability, consolidation, or cohesion.
- Mix designs formulated with manufactured (crushed) aggregate (M4.01.2) containing rough, angular, or elongated particles that reduce workability and require a higher PC_{AIR}/VC_{MIX} ratio.
- Mix designs formulated with natural sand or gravel aggregate (M4.01.2) containing smooth or rounded particles that increase workability and require a lower PC_{AIR}/VC_{MIX} ratio.
- No visual signs of segregation, poor consolidation, or insufficient cohesion, while the concrete is being discharged and during AASHTO T 119, as specified in Table M4.06.1-3.

[2] The paste content (with air) to mix design void content (PC_{AIR}/VC_{MIX}) ratio shall be determined through the following equations, where VC = Void Content (%) and V = Volume (ft3):
- $VC_{MIX} = VC_{AASHTO\ T\ 119} * V_{AGGREGATE} / V_{MIX}$
- PC_{AIR} = Paste Content (%) + Air Content (%)
- PC_{AIR}/VC_{MIX} = Paste Content (with air) to Mix Design Void Content ratio

[3] Optimized PC_{AIR}/VC_{MIX} ratio targets are provided for the following applications:
- Low range of target limits: Slip form and other applications where decreased workability is required.
- Mid-range of target limits: Chute, buggy, wheelbarrow, conveyor belt, bucket, and other similar depositing methods.
- High range of target limits: Pumping and other applications where increased workability is required.

M4.02.0: Concrete Produced by Stationary and Truck Mixers

Concrete produced by stationary and truck mixers shall meet AASHTO M 157 and the requirements specified herein. The Producer shall maintain qualification on the QCML.

M4.02.1: Control, Handling, and Storage of Constituent Materials

Producers shall verify specification conformance of all constituent materials present at the plant or facility, through review of Manufacturer mill certifications, Manufacturer test reports, and Producer Quality Control sampling, testing, and inspection reports. Control, handling, and storage of constituent materials shall meet the requirements specified herein.

The Producer shall conduct routine quality control (QC) inspection at the plant prior to the start of production, to ensure uniformity, consistency, and control of the material per the requirements specified herein. At a minimum, the following items shall be inspected by the Producer's QC personnel:

- Foundations of stockpiles for proper separation and adequate drainage
- Bins for adequate partitions to prevent intermingling of aggregates
- Scales with test weights throughout range to be used
- Scales for seals
- Water meter for accuracy
- Leakage of lines
- Capacity of boilers and chillers during adverse conditions (M4.09.2.D: Protection from Adverse Conditions)
- Admixture dispensers for accuracy
- Mixers for hardened concrete around blades
- Concrete hauling units for cleanliness
- Department Approval of constituent materials and mix design formulation
- Prohibit segregation and contamination during stockpiling operations
- Prohibit segregation and contamination during charging of the bins
- Review aggregate moisture tests to apply adjustments to the mix design formulation mixing water content accordingly
- Batching operations at the start of production with periodic inspection during production
- Scales for zeroing
- Ensure proper batch weights are set on the scales

M4.02.1.A: Hydraulic Cement and Supplementary Cementitious Materials

Hydraulic cement and supplementary cementitious materials (M4.01.1) shall be sufficiently controlled, handled, and stored through prevention of moisture absorption, cement caking, and contamination. Hydraulic cement and supplementary cementitious materials shall be stored in weathertight, sufficiently ventilated structures to prevent absorption of moisture. Silos shall be equipped with non-clogging air-diffuser flow pads through which small quantities of dry, oil-free, low-pressure air can be introduced intermittently to loosen cement that has settled tightly in the silos. Storage silos shall be sufficiently maintained to prevent cement caking. Each bin compartment from which cement is batched shall include a separate gate, screw conveyor, air slide, rotary feeder,

or other conveyance that allows both constant flow and precise cutoff to obtain accurate batching of cement.

Sources of contamination include incorrect sources placed into storage structures and dust contaminants. Storage structures shall be sufficiently labeled to avoid contamination. Contamination shall be sufficiently monitored and controlled during loading and transferring.

M4.02.1.B: Aggregate

Aggregate (M4.01.2) shall be sufficiently controlled, handled, and stored to prevent gradation variation due to segregation and undersized particles, moisture content variation, contamination, degradation, and fracture.

M4.02.1.B.1: Variation in Gradation

Aggregate gradation shall be sufficiently monitored to maintain control of the mix design. Segregation of aggregate shall be managed through the following practices:

- Stockpiling aggregate in thin horizontal layers of uniform thickness to limit segregation
- Limiting the size of conical piles
- Conducting proper loader operations
- Dividing the coarse aggregate into several different sized sub-groupings with smaller ranges to be batched separately
- For maximum aggregate size less than 1 in.: Limiting the maximum to minimum aggregate size ratio to for a given aggregate size grouping to a 4 to 1 ratio
- For maximum aggregate size greater than or equal to 1 in.: Limiting the maximum to minimum aggregate size ratio for a given aggregate size grouping to a 2 to 1 ratio

Undersized particles for a given coarse aggregate size grouping shall be defined as material passing the sieve size with an opening ⅝ of the nominal minimum size of the coarse aggregate size grouping. Coarse aggregate shall be rescreened as it is charged to the bins to remove undersized particles and undesirable fines if handling and storage methods are unsatisfactory and variations in gradation exceed allowable tolerances.

Storage bins (hoppers) shall be circular or nearly square and their bottoms shall have adequate slope to allow for free movement with various moisture conditions. External vibration may be used to facilitate loading. During bin loading, the aggregate shall be discharged directly above and fall vertically into the center of the bin. Discharging aggregate against the side of the bin or baffle wall causes segregation and shall be prohibited. Baffle plates or dividers can minimize segregation. Bins shall be filled to limit variation in gradation caused by withdrawal of material, segregation, and breakage of aggregate particles. Dry fine aggregate when dropped from buckets or conveyors shall be sufficiently shielded from wind and other external forces to prevent loss of fines. Fine aggregate may require dampening to prevent segregation of material.

M4.02.1.B.2: Variation in Moisture Content

Aggregate moisture content shall be sufficiently monitored to maintain control of the mix design. Coarse aggregate shall be wetted to keep the aggregate in a constantly saturated condition, to compensate for aggregates with high absorption, and to provide cooling. Aggregate shall be sufficiently dewatered and drained to form a uniform moisture content and to prevent transfer of

excessive free water to the bins. Fine aggregate, due to its surface area, contributes the largest amount of free water added to the mix design. Moisture meters can indicate variations in the moisture of aggregate and moisture compensators can be used for rapid batch weight adjustments, to limit moisture variations in the aggregate. Aggregates washed to remove contaminants shall be stockpiled well before use so that they can drain to a uniform moisture content.

M4.02.1.B.3: Contamination

Sources of contamination include overlapping of different aggregate sizes from adjacent stockpiles, aggregate leakage through or around bulkheads in storage bins, underlying soil, dislodged clay lumps and other contaminants from transporting unit, leaves and vegetation, freezing aggregate, incorrect delivery from aggregate manufacturer, and incorrect aggregate size placed into a bin or stockpile. Stockpiles shall be placed on a hard base with sufficient drainage to prevent contamination from underlying material. Bulkheads, dividers, and partitions with sufficient height and ample spacing between piles shall be utilized to avoid cross-contamination and overlapping of different aggregate sources, types, and size groupings between stockpiles. Storage areas shall be sufficiently labeled to avoid contamination. Clay lumps or clay balls shall be removed from the aggregate by placing a scalping screen over the batch plant bin. Aggregate may require washing to remove contaminants. During cold temperatures, bins shall be covered or underground to prevent the freezing of aggregate. Frozen aggregate shall be prohibited from use. Aggregates may require heating to maintain an acceptable aggregate temperature and prevent freezing. Trucks, loaders, dozers, and other heavy transport equipment shall not be operated on the stockpiles due to the potential for aggregate particle fracture and contamination of track dirt onto the piles. Additional measures, including storage area coverings, shall be instituted in cases where storage areas are subject to other sources of contamination.

M4.02.1.C: Mixing Water

Mixing water (M4.01.3) shall be sufficiently controlled, handled, and stored to prevent contamination.

M4.02.1.D: Chemical Admixtures

Chemical admixtures (M4.01.4) shall be sufficiently controlled, handled, and stored to prevent contamination. Sources of contamination include freezing, evaporation, sunlight, ultraviolet (UV) radiation, and incorrect chemical admixture sources placed into chemical admixture tanks. When ambient temperatures approach freezing, chemical admixtures shall be stored in heated environments to prevent freezing. Incorporation of frozen chemical admixtures into the concrete shall be prohibited. Long-term storage of liquid admixtures in vented tanks, resulting in evaporation, shall be prohibited. Chemical admixtures prone to sunlight and ultraviolet (UV) radiation shall be protected in the storage tanks. Storage tanks shall be labeled to avoid contamination. Chemical admixtures shall be stored in accordance with the chemical admixture manufacturer’s recommendations.

M4.02.1.E: Fibers

Fibers (M4.01.5) shall be sufficiently controlled, handled, and stored to prevent fiber ball development, moisture exposure, corrosion, and contamination.

M4.02.2: Measuring Materials

Materials shall be measured in accordance with Section 8 of AASHTO M 157. Calibration of scales, water meters, and admixture dispensers shall be conducted at a minimum frequency of one per year. Additionally, calibrations shall be conducted on equipment as accuracy issues occur and are identified.

M4.02.3: Batching

The batching plant, equipment, devices, scales, and procedures used for the batching of cement concrete shall meet Section 9 of AASHTO M 157 and the requirements specified herein.

M4.02.3.A: Automatic Proportioning Plants

All plants shall be equipped with an approved automatic weighing, cycling, and monitoring system installed as part of the batching equipment. Each plant shall include equipment for accurate proportioning of batches containing the various components by weight or by volume for admixtures and water in the proper sequence and for controlling the sequence and timing of mixing operation. The automatic proportioning system shall be capable of consistently delivering each constituent material within the tolerances specified in M4.02.1: Control, Handling, and Storage of Constituent Materials.

Interlocks shall be provided which will hold or delay the automatic batch cycling whenever the batched quantity of any constituent material is not within the specific weight tolerance, if any aggregate bin becomes empty, or if there is a malfunction in any portion of the control system. The weight setting and time controls shall be so equipped that they may be locked when directed by the Department. The weighing equipment shall be so arranged that the batch plant operator can conveniently observe all scales from their operation station. Each weighing unit shall include a springless dial which shall indicate the scale load at all stages of the weighing operation from zero to full capacity.

Batching controls shall be set so that:

- The batcher inlet gates shall not be opened while the discharge gates are open.
- The batcher discharge gates shall not be opened until the full batch weights are registered on the scales, while the weigh hopper is being filled, or if the batch weights are not within the tolerances specified in M4.02.2: Measuring Materials.
- A new batch shall not be weighed until the hopper is entirely empty of the previous batch and all scales have returned to zero.

Discharge chutes shall be so arranged that they are not suspended from any part of the weighing system and so that no materials will lodge therein or be lost on discharge.

If at any time the automatic proportioning system becomes inoperative, the Producer will be permitted to batch materials manually for no more than two working days. Manual batching for longer periods shall require approval from the Department. Prior to production, plant scales shall be calibrated and tested by qualified Producer QC personnel or when otherwise required by the Department.

M4.02.3.B: Chemical Admixture Dispensing Systems

Plants shall be equipped with a separate dispensing system necessary to incorporate each of the required chemical admixtures into the concrete.

M4.02.3.C: Batch Ticketing

Batch ticketing shall meet Section 16 of AASHTO M 157 and the requirements specified herein. At a minimum, batch tickets shall report the following:

- Concrete Producer Company Name and Plant Location
- Contractor
- Contract Number and Description
- Ticket Number
- Date of Delivery
- Truck Number
- Time of Ticketing, Loading, Arrival, Start of Discharge, End of Discharge
- Type of Structure
- Batching Quantity
- Mix Identification Number and Type, and w/cm Ratio
- Design Targets for Compressive Strength, Slump (or Slump Flow), Air Content, Unit Weight, and Water-Cementitious (w/cm) Ratio
- Source, Type, and Design Target for each Constituent Material (M4.01.0)
- Actual Batching w/cm Ratio
- Actual Batching Quantity for each Constituent Material
- Aggregate Moisture Content and Total Volume of Moisture from Aggregate
- Percent Variance of Design Target to Actual Batching Quantity for each Constituent Material
- Adjustments (M4.02.5.B): Aggregate, Chemical Admixtures, Hold-Back Water, and Retempering of Hold-Back Water

Concrete batching plants equipped with automatic proportion systems shall contain digital recording instruments that are readily accessible and readable to the operator from their normal workstation. The recording instruments shall be designed to record the quantities of each constituent material for each batch of concrete produced. Producers shall confirm the mix design formulation identified on the batch ticket meets the Department approved mix design formulation. Upon the request of the Department, Producers shall provide the Department approved mix design sheet, to verify conformance. Excessive deviation from the Department approved mix design sheet will result in rejection of the concrete. Batch tickets shall accurately and clearly report the required information as specified herein.

M4.02.4: Mixers and Agitators

Mixers and agitators shall meet Section 10 of AASHTO M 157. All wash water shall be removed from truck mixers and truck agitators prior to charging with a fresh load. Subject to Department review and approval, wash water may remain for concrete that incorporates chemical admixtures (M4.01.4) with retarding (Type B, Type D, or Type G) and hydration stabilizing properties (identified on product's technical data sheet).

M4.02.5: Mixing and Delivery

Mixing and delivery shall meet Section 11 of AASHTO M 157 and the requirements specified herein. Modifications to Department approved mix design formulations, including mix type, sources of constituent materials, design quantities, and design targets shall be prohibited, unless otherwise specified herein. Subject to Department review and approval, the maximum specified delivery time may be exceeded for concrete that incorporates chemical admixtures (M4.01.4) with retarding (Type B, Type D, or Type G) and hydration stabilizing properties (identified on product's technical data sheet).

M4.02.5.A: Batch Tickets

Batch tickets shall meet M4.02.3.C: Batch Ticketing and be generated by the Producer for each delivery of concrete. Batch tickets shall be submitted to the Contractor's Quality Control and Department's Acceptance technicians for review, prior to placement, as specified herein. Producer batch tickets shall be made available upon the request of the Department.

M4.02.5.B: Adjustments

Proposed adjustments to approved aggregate, chemical admixture, and total water (hold-back and retempering) quantity design targets will be considered by the Department as specified herein. The Producer shall submit to the Department a request to review the proposed adjustments prior to placement. The Producer shall report the adjusted quantities onto the batch ticket. Adjustments without Department review and consent shall be prohibited.

M4.02.5.B.1: Aggregate Quantity Adjustments

Slight adjustments to the approved aggregate design quantity targets will be considered to compensate for variations in specific gravity, aggregate gradation, and aggregate moisture content test results, to maintain the approved mix design formulation's original yield, combined aggregate system, and total water content design targets. The Producer shall report the adjusted quantity of the aggregate and time of aggregate adjustment onto the batch ticket.

M4.02.5.B.2: Chemical Admixture Dosage Adjustments

Slight adjustments to the approved chemical admixture design quantity targets will be considered to compensate for slump or air content test results that are not within the specified design target limits. The Producer shall report the adjusted quantity of chemical admixture and time of chemical admixture adjustment onto the batch ticket.

M4.02.5.B.3: Hold-Back Water

Holding back water from the approved total water quantity design target during initial mixing at the plant will be considered to facilitate retempering at the job site and to compensate for variations in environmental conditions. Hold-back water shall be defined as the total quantity of water trimmed from the approved total water quantity design target. The Hold-back water shall be calculated by subtracting the total quantity of water presently mixed in the concrete from the approved total water quantity design target. The total quantity of water presently mixed in the concrete includes the total quantity of mixing water, ice, wash water, free moisture from aggregate, and other sources of free water. Hold-back water shall not exceed 10% of the approved total water design quantity, during the initial mixing at the plant. The Producer shall report the hold-back

water percentage, quantity of hold-back water (gal./yd^3), and recalculated w/cm ratio onto the batch ticket.

M4.02.5.B.4: Retempering of Hold-Back Water into the Concrete

Retempering of the hold-back water into the concrete shall meet AASHTO M 157, occur prior to the discharging of the first one-third of the load, occur no more than once (unless otherwise approved by the Department), occur prior to initial set, and occur at a rate not to exceed the Department reviewed w/cm ratio design target. The Producer shall report the hold-back water percentage, quantity of hold-back water, quantity of hold-back water retempered into the concrete, time of retempering of hold-back water, quantity of concrete placed prior to tempering, recalculated w/cm ratio, and other relevant calculations onto the batch ticket. The amount of hold-back water incorporated into the cement concrete shall be verified through sight glass increments or in-line meter readings. At no point shall the water-cementitious (w/cm) ratio exceed the Department approved design target.

M4.03.0: Concrete Produced by Volumetric Mixers

Concrete produced by volumetric mixers shall meet AASHTO M 241 and the requirements specified herein. The Producer shall maintain certification from the Volumetric Mixer Manufacturers Bureau (VMMB) and qualification on the QCML.

M4.03.1: Calibration and Verification Testing

Calibration and verification testing shall be conducted annually, in the presence of the Department, as specified herein. A request for calibration and verification testing shall be submitted by the Producer to the Department for review. Producers shall report proposed mix design formulations in accordance with M4.01.6: Mix Design Formulation and submit to the Department for review prior to calibration and verification testing. Verification sampling and testing shall be conducted in accordance with M4.06.0: Cement Concrete. At a minimum, Producers shall calibrate scales, gate settings, and yield (0.25 cy). Yield verification shall be conducted per AASHTO M 241 and the requirements specified herein. Producers shall prepare calibration reports for each proposed volumetric mixer. Calibration reports shall include all the intermediary calculations needed to calibrate the gate settings. Producers shall submit calibration reports to the Department for review.

M4.03.2: Producer Quality Control

Quality control (QC) shall be established, maintained, and conducted by the Producer to monitor, assess, and adjust production activities, to maintain continuous control of the process, and to ensure that the final material or product will meet the specified level of quality, as specified herein.

M4.03.2.A: Quality Control Operating Documents

At least 30 days prior to the start of construction, the specified QC operating documents shall be prepared by the Producer and submitted to the Department for review and approval. The Contractor shall adhere to all policies, practices, procedures, and activities identified in Department approved QC operating documents.

M4.03.2.A.1: Quality System Manual

The quality system manual (QSM) shall document the overall internal QC operating procedures of the QC system and meet AASHTO R 18, AASHTO R 38, and the requirements specified by the Department.

M4.03.2.A.2: Quality Control Plan

Quality control plans for specified work items shall document all QC personnel and procedures utilized to maintain control of activities. Quality control plans for each specified work item shall meet the Northeast Transportation Training Certification Program (NETTCP) Model Quality Control Plan standard format.

M4.03.2.B: Quality Control Laboratory

The QC laboratory shall meet the quality system requirements specified in AASHTO R 18 and the requirements specified herein. The QC laboratory shall maintain active accreditation or qualification through one or more of the following programs:

- Northeast Transportation Training Certification Program (NETTCP) Laboratory Qualification Program
- AASHTO Accreditation Program (AAP)
- Other Department recognized program

The QC laboratory shall be capable of conducting all required QC sampling, testing, and inspection specified for the work item. All required field sampling, testing, and inspection equipment shall be onsite and available for use during all phases of production. The equipment shall meet all applicable AASHTO or ASTM standards, maintain required calibration schedules, and be in acceptable working condition.

M4.03.2.C: Quality Control Organization

The QC organization shall be comprised of an acceptable number of experienced, trained, skilled, and qualified personnel to support the size and scope of the operation. The frontline personnel, QC technicians, and QC manager shall be onsite and present during all phases of the operation, maintain continuous communication to ensure conformance to specification requirements, and conduct corrective action for non-conforming results and activities.

M4.03.2.C.1: Frontline Personnel

The frontline personnel that are directly responsible for the production operations shall conduct best practices in accordance with QC operating documents, Department recognized standards, organizations, and programs, and the requirements specified herein. Additionally, frontline personnel shall conduct continuous self-inspection throughout the entire operation, to ensure quality workmanship is performed, through observation and verification of:

- Proper tools and equipment are utilized to conduct the work
- Routine maintenance, calibration, and cleaning of tools and equipment
- Proper procedures for control, handling, storage, and shipping of materials and products
- Best practices for workmanship are incorporated throughout the operation
- Quality appearance of finished materials and products

The frontline personnel shall be capable of identifying unacceptable materials and products prior to completing the operation and shall notify potential non-conformances to the QC manager.

M4.03.2.C.2: Quality Control Technicians

The QC technicians shall maintain an active NETTCP Field Technician or American Concrete Institute (ACI) Concrete Field Testing Technician – Grade I certification. The principal responsibilities of QC technicians shall include:

- Conducting QC sampling, testing, and inspection at the construction site
- Preparing and signing QC test report forms (TRFs) and inspection report forms (IRFs)
- Providing routine feedback based on sampling, testing, and inspection results to the production personnel, construction personnel, and QC manager

M4.03.2.C.3: Quality Control Manager

The QC manager shall be employed full-time (or through engaged consultants) throughout the entire operation or specified work item. The QC manager shall maintain an active NETTCP Field Technician or American Concrete Institute (ACI) Concrete Field Testing Technician – Grade I certification The principal responsibilities of the QC manager shall include:

- Preparing QC operating documents
- Establishing the QC system in accordance with Department approved QC operating documents
- Managing and monitoring the activities of QC technicians
- Communicating routinely with frontline personnel, QC technicians, and the Department
- Initiating non-conformance reports and work suspensions (when necessary), for non-conforming results and activities
- Responding to non-conformance reports (NCRs) and deficiency reports (DRs) issued by the Department
- Verifying all non-conformances have been resolved
- Document management

M4.03.2.D: Quality Control Sampling, Testing, and Inspection

The quality measurements obtained through QC sampling, testing, and inspection shall be conducted by qualified QC technicians in accordance with the Department approved QC operating documents and the requirements specified for the work item(s) and herein.

Quality control sampling, testing, and inspection shall be conducted to provide measurement of properties and quality characteristics, to determine the degree of uniformity or the measured variability, to monitor the quality, to visually inspect equipment, environmental conditions, materials, and workmanship, and to evaluate the control of the operation. The QC results shall be reported on standardized sample report forms (SRFs), test report forms (TRFs), and inspection report forms (IRFs) and submitted to the QC manager for review. The QC results shall meet the quality limits specified for the work item(s).

The QC manager shall initiate non-conformance reports (NCRs) and if necessary, work suspensions, for non-conforming results and uncontrolled processes. The QC manager shall report the non-conformance, root cause, proposed corrective action, and action to prevent recurrence onto the

non-conformance report (NCR). The corrective action taken shall be reported onto the non-conformance report (NCR), conducted in accordance with the accepted disposition, and verified by the QC manager and the Department. Non-conformance reports (NCRs) shall be made available upon the request of the Department.

M4.03.2.D.1: Quality Control Sampling

The QC sampling for testing and inspection shall be conducted in accordance with the required procedures for obtaining or inspecting representative materials or products. The QC sampling population shall be comprised of lots and sublots. A lot shall be defined as a specific quantity of material from a single source which is assumed to be produced or placed by the same controlled process. A lot shall be used to represent the population of the produced material and constructed product. The lot size shall be the specified quantity of material produced and placed. A sublot shall be defined as a subdivision of a lot. The sublots shall be used to assess the inspection attributes and quality characteristics of the lot. The sublot size shall be the specified subdivision of quantity for a given lot.

Table M4.03.2-1: Sampling Requirements for QC Testing

Material	Lot Size	Sublot Size	Test Method	Frequency
Aggregate	Total quantity of aggregate (tons) used for the production of concrete, per source, per type, per size	-	AASHTO T 27	One per week
			AASHTO T 255	One per day
Concrete	Total quantity of concrete (cy) produced on the contract, per the contract bid item, per approved mix design formulation	100 cy	Table M4.03.2-3 Table M4.03.2-4	One per sublot or fraction thereof, minimum one per day

The sampling population for testing and inspection shall be randomly sampled in accordance with ASTM D3665. Random sampling shall be defined as a small quantity of material or measurement obtained from a lot or sublot, whereby each sample obtained from the lot or sublot has an equal probability of being selected. Selective (non-random) sampling may also be conducted to provide supplemental information to assist in maintaining control of all production and placement processes. Selective sampling shall not replace random sampling and shall not be incorporated into the sampling population for quality testing and quality inspection.

M4.03.2.D.2: Quality Control Testing

The QC testing shall be conducted in accordance with the specified test method, the quality characteristics and limits identified on the standardized test report form (TRF), and the requirements specified herein. The QC test results shall meet the requirements specified in the following tables.

Table M4.03.2-2: QC Testing Requirements for Aggregate

Property	Test Method	Quality Characteristic	Limits	
			Min.	Max.
Uniformity	AASHTO T 27	Mass of Material Passing (%)	M4.01.2	
Moisture	AASHTO T 255 [1]	Moisture Content (%)	[2]	

[1] Fine aggregate moisture content testing is not required for facilities outfitted with in-line fine aggregate moisture meters. However, coarse aggregate moisture content testing is required.
[2] Fabricator shall adjust mix design formulations to account for the moisture content of the aggregate.

Table M4.03.2-3: QC Testing Requirements for Fresh Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO M 157	Batching Quantities of Constituent Materials		M4.02.3	
AASHTO T 121	Unit Weight (lb/ft^3)		Target - 3.0	Target +3.0
AASHTO T 119[1]	Slump (in.)	< 4 in.	Target -1.0	Target +1.0
		4 – 8 in.	Target -1.5	Target +1.5
	Segregation Resistance [2]		Pass [3]	
AASHTO T 347[4]	Slump Flow (in.)		Target -2.0	Target +2.0
AASHTO T 152[5] AASHTO T 196[6]	Air Content (%)		Target -1.5	Target +1.5
AASHTO T 309	Concrete Temperature (°F)		50	90

[1] Not required for self-consolidating concrete (M4.06.6).
[2] Visual inspection for segregation resistance, consolidation, and cohesion shall be conducted while the concrete is being discharged and during AASHTO T 119.
[3] Non-conforming visual signs of segregation include coarse particles advancing in front of or behind the fine particles and mortar and a tendency for coarse aggregate to separate from the mortar, particularly when the mixture is being consolidated. The concrete shall exhibit quality consolidation and cohesion.
[4] For self-consolidating concrete (M4.06.6).
[5] For normal weight concrete.
[6] For lightweight concrete (M4.06.5).

Table M4.03.2-4: QC Testing Requirements for Hardened Concrete [1]

Test Method	Quality Characteristic			Limits	
				Min.	Max.
Select One Method	AASHTO T 22 [2] ASTM C1074 AASHTO T 412	Compressive Strength (psi) for High Early Strength Concrete (M4.06.3)	12 Hours	Informational	
			24 Hours	2500	–
			3 Days	4000	–
		Compressive Strength (psi) for Rapid Hardening Concrete (M4.06.4)	2 Hours	Informational	
			4 Hours	2500	–
			6 Hours	Informational	
			24 Hours	4000	–

[1] QC testing for hardened concrete is only required for high early strength concrete (M4.06.3) and rapid hardening concrete (M4.06.4).
[2] Three 4 x 8 in. cylinders shall be cast and tested for each set specified for maximum aggregate size less than 1-½ in. Two 6 x 12 in. cylinders shall be cast and tested for each set specified for maximum aggregate size greater than 1 in.

M4.03.2.D.3: Quality Control Inspection

The QC inspection shall be conducted through visual examination or physical measurement in accordance with the specified inspection method, the inspection components, attributes, conformance measures, and limits identified on the standardized inspection report form (IRF), and the requirements specified herein.

M4.03.2.E: Quality Control Document Management

Quality control document management shall be conducted in accordance with the Department approved QC operating documents and the requirements specified herein. At a minimum, the following items shall be retained and be made available upon the request of the Department:

- Required items specified for the work item
- Contract documents and special provisions
- Department approved QC operating documents, concrete mix design sheet(s), and concrete mix design approval letter(s)
- Manufacturer product technical data sheets (TDS) and mill certifications
- QC laboratory qualification(s) and certification(s)
- Qualifications and certifications for each member of the QC organization
- Volumetric mixer certification(s)
- Concrete batch tickets for each load delivered
- Random sampling report forms with material quantities manufactured, fabricated, produced, and placed by lot and sublot
- QC inspection report forms (IRFs) and test report forms (TRFs)
- Analysis of QC results through statistical analysis and control charts
- Non-conformance reports (NCRs)
- Equipment calibrations, verifications, and maintenance documentation

M4.03.3: Department Acceptance

Acceptance will be conducted by the Department, including consultants under direct contract with the Department, in accordance with Subsection: 901: Cement Concrete, Department Acceptance.

M4.04.0: Cementitious, Grout, Mortar, and Concrete Products

Concrete and high strength mortar products (M4.04.1), rapid hardening cementitious products for concrete repairs (M4.04.2), mortar products for unit masonry (M4.04.3), grout products for unit masonry (M4.04.4), and non-shrink grout products (M4.04.5) shall maintain qualification on the QCML, meet the requirements and performance criteria of the product's technical data sheet (TDS), and meet the requirements specified herein.

Cementitious, grout, mortar, and concrete products shall be packaged, dry, and preblended with preformulated constituent materials (excluding mixing water) to produce a material with acceptable quality characteristics and material properties, including time of set, compressive strength, flexural strength, slant shear bond strength, and resistance to alkali silica reaction, freezing, thawing, and de-icing cycles, shrinkage, expansion, and sulfate reaction.

Mortar products shall be defined as products containing aggregate of which less than 5% by mass of the total mixture is retained on the ⅜ in. sieve. Mortar products for concrete repairs shall be used only on repair depths of 2 in. or less. Concrete products shall be defined as products containing aggregate of which 5% or more by mass of the total mixture is retained on the ⅜ in. sieve. Concrete products for concrete repairs shall be used only on repair depths greater than 2 in. The aggregate included in the prepackaged product or extended into the product shall meet M4.01.2: Aggregate.

M4.04.0.A: Technical Data Sheet

The Manufacturer shall submit the product's technical data sheet (TDS) to the Department for review. At a minimum, the product's technical data sheets shall include:

- Product Name
- Manufacturer, including address and contact information
- Packaging
- Yield
- Product Description, including an overview of the product and its intended application(s) and use(s).
- Technical Data, including quality characteristics and corresponding performance criteria with the AASHTO and/or ASTM standard test methods identified.
- Recommended Equipment
- Instructions, including surface preparation, mixing, forming, placing, finishing, curing, and protection from adverse conditions, such as precipitation, cold conditions, and hot conditions.
- Limitations
- Storage and Shelf Life
- Safety

M4.04.0.B: Mix Design Formulation

Mix design formulation reporting and submission to the Department for review and approval is not required for grout, cementitious mortar, and concrete products. However, products extended with aggregate not included in the original product packaging shall meet M4.01.6: Mix Design Formulation and be formulated per the product's technical data sheet.

M4.04.0.C: Product Verification Testing

Product verification testing for cementitious, grout, mortar, and concrete products shall be conducted by Department recognized independent laboratories or evaluation programs. Products extended with aggregate not included in the original product packaging shall meet the verification sampling and testing requirements specified in M4.06.0: Cement Concrete. Verification test results shall meet the limits identified on the product's technical data sheet (TDS) and specified herein.

M4.04.1: Concrete and High Strength Mortar Products

Concrete and high strength mortar products shall meet ASTM C387.

M4.04.2: Rapid Hardening Cementitious Products for Concrete Repairs

Rapid hardening cementitious products for concrete repairs shall meet Table M4.04.2-1, Table M4.04.2-2, and ASTM C928.

Table M4.04.2-1: Types of Rapid Hardening Cementitious Products for Concrete Repairs

Type	Description	Application [1]
R1	General Rapid Hardening	Vertical and Overhead Repairs
R2	Medium Rapid Hardening	Vertical and Overhead Repairs
R3	Very Rapid Hardening	Horizontal, Vertical, and Overhead Repairs

[1] Products for vertical and overhead repair applications shall be able to be placed on a vertical or overhead surface without the need of formwork.

Table M4.04.2-2: Verification Testing Requirements for Hardened Properties

Test Method	Quality Characteristic			Limits	
				Min.	**Max.**
ASTM C928 [1]	Compressive Strength [2], Bond Strength, Length Change, Consistency, and Scaling Resistance			ASTM C928	
AASHTO T 197	Initial Set (min.)			TDS	
	Final Set (min.)			TDS	
AASHTO T 97 [3]	Flexural Strength (psi)	24 Hours	Types R1 and R2	Informational	
			Type R3	650	–
		7 Days	Types R1, R2, R3	Informational	
Select One Method for Chloride Ion Penetration Resistance	AASHTO T 358 [4]	Apparent Surface Resistivity (kΩ-cm)		Table M4.06.2-4	
	AASHTO T 402 [4]	Bulk Resistivity (Ω-m)		Table M4.06.2-4	
AASHTO T 161 (A)	Relative Durability Factor			90	–
	Mass Loss (%)			–	6.0

[1] All test methods identified in ASTM C928 shall be conducted.
[2] For concrete products: Three 4 x 8 in. cylinders shall be cast for each specified age for maximum aggregate size less than 1-½ in. Two 6 x 12 in. cylinders shall be cast for each specified age for maximum aggregate size greater than 1 in.
[3] For concrete products: Two 6 x 6 x 20 in. beams shall be cast for each age specified. Not applicable to vertical and overhead repair applications.
[4] Specimens shall be prepared and test method incompatibility shall be addressed as specified in Table M4.06.1-4.

M4.04.3: Mortar Products for Unit Masonry

Mortar products for unit masonry ASTM C1714. Field proportioned mortar shall meet Type M specified in ASTM C270.

M4.04.4: Grout Products for Unit Masonry

Grout products for unit masonry shall meet ASTM C476.

M4.04.5: Non-Shrink Grout Products

Non-shrink grout products shall meet ASTM C1107. Non-shrink grout products shall be intended for use under applied load, including supporting a structure, transfer medium between load-bearing members, shear keys, and other non-shrink applications, where a change in height below initial placement height is to be avoided.

M4.05.0: Brick, Block, and Drycast Segmental Retaining Wall Units

Concrete masonry units for catch basins and manholes (M4.05.1), clay brick for sewer and manholes (M4.05.2), sidewalk brick (M4.05.3), precast concrete block for slope paving (M4.05.4), and drycast segmental retaining wall units (M4.05.5) shall maintain qualification on the QCML and meet the requirements specified herein.

M4.05.1: Concrete Masonry Units for Catch Basins and Manholes

Concrete masonry units for catch basins and manholes shall meet ASTM C139. Cement masonry units shall be sampled and tested in accordance with ASTM C140.

M4.05.2: Clay Brick for Sewer and Manholes

Clay brick for sewer and manholes shall meet Grade MS of ASTM C32. Clay brick shall be sampled and tested in accordance with ASTM C67.

M4.05.3: Sidewalk Brick

Sidewalk brick shall meet ASTM C902.

M4.05.4: Precast Concrete Block for Slope Paving

Precast concrete block for slope paving shall meet ASTM C90. Precast concrete block for slope paving shall be sampled and tested in accordance with ASTM C140.

M4.05.5: Drycast Segmental Retaining Wall Units

Drycast segmental retaining wall units shall meet ASTM C1372.

M4.06.0: Cement Concrete

Cement concrete shall be designed and produced with precise proportions of constituent materials to form a homogenous composition with a well distributed, spaced, and sized air void system. Cement concrete shall exhibit acceptable quality characteristics and material properties, including uniformity, workability, bleeding and settlement, setting, thermal effects, shrinkage control, strength, modulus of elasticity, aesthetics, long-term durability, and resistance to premature deterioration due to alkali silica reaction, iron sulfide reaction, freezing, thawing, and de-icing cycles, corrosion of steel reinforcement, abrasion and erosion, sulfate reaction, salt crystallization, acid disintegration, carbonation reaction, delayed ettringite formation, and marine environments for the expected service life of the structure. Cement concrete shall meet the requirements specified herein.

M4.06.0.A: Verification Testing

Verification testing (trial batch testing) of cement concrete mix design formulations shall be required under the following conditions:

- Producer or plant location is not currently prequalified.
- Proposed mix design formulation incorporates new sources of constituent materials not currently prequalified.
- Proposed mix design formulation incorporates new design quantities and design targets that have never been approved.
- At the discretion of the Department.

A request for cement concrete verification testing shall be submitted by the Producer to the Department for review. Producers shall report proposed mix design formulations on the Department issued mix design sheet in its entirety and submit to the Department for review prior

to verification testing. Producers shall select a Department recognized independent laboratory to conduct the required field and laboratory verification sampling and testing as specified herein.

Field verification sampling and testing shall be conducted by certified technicians with American Concrete Institute (ACI) Concrete Field Technician – Grade I (or higher), in the presence of Department acceptance technicians. All field verification sampling and testing activities conducted by the independent laboratory shall be witnessed by the Department. The Department will obtain the sampled concrete cylinders to conduct the required compressive strength and chloride ion penetration resistance laboratory testing as specified herein. All other required laboratory testing shall be conducted by the independent laboratory.

Adjustments to proposed slump (or slump flow), air content, or compressive strength design targets shall be requested by the Producer for Department review. Adjustments to these design targets shall be based on the verification test results and are subject to Department approval. Verification test results shall meet the limits specified herein.

M4.06.1: Conventional Concrete

Conventional concrete (CC) shall meet the requirements specified herein. Conventional concrete shall be designed for drainage structures, water systems, curb and edging, sign supports, noise barrier, and other specified applications.

M4.06.1.A: Mix Design Formulation

Conventional concrete shall meet the mix design formulation target requirements specified in Table M4.06.1-1 and Table M4.06.1-2.

Table M4.06.1-1: Mix Design Formulation Target Requirements

28-Day Compressive Strength (psi) [1]	Nominal Maximum Aggregate Size (in.)					Total Cementitious Content (lb/yd^3)
2,500	⅜	½	¾	1	1-½	[2]
3,000						
3,500						
4,000						
4,500						
5,000						

[1] For mass placement (M4.06.9) of cast-in-place conventional concrete, the target shall be attained at 56 days.

[2] The total cementitious content of the mix design formulation shall be optimized to meet the specified quality characteristics and material properties and the equivalent cement content design targets for a given concrete member dimension as specified in Table M4.01.6-4.

Table M4.06.1-2: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Applicable F Exposure Class	Table M4.01.6-7
Type M-CIA Content	Applicable C Exposure Class	Table M4.01.6-8 [1]
Air Content	Applicable F Exposure Class	Table M4.01.6-10
Water-Cementitious (w/cm) Ratio	Applicable F or W Exposure Class	Table M4.01.6-11
Water-Cementitious (w/cm) Ratio	Applicable S Exposure Class	Table M4.01.6-12
Water-Cementitious (w/cm) Ratio	Applicable C Exposure Class	Table M4.01.6-13 [1]

[1] Design target shall only apply to concrete with non-coated steel reinforcement.

M4.06.1.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified in Table M4.06.1-3.

Table M4.06.1-3: Verification Testing Requirements for Fresh Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO M 157	Batching Quantities of Constituent Materials		M4.02.3	
AASHTO T 121	Unit Weight (lb/ft^3)		Target -3.0	Target +3.0
AASHTO T 119	Slump (in.)	< 4 in.	Target -1.0	Target +1.0
		4 – 8 in.	Target -1.5	Target +1.5
	Segregation Resistance, Consolidation, and Cohesion [1]		Pass [2]	
AASHTO T 152	Air Content (%)		Target -1.5	Target +1.5
AASHTO T 309	Concrete Temperature (°F)		50	90

[1] Visual inspection for segregation resistance, consolidation, and cohesion shall be conducted while the concrete is being discharged and during AASHTO T 119

[2] Non-conforming visual signs of segregation include coarse particles advancing in front of or behind the fine particles and mortar and a tendency for coarse aggregate to separate from the mortar, particularly when the mixture is being consolidated. The concrete shall exhibit quality consolidation and cohesion.

M4.06.1.C: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified in Table M4.06.1-4.

Table M4.06.1-4: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic			Limits	
				Min.	Max.
AASHTO T 22 [1][2]	Compressive Strength (psi)		3 Days	Informational	
			7 Days	Informational	
			28 Days [3]	Target	–
			56 Days	Informational	
Select One Method for Chloride Ion Penetration Resistance	AASHTO T 358 [1][4][5]	Apparent Surface Resistivity (kΩ-cm)	7 Days	Informational	
			28 Days	Informational	
			56 Days	Informational	
	AASHTO T 402 [1][4][5]	Bulk Resistivity (Ω-m)	7 Days	Informational	
			28 Days	Informational	
			56 Days	Informational	
Select One Method for Alkali Silica Reaction Resistance	ASTM C1260	100% Cement Expansion (%) [6]	14 Days	–	0.10
	ASTM C1567	SCM Mitigation Expansion (%) [7]	14 Days	–	0.10
	AASHTO T 380	100% Cement Expansion (%) [6]	56 Days [8]	–	0.030 [8]
		SCM Mitigation Expansion (%) [7]	56 Days	–	0.019
	AASHTO TP 142	100% Cement Expansion (%) [6]	45 Days	–	0.039
		SCM Mitigation Expansion (%) [7]	75 Days [9]	–	0.039 [9]
			90 Days [10]	–	0.039 [10]
		Mix Design Expansion (%) [11]	120 Days	–	0.039
	AASHTO TP 144	Reactivity Index	21 Days	Non-reactive	

[1] Three 4 x 8 in. cylinders shall be cast for each specified age for maximum aggregate size less than 1-½ in. Two 6 x 12 in. cylinders shall be cast for each specified age for maximum aggregate size greater than 1 in.

[2] Subject to Department review and approval, the following in-place, non-destructive test methods may be used as an alternative to AASHTO T 22 for determining early age strength during construction for Department approved applications as specified in the contract documents, special provisions, or Division II: Construction Details:
- ASTM C1074
- AASHTO T 412

[3] For mass placement (M4.06.9) of cast-in-place conventional concrete, the target shall be attained at 56 days.

[4] Test specimens shall be moist cured in accordance with AASHTO M 201, shall remain in a 100 percent relative humidity condition from the moment of mold removal to the moment of the test, and be in saturated surface dry (SSD) condition during testing.

[5] Concrete containing conductive constituents, including steel fibers (M4.01.5) or chemical admixtures (M4.01.4) with suspended carbon materials and ionic salts (calcium nitrite, calcium nitrate, and sodium thiocyanate), is incompatible with the noted electrical indication test methods. The Producer is permitted to request an additional set of cylinders to be cast and tested without the conductive constituents. The omitted conductive chemical admixture(s) shall be replaced by an equivalent volume of water. An additional sample set may be cast and tested with the incompatible constituent materials for informational purposes only. If the conductive constituents cannot be omitted from the concrete,

Department approved alternative test methods shall be conducted and the test results shall meet the limits specified by the Department.

[6] For determining the degree of alkali silica reactivity of aggregate, the test specimens shall be prepared with 100% cement without SCM mitigation.

[7] If the aggregate is determined to be alkali silica reactive, additional testing for the effectiveness of SCM mitigation shall be conducted per the proposed SCM content of the mix design formulation.

[8] Aggregate with 56-day expansion results greater than 0.03% but less than or equal to 0.04% shall be considered nonreactive if the average two-week rate of expansion from day 56 to day 84 is less than or equal to 0.01%, otherwise, expansion results shall be considered reactive.

[9] For moderately reactive aggregate.

[10] For slowly reactive aggregate.

[11] For determining mix design formulation effectiveness to resist alkali silica reaction, when the aggregate is determined to be alkali silica reactive.

M4.06.2: High Performance Concrete

High performance concrete (HPC) shall meet the requirements specified herein. When combined with other types of mix design formulations, high performance concrete shall also meet the requirements specified for those types. High performance concrete shall be designed for concrete barrier, steel reinforced exterior concrete slabs, driven piles, drilled shafts, precast bridge elements, prestressed concrete products, prefabricated bridge units, structural reinforced concrete components, field-cast connections between structural precast components, and other specified applications. High performance (M4.06.2) exterior slab concrete (M4.06.7) shall be designed for steel reinforced exterior concrete flatwork, including approach slabs, bridge sidewalk, and bridge decks.

M4.06.2.A: Mix Design Formulation

High performance concrete shall meet the mix design formulation target requirements specified in Table M4.06.2-1 and Table M4.06.2-2.

Table M4.06.2-1: Mix Design Formulation Target Requirements

28-Day Compressive Strength (psi) [1]	Nominal Maximum Aggregate Size (in.)					Total Cementitious Content (lb/yd^3)
5,000	⅜			½		[2] and ≤ 710
5,000	¾					[2] and ≤ 685
5,000	1			1-½		[2] and ≤ 660
6,500 8,000 10,000	⅜	½	¾	1	1-½	[2]

[1] For mass placement (M4.06.9) of cast-in-place high performance concrete, the target shall be attained at 56 days.

[2] The total cementitious content of the mix design formulation shall be optimized to meet the specified quality characteristics and material properties and the equivalent cement content design targets for a given concrete member dimension as specified in Table M4.01.6-4.

Table M4.06.2-2: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Exposure Class F3	Table M4.01.6-7
Type M-CIA Content	Exposure Class C3	Table M4.01.6-8 [1]
Type S-SCA Content	Shrinkage Resistance	Table M4.01.6-9 [2][3]
Type S-SRA Content	Shrinkage Resistance	Table M4.01.6-9 [2][3]
Type S-CRA Content	Shrinkage Resistance	Table M4.01.6-9 [2][3]
Air Content	Exposure Class F3	Table M4.01.6-10
Water-Cementitious (w/cm) Ratio	Exposure Class F3	Table M4.01.6-11
Water-Cementitious (w/cm) Ratio	Exposure Class S3	Table M4.01.6-12
Water-Cementitious (w/cm) Ratio	Exposure Class C3	Table M4.01.6-13 [1]
Shilstone Workability-Coarseness	Enhanced Workability	Figure M4.01.6-1 [2] Table M4.01.6-14 [2]
Tarantula Curve	Enhanced Workability	Table M4.01.6-15 [2][4]
Paste Content	Shrinkage Resistance	Table M4.01.6-16 [2][3]
PC_{AIR}/VC_{MIX} Ratio	Enhanced Workability	Table M4.01.6-17 [2]

[1] Design target shall only apply to concrete with steel reinforcement.
[2] Design target is not applicable to high performance self-consolidating concrete (M4.06.6) mix design formulations.
[3] Design target is not applicable to high performance fiber reinforced concrete (M4.06.10) mix design formulations.
[4] Design target shall only apply to high performance exterior slab concrete (M4.06.7) mix design formulations.

M4.06.2.B: Aggregate Properties

The aggregate properties shall meet the requirements specified in Table M4.06.2-4.

Table M4.06.2-3: Verification Testing Requirements for Aggregate Properties

Test Method	Quality Characteristic	Limits	
		Min.	Max.
AASHTO T 19	Composite Void Content of Combined Aggregate System (%)	[1]	

[1] The composite void content of the combined aggregate system shall be reported onto the Department issued cement concrete mix design sheet to calculate the paste content (with air) to mix design void content (PC_{AIR}/VC_{MIX}) ratio as specified in Table M4.01.6-17.

M4.06.2.C: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3).

M4.06.2.D: Hardened Concrete Properties

The hardened concrete properties shall meet the compressive strength and alkali silica reaction (ASR) resistance requirements specified for conventional concrete (Table M4.06.1-4) and the requirements specified in Table M4.06.2-4.

Table M4.06.2-4: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic				Limits	
					Min.	Max.
Select One Method for Chloride Ion Penetration Resistance	AASHTO T 358 [1]	Apparent Surface Resistivity (kΩ-cm)	7 Days		Informational	
			28 Days [2]	4 x 8 in. cylinders	21	–
				6 x 12 in. cylinders	16.5	–
			56 Days		Informational	
	AASHTO T 402 [1]	Bulk Resistivity (Ω-m)	7 Days		Informational	
			28 Days [2]		104.0	–
			56 Days		Informational	

[1] Specimens shall be prepared and test method incompatibility shall be addressed as specified in Table M4.06.1-4.
[2] For mass placement (M4.06.9) of cast-in-place high performance concrete, the target shall be attained at 56 days.

M4.06.3: High Early Strength Concrete

High early strength concrete (HESC) shall meet the requirements specified herein. When combined with other types of mix design formulations, high early strength concrete shall also meet the requirements specified for those types. High early strength concrete shall be designed to accelerate repairs, construction, and hydration in cold conditions.

M4.06.3.A: Mix Design Formulation

High early strength concrete shall meet the mix design formulation target requirements specified in Table M4.06.3-1.

Table M4.06.3-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
7-Day Compressive Strength (psi)	Design Target	≥ 5,000
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content	Design Target	Table M4.06.1-1
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Exposure Class F3	Table M4.01.6-7
Type M-CIA Content	Applicable C Exposure Class	Table M4.01.6-8 [1]
Type S-SCA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-SRA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-CRA Content	Shrinkage Resistance	Table M4.01.6-9
Air Content	Exposure Class F3	Table M4.01.6-10
Water-Cementitious (w/cm) Ratio	Exposure Class F3	Table M4.01.6-11
Water-Cementitious (w/cm) Ratio	Exposure Class S3	Table M4.01.6-12
Water-Cementitious (w/cm) Ratio	Exposure Class C3	Table M4.01.6-13 [1]
Shilstone Workability-Coarseness	Enhanced Workability	Figure M4.01.6-1 Table M4.01.6-14
Paste Content	Shrinkage Resistance	Table M4.01.6-16

[1] Design target shall only apply to concrete with steel reinforcement.

M4.06.3.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3).

M4.06.3.C: Hardened Concrete Properties

The hardened concrete properties shall meet the alkali silica reaction (ASR) resistance requirements specified for conventional concrete (Table M4.06.1-4), the chloride ion penetration resistance requirements specified for high performance concrete (Table M4.06.2-4), and the requirements specified in Table M4.06.3-2.

Table M4.06.3-2: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic			Limits	
				Min.	**Max.**
AASHTO T 22 [1]	Compressive Strength (psi)		12 Hours	Informational	
			24 Hours	2500	–
			3 Days	4000	–
			7 Days	5000	–
			28 Days	Informational	
AASHTO T 97 [2]	Flexural Strength (psi)		12 Hours	Informational	
			24 Hours	400	–
			3 Days	550	–
			7 Days	650	–
			28 Days	Informational	
ASTM C882	Slant Sheared Bond Strength (psi)		24 Hours	1200	–
			7 Days	1900	–
			28 Days	2200	–
AASHTO T 197	Initial Set (min.)			Informational	
	Final Set (min.)			Informational	
AASHTO T 160 [3]	Unrestrained Volume Change (με)		28 Days	–	420
Select One Method for Restrained Shrinkage [3]	ASTM C1581 [4]	No Cracking [6] (days)		28	–
	AASHTO T 363 [5]	Average Stress (psi)	7 Days	–	0.6T [7]

[1] Specimens shall be prepared as specified in Table M4.06.1-4.
[2] Two 6 x 6 x 20 in. beams shall be cast for each age specified.
[3] Subject to Department review and approval, the unrestrained and restrained shrinkage testing requirements may be waived under one or more of the following conditions:
- Mix designs formulated with shrinkage inhibiting chemical admixtures identified in Table M4.01.6-9.
- Mix designs formulated with paste content meeting the limits specified in Table M4.01.6-16.

[4] For nominal maximum aggregate sizes less than or equal to ½ in.
[5] For any nominal maximum aggregate size.
[6] Cracking is defined as the sudden decrease in compressive strain greater than 30 με.
[7] The splitting tensile strength (T) at 28 days shall be determined by AASHTO T 198.

M4.06.4: Rapid Hardening Concrete

Rapid hardening concrete (RHC) shall meet the requirements specified herein. When combined with other types of mix design formulations, rapid hardening concrete shall also meet the requirements specified for those types. Rapid hardening concrete shall be designed for accelerated construction applications, including repairs and field-cast connections between structural precast components.

M4.06.4.A: Mix Design Formulation

Rapid hardening concrete shall be formulated with rapid hardening hydraulic cement (M4.01.1) and meet the mix design formulation target requirements specified in Table M4.06.4-1.

Table M4.06.4-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
7-Day Compressive Strength (psi)	Design Target	≥ 5,000
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content	Design Target	Table M4.06.1-1
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Exposure Class F3	Table M4.01.6-7
Type S-SCA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-SRA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-CRA Content	Shrinkage Resistance	Table M4.01.6-9
Air Content	Exposure Class F3	Table M4.01.6-10
Water-Cementitious (w/cm) Ratio	Exposure Class F3	Table M4.01.6-11
Water-Cementitious (w/cm) Ratio	Exposure Class S3	Table M4.01.6-12
Water-Cementitious (w/cm) Ratio	Exposure Class C3	Table M4.01.6-13 [1]
Paste Content	Shrinkage Resistance	Table M4.01.6-16

[1] Design target shall only apply to concrete with steel reinforcement.

M4.06.4.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3).

M4.06.4.C: Hardened Concrete Properties

The hardened concrete properties shall meet the alkali silica reaction (ASR) resistance requirements specified for conventional concrete (Table M4.06.1-4), the chloride ion penetration resistance requirements specified for high performance concrete (Table M4.06.2-4), the initial set, final set, unrestrained shrinkage, and restrained shrinkage requirements specified for high early strength concrete (Table M4.06.3-2), and the requirements specified in Table M4.06.4-2. Subject to Department review and approval, the unrestrained and restrained shrinkage testing requirements may be waived for mix designs formulated with calcium sulfoaluminate based rapid hardening hydraulic cement (M4.01.1).

Table M4.06.4-2 Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO T 22 [1]	Compressive Strength (psi)	2 Hours	Informational	
		4 Hours	2500	–
		6 Hours	Informational	
		24 Hours	4000	–
		7 Days	5000	–
		28 Days	Informational	
AASHTO T 97 [2]	Flexural Strength (psi)	2 Hours	Informational	
		4 Hours	400	–
		6 Hours	Informational	
		24 Hours	550	–
		7 Days	650	–
		28 Days	Informational	
ASTM C882	Slant Sheared Bond Strength (psi)	24 Hours	1200	–
		7 Days	1900	–
		28 Days	2200	–

[1] Specimens shall be prepared as specified in Table M4.06.1-4.
[2] Specimens shall be prepared as specified in Table M4.06.3-2.

M4.06.5: Lightweight Concrete

Lightweight concrete (LWC) shall meet the requirements specified herein. When combined with other types of mix design formulations, lightweight concrete shall also meet the requirements specified for those types. Lightweight concrete shall be designed for structural components requiring a reduced dead load.

M4.06.5.A: Mix Design Formulation

Lightweight concrete shall be formulated with lightweight aggregate (M4.01.2) and meet the mix design formulation targets specified for conventional concrete (Table M4.06.1-1 and Table M4.06.1-2).

M4.06.5.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3), with the following exception: Air content testing shall be conducted in accordance with AASHTO T 196.

M4.06.5.C: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-4) and Table M4.06.5-1.

Table M4.06.5-1: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic	Limits	
		Min.	Max.
ASTM C567	Calculated Equilibrium Density, E_c (lb/ft^3) [1]	–	115.0

[1] Measured oven dry density (O_m) shall be used for calculated equilibrium density (E_c).

M4.06.6: Self-Consolidating Concrete

Self-consolidating concrete (SCC) shall meet the requirements specified herein. When combined with other types of mix design formulations, self-consolidating concrete shall also meet the requirements specified for those types. Self-consolidating concrete shall be designed as a non-segregating concrete that is sufficiently flowable to fill formwork, spread into place, and encapsulate reinforcing steel, requiring minimal or no mechanical vibration to avoid segregation of the plastic concrete mixture.

M4.06.6.A: Mix Design Formulation

Self-consolidating concrete shall meet the mix design formulation targets meet the mix design formulation targets specified for conventional concrete (Table M4.06.1-1 and Table M4.06.1-2) and in Table M4.06.6-1.

Table M4.06.6-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
Slump Flow (in.)	Design Target	24.0 – 27.0
Fine Aggregate Content [1]	Design Target	≤ 50.0

[1] By total mass of combined aggregate system.

M4.06.6.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3, apart from AASHTO T 119) and the requirements specified in Table M4.06.6-2.

Table M4.06.6-2: Verification Testing Requirements for Fresh Concrete [1]

Test Method	Quality Characteristic	Limits	
		Min.	Max.
AASHTO T 347	Slump Flow (in.)	Target -2.0	Target +2.0
AASHTO T 347 AASHTO T 345	Passing Ability (in.) [2]	–	2.0
AASHTO T 351	Visual Stability Index	0 or 1	
ASTM C1610	Column Segregation (%)	–	15

[1] The additional test methods identified in Section 3.2.2 of ACI 544.2R shall be conducted for fiber reinforced (M4.06.10) self-consolidating concrete (M4.06.6) mix design formulations.

[2] The passing ability shall be defined as the difference between AASHTO T 347 Slump Flow of Self-Consolidating Concrete (SCC) and AASHTO T 345 Passing Ability of Self-Consolidating Concrete (SCC) by J-Ring.

M4.06.6.C: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-4).

M4.06.7: Exterior Slab Concrete

Exterior slab concrete (ESC) shall meet the requirements specified herein. When combined with other types of mix design formulations, exterior slab concrete shall also meet the requirements specified for those types. Exterior slab concrete shall be designed for non-reinforced (plain) exterior concrete flatwork, including base course, sidewalk, pedestrian curb ramps, driveways, impact attenuator slabs, and waterway slabs. High performance (M4.06.2) exterior slab concrete (M4.06.7) shall be designed for steel reinforced exterior concrete flatwork, including approach slabs, bridge sidewalk, and bridge decks.

M4.06.7.A: Mix Design Formulation

Exterior slab concrete shall meet the mix design formulation targets specified in Table M4.06.7-1.

Table M4.06.7-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
28-Day Compressive Strength	Design Target	Table M4.06.1-1
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content	Design Target	Table M4.06.1-1
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Type AEA Content	Exposure Class F3	Table M4.01.6-7
Air Content	Exposure Class F3	Table M4.01.6-10
Type S-SCA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-SRA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-CCA Content	Shrinkage Resistance	Table M4.01.6-9
Water-Cementitious (w/cm) Ratio	Exposure Class F3	Table M4.01.6-11
Water-Cementitious (w/cm) Ratio	Applicable S Exposure Class	Table M4.01.6-12
Shilstone Workability-Coarseness	Enhanced Workability	Figure M4.01.6-1 Table M4.01.6-14
Tarantula Curve	Enhanced Workability	Table M4.01.6-15
Paste Content	Shrinkage Resistance	Table M4.01.6-16
PC_{AIR}/VC_{MIX} Ratio	Enhanced Workability	Table M4.01.6-17

M4.06.7.B: Aggregate Properties

The aggregate properties shall meet the requirements specified in Table M4.06.2-3.

M4.06.7.C: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3).

M4.06.7.D: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-4).

M4.06.8: Pavement Concrete

Pavement concrete (PC) shall meet the requirements specified herein. When combined with other types of mix design formulations, pavement concrete shall also meet the requirements specified for those types. Pavement concrete shall be designed for concrete pavement.

M4.06.8.A: Mix Design Formulation

Pavement concrete shall meet the mix design formulation target requirements specified in Table M4.06.8-1.

Table M4.06.8-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
28-Day Compressive Strength (psi)	Design Target	≥ 5,000
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content	Design Target	Table M4.06.1-1
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Exposure Class F3	Table M4.01.6-7
Type S-SCA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-SRA Content	Shrinkage Resistance	Table M4.01.6-9
Type S-CCA Content	Shrinkage Resistance	Table M4.01.6-9
Air Content	Exposure Class F3	Table M4.01.6-10
Water-Cementitious (w/cm) Ratio	Exposure Classes F3, S3, C3	Table M4.01.6-11 Table M4.01.6-12 Table M4.01.6-13 [1]
Shilstone Workability-Coarseness	Enhanced Workability	Figure M4.01.6-1 Table M4.01.6-14
Tarantula Curve	Enhanced Workability	Table M4.01.6-15
Paste Content	Shrinkage Resistance	Table M4.01.6-16
PCAIR/VCMIX Ratio	Enhanced Workability	Table M4.01.6-17

[1] Design target shall only apply to concrete with steel reinforcement.

M4.06.8.B: Aggregate Properties

The combined aggregate system properties shall meet the requirements specified in Table M4.06.2-3 and the requirements specified in Table M4.06.8-2.

Table M4.06.8-2: Verification Testing Requirements for Aggregate Properties

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO T 161 [1]	Deterioration Cracking (D-Cracking) Resistance	Durability Factor	90	–
		Mass Loss (%)	–	6.0

[1] Specimens shall be prepared per ASTM C1646. Testing shall be conducted per Procedure A of AASHTO T 161. Freezing and thawing cycles shall be conducted per Department cycling procedures and parameters.

M4.06.8.C: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3) and the requirements specified in Table M4.06.8-3.

Table M4.06.8-3: Verification Testing Requirements for Fresh Concrete

Test Method	Quality Characteristic	Limits	
		Min.	Max.
AASHTO T 396 [1]	Edge Slump (in.)	–	0.25
	Condition of Surface Category	–	2
	Surface Voids (%)	–	30
AASHTO T 395	System Air Metric (SAM) Number (psi) for Freezing and Thawing Resistance	–	0.20 [2]

[1] For slip formed paving applications or slump target ≤ 3 in.
[2] If test results do not meet the specified limits, AASHTO T 161 shall be conducted as specified in Table M4.06.8-4.

M4.06.8.D: Hardened Concrete Properties

The hardened concrete properties shall meet the compressive strength and alkali silica reaction (ASR) resistance requirements specified for conventional concrete (Table M4.06.1-4), the chloride ion penetration resistance requirements specified for high performance concrete (Table M4.06.2-4), the unrestrained shrinkage and restrained shrinkage requirements specified for high early strength concrete (Table M4.06.3-3), and the requirements specified in Table M4.06.8-4.

Table M4.06.8-4: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO T 336 [1]	Coefficient of Thermal Expansion (με/°F)		Target -0.5	Target +0.5
AASHTO T 97 [2]	Flexural Strength (psi)	3 Days	Informational	
		7 Days	Informational	
		28 Days	650	–
		56 Days	Informational	
AASHTO T 161 [3]	Freezing and Thawing Resistance	Durability Factor	90	–
		Mass Loss (%)	–	6.0
AASHTO T 365	Calcium Oxychloride Content (g CA_{OXY} / g Paste) for De-icing Resistance		–	0.14

[1] Structural design target shall be established by the Engineer of Record.
[2] Specimens shall be prepared as specified in Table M4.06.3-2.
[3] Only required if AASHTO T 395 test results do not meet the limits specified in Table M4.06.8-3. Testing shall be conducted per Procedure A of AASHTO T 161. Freezing and thawing cycles shall be conducted per Department cycling procedures and parameters.

M4.06.9: Mass Placement Concrete

Mass placement concrete (MPC) shall meet the requirements specified herein. When combined with other types of mix design formulations, mass placement concrete shall also meet the requirements specified for those types. Mass placement concrete shall be designed for mass placement of cast-in-place concrete, to control internal and external temperatures and prevent thermal cracking, delayed ettringite formation (DEF), and decreased durability. Mass placement of cast-in-place concrete shall be defined as:

- Concrete mix design formulations not meeting the equivalent cement content targets for a given concrete member dimension as identified in Table M4.01.6-4.
- Cement concrete placements of any volume in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat of hydration or when cement concrete placements are specifically designated as mass cement concrete on the plans.

M4.06.9.A: Mix Design Formulation

Mass placement concrete shall meet the mix design formulation target requirements specified for conventional concrete (Table M4.06.1-1 and Table M4.06.1-2).

M4.06.9.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3).

M4.06.9.C: Hardened Concrete Properties

The hardened concrete properties for mass placement of cast-in-place conventional concrete (M4.06.1) shall meet the requirements specified for conventional concrete (Table M4.06.1-4).

The hardened concrete properties for mass placement of cast-in-place high performance concrete (M4.06.2) shall meet the compressive strength and alkali silica reaction (ASR) resistance requirements specified for conventional concrete (Table M4.06.1-4) and the chloride ion penetration resistance requirements specified for high performance concrete (Table M4.06.2-4).

M4.06.9.D: Heat of Hydration Analysis and Thermal Control Plan

At a minimum of 30 days prior to mass placement of cast-in-place concrete, the Contractor shall submit the heat of hydration analysis and thermal control plan to the Department for review. Modifications to the proposed dimensions, application, or mix design formulation's source of constituent materials, design quantities, mix type, combined aggregate system, and air void system shall require either:

- A new heat of hydration analysis and thermal control plan submission; or
- A secondary analysis submission with calculations signed by a certified professional engineer (PE), showing the modification will not result in concrete temperatures exceeding that of the original mix design formulation and that no additional heat of hydration analysis, thermal modeling, or temperature control plan is required.

The concrete temperature differential between the center (hottest) and surface (coolest) shall not exceed 35°F and at no point shall the concrete temperature exceed 158°F. The heat of hydration analysis shall be conducted by a Department recognized independent laboratory and meet the requirements specified in Table M4.06.9-1.

Table M4.06.9-1: Verification Testing Requirements for Heat of Hydration Analysis

Test Method	**Quality Characteristic**		**Limits**	
			Min.	**Max.**
ACI 207 [1]	Thermal Modeling [1]	Temperature Differential (°F)	–	35°F [2]
		Concrete Temperature (°F)	–	158°F
		Thermal Control Plan	[3]	
Select One or More Method(s) for Heat of Hydration [4]	ASTM C1679	Heat of Hydration Kinetics Using Isothermal Conduction Calorimetry	[4]	
	ASTM C1702	Heat of Hydration Using Isothermal Conduction Calorimetry	[4]	
	ASTM C1753	Early Hydration Using Semi-Adiabatic Calorimetry	[4]	

[1] Thermal modelling shall be conducted in accordance with the guides, reports, or codes of ACI Committee 207 Mass and Thermally Controlled Concrete and the requirements specified herein. The mix design formulation shall be cast into a 3 x 3 x 3 ft cube specimen (or larger) to analyze the heat of hydration. The methods, procedures, equipment, specimen dimensions, and equations utilized for this analysis shall be reported in the thermal control plan. Temperature gradients shall be estimated with finite element software or by the finite difference method (Schmidt) as identified in ACI 207.2R.

[2] Subject to Department review and approval, the maximum temperature differential limit may be waived due to certain placement dimensions, reinforcement configuration, concrete properties including, tensile strength, coefficient of thermal expansion, modulus of elasticity, creep, and aggregate (M4.01.2) minerology, and other factors. Determination of the maximum temperature differential limit shall be conducted in accordance with the guides, reports, or codes of ACI Committee 207 Mass and Thermally Controlled Concrete.

[3] Thermal control plan shall meet the requirements specified herein.

[4] Optional, when directed by the Department, one or more of the heat of hydration test methods identified in the table shall be incorporated into the analysis and thermal modeling.

The thermal control plan shall be developed from the heat of hydration analysis and stamped by a certified professional engineer (PE). At a minimum, the thermal control plan shall include:

- Department issued cement concrete mix design sheet
- Description of heat of hydration standard test method(s) and thermal analysis technique(s) utilized
- Calculated or measured adiabatic temperature rise of concrete
- Upper limits for concrete temperature at time of placement
- Description of specific measures and equipment that will be used to ensure maximum temperature limit
- Calculated maximum temperature in placement based on expected conditions at time of placement and use of proposed measures to control temperatures
- Description of specific measures and equipment that will be used to ensure temperature difference will not exceed specified temperature difference limit

- Calculated maximum temperature differential in placement based on expected conditions at time of placement and use of proposed measures to control temperature differences
- Description of equipment and procedures that will be used to monitor and log temperatures and temperature differences
- Drawing of locations for temperature sensors in placement
- Description of format and frequency of providing temperature data
- Description of measures to address and reduce excessive temperatures and temperature differences if they occur
- Description of curing procedures, including materials and methods, and curing durations
- Description of formwork removal procedures to ensure temperature difference at temporarily exposed surface will not exceed temperature difference limit, and how curing will be maintained

M4.06.10: Fiber Reinforced Concrete

Fiber reinforced concrete (FRC) shall meet the requirements specified herein. When combined with other types of mix design formulations, fiber reinforced concrete shall also meet the requirements specified for those types.

Table M4.06.10-2: Types of Fiber Reinforced Concrete

Specification	Type	Properties
ASTM C1116	I	Steel Fiber Reinforced Concrete
ASTM C1116	II	Glass Fiber Reinforced Concrete
ASTM C1116	III	Synthetic Fiber Reinforced Concrete
ASTM C1116	IV	Natural Fiber Reinforced Concrete

M4.06.10.A: Mix Design Formulation

Fiber reinforced concrete shall be formulated with steel, synthetic, glass, or natural fibers (M4.01.5). Proportioning and production of fiber reinforced concrete shall meet the procedures and methods identified in ACI 544.3R, the Manufacturer's technical data sheet, and the requirements specified herein. Fiber reinforced concrete shall meet the mix design formulation targets specified for conventional concrete (Table M4.06.1-1 and Table M4.06.1-2).

M4.06.10.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3) and the requirements specified in Table M4.06.10-3.

Table M4.06.10-3: Verification Testing Requirements for Fresh Concrete

Test Method	Quality Characteristic	Limits	
		Min.	Max.
AASHTO T 119 [1]	Fiber Dispersion	Pass [2]	
ACI 544.2R [3][4]	Fiber Dispersion and Orientation	[5]	
ASTM C1579 [3]	Plastic Shrinkage Cracking Reduction Ratio (%)	[5]	
ACI 544.2R [6]	Fresh State Performance Tests for Fiber Reinforced Self-Consolidating Concrete	[5]	

[1] Visual check for acceptable dispersion of fibers shall be conducted during AASHTO T 119 testing.
[2] Fibers incorporated into the cement concrete shall be uniformly distributed and free of balling.
[3] Optional, when directed by the Department.
[4] Fiber dispersion and orientation shall be evaluated using one of the procedures and methods identified in ACI 544.2R.
[5] Test results shall be informational, meet the limits specified in the contract documents and special provisions, or meet the limits identified in ACI 544.2R, as directed by the Department.
[6] The test methods identified in Section 3.2.2 of ACI 544.2R shall be conducted for fiber reinforced (M4.06.10) self-consolidating concrete (M4.06.6) mix design formulations.

M4.06.10.C: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-4) and the requirements specified in Table M4.06.10-4.

Table M4.06.10-4: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO T 22 [1]	Compressive Strength (psi)		Table M4.06.1-4	
Select One Method for Chloride Ion Penetration Resistance	AASHTO T 358 [2]	Apparent Surface Resistivity (kΩ-cm)	Table M4.06.1-4	
	AASHTO T 402 [2]	Bulk Resistivity(Ω-m)	Table M4.06.1-4	
ASTM C1609	First Peak Strength (psi)		[4]	
	Ultimate Strength (psi)		[4]	
	Residual Strength at Net Deflection (L/600)		[4]	
	Residual Strength at Net Deflection (L/150)		[4]	
	Flexural Toughness (Joules) [3]		[4]	
ASTM C1399	Average Residual Strength (psi)		[4]	
ASTM C1550 [5]	Energy Absorption (Joules)		[4]	

[1] Specimens shall be prepared as specified in Table M4.06.1-4, with the following exceptions: Specimens shall be filled in one lift and consolidated using external or internal vibration per AASHTO R 100. Rodding of test specimens shall be prohibited.
[2] Specimens shall be prepared and test method incompatibility shall be addressed as specified in Table M4.06.1-4.
[3] Flexural toughness shall be calculated by determining the area under the load versus net deflection curve from 0 to L/150.
[4] Test results shall be informational or meet the limits specified in the contract documents and special provisions, as directed by the Department.
[5] For fiber reinforced shotcrete applications.

M4.06.11: Ultra-High Performance Concrete

Ultra-high performance concrete (UHPC) shall meet the requirements specified herein. Ultra-high performance concrete shall be designed for repair applications, link slabs, joint headers, overlays, field-cast connections between structural precast components (closure joints), and other structural applications.

M4.06.11.A: Technical Data Sheet

Manufacturers or Producers supplying ultra-high performance concrete mix design formulations that incorporate prepackaged cementitious-binder or cementitious-binder-fine aggregate blended products shall submit the product's technical data sheet (TDS) to the Department for review. The components of these prepackaged products shall meet the requirements specified in sections M4.01.1: Cementitious Materials and M4.01.2: Aggregate. Prepackaged products containing one or more chemical admixtures shall meet M4.01.4: Chemical Admixtures. Constituent materials not included in the original packaging of the cementitious-binder or cementitious-binder-fine aggregate blended product shall be formulated per the product's technical data sheet (TDS) and be properly reported on the Department issued mix design sheet. At a minimum, the product's technical data sheets shall include:

- Product Name
- Manufacturer, including address and contact information
- Packaging
- Yield
- Product Description, including an overview of the product and its intended application(s) and use(s)
- Technical Data, including quality characteristics and corresponding performance criteria with the AASHTO and/or ASTM standard test methods identified
- Recommended Equipment
- Instructions, including proportioning, surface preparation, mixing, forming, placing, finishing, curing, and protection from adverse conditions, such as precipitation, cold conditions, and hot conditions
- Limitations
- Storage and Shelf Life
- Safety

Ultra-high performance concrete shall meet the performance criteria of the product's technical data sheet (TDS) and the requirements specified herein.

M4.06.11.B: Mix Design Formulation

Ultra-high performance concrete shall meet the mix design formulation targets specified in Table M4.06.11-1.

Table M4.06.11-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
28-Day Compressive Strength (psi)	Design Target	≥ 18,000
Nominal Maximum Aggregate Size	Design Target	Fine
Air Content (%)	Design Target	0.0
Water-Cementitious (w/cm) Ratio [1]	Design Target	≤ 0.25
Steel Fiber Content (lb/yd^3)	Design Target	[2]
Synthetic Fiber Content [3]	Rheology	[2]

[1] Non-reactive, inert mineral fillers incorporated into the reactive cementitious materials shall meet ASTM C1797 for use in Hydraulic Cement Concrete and be excluded from the water-cementitious (w/cm) ratio calculation.
[2] Dosage (lb/yd^3) per Manufacturer's recommendations.
[3] Subject to Department review and approval, synthetic fibers (M4.01.5) may be incorporated into the mix design formulation to control the rheology of the material for applications where the slope (grade) of the placement is of concern and reported on the Department issued mix design sheet.

M4.06.11.C: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified in Table M4.06.11-2.

Table M4.06.11-2: Verification Testing Requirements for Fresh Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO T 309	Concrete Temperature (°F)	≤ 5 Minutes	50 [1]	90 [1]
		15 Minutes	50 [1]	90 [1]
ASTM C1437 [2]	Flow (in.)		Target -1.5	Target +1.5
ASTM C1579 [3]	Plastic Shrinkage Cracking Reduction Ratio (%)		[4]	

[1] Or otherwise identified on the Manufacturer's technical data sheet.
[2] Test method shall be modified and conducted without drops per ASTM C1856.
[3] Optional, when directed by the Department.
[4] Test results shall be informational or meet the limits specified in the contract documents and special provisions, as directed by the Department.

M4.06.11.D: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified in Table M4.06.11-3.

Table M4.06.11-3: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic			Limits	
				Min.	Max.
AASHTO T 22 [1]	Compressive Strength (psi)		12 Hours	Informational	
			24 Hours	Informational	
			3 Days	Informational	
			7 Days	Informational	
			28 Days	18000	–
			56 Days	Informational	
AASHTO T 336 [2]	Coefficient of Thermal Expansion (με/°F)			Target -0.5	Target +0.5
AASHTO T 397	Direct Tension Cracking Strength (psi)		28 Days	720	–
	Direct Tension Sustained Post-Cracking Tensile Strength (psi)		28 Days	[3]	–
ASTM C1583 [4]	Direct Tension Bond Strength (psi)		28 Days	[5]	
ASTM C469	Modulus of Elasticity (ksi)		28 Days	6000	–
Select One Method for Chloride Ion Penetration Resistance	AASHTO T 358 [6]	Surface Resistivity (kΩ-cm)	7 Days	Informational	
			28 Days	255	–
			56 Days	Informational	
	AASHTO T 402 [6]	Bulk Resistivity (Ω-m)	7 Days	Informational	
			28 Days	1275.0	–
			56 Days	Informational	
ASTM C1581	Restrained Shrinkage		28 Days	No Cracking [7]	
ASTM C512	Creep Coefficient			–	0.8
	Specific Creep (millionths/psi)			–	0.30

[1] Three 3 x 6 in. cylinders shall be cast and tested per ASTM C1856 for each age specified.
[2] Structural design target shall be established by the Engineer of Record.
[3] Test result shall be greater than or equal to the direct tension cracking strength test result.
[4] For applications where bond strength to the substrate or the tensile strength of either the overlay or substrate is desired.
[5] Assume bond to an exposed aggregate concrete surface. 100% failure in a concrete substrate with compressive strength greater than or equal to 4000 psi shall be attained.
[6] Specimens shall be prepared and test method incompatibility shall be addressed as specified in Table M4.06.1-4.
[7] Cracking is defined as the sudden decrease in compressive strain greater than 30 με.

M4.06.12: Shotcrete

Shotcrete (SHOT) shall meet the requirements specified herein. Shotcrete shall be designed to pneumatically project onto a surface at high velocity, via the dry mix or wet mix method, for horizontal and vertical repairs (without sagging), soil nail walls, applications requiring no formwork, and other applications. The dry mix method shall be defined as the process of propelling

a premixed blend of cementitious materials and damp aggregate, with the use of compressed air through a hose to a nozzle. Water is added to the constituents at the nozzle as the shotcrete is projected onto the surface. The wet mix method shall be defined as the process of pumping the premixed shotcrete though a hose to the nozzle, where compressed air is added to increase the velocity and propel the shotcrete onto the surface.

M4.06.12.A: Mix Design Formulation

Wet mix method shotcrete shall meet the mix design formulation targets specified in Table M4.06.12-1 and Table M4.06.12-2. Dry mix method shotcrete shall be designed to meet the hardened concrete properties specified in Table M4.06.12-3.

Table M4.06.12-1: Wet Mix Method Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
28-Day Compressive Strength	Design Target	Table M4.06.1-1
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content	Design Target	Table M4.06.1-1
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Exposure Classes F1, F2, F3	Table M4.01.6-7
Type M-CIA Content	Applicable C Exposure Class	Table M4.01.6-8 [1]
Air Content (%)	Shotcrete Exposure Class F3	≥ 6.0
Water-Cementitious (w/cm) Ratio	Exposure Classes F3, S3, C3	Table M4.01.6-11 Table M4.01.6-12 Table M4.01.6-13

[1] Design target shall only apply to concrete with steel reinforcement.

Table M4.06.12-2: Wet Mix Method Mix Design Formulation Combined Aggregate System Target Requirements

Sieve Opening	Percent by Mass Passing Targets (%)	
	Mortar Mix Design [1]	**Concrete Mix Design [2]**
2 in.	–	–
1-½ in.	–	–
1 in.	–	–
¾ in.	–	–
½ in.	–	100
⅜ in.	100	90–100
No. 4	95–100	70–85
No. 8	80–98	50–70
No. 16	50–85	35–55
No. 30	25–60	20–35
No. 50	10–30	8–20
No. 100	2–10	2–10
No. 200	–	–

[1] Mix design incorporating fine aggregate only.
[2] Mix design incorporating coarse aggregate.

M4.06.12.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3, wet-mix only).

M4.06.12.C: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-4, wet-mix only) and the in-situ (materials test panel) requirements specified in Table M4.06.12-3 (both dry-mix and wet-mix).

Table M4.06.12-3: Verification Testing Requirements for In-Situ Hardened Concrete [1]

Test Method	Quality Characteristic			Limits	
				Min.	Max.
ASTM C1604 [2]	Drilled Cores Compressive Strength (psi)		3 Days	Informational	
			7 Days	Informational	
			28 Days	[3]	–
ASTM C457	Air-Void System	Air Content (%)		4.5	–
		Air Void Spacing Factor (in.)		–	0.01
ASTM C1550 [4]	Energy Absorption (Joules)			[5]	

[1] The minimum dimensions of the shotcrete test panel shall accommodate all required in-situ testing specified in the table. The shotcrete applied onto the test panel shall include the intended chemical admixtures (M4.01.4) applied at the nozzle (if any).
[2] Three specimens shall be cored from the shotcrete test panel for each specified age when the shotcrete is strong enough to permit sample removal without disturbing the bond between the mortar, coarse, aggregate, and fibers (if incorporated).
[3] The average compressive strength test result of all extracted core specimens shall exceed 85% of f'_c and no individual core specimen compressive strength test result shall be less than 75% of f'_c.
[4] For fiber reinforced shotcrete applications.
[5] Test results shall be informational or meet the limits specified in the contract documents and special provisions, as directed by the Department.

M4.06.13: Underwater Concrete

Underwater concrete (UWC) shall meet the requirements specified herein. Underwater concrete shall be designed for tremie pipe and pump line placements in slurry, underwater, and marine applications, including stabilization, repairs, foundations, footings, bridge piers, drilled shafts, cofferdams, and other applications. Underwater concrete requiring pneumatic application shall meet both M4.06.12: Shotcrete and the requirements specified herein.

M4.06.13.A: Mix Design Formulation

Underwater concrete shall meet the mix design formulation target requirements specified in Table M4.06.13-1.

Table M4.06.13-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
28-Day Compressive Strength	Design Target	Table M4.06.1-1
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content (lb/yd^3)	Design Target	≥ 650
Slump (in.)	Design Target	6.0 – 9.0
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3
Equivalent Cement Content	DEF and Thermal Cracking Resistance	Table M4.01.6-4
Cementitious Materials	Applicable S Exposure Class	Table M4.01.6-5
Internal Chloride Ion Content	Applicable C Exposure Class	Table M4.01.6-6 [1]
Type AEA Content	Enhanced Workability	[2]
Type S-AWA Content	Enhanced Cohesion	[2]
Type A Synthetic Fiber Content [3]	Enhanced Cohesion	[2]
Air Content	Applicable F Exposure Class	Table M4.01.6-10
Water-Cementitious (w/cm) Ratio	Design Target	≤ 0.45
Water-Cementitious (w/cm) Ratio	Exposure Class C2	Table M4.01.6-13 [1]
Shilstone Workability-Coarseness	Enhanced Workability	Figure M4.01.6-1 Table M4.01.6-14

[1] Design target shall only apply to concrete with steel reinforcement.
[2] Dosage (fl. oz./yd^3) per Manufacturer's recommendations.
[3] Optional, when directed by the Department.

M4.06.13.B: Fresh Concrete Properties

The fresh concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-3).

M4.06.13.C: Hardened Concrete Properties

The hardened concrete properties shall meet the requirements specified for conventional concrete (Table M4.06.1-4).

M4.06.14: Drycast Concrete

Drycast concrete (DC) shall meet the requirements specified herein. Drycast concrete shall be designed for concrete masonry units for catch basins and manholes (M4.05.1), drycast segmental retaining wall units (M4.05.5), reinforced concrete pipe (M5.02.1), reinforced concrete pipe flared ends (M5.02.2), and other applications.

M4.06.14.A: Mix Design Formulation

Drycast concrete shall meet the mix design formulation target requirements specified in Table M4.06.14-1.

Table M4.06.14-1: Mix Design Formulation Target Requirements

Design Parameter	Property	Design Target
28-Day Compressive Strength	Design Target	Table M4.06.1-1
Nominal Maximum Aggregate Size	Design Target	Table M4.06.1-1
Total Cementitious Content	Design Target	Table M4.06.1-1
Slump (in.)	Design Target	0.0
Cement Replacement	Enhanced Durability and Sustainability	Table M4.01.6-3

M4.06.14.B: Fresh Concrete Properties

The fresh concrete properties shall meet the batching quantities of constituent materials, unit weight, and concrete temperature requirements specified for conventional concrete (Table M4.06.1-3). Testing for slump and air content is not required.

M4.06.14.C: Hardened Concrete Properties

The hardened concrete properties shall meet the alkali silica reaction (ASR) resistance and chloride ion penetration resistance requirements specified for conventional concrete (Table M4.06.1-4) and the requirements specified in Table M4.06.14-2.

Table M4.06.14-2: Verification Testing Requirements for Hardened Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
ASTM C457	Air Content (%)		Informational	
ASTM C497 (Section 12)	Compressive Strength (psi)	3 Days	Informational	
		7 Days	Informational	
		28 Days	Target	–
		56 Days	Informational	

M4.07.0: Elastomeric Concrete

Elastomeric concrete (EC) for use in strip seal bridge joint systems, shall consist of a two-component polyurethane material that shall be mixed and placed at the job site. The cured elastomeric concrete shall meet the requirements specified in Table M4.07.0-1.

Table M4.07.0-1: Physical Properties of Elastomeric Concrete

Property	Test Method	Limits
Compressive Stress @ 5% deflection	ASTM D695	800 psi minimum
Resilience @ 5% deflection	ASTM D695	70% minimum
Impact Resistance @ -20°F, 32°F and 158°F	ASTM D3209	No cracks

M4.08.0: Controlled Low-Strength Materials

Controlled low-strength materials (CLSM) shall meet the requirements specified herein. Controlled low-strength materials is a mix design used as an alternative to compacted granular fills, including backfill, structural fill, utility fill, pavement base, subgrade, subbase, base course, conduit bedding, erosion control, and void filling. Controlled low-strength materials are designed to be a self-compacting, self-leveling, flowable, excavatable or non-excavatable, low strength, rigid setting, and unshrinkable material. Verification testing shall be conducted in accordance with M4.06.0: Cement Concrete. Verification test results shall meet the limits specified herein.

M4.08.0.A: Mix Design Formulation

Controlled Low Strength Materials mix design formulations shall be classified and reported according to the 90-day ultimate compressive strength target, nominal maximum aggregate size (NMAS), and CLSM mix type. Classification is subject to meeting the requirements specified herein. Producers shall report proposed mix design formulations on the Department issued mix design sheet in accordance with M4.01.6: Mix Design Formulation. Controlled low-strength materials shall meet the mix design formulation target requirements specified in Table M4.08.0-1.

Table M4.08.0-1: Mix Design Formulation Target Requirements

Type	Slump Flow Target (in.)	90-Day Ultimate Compressive Strength Target (psi)
CLSM – Manual Excavatable [1][2]	10.0	0 – 100
CLSM – Mechanical Excavatable [1][2]	10.0	101 – 300
CLSM – Structural Non-Excavatable [3]	10.0	> 300

[1] In addition to the ultimate compressive strength target requirements, CLSM – Manual Excavatable and CLSM – Mechanical Excavatable shall meet the removability modulus (RE) requirements specified in Table M4.08.0-2.
[2] The coarse aggregate content of the mix design shall also be considered. Mixtures using high coarse aggregate quantities may be difficult to excavate.
[3] CLSM – Structural Non-Excavatable is intended for permanent installation.

M4.08.0.B: Fresh CLSM Properties

The fresh CLSM properties shall meet the requirements specified in Table M4.08.0-2.

Table M4.08.0-2: Verification Testing Requirements for Fresh CLSM

Test Method	Quality Characteristic		Limits	
			Min.	Max.
ASTM D6023	Unit Weight (lb/ft^3)		Target -3.0	Target +3.0
	Air Content (%)	≤ 9.0%	Target -1.5	Target +1.5
		9.5% to 20%	Target -3.0	Target +3.0
		> 20%	Target -4.0	Target +4.0
ASTM D6103	Slump Flow (in.)		8.0	12.0
	Segregation Resistance [1]		Pass [2]	
AASHTO T 309	Concrete Temperature (°F)		50	90

[1] Visual inspection for segregation, consolidation, and cohesion shall be conducted while the CLSM is being discharged and during ASTM D6103.

[2] Non-conforming visual signs of segregation include coarse particles advancing in front of or behind the fine particles and mortar and a tendency for coarse aggregate to separate from the mortar, particularly when the mixture is being consolidated. The CLSM shall exhibit quality consolidation and cohesion.

M4.08.0.C: Hardened CLSM Properties

The hardened CLSM properties shall meet the requirements specified in Table M4.08.0-3.

Table M4.08.0-3: Verification Testing Requirements for Hardened CLSM

Test Method	Quality Characteristic			Limits	
				Min.	Max.
ASTM D4832 [1]	Ultimate Compressive Strength (psi)	Manual Excavatable	28 Days	Informational	
			56 Days	Informational	
			90 Days	–	100
		Mechanical Excavatable	28 Days	Informational	
			56 Days	Informational	
			90 Days	101	300
		Structural Non-Excavatable	28 Days	Informational	
			56 Days	Informational	
			90 Days	301	–
ACI 229R ASTM D4832	Removability Modulus (RE) [2]	Manual Excavatable	28 Days	–	1.0
		Mechanical Excavatable	28 Days	1.1	–
ASTM D5084 [3]	Coefficient of Water Conductivity (cm/s)			0.004	–

[1] Two 6 x 12 in. cylinders shall be cast and tested for each age specified.
[2] The Removability Modulus is determined by the equation $RE = [(W^{1.5} \times 104 \times C^{0.5}) / 10^6]$, where RE = Removability Modulus, W = Hardened Unit Weight (lb/ft^3), and C = 28 Day Compressive Strength (psi) determined by ASTM D4832. Round up to the nearest 0.1.
[3] Optional, when directed by the Department, for CLSM being placed in areas where sufficient drainage is required, including areas adjacent to roadways or concrete footings. The permeability of controlled low-strength materials shall be greater than or equal to the surrounding soil. For design purposes, the criteria shall meet or exceed the permeability of uniform fine sand (0.004) as specified in the table.

M4.09.0: Precast, Prestressed, and Prefabricated Concrete Products

Precast, prestressed, and prefabricated concrete products shall meet the requirements specified herein. Fabricators of precast concrete highway products, precast concrete bridge elements, precast concrete deck panels, and prefabricated bridge units (PBU) shall maintain certification from the National Precast Concrete Association (NPCA) Plant Certification or Precast/Prestressed Concrete Institute (PCI). Fabricators of prestressed concrete products shall maintain certification (Category B3 level or higher) from the Precast/Prestressed Concrete Institute (PCI).

Table M4.09.0-1: Categories of Precast, Prestressed, and Prefabricated Concrete Products

Category	Products
Precast Concrete Highway Products	Standard Temporary Median Barrier, Standard Permanent Median Barrier, Noise Barrier, Box Culverts (Spans ≤ 10 ft), Catch Basins, Drainage Pipes (Non-Dry Cast), Manholes, Retaining Wall Systems, Traffic Light Pole Bases, and Luminaire Bases
Precast Concrete Bridge Elements	Abutments, Piers, Footings, Wingwalls, Approach Slabs, Pile Caps, Highway Guardrail Transitions, Box Culverts (Spans > 10 ft), and Three-Sided Frames/Arches (Spans > 10 ft)
Precast Concrete Exterior Slabs and Pavement	Sidewalk, Pavement, and other Exterior Slabs
Precast Concrete Deck Panels	Deck Panels (Non-Prestressed)
Prestressed Concrete Products	Northeast Extreme Tees (NEXT D and NEXT F), Northeast Bulb Tees (NEBT and NEBT D), Box Beams, Adjacent or Spread Deck Beams, and Deck Panels (Prestressed)
Prefabricated Bridge Units (PBU)	Prefabricated Bridge Units (PBU)

M4.09.1: Materials

Materials shall meet the requirements specified in Section M4: Cement Concrete and Related Materials and the following Subsections:

Material	Subsection
General	M4.00.0
Constituent Materials	M4.01.0
Concrete Produced by Stationary and Truck Mixers	M4.02.0
Rapid Hardening Cementitious Products for Concrete Repairs	M4.04.2
Conventional Concrete	M4.06.1
High Performance Cement Concrete [1]	M4.06.2
Lightweight Concrete	M4.06.5
Self-Consolidating Concrete	M4.06.6
Exterior Slab Concrete	M4.06.7
Pavement Concrete	M4.06.8
Mass Placement Concrete	M4.06.9
Fiber Reinforced Concrete	M4.06.10
Ultra-High Performance Concrete	M4.06.11
Drycast Concrete	M4.06.14
Concrete Crack Sealers	M4.10.2
Evaporation Reducers	M4.11.0
Curing Materials	M4.12.0
Protective Sealing Compounds [2]	M4.13.0

Material	Subsection
Reinforcing Bars	M8.01.0
Epoxy Coated Reinforcing Bars [3]	M8.01.7
Galvanized Reinforcing Bars [3]	M8.01.8
Galvanized 1-in. Dowel Bars (Grade 60) [4]	AASHTO M
Galvanized Connector Pin Assembly [4]	ASTM A36
Primer and Damp-Proofing	M9.09.0

[1] Precast concrete median barrier, precast concrete bridge elements, precast concrete deck panels, prestressed concrete products, and prefabricated bridge units shall be fabricated with high performance concrete (M4.06.2).
[2] Protective sealing compounds shall be applied to precast, prestressed, and prefabricated concrete products having direct contact with freezing, thawing, and de-icing cycles, including precast concrete median barrier, guardrail transitions, and parapets as specified herein. Application of protective sealing compounds to concrete surfaces previously applied with liquid membrane-forming compounds for curing and sealing is not required.
[3] Precast concrete median barrier, precast concrete box culverts (spans ≤ 10 ft), precast concrete retaining wall systems, precast concrete traffic light pole bases, precast concrete luminaire bases, precast concrete bridge elements, precast concrete deck panels, prestressed concrete products, prefabricated bridge units, and other non-drainage precast concrete items shall be fabricated with epoxy coated or galvanized reinforcing bars.
[4] Shall be galvanized in accordance with AASHTO M 111.

M4.09.2: Fabrication Methods

Precast, prestressed, and prefabricated concrete products shall be fabricated in accordance with the following Subsections of Division II: Construction Details and the requirements specified herein:

Material	Subsection
Temperature Control	901.32
Protection from Adverse Conditions	901.33
Forms, Falsework, and Centering	901.34
Reinforcement	901.35
Mixing, Delivery, Handling, and Placing of Concrete	901.36
Finishing	901.37
Curing	901.38
Form Removal, Falsework, and Loading on Structures	901.39
Protective Sealing	901.41

Precast, Prestressed, and Prefabricated Concrete Products shall be fabricated by a Department approved precast or prestressed concrete Fabricator, under the controlled settings of the approved Fabricator's facility, with a Department approved mix design formulation, as specified herein. Precast and prestressed concrete Fabricators and concrete mix design formulations shall maintain qualification on the QCML. Precast, prestressed, and prefabricated concrete products shall be fabricated in conformance with:

- Department Standard Details and Drawings

- Approved Shop Drawings
- AASHTO *LRFD Bridge Construction Specifications*
- National Precast Concrete Association (NPCA) Quality Control Manual for Precast Concrete Plants
- Precast Concrete Institute (PCI) MNL-116 Manual for Quality Control for Plants and Production of Structural Precast Concrete Products
- Requirements specified herein

Circular vertical precast reinforced concrete manholes and structures used in sewer, drainage, and water works shall meet AASHTO M 199. Reinforced concrete drainage pipes intended to be used for the conveyance of sewage, industrial wastes, and storm water shall meet AASHTO M 170.

M4.09.2.A: Standard Drawings and Details

At least 30 days prior to the start of fabrication, the Fabricator shall prepare and submit standard drawings and details for standard precast concrete highway products in accordance with:

- MassDOT Construction Standard Details
- MassDOT Standard Drawings for Traffic Signals and Highway Lighting
- MassDOT Overhead Signal Structure and Foundation Standard Drawings
- MassDOT Standard Drawings for Signs and Supports

M4.09.2.B: Contract Specific Shop Drawings

At least 30 days prior to the start of fabrication, the Fabricator shall prepare and submit contract specific shop drawings (drawn to scale) to the Engineer of Record for review and approval, as specified herein.

M4.09.2.B.1: Fabrication Shop Drawings

The Fabricator shall prepare and submit proposed fabrication shop drawings for non-standard precast concrete highway products, precast concrete bridge elements, precast concrete deck panels, prestressed concrete products, and prefabricated bridge units, in accordance with the relevant provisions of Subsection 5.02 and shall, at a minimum, contain the following, where applicable:

- Fabricator's name and address on each sheet
- Category and type of product, unit identification number
- Overall length, width, and height
- Skew angle
- Location and spacing of strands, draped strands and their geometry, and location and spacing of strands to be debonded including the length of each strand's debondment
- Location, size, and geometry of all steel reinforcement, including mechanical reinforcing bar splicers to be used for connecting products together in the field (if called for on plans)
- Location and details of all inserts, anchors, vertical adjustment assemblies, and any other items required to be cast into the product (whether detailed on the plans by the Engineer of Record or provided for the Contractor's convenience)
- Locations and details of the lifting devices, including supporting calculations, type and amount of any additional reinforcing required for lifting

- Design all lifting devices based on the no cracking criteria in the latest edition of the PCI Design Handbook
- The minimum concrete compressive strength required prior to handling the product
- Specified compressive strength (f'c), Nominal Maximum Aggregate Size (NMAS), and Mix Type

The fabrication shop drawings shall not include procedures for placement, finishing, and curing of concrete. These details shall be included in the Fabricator's quality control plan as specified herein.

M4.09.2.B.2: Dunnage Plan Shop Drawings

The Fabricator shall prepare and submit proposed dunnage plan shop drawings for precast concrete bridge elements, precast concrete deck panels, and prestressed concrete products. The Dunnage Plan shall include the following:

- Proposed layout of the Precast Concrete Bridge Elements for storage in yard and during shipping
- Support and blocking point locations
- Support and blocking materials

M4.09.2.C: Temperature Control

The Fabricator shall conduct temperature control in accordance with 901.32: Temperature Control and the requirements specified herein.

M4.09.2.C.1: Precast Concrete Highway Products

The Fabricator shall continuously monitor, record, and report the ambient temperatures surrounding the concrete without interruption, at a minimum frequency of once per hour, until 100% of f'c is attained.

M4.09.2.C.2: Precast Concrete Bridge Elements, Precast Concrete Deck Panels, Prestressed Concrete Products, and Prefabricated Bridge Units

The Fabricator shall continuously monitor, record, and report the temperatures of the form, ambient temperatures surrounding the concrete, and temperatures of the concrete, without interruption, at a minimum frequency of once per hour, until the curing duration is achieved, 100% of f'c is attained, and the temperature differential of the concrete and ambient temperature is less than or equal to 30°F. At least two temperature sensors (thermocouples) shall be positioned to record the maximum and minimum anticipated concrete temperatures. The anticipated minimum temperature shall be measured with one or more thermocouples at a distance no greater than 2 in. from the surface of the thinnest section. The anticipated maximum temperature shall be measured with one or more thermocouples at the center of the thickest section. Proposed temperature measurement locations shall be submitted to the Department for approval. Temperature recording devices shall be located within the curing enclosure per Section 4.18.4 of the PCI MNL-116-21 Manual for Quality Control Plants and Production of Structural Precast Concrete Products (5th Edition). Temperature recording devices shall be calibrated at a minimum of once per six months by ISO accredited calibration or by NIST calibrated equipment.

M4.09.2.D: Protection from Adverse Conditions

The Fabricator shall conduct protection from adverse conditions in accordance with 901.33: Protection from Adverse Conditions.

M4.09.2.E: Formwork

Precast, prestressed, and prefabricated concrete products shall meet 901.34: Forms, Falsework, and Centering, PCI Manual 116-21, Section 2.4 Forms/Molds, and the requirements specified herein. Precast concrete barrier shall be cast with the forms in a 180° inverted position and compacted with an approved vibrator.

M4.09.2.F: Reinforcement

Precast, prestressed, and prefabricated concrete products shall meet 901.35: Reinforcement and the materials requirements specified herein. Precast concrete barrier shall be fabricated with epoxy coated reinforcing bars (M8.01.7) or galvanized reinforcing bars (M8.01.8) as specified herein. The galvanized (AASHTO M 111) 1-in. plain dowel bars shall be Grade 60 (AASHTO M 31) for precast concrete barrier shall be accurately set true to a plane at right angles to the plane of the end of the unit.

M4.09.2.G: Mixing, Delivery, Handling, and Placing of Concrete

The Fabricator shall conduct mixing, delivery, handling, and placing of concrete in accordance with 901.36: Mixing, Delivery, Handling, and Placing of Concrete.

M4.09.2.H: Finishing

The Fabricator shall conduct the finishing procedures, operations, and sequencing in accordance with 901.37: Finishing, Part G: Exterior Flatwork and the requirements specified herein.

- Precast concrete sidewalk and medians shall be textured in accordance with broomed texturing.
- Precast concrete deck panels (and precast deck panels for prefabricated bridge units) receiving a cast-in-place safety curb, barrier, or sidewalk shall have a raked finish with a ¼-in. amplitude applied longitudinally along the length of the panels.
- Prestressed concrete beams, except for NEXT D and NEBT D beams, shall be given a raked finish with a ¼-in. amplitude applied transversely across the beam to the limits shown on the plans. NEXT D and NEBT D beams shall be given a float finish except for those areas that will have concrete cast against them. Those areas shall receive a rake finish with a ¼-in. amplitude applied longitudinally along the length of the beam to the limits shown on the plans.

M4.09.2.I: Curing

The Fabricator shall conduct curing in accordance with 901.38: Curing and the requirements specified herein.

Table M4.09.2-1: Curing Method Requirements

Category [1]	**Curing Method**		
	Subsection	**Description**	**Duration** [2]
Precast Concrete Highway Products (Excluding Median Barrier)	901.38	[3]	70% of f'_c [4]
Precast Concrete Median Barrier, Precast Concrete Bridge Elements, and Prestressed Concrete Products (Excluding Deck Panels)	901.38.A	Curing Water Nozzles	≥ 3 Days and 70% of f'_c [4]
	901.38.B	Saturated Covers	
	901.38.C	Sheet Materials	
	901.38.D [5]	Liquid Membrane-Forming Compounds	
	901.38.E	Accelerated Curing	[6]
Precast Concrete Exterior Slabs and Pavement	901.38.A	Curing Water Nozzles	≥ 7 Days [7] and 70% of f'_c [4]
	901.38.B	Saturated Covers	
	901.38.C	Sheet Materials	
	901.38.D[5]	Liquid Membrane-Forming Compounds	
	901.38.E	Accelerated Curing	[6]
Precast Concrete Deck Panels and Prefabricated Bridge Units	901.38.A	Curing Water Nozzles	≥ 10 Days [7][8] and 70% of f'_c [4]
	901.38.B	Saturated Covers	
	901.38.C	Sheet Materials	
	901.38.D [5]	Liquid Membrane-Forming Compounds	
	901.38.E	Accelerated Curing	[6]

[1] Curing method requirements for concrete categories not identified in Table 901.38-1 shall be determined by the Department prior to fabrication.
[2] Concrete shall be cured with sustained ambient temperatures greater than or equal to 40°F and less than or equal to 85°F throughout the entire duration of the curing cycle.
[3] Concrete shall be form cured. Curing materials, methods, and procedures shall be applied to all exposed surfaces not being cured by the form as specified herein.
[4] The concrete shall be protected from all adverse conditions (901.33) during curing (901.38) until 100% of f'_c is attained.
[5] If the liquid membrane-forming compound is to be removed due to compatibility or bonding concerns, removal shall not take place until the specified application duration is met.
[6] The initial delay period, temperature increase period, constant maximum temperature period, and temperature decrease period shall meet 901.38.E: Accelerated Curing.
[7] Subject to Department review and approval, concrete surfaces applied with a liquid membrane-forming compound may be exposed to pedestrian or vehicular traffic prior to the completion of the specified duration, so long as the product is capable of withstanding early age exposure and has dried on the surface, 70% of f'_c has been attained, and ambient temperatures remain ≥40°F and ≤ to 85°F throughout the entire duration of the curing cycle.
[8] Curing duration of ≥5 days for precast concrete deck panels and prefabricated bridge units receiving spray-applied waterproofing membrane.

M4.09.2.J: Form Removal

The Fabricator shall conduct form removal in accordance with 901.39: Form Removal, Falsework, and Loading on Structures.

M4.09.2.K: Prestressing Strand Release

The Fabricator shall not release strands or handle the prestressed concrete product until 80% of f'c is attained or the specified detensioning compression strength as indicated on the approved shop drawings is attained. Initial camber measures shall be conducted within 72 hours after the transfer of stress.

M4.09.2.L: Shear Key Texturing

Shear keys cast on the sides of adjacent deck and box beams shall be abrasive blasted prior to shipment. Closure pour shear keys cast on the sides of beam flanges shall have an exposed aggregate finish. The closure pour reinforcing steel and its coating shall not be damaged by the process for creating the exposed aggregate surface. The Fabricator may utilize a surface retarder with water blast, abrasive blast, or a combination of both to achieve the desired shear key finish. The abrasive blast shall use oil free compressed air. The profile of the shear key surfaces shall be similar to that of 60 grit sandpaper. If ultra-high performance concrete (M4.06.11) is used as the closure pour concrete, the closure pour shear key shall be prepared per the Manufacturer's recommendations.

M4.09.2.M: Handling and Storage of Concrete Products

Concrete products shall not be handled until form removal strength and prestressing strand release strength (if prestressed concrete) has been attained. Concrete products shall be lifted at the designated points by approved lifting devices embedded in the concrete and in accordance with proper lifting and handling procedures. Storage areas shall be level and well compacted to prevent damage due to differential settlement. Concrete products shall be supported on the ground by means of continuous blocking, in conformance with the approved dunnage plan. The concrete shall be protected from all adverse conditions, including precipitation, cold conditions, and hot conditions, until 100% of f'c is attained, as specified in M4.09.2.D: Protection from Adverse Conditions.

M4.09.2.N: Primer and Damp-Proofing of Precast Concrete Drainage Structures

The Fabricator shall apply primer and damp-proofing materials, methods, and procedures to the outside surface of the tapered or cone section of precast concrete drainage structures. Precast concrete drainage structures shall be damp-proofed in accordance with 970: Damp-Proofing.

M4.09.2.O: Repairs and Replacement

Defects identified during inspection shall be categorized and addressed as specified herein. Repair materials shall meet M4.04.2: Rapid Hardening Cementitious Products for Concrete Repairs, M4.10.2: Concrete Crack Sealers, and M4.06.2: High Performance Concrete. All repairs and replacement shall be conducted at the expense of the Fabricator.

Table M4.09.2-2: Reporting, Repair, and Replacement for Defects

Defect Category	Report Defect on Inspection Report Form (IRF)	Report Defect on Non-Conformance Report (NCR)	Repair	Replace
Category 1 Surface Defects	X			
Category 2 Minor Defects	X		X [1]	[2]
Category 3 Major Defects	X	X [3][4]	X [5]	[6]
Category 4 Rejectable Defects	X	X [3]		X

[1] Category 2 minor defects shall be repaired in accordance with PCINE-18-RNPCBE. Cracks shall be sealed in accordance with the PCI Repair Procedure Number 14 in PCINE-18-RNPCBE.
[2] If the repair is not acceptable, the product shall be rejected and replaced.
[3] The Fabricator shall report the root cause, proposed corrective action, and action to prevent recurrence on the NCR for Department review and acceptance.
[4] The proposed corrective action shall include the proposed repair procedures and other supplementary information.
[5] Category 3 major defects shall be repaired in accordance with the Department accepted NCR corrective action and in the presence of the Department. Repairs of category 3 defects shall not be conducted prior to Department acceptance of the NCR proposed corrective action.
[6] If the NCR proposed corrective action is not accepted by the Department or the repair is not acceptable, the product shall be rejected and replaced.

Table M4.09.2-3: Categories of Defects for Precast Concrete Highway Products

Defect Category	Defect Description
Category 1 Surface Defects	• Surface voids or bug holes that are less than 0.625 in. in diameter and less than 0.250 in. in depth, except when classified as Category 3. • Cracks less than or equal to 0.006 in. in width.
Category 2 Minor Defects	• Spalls, honeycombing, surface voids that are less than 2 inches in depth and have no dimension greater than 12 in. • Cracks greater than 0.006 in. and less than or equal to 0.060 in. in width. • Broken or spalled corners without exposed reinforcing steel.
Category 3 Major Defects	Not Applicable
Category 4 Rejectable Defects	• Surface defects on more than 5% of the surface area. • Minor defects that in total make up more than 5% of the surface area of the unit. • Concentrated area of defects consisting of four or more Category 2 Defects within a 4-square foot area. • Exposed reinforcing steel. • Spalls, honeycombing and surface voids that are deeper than 2 in. or have any dimension greater than 12 in., when measured along a straight line. • Cracks greater than 0.060 in. in width. • Elements fabricated outside of the specified tolerances. • Compressive strength does not meet the specified compressive strength (f'c).

Table M4.09.2-4: Categories of Defects for Precast Concrete Bridge Elements, Precast Concrete Deck Panels, Prestressed Concrete Products, and Prefabricated Bridge Units

Defect Category	Defect Description
Category 1 Surface Defects	• Surface voids or bug holes that are less than 0.625 inches in diameter and less than 0.25 in. deep, except when classified as Category 4. • Cracks less than or equal to 0.006 in. wide. • Cracks less than or equal to 0.125 in. wide on surfaces that will receive a concrete overlay or spray-applied membrane waterproofing.
Category 2 Minor Defects	• Spalls, honeycombing, surface voids that are less than 2 in. deep and have no dimension greater than 12 in. • Cracks less than or equal to 0.016 in. that will not receive a concrete overlay or spray-applied membrane waterproofing. • Broken or spalled corners that will be covered by field-cast concrete.
Category 3 Major Defects	• Spalls, honeycombing and surface voids that are deeper than 2 inches or have any dimension greater than 12 in., when measured along a straight line. • Concentrated area of defects consisting of four or more Category 2 Defects within a 4-square foot area. • Exposed reinforcing steel. • Cracks greater than 0.016 in. and less than or equal to 0.060 in. in width that will not receive a concrete overlay or spray-applied membrane waterproofing. • Bearing area spalls with dimensions not exceeding 3 inches. • Cracks, spalls and honeycombing that will be encased in cast-in-place concrete need not be repaired, but the limits and location of the defects shall be documented with an NCR.
Category 4 Rejectable Defects	• Surface defects on more than 5% of the surface area which will be exposed to view after installation. • Minor defects that in total make up more than 5% of the surface area of the unit. • Cracks greater than 0.060 in. in width except as noted in Category 1. • Elements fabricated outside of the specified tolerances. • Compressive strength does not meet the specified compressive strength (f'c).

M4.09.2.P: Protective Sealing

The Fabricator shall apply protective sealing compounds to the concrete surface in accordance with 901.41: Protective Sealing (not applicable to concrete surfaces previously applied with M4.12.4.B: Liquid Membrane-Forming Compounds for Curing and Sealing.

M4.09.2.Q: Prior to Loading

Prior to loading the concrete product on to the truck for shipping, the Fabricator shall provide the Department acceptance inspector a minimum of seven days' notice of the Fabricator's intent to load the concrete product. Inspection by the Department acceptance inspector shall take place while the element is still on dunnage in the yard. The element shall not be loaded onto the truck until the Department acceptance inspector has performed the inspection. Prior to the loading of prestressed concrete products, camber measurements shall be conducted, documented, and provided to the Department acceptance inspector.

M4.09.2.R: Loading

Concrete products shall be loaded on a trailer with continuous blocking, in accordance with the approved dunnage plan. Shock-absorbing cushioning material shall be used at all bearing points. Blocking shall be provided at all locations of tie-down straps. Concrete products shall not be subjected to damaging torsional or impact stresses.

M4.09.2.S: Shipping

Prior to shipment, the Fabricator shall perform the following actions and provide the required documentation to the Department acceptance inspector:

- Precast, prestressed, and prefabricated concrete products shall remain at the Fabricator's plant for a minimum of seven days after cast date, unless otherwise permitted by the Department.
- QC Inspection report forms (IRFs) shall be signed by the quality control manager and provided to the Department acceptance inspector.
- QC test report forms (TRFs) with test results meeting the limits specified herein, for the representative sublot, shall be generated by the Fabricator and provided to the Department acceptance inspector.
- Certificate of compliance shall be generated by the Fabricator as described under the Fabricator quality control section and provided to the Department acceptance inspector.
- Department reviewed corrective actions submitted on the non-conformance reports (NCR) shall be verified to have been completed by the Department acceptance inspector (or quality control manager when permitted by the Department).
- NCRs shall contain all the required signatures.
- QC inspection stamp shall be applied to each unit after loading.

M4.09.2.T: Delivery

Upon Delivery, the following documentation shall be provided to the Department resident engineer or designee:

- QC compressive strength test report forms attaining the specified compressive strength (f'c) for the precast prestressed, and prefabricated concrete product's representative sublot.
- Certificate of compliance generated by the Fabricator as described under the Fabricator quality control section.
- QC Inspection Reports signed by the quality control manager.

The Contractor shall inspect the concrete product upon receipt at the site. Concrete products damaged during delivery shall be repaired or replaced per the Department's direction, at the Contractor's expense.

M4.09.3: Fabricator Quality Control

Quality control (QC) shall be established, maintained, and conducted by the Fabricator to monitor, assess, and adjust production and fabrication activities, to maintain continuous control of the process, and to ensure that the final material or product will meet the specified level of quality, as specified herein.

M4.09.3.A: Quality Control Operating Documents

At least 30 days prior to the start of construction, the specified QC operating documents shall be prepared by the Fabricator and submitted to the Department for review and approval. The Fabricator shall adhere to all policies, practices, procedures, and activities identified in Department approved QC operating documents.

M4.09.3.A.1: Quality System Manual

The quality system manual (QSM) shall document the overall internal QC operating procedures of the QC system and meet AASHTO R 18 Standard Recommended Practice for Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories, AASHTO R 38, and the requirements specified by the Department.

M4.09.3.A.2: Quality Control Plan

The QC plans for the fabrication of precast concrete bridge elements, precast concrete deck panels, prestressed concrete products, and prefabricated bridge units (PBU) shall document all QC personnel and procedures utilized to maintain control of activities and meet the Northeast Transportation Training Certification Program (NETTCP) Model Quality Control Plan standard format.

M4.09.3.B: Quality Control Laboratory

The QC laboratory shall meet the quality system requirements specified in AASHTO R 18 and the requirements specified herein. The QC laboratory shall maintain active accreditation or qualification through one or more of the following programs:

- Northeast Transportation Training Certification Program (NETTCP) Laboratory Qualification Program
- AASHTO Accreditation Program (AAP)
- Other Department recognized program

The QC laboratory shall be capable of conducting all required QC sampling, testing, and inspection specified for the work item. All required field sampling, testing, and inspection equipment shall be onsite and available for use during all phases of fabrication and production. The equipment shall meet all applicable AASHTO or ASTM standards, maintain required calibration schedules, and be in acceptable working condition.

The QC laboratory shall have an area dedicated for the sole purpose of conducting QC testing, storing QC equipment, and managing QC documentation, as specified herein. The area shall be located at the site of the facility and be of acceptable size and condition, with sufficient lighting, temperature, and ventilation. The room shall contain a clean workspace that includes a desk and filing cabinet. An additional workspace shall be provided for Department acceptance technicians.

Table M4.09.3-1: QC Sampling and Testing Equipment Requirements

Material	Test Method	Description
Aggregates	AASHTO T 19	Bulk Density ("Unit Weight") and Voids in Aggregate
Aggregates	AASHTO T 27	Sieve Analysis of Fine and Coarse Aggregates
Aggregates	AASHTO T 255	Total Evaporable Moisture Content of Aggregate by Drying
Fresh Concrete	AASHTO T 119[1]	Slump of Hydraulic Cement Concrete
Fresh Concrete	AASHTO T 347 [2]	Slump Flow of Self-Consolidating Concrete (SCC)
Fresh Concrete	AASHTO T 121	Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
Fresh Concrete	AASHTO T 152 [3]	Air Content of Freshly Mixed Concrete by the Pressure Method
Fresh Concrete	AASHTO T 196 [4]	Air Content of Freshly Mixed Concrete by the Volumetric Method
Fresh Concrete	AASHTO T 309	Temperature of Freshly Mixed Portland Cement Concrete
Hardened Concrete	AASHTO T 22 [5]	Compressive Strength of Cylindrical Concrete Specimens

[1] Not required for self-consolidating concrete (M4.06.6).
[2] Required for self-consolidating concrete (M4.06.6).
[3] For normal weight concrete.
[4] Required for lightweight concrete (M4.06.5).
[5] The Fabricator may select an independent laboratory meeting the requirements specified herein to conduct this testing.

M4.09.3.C: Quality Control Organization

The QC organization shall be comprised of an acceptable number of experienced, trained, skilled, and qualified personnel to support the size and scope of the operation. The frontline personnel, QC technicians, and QC manager shall be onsite and present during all phases of the operation, maintain continuous communication to ensure conformance to specification requirements, and conduct corrective action for non-conforming results and activities.

M4.09.3.C.1: Frontline Personnel

The frontline personnel that are directly responsible for the production and fabrication operations shall conduct best practices in accordance with QC operating documents, Department recognized standards, organizations, and programs, and the requirements specified herein. Additionally, frontline personnel shall conduct continuous self-inspection throughout the entire operation, to ensure quality workmanship is performed, through observation and verification of:

- Proper tools and equipment are utilized to conduct the work
- Routine maintenance, calibration, and cleaning of tools and equipment
- Proper procedures for control, handling, storage, and shipping of materials and products
- Best practices for workmanship are incorporated throughout the operation
- Quality appearance of finished materials and products

The frontline personnel shall be capable of identifying unacceptable materials and products prior to completing the operation and shall notify potential non-conformances to the QC manager.

M4.09.3.C.2: Quality Control Technicians

The QC technicians shall meet the certification and experience requirements specified in Table M4.09.3-2 and be onsite and present during all phases of fabrication. The principal responsibilities of QC technicians shall include:

- Conducting QC sampling, testing, and inspection at the fabrication site
- Preparing and signing QC test report forms (TRFs) and inspection report forms (IRFs)
- Providing routine feedback based on sampling, testing, and inspection results to the production personnel, fabrication personnel, and QC manager

Table M4.09.3-2: QC Technician Requirements

Category	Active Certifications	Minimum Experience [1]
Precast Concrete Highway Products	ACI Concrete Field Testing Technician – Grade I or higher	6 months
Precast Concrete Bridge Elements, Deck Panels, and Prefabricated Bridge Units	PCI Technician/Inspector – Level I or higher or NETTCP Precast Concrete Inspector	6 months
Prestressed Concrete Products	PCI Technician/Inspector – Level II or higher	6 months

[1] Continuous experience or training under the supervision of an experienced certified QC technician in quality control sampling, testing, and inspection for the corresponding product category.

M4.09.3.C.3: Quality Control Manager

The QC Manager shall meet the certification and experience requirements specified in Table M4.09.3-3 and be employed full-time (or through engaged consultants) throughout the entire operation. The principal responsibilities of the QC manager shall include:

- Preparing QC operating documents
- Establishing the QC system in accordance with Department approved QC operating documents
- Managing and monitoring the activities of QC technicians
- Communicating routinely with frontline personnel, QC technicians, and the Department
- Initiating non-conformance reports and work suspensions (when necessary), for non-conforming results and activities
- Responding to non-conformance reports (NCRs) and deficiency reports (DRs) issued by the Department
- Verifying all non-conformances have been resolved
- Document management

Table M4.09.3-3: QC Manager Requirements

Category	Active Certifications	Minimum Experience [1]
Precast Concrete Highway Products	ACI Concrete Field Testing Technician – Grade I or higher	6 months
Precast Concrete Bridge Elements, Deck Panels, and Prefabricated Bridge Units	PCI Technician/Inspector – Level I or higher or NETTCP Precast Concrete Inspector	4 years
Prestressed Concrete Products	PCI Technician/Inspector – Level II or higher	5 years

[1] Continuous experience in quality control sampling, testing, and inspection for the corresponding product category as a certified quality control technician.

M4.09.3.D: Quality Control Sampling, Testing, and Inspection

The quality measurements obtained through QC sampling, testing, and inspection shall be conducted by qualified QC technicians in accordance with the Department approved QC operating documents and the requirements specified for the work item(s) and herein.

Quality control sampling, testing, and inspection shall be conducted to provide measurement of properties and quality characteristics, to determine the degree of uniformity or the measured variability, to monitor the quality, to visually inspect equipment, environmental conditions, materials, and workmanship, and to evaluate the control of the operation. The QC results shall be reported on standardized sample report forms (SRFs), test report forms (TRFs), and inspection report forms (IRFs) and submitted to the QC manager for review. The QC results shall meet the quality limits specified for the work item(s).

The QC manager shall initiate non-conformance reports (NCRs) and if necessary, work suspensions, for non-conforming results and uncontrolled processes. The QC manager shall report the non-conformance, root cause, proposed corrective action, and action to prevent recurrence onto the non-conformance report (NCR). The corrective action taken shall be reported onto the non-conformance report (NCR), conducted in accordance with the accepted disposition, and verified by the QC manager and the Department. Non-conformance reports (NCRs) shall be made available upon the request of the Department.

M4.09.3.D.1: Quality Control Sampling

The QC sampling for testing and inspection shall be conducted in accordance with the required procedures for obtaining or inspecting representative materials or products. The QC sampling population shall be comprised of lots and sublots. A lot shall be defined as a specific quantity of material from a single source which is assumed to be produced or placed by the same controlled process. A lot shall be used to represent the population of the produced material and constructed product. The lot size shall be the specified quantity of material produced and placed. A sublot shall be defined as a subdivision of a lot. The sublots shall be used to assess the inspection attributes and quality characteristics of the lot. The sublot size shall be the specified subdivision of quantity for a given lot.

Table M4.09.3-4: Sampling Requirements for QC Testing

Material	Lot Size	Sublot Size	Test Method	Frequency
Aggregate	Total quantity of aggregate (tons) used for the production of concrete, per source, per type, per size	–	AASHTO T 27	1 per week
			AASHTO T 255	1 per day
Precast Concrete Highway Products	Total quantity of concrete (cy) produced in a year, per approved mix design formulation	50 cy	Table M4.09.3-6 Table M4.09.3-7	1 per sublot or fraction thereof, minimum 1 per day
Precast Concrete Bridge Elements and Deck Panels	Total quantity of concrete (cy) produced on the contract, per type of element fabricated, per approved mix design formulation	20 cy	Table M4.09.3-6 Table M4.09.3-7	1 per sublot or fraction thereof, minimum 1 per day
Prestressed Concrete Products and Prefabricated Bridge Units	Total quantity of product (units) fabricated per the contract bid item, per approved mix design formulation	1 Unit	Table M4.09.3-6 Table M4.09.3-7	1 per sublot

The sampling population for testing and inspection shall be randomly sampled in accordance with ASTM D3665. Random sampling shall be defined as a small quantity of material or measurement obtained from a lot or sublot, whereby each sample obtained from the lot or sublot has an equal probability of being selected. Selective (non-random) sampling may also be conducted to provide supplemental information to assist in maintaining control of all production and placement processes. Selective sampling shall not replace random sampling and shall not be incorporated into the sampling population for quality testing and quality inspection.

M4.09.3.D.2: Quality Control Testing

The QC testing shall be conducted in accordance with the specified test method, the quality characteristics and limits identified on the standardized test report form (TRF), and the requirements specified herein. The QC test results shall meet the requirements specified in the following tables.

Table M4.09.3-5: QC Testing Requirements for Aggregate

Property	Test Method	Quality Characteristic	Limits	
			Min.	Max.
Uniformity	AASHTO T 27	Mass of Material Passing (%)	M4.01.2	
Moisture	AASHTO T 255 [1]	Moisture Content (%)	[2]	

[1] Fine aggregate moisture content testing is not required for facilities outfitted with in-line fine aggregate moisture meters. However, coarse aggregate moisture content testing is required.
[2] Fabricator shall adjust mix design formulations to account for the moisture content of the aggregate.

Table M4.09.3-6: QC Testing Requirements for Fresh Concrete

Test Method	Quality Characteristic		Limits	
			Min.	Max.
AASHTO M 157	Batching Quantities of Constituent Materials		M4.02.3	
AASHTO T 121	Unit Weight (lb/ft^3)		Target - 3.0	Target +3.0
AASHTO T 119 [1]	Slump (in.)	< 4 in.	Target -1.0	Target +1.0
		4 – 8 in.	Target -1.5	Target +1.5
	Segregation Resistance [2]		Pass [3]	
AASHTO T 347 [4]	Slump Flow (in.)		Target -2.0	Target +2.0
AASHTO T 152 [5] AASHTO T 196 [6]	Air Content (%)		Target -1.5	Target +1.5
AASHTO T 309	Concrete Temperature °F)		50	90

[1] Not required for self-consolidating concrete (M4.06.6).
[2] Visual inspection for segregation resistance, consolidation, and cohesion shall be conducted while the concrete is being discharged and during AASHTO T 119.
[3] Non-conforming visual signs of segregation include coarse particles advancing in front of or behind the fine particles and mortar and a tendency for coarse aggregate to separate from the mortar, particularly when the mixture is being consolidated. The concrete shall exhibit quality consolidation and cohesion.
[4] For self-consolidating concrete (M4.06.6).
[5] For normal weight concrete.
[6] For lightweight concrete (M4.06.5).

Table M4.09.3-7: QC Testing Requirements for Hardened Concrete [1]

Test Method	Quality Characteristic			Limits	
				Min.	Max.
Select One Method	AASHTO T 22 [2][3] ASTM C1074 AASHTO T 412	Compressive Strength (psi)	Form Removal	70% of f'_c	–
			Prestressing Strand Release	80% of f'_c	–
			Termination of Protection from Adverse Conditions and Shipping	100% of f'_c	–

[1] The specified compressive strength (f'_c) is defined as the minimum compressive strength required to be attained at a specified age for a given concrete structure, as identified in construction standard specifications, contract document special provisions, and design plans.
[2] Three 4 x 8 in. cylinders shall be cast and tested for each set specified for maximum aggregate size less than 1-½ in. Two 6 x 12 in. cylinders shall be cast and tested for each set specified for maximum aggregate size greater than 1 in.
[3] For fiber reinforced concrete, specimens shall be filled in one lift and consolidated using external or internal vibration per AASHTO R 100. Rodding of test specimens shall be prohibited.

M4.09.3.D.3: Quality Control Inspection

The QC inspection shall be conducted through visual examination or physical measurement in accordance with the specified inspection method, the inspection components, attributes, conformance measures, and limits identified on the standardized inspection report form (IRF), and

the requirements specified herein. The QC inspection results shall meet the requirements specified in the following tables.

Table M4.09.3-8: QC Inspection Requirements Prior to Concrete Placement

Inspection Component	Inspection Attribute		Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration		1 / Unit	Equipment	Visual
	Form Dimensions and Conditions		1 / Day	Form	Visual
Document Control	Quality Control Records, Documentation, and Analysis		1 / Day	File	Visual
Environmental Conditions	Protection from Adverse Conditions		1 / Unit	Form	Visual
	Ambient Temperature Range		1 / Unit	Form	Record and Monitor
	Form Temperature		1 / Form	Form	Record and Monitor
Materials	Control, Handling, and Storage	Hydraulic Cement	1 / Day	Silo and Bins	Visual
		SCMs	1 / Day	Silo and Bins	Visual
		Aggregate	1 / Day	Stockpile and Bins	Visual
		Chemical Admixtures	1 / Day	Tank	Visual
		Fibers	1 / Day	Storage	Visual
		Steel Reinforcement	1 / Day	Storage	Visual
	Department Approved Mix Design and Constituent Materials Sources		1 / Batch	File and Batching Computer	Visual
	Batching Adjustments based on QC Aggregate Test Results		1 / Day	Report Form and Batching Computer	Visual
Workmanship	Form Set-up Width, Length, and Depth		1 / Unit	Form	Measurement
	Hold-down Placement and Locations		1 / Unit	Form	Measurement
	Strand Placement and Number		1 / Unit	Form	Measurement
	Coil Number		1 / Unit	Form	Record
	Tensioning Calculations and Initial Sheet		1 / Unit	Form	Visual
	Pulling of Strands (Sequence, Initial/Final, Elongation)		1 / Unit	Form	Visual
	Block Outs Locations		1 / Unit	Form	Measurement
	Squareness / Skew		1 / Unit	Form	Measurement
	Reinforcing Steel Size and Placement		1 / Unit	Form	Measurement
	Plates and Inserts Locations		1 / Unit	Form	Measurement
	Lifting Device Locations		1 / Unit	Form	Measurement

Table M4.09.3-9: QC Inspection Requirements for Placing and Finishing of Concrete

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
Environmental Conditions	Protection from Adverse Conditions	1 / Unit	Form	Visual
	Ambient Temperature Range	1 / Unit	Form	Record and Monitor
Materials	Department Approved Mix Design and Batching Quantities of Constituent Materials	1 / Batch	Batch Ticket	Visual
	QC Fresh Concrete Test Results	Table M4.09.3-14	Report Form	Visual and Record
	Batching Adjustments of Chemical Admixtures based on QC Plastic Test Results	1 / Batch	Batch Ticket	Visual and Record
	Cast QC Compressive Strength Cylinders for Form Removal	Table M4.09.3-15	Form	Visual
Workmanship	Delivery of Concrete	1 / Unit	Form	Visual
	Transporting of Concrete	1 / Unit	Form	Visual
	Depositing of Concrete	1 / Unit	Form	Visual
	Consolidation of Concrete	1 / Unit	Form	Visual
	Start Time, End Time, and Duration of Placing of Concrete	1 / Unit	Form	Record and Monitor
	Finishing of Concrete	1 / Unit	Form	Visual

Table M4.09.3-10: QC Inspection Requirements for Curing of Concrete

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
Environmental Conditions	Protection from Adverse Conditions	1 / Unit	Unit	Visual
	Ambient Temperature Range	1 / Unit	Unit	Record and Monitor
	Concrete Temperature Range	1 / Unit	Unit	Record and Monitor
Materials	Curing Materials for Concrete	1 / Unit	Unit	Visual
	QC Compressive Strength Test Results for Curing Termination	Table M4.09.3-15	Report Form	Visual and Record
Workmanship	Curing Method(s), Application Date, Termination Date, and Duration	1 / Unit	Unit	Visual, Record, and Monitor

Table M4.09.3-11: QC Inspection Requirements for Form Removal and Strand Release

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
	Cut-down Equipment	1 / Unit	Equipment	Visual
Environmental Conditions	Protection from Adverse Conditions	1 / Unit	Unit	Visual
	Ambient Temperature Range	1 / Unit	Unit	Record and Monitor
	Concrete Temperature Range	1 / Unit	Unit	Record and Monitor
Materials	Curing Materials for Concrete	1 / Unit	Unit	Visual
	QC Compressive Strength Test Results for Form Removal	Table M4.09.3-15	Report Form	Visual and Record
	QC Compressive Strength Test Results for Prestressing Strand Release	Table M4.09.3-15	Report Form	Visual and Record
Workmanship	Form Removal and Date	1 / Unit	Unit	Visual and Record
	Shear Key Texturing	1 / Unit	Unit	Visual
	Immediate surface preparation and application of curing materials on all exposed surfaces	1 / Unit	Unit	Visual
	Strand Cut-down Method	1 / Unit	Unit	Visual and Record
	Strand Detensioning Sequence	1 / Unit	Unit	Visual
	Overall Finish and Color	1 / Unit	Unit	Visual
	Finished Dimensions (Camber, Length, Width, Depth)	1 / Unit	Unit	Measurement
	Squareness, Skew, Sweep	1 / Unit	Unit	Measurement
	Cracking, Spalling, and Other Deficiencies	1 / Unit	Unit	Visual
	Exposed Reinforcing Steel	1 / Unit	Unit	Visual
	Block Outs and Inserts (Location, Alignment, Capped)	1 / Unit	Unit	Measurement

Table M4.09.3-12: QC Inspection Requirements for Handling and Storage of Concrete Products

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
Environmental Conditions	Protection from Adverse Conditions	1 / Unit	Form	Visual
	Ambient Temperature Range	1 / Unit	Unit	Record and Monitor
	Concrete Temperature Range	1 / Unit	Unit	Record and Monitor
Materials	Curing Materials for Concrete	1 / Unit	Unit	Visual
	QC Compressive Strength Test Results for Handling and Storage	Table M4.09.3-15	Report Form	Visual and Record
	QC Compressive Strength Test Results for Termination of Protection from Adverse Conditions	Table M4.09.3-15	Report Form	Visual and Record
Workmanship	Date of Storage	1 / Unit	Unit	Record
	Camber	1 / Unit	Unit	Visual
	Overall Condition of Unit	1 / Unit	Unit	Visual
	Final Dimension Check	1 / Unit	Unit	Measurement
	Unit Marking Per Shop Drawing	1 / Unit	Unit	Visual
	Unit Support at Appropriate Locations	1 / Unit	Unit	Visual
	Unit on Appropriate Dunnage per Approved Plan (Continuous Blocking)	1 / Unit	Unit	Visual

Table M4.09.3-13: QC Inspection Requirements for Primer and Damp-Proofing of Concrete

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
Environmental Conditions	Ambient Temperature Range	1 / Unit	Unit	Record and Monitor
Materials	Primer and Damp-Proofing Materials for Concrete	1 / Unit	Unit	Visual
Workmanship	Primer and Damp-Proofing of Concrete and Date	1 / Unit	Unit	Visual and Record

Table M4.09.3-14: QC Inspection Requirements for Protective Sealing of Concrete[1]

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
Environmental Conditions	Ambient Temperature Range	1 / Unit	Unit	Record and Monitor
Materials	Protective Sealing Compounds for Concrete	1 / Unit	Unit	Visual
Workmanship	Protective Sealing, Application Date, and Duration from date of placing of concrete	1 / Unit	Unit	Visual and Record
	Surface Preparation	1 / Unit	Unit	Visual

[1] QC inspection for protective sealing of concrete is only required for precast, prestressed, and prefabricated concrete products having direct contact with freezing, thawing, and de-icing cycles, including precast concrete barrier, guardrail transitions, and parapets.

Table M4.09.3-15: QC Inspection Requirements for Repairs and Replacement

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Equipment	Condition and Calibration	1 / Unit	Equipment	Visual
Materials	Repair Material	1 / Unit	Unit	Visual
Environmental Conditions	Ambient Temperature Range	1 / Unit	Unit	Record and Monitor
Workmanship	Date of Repair	1 / Unit	Unit	Record
	Category of Surface Defect	1 / Unit	Unit	Visual and Record
	QC Initiation of Non-Conformance Report (if required)	1 / Unit	Report Form and Unit	Visual
	QC Proposed Disposition	1 / Unit	Report Form and Unit	Visual
	Department Review of Disposition	1 / Unit	Report Form and Unit	Visual
	QC Completed Corrective Action	1 / Unit	Report Form and Unit	Visual

Table M4.09.3-16: QC Inspection Requirements for Loading, Shipping, and Delivery of Products

Inspection Component	Inspection Attribute	Minimum Inspection Frequency	Point of Inspection	Inspection Method
Materials	QC Compressive Strength Test Results for Shipping	Table M4.09.3-15	Report Form	Visual
Workmanship	Casting Date, Shipping Date, and Duration of Casting to Shipping Date	1 / Unit	Unit	Record
	Unit Support at Appropriate Locations	1 / Unit	Unit	Visual
	Unit on Appropriate Dunnage per Approved Plan (Continuous Blocking and Shock-absorbing)	1 / Unit	Unit	Visual
	Completion of Non-Conformance Report Corrective Action	1 / Unit	Report Form and Unit	Visual
	Certificate of Compliance	1 / Unit	Unit	Visual
	Bill of Lading	1 / Unit	Unit	Visual
	QC Final Inspection Stamp	1 / Unit	Unit	Visual

M4.09.3.F: Quality Control Document Management

Quality control document management shall be conducted in accordance with the Department approved QC operating documents and the requirements specified herein. At a minimum, the following items shall be retained and be made available upon the request of the Department:

- Required items specified for the work item
- Contract documents and special provisions
- Department standard drawings and details
- Department reviewed contract specific shop drawings
- Department approved QC operating documents, concrete mix design sheet(s), and concrete mix design approval letter(s)
- Manufacturer product technical data sheets (TDS) and mill certifications
- QC laboratory qualification(s) and certification(s)
- Qualifications and certifications for each member of the QC organization
- Plant certification(s)
- Concrete batch tickets for each load delivered
- QC sampling report forms (SRFs), test report forms (TRFs), and inspection report forms (IRFs)
- Analysis of QC results through statistical analysis and control charts
- Non-conformance reports (NCRs)
- Equipment calibrations, verifications, and maintenance documentation

M4.09.4: Department Acceptance

Acceptance will be conducted by the Department, including consultants under direct contract with the Department, in accordance with Subsection: 901: Cement Concrete, Department Acceptance, with the following exception: the acceptance sampling population shall be comprised of lots and sublots, as specified in Table M4.09.4-1.

Table M4.09.4-1: Sampling Requirements for Acceptance Testing

Material	Lot Size	Sublot Size	Test Method	Frequency
Precast Concrete Highway Products	Total quantity of concrete (cy) produced in a year, per approved mix design formulation	50 cy	Table 901.64-2 Table 901.64-3	1 per sublot or fraction thereof, minimum 1 per day
Precast Concrete Bridge Elements and Deck Panels	Total quantity of concrete (cy) produced per the contract, per type of element fabricated, per approved mix design formulation	20 cy	Table 901.64-2 Table 901.64-3	1 per sublot or fraction thereof, minimum 1 per day
Prestressed Concrete Products and Prefabricated Bridge Units	Total quantity of product (units) fabricated per the contract bid item, per approved mix design formulation	1 Unit	Table 901.64-2 Table 901.64-3	1 per sublot

M4.10.0: Epoxy Resin Adhesive Products

Base bonding system for concrete (M4.10.1) and concrete crack sealers (M4.10.2) shall maintain qualification on the QCML, meet the requirements and performance criteria of the product's technical data sheet, and meet the requirements specified herein.

M4.10.1: Base Bonding System for Concrete

Base bonding system for concrete shall meet Types III, IV, or V of AASHTO M 235.

M4.10.2: Concrete Crack Sealers

Concrete crack sealers shall meet Type IV, Grade I of AASHTO M 235.

M4.11.0: Evaporation Reducing Materials

Liquid-applied evaporation reducers (M4.11.1) and fogging nozzles (M4.11.2) shall meet the requirements and performance criteria of the product's technical data sheet (TDS) and the requirements specified herein.

M4.11.1: Liquid-Applied Evaporation Reducers

Liquid-applied evaporation reducers shall meet the performance criteria of the product's technical data sheet (TDS) and the requirements specified herein. Liquid-applied evaporation reducers produce an effective monomolecular film over the bleed water layer, to reduce plastic shrinkage and the rate of evaporation of the bleed water from the surface.

M4.11.2: Fogging Nozzles

Fogging nozzles shall atomize water into a fog-like mist, without marring, ponding, or penetrating the surface, to remain visibly suspended above the surface, to increase the humidity of the air around the surface, and to reduce the rate of evaporation and the tendency for a crust to form on top of the surface. Fogging nozzles shall generate atomized water droplets that are uniformly distributed at a rate greater than or equal to 10.6 gal./hr/yd^2, with an average droplet diameter less than or equal to 0.003 in. The curing water shall meet M4.12.0: Curing Materials.

M4.12.0: Curing Materials

Curing water nozzles (M4.12.1), saturated covers (M4.12.2), sheet materials (M4.12.3), and liquid membrane-forming compounds (M4.12.4) shall meet the requirements specified herein. Curing materials applied to the concrete shall allow the concrete to mature sufficiently to achieve its designed and desired properties, including strength, volume stability, permeability, durability, and resistance to freezing, thawing, and de-icing cycles. Curing water shall be free of deleterious impurities, causing staining and deterioration. The potential staining ability of curing water shall be evaluated by means of CRD-C401 (US Army Corps of Engineers 1975) for instances where curing water quality is of concern.

M4.12.1: Curing Water Nozzles

Curing water nozzles shall provide the surface of cement concrete with a continuous fine spray of water.

M4.12.2: Saturated Covers

Saturated covers shall meet AASHTO M 182, Class 3. Saturated covers shall be in good condition, free from holes, tears, or other defects that would render it unsuitable for curing cement concrete. Saturated covers shall be dried to prevent mildew when storing. Saturated covers shall be of sufficient thickness to maximize moisture retention. Saturated covers shall be free of harmful substances that are deleterious or cause discoloration to cement concrete and cementitious materials. Saturated covers shall have the ability to retain sufficient moisture from continuous watering so that a film of water remains on the surface of cement concrete.

M4.12.3: Sheet Materials

Sheet materials shall meet ASTM C171. Sheet materials shall inhibit moisture loss and reduce temperature rise in concrete exposed to radiation from the sun.

M4.12.3.A: Polyethylene Film

Polyethylene film shall be clear or white in color and consist of a single sheet manufactured from polyethylene resins, be free of visible defects, including tears, wrinkles, and discontinuity. The film shall prohibit mottling and uneven spots from appearing on the surface of concrete, due to variations in temperature, moisture content, or both. Polyethylene film shall accommodate concrete surfaces with constant contact without damage. White polyethylene film shall minimize heat gain caused by absorption of solar radiation. Clear polyethylene films shall inhibit absorption of solar radiation.

M4.12.3.B: White Burlap-Polyethylene Sheeting

White burlap-polyethylene sheeting shall be securely bonded to the burlap so to avoid separation of the materials during handling and curing of the concrete.

M4.12.3.C: Reinforced Impervious Paper

Reinforced impervious paper shall be white in color, consist of two sheets of kraft paper cemented together with a bituminous adhesive, and reinforced with embedded cords or strands of fiber running in both directions. Reinforced impervious paper shall be free of holes, tears, and pin holes from deterioration of the paper through repeated use. Reinforced impervious paper shall be treated

to prevent tearing when wetted and dried. Reuse of reinforced impervious paper shall be permitted so long as it is able to retain moisture on the surface of concrete. The paper shall be discarded and prohibited from use when moisture is no longer retained in the material.

M4.12.4: Liquid Membrane-Forming Compounds

Liquid membrane-forming compounds, including compounds with curing properties and compounds with both curing and sealing properties, shall maintain qualification on the QCML, and meet the requirements specified herein.

M4.12.4.A: Liquid Membrane-Forming Compounds for Curing

Liquid membrane-forming compounds for curing shall meet the requirements specified in Table M4.12.4-1.

Table M4.12.4-1: Types of Liquid Membrane-Forming Compounds for Curing [1]

Specification	Class of Dissolved Solids	Type	Description
ASTM C309	A: No Restrictions [2] B: Resin-based [3]	Type 1	Clear or translucent without dye
		Type 1-D	Clear or translucent with fugitive dye
		Type 2	White pigmented

[1] Compounds shall meet the local and federal allowable volatile organic compound (VOC) content limits.
[2] The product's technical data sheet (TDS) shall identify the dissolved solid(s) incorporated into Class A compounds.
[3] As defined in ASTM D883.

M4.12.4.B: Liquid Membrane-Forming Compounds for Curing and Sealing

Liquid membrane-forming compounds for curing and sealing shall meet the requirements specified in Table M4.12.4-2.

Table M4.12.4-2: Types of Liquid Membrane-Forming Compounds for Curing and Sealing [1]

Specification	Class	Type	Description
ASTM C1315	A: Non-yellowing	Type I	Clear or translucent
		Type II	White pigmented

[1] Compounds shall meet the local and federal allowable volatile organic compound (VOC) content limits.

M4.13.0: Protective Sealing Compounds

Protective sealing compounds for concrete shall maintain qualification on the QCML, meet the requirements and performance criteria of the product's technical data sheet (TDS), and meet the requirements specified in Table M4.13.0-1.

Table M4.13.0-1: Types of Protective Sealing Compounds [1]

Specification	Type	Description
AASHTO M 224	Coating	Epoxy Resin
		Coal Tar Epoxy
		Tar Primer and Seal
	Penetrant	Linseed Oil
		Silanes
		Siloxanes
	Coating or Penetrant	Methacrylates
		Sodium Silicate
		Urethane

[1] Compounds shall meet the local and federal allowable volatile organic compound (VOC) content limits.

SECTION M5: PIPE, CULVERT SECTIONS AND CONDUIT

M5.00.0: Pipe, Culvert Sections and Conduit

These shall consist of individual sections of the kinds and sizes shown on the plans and as directed. They shall conform to the requirements of the applicable following subsections.

All pipes shall be subject to inspection at the point of manufacture as well as the site of the work. The purpose of the inspection shall be to cull and reject pipes which, independent of the physical tests, fail to con-form to the specification in the particulars of dimension, workmanship, finish, blisters, cracks or fractures.

M5.01.0: Joint Materials for Pipe

- Jute or oakum furnished for use in pipe joints shall be of an accepted grade approved for common usage.
- Mortar shall conform to the requirements of M4.04.0: Cementitious, Grout, Mortar, and Concrete Products.
- Standard couplers as approved by the manufacturer shall be used to join corrugated metal pipe.
- Rubber ring or plastic gaskets for concrete pipe joints, or manholes section joints shall be of tough, flexible, chemical-resistant material, and of such size and shape as to ensure satisfactory pipe joints when incorporated in the work and shall conform to AWWA C153.
- Rubber gasket joints for ductile iron pipe shall be Styrene-Butadiene Rubber (SBR), Ethylene Propylene Diene Monomer (EPDM) or Nitrile and conform to AWWA C111.

M5.02.1: Reinforced Concrete Pipe

Reinforced concrete pipe shall conform to the requirements of AASHTO M 170 for the class of pipe specified in the contract documents.

- All pipe 24 in. in diameter or smaller shall be of the bell-and-spigot type.
- Pipes larger than 24 in. in diameter shall be tongue and groove or bell and spigot.

M5.02.2: Reinforced Concrete Pipe Flared Ends

Flared end sections shall be fabricated to comply with the Construction Standard Details. The method of fabrication and materials used shall conform to the requirements of AASHTO M 170, Class III, except that the three edge bearing tests shall not be required. The flare shall be of the same thickness and materials as the barrel and have steel reinforcement equaling or exceeding the amount shown on the table for AASHTO M 170, Class III, except that a double row of steel will not be required.

M5.03.0: Corrugated Metal Pipe

This pipe shall consist of metallic coated (galvanized or aluminized) corrugated metal pipe and couplings. The coating shall completely cover the inside and outside of all pipe and couplings.

Galvanizing shall conform to M7.10.0: Galvanized Coatings.

Aluminizing shall conform to M7.15.0: Metallized Coatings.

Aluminized and galvanized pipe components shall not be used together in a pipe run.

The pipe shall conform to AASHTO M 36. Pipe 8 in. or less in diameter shall be constructed of sheets not less than 0.052 in. thick. End sections shall be 16 gage for all pipes 24 in. in diameter and under, 14 gage for all 30- and 36-in. diameter pipes and 12 gage for all diameters greater than 36 in. The coating on end sections shall match the coating on the pipe connected to it.

M5.03.1: Perforated Corrugated Metal Pipe

This pipe shall meet the requirements of M5.03.0: Corrugated Metal Pipe and contain perforations conforming to AASHTO M 36, Type III. The pipe shall conform to AASHTO M 36 except that reinforcing the ends of the pipe will not be required.

M5.03.6: Metal End Sections

Metal End Sections shall be fabricated to conform with the Construction Standard Details. The method of fabrication and materials used shall conform to the applicable requirements of AASHTO M 36.

M5.03.7: Plastic (PVC) Pipe

Plastic (PVC) Pipe shall meet ASTM D1785 Standard Specification for Poly Vinyl Chloride (PVC) and Chlorinated Poly Vinyl Chloride (CPVC) Plastic Pipe, Schedule 40, 80, and 120. The pipe shall be PVC, Type I Schedule 80. Fittings, such as adapters, couplings, etc. shall be the same material as the pipe. Joints shall be made in accordance with ASTM D2855 Recommended Practice for Making Solvent-cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings. Cements shall meet ASTM D2564.

M5.03.8: Polymeric Precoated Corrugated Metal Pipe

Polymeric precoated corrugated metal pipe shall conform to the requirements of AASHTO M 246, Type B with the thinner polymeric coating a minimum of 3 mils.

M5.03.9: Slot-Perforated Corrugated Plastic Pipe

This pipe or tubing shall consist of slot-perforated corrugated polyethylene tubing, couplings and fittings. Materials, dimensions, physical properties and fabrication shall be in conformance with AASHTO M 252.

M5.03.10: Corrugated Plastic Pipe

Pipe shall consist of corrugated polyethylene or polypropylene tubing, flare ends, couplings and fittings. Materials, dimensions, physical properties and fabrication shall be in accordance with AASHTO M 294, Type S or D or AASHTO M 330 Type S or D. Perforated pipe shall meet Type SP, DP or CP.

M5.03.11: Porous Concrete Pipe

Porous Concrete Pipe shall meet the requirements of AASHTO M 176 for Extra-Strength Porous Concrete Pipe. Aggregates for the concrete may consist of inert carbon material.

M5.04.0: Asphalt Coated Corrugated Metal Pipe Arches

Asphalt coated corrugated metal pipe arches shall consist of corrugated metal pipes which have been reformed to multi-centered pipe having arch shaped tops with a slight outwardly curved integral bottom. The pipe shall be fabricated from standard length culvert sheet and factory riveted to form a continuous length pipe arch.

Asphalt coated corrugated metal pipe arches, including coupling bands, shall conform to the requirement of AASHTO M 36 or AASHTO M 196 for corrugated metal pipe meeting the requirements for base metal, rivets, sampling, testing, brands, corrugations, end finish, weight, bands and workmanship.

M5.04.1: Fabrication

M5.04.1.A: Dimensions

Dimensions, tolerances, and areas shall be in accordance with AASHTO M 36.

The lapped longitudinal seams shall be factory riveted and shall be placed in the top arch and be staggered so as to alternate on each side of the center of the top of the arch by approximately 15% of the periphery.

M5.04.1.B: Asphalt Coating

The insert of the pipe arch shall be coated with asphalt conforming to AASHTO M 190. Type C Coating, so as to form a smooth pavement to widths of 40% of the circumference of the pipe arch. These widths are determined by 40% of the circumference of equivalent diameters. It shall be applied in such a manner that the corrugations are completely filled and that, excepting where the upper edges intersect the corrugations, the pavement has a minimum thickness of ⅛ in. above the crests of the corrugations. The remainder of the inside of the pipe arch and the entire outside shall be uniformly coated with asphalt cement to a minimum thickness of 0.05 in. The thickness shall be measured on the crests of the corrugations. All coupling bands shall be coated to same requirements as the pipe arch except the pavement shall be omitted.

M5.04.1.C: Bituminous Materials

The asphalt cement used for coating shall conform to the requirements in M5.03.0: Corrugated Metal Pipe.

M5.04.2: Structural Plate for Pipe and Pipe Arches

All materials, including base metal analysis, galvanizing, bolts, nuts, corrugations, gauge determination and acceptance of plates, forming and punching holes, bearing shapes, fabrication and incidental items shall conform to AASHTO M 167 and the following:

- The gauge of plates shall be as specified on the Plans.
- Bituminous Coating for Metal Surfaces. The bituminous coating shall be a coal tar blend conforming to the requirements of M7.04.01.

M5.04.3: Asphalt Coated Smooth Steel Liner Helically Corrugated Shell Metal Pipe

This pipe shall conform to AASHTO M 36, 8.1.1, Type 1A pipe. The coating shall conform to AASHTO Designation M 190, Type A.

M5.05.3: Ductile Iron Pipe and Fittings

Ductile iron pipe shall conform to the requirements of AWWA C150, C151, C111 and shall be double cement lined and asphalt seal coated in accordance with AWWA C104. The wall thickness shall be Class 52.

Ductile iron fittings for pipes 3 in. through 24 in. in diameter shall be of the compact type and conform to the requirements of AWWA C153 American National Standard for Ductile-Iron compact Fittings, 3 in. through 24 in., for water and other liquids.

Ductile iron fittings for pipes greater than 24 in. and up to 48 in. in diameter shall conform to the requirements of AWWA C110 American National Standard for Ductile-Iron and Gray-Iron Fittings, 3 in. through 48 in., for water and other liquids.

M5.05.3.A: Hydrants

Hydrants shall conform to the requirements of AWWA Standard C502, and/or to the type used by the municipality as specified in the Special Provisions.

M5.05.3.B: Gate Valves

Gate valves shall conform to the requirements of AWWA Standard C500 and/or to the type used by the municipality as specified in the Special Provisions.

M5.05.4: Acrylonitrile - Butadiene - Styrene (ABS) Pipe

This type of pipe shall conform to the requirements of AASHTO M 265.

M5.06.0: Copper Tubing

Copper Tubing shall conform to the requirements of ASTM B88, Type k, “annealed.”

M5.07.0: Electrical Conduit-Rigid Nonmetallic (Type NM)

Rigid Nonmetallic Electrical Conduit and associated fittings shall conform to Article 352 of the NEC, NEMA TS2, UL 514B and UL 651.

Unless encased in concrete, all Type NM conduit installed underground shall be Schedule 80 (Electric Polyvinyl Chloride-80).

The walls of the conduit shall have a smooth interior surface free from all substances which may injure any wire or cable covering such as is used on rubber covered or thermoplastic insulated wire or cable.

The bore of the conduit shall be circular in cross section and straight and true so as to pass freely a mandrel 3 ft long and ¼ in. less in diameter than the nominal inner diameter of the conduit.

The bore of bends, elbows, and other fittings shall pass freely a ball of ¼ in. less in diameter than the nominal inner diameter of the conduit. Couplings, elbows, bends, adapters, reducers, increasers and bell ends, shall be of the same material as the conduit.

The minimum acceptable radii dimensions for elbows and bends shall conform to the requirements of the NEC. Joints shall be machined to an accurate taper on both ends to permit a tight joint when assembled with suitable couplings or fittings.

One tapered joint coupling shall be supplied with each length of conduit and each elbow or bend.

At least 85% of the conduit in any lot shall be furnished in standard length; sections of conduit less than 5 ft will not be accepted. A tolerance of ±1 in. is permissible in the conduit lengths specified.

Each length of conduit and all associated fittings shall be clearly and durably marked at least every 10 ft with the manufacturer's name, trademark, or other descriptive marking by which the fabricator can be identified. The material type, trade size, and UL labelling shall also be included in the marking.

M5.07.1: Electrical Conduit-Rigid Metallic (Type RM)

Rigid Metallic Electrical Conduit and associated fittings shall conform to Article 344 of the NEC and the following:

- Class 1 – Type A –UL Standard 6 – Rigid Metal Electrical Conduit.
- Class 2 – Type A – UL Standard 1242 – Intermediate Metal Conduit.
- Class 1 and 2 – Types B, C, and D – UL Standard 514B – Fittings for Conduit and Outlet Boxes.

Each length of conduit and all associated fittings shall be clearly and durably marked at least every 10 ft with the manufacturer's name, trademark, or other descriptive marking by which the fabricator can be identified. The material type, trade size, and UL labelling shall also be included in the marking.

M5.07.2: Electrical Conduit-Flexible Metallic (Type FM)

Flexible Metallic Electrical Conduit and associated fittings shall be liquid-tight and conform to Article 350 of the NEC and UL-360.

Each length of conduit and all associated fittings shall be clearly and durably marked at least every 10 ft with the manufacturer's name, trademark, or other descriptive marking by which the fabricator can be identified. The material type, trade size, and UL labelling shall also be included in the marking. Type FM conduit suitable for direct burial shall also be so marked.

M5.08.0: Pull and Junction Boxes – Metallic

Metallic pull and junction boxes made of cast iron, welded sheet steel or cast aluminum shall conform to UL 514A Metallic Outlet Boxes.

SECTION M6: ROADSIDE DEVELOPMENT MATERIALS

M6.00.0: General

This section describes requirements for materials used for soil amendments, seed, plant material, mulches, and other materials required for the care and establishment of plants.

M6.01.0: Inorganic Amendments

Limestone shall consist of pulverized limestone obtained by grinding either calcareous or dolomitic limestone such that 95% of the material will pass a 20-mesh sieve and at least 50% will pass a 100 mesh sieve. The limestone shall meet the applicable provisions of State and Federal laws which relate to commercial fertilizers.

Sulfur for adjustment of loam pH shall be elemental or flours of sulfur, unadulterated, and shall be delivered in containers with the name of the manufacturer, material, and net weight appearing on each container.

Gypsum for soil structure amendment and de-icing salt mitigation shall be agricultural grade, 80 percent calcium sulphate ($CaSO_4 \times 2H_2O$), in granular or slurry form, with 100% passing a 2 mm screen, and 90% passing through 150 µm screen. Gypsum may be derived from natural sources or from recycled wallboard.

Soil wetting agent shall be a synthetic, non-toxic acrylic polyacrylamide or natural soluble plant extract. Application rates shall be per manufacturer's recommendations. Submit supplier specifications and certification.

M6.02.0: Fertilizer

Fertilizer shall meet the applicable provisions of State and Federal laws and be furnished in containers plainly marked with the chemical analysis of the product.

Fertilizer for general planting shall be slow release and shall be commercial grade 10-10-10, or sufficient to meet the recommendations for soil amendment. At least 40% of the nitrogen content shall be slow release, phosphorus shall be available phosphoric acid, and potassium shall be water-soluble potash.

M6.03.0: Long Term Seed Mixes for Lawns and Slopes

The seed mixture specified for slopes and shoulders consists of a tough hardy type for use on slopes graded at the rate of 1 vertical to 4 horizontal, and steeper slopes, and on shoulders adjacent to the roadway pavement or as otherwise directed. The mixture for lawn grass plots is of a finer type that will produce finer turf.

Grass seed shall be of the previous year's crop and in no case shall the weed seed content exceed 1% by mass. All Bluegrass, Fescue, and Ryegrass shall be within top 25% of either of two most recent National Turfgrass Evaluation Program reports. The grass seed shall conform to the requirements of the following tables:

Table M6.03.0-1: Grass Seed Requirements for Lawn Grass Areas

Grass Type	Proportion	Germination Minimum	Purity Minimum
Creeping Red and/or Chewings Fescue	59%	85%	95%
Kentucky Blue	30%	85%	90%
Perennial Rye	5%	90%	98%
Redtop	5%	85%	92%
Dutch White Clover	1%	85%	96%

Table M6.03.0-2: Grass Seed Requirements for Slopes and Shoulders

Grass Type	Proportion	Germination Minimum	Purity Minimum
Creeping Red, Chewings, and/or Hard Fescue	50%	85%	95%
Tall Fescue	35%	85%	90%
Perennial Rye	5%	90%	98%
Redtop	5%	85%	92%
Dutch White Clover	5%	85%	96%

The seed shall be furnished and delivered premixed in the proportions specified above. All seed shall comply with State and Federal seed laws. Clover shall be pre-inoculated.

Contractor will supply a manufacturer's Certificate of Compliance to the specifications shall be submitted by the manufacturers with each shipment of each type of seed mix. Certificates will be attached to the seed bags for inspection. These certificates shall include the guaranteed percentages of purity, weed content and germination of the seed, and also the net mass and date of shipment. No seed may be sown until the Contractor has submitted the certificates.

M6.03.1: Short Term Erosion Control Seed

This seed shall consist of a mixture of the previous year's crop and shall contain the following mixture by weight with 98% purity:

Table M6.03.1-1: Requirements for Short-Term Erosion Control Seed

Seed Type	% by Weight	Germination Minimum
Winter Rye	80 minimum	85%
Red Fescue (Creeping)	5 minimum	80%
Perennial Rye Grass	5 minimum	90%
Dutch White Clover	3 minimum	90%
Other Crop Grass	0.5 maximum	
Noxious Weed Seed	0.5 maximum	
Inert Matter	1.0 maximum	

A manufacturer's certificate of compliance will be required as specified in M6.03.0: Long Term Seed Mixes for Lawns and Slopes.

M6.04.0: Mulch

Materials to be used in mulching shall conform to the following requirements:

M6.04.1: Hay Mulch

Hay Mulch shall consist of mowed and properly cured grass, clover or other acceptable plants.

M6.04.2: Straw Mulch

Straw Mulch shall be seed free, consisting exclusively of stalks or stems of grain after threshing.

M6.04.3: Wood Chip Mulch

Wood chip mulch shall consist of wood chips produced by cutting branches, limbs of trees, brush or shrubs with chippers or from the chipping of stumps, and shall be free of topsoil, stones, and other extraneous material. The chippers shall be approved for use by the Engineer. Wood chip mulch must be free from long stringy material over 4 in. in length and from live, rot-free wood and bark, except that 35% or less by volume of the wood chip mulch may consist of "slab wood," chipped to an acceptable size by chippers equipped with a ¼ in. knife set and thoroughly mixed with the live material. Wood Chip Mulch containing an excess of fine particles, such that mulch will blow or wash away, decay too quickly, or percolate too slowly, will not be acceptable. Wood Chip Mulch may be produced on the project from acceptable cuttings. Wood chip mulch containing remnants of invasive species such as Japanese Knotweed and Bittersweet shall not be used.

M6.04.4: Wood Fiber Mulch

Wood Fiber Mulch shall consist of wood fiber produced from clean, whole uncooked wood, formed into resilient bundles having a high degree of internal friction and shall be dry when delivered on the project. Recycled material may be evaluated for acceptance based on evaluation of submitted sample, specifications and certified test results from an approved laboratory, per the requirements of M1.06.0: Organic Soil Additives.

M6.04.5: Aged Pine Bark Mulch

This mulch shall consist of the outer bark of pine trees and a minimum of hardwood bark. Bark shall be processed by removal from the limbs and trunks of trees.

Bark mulch shall be shredded pine bark aged a minimum of 6 months. The mulch shall be dark brown in color, free of chunks and pieces of wood thicker than ¼ in. and shall not contain, in the judgment of the Engineer, an excess of fine particles. Do not use wood chips, recycled, dyed, wood product, or crumb rubber mulch.

Mulch must be free from long stringy material.

M6.05.0: Sod

Sod shall be composed of the grass mixture recommended by the New England Sod Producer's Association and shall be specified as:

Table M6.05.0-1: Sod Type 1 for Full Sun Turf Areas (6 or More Hours Direct Sunlight in Growing Season)

Species	Percent by Turf Area*
Kentucky Bluegrass	50% to 80%
Fine Fescues	10% to 30%
Perennial Ryegrass	0 to 20%

* All species with >70% of the mix shall have at least 3 varieties; >40% shall have at least 2 varieties.

Table M6.05.0-2: Sod Type 2 for Partial Shade Turf Areas (4 to 6 Hours Minimum Direct Sunlight in Growing Season)**

Species	Percent by Turf Area*
Fine Fescues	75% to 90%
Kentucky Bluegrass	10% to 25%
Perennial Ryegrass	0 to 10%

* All species with >70% of the mix shall have at least 3 varieties; >40% shall have at least 2 varieties.
** Areas receiving less than 4 hours per day of direct sun during growing season should not receive sod.

Table M6.05.0-3: Sod Type 3 for Multi-Use Turf Areas (and 4 to 6 Hours Minimum Direct Sunlight in Growing Season)

Species	Percent by Turf Area*
Tall Fescue	50% to 90%
Fine Fescues	20% to 50%
Kentucky Bluegrass	0 to 20%
Perennial Ryegrass	0 to 20%

* All species with >70% of the mix shall have at least 3 varieties; >40% shall have at least 2 varieties.
** Areas receiving less than 4 hours per day of direct sun during growing season should not receive sod.

Lawn sods shall have been nursery grown on cultivated agricultural land used specifically for sod purposes. Grasses shall be drought tolerant cultivars.

The sods shall be free of objectionable grassy and broadleaf weeds. Sods shall be considered free of such weeds if less than 5 such plants are found per 10 yd² of area.

The sod shall be machine cut at a uniform minimum thickness of ¾ in. at the time of cutting. Measurement for thickness shall exclude top growth and thatch.

Individual pieces of sod shall be cut to the supplier's standard width and length. Maximum allowable deviation from standard widths and lengths shall be 5%. Broken pads and torn or uneven ends will not be acceptable.

Sod that has dried out, or that has been unplanted over 3 days (including weekends) since harvest, will be rejected.

M6.06.0: General Planting

The Contractor shall furnish all plants as shown on the plans.

M6.06.1: Nursery Stock – General

All scientific and common plant names of the items specified shall conform to the current edition of Hortus Third, compiled by the staff of the L.H. Bailey Hortorium, Cornell University. These standards shall determine all requirements of acceptable shrub and seedling nursery stock names. All plants will have durable, non-fading labels applied at the nursery that clearly bears the correct botanical name, including cultivar, as well as common name and size. Caliper or spread shall govern over height specifications. The Contractor must obtain written permission from the Engineer for any substitutions of types or sizes specified.

All plants shall be grown in a certified nursery. All plants shall be typical of their species or variety in growth habit. Plant sizes, habit, rootball dimensions, stem and cane count shall conform to the requirements of the American Standards for Nursery Stock (ASNS) standards as a minimum requirement for acceptance. Container sizes shall also be consistent with the guidance per plant size per the ASNS. Each plant shall have plenty of fibrous roots, healthy buds, and shall be free of disease and insect pests. No plant material from cold storage will be accepted. All plant parts shall show active green cambium when cut and shall be densely foliated when in leaf.

Deciduous shrubs shall have 4 to 6 canes coming from the roots and shall have a well-branched root system.

Vines and ground cover shall be minimum 2-year No. 1 stock. Herbaceous plants shall be minimum 1-year No. 1 stock, and clumps shall have not less than 6 buds, eyes, or crowns.

The trunk of each tree shall be free from sunscald, frost cracks, or wounds resulting from abrasions, animal pest, fire or other causes. Pruning wounds shall be no larger than 2 in. and shall show vigorous scar tissue. No trees with double-leaders or twin-heads will be acceptable without the written approval. The plants must be in a vigorous condition and free from dead wood, bruises and other root or branch injuries. Deficient plants may be rejected at any time.

Any species (including all cultivars) listed on the Massachusetts Department of Agricultural Resources Prohibited Plant List shall not be used including but not limited to the following:

- Norway Maple (*Acer platanoides*)
- Sycamore Maple (*Acer pseudoplatanus*)
- Japanese Barberry (*Berberis thunbergii*)
- Autumn Olive (*Eleagnus umbellata*)
- Burning Bush or Winged Euonymus (*Euonymus alatus*)
- Glossy or European Buckthorn (*Frangula alnus*)
- Dames Rocket (*Hesperis matronalis*)
- Yellow Iris (*Iris pseudoacoris*)
- Border Privet (*Ligustrum obtusifolium*)
- Honeysuckle -- Japanese, Amur, Morrow's, Tatarian, Bell's (*Lonicera japonica, L. maackia, L. morrowii, L. morrowii x tartarica*)
- Plume grass (*Miscanthus sacchariflorus*)
- Forget-me-not (*Myosotis scorpoides*)
- Reed Canarygrass (*Phalaris arundinacea*)
- Amur Cork Tree (*Phellodendron amurense*)
- Common Buckthorn (*Rhamnus cathartica*)
- Black Locust (*Robinia pseudoacacia*)
- Wild Rose (*Rosa multiflora*)

M6.06.2: Nursery Stock – Balled and Burlapped

All plants that are to be balled and burlapped previous to shipment are designated "B&B." B&B plants shall be dug so as to retain as many fibrous roots as possible. All B&B plants shall come from soil that will hold a firm root ball and the solidity of the ball shall be carefully preserved. B&B plants shall be wrapped with untreated 8-oz burlap, firmly held in place by a stout cord or wire. Wire containers shall be of adequate size to allow root development for the plant size as per ASNS requirements. Plants prepared with plastic or other non-biodegradable wrappings will not be accepted. Rootballs shall remain intact during all operations. No plant will be accepted if the rootball has been cracked or broken prior to, or during, the process of planting. All plant materials shall be dug with reasonable care and skill immediately prior to shipment.

M6.06.3: Nursery Stock – Container Grown

All container-grown plants shall be healthy, vigorous and well rooted in the container in which they are sold. They shall have tops that are of good quality and are in healthy growing condition. No single-stemmed shrubs or sparsely leafed plants will be accepted. The side branches must be generous and well twigged, and the plant as a whole must be well-branched to the ground or typical of the species or cultivar. Container-grown stock shall have been grown in the container long enough for the root system to develop sufficiently to hold the soil together firmly. No plants shall be loose in the container. Container-grown plants shall not be pot bound with spiraling roots or roots growing densely against the sides of the container. The container shall be sufficiently rigid to protect the root mass during shipment and sizes shall be provided in accordance with the ASNS standards. The size of plant, as well as minimum number of stems or canes, will conform to the type of plant per ASNS standards.

The soil medium for container-grown plant material shall be a uniformly blended, stable medium free from weeds, weed seeds, disease organisms, insects, herbicide residue, and all other harmful organisms or materials. The soil shall fill the container to at least 85% of its height, serving as a stable base for the anchorage and support of the plant growing in it. It shall be well-aerated sandy loam or fine sandy loam, per USDA Soil Classification, and of sufficient structure to provide adequate moisture to plants.

The certificate of compliance for container grown plants shall contain, in addition to the requirements listed in 771.40: General, the guaranteed composition of the potting mixture and the date of planting in the container. Plants shall have been grown in the container for a minimum of 12 weeks. A random sample is required from each delivery for soil and root inspection upon request of the Engineer.

M6.06.4: Nursery Stock – Bare-Root

Bare-root material shall be dug during dormancy within 72 hours of shipping and shall be kept moist and stored in a cool, shaded location until planting. All bare-root material shall be accompanied by certification of digging date. The roots of bare-rooted material shall be dipped in soil wetting agent and carefully protected with wet straw, moss or other suitable material that will ensure the arrival of the plants at the site of the work in good condition. All bare-root material shall be installed within 48 hours of arrival on the construction site, and shall be kept moist and out of wind or direct sunlight until planting. Maximum time between digging for shipping and installation shall be one week.

M6.06.5: Nursery Stock – Seedlings

Seedlings shall have well developed root systems and shall be acclimated and suitable in all respects for field planting. All conifers must have dormant buds and secondary needles.

Evergreen seedlings shall be two-year transplants, bare rooted.

Lining out stock seedlings shall be two-year seedlings.

Root cuttings shall be established in peat pots 2.5 in. deep by 2 in. wide at the open end and tapered to 1 in. wide at the closed end (inside measure).

M6.06.6: Nursery Stock – Trees

Per the requirements of the ASNS, the sizes of trees shall be as called for on the plans and measurements shall be determined by caliper at a point 6 in. above the ground for plants specified up to 4 in. in caliper. Larger minimum caliper shall be measured 12 in. from ground.

Trees for streetscape plantings (i.e., in or adjacent to walkways) shall have a single straight leader not cut back.

They shall have a symmetrical development of strong, healthy branches beginning at least 7 ft from the ground; and below this point, the trunk shall be clean for street trees. Coniferous Evergreens shall be dug before spring “candling” of new growth.

Grafted and budded trees may branch lower and be pruned off 2 ft from the ground where directed. Flowering trees shall be balled and burlapped and kept moist for delivery.

M6.06.7: Nursery Stock – Shrubs, Vines, Groundcover and Perennials

Shrubs shall have the form required per ASNS. Specified spread shall govern over height requirements.

Vines and ground cover in this group shall be 2-year, No. 1 stock.

Herbaceous plants in this group shall be minimum 1-year, No. 1 year stock, and clumps shall have not less than 6 buds, eyes or crowns.

M6.07.0: Delivery and Protection

All plants shall be packed so as to arrive at the delivery point in good growing condition and shall be kept moist for delivery and during transit. Special precautions shall be taken to avoid any unnecessary injury to, or removal of, fibrous roots. Each species or variety shall be handled and packed in the approved manner for that particular plant having regard to the soil and climatic conditions at the time and place of digging, transit and delivery, and to the time that will be consumed in transit. All precautions that are customary in good trade practice shall be taken to ensure the arrival of the plants at the site of the project in good condition for successful growth.

Shipment of plant material shall be scheduled to minimize the time between arrival and installation at the construction site. Plants may be stored at the construction site for up to 3 days on in an approved location that is out of direct sunlight and wind. Contractor shall store plants in wood chips and shall provide watering to maintain containers and root balls in moist condition at all times prior to installation.

M6.07.1: Wrapping for Transport

Wrapping material shall be used for transport only. Wrapping material for root balls shall be 8-ounce jute burlap; plastic is not acceptable. Material for tree trunks shall be 4 to 6 in. wide strips of burlap, paper, cardboard, or plastic manufactured for this purpose. Fastening for the wrapping material shall be either adhesive weather resistant tape or a minimum of 3-ply jute twine. Wrapping must be removed once tree has been installed.

M6.08.0: Materials for Guying and Staking

The stakes shall be unpainted spruce or other suitable wood free from large knots, dimensioned 2x2 by 8 ft in length and sharpened at one end. Binding and guying shall be biodegradable webbing. Stake fastenings shall be 10 penny galvanized nails. Trees shall not be wrapped.

M6.08.1: Temporary Fencing for Tree Protection

Temporary Tree Protection Fence shall be brightly colored polypropylene barricade or wooden snow fencing for tree protection or safety fencing. Fencing shall be a minimum of 4 ft high and supported by steel or hardwood stakes spaced at a maximum of 8 ft on center or by other means acceptable to the Engineer.

M6.08.2: Trunk Cladding for Tree Protection

Cladding for trunk protection shall be 2x4 or 2x3 nominal lumber, at least 6 ft in length, sufficiently tall to protect tree trunk from construction activities, and bound together with wire. Alternatively, trunks may be shielded with sections of corrugated plastic pipe of sufficient diameter and height to

shield trunk from construction activities. Trunk protection shall include burlap, which shall be untreated 8-oz burlap.

M6.08.3: Sheeting for Tree Root Protection

Sheeting for tree root protection shall be minimum ¾-in. thickness plywood, cut and trimmed to required sizes and configurations.

M6.09.0: Water for Irrigation

Water used for irrigation of plant materials shall be free from any substance injurious to vegetation, such as oil, acids, alkalis and salts. Water shall be free from impurities injurious to vegetation.

Submittal shall be required, including anticipated demand, irrigation method, watering schedule, sources of water, and any incidental work required to provide water for the plants.

SECTION M7: PAINTS, PROTECTIVE COATINGS AND PAVEMENT MARKINGS

M7.00.0: General Requirements for Paints and Protective Coatings

All paint shall conform to the following general requirements.

M7.00.0.A: Materials

The raw materials used in the following specifications for paints and protective coatings shall conform to the specification designed by ASTM or AASHTO specifications.

M7.00.0.B: Proportions

Paint proportions and percentages given in the following specification are expressed by weight.

M7.00.0.C: Condition in the container

Paint and protective coatings shall be homogeneous, free of contaminant and of a consistency suitable for use in the capacity for which it is specified. The finished product shall be well ground and the pigment shall be properly dispersed and suspended in the vehicle according to the requirements of the paint or protective coating. The dispersion shall be of such nature that the pigment does not settle badly, does not cake or thicken in the container, and does not become granular, jelled or curdled. Any settlement of pigment in the paint or protective coating shall be a thoroughly wetted soft mushy mass permitting the complete and easy vertical penetration of a paddle. Settled pigment shall be easily dispersed, with a minimum resistance to the sidewise manual motion of the paddle across the bottom of the container, to form a smooth uniform product of the proper consistency.

M7.00.0.D: Packaging

The finished paint or protective coating shall be furnished in new 5-gal, round, non-tapered containers. The containers shall meet U.S. Department of Transportation Hazardous Materials Shipping Regulations.

The following information shall be labeled on each can in a clear legible manner:

- Name of Manufacturer
- Place of Manufacture
- Manufacturer's Batch Number
- MassDOT Specification Number
- Date of Manufacture

Precautions concerning the handling and the application of the paint or protective coating shall be shown on the label.

M7.00.0.E: Testing

Testing of paints will be done by the Department in accordance with the methods of Federal Test Method Standard Number 141, AASHTO and ASTM methods described below.

In addition, the Department reserves the right to make use of any information or methods of testing to determine the quality of paint and paint materials.

M7.01.03 Liquid Thermoplastic Striping Material

M7.01.03.A: General

This specification covers a reflectorized thermoplastic pavement striping material that is extruded onto the pavement in a molten state by mechanical means with the application of glass beads. When applied properly and at the designated thickness and width the stripe shall, upon cooling, be reflectorized and be able to resist deformation by traffic. The material shall be placed on bare pavement or existing thermoplastic markings.

Prequalified batches of acceptable thermoplastic materials are listed on the QCML.

All thermoplastic material shall meet the requirements of AASHTO M 249 and tested in accordance with AASHTO T 250 and the following:

- Glass Beads (Pre-Mix) used in the manufacture of thermoplastic shall be uncoated and meet the requirements of AASHTO M 247, Type I and M7.01.07: Glass Beads.
- The resin shall be alkyd or hydrocarbon and meet the requirements of table M7.01.3-1.

Table M7.01.3-1 Thermoplastic Resin Requirements

Properties	Hydrocarbon	Alkyd
% Binder, Minimum	22	20
Indentation Resistance @ 115°F, ASTM D7735	--	40-75 units (Type A)
Bond Strength, Minimum, psi	180	200

The material manufacturer shall have the option of formulating a hydrocarbon resin-based or an alkyd resin-based system. However, the physical and chemical properties contained in this specification shall apply regardless of the type of formulation used. The binder must consist of a mixture of resins, at least one of which is a solid at room temperature, and high boiling point plasticizers. At least one third of the binder composition of an alkyd-based system must be maleic-modified glycerol ester of rosin and must be no less than 8% of the entire material formulation. Material of either binder type upon heating to the application temperature shall not evolve fumes which are toxic, or injurious to persons or property. The pigment, beads and filler shall be well dispersed in the resin. The material shall be free from all skins, dirt, and foreign objects.

The thermoplastic pavement marking material may be supplied in block or granular form. Block material shall be packaged in suitable containers to which it will not adhere to during shipment or storage. The blocks shall be approximately 12 in. x 36 in. x 2 in. Granular material shall be packaged in bags that when introduced to the mix hopper of the application equipment, it will become part of the mix with no adverse effect to the performance of the thermoplastic material. The packages of either type shall weigh approximately 50 lb. Each container label shall designate the color, manufacturer's name, batch number and date of manufacture. Each batch manufactured shall have its own separate number. The label shall warn the user that the material shall be heated in the range of 400°F-425°F during application.

M7.01.03.B: Sampling and Testing

M7.01.03.B.1: Sampling

Provide one bag of thermoplastic material for verification testing per batch. A batch is a unit of production that is consistent in appearance, formulation, proportions and can be identified by a unique number know as a Batch Number. Each batch shall consist of a minimum of 3,000 lb and a maximum of 44,000 lb.

M7.01.03.B.2: Testing

Tests on White and Yellow Thermoplastic Striping Material shall be reported by an Independent Testing Laboratory and performed in accordance with these Specifications and AASHTO T 250.

The Independent Test Results shall be for each batch and shall identify the material by manufacturer including name and address, batch number(s), date and place of manufacture and any other information that will assist in identifying the product. It shall also note the test method used for each test. The report shall include the date tested and shall be signed by a person responsible for authenticating the veracity of the test. Below the signature shall be the person's printed name and title.

Request for prequalification for each thermoplastic material batch shall be submitted to RMS, accompanied by:

- Certificate of Compliance stating that the material complies with AASHTO M 249, AASHTO T 250, this specification and all applicable MassDOT requirements.
- Independent Lab test results; and
- One bag of thermoplastic striping material per batch in sample bags meeting the specifications above for verification testing. The bag shall be sent to the attention of the Director of Research & Materials, MassDOT/Highway, 5 Macadam Road, Hopkinton, MA 01748.

M7.01.04: Fast Drying White and Yellow Waterborne Traffic Paint

Approved waterborne traffic paint shall be tested in accordance with AASHTO M 348 and be listed on the QCML. The dry paint film shall be under the Toxicity Characteristic Leaching Procedure (TCLP) limits for all contaminants listed in 40 CFR 261.24.

The markings shall be installed using reflective glass beads meeting the requirements of M7.01.07: Glass Beads. For waterborne yellow paint use Organic Yellow No. 65 or No.75 pigment.

M7.01.07: Glass Beads

This specification covers the requirements for glass beads which are to be dropped or sprayed on pavement markings. Glass bead suppliers and approved batch numbers are listed on the QCML.

All glass beads shall meet the requirements of AASHTO M 247, and be tested in accordance with AASHTO T 346 and the following:

- A minimum of 80% of the glass beads shall be true spheres when tested in accordance with ASTM D1155, Procedure A.
- The glass beads shall be manufactured from commercial grade soda lime glass cullet and shall meet the AASHTO concentration for heavy metals, 200 ppm maximum, as tested in accordance with EPA test methods 3052, 6010B and 6010c, or AASHTO T 392. The silica content shall be 60% minimum (ASTM C169).
- Moisture Resistance - The Type 1 and Type 4 glass beads shall be treated with a moisture proof coating and be moisture resistant as tested by AASHTO T 346, Referee Method.
- Adherence - The Type 4 glass beads shall be coated with a silane-type adherence coating to enhance embedding in, and adherence to, the applied binder film. The coated beads shall emit a yellow-green fluorescence when tested by the Dansyl Chloride test procedure.
- Intermix glass beads used in the manufacture of thermoplastic pavement markings shall meet the requirements of AASHTO M 247, Type 1 glass beads. A moisture proof coating is optional.

M7.01.07.A: Gradation

The glass beads shall be tested in accordance with ASTM D1214 (by use of U.S. Standard Sieves).

Standard gradation beads shall meet the requirements of AASHTO M 247, Type 1.

Large gradation beads shall meet the requirements of AASHTO M 247, Type 4.

M7.01.07.B: Packaging

The beads shall be packaged in 50-lb or greater polyethylene-lined paper bags or equal container; such containers guaranteed to furnish dry and undamaged beads. The following information shall be indelibly labeled in a clear and legible manner on each container:

- The name of the manufacturer.
- The place of manufacture.
- The words: "Glass Beads-Traffic".
- Size/Type/Coating.
- Materials Specification Number.
- The date of shipment (month and year).
- The batch number.
- Net weight.

M7.01.07.C: Approval Procedure

Requests for approval shall be submitted to the Department accompanied by:

- Certificate of Compliance stating that the material complies with AASHTO M 247, and tested in accordance with AASHTO T 346 and all applicable MassDOT requirements;
- Independent lab test results; and
- One bag of glass beads per batch in sample bags meeting the specifications above for verification testing.

M7.02: Structural Paint

M7.02.A: General

New coatings systems shall be a low VOC that meets current VOC regulations. Coating systems shall be selected from the MassDOT QCML-NEPCOAT Qualified Products List "B." Structural paint will be tested according to the following:

- ASTM D 562 Consistency
- ASTM D 1475 Density
- ASTM D3723 Pigment
- ASTM D 2369 Volatile Content
- AMS STD 595 Federal Color Index

M7.02.B: Sampling

M7.02.B.1: QCML

Each year manufacturers shall send samples of each product for each color to be used to The Department for testing. Approved paint products and colors will be posted on the QCML. If Paint products are not listed on QCML but are Nepcoat qualified products, samples shall be obtained from the project site. Samples must be taken in clean, dry, airtight, widemouthed metal quart cans. The sample container must be filled within 2 in. from the top of the can and sealed properly. Each sample must be labeled with the name of the manufacturer, brand, coat, and color prior to shipping to the Department.

M7.02.B.2: Project Site samples

Samples from project sites are not required if the paint to be used on the project is on the QCML. If samples are obtained from the project, paint must be agitated by the contractor before sampling. Contractors shall not combine individual paint components prior to sampling. One quart sample shall be taken in containers described below. All samples shall be from the same batch.

Samples must be taken in clean, dry, airtight, widemouthed metal quart cans. The sample container must be filled within 2 in. from the top of the can and sealed properly. Each sample must be labeled with the name of the manufacturer, brand, coat, and color prior to shipping to the Department.

Project paint quantities of 40 total gallons or less shall not require sampling and testing. In lieu of sampling and testing, the contractor shall submit a letter stating the total amount of paint to be used on the project will be 40 gallons or less. A manufacturer's certificate of compliance shall be submitted with the letter.

M7.03: Enamels

- M7.03.02 Sign and Equipment Enamel

M7.04: Miscellaneous Coatings

- M7.04.01 Coal Tar Protective Coatings
- M7.04.02 Primer, Paint, Exterior, (Undercoat for Wood, Ready Mixed White and Tints)
- M7.04.03 Paint, Zinc Yellow, Iron Oxide Base Ready Mixed (Type II)
- M7.04.04 Paint, Ready Mixed, International Orange

- M7.04.05 Paint, Exterior, Black Ready Mixed
- M7.04.06 Primer Coating, Basic Lead Silico Chromate, Ready Mixed
- M7.04.07 Primer Coating, Zinc Dust-Zinc Oxide (for galvanized surfaces). Material shall meet ASTM A780, Annex A2, containing a minimum of 92% zinc by weight in the dry film. Material conforming to this specification shall be compatible with additional coats of an approved coating system to match existing coating system.
- M7.04.08 Enamel Undercoat Interior, Tints and White
- M7.04.09 Paint, Outside, Dull-Black (Formula 104)
- M7.04.10 Primer, Pretreatment (Formula 117 for Metals)
- M7.04.11 Paint, High Zinc Dust Content, Galvanizing Repair. Material shall meet ASTM A780, Annex A2, containing a minimum of 92% zinc by weight in the dry film. Material conforming to this specification shall be acceptable as the final condition, without additional coatings.

M7.05: Epoxy Protective Coating

- M7.05.01 Epoxy- Polyamide Red Lead Paint
- M7.05.02 Epoxy- Polyamide Green Paint
- M7.05.03 Epoxy - Polyamine Concrete Coating
- M7.05.05 One Coat High Build Epoxy Mastic Coating
- M7.05.11 Epoxy - Polyamide Primer Paint (non-lead)
- M7.05.12 Brown Epoxy - Polyamide Top Coat (non-lead)
- M7.05.13 Green Epoxy - Polyamide Top Coat (non-lead)
- M7.05.15 One Coat Hi Build Mastic Coating
- M7.05.21 Coal Tar Epoxy Polyamide Paint
- M7.05.31 Self-Priming Epoxy Coating

Or those coatings listed in the QCML.

M7.10.0: Galvanized Coatings

Galvanized coatings shall conform to the following requirements:

- AASHTO M 232 (ASTM A153): Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- AASHTO M 298 (ASTM B695): Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel.
- AASHTO M 111 (ASTM A123): Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.
- ASTM A780: Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings

Hardware shall be supplied galvanized in accordance with the applicable standard above. All hardware shall be supplied with the appropriate documentation including Material Test Reports and Certificates of compliance in accordance with 6.00: Control of Materials and delivered in sealed containers.

All structural steel shall be hot dip galvanized in accordance with the above specifications and M8.06.9.K.3: Galvanizing. Material shall be subject to inspection prior to, during and final inspection at the galvanizer at the discretion of the Engineer. Material shall meet all the requirements of AASHTO M 111 prior to shipment. All materials shall be shipped with Certificates of Compliance in accordance with 6.00: Control of Materials.

M7.15.0: Metallized Coatings

The wire used for metallizing shall be zinc or 85/15 zinc/aluminum per ASTM B833, Standard Specification for Zinc Wire for Thermal Spraying (Metallizing). The fabricator shall provide material certificates from the supplier that includes the chemical composition and lot number of the wire. When required by the contract documents, thermal spray wire must be manufactured domestically.

Sealer used for metallized coatings shall be suitable for sealing thermal spray coatings. It shall meet the current regulations for VOC requirements. Sealer shall be used prior to shelf life expiration. Metallized Coatings shall be applied in accordance with M8.06.9.K.4: Thermal Spray Coating (Metalizing).

M7.20.0: Anodized Coatings

Aluminum extrusions to be anodized shall be finished in a dark bronze Architectural Integral-Color Anodized finish conforming to Aluminum Association designation AA-M10-C22-A44. The anodic coating shall be Aluminum Association Architectural Class 1 with a minimum thickness of 0.7 mils and a minimum weight of 35 mg/in^2.

Prior to production, the finisher shall submit surface smoothness samples and color range samples to RMS for the Engineer's approval, to establish inspection limits of allowable surface smoothness and allowable color shade range.

Samples of anodized extrusions from production lots, as selected by the Engineer, shall be tested in accordance with ASTM B137, ASTM B244, and ASTM B136.

M7.25.0: Powder Coatings

Aluminum to be powder coated shall be finished in a dark bronze powder coat finish to match the color of the anodized extrusions. The coating shall be a polyester-TGLC (triglycidyl isocyanurate) resin system conforming to the following:

Table M7.25.0-1: Physical and Mechanical Properties of Powder Coatings

Quality	Test	Limits
Abrasion	ASTM D4060 Taber Abraser CS-10, 1,000 gram load, 1,000 cycles	100 mg maximum weight loss
Adhesion	ASTM D3359 Initial - 1,000 hours -	 5A 5A
Gloss	ASTM D523 60°F - 600 hours 60°F - 1,000 hours	 82% Retention 90% Retention (washed)
Hardness	ASTM D3363	2H – No Gouge
Impact	ASTM D2794, Direct	Pass 80 in.-lb.
Salt Spray Resistance	ASTM B117, ASTM D1654 1,000 hours unscribed - 400 hours Scribed -	 Table 2 - 10 Table 1 - 10
Weather	ASTM G23 1,000 hours, 18 minutes Waterspray, 102 minute Light	No film failure
Color	Dark Bronze, to match color of anodized aluminum framework	n/a
Identify	Infrared Fingerprint	Match
Flexibility	180° bend with ½-in. diameter mandrel within 10 seconds	No breaks, flaking or cracks Tested with a Q- panel with 2 mils or less of coating
Humidity	ASTM D2247, 1,000 hours	No blister or film failure
Thickness	n/a	4 ±1 mils
Mar Resistance	n/a	Good

Aluminum to be powder coated shall be bare and free of oil or any mill coating. The aluminum shall be caustic cleaned to standard near white. A chromic conversion coating shall be applied after caustic cleaning. The finish coating shall be applied immediately after chromic coating as an electrostatically charged dry powder, sprayed onto the grounded aluminum using an electrostatic spray gun. The coated aluminum shall be heated in accordance with the powder manufacturer's recommend procedure to provide a fully cured finish. The coating thickness after cure shall be a minimum of 3 mils.

Prior to production, the coater shall submit a 3 ft by 1 ft coated sample and color range samples to RMS for the Engineer's approval to establish inspection limits of allowable coating coverage and color shade range.

All stainless steel fasteners shall be colored by a thermal conversion process to match the dark bronze color of the aluminum extrusions. The finish shall be such that it does not peel, chip or crack. Samples of all fasteners shall be submitted along with material certificates to the Engineer for approval.

SECTION M8: METALS AND RELATED MATERIALS

M8.00.0: General

All structural steel and miscellaneous steel products shall be welded in accordance with the requirements of the AASHTO/AWS Bridge Welding Code (ANSI/AASHTO/AWS D1.5). All aluminum material shall be welded in accordance with the AWS Structural Welding Code - Aluminum (ANSI/AWS D1.2). All stainless steel material shall be welded in accordance with the AWS Structural Welding Code – Stainless Steel (ANSI/AWS D1.6). All steel tubular material shall be welded in accordance with the AWS Structural Welding Code - Steel (ANSI/AWS D1.1). All steel reinforcing shall be welded in accordance with the AWS Structural Welding Code – Reinforcing (ANSI/AWS D1.4).

Aluminum castings shall be of uniform quality and condition, free from cracks, blow holes, porous places, hard spots or shrinkage defects which affect the suitability of the castings for their intended use.

At the discretion of the Engineer, MassDOT will assign a Verification Inspector either employed by MassDOT or a Consultant inspector to act on behalf of the Department.

Samples for testing shall be taken in accordance with the applicable ASTM and/or AASHTO specification for the material. Samples shall be taken in the presence of the Verification Inspector when required. Field samples shall be taken by the Resident Engineer. Testing will be done in accordance with latest standard procedures of ASTM and/or AASHTO.

M8.01.0: Reinforcing Bars

Reinforcing bars shall be from an approved supplier and manufacturer listed on the QCML. Reinforcing bars shall consist of deformed bars rolled from new billet steel conforming to the requirements of AASHTO M 31, Grade 60. Spiral reinforcement for columns shall be plain steel meeting the requirements of AASHTO M 31, Grade 60.

Coated reinforcement steel shall be secured using epoxy or plastic-coated tie wire.

Steel for reinforcing shall be free from imperfections, dirt, loose scale, paint, oil, or other foreign substance that might tend to prevent bonding with concrete. Rust that occurs in scales or that pits the steel will be considered an imperfection. Surface rust will not be considered an imperfection, but the surface shall be brushed to remove loose material.

M8.01.1: Cold Drawn Steel Wire

This material shall conform to AASHTO M 336.

M8.01.2: Welded Steel Wire Fabric

Welded Steel Wire Fabric shall be from an approved supplier and manufacturer listed on the QCML. This material shall conform to AASHTO M 336.

M8.01.3: Steel Bar Mats

This material shall conform to AASHTO M 54.

M8.01.4: Tie Bars and Bolts

Tie bars for longitudinal joints shall be either deformed bars of new billet steel (AASHTO M 31, Grade 60) or approved tie bolts as shown on the plans which shall conform in all respects to the standard requirements specified for strength and design.

M8.01.5: Anchor Bolts, Nuts, and Washers

All anchor bolts shall be headed through the use of a preformed bolt head or other means, such as a nut, flat washer, or plate. Hooked bar anchor bolts are not permitted. All Anchor Bolts cast in concrete, including the washers and nuts, shall be galvanized mechanically meeting the requirements of ASTM B695, Class 55, Type 1, or hot dipped galvanized conforming to AASHTO M 232. Anchor Bolts shall be UNC thread pitch.

M8.01.5A: Used for Anchoring Bridge Railing Base Plates to Concrete

Anchor bolts shall conform to the requirements of ASTM F1554 Grade 105. Nuts shall conform to ASTM A563, Grade DH. Flat, hardened washers shall conform to ASTM F436.

M8.01.5B: Used for Anchoring Bridge Railing Base Plates to Concrete

Anchor bolts shall conform to the requirements of ASTM F1554 Grade 105. Nuts shall conform to ASTM A563, Grade DH. Flat, hardened washers shall conform to ASTM F436.

M8.01.5.C: Used for Anchoring Signal Lighting and Sign Structures

Anchor bolts shall conform to the requirements of ASTM F1554, Grade 55 or 105 as specified in the contract documents. Grade 55 nuts shall conform to ASTM A563, Grade A. Grade 105 nuts shall conform to ASTM A563, Grade DH. Flat, hardened washers shall conform to ASTM F436.

M8.01.5.D: High Strength Bolts for Anchoring

High strength bolts for anchoring, where specified, shall conform to M8.04.3: High Strength Bolts. A hardened flat washer conforming to ASTM F436 shall be furnished with each bolt.

M8.01.7: Epoxy Coated Reinforcing Bars

Epoxy coated reinforcing bars shall be bars conforming to M8.01.0: Reinforcing Bars shall be epoxy coated in accordance with ASTM A775. The epoxy coating shall conform to M7.05: Epoxy Protective Coating.

M8.01.8: Galvanized Reinforcing Bars

Galvanized Reinforcing Bars shall be bars conforming to M8.01.0: Reinforcing Bars and shall be galvanized in accordance with ASTM A767 C1.

M8.01.9: Mechanical Reinforcing Bar Splicer

Mechanical reinforcing bar splicers are devices to join two steel reinforcing bars subject to tension and compression. All mechanical reinforcing bar splicers shall meet the following requirements:

Table M8.01.9-1: Requirements for Mechanical Reinforcing Bar Splicers

Description	Test Method	Requirement
Ultimate Tensile Strength of Mechanical Splicer System	ASTM A1034 (Monotonic Tension Test)	100% of ultimate tensile strength of reinforcement bars per AASHTO M 31
Allowable Slip	California Test No. 670 – Slip Test	0.01 in., maximum for #14 and smaller bars, 0.03 in. maximum for #18 bars

The mechanical splicer coating shall be consistent with the reinforcement to be spliced; therefore, uncoated splicers shall be used for uncoated rebar, epoxy coated splicers for epoxy coated rebar, and galvanized splicers for galvanized rebar. The mechanical splicer coating shall be in conformance with the applicable requirements of M8.01.7: Epoxy Coated Reinforcing Bars or M8.01.8: Galvanized Reinforcing Bars. The mechanical reinforcing bar splicer system shall be evaluated with the applicable coating.

Mechanical reinforcing bar splicers shall be tested for conformance with the above requirements. Reinforcing bar splicers that meet these requirements (coated or uncoated) shall be placed on the QCML. Only products listed on the QCML are acceptable for use.

Damage to the mechanical reinforcing bar splicer coating shall be repaired in accordance with 901.62: Reinforcement. For mechanical splicer systems that cannot be effectively sealed with an epoxy or galvanizing repair coating they shall be protected with an approved corrosion protection wrap system listed on the QCML.

M8.02.0: Drilled Steel Rods

This material shall conform to the requirements of AISI – W1.

M8.03.0: Iron Castings

Gray Iron Castings shall conform to the requirements of AASHTO M 105, Class 35B. Test bars shall conform to the requirements of tension test specimen B with a minimum of 1 in. thread on each end. The thread size shall be 1-⅛ in. – 7 UNC. Ductile Iron Casting for double grates shall conform to the requirements of ASTM A536 Grade 80-55-06. Test bars shall conform to the requirements of standard round tension specimen (2 in. gage length) with a minimum of 1 in. thread on each end. The thread size shall be ⅞ in. – 9 UNC.

All iron castings shall conform to the requirements of AASHTO M 306 and shall be manufactured true to pattern in form and dimensions, free from pouring faults, cracks, blow holes and other defects affecting their strength and value for the service intended. The casting shall be boldly filleted at angles and the arises shall be sharp and perfect. The surfaces shall have a workmanlike finish.

M8.03.2: Steel Castings

Type A-3 grates shall be cast to the dimensions shown on the plans and composed of cast steel conforming to the requirements of AASHTO M 103, Grade 65-35, full anneal.

Steel castings shall be true to pattern in form and dimensions, without sharp unfilleted angles or corners and shall be free from pouring faults, sponginess, cracks, blow holes and other defects in positions affecting their strength and value for the service intended.

Castings shall be shot blasted prior to painting. Painting shall consist of a coating system approved by RMS.

M8.04.1: Stud Shear Connectors

All studs shall be qualified by AASHTO/AWS D1.5 of the Bridge Welding Code, Type B. Shear stud connectors shall conform to AASHTO M 169. Grades C1010 to C1020 and either semi-killed or fully-killed. Shear connector studs shall be of a design suitable for end welding to steel beams and girders with automatically timed stud welding equipment. Flux for welding shall be attached to the end of each stud for the welding operation.

An arc shield (ferrule) of heat-resistant ceramic or other suitable material shall be furnished with each stud. The material shall not be detrimental to the welds or cause excessive slag and shall have sufficient strength so as not to crumble or break due to thermal or structural shock before the weld is completed. The manufacturer shall certify that the studs as delivered are in accordance with the material requirements of this Section. Certified copies of in-plant QC test reports shall be furnished to the Engineer.

M8.04.3: High Strength Bolts

All Bolts shall be Heavy Hex Head bolts, meeting the requirement of ASTM F3125, grade A325, Type 1. Hardened washers shall meet the requirements of ASTM F436. Nuts shall meet the requirements of ASTM A563. All bolting assemblies shall be of the same finish and shall be galvanized for coated applications or type 3 for weathering steel applications. Galvanized nuts shall be lubricated with a lubricant containing a dye of any color that contrasts with the color of the galvanizing. Black fasteners must be “oily” to the touch when installed. Weathered or rusted fasteners shall be cleaned and re-lubricated prior to installation using manufacturer recommended procedures. All bolts, nuts and washers shall be marked by the manufacturer.

If galvanized assemblies are supplied, assemblies shall be mechanically galvanized conforming to ASTM B695, Class 55, Type 1, or Hot dipped galvanized conforming to AASHTO M 232/ASTM A153 Class C.

All Assemblies shall be supplied with Rotational-Capacity (Ro-Cap) Testing Reports for each Ro-Cap lot. Ro-Cap tests are required and shall be performed on all black or galvanized (after galvanizing) bolt, nut and washer assemblies by the manufacturer or distributor prior to shipping. Washers are required as part of the test even though they may not be required as part of the installation.

All assemblies shall be shipped in sealed containers with all required documentation including Certificate of Compliance, Mill Test Reports and Ro-Cap Test Reports.

M8.05.0: Bridge Related Structural Steel

All structural steel for bridge substructure, superstructure, bearings, railings, joints and other bridge components are covered in this section.

All steel shall conform to the requirements of AASHTO M 270 various grades, as detailed in the contract documents. Tension sustaining primary components shall be designated on the design drawings noting "T" for Non-Fracture-Critical Tension Components or "F" Fracture-Critical Tension Components. CVN test results are required for all "T" and "F" material. Material requiring "T" or "F" designation that does not have CVN test results on the mill certification, shall require CVN testing from a sample taken in the presence of the Verification Inspector and sent to a qualified lab for testing. Orientation of the test bars for the CVN test specimens shall be longitudinal to the direction of final rolling. The "H" frequency of testing shall be used in accordance with ASTM A673. CVN impact testing temperatures shall be in accordance with those specified for Zone 2.

Fracture Critical Member (FCM) Material shall conform to the same requirements as primary members, but shall have increased CVN test samples, tested at the "P" frequency. All NSTM material and welds shall conform to the Fabricator's fracture control plan as required by AASHTO/AWS D1.5 - Bridge Welding Code, Clause 12.

All primary bridge components shall be HSS structural steel conforming to ASTM A1085 with supplemental S1 Heat treatment.

All other bridge components shall be HSS structural steel conforming to ASTM A500.

M8.05.1: Steel Piles

Steel piles shall consist of new structural steel shapes of the section shown on the plans. The pile steel and mechanical splice, if used, shall conform to the minimum requirements of ASTM A709 Grade 50. All welding and preparation shall conform to AASHTO/AWS D1.5 Bridge Welding Code. The pile shall be welded with a complete joint penetration V-groove weld through flanges and web, unless a mechanical splicer is utilized. Runoff tabs shall be removed after welding, and all edges shall be ground smooth. If a mechanical splice is utilized, partial joint penetration V-groove welds shall be performed on the flanges and fillet welds of appropriate size shall attach the mechanical splice to the pile. Welding procedures shall be submitted to the Engineer for approval. Preparation of pile for welding is recommended to be done at the fabricator. Radii for weld access holes shall have a minimum 1 in. radius, smooth and free of gouges.

Heavy-duty pile points shall be installed on the tips of all piles. Prefabricated pile points may be used if approved by the Engineer. Material requirements shall conform to M8.03.2: Steel Castings.

M8.05.4: Steel Sheeting

Steel sheeting shall be an approved standard section either new or used, weighing not less than 22 pounds per square foot of wall. Used steel sheet piling in good condition as determined by the Department is acceptable. The steel sheeting which is to be left in place shall conform to the requirements of AASHTO M 202.

M8.05.5: Steel Pipe Piles

This specification covers cylindrical steel pipe of uniform cross section and diameter throughout its length and in which the cylindrical pipe acts as a permanent load-carrying member.

The steel pipe shall be new and shall conform to the requirements of ASTM A252, Grade 2 or 3 as needed.

Pipe having seams of spiral-lap welded construction will not be permitted under this specification. Pipes having spiral welded butt joint construction will not be permitted except where the pipe is concrete filled.

The outside diameter and wall thickness of the pipe shall be as shown on the plans. Pipe piles shall be spliced using a complete joint penetration V-groove weld and continuous, tight fitting backing bar. The top end of the pipe shall not be beveled. The bottom end of the pipe shall be beveled in accordance with an approved welding procedure, and the top end of the pipe shall not be beveled until after driving. The bottom of the pipe shall either have a flat plate or a conical tip attached by welding, using a complete joint penetration weld and a continuous, tight fitting backing bar. The weld shall develop the full strength of the pipe in compression and tension. The steel plate shall have the same outside diameter as the pipe and thickness as detailed in the contract documents. The conical tip shall have the same diameter as the pipe, and the length of the cone shall be as shown on the plans. All welding shall be in accordance with AWS D1.1.

M8.05.6: Steel Casing for Drilled Shaft Foundations

This specification covers cylindrical steel casings of uniform cross section and diameter throughout its length in which the cylindrical casing acts as either a temporary or permanent load-carrying member. Casings shall be welded using approved procedures with vertical seem welds, offset at splice welds. All welding shall be in accordance with AWS D1.1 and tested using ultrasonic testing.

Temporary casings shall be the responsibility of the Contractor and shall be of sufficient strength to resist the handling, transportation, installation, and external stresses of the subsurface materials. The Designer shall review and approve the material. Temporary casings that are used and are in good condition without strength impairing defects are acceptable for use as temporary casings. Temporary casings that are left in place and connected to permanent casings shall meet the requirements of permanent casings.

Permanent steel casings shall conform to the requirements of ASTM A252. Permanent casings shall not have been previously used. Casings having seams of spiral-lap welded construction will not be permitted for use as permanent steel casings. The outside diameter and wall thickness of the permanent steel casings shall be as shown on the plans. When permanent casings are used to carry part of the design load, all joints shall have full-penetration V-groove welds, using approved continuous backing. Any attachment between permanent and temporary casings shall be welded with full-penetration V-groove welds using approved continuous backing ring. All welds shall develop the full strength of the casings in compression and tension.

M8.05.7: Micropiles

Permanent steel casing/pipe used as reinforcement shall be new “Prime” steel meeting the requirements of any API 5L PSL1 pipe with a yield strength of 52 ksi with SR15 supplemental requirements. The grade of the prime steel casing shall conform to the properties shown on the Plans. For steel pipe that is to be welded, the Carbon Equivalency, as defined in AWS D1.1 Section XI.1, shall be less than or equal to 0.45, as demonstrated by mill certificates. The sulfur content shall not exceed 0.05%, as demonstrated by mill certificates.

Permanent steel casing shall consist of ERW (Electric Resistance Welded) and/or seamless steel casing and shall be designed to withstand the design loadings determined by the Engineer or shown on the Plans and the verification/proof test loading described in this specification. Joints shall

develop the full vertical capacity, and at least 60% of the moment capacity of the casing. As installed, there shall be no joints within three feet or as shown on the plans from the bottom of the pile cap.

New "mill secondary" steel pipe/casing will not be accepted regardless of if they are accompanied by coupon test results. Steel casing shall have certified mill test reports and shall be submitted for record purposes as the materials are delivered. The steel shall be traceable back to the mill certifications, and be free from defects (dents, cracks, tears, etc.).

Temporary steel casing/pipe shall consist of flush joint type steel pipe of thickness specified in the contract documents.

Central reinforcing steel shall be full-length, continuously threaded bars. The bars shall conform to AASHTO M 31 Grade 60 or Grade 75, or AASHTO M 275 Grade 150.

M8.05.8: Steel Extrusions

Material utilized to produce steel extrusions suitable to mechanically lock elastomeric strip seals shall conform to properties of ASTM A709 and shall be hot dipped galvanized after attachment of anchorage devices. Steel extrusions shall have a minimum thickness of ¼ in. as measured from the internal locking mechanism cavity to the top surface of the steel extrusion shape. Steel shapes shall be monolithic with the extrusion cavity. All welding shall be in accordance with AASHTO/AWS D1.5.

M8.05.9: Bridge Railing, Steel

Fabrication shall conform to M8.06.0: Fabrication Requirements, with the exception that hollow pickets, embedded anchor plates and HSS tubing do not require SSPC-SP10 Pre-blast. All fabrication shall conform to the plans, any changes shall be requested in writing for approval from the Engineer.

Posts and base plates shall conform to the requirements of AASHTO M 270 Grade 50. CVN tests are required at the "H" frequency.

Rails shall be made from hollow structural tubing and shall conform to the requirements of ASTM A500 Grade B or C with a minimum yield strength of 50 ksi. CVN tests are required.

Anchor plates and splice tube plates shall conform to AASHTO M 270 Grade 36.

Picket tubes shall conform to the requirements of ASTM A513 grade 36 or ASTM A500 Grade B.

Carrier angles shall conform to the requirements of AASHTO M 270 Grade 36.

Round headed bolts shall conform to the requirements of ASTM F3125, A325, Type 1 Galvanized. Rotational capacity tests are not required.

High strength bolts shall conform to M8.04.3: High Strength Bolts.

Anchor bolts shall conform to M8.01.5: Anchor Bolts, Nuts, and Washers.

Molded fabric bearing pad shall conform to M9.16.2: Molded Fabric Bearing Pad.

Screws shall be hardened countersunk machine screws with nut and lock washer.

All steel components shall be galvanized and painted in accordance with M7.10.0: Galvanized Coatings. All pipe sleeves that are not welded to the tube shall be galvanized separately and not while bolted to the rail. All galvanized steel except anchor plate, anchor bolts and fasteners shall be painted. Round head fasteners shall have the head coated to match the rail. The color shall be Dark Bronze, Federal Std. 595B COLOR NO. 10045. Components that are finish coated shall be protected from damage during shipment and storage.

M8.06.0: Fabrication Requirements

All structural steel and appurtenant metal materials shall be designed and fabricated, in accordance with the following specifications as applicable: AASHTO *LRFD Steel Bridge Fabrication Specifications* and the AASHTO *Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. All structural steel for bridge elements shall be welded in accordance with the requirements of the AASHTO/AWS D1.5 - Bridge Welding Code. All miscellaneous steel and non-bridge related structural steel shall be welded in accordance with the AWS D1.1- Structural Welding Code – Steel. All aluminum material shall be welded in accordance with the AWS D1.2 – Structural Welding Code - Aluminum. All sheet steel shall be welded in accordance with AWS D1.3- Structural Welding Code – Sheet Steel. All reinforcing steel shall be welded in accordance with the AWS D1.4 - Structural Welding Code – Steel Reinforcing Bars. All stainless-steel material shall be welded in accordance with the AWS D1.6 Structural Welding Code – Stainless Steel.

Unless otherwise specified within Section M8: Metals and Related Materials, all permanent steel greater than $^{3}/_{16}$ in. shall be blast cleaned prior to the start fabrication (pre-blast) in accordance with SSPC-SP10/NACE No. 2 - Near White Blast Cleaning. Fabrication includes cutting, drilling, bending, welding, etc. All steel shall be verified to meet the requirements of ASTM A6. This inspection shall happen immediately after blasting. When relieved of preblast requirement, all welding areas shall be prepared in accordance with the applicable AWS welding code.

M8.06.1: Fabrication Shop Approval

All metal fabrication facilities shall be approved by MassDOT in the category for which they want to produce work. MassDOT will perform an audit of the facility requesting approval and will assign approval of the category and endorsements accordingly. Fabricators must hold a current AISC certification in the applicable category for which they want to work. Fabricators shall be approved for work in one or more of the following MassDOT categories: Advanced Bridge Fabricators; Intermediate Bridge Fabricators; Simple Bridge Fabricators; Bridge Components and Miscellaneous Fabricated Metal Products; or Signs, Luminaires and Signal Supports. Fabrication of Fracture Critical Material requires MassDOT FCM endorsement. The application of coating at the fabrication facility requires MassDOT sophisticated coatings endorsement. Fabricators approved to perform work in a higher bridge category are also approved to perform work in the lower bridge and component categories. If a fabricator has facilities in multiple locations, each facility shall require approval prior to that facility performing any work. A list of approved fabricators and instructions on how to become an approved fabricator may be found at: https://www.mass.gov/massdot-approved-fabricators.

Advanced Bridge fabricators (ABR) are approved to perform work on bridges requiring an additional standard of care in fabrication and erection, particularly with regard to geometric tolerances. These fabricators must maintain an AISC Bridge Fabricator – Advanced certification. Examples include, but not limited to: Tub or trapezoidal box girders, Closed box girders, Large or

non-preassembled trusses, Arches, Bascule bridges, Cable-support bridges, Moveable bridges, and Bridges with particularly tight curve radius. ABR fabricators can also fabricate Intermediate, Simple and Miscellaneous category work.

Intermediate Bridge fabricators (IBR) are approved to perform work on typical bridges that do not require extraordinary measures. These fabricators must maintain an AISC Bridge Fabricator – Intermediate or Advanced certification. Typical examples might include but are not limited to: A rolled beam bridge with cover plates, either straight or with a radius over 500 ft; A rolled beam bridge with field or shop splices, either straight or with a radius over 500 ft; A built-up I-shaped plate girder bridge with constant web depth (except for dapped ends), with or without splices, either straight or with a radius over 500 ft; A built-up I-shaped plate girder with variable web depth (e.g., haunched), either straight or with a radius over 1000 ft; A truss with a length of 200 ft or less that is entirely or substantially pre-assembled at the certified bridge fabricator facility. IBR fabricators can also fabricate Simple and Miscellaneous category work.

Simple Bridge fabricators (SBR) are approved to perform work on unspliced rolled sections. These fabricators must maintain an AISC Bridge Fabricator – Simple, Intermediate or Advanced certification. SBR fabricators can also fabricate Miscellaneous category work.

Bridge Component and Miscellaneous Fabricated Products fabricators (BCM) are approved to fabricate and supply specific components, composed primarily of metal, to bridge and highway construction projects. These fabricators must maintain an AISC Highway Component Manufacturer certification. Components include bracing not designed for primary loads, such as diaphragms, cross frames and lateral bracing. Other bridge related items include: Bridge rail, Grid decks, Drains, Scuppers, Expansion joints, Bearings, Ballast plates, and Mechanical moveable bridge equipment. Other miscellaneous fabricated items can include: Stairs, Handrails, Walkways, and other items that are project specific.

Signs, Luminaires, and Signal Supports fabricators (SLS) are required to have AISC Highway Component Manufacturer certification. SLS fabricators are approved to fabricate overhead and cantilever sign supports, highway and high mast lighting supports, strain poles, traffic signal supports and other traffic and lighting related items.

Fracture Critical Member endorsement (FCM) is required for any fabricator performing fabrication of material designated as fracture critical. At a minimum, the fabricator is required to have AISC fracture control endorsement.

Sophisticated coatings endorsement (P) is required for all fabricators or applicators that perform surface preparation and coating application at their facility. Coating applicators are required to have the SSPC-QP3 Shop Painting Certification or AISC Complex coating certification and be approved by MassDOT Metals Control Section. Metalizing applicators require SSPC-QP6, Thermal Spray certification.

Approval is valid indefinitely, however if the fabricator has not performed work for MassDOT within a 5-year period, the approval will expire. It shall then be the responsibility of the fabricator to reapply for approval. Metals Control Section shall be notified of any changes to the Quality Manual, including but not limited to personnel. The fabricator shall update MassDOT on the status of their AISC Fabrication Certification within 7 days of its expiration. A new certification shall be forwarded to Metals Control within 7 days of receipt.

Approval may be revoked at the discretion of the Engineer if the fabricator fails to meet the contract requirements. A fabricator may reapply after the end of their revocation period as outlined by the Engineer.

A fabricator may subcontract work to another approved fabricator by submitting a request for approval from the Engineer with sufficient time to schedule a Verification Inspector. The fabricator shall assure that appropriate QC oversight is provided by the sub-fabricator, or the fabricator will be required to supply QC. Verification inspection shall be at the discretion of the Engineer.

M8.06.2: Fabrication Shop Documents

All Fabrication facilities must have a Quality Manual outlining the quality control processes for the facility, including non-conformance processes. A full access copy shall be made available to MassDOT upon request.

All Fabrication facilities must have an organization chart with names and positions clearly defined. All positions shall have a description of the incumbent's job duties.

Procedures must be approved prior to the start of fabrication. Fabricators are required to have written procedures submitted and approved by the Engineer for the following fabrication processes including, but not limited to hot bending, welding, hot and cold cambering, heat curving, shop assembly/laydown, post-heat and stress-relieving, shop installation of fasteners, and surface preparation and coating. Welding shall not commence until the welding procedures have been approved by the Engineer. All welding procedures shall conform to the applicable AWS welding code.

These procedures may be standardized and are not required to be resubmitted for approval for each project. Prior to the start of each project, the fabricator shall submit all procedures to be used on the project, both previously approved and to be approved. Shop welders shall be certified in accordance with the applicable AWS Welding Code as determined by the Engineer.

M8.06.3: Fabrication Shop Drawings

After the contract has been awarded, and before any shop work is commenced, the Contractor shall submit complete sets of the shop drawings in accordance 5.02: Plans and Detail Drawings. The name of the fabricator performing the work shall be clearly listed on the approved shop drawing. All Tension and Fracture Critical zone diagrams shall be clearly shown on the shop drawing meeting the design drawing. Any subcontracted work shall be clearly marked with the sub-fabricator's name and address in the title block.

On projects that contain more than one bridge, each bridge will be considered separately in submitting shop drawings. Shop work may commence on each bridge when the entire set of shop drawings for that bridge are approved.

On projects which contain complicated steel structures such as a viaduct, long span bridge, etc., the Contractor shall submit a fabrication schedule showing how the steel structure will be divided into work packages. After this schedule is approved, shop work may commence on each work package as the shop drawings for that work package are approved.

Fabrication shall not begin until the drawings are approved and distributed to the appropriate parties per the contract documents. Work performed prior to shop drawing approval will be rejected.

When the fabricator requires temporary attachments for fabrication, coating, or lifting the attachment shall be shown on the approved shop drawing and shall be NDT tested upon removal.

All temporary miscellaneous holes for lifting, coating or drainage shall be located on the approved shop drawings and the final condition of the hole shall be noted.

M8.06.4: Fabrication Shop Schedule

Prior to the start of fabrication or the restart after a stoppage, the Contractor shall submit a shop schedule to the Engineer. A pre-fabrication meeting shall be scheduled, at the time of request, between the Engineer, Contractor, and fabricator, prior to fabrication. The shop schedule shall be provided 14 days prior to the commencement of fabrication. The Engineer will determine the level of verification inspection required and will arrange for the inspector's attendance based on the work performed on each shift. The shop schedule shall include the MassDOT project information, scope of work, date fabrication will begin, the approximate date it will be completed, and hours of operation including the work which is to be performed on all shifts. All overtime activities shall be requested in advance by the fabricator. Any revision to the approved schedule shall be submitted 7 days in advance of taking effect.

M8.06.5: Fabrication Verification Inspection

Verification Inspectors will inspect all processes during fabrication including cutting, drilling, welding, Non-Destructive Testing, and coating. Verification Inspectors will be employed by, or act on behalf of, the Department. The inspector has the authority to act for the Engineer on matters relating to quality, including inspection and testing, within the scope of the contract. Verification Inspectors will be assigned at the discretion of the Engineer. The presence or absence of the Verification Inspector does not relieve the fabricator of their quality control responsibility.

The fabricator shall provide office space for the Verification Inspectors separate from the fabricator's personnel yet in direct proximity to the work. These facilities shall include a secure office with a desk and chair for each inspector, a file cabinet, and a table adequate to review drawings. The office shall have a minimum floor area of 100 square feet; high speed internet access, a system of heating and cooling that will maintain a temperature of 68 to 72°F, adequate lighting, and safe access to the work. The fabricator shall also supply ready access to copy machines and adequate parking. The cost of furnishing, maintaining, and repairing or replacing the inspector's office shall be incidental to the work.

M8.06.6: Fabrication Quality Control Inspection

Quality control (QC) inspection and testing is the responsibility of the Fabricator and shall be performed by a sufficient number of qualified inspectors to guarantee product integrity. QC inspection shall be performed throughout the entire fabrication process from receiving material to shipping the final product. The fabricator's QC shall keep all records of the fabrication process. A QC Inspector with a current AWS Certified Welding Inspector (CWI) shall be present during all fabrication processes.

Quality control Inspectors at the fabricating shop shall be certified by the AWS in accordance with the provisions of the Standard for Qualification and Certification of Welding Inspectors (AWS QC1). The lead inspector on each shift shall be a CWI. This inspector shall have a minimum of 3 years' experience relevant to the work to be performed. Assistant inspectors may be used to perform specific inspections under the direct supervision of a CWI. There shall be a clear separation between QC personnel and production. QC personnel shall not be part of the production team. For projects requiring greater than 1,500 square feet of steel surface to be coated, the QC inspector shall have completed, as a minimum, AMPP Level I certification or received other formal training acceptable to the Engineer.

M8.06.7: Fabrication Required Material Documentation

The Fabricator will be required to submit to the Department's Inspector, for review and approval, one certified copy of the Mill Test Reports (MTR) for each heat number of material furnished. The MTR shall clearly specify the melt and manufacture location of the material. These certificates shall certify compliance with the specifications and shall give the chemical and physical analysis of the metal. Any cost involved in furnishing the certificates shall be considered incidental to the work. These reports shall be given to the Verification Inspector in advance of fabrication so that this inspector has sufficient time to thoroughly review the reports. No material shall be shipped until the reports are reviewed and approved by the Verification Inspector. MTRs shall be provided for all steel, aluminum and other metal materials used in fabrication. The MTR shall originate from the producer of the material, not the supplier. Supporting documentation from the supplier or distributor shall be identified with the MassDOT contract number, material specification, and heat number.

M8.06.8: Fabrication Non-conformances

The fabricator shall have an established Quality System outlined in their Quality Manual for controlling nonconforming material which shall include procedures for identification, isolation, and disposition.

Items that are deficient and can be immediately be reworked to meet requirements do not require a Non-Conformance Report (NCR) submittal to MassDOT but shall be documented by QC. Items that are found to be deficient to the contract requirements, and which are not (or cannot be) immediately corrected, shall be documented on an NCR.

The Fabricator shall properly document all nonconformances using an NCR form. The NCR shall be submitted through the contractor to the Engineer for approval and shall document any deviation from the Quality Manual, approved shop drawings, project plans, and/or specifications and applicable welding codes. This form shall include the following items: company name and address; report title; a unique nonconformance report number; date; company job number; piece mark; general contractor name; MassDOT contract number and project location; a detailed description of the nonconformance; photograph, sketch and/or drawing; proposed repair/disposition; root cause; corrective action; and the quality control manager's signature and date. A repair procedure for corrective action shall be submitted to the Engineer for Approval.

The Designer of Record shall review the disposition for conformance with the design. The NCR shall be approved by the Engineer prior to the disposition being carried out. All required documentation for the repairs shall be submitted to the Verification Inspector for review.

The fabricator shall submit, for approval, standard repair procedures in advance for minor fabrication issues such as undercut, undersize, minor cracks and surface inclusions and weld profile. Repeated minor fabrication issues may result in a stop work. To facilitate the fabrication schedule, other repair procedures may be submitted for information, however specific application of the procedure shall require the Engineer's approval. If more than two excavatable weld repairs are required at the same location, an NCR shall be submitted and approved prior to proceeding with consecutive repairs. Repeated similar repairs at various locations may require submittal of an NCR at the discretion of the Engineer. All removal and excavation repairs shall be done in the presence of Quality Control Inspector and the Verification Inspector.

M8.06.9: Fabrication Process

M8.06.9.A: General

All required submittals shall be approved prior to the start of fabrication.

All fabrication, non-destructive testing, and repair work must be in the presence of quality control personnel and the Verification Inspector.

All primary members must maintain heat number traceability throughout the fabrication process. Heat numbers shall be transferred in the presence of the Verification Inspector. Primary members are defined in the contract documents. Heat numbers are not required to be transferred to component parts of secondary members or to minor components of a primary member, i.e., stiffeners, clip angles, etc.

For primary members, the plate components and splice plates shall be cut with the direction of rolling, parallel to the direction of primary stresses.

For weathering steel structures, all deleterious material, such as oil, grease, dirt, slag, etc. shall be removed from unpainted portions prior to shipping. At a minimum, SSPC SP-1 and SSPC SP-3 are required prior to shipping to allow for uniform weathering appearance. Fascia beams, girders, truss members and any other surface designated as fascia in the contract documents shall be abrasive blast cleaned in accordance with SSPC SP-6 to remove staining and heat marks.

If steel expansion joint assemblies are used, they must be properly fitted in the shop, after coating, and shipped with a device for maintaining proper spacing and fit as shown on the plans.

M8.06.9.B: Fabricated Holes for High-Strength Bolts

Bolt holes shall be fabricated to the size, tolerance and workmanship required by the applicable standard as listed in the general section of this specification and as identified on the contract documents. All holes shall conform to ANSI B46.1 requirements for roughness.

When holes are made using plasma, water jetting, or thermally cut, the hole shall be started in the center and spiral outwards.

Fabricating of holes may be done by the following methods; punching, drilling, plasma cutting and water-jetting. Thermal cutting shall not be permitted.

Sub-size holes may be made by any means, provided that the holes are at least $^{3}/_{16}$ in. smaller diameter than required on the plans.

Secondary members holes may be fabricated full-size by plasma cutting, water-jetting, punching or drilling. The material may not be thicker than the fastener diameter.

Holes in any other location including longitudinal primary load-carrying members, transverse floor beams, and any components designated as FCMs, shall not be punched, plasma cut or water-jetted full-size. These shall either be drilled full size or sub-sized and reamed to full size.

When punching, hole diameter is limited to material thickness no greater than ¾ in. for carbon steel, ⅝ in. for high-strength low-alloy structural steel, and ½ in. for high-strength quenched and tempered structural steel. If holes are to be punched full-size, punch diameter shall not me more than $^{1}/_{16}$ in. smaller than the die.

If there are more than 5 layers of steel in the connection, the holes shall be sub-sized and then reamed or drilled full size while in assembly.

Holes, after drilling and any reaming, may be $^{1}/_{32}$ in. greater than the nominal hole dimension. Holes exceeding this tolerance shall be treated as the next larger size and shall be rejected. Any mislocated hole shall be considered rejected.

For aluminum material, holes shall be drilled full size, or sub-sized and then reamed or drilled to the full size. The difference between a sub punched/subdrilled hole diameter and the full-size diameter shall be at least one-fourth the thickness for the part and in no case less than $^{1}/_{32}$ in.

Use of splice plates, cover plates or similar connectors in lieu of reusable templates is permitted only once, provided that no damage occurs during reaming or drilling of the holes.

M8.06.9.C: Cutting Plates and Shapes

Steel plates for primary member components and splice plates shall be cut and fabricated with the direction of rolling parallel to the direction of primary stresses, except that the direction of rolling may be in either direction for web splice plates, gusset plates not serving as chord splices, and connection plates.

All plates and shapes shall be fabricated to the size, tolerance and workmanship required by the applicable standard as listed in the general section and as identified on the contract drawings and documents. This also covers fabricated holes, other than for high strength bolts, such as drainage, access, or any other specified holes in a member. All edges shall conform to ASME B46.1 requirements for roughness.

Mechanically assisted thermal cutting shall be allowed, no freehand thermal cutting is permitted. All thermally cut edges shall be ground to remove hardness and be broken (i.e. slightly chamfered or radiused by grinding) prior to coating activities.

All thermally cut edges shall be free of slag and primary members shall have a Rockwell C hardness value less than C30. The fabricator shall employ a portable Rockwell Hardness Tester for all thermally cut edges. The Verification Inspector shall be present to verify the conformance with the requirement.

Sheared edges of plates thicker than ⅝ in. that will remain exposed after fabrication shall be planed, milled, or ground to a depth of ¼ in.

Edges shall be free of notches and gouges.

Angles requiring modification or chamfering at the convex corner shall maintain nominal thickness through the thinnest section of the angle. All corners should be radiused as opposed to chamfering when such modification is required.

M8.06.9.D: Shop Welding

All welders shall be qualified by the applicable AWS welding code. The fabricator is responsible for maintaining the welder's qualification in the fabrication shop.

All welding procedures shall be approved by the Engineer and shall be in accordance with the requirements of the contract documents and applicable AWS welding code. Weld size shall be as stated on the contract drawings and may only be altered to conform to the fit-up tolerances of the applicable welding code.

Welders shall have copies of approved welding procedure on the shop floor at all times. Welding shall conform to the approved shop procedures.

The Engineer may request that a welder be requalified if they show inability to complete compliant welds. If the welder repeatedly produces unsatisfactory welds, the shop may be required to remove the welder from MassDOT work.

Shop equipment must be routinely calibrated and maintained according to the manufacturer's recommendations. If the equipment continues to malfunction repeatedly, the Engineer may request it be taken out of service.

M8.06.9.E: Shop Splicing

When shop splices are required, the location shall be marked on the approved shop drawing. Other than width or thickness transition splices, no more than two additional splices shall be permitted on flanges and webs of girders. These additional splices shall be located near the third point of the individual member; approximately midway between adjacent diaphragm connections; at least six inches from transverse stiffeners and welded connection plates; not less than ten feet from a bolted field splice, a bearing point at piers and abutments, or other splice welds that are required by the plans. The Engineer shall approve the final location of additional welded splices.

For tubular members, welded splices shall be offset at least six inches from any other weld.

M8.06.9.F: Cambering and Curving

M8.06.9.F.1: General

All procedures for cambering and curving shall be submitted to the Engineer for approval, accompanied by PE Stamped calculations.

Camber shall be introduced uniformly and gradually to avoid abrupt kinks.

Structural rolled beams shall be cambered to the amount shown on the plans with a tolerance, at the midspan, of -0, +½ in. for beams 50 ft or less. For beams greater than 50 ft, the plus tolerance of ½ in. shall be increased by ⅛ in. for each 10 ft or fraction thereof in excess of 50 ft.

Plate girders shall be cambered to the amount shown on the plans with tolerances as specified in the AASHTO/AWS D1.5 Bridge Welding Code.

The beams and girders shall be handled and stored in such a manner that they will have the required camber after erection.

Camber shall be measured at a minimum of tenth points, the camber of each single erection piece, after fabrication, shall be in accordance with the approved shop drawings. When shop assembly is required full line camber measurements shall also be made on the assembled members in accordance with the approved shop drawings.

Camber and curving measurements shall be taken in the presence of the Verification Inspector.

All cambering and curving for sweep shall conform to AASHTO *LRFD Steel Bridge Fabrication Specifications*.

M8.06.9.F.2: Heat Cambering and Curving

Minimum heat input shall be 700°F. The Maximum allowable temperature when applying heat to the steel is 1,200°F for AASHTO M 270 Grades 36,50 and 50W steels and 1,100°F for AASHTO M 270 Grades HPS50W and HPS70W steels.

When heating with the web in the vertical position, the supports shall be spaced to take maximum advantage of the deadload of the member and shall be placed prior to heating. If the web is in a horizontal position, care shall be taken to avoid excessive sweep correction. When applying the external force and safety catch blocks shall be used to prevent sudden spring back of the beam in case the jacks slip.

Bending and curving may be accelerated using external forces (preload). The stresses induced due to the preload (including loads induced by the member weight) shall be limited to half of the material yield strength. Calculations showing the maximum external force to apply shall be submitted to and approved by the Engineer. The Contractor shall show the relationship between the maximum allowable external force and the maximum allowable stress. The external force shall be applied before heating and not increased by external means during heating or cooling. Jacks shall not impede contraction during the cooling phase, and they shall not produce local buckling.

Heat patterns shall be marked on the steel prior to heating. The steel shall be brought to the appropriate temperature as rapidly as possible. Heating torches shall be manipulated to avoid overheating the steel. The temperature of the steel shall be monitored with temperature sensitive crayons, pyrometers, or infrared non-contact thermometers. All instrumentation shall be calibrated annually. All crayons shall be clearly marked with temperature and expiration date. Crayons shall not be used past their expiration date. The temperature shall be measured 5 to 10 seconds after the heating flame leaves the area to be tested. After the steel has cooled to 600°F, rapid cooling with dry compressed air is permitted. No water or misting is permitted.

The steel shall be cooled to below 250°F before applying another set of heat patterns. When using V-heat patterns, a location may be reheated after applying at least three sets of heating patterns at other locations.

Overheating of material shall be cause for rejection.

If a member needs correction, a procedure shall be submitted by the fabricator and approved by the Engineer. Camber and sweep correction must be achieved using heat. Correction using cold bending shall not be permitted.

M8.06.9.F.3: Cold Cambering and Curving

Cold cambering and curving (at room temperature) procedures shall be submitted for approval by the Engineer. Mechanical methods for cold cambering and curving shall apply to rolled shapes. Built up members shall not be cold-cambered and curved. Methods for cold cambering and curving shall result in material free of gouges or abrupt kinks.

Cold cambering and curving shall take place prior to attachment of stiffeners, cover plates and other attachments. Any attachments already in place shall be verified with MT after bending.

Cold cambering and curving shall require MT or PT including 2 in. on either side of the bending location and a visual inspection of the bending area.

Excess camber or sweep shall not be corrected by cold bending.

M8.06.9.F.4: Plate Bending

All plates shall be visually inspected for major deformations and edges shall be broken.

All plates, including Fracture critical material, shall be cold bent unless otherwise approved by the Engineer. The minimum bend radii for cold bending measured to the concave face of the plate, shall be in accordance with AASHTO *LRFD Steel Bridge Fabrication Specifications*.

Whenever possible the bend lines shall be oriented perpendicular to the direction of final rolling of the plate.

Heat assisted mechanical bending shall be requested in writing.

M8.06.9.G: Non-Destructive Testing (NDT)

Shop procedures and personnel certifications shall be submitted to the Engineer prior to use.

Personnel performing radiographic (RT), ultrasonic (UT), magnetic particle (MT) and dye penetrant (PT) tests shall be certified by a Level III technician who shall have attained certification by examination. Personnel performing these tests shall be qualified and recertified, as required, in accordance with the current edition of the American Society for Nondestructive Testing, Recommended Practice SNT-TC-1A. Only individuals with a minimum qualification for NDT Level II and certified as noted above may perform these tests. The technician is subject to the Engineer's approval. Digital Radiography shall be requested in writing to the Engineer.

Nondestructive testing shall be performed by the Fabricator in accordance with the procedures and standards set forth in the AASHTO/AWS Bridge Welding Code or other applicable code. The Engineer reserves the right to perform additional testing at its own cost during fabrication and up to final acceptance of the project. All welding must meet acceptable quality standards which are defined by the acceptance criteria for the particular test method.

All nondestructive testing shall be witnessed by Verification Inspector. Quality control shall maintain NDT records for the project. In addition to that required by the Bridge Welding Code, all radiographs shall be identified with the date of test, the MassDOT contract number, bridge number (if applicable) and girder, beam number, sign structure or lighting structure identification number. All radiographs shall be reviewed and accepted by the fabricator's qualified personnel, at the discretion of the Engineer. The fabricator shall supply the Engineer with the radiographs within one

week of the test for the Engineer to review and accept the film. All costs for these tests, including necessary rework and repair, shall be at the Fabricator's expense. A copy of all NDT reports shall be given to the Verification Inspector.

M8.06.9.H: High Strength Bolting

M8.06.9.H.1: General

Bolt assemblies shall meet the requirements of M8.04.3: High Strength Bolts. A high-strength bolt assembly typically consists of one high-strength bolt, one heavy hex nut, and one hardened circular washer. Provide a high-strength bolt assembly for each hole in the connection of structural joints. Provide sufficient additional assemblies of each bolt lot group than required to satisfy all testing requirements. Use the same lot combinations of high-strength bolt assemblies in the shop that will be used for field assembly of structural joints. The lot shall be the same as those tested and approved by the Engineer.

All oversize and slotted holes shall be required to have proper sized washers or plates that sufficiently cover the entire hole.

Containers must remain sealed until the beginning of the work shift. The number of containers opened, and bolts removed shall be limited to the number needed to complete the bolting work for that shift. Upon opening the containers, the bolts shall be inspected for presence of lubricant. All bolts shall remain in their original containers until they are installed. If lubrication is insufficient, bolts shall be relubricated per manufacturers recommendation. Any bolts showing signs of corrosion shall be rejected and removed from the shop floor. Wire brushing to remove rust will not be acceptable. Any bolts that are left over at the end of the shift and that are in acceptable condition may be returned to the correctly marked container, which will then be properly sealed and returned to the storage location.

If there is only one production lot number for each size of nut and washer, the nuts and washers may be in separate containers. Each container shall be permanently marked on the container, not the lid, with the rotational-capacity lot number such that identification will be possible at any stage prior to installation.

The certification, testing, pre-installation, installation, and inspection for all high strength bolts shall conform to the requirements of the fabricator's approved Bolting procedure. The procedure shall meet the requirements of the MassDOT contract and AASHTO *LRFD Steel Bridge Fabrication Specifications*. All Bolts, nuts and washers shall be clearly designated on the shop drawings. Acceptable bolting methods shall be the turn-of-the-nut method, the calibrated wrench method or the combined method, as per the Research Council on Structural Connections (RCSC)specification. Material acceptance documentation shall be in accordance with M8.04.3: High Strength Bolts.

M8.06.9.H.2: Rotational Capacity Test (RCT)

The rotational capacity test is intended to evaluate the presence of a lubricant, the efficiency of the lubricant and the compatibility of assemblies as represented by the components selected for testing. Fastener components shall be assigned lot numbers, including rotational-capacity lot numbers, prior to shipping. The manufacturer or distributor shall be required to perform rotational capacity tests (RCT) on fastener assemblies in accordance with ASTM F3125. RCTs are required to be performed on all types of assemblies after galvanizing and lubrication.

The tests need not be witnessed by a representative of MassDOT; however, the manufacturer or distributor that performs the tests shall certify that the results recorded are accurate. The minimum frequency of testing shall be two assemblies per rotational-capacity lot.

If condition of assemblies requires re-lubricating, Rotational capacity testing must be performed on the re-lubricated assemblies prior to installation following the RCSC specification.

M8.06.9.H.3: Pre-installation Verification (PIV) Testing

All PIV testing shall be performed by the fabricator per applicable method outlined by the RCSC specification.

Installation shall be performed by the fabricator per applicable method outlined by the RCSC specification. Quality control personnel and Verification Inspector shall be notified prior to all verification inspection testing and bolting operations.

For calibrated wrench method, the QC Inspector and the Verification Inspector shall witness daily instrument calibration. Perform additional instrument calibration tests when changes in conditions meet RCSC 8.2.2. The QC Inspector and the Verification Inspector shall verify snug tight condition has been achieved. After torquing all bolts in the connection, the torque shall be verified for 10% of the bolts, minimum 2 bolts, for each connection.

For turn-of-the-nut method, both the QC Inspector and Verification Inspector shall verify snug tight condition has been achieved. Both the QC Inspector and Verification Inspector shall verify match marking prior to final tensioning. Any bolt not match marked shall be cause for rejection of the joint. All connections shall be accepted upon visual inspection of rotation for all bolts of the match marked joint.

For the combined method, both the QC Inspector and Verification Inspector shall verify initial torque values are achieved. After initial torque, all bolts are to be match marked prior to tensioning. Any bolt not match marked shall be cause for rejection of the joint. All connections shall be accepted upon visual inspection of rotation for all bolts of the match marked joints.

If there is cause to believe proper pre-tensioning has not been achieved, the RCSC Arbitration steps shall be followed.

M8.06.9.I: Shop Preassembly and Laydown

In order to facilitate proper field erection, Fabrication Shops should maintain a preassembly procedure in their QC documents. In the case of Advanced bridge fabrication, shop preassembly and laydown will be required, and a procedure or plan shall be included in the approved shop drawings for the structure. At a minimum, the plan shall include a description of how the members will be temporarily supported, methods for geometry check, and a minimum of 3 consecutive longitudinal sections and connections between, assembled in the yard. Bolts for the shop fit up and laydown shall be of the same diameter as the production bolts for the connection. Pins for the shop fit up and laydown shall be of the same size diameter as the hole in the member. The installation of bolts and pins shall be done in a way that does not damage the connection. At the Engineer's discretion, a second laydown may be required for galvanized structures.

Prior to splice plate drilling, the Verification Inspector shall confirm final camber and geometry of the member. Splice connections must be preassembled, and match drilled at the shop.

M8.06.9.J: Shop Welded Stud Shear Connectors

Based on design requirements, Fabrication shops that are required to weld shear studs at the shop, shall maintain shop welding procedures and qualifications that shall be submitted to the Engineer as necessary. The welding of stud shear connectors shall conform to the latest edition of the AASHTO/AWS D1.5 Bridge Welding Code. The shop shall not use production members for test studs. Material used for test studs shall be representative of the production material in dimension and type.

For galvanized structures, the shear studs may be galvanized with the beam after welding studs in the shop. For painted or metalized structures, the top flange shall be mist-coated with 1-1.5 mils prime coat after welding studs.

The Fabricator shall submit to the Verification Inspector for acceptance the following information on the studs:

- The name of the manufacturer.
- A detailed description of the stud and arc shield ferrule to be furnished.
- A certification from the manufacturer that the stud is qualified.
- A copy of the qualification test report as certified by the testing laboratory.

A WPS shall be submitted and approved by the Engineer for repair of stud shear connectors.

Studs on which a full 360° flash does not exist, stud may be weld repaired by adding a $^{5}/_{16}$-in. fillet weld in place of the missing flash. The repair shall extend at least ⅜ in. beyond each end of the discontinuity being repaired. The repaired stud will also be tested, bending 15° off the vertical in the opposite direction of the weld.

For base metal repairs from shear stud failures, base metal shall be preheated according to AWS D1.5 minimum preheat requirements for base metal thickness.

If the fabricator requires the installation of hand welded studs for special cases, such as scuppers, expansion joints, etc., the SMAW process is required, and a Welding Procedure Specification shall be required to be approved by the Engineer. The size of the fillet weld shall be indicated on the approved shop drawings.

M8.06.9.K: Coatings

M8.06.9.K.1: General

Fabrications shops that apply coatings must be on the MassDOT Approved Fabricators list with sophisticated coating endorsement (P). Coatings facilities not on the MassDOT Approved Fabricator List are required to be approved by the Engineer prior to fabrication. Fabricator shall submit to the Engineer, shop name and location, shop procedure, and required certifications for approval. All submittals should be in accordance with the contract documents. Facility shall meet the requirements of M8.06.1: Fabrication Shop Approval with an acceptable Quality Control Manual to be considered for approval.

The fabricator shall notify MassDOT Metals Control 14 days in advance when and where materials are to be coated in order to provide inspection. A coating application schedule and scope shall be submitted upon request of inspection by the fabricator.

Prior to any coating application, all fabrication must be completed and verified by the MassDOT Verification Inspector. Coating application, which includes surface preparation, is required to be witnessed by a Verification Inspector. All material and documentation must be stamped after final inspection for shipping. All shipping and handling after coating shall conform to the subsection below.

Coating thickness shall be tested in accordance with the Association for Materials Protection and Performance (AMPP) PA 2, Determining Compliance to Required Dry Film Thickness Level 2.

All paint systems used shall be an approved system on the QCML. Prior to the start of painting, each batch of paint shall be sampled, tested, and approved in accordance with Section M7: Paints, Protective Coatings and Pavement Markings, Protective Coatings. All coats of paint shall be applied in the shop. Areas where welding and bolting will take place in the field shall be masked after prime coat prior to additional paint layers. Layers shall be stepped back 2-3 in. so that final touch up can be properly achieved and feathered.

When material is specified to be galvanized or metalized, prime coat shall be replaced with galvanization or thermal spray coating (TSC) and 1 coat of sealer. Refer to M8.06.9.K.3: Galvanizing and M8.06.9.K.4: Thermal Spray Coating (Metalizing), respectively.

M8.06.9.K.2: Paint

M8.06.9.K.2.A: Prime Coat

All surfaces shall be returned to an SSPC-SP10/NACE No. 2 condition. There shall be no evidence of oil, grease, dirt, or other foreign matter on the steel. The steel shall have a surface profile of 1 to 3 mils maximum, measured with a profile depth tape and micrometer. Profile depth tape measurements shall be witnessed by the Verification Inspector and documented. The abrasive cleaning material shall meet the requirements of SSPC-AB 1, “Mineral and Slag Abrasives,” SSPC-AB2, “Cleanliness of Recycled Ferrous Metallic Abrasives,” or SSPC-AB 3, “Newly manufactured or Re-Manufactured Steel Abrasives,” and the condition and cleanliness of the recycled abrasives shall be checked daily or as directed by the Verification Inspector.

All sharp corners shall be broken prior to final cleaning (profiling) and prime painting. Sharp corners may usually be removed by a single pass with a grinder to approximately $^{1}/_{16}$ in. radius. Thermal cut edges to be painted shall be ground before final cleaning. Refer to M8.06.9.C: Cutting Plates and Shapes.

To provide adequate film thickness in areas or places prone to breakdown such as edges, corners, bolts, nuts, and welds shall be striped by brush painting. The paint, when applied, shall be manipulated under the brush as to produce a uniform even coating, conforming to the dry film thickness, as specified by the manufacturer on the surface being painted. Stripe coating of the primer shall be completed prior to the application of the full prime coat. The steel shall then receive one shop coat, having after application, a minimum dry film thickness of 3 mils. Maximum dry film thickness shall be no more than the manufacturer’s recommendation.

Faying surfaces, and the opposite side of the connection plate shall be masked after prime coat, 1 in. beyond the edge of the adjacent plate to be connected. No coats of paint other than primer shall be between the nut and the head of the bolt.

M8.06.9.K.2.B: Intermediate and Finish Coat

When specified, primed, galvanized or metallized steel shall receive an intermediate coat and a finish coat. The current data sheet manufacturers' recommendations for the additional coats shall be followed.

M8.06.9.K.2.C: Girder Stenciling

As an option to the Contractor, the Fabricator may stencil the bridges at the fabrication shop. Bridge Identification Markings shall be painted on fascia girders of all bridges, except weathering steel bridges, after the finish coat of paint has been applied. The date (year, month) of painting and the bridge and BIN numbers shall be stenciled on the bridge as directed by the Engineer. The characters shall be 3 in. tall, black on a white background sized appropriately for the information required. The information shall be applied to the end of the girder in middle of the web on the right side in the direction of travel. Markings shall be furnished by the Fabricator at their expense and applied as directed by the Engineer.

M8.06.9.K.2.D: Box Girders

The interior for Box Girders and Tub girders shall only be coated with prime coat and intermediate coat of the same approved system. Interior intermediate coat shall be white. Interior splice connections may be left in primer condition. Station markings shall be applied using the finish coat of the approved system, the color shall be black. The stencil and layout shall be in accordance with the contract documents.

M8.06.9.K.3: Galvanizing

All material designated to be galvanized shall be either galvanized or coated over galvanizing according to the contract documents.

The fabrication shop shall give a minimum of 7 days notice for coating activities. If material is being returned to the fabricating shop after galvanizing, material will be final inspected by QC and the Verification Inspector. If material is being shipped directly to the contractor, the Fabricator shall provide QC inspection reports for the material, and the Verification Inspector will perform final inspection at the galvanizing facility. Subsequent coatings, including coating at additional facilities shall follow the same process.

All galvanizing shall meet the requirements of M7.10.0: Galvanized Coatings. All fabrication shall be completed, and all weld areas shall be free from all weld spatter prior to the galvanization process. All fabrication shall be inspected prior to galvanizing. Fabricators shall submit to the Engineer the name and location of the galvanizing facility with sufficient time to arrange for a Verification Inspector. The Fabricator is responsible for the quality of the galvanized coating on their product. Final QC and verification inspection may happen either at the fabricator or the galvanizing facility.

Duplex coating systems for coating over galvanizing shall be submitted by the fabricator for approval by the Engineer. The submittal shall contain a minimum 2 year field history of the proposed system with a minimum of 5 uses in the Northeast on galvanized surfaces utilizing a minimum of 25 total gallons. The end user contact information shall also be included. Coating Applicator shall be approved by the Engineer as required in M8.06.9.K.1: General.

The Galvanizer shall provide MassDOT with a copy of the galvanizing certificate of compliance and quality control reports including repair documentation.

The faying surfaces of all field bolted connections shall be coated based on the design of the connection. Class B connections shall be masked prior to galvanizing to allow for application of an approved primer with class B slip coefficient. After galvanizing, the masked surface will be cleaned in accordance with SSPC-SP11 and coated with the approved zinc rich primer. A galvanized connection will result in a faying surface meeting a class C slip coefficient. When class D is specified, a galvanized to class B slip coating shall be acceptable.

Bearing members to be milled shall be galvanized prior to milling. A thin layer of a rust inhibitor shall be applied to the milled surface. Galvanized members that are to be welded after galvanizing shall be masked 3 in. on either side of the weld center line prior to galvanizing.

The galvanizing shall be repaired in accordance with ASTM A780. The zinc shall be applied such as to achieve a dry film thickness of a minimum of 3 mils and not more than 5 mils. Application methods shall be in accordance with the manufacturer's current data sheet, except that no aerosol application shall be allowed.

When coating over galvanizing is specified in the contract documents, the coating shall take place within 14 calendar days of galvanizing. The coating applicator shall take all necessary measures to prevent wet storage stain and accumulation of dirt, dust, grease, or oil while being handled or staged prior to application of the coating.

All galvanized pieces shall be visually inspected to determine the cleanliness of the surface. All contaminated surfaces shall be cleaned in accordance with SSPC-SP-1.

All material shall be checked for wet storage stain. Wet storage stain shall be removed prior to abrasive blasting in accordance with SSPC-SP-16 Appendix A.

Prior to surface preparation, all components shall have a finish that is smooth and uniform. The surface shall be free of protrusions greater than ⅛ in. above the surrounding surface and meet the requirements of ASTM A123 section 6.2

The thickness of the galvanizing shall be checked before and after the completion of abrasive blasting using SSPC PA-2 to confirm that prepared surfaces still have the minimum thickness requirements of AASHTO M 111 or AASHTO M 232, as applicable.

Provide abrasives that are clean, dry, and sized properly to provide the specified surface profile. The profile shall be dense, uniform and of sufficient angularity to be acceptable for the application of the coating. Abrasives shall conform to the following as applicable:

- SSPC-AB 1 for mineral slag abrasives
- SSPC-AB 2 for recycled ferrous metal abrasives
- SSPC-AB 3 for new steel abrasives

The abrasive shall be tested weekly for grease, oil or non-abrasive residue using ASTM D7393. Contaminated abrasives shall be changed out and not be used for surface preparation. The use of steel shot abrasive is not allowed for final blasting prior to coating application.

All compressed air sources shall have properly sized and operational oil and moisture separators to allow for oil and moisture free air.

Surfaces to be coated shall be blast cleaned in accordance with requirements of SSPC SP16 "Brush-off Blast Cleaning Non-Ferrous Metals" producing a minimum surface profile of 1 mil. Profile shall meet the requirements of the manufacturer for the coating being applied. Abrasives, nozzle size, nozzle pressure and dwell time shall be sufficient and controlled to thoroughly clean and produce a uniform surface profile. Surface preparation shall not loosen, cause flaking or disbonding of the galvanized surface. Unacceptable thickness and damage shall be cause for rejection of the entire piece.

Surfaces unacceptable after abrasive blasting and approved for repair shall be repaired in accordance with ASTM A780. Surface preparation of approved repair areas shall be done in accordance with SSPC SP-10 or SP-11. Repairs to the galvanized surface in excess of one percent of the total surface area of the piece being repaired are not allowed. The repair coating shall be a zinc rich primer as specified by the coating manufacturer compatible with the coating system approved.

Prior to coating bolted connections, galvanized fasteners shall be cleaned of all lubricating wax. Cleaning shall be in accordance with SSPC-SP-1, Solvent Cleaning, method 4.1.1. The galvanizer is responsible to identify the solvent and method needed to remove all lubricant. Cleanliness will be determined by the use of a white cloth wipe test. The wipe test will be performed by the Verification Inspector using a clean white cloth and the same solvent used for cleaning. The cloth shall be wetted and rung to a damp condition, placed on the selected fasteners and rubbed with a twisting motion around the entire surface of the previously waxed surfaces. Acceptance is with no color transfer to the cloth.

Coating application shall be completed within six hours after surface preparation has been accepted by the applicator and the Engineer.

Coating over galvanizing shall either be an approved liquid paint system or powder coat process.

Liquid paint system shall be applied per M8.06.9.K.2: Paint. The coating system shall consist of a polyamide epoxy intermediate coat and an aliphatic polyurethane top coat over the galvanizing. All paint shall be applied in accordance with these specifications and the coating manufacturer's product datasheet.

Powder coat process shall be applied per subsection M8.06.9.K.7: Powder Coating. The coating shall be a two-coat, electrostatically shop-applied, oven-baked, powder coat system. The first coat shall be an epoxy primer suitable for application over galvanized steel. The finish coat shall be polyester TGIC super durable powder. All coats of the applied system shall be from the same manufacturer. All powder shall be stored per the manufacturer's data sheet.

M8.06.9.K.4: Thermal Spray Coating (Metalizing)

The fabricator or applicator performing the work shall be approved per M8.06.1: Fabrication Shop Approval. The Fabricator shall submit a metallizing procedure for approval prior to start of fabrication. Included in the submittal, Applicator's certification, QSM, Manufacturers data sheet for selected coatings, class B slip certificate, procedures for surface preparation and required materials, application of TSC, application of subsequent coatings, touch up and repair. Also included in the

submittal, the shop shall identify a work schedule, giving a minimum of 7 days' notice for coating activities.

Provide safe access and sufficient time for MassDOT inspection for any and all phases of the work, including but not limited to surface preparation, the application of each coat and for final inspection of the completed system and shipping.

The fabricator shall provide material certificates from the supplier that includes the chemical composition and lot number of the wire. When required by the contract documents, thermal spray wire must be manufactured domestically. The quality control reports including repair documentation shall be made available to the Verification Inspector and MassDOT upon request.

M8.06.9.K.4.A: Abrasives

Provide abrasives that are clean, dry, and sized properly to provide the specified surface profile. The profile shall be dense, uniform and of sufficient angularity to be acceptable for the application of TSC.

Abrasives shall conform to the following as applicable:

- SSPC-AB 1 for mineral slag abrasives
- SSPC-AB 2 for recycles ferrous metal abrasives
- SSPC-AB 3 for new steel abrasives

M8.06.9.K.4.B: Material

All material for metallizing shall meet the requirements of M7.15.0: Metallized Coatings. The wire material shall be Zinc-Aluminum mix applied at 9-12 mils when painted over TSC and 12-15 mils when sealed only. The paint system shall be a NEPCOAT "B" system on the MassDOT QCML compatible with the TSC.

M8.06.9.K.4.C: Quality Control

The coating applicator shall have completed a minimum of three structural steel TSC projects that utilized the same coating system as that being specified on this project. Provide project locations, TSC/painting; name, e-mail address, and the telephone number of the owner or owner's representative. Provide an on-site Quality Control Specialist (QCS) who shall function as a TSC inspector with a minimum of five years of each TSC and coating application experience; and possess SSPC BCI Level 1 or NACE Certified Level 3 or other related certification as accepted by the Engineer. The QCS shall not be a foreman or a member of the Applicator's production staff. The QCS's sole purpose shall be quality control testing, inspection and reporting.

M8.06.9.K.4.D: Personnel Qualification

The applicators of the thermally applied material shall be individually qualified to apply the TSC as follows. Each applicator must complete a practical test designed to demonstrate the ability to set up and operate the equipment to apply the material to the specified thicknesses to a minimum of 10 square feet of representative steel surfaces, and to successfully pass the surface preparation, bend, and cut tests specified herein. Administer the qualification testing, document the results in writing, and retain the bend test coupons for the duration of the project. At the discretion of the Engineer, requalify the applicators at any time during the project to reconfirm the proficiency and the quality

of the workmanship being provided. This may be required at any time due to unacceptable or failing results of the bend test, cut test, or poor workmanship.

M8.06.9.K.4.E: Shop Qualifications

Prior to proceeding with the production blast cleaning operations, prepare a minimum of five Job Reference Standards (JRS) test plates. Blast clean all surfaces of each test plate using the same equipment and abrasive that will be used for the production work. After acceptance of the surface cleanliness and profile, apply the TSC to all surfaces of each test plate. After acceptance of the TSC apply the sealer to be used with the three coat system to three test plates excluding the bottom surface of all test plates. After curing apply a coat of epoxy to two of the three test plates excluding the bottom surface. After curing apply a coat of the polyurethane topcoat to one test plates on all surfaces excluding the bottom surface. Apply the clear sealer to the last remaining TSC plate. Bottom surfaces of the prepared plates shall be used for cut testing as specified. Surface preparation and application shall be witnessed by a Verification Inspector. See Figure M8.06.9-1 for dimensions and construction

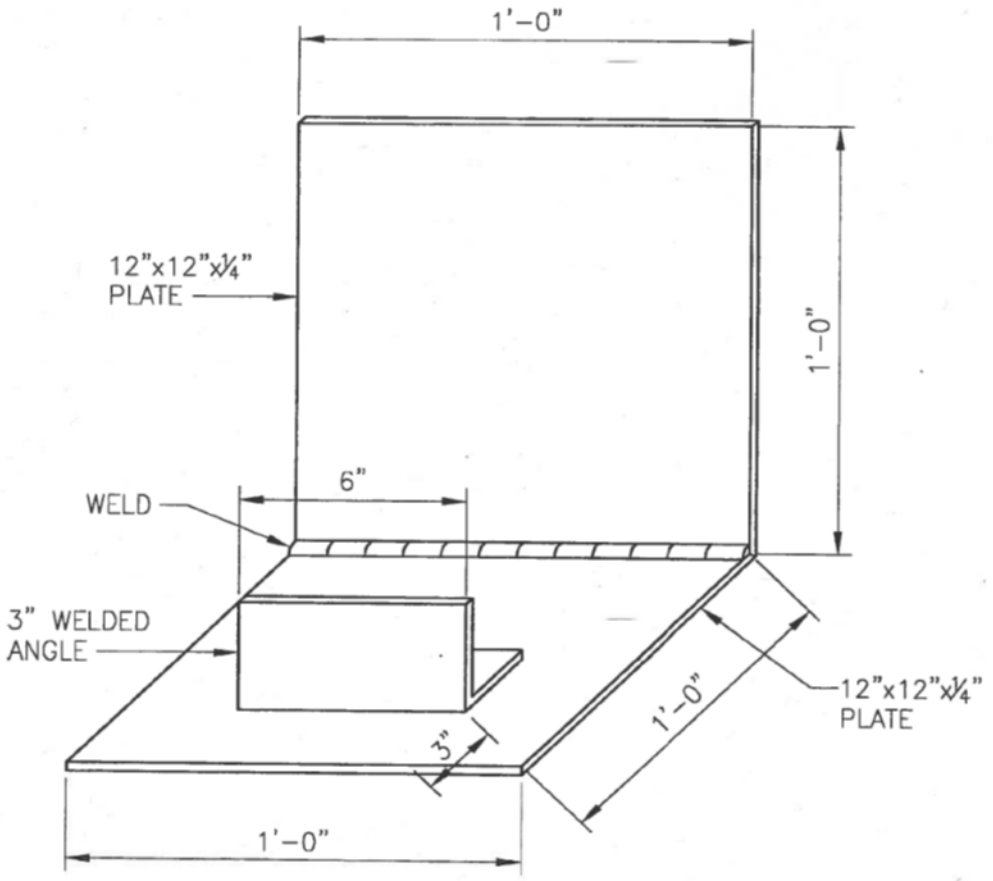


Figure M8.06.9-1: Configuration of JRS Test Plates

M8.06.9.K.4.F: Surface Preparation

For cleaning that utilizes compressed air, utilize only clean, dry air. Conduct blotter test(s) in accordance with ASTM D4285 a minimum of one time each shift for each compressor system in use to verify that the air supply is free of moisture and oil contamination. Conduct the tests in the presence of the Verification Inspector.

M8.06.9.K.4.G: Weld Spatter, Sharp Edges, Flame-Cut Steel, Holes, Fins, and Silvers

Remove slag, flux deposits, fins, slivers, burrs, and weld spatter from the steel. Grind any sharp edges around holes. Break all flame-cut and sheared edges. If blast profile is degraded by grinding restore profile by abrasive blasting.

M8.06.9.K.4.H: Solvent Cleaning

Where oil and grease are present on the bare steel, remove by solvent cleaning to SSPC-SP 1 prior to blast cleaning. If contamination remains after blast cleaning, reclean with solvent prior to application of the TSC.

Cleaning of all lubricating wax from galvanized bolts prior to the application of paint to bolted connections. Cleaning shall be in accordance with SSPC-SP-1, Solvent Cleaning, method 4.1.1. The applicator is responsible to identify the solvent and method needed to remove all lubricant. Cleanliness will be determined by the use of a white cloth wipe test. The test will be performed by the applicator using a clean white cloth and the same solvent used by the applicator for cleaning. The cloth shall be wetted and rung to a damp condition, placed on selected fasteners and rubbed with a twisting motion around the entire exposed surface of the previously waxed surfaces of the fastener. A minimum of 3 alternating rotations shall be done. Acceptance of cleanliness is with no color transfer to the cloth. A minimum of 10% of the bolts at each bolted connection shall be tested for cleanliness.

M8.06.9.K.4.I: Abrasive Blasting

Blast clean all steel to, SSPC-SP5 “White Metal Surface Cleanliness.” Determine the SP5 condition by use of SSPC-Vis 1. In the event of a conflict between the pictorial standard and the written definition, the written definition shall prevail. Abrasive blast cleaned surfaces shall have a dense, uniform pattern of sharp, angular depressions and ridges, between 3.5-5.5 mils.

Surface preparation is defined as complete when all remedial repairs have been performed and the piece is accepted by both QC and Verification Inspector.

Verification of the profile height will be performed in accordance with ASTM D 4417 Method C.

Manual Blasting shall have a minimum of one profile depth measurement every 10 to 20 ft^2, of blasted surface.

Automated Blasting shall have a minimum of two profile depth measurements every 100 ft^2. When acceptable results are obtained on three consecutive days in which testing is conducted, the test frequency may be reduced to two spot readings for every 1,000 ft^2 providing the preparation method remains unchanged. If unacceptable results are encountered during testing or the preparation method has changed in any way, testing will revert back to a frequency of two tests per every 100 ft^2, until acceptable results are once again achieved over a three day period.

Profile replica tape shall be filed with the project inspection records.

The use of steel shot is not permitted.

M8.06.9.K.4.J: TSC and Coating Application

M8.06.9.K.4.J.a: Bend Testing for Evaluation of the TSC

Conduct bend tests of applied TSC each day prior to production application. Unless otherwise directed by the Verification Inspector, each day that TSC will be applied, conduct bend testing before beginning the production work. For each TSC applicator, blast clean five carbon steel coupons measuring 0.05 in. in thickness, 2 in. width, and between 5 and 8 in. in length. Use the same equipment and abrasive used for the production work. Have each applicator apply the TSC to five coupons in accordance with the requirements of this Section to dry film thickness between 8 and 15 mils. Conduct 180° bend testing on all five coupons using the appropriate mandrel in accordance with the requirements and acceptance criteria of SSPC-CS 23. Minor cracks that cannot be lifted from the substrate with a knife blade are acceptable. If lifting on any of the coupons is possible, modify the surface preparation/TSC process until acceptable results are achieved before proceeding with the production work.

M8.06.9.K.4.J.b: TSC Application

Apply the TSC within six hours after the final abrasive blast cleaning is performed and accepted. If the steel is blast cleaned and remains unmetallized for longer than six hours, or if cleaned steel exhibits evidence of rustback, blast clean it again prior to metalizing. Remove abrasive residue and dust from the surface. Apply the TSC in accordance with the requirements of the material supplier, this specification, approved procedures and SSPC-CS 23.

The completion of TSC is defined as after the spraying of TSC is complete and all remedial repairs have been performed and the piece is accepted by both QC and Verification Inspector.

Touch-up of bare steel and/or TSC damage shall be done with organic zinc rich primer. The total area subject to repair shall be no more than 0.50% of the total square foot of the piece requiring repair. The dry film thickness of the applied coating shall be a minimum of 5 mils. Surface preparation for all repair areas shall be as specified in Surface Preparation. The maximum individual repair shall be limited to 1 square foot. Areas larger than 1 square foot shall be re-blasted and the TSC applied in accordance with this document.

M8.06.9.K.4.J.c: Paint Storage, Testing and Sampling

The Applicator shall provide protection from the elements and ensure that the paint is not subjected to temperatures outside the manufacturer's recommended extremes.

Before the Applicator will be permitted to use any paint, the material provided for application shall have been sampled, tested and approved in accordance with M7.02: Structural Paint. Material not listed on the QCML needs a minimum of fourteen days after the receipt of samples to test and approve.

Sealers do not require sampling and testing.

M8.06.9.K.4.J.d: Paint Mixing and Thinning

Before the paint is applied, each component shall be mechanically mixed to ensure the pigment is completely dispersed. Mixing of components shall be accomplished by mechanical mixing. Boxing or hand mixing of components will not be allowed. Any special precautions or requirements for mixing by the manufacturer shall be followed. Paint shall be kept thoroughly mixed in spray pots or containers during application. The pot life shall not be exceeded nor shall attempts be made to extend pot life with the addition of solvent.

If it is necessary for any reason to thin paint it will be done in the presence of the Verification Inspector, in accordance with the manufacturer's recommendations. Thinning must be performed using a measuring cup marked in ounces or milliliters. Other methods, such as eyeballing, are not acceptable. Thinner shall be supplied from and recommended by the same manufacturer as the paint system.

For multi component paints, the mixing of half or partial kits is not allowed. If the need for small quantities of paint is anticipated, the applicator should order materials accordingly.

M8.06.9.K.4.J.e: Application

Prior to the application of any paint or sealer, TSC must be accepted by the Verification Inspector. Paint shall be applied as per M8.06.9.K.2: Paint and the manufacturers' recommendation. Typically, the seal coat is applied at a spreading rate resulting in a theoretical 1.5 mils dry film thickness. Apply the seal coat in accordance with the manufacturer's instructions as soon as possible after the application of the TSC but in no case greater than 6 hours.

M8.06.9.K.4.J.f: Paint

Applied coatings shall not exhibit, runs, sags, holidays, wrinkling, pinholes, nap hair, topcoat gloss or color variations, or other film discontinuities.

Repair of unacceptable areas that involve removal of the coating system or part of it, shall require surface preparation and coating equal to that specified. Repair procedures used for any unacceptable coating shall be those supplied by the contractor and approved by the Engineer.

Application of full coats of paint shall be accomplished by spray equipment. Spray equipment shall meet the requirements of the coating manufacturer and be in proper working order.

Application by brush and roller will be allowed for limited access areas. Brushes and roller covers recommended by the coating manufacturer shall be used. Areas brushed and rolled will have a uniform thickness and be free of defects and excessive coating thickness.

All coating shall be applied according to the latest manufacturer's data sheet or approved recommendations. The maximum recoat times of the primer, intermediate and finish coats shall not be exceeded.

Application of coatings shall not be done when the relative humidity is above 85% or when the surface temperature of the steel is less than 5°F above the Dew Point. Paint shall not be applied when the surface temperature is below 50°F or when the surface temperature is above 110°F.

If requested by the Verification Inspector the applicator shall provide written instructions from the coating manufacturer indicating the length of time that each coat must be protected from cold or inclement weather (e.g., exposure to rain) during its curing or drying period.

Paint shall not be applied when, in the Verification Inspector's judgment, conditions are or will become unsatisfactory for application and proper cure. All changes as to the application parameters other than specified must be the manufacturer's and presented in writing and approved by the Engineer. Ambient conditions should be closely monitored so that proper cure/drying is achieved prior to recoat. In no case shall a succeeding coat of paint be applied before the previous coat has cured/dried sufficiently for recoat as per manufactured data sheet.

If required, contaminated surfaces shall be cleaned in accordance with SSPC-SP 1 Solvent Cleaning method 4.1.1.

Measurement of the ambient conditions shall be done in accordance with ASTM E337 .

When the primer has cured sufficiently for recoat, all bridge components to be painted shall receive a full intermediate coat.

When the intermediate coat has cured sufficiently for recoat, all bridge components to be painted shall receive the finish coat.

M8.06.9.K.4.J.g: Sealer Coat

The seal coat shall be thin enough when applied to penetrate into the body of the TSC and seal the porosity. Added thickness to porous TSC should not be measurable. Typically, the seal coat is applied at a spreading rate resulting in a theoretical 1.5 mils dry film thickness. Apply the seal coat in accordance with the manufacturer's instructions as soon as possible after the application of the TSC but in no case greater than 6 hours. Verify that the TSC surface is clean and dry prior to the application of the sealer. If grease, oil, or similar contaminants become deposited on the TSC, remove them in accordance with SSPC-SP 1 prior to the application of the seal coat. Seal coat is acceptable under the heads of bolts or nuts, but shall not be applied to faying surfaces.

M8.06.9.K.4.J.h: Coating Thickness

TSC thickness shall be 12-15 mils prior to sealing with an approved sealer. Material designated to be painted after TSC, shall have a TSC thickness of 9-12 mils prior to painting with an approved paint system. Intermediate and topcoat shall be applied per the manufacturers' recommended thickness.

Determine the cumulative dry film thickness of each coat using a magnetic dry film thickness gauge in accordance with SSPC-CS 23 and SSPC-PA 2 and the following. Take readings on each 100 square-foot increment of the surface. The minimum specified thickness of the TSC must be achieved at each individual spot measurement location (i.e., the 20 percent under run allowed by SSPC-PA 2 is not permitted for the metalizing). If the thickness of any coat (TSC, seal coat, intermediate coat or topcoat) is less than specified, apply additional material in accordance with the manufacturer's instructions and this Section before applying the next coat. Before applying additional TSC, visually confirm that there is no evidence of oxidation or contamination on the surface.

Thickness of applied TSC greater than the contract specified shall be reported to the Verification Inspector in writing prior to the end of the shift. The thickness of the applied TSC shall not be more than 120% of the specified maximum.

Application of TSC to faying surfaces that require a slip rating shall not be more than the maximum thickness specified.

The minimum adhesion value of the unsealed TSC shall be the average of 3 spot readings. The average of the readings must be greater than 700psi. Test shall be done for each 500 sq/ft.

M8.06.9.K.4.J.i: Touch-Up and Repair

Touch-up of bare steel and/or metallized surface damage shall be done with organic zinc rich primer. The total area subject to repair shall be no more than 0.50 % of the total square foot of the piece requiring repair. The dry film thickness of the applied coating shall be a minimum of 5 mils. The maximum individual repair shall be limited to 1 square foot. Areas larger than 1 square foot shall be re-blasted and the metallizing reapplied.

All metallized surfaces shall be sealed unless otherwise noted. Faying surfaces in direct contact with adjacent faying surfaces shall not be sealed. Surfaces under bolt heads, washers and nuts shall be sealed.

M8.06.9.K.5: Coating of Weathering Steel

Structural steel meeting AASHTO M 270 50W and other weathering steels shall not be coated except when and where specifically called for on the plans. Where coating is required on the plans, the coating shall be an approved 3 coat paint system. Surface preparation for coating shall be in accordance with SSPC-SP6/NACE No.3. When weathering steel is painted, the finish coat color shall conform to Federal Standard 595B, “Colors Used in Government Procurement,” color chip no. 30045.

All uncoated areas shall be cleaned free of any marks, including but not limited to heating and welding areas. Fascia surfaces shall be re-blasted and prepared so as to weather uniformly.

M8.06.9.K.6: Anodizing

The fabrication shop shall give a minimum of 7 days notice for coating activities. If material is being returned to the fabricating shop after anodizing, material will be final inspected by the QC Inspector and the Verification Inspector. If material is being shipped directly to the contractor, the Fabricator shall provide QC inspection reports for the material, and the Verification Inspector will perform final inspection at the anodizing facility.

Anodizing shall conform to M7.20.0: Anodized Coatings.

M8.06.9.K.7: Powder Coating

The fabrication shop shall give a minimum of 7 days notice for coating activities. If material is being returned to the fabricating shop after powder coating, material will be final inspected by the QC Inspector and the Verification Inspector. If material is being shipped directly to the contractor, the Fabricator shall provide QC inspection reports for the material, and the Verification Inspector will perform final inspection at the powder coating facility.

Powder Coating shall conform to M7.25.0: Powder Coatings.

M8.06.9.L: Shipping and Handling

Final inspection occurs when material is transferred from the fabricator to the contractor.

All handling shall conform to the approved construction erection procedures and standard shop procedures. Proper consideration shall be given to guard against lateral buckling of unsupported beams and girders during handling. Fabricated material shall be handled with chain softeners and secured safely during shipping and handling.

The Fabricator shall give the Verification Inspector all proper documentation including, but not limited to, shipping documents, Mill Test Reports, NDT reports, QC checklists, coatings certificates and certificates of compliance prior to loading material for shipment. All documentation shall be reviewed and approved by the Verification Inspector and receive the Inspector's stamp. After all paperwork has been reviewed and approved, conforming material may be loaded for transportation in a manner that does not cause damage to the material or the coatings.

Prior to any material being shipped, the Fabricator shall refer to Subsection 7.03: Permits and Licenses regarding permits and licenses required for shipping of overweight and over-dimensional vehicles and loads. All shop fabrication shall be completed and inspected prior to coating. All shop coatings shall be completed and inspected prior to final inspection. All Non-conformance reports shall be closed out prior to shipping from the Fabricator. No material shall be shipped to the job site without receiving final inspection by the Verification Inspector. Material shall receive the Inspector's stamp.

Fasteners shall be stored in their sealed containers, free from contamination and moisture until ready for use on the job. Visible corrosion or contamination is a cause for rejection of the fasteners. Pins, small parts, and small packages of bolts, rivets, washers, and nuts shall be stored in boxes, crates, kegs, or barrels.

If the material is being stored at the fabricator for any length of time, the Verification Inspector will return for final inspection prior to shipping. The fabricator must give sufficient notification to the Engineer for inspection. All fabricated material shall be stored off the ground on skids or other supports in a way to prevent damage to coatings or structural integrity. Material shall be on firm base to prevent sinking or tipping. Pad structural steel members in storage at points of contact. Storage shall facilitate the ability to make subsequent inspections and does not compromise the safety of personnel. Material shall be kept free of dirt, grease, and other foreign matter and shall be stored in a way to facilitate drainage when stored outside. The Fabricator shall support material at Designer specified intervals to prevent deflection, distortion or change in camber or curvature in members during storage. Other storage configurations shall require calculations by a licensed Professional Engineer that demonstrate that the member will not be overstressed.

M8.07.0: Guardrail

The materials for this work shall conform to AASHTO M 180 and the suppliers/manufacturers of guardrail and guardrail components shall be listed on the QCML.

All steel components and hardware shall be galvanized. All metal fabrication work shall be done in the shop. No punching, cutting or welding shall be done in the field. Fabrication shall include all

operations such as shearing, cutting, punching, forming, drilling, milling, bending, welding and riveting. Components of bolted assemblies shall be galvanized separately before assembly. When it is necessary to straighten any sections after galvanizing, such work shall be performed without damage to the zinc coating.

Galvanized surfaces that are abraded or damaged at any time after application of the zinc coating shall be repaired by thoroughly wire brushing the damaged areas and removing all loose and cracked coating after which the cleaned areas shall be painted with two coats of paint, high zinc dust content, conforming to the requirements of M7.04.11.

M8.07.0.A: Posts

M8.07.0.A.1: Steel Posts

Steel posts and channel members for anchor posts shall be fabricated from new structural steel sections conforming to the dimensions and design shown on the plans.

Posts shall conform to the requirements of ASTM A36. Galvanizing shall meet the requirements of M7.10.0: Galvanized Coatings.

M8.07.0.A.2: Wood Posts

The posts shall be rough sawn (unplaned) with nominal dimensions as indicated on the plans and with tolerances of 1 in. in length and ¼ in. in width and thickness. All holes in the posts shall be drilled prior to pressure application of the preservative at a wood preserving facility.

The stress grade shall be 1,000 psi or more in extreme fiber bending. Grading for stress-graded timber shall be in accordance with AASHTO M 168.

Prior to treatment, all posts shall be seasoned, conditioned, and completely machined in accordance with AWPA M1.

Posts shall be treated with chromated copper arsenate, type C (CCA-C) conforming to AWPA P23, to a minimum retention of 0.60 pcf. Treatment shall be full length under pressure by the empty-cell or full-cell process in accordance with AWPA U1.

Manufacturers shall adhere to the processing and treatment limitations in AWPA T1. No unnecessary cutting of treated posts will be allowed after treatment. All posts with surfaces damaged by cutting, drilling or any other cause shall be field treated with a preservative solution in accordance with AWPA M4.

Certificates of compliance and certificates of inspection bearing the independent inspection agency's verification for each lot of wood must be presented before installation and contain the species of wood, the type of preservative, the retention rate and penetration of the preservative.

The certificates of inspection and compliance do not signify mandatory acceptance of the entire lot. The Department still has the option of rejecting posts (included in any particular lot) that the Engineer considers sub-standard because of unsound knots and shakes, excessive checking or other defects that may be detrimental to the structural integrity of the posts.

The fabricator shall retain an independent inspection agency to inspect and certify the treated posts in accordance with these specifications and AWPA M2, Part A.

All treated posts shall be marked in accordance with AWPA U1 (and M6 as required). (The mark is to include the identifying lot and/or charge number). The post shall also be stamped with the Inspector's identification. The mark is to be placed on the upper side head of the post and located so that it is not obstructed by the offset blocks, rails, or any other appurtenances. The Inspector's stamp shall be legibly hammer-stamped on the head of the post, in accordance with AWPA M2 and the above.

M8.07.0.B: Offset Blocks

The blocks shall be of the same type throughout the project. Requirements for specific material types are as follows:

- Wood Offset Blocks: Wood offset blocks shall meet the requirements of A. Posts, Wood Posts, above. When wood offset blocks are used on wood posts, they shall be the same species as the posts.
- Plastic Offset Blocks: Plastic offset blocks shall meet all applicable performance requirements of MASH and be listed on the QTCE. Each block shall be stamped at the factory with the manufacturer's identification and lot number and conform to the dimensions shown on the plans.

Prior to approval and use of the plastic guardrail offset blocks, the manufacturer shall submit to the Engineer, the manufacturers name, the product brand name and/or model number, a copy of the MASH test results, a Material Safety Data Sheet, and a sample block. Acceptance of the material will be based on the manufacturer's certification.

M8.07.0.C: Rail Element and Terminal Sections

The steel rail element, transition panels, terminal sections and connecting hardware shall conform to AASHTO M 180, Type II, Class A with the following additions:

The length of the rail shall be according to the plans.

Each end of the steel rail for every stretch of guard shall be fitted with a terminal section as shown on the plans.

The projecting heads of all connection and splice bolts shall be button head type so no appreciable projection will obstruct a vehicle sliding along the rail. Steel rail elements with a radius of 150 ft or less shall be shop bent.

The manufacturers are required to submit a Brand Registration and Guarantee document annually to RMS showing compliance of the Guardrail Components with AASHTO M 180 Specification.

M8.07.1: Guardrail End Treatment

The same type of tangent end or flared end treatment shall be used throughout the project.

All steel components and hardware shall conform to M8.07.0: Guardrail. All metal work shall be done in the shop.

The approach end shall have Type 3 Object Marker sheeting that conforms to the requirements of the MUTCD. The sheeting material shall meet the requirements of M9.30.0: Retroreflective Sheeting.

M8.09.0: Chain Link Fences and Gates

Materials for this work shall conform to the following requirements:

M8.09.0.A: General

All material used shall conform to AASHTO M 181 except as noted herein. The fence fabric shall be Type II - Aluminum Coated Steel or Type IV -- Polyvinyl Chloride (PVC) - Coated Steel. All tubular posts and rails, and roll-formed "C" section posts and rails shall be zinc-coated steel. All wire shall have a diameter tolerance of ±0.005 in. diameter. For chain link fabric used on bridge protective screens Type I and II see M8.13.3: Aluminum Handrail and Protective Screen Type I and Type II. Spring tension wire shall be aluminum coated steel. Aluminum coated fence fabric and spring tension wire shall be tested in accordance with AASHTO T 213. All zinc coated posts, hardware, and fittings shall be in conformance with AASHTO M 232. Polyvinyl Chloride (PVC) coated steel fence fabric, posts, rails, gates and accessories shall conform to M8.09.1: Bonded Vinyl Coated Chain Link Fences, Posts, Rails, Fabric, Gates and Accessories. Post caps, rail end and other fittings and appurtenances shall be pressed steel or malleable iron. All materials shall be new and undamaged when installed. Imperfectly coated materials will be rejected.

M8.09.0.B: Posts

Steel round pipe posts and "C" sections shall have a tolerance of ±10% from specified weight and ±5% from specified dimensions.

Type B round pipe shall conform to ASTM A 1011. Roll-formed "C" section shall conform to ASTM F1043.

Galvanized steel Line, End, Corner and Intermediate Posts shall conform to the sizes in Table M8.09.0-1:

Table M8.09.0-1: Post Sizes for Chain Link Fence

Post Type	Under 5 Ft in Height	5 Ft and Over in Height
Line Post	1) Round Pipe - 1.90-in. O.D. Type B @ 2.29 lb per ft; or 2) "C" section - 1 ⅞ x 1 ⅝ in. @ 2.28 lb per ft	1) Round Pipe - 2 ⅜-in. O.D. Type B @ 3.117 lb per ft; or 2) "C" section-2 ¼ x 1.70 in. @ 2.64 lb per ft
End Post and Corner Post	1) Round Pipe - 2 ⅜-in. O.D. Type B @ 3.117 lb per ft	1) Round Pipe - 2 ⅞ -in. O.D. Type B @ 4.64 lb per ft
Intermediate Brace Posts	1) Round Pipe - 2 ⅜-in. O.D. Type B @ 3.117 lb per ft; or 2) "C" section - 2 ¼ x 1.70 in. @ 2.64 lb per ft	1) Round Pipe - 2 ⅞-in. O.D. Type B @ 4.64 lb per ft

Gate posts shall be 4 in. O.D. pipe, Type B with a weight of 6.56 lb per ft.

The galvanizing for "C" sections shall not be less than 2.0 oz per ft² of metal surface as per AASHTO M 232. For Type B round pipe the external coating shall be 0.9 oz of galvanizing per ft² minimum, 15 µg of chromate per in.² minimum, plus 0.3 mils minimum of clear cross-linked polyurethane acrylic coating. The internal surface shall be coated with zinc-rich based organic coating containing

not less than 87% zinc powder and capable of providing galvanic protection. All round posts shall be fitted with an approved top, so designed as to fit securely over the post and carry the top rail or cable. The base of the top fitting shall carry an apron around the outside of the post.

M8.09.0.C: Top Rail and Spring Tension Wire

- Rail shall have a tolerance of ±10% from specified weight and ±5% from specified dimensions. Steel top rails shall be Type B 1.66 in. O.D. tubular pipe with a weight of 1.83 lb per ft, or 1.625 x 1.25 in. roll-formed "C" section with a weight of 1.40 lb per ft.
    - The protective coating for top rails shall meet the requirements of paragraph B above.
    - Couplings or expansion sleeves shall be outside sleeve type and at least 6 in. long.
- Spring tension wire shall be coil spring steel 7 gage (0.177 in.). The base metal shall have a minimum breaking strength of 1,950 lb coated with aluminum applied at a rate of not less than 0.40 oz per ft² of surface area.

M8.09.0.D: Braces and Truss Rods

Compression braces shall be the same type and size as top rail. Tension truss rods shall be $^{5}/_{16}$-in. minimum round rods with drop forged turnbuckles, or other approved type of adjustments.

M8.09.0.E: Fence Fabric

The fabric shall consist of 9 gage (0.148 in.) wire having a minimum breaking strength of 1,290 lb coated with aluminum applied at the rate of not less than 0.40 oz per ft² of uncoated wire surface. It shall be woven into approximately 2 in. diamond mesh. The width of the fabric shall be specified or shown on current standard drawings. Fabric for chain link fence less than 6 ft in height shall be finished at top and bottom with a "knuckled" selvage. All other fence sizes shall have a knuckled selvage at the bottom and twisted selvage at the top. Barbing shall be done by cutting the wire on the bias.

M8.09.0.F: Bands and Stretcher Bars

All bands shall be a minimum of 12 gage (0.106 in.) and at least ¾ in. in width. Tension or stretcher bars shall be no less than $^{3}/_{16}$ in. x ¾ in. stock. Galvanizing shall conform to the requirements of AASHTO M 232.

M8.09.0.G: Tie Wire and Hog Rings

Aluminum tie wire shall be a minimum of 6 gage (0.192 in.) round wire Alloy 1350-H19 or equal. Aluminum hog rings shall be a minimum of 11 gage (0.120 in.) round wire Alloy 1350-H19 or equal.

M8.09.0.H: Barbed Wire

Barbed wire shall consist of two strands of 0.0985 in. diameter wire with 0.08 in. diameter 4-point barbs approximately 5 in. apart, shall be aluminum coated and conform to the requirements of AASHTO M 280.

Barbed wire Extension Arms shall be at an angle of approximately 45° and shall be fitted with clips or other means for attaching three lines of barbed wire, and with top outside wire approximately

12 in. horizontally from the fence line and the other wires spaced uniformly between the top of the fence fabric and the outside barbed wire.

M8.09.0.I: Gates

Gate frames shall be constructed of galvanized steel of sizes and weights shown below. The corners of the gate frame shall be fastened together and reinforced with suitable fittings designed for the purpose or they may be welded.

Single gate frames 6 ft or less in width shall be 1.66 in. O.D. pipe galvanized steel conforming to Section C of this specification.

Single gate frames over 6 ft wide shall be 1.90 in. O.D. galvanized steel pipe conforming to Section B of this specification.

Cross trussing shall be $^{5}/_{16}$-in. galvanized iron adjustable rods.

Chain link fence fabric for filling the gage frame shall conform to Section E of this specification.

Each gate shall be furnished complete with necessary hinges, latch and drop bar locking device designed for the type of gate post and gate used.

Gate sizes shall be as specified with the height conforming to the height of the fence.

M8.09.0.J: Drive Anchors and Shoes

Drive anchors shall be galvanized steel angle iron or extruded aluminum alloy 6061-T6. Minimum dimensions shall be 1 ¼ in. x 1 ¼ in. x ⅛ in. The weight of zinc for galvanized components shall be 1.5 oz per ft² of metal surface.

Shoes for drive anchors shall be galvanized cast or malleable steel, or extruded aluminum alloy 6061-T6. The weight of zinc for galvanized components shall be 2.0 oz per ft² of metal surface.

M8.09.1: Bonded Vinyl Coated Chain Link Fences, Posts, Rails, Fabric, Gates and Accessories

The fence shall have a bonded polyvinyl chloride (PVC) coating over aluminum coated or galvanized steel. All material used shall conform to AASHTO M 181. Polyvinyl chloride coated by dipping, thermal fusion or any other method that meets the requirements of this specification.

The fence fabric shall be PVC coated wire that is woven into a 2 in. diamond mesh. The coating shall not crack, craze, or peel. The color of the PVC coated fabric and accessories shall be medium green as defined in AASHTO M 181.

All materials shall have dimensions and weights as specified in M8.09.0: Chain Link Fences and Gates except as follow:

Property	Description
Spring Tension Wire	9 gage.
Ties	Aluminum 10 gage
Hog Rings	Aluminum 11 gage

The bonded PVC coating shall be a minimum of 0.007 in. as determined by measuring the diameter of the coated wire, stripping off the coating, measuring the diameter of the stripped wire and dividing the difference by two.

M8.10.0: Steel Pipe Rail or Fence

Fabrication shall conform to the requirements of M8.06.0: Fabrication Requirements. Materials for this work shall conform to the following requirements:

M8.10.0.A: Rails and Posts

Steel pipe for rails and posts shall conform to requirements of ASTM A53, Grade B., galvanized, or ASTM A500 Grade B or C. ASTM A500 pipe shall be hot dip galvanized after fabrication in accordance with ASTM A123. Diameter and thickness shall match the requirements in the contract documents. All vent holes shall be plugged after galvanizing with zinc plugs.

M8.10.0.B: Fittings and Clamps

Clamps and other fittings shall conform to the requirements of ASTM A36. They shall be galvanized in accordance with ASTM A123. All bolts, other than anchor bolts, shall be steel conforming to ASTM A30 and galvanized in accordance with ASTM A153.

M8.13.0: Aluminum Handrail, Protective Screen, and Snow Fence

Fabrication shall conform to M8.06.0: Fabrication Requirements. Material used in the fabrication of Handrail, Protective Screen Type I and Type II, and Snow Fence shall conform to the following requirements:

- All materials shall be new. All castings shall be sound, free from blowholes or other imperfections, and shall have smooth surfaces. Aluminum shall be Anodized after fabrication in accordance with M7.20.0: Anodized Coatings.
- Aluminum extrusions and plates shall conform to ASTM B221, Alloy 6061-T6.
- Aluminum pipe shall be schedule 40.
- Chain link fabric shall conform to AASHTO M 181 Type III (aluminum alloy 6061-T89 or T94). 1-in. mesh shall be 9 gauge. 2-in. mesh shall be 6 gauge. Prior to bending and coating, the wire shall meet the minimum tensile strength of 54 ksi as specified in AASHTO M 181. Fence fabric shall be powder coated after weaving in accordance with M7.25.0: Powder Coatings.
- Protective Screen Type II and Snow Fence self-tapping stainless steel type 304 screws.
- Anchor bolts and washers shall conform to ASTM F3125/A325 Type 1 galvanized. No rotation-capacity testing shall be required. The bolts and washers shall be galvanized in accordance with AASHTO M 232. The anchor cage shall be galvanized in accordance with AASHTO M 111
- Tee Bolts shall conform to ASTM A307 and shall be galvanized in accordance with AASHTO M 232. Type 304 stainless steel Tee Bolts may be substituted for the galvanized A307 Tee Bolts.
- Cover Plate Bolts shall be stainless steel type 304 with oversized washer and stainless steel nylon nut.
- All other fasteners, nuts and washers shall be as called for on the drawings.
- Type 1 fence bolts shall be ASTM B316 2024-T4 and nuts shall be ASTM B316 6061-T6.

M8.14.0: Load Transfer Assembly

Load transfer assemblies for transverse joints shall consist of slip-bars and a metal device so designed as to hold the slip-bars exactly and firmly in their correct positions during concreting operations. The complete assembly shall conform to the requirements and dimensions as shown on the plans or as approved by the Engineer.

The slip-bars shall be fabricated from either plain new billet steel of the grade designated or plain rail steel. They shall be free from burring or other deformations restricting slippage in the concrete.

One half the length of each slip-dowel bar of load transfer units shall be rendered bondless with a coat of either a graphite lubricant or a wax base grease.

The graphite lubricant shall consist of flake graphite mixed with a vehicle having quick drying characteristics. The graphite paste shall be thoroughly mixed and have a composition that conforms to Table M8.14.0-1.

Table M8.14.0-1: Graphite Paste Composition (Percentage by Weight)

	Minimum	**Maximum**
Pigment: (Flake Graphite)	55%	65%
Graphite Carbon	85%	
Passing No. 100 Sieve	84%	92%
Passing No. 325 Sieve	46%	50%
Vehicle	35%	45%

Vehicle shall consist of 52% fixed oils; remainder to be volatile thinners and driers.

To prepare lubricant for application, approximately 3 to 4 lb of the graphite paste shall be placed in a suitable container and 40% by weight of 60/40 mixture of carbon tetrachloride and naphtha shall be added thereto. The resulting lubricant shall be thoroughly mixed.

The wax base grease shall be applied hot at temperatures of 170°F to 190°F. It shall conform to the following requirements:

Property	**Description**
Consistency, cone penetration at 77°F	120-160
Melting point	140°F (minimum)
Stability	No separation at 200°F to 210°F for 1 hr
Abrasives	Free from abrasives
Volatile matter (% by weight)	2% maximum when heated at 210°F ±3°F for 0.5 hr
Drying	Shall not dry in 14 days
Corrosion	There shall be no evidence of corrosion on steel
Acidity (pH)	5 (minimum)
Adhesion	Shall not slip, sag or drip at 130°F
Removability	Shall be readily removable with a cleaning solvent

M8.15.0: Strand Chuck

The chuck shall be of a design suitable for securely gripping high tensile strand steel without deformation or slippage. It shall be manufactured from a corrosion resistant steel alloy capable of withstanding repeated use and overload conditions in excess of the ultimate tensile strength of the strand without fatigue or failure. The surface body of the chuck shall be treated to increase corrosion resistance.

M8.16.0: Electrical Wire & Cable

This specification covers all electrical wire and cable for traffic control devices, traffic signals, ITS systems, highway lighting, signs and supports. All wire and cable herein are for copper conductors rated for 600V. All traffic signal cable conductors shall not be less than #14 AWG, with an exception for individual conductor drops between a span wire hub and the signal head, which shall be not less than #16 AWG. All traffic signal conductors shall be stranded.

M8.16.1: Type 1 Traffic Signal Cable (Installed above ground or in Duct)

Traffic signal cable shall be thermoplastic and conform to requirements of IMSA Specification 19-1.

M8.16.2: Type 2 Traffic Signal Cable (Installed above ground or in Duct)

Traffic signal cable shall be thermoplastic and conform to requirements of IMSA Specification 20-1.

M8.16.3: Type 3 Traffic Signal Cable (Installed above ground)

Traffic signal cable shall be thermoplastic and conform to requirements of IMSA Specification 19-3 or 20-3.

M8.16.4: Type 4 Traffic Signal Cable (Installed above ground)

Traffic signal cable shall be thermoplastic and conform to requirements of IMSA Specification 19-4 or 20-4.

M8.16.5: Type 5 Traffic Signal Cable (Direct Burial)

Traffic signal cable shall be thermoplastic and conform to requirements of IMSA Specification 19-5 or 20-5.

M8.16.7: Type 7 General Purpose Wire (XHHW-2 with XLP Jacket)

General Purpose Wire shall conform to requirements of UL Standard UL-44 “Rubber-Insulated Wires and Cable.” Type 7 Wire installed in a tunnel shall have a VW-1 Rating.

M8.16.8: Type 8 Direct Burial Wire (USE)

Direct burial wire shall be insulated as specified for Type 8 and conform to requirements of UL Standard UL-854 “Service-Entrance Cables” for USE listed cable.

M8.16.9: Type 9 Special Purpose Wire (TW-THW-UF)

Special purpose wire shall be TW or THW conforming to requirements of UL Standard UL-83 “Thermoplastic-Insulated Wires” or UF conforming to the requirements of UL Standard UL-719 “Nonmetallic-Sheathed and Underground Feeder Cables” as specified.

M8.16.10: Type 10 Grounding and Bonding Conductors (Solid or Standard, Insulated or Bare)

Grounding and bonding conductors shall not be less than #14 AWG. Ground and bonding conductors shall be copper conforming to requirements of ASTM-B3 for soft or annealed copper wire, ASTM-B8 for stranded copper wire.

Where wire is provided with an individual covering, the covering shall be finished a continuous green color or a continuous green color with one or more yellow stripes.

M8.16.11: Shielded Loop Detector Lead-In cable

Two-conductor #14 AWG, tinned copper stranded (19 x 27) conductors, polyethylene insulated (0.032 in. thick), conductors cabled, aluminum-polyester shield (100% shielding), #16 AWG stranded tinned copper drain wire. Chrome vinyl outer jacket (0.035 in. thick), nominal cable outside diameter 0.340 in. and conform to the requirements of IMSA specification 50-2.

M8.16.12: Type 12 Multi-conductor heavy duty portable power cord

This material shall conform to the requirements of Underwriters Laboratories Standard UL-62, Flexible Cord and Fixture wire for Type 50, 600V flexible cord.

M8.16.13: Type 13 Loop Detector Wire THHN with Tube

Loop detector wire shall be PVC insulated, nylon jacketed, loose encased in a PVC or PE tube and conform to requirements of IMSA specification 51-5.

M8.16.14: Type 14 Coaxial Cable

Coaxial Cable shall be a 75-ohm, precision video cable with 20-gauge solid bare copper conductor (9.9 ohms/M), solid polyethylene insulating dielectric, 98% (minimum) tinned copper double-braided shield and black polyethylene outer covering. The signal attenuation shall not exceed 0.78 dB per 100 ft. at 10 MHz. The nominal outside diameter shall be 0.304 in. Coaxial Cable shall be suitable for installation in conduit or overhead with appropriate span wire.

M8.16.15: Type 15 Cat5e Ethernet Cable

Cat5e Ethernet Cable shall consist of a 4-pair, #24 AWG solid, color-coded conductors contained within an insulated jacket. The insulation material of the inner conductors shall be Polyolefin (PO), the insulation material of the outer jacket shall be Polyethylene (PE). The outer shield shall be aluminum foil/polyester tape and cover 100% of the inner conductors. The outer shield drain wire shall be tinned copper. Cat5e Ethernet Cable shall have an operating temperature range of -30°C to +75°C, a maximum pulling tension of 110 N, and a minimum bending radius of 50.4 mm.

Cat5e Ethernet Cable shall meet TIA/EIA 568-c.2 Category 5e, NEMA WC-63.1 Category 5e, and IEC 11801 Category 5e.

M8.16.16: Type 16 Twisted Pair Copper Cable

Twisted Pair Copper Cable shall be a flexible power cable consisting of three #16 AWG, stranded, insulated conductors contained within an insulated jacket. The operating voltage of the cable shall be rated at 300V RMS, maximum. The insulation material shall be thermoplastic elastomer (TPE) with an insulation thickness of 0.031 in. (nominal) and an insulated conductor diameter of 0.120 in.

(nominal). The cable filler type shall be polypropylene and the separator wrap shall be paper tissue. The cable shall have a temperature rating of -50°C to +105°C.

Twisted Pair Copper Cable shall meet UL Standard 62, CSA 22.2 No. 49, and NEC article 400.

M8.16.17: Type 17 Twisted Pair Copper/Fiberoptic Hybrid Cable

Twisted Pair Copper/Fiberoptic Hybrid Cable shall be a fiberoptic/power hybrid cable capable of supporting single point camera system which utilizes fiber optic-based communications for video transmission. The cable shall be of rugged, outdoor rated hybrid design consisting of four tight buffered breakout fibers and two copper conductors encased in a flame-retardant outer jacket. The cable shall also consist of aramid yarns encapsulating the tight buffered fibers under a sub-unit jacket. The cable shall contain a ripcord to facilitate outer jacket removal.

The fiber strands shall be OM3 multimode 50/125 BIF, 10 GIG. The copper conductors shall be stranded copper #16 AWG. The outer jacket shall be UV-resistant black flame-retardant PVC with a diameter of 0.40-0.42 in. The cable sub-jacket shall consist of thermoplastic elastomeric (TPE) with a diameter of 0.095 in. The central strength member shall be epoxy glass rod. The cable shall be temperature rated for a range of -40°C to +70°C.

The cable shall be RoHS compliant and meet IEC 60793-2-10 and TIA-492AAAD Optical Fiber specifications.

M8.17.0: Ground Rod

Ground Rods shall be nominal ⅝ in. diameter (measured diameter shall not be less than 0.558 in.) by a minimum of 8 ft long copper bonded to steel rod, with bolt type clamps, conforming to the requirements of UL-467.

M8.18.0: Traffic Signal, Highway Lighting, and Sign Supports

This section covers the poles, posts, masts, arms and bases for traffic signals, highway lighting and sign supports.

Fabricators shall be selected from the department's list of approved Signs, Luminaires and Signal Supports fabricators (SLS). All fabrication and coating application shall conform to M8.06.0: Fabrication Requirements, except that tubular sections, manufactured or fabricated, shall not require SSPC-SP10 pre-blast prior to fabrication. However, material for attachments and weldments greater than $^{3}/_{16}$ in. thick are subject to the pre-blast requirement, including but not limited to base plates. All surfaces shall be visually inspected, and any mill deficiencies shall be brought to the attention of the quality assurance inspector. All areas to be welded shall be cleaned and prepped meeting the requirements of AWS D1.1 Structural Welding Code - Steel.

All welds shall be visually inspected and NDT tested per AASHTO *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. All full-penetration groove welds shall be inspected by magnetic particle testing (MT) or ultrasonic testing (UT), based on the thinnest mating material. Material thickness less than ¼ in. shall be tested using MT, and material thickness ¼ in. or greater shall be tested using UT. The QC Inspector and the Verification Inspector shall select, at random, 25 % of structures to have partial penetration and fillet welds tested using MT or UT for minimum 10% of the length of the welds. Additionally, after fabrication and galvanizing, multisided tubes welded to base plates shall be tested with UT.

Shop Drawings for these items shall meet the requirements of Subsection 5.02: Plans and Detail Drawings and also include the Ancillary Structure Program (ASP) Structure ID Number.

Provisions for cambering shall be shown to ensure that horizontal cross beams will not deflect below the horizontal.

M8.18.1: Traffic Signal Supports

Strain Poles and Mast Arms shall be made of steel. Structural steel material over ½ in. thick that is part of main load carrying tension members shall meet the Charpy V Notch impact requirements of 20 ft-lb at 40°F.

Tapered shafts shall conform to ASTM A595, Grade A, or AASHTO M 270 Grade 50.

The arms shall conform to ASTM A595, Grade A; or ASTM A1011, or ASTM A500 Grade B or C. Steel shall have a minimum yield of 50 ksi.

The shaft cap shall conform to ASTM A126, Class A.

All hardware shall be stainless steel or ASTM F3125, fully galvanized.

Baseplates and all other standard structural shapes shall conform to AASHTO M 270 Grade 50.

Galvanizing shall be in accordance with Section M7: Paints, Protective Coatings and Pavement Markings.

M8.18.2: Highway Lighting Poles and Arms

M8.18.2.A: Steel

Structural steel material over ½ in. thick that is part of main load carrying tension members shall meet the Charpy V Notch impact requirements of 20 ft-lb at 40°F.

Tapered components shall be fabricated from steel conforming to ASTM A595, Grade A; or ASTM A1011, Grade 55; or AASHTO M 270, Grade 50.

Gussets, flanges, baseplates, wing plates, connecting end plates, and all other standard structural shapes shall conform to AASHTO M 270 Grades 36 or 50 as specified in the contract documents.

M8.18.2.B: Anchor Bolts

Anchor bolts shall conform to M8.01.5: Anchor Bolts, Nuts and Washers and be fully galvanized.

M8.18.3: Sign Supports

Structural steel material over ½ in. thick that is part of main load carrying tension members shall meet the Charpy V Notch impact requirements of 20 ft-lb at 40°F.

Supports shall be fabricated from steel conforming to ASTM A595, Grade A; ASTM A1011, Grade 55; AASHTO M 270, Grade 50; ASTM A500, Grade B or C; or API-5LX-52.

Gussets, flanges, baseplates, wing plates, connecting end plates, and all other standard structural shapes shall conform to AASHTO M 270 Grades 36 or 50 as specified in the contract documents.

Truss and cantilever beam connections shall be furnished with the necessary beam support clamps. The ends of beams shall have a mounting clevis and closure plate fabricated from steel plate as an assembly.

All structural steel and steel hardware shall be galvanized in accordance with M8.06.9.K.3: Galvanizing. Anchor bolts, nuts, and washers shall conform to M8.01.5.C: Used for Anchoring Signal Lighting and Sign Structures and be fully galvanized.

No transverse welds will be permitted in the tubular members, except at the base plate and flange plate connections or where reinforcing sleeves are required. Base plate and flange plate connections shall be socket-type connections with two continuous welds, one on the inside of the plate at the end of the tubular member and the other on the outside surface of the plate. Alternatively, base plate and flange plate connections may be full-penetration groove-welded tube-to-transverse plate connections with backing ring attached to the plate with a full penetration weld, or with a continuous fillet-weld around the interior face of backing ring, combined with the backing ring welded to the interior of the tube with a continuous fillet-weld at the top face of the backing ring. All welds shall develop the full strength of the section at the point of connection.

M8.18.3.A: Sign Posts – P5

M8.18.3.A.1: Square Tube Posts

Square tube posts shall be square tube fabricated from 12 gauge hot-rolled carbon steel conforming to the requirements of ASTM A1011, Grade 50.

Galvanizing shall be in accordance with ASTM A653, Coating Designation G90 with a minimum coating of 0.9 oz per ft^2 and sealed with a corrosion inhibitor topcoat.

Posts shall be welded directly in the corner by high frequency resistance welding or equal and externally scarfed to agree with standard corner radius of 0.15625 in. ±0.015625 in. The corner weld and holes shall be zinc coated after scarfing operations. Holes shall be 0.4375 in. in diameter and shall be placed 1 in. on center.

M8.18.3.A.2: U Channel Posts

U-channel posts shall be fabricated from re-rolled rail steel or an equivalent steel and shall conform to the mechanical requirements of ASTM A499, Grade 60 and the mechanical requirements of ASTM A1. All steel U-channel posts shall weigh at least 4 lb per ft and be entirely galvanized in accordance with Section M7: Paints, Protective Coatings and Pavement Markings. Holes shall be 0.4375 in. in diameter spaced at 1 in. on center and be punched prior to the galvanizing of the posts.

All bolts, nuts and washers shall conform to the requirements of ASTM A307, Grade A. Bolts, nuts and washers shall be galvanized in accordance with the requirements of Section M7: Paints, Protective Coatings and Pavement Markings.

Steel posts, sign post anchors, anchor sleeves, slipbases, lap splices, and any related hardware shall all be from the same manufacturer. No mixing of brands shall be allowed.

M8.19.1: Aluminum Sign Panels

Aluminum sign panels shall be fabricated from ASTM-B209, Alloy 6061-T6, (0.080 in. thick) with 3 in. minimum diameter amber reflectors affixed thereto.

M8.20.4: Anti-Glare Systems

Anti-Glare Systems shall consist of modular sections consistent in length with standard length of concrete median barrier. Glare blocking shall be accomplished by vertical blades or panels attached to a horizontal base to create the modular units.

The anti-glare system shall be of a type listed on the QTCE.

M8.21.0: Stay-in-Place Bridge Deck Forms

Stay-in-Place Bridge Deck Forms and supports shall be fabricated from steel conforming to ASTM A653 (Grades 33, 37, 40, 50 Class 1 and 2, and 80) having a coating class of G165 according to ASTM A924.

M8.22.0: Cross Hole Sonic Testing Access Pipes

Steel pipe for cross hole sonic testing access pipes shall be Schedule 40 and shall conform to ASTM A53, Grade B.

SECTION M9: MISCELLANEOUS MATERIALS

M9.00.0: General

All materials in this category shall be sampled and tested in accordance with the standard methods applicable to that particular material.

M9.01.0: Calcium Chloride

Calcium Chloride shall conform to the requirements of AASHTO M 144, Type I or Type II.

M9.01.1: Sodium Chloride

Sodium Chloride to be used for road purposes shall conform to the requirements of AASHTO M 143, except that the grading shall conform to the following:

Table M9.01.1-1: Gradation Requirements for Sodium Chloride

Sieve	Percent Passing
⅜ in.	100
No. 4	82 (maximum)
No. 8	50 (maximum)
No. 30	7 (maximum)

M9.02.0: Herbicides

These specifications cover chemicals used to destroy and/ or control the growth of plants both indiscriminately (non-selective herbicides) and selectively (selective herbicides). Only those herbicides currently approved by the State Pesticide Board and the Department may be used.

M9.03.0: Insecticides

These specifications cover chemicals to be used in the control of insects which are harmful to trees and desirable growth. Only those insecticides currently approved by the State Pesticide Board and the Department may be used.

M9.04.0: Curb and Edging

All granite curb and edging shall be basically light gray in color, free from seams and other structural imperfections or flaws which would impair its structural integrity, and of a smooth splitting appearance. Natural color variation characteristic of the deposit from which the curbing is obtained will be permitted.

Whenever curbing is sawed, all surfaces that are to be exposed shall be thoroughly cleaned and any iron rust or iron particles removed by sand blasting or other approved methods satisfactory to the Engineer and any saw mark in excess of ⅛ in. shall be removed.

M9.04.1: Granite Curb

The stones for the several types of granite curb shall be cut to the dimensions and curvature hereinafter stated:

Table M9.04.1-1: Standard Granite Curbstone Dimensions

Type	Minimum Length	Width at Top	Depth	Minimum Width at Bottom
VA1	6 ft	7 in	17 in. to 19 in.	4 in. (for ⅔ length)
VA2	6 ft	7 in.	19 in. to 21 in.	4 in. (for ⅔ length)
VA3	6 ft	6 in.	19 in. to 21 in.	4 in. (for ⅔ length)
VA4	6 ft	6 in.	17 in. to 19 in.	4 in. (for ⅔ length)
VA5	5 ft	6 in.	See Plans	5 in. (for ⅔ length)
VB	3 ft	5 in.	15 in. to 17 in.	3 ½ in. (for ⅔ length)

Except for the 3 following conditions, 10% of the length of each type of VA curb installed on the project may consist of stones no more than 6 in. shorter than the length specified in either table.

1. Stones used in making closures may be as much as one third shorter than specified in either table, except that for VA5 the closure piece shall have a minimum length of 4 ft.
2. Stones used in making closures on bridge decks at paraffin joints may have one piece, no less than 4 ft between any two paraffin joints or between one paraffin joint and the end of the run of curbing.
3. On curves with radii greater than 100 ft but less than 500 ft, type VA stones may be 4 ft to not more than 6 ft in length.

Type VA stones to be set on a radius of 100 ft or less shall be cut to the required curvature and except for making closures shall be of minimum lengths as follows:

Table M9.04.1-2: Minimum Lengths of Curved Granite Curbstone

Radius	Minimum Length
50 ft to 100 ft	6 ft
25 ft to less than 50 ft	4.5 ft
Less than 25 ft	3 ft

Type VB stones to be set on a radius of 100 ft or less shall be cut to the required curvature.

All VB stones shall have a minimum length of 3 ft regardless of curvature.

The ends of all curved stones shall be cut on radial lines.

Finish

The finish and surface dimensions for the several types of curb shall conform to the following requirements:

M9.04.1.A: Type VA Curb

This type of curbstone shall have a top surface free from wind, shall be peen hammered or sawed to an approximately true plane, and shall have no projections or depressions greater than ⅛ in. The front and back arris lines shall be pitched straight and true and there shall be no projection on the

back surface for 3 in. down from the top which would exceed a batter of 4 in. in 1 ft, except on V A5 the back surface shall have no projection or depression greater than 1.5 in.

The front face shall be at right angles to the planes of the top and ends and shall be smooth quarry split. free from drill holes and with no projection of more than 1 in. and no depression of more than ½ in. measured from the vertical plane of the face through the arris or pitch line for a distance down from the top of 8 in. for types VA1 and VA4, 10 in. for VA2 and VA3, and the full depth of VA5. For the remaining distance there shall be no projection or depression greater than 1 in. measured in the same manner.

The ends of all stones shall be square with the planes of the top and face so that when the stones are placed end to end as closely as possible no space shall show in the joint at the top and face of more than ½ in. for the full width of the top and for 8 in. down on the face for Type VA1 and VA4, 10 in. for VA2 and VA3, and the full depth of VA5, after which the end may break back not over 8 in. from the plane of the joint. The arris formed by the intersection of the plane of the joint with the planes of the top and exposed faces shall have no variation from the plane of the top and exposed faces greater than ⅛ in.

M9.04.1.B: Type VB Curb

This type of curbstone shall have a top surface free from wind, shall be pointed, peen hammered or sawed to an approximately true plane and shall have no projections or depressions greater than 0.25 in. The front and back arris lines shall be pitched straight and true.

The front face shall be at right angles to the plane of the top, and shall be smooth quarry split, free from drill holes and with no projection of more than 1.5 in. and no depression greater than 1 in. measured from the vertical plane of the face through the arris or pitch lines for the full depth of the face.

The ends of all stones shall be square with the planes of the top and face so that when stones are placed end to end as closely as possible no space shall show in the joint in the top and face of more than ½ in. for the full width of the top and 8 in. down on the face after which the ends may break back not more than 1 ft from the plane of the joint. On pieces less than 4 ft in length, the ends shall not break back more than 9 in. The arris formed by the intersection of the plane of the joint with the planes of the top and exposed faces shall have no variation from the plane of the top and exposed faces greater than ⅛ in.

M9.04.2: Granite Edgestone

The stones for the several types of edging shall be cut to the dimensions given in Table M9.04.2-1.

Table M9.04.2-1: Granite Edgestone Dimensions

	Type SA	**Type SB**	**Type SC**
Minimum Length	3 ft	2 ft	1 ft
Maximum Length	6 ft	6 ft	6 ft
Thickness	5 in. to 8 in.	3 in. to 6 in.	3 in. to 6 in.
Width of Face	12 in.	11 in. to 13 in.	11 in. to 13 in.

When the edging is used on a curve of 160 ft radius or less the length shall be as directed by the Engineer except that where the edging is to be set on a radius of 10 ft the maximum length shall be 1 ft.

M9.04.2.A: Finish

M9.04.2.A.1: Type SA Edging

The exposed face shall be smooth quarry split to an approximately true plane having no projections or depressions which will cause over 1 in. to show between a 2-ft straight-edge and the face when the straightedge is placed as closely as possible on any part of the face.

If projections on the face are more than that specified they shall be dressed off. The top and bottom lines of the face shall be pitched off to a straight line and shall not show over 0.5 in. between stone and straightedge when straight-edge is placed along the entire length of the top and bottom lines and when viewed from a direction at right angles to the plane of the face, and for the top line only not over ½ in. when viewed from a direction in the plane of the face. The ends shall be square to the length at the face and so cut that when placed end to end as closely as possible no space shall show in the joint at the face of over ¾ in., except that where the edging is to be used on a curve having a radius of 10 ft or less the ends of the stones shall be so cut as to provide a finished joint at the face of not more than ½ in. The arris formed by the intersection of the plane of the face with the plane of the end joint shall not vary from the plane of the face or the plane of the joint more than ¼ in. Drill holes may show on the exposed face but only along the bottom edge. The sides shall not be broken under the square more than 4 in. and the side adjacent to the grass shall not project over 1 in.

M9.04.2.A.2: Type SB Edging

The exposed face shall be smooth quarry split to an approximately true plane having no projections or depressions which will cause over 1 in. to show between a 2 ft straight-edge and the face when the straight-edge is placed as closely as possible on any part of the face.

If projections on the face are more than that specified they shall be dressed off. The top and bottom lines of the face shall be pitched off to a straight line and shall not show over 1 in. between stone and straight-edge when straight-edge is placed along the entire length of the top and bottom lines and when viewed from a direction at right angles to the plane of the face, and for the top line only not over 1 in. when viewed from a direction in the plane of the face. The ends shall be square to the length at the face and so cut that when placed end to end as closely as possible, no space shall show in the joint at the face of over 1.5 in., except that where the edging is to be used on a curve having a radius of 10 ft or less the ends of the stones shall be so cut as to provide a finished joint at the face section of not more than ½ in. The arris formed by the intersection of the plane of the face with the plane of the end joint shall not vary from the plane of the face more than ¼ in. Drill holes not more than 3.5 in. in length and ½ in. in depth will be permitted. The sides shall not be broken under the square more than 4 in. and the side adjacent to the grass shall not project over 1 in.

M9.04.2.A.3: Type SC Edging

The exposed face shall be smooth quarry split to an approximately true plane having no projections or depressions which will cause over ½ in. to show between a 2 ft straight-edge and the face when the straightedge is placed as closely as possible on any part of the face. If projections on the face are more than that specified they shall be dressed off. The top and bottom lines of the face shall be

pitched off to a straight line and shall not show over 1 in. between stone and straight-edge when straight-edge is placed along the entire length of top and bottom lines and when viewed from a direction at right angles to the plane of the face, and for the top line only, not over 1 in. when viewed from a direction in the plane of the face. The ends shall be square to the length at the face and so cut that when placed end to end as closely as possible no space shall show in the joint at the face of over 1.5 in., except that where the edging is to be used on a curve having a radius of 10 ft or less the ends of the stones shall be so cut as to provide a finished joint at the face of not more than ½ in. The arris formed by the intersection of the plane of the face with the plane of the end joint shall not vary from the plane of the face more than ¼ in. Drill holes not more than 3.5 in. in length and ½ in. in depth will be permitted. The sides shall not be broken under the square more than 4 in. and the side adjacent to the grass shall not project over 1 in.

M9.04.4: Stone for Stone Masonry Walls

Stone for stone masonry walls shall consist of sound durable blasted or field stone free from seams, cracks and other structural defects and of an approved and satisfactory quality and shape.

The stone shall consist of angular blasted or field stones having straight edges without re-entrant angles. The faces shall be flat but not necessarily rectangular in shape.

Individual stone shall have, when set in the wall, no face dimension less than 8 in. Stretchers shall have a depth in the wall at least 1.5 times the rise, and a length on the face at least twice the rise. Headers shall have a length on the face at least equal to the rise. Headers shall hold in the heart of the wall the same size as shown on the face and shall extend at least 12 in. more than the stretchers into the backing.

M9.04.5: Granite Curb Inlets

The granite for curb inlet shall conform to M9.04.0: Curb and Edging. It shall have a horizontal bed and the top shall be free from wind. The stone shall be sawn or peen hammered on top and the front and back edges shall be pitched true to line. The back face for a distance of 3 in. down from the top shall have no projection greater than 1 in. The front face shall be straight split, free from drill holes, and it shall have no projection greater than 1 in or depression greater than 0.5 in. for a distance of 10 in. down from the top, and for the remaining distance there shall be no depression or projection greater than 1 in. The ends shall be squared with the top for the depth of the face finish and so cut that the curb inlet can be set with joints of not more than ½ in.

The granite curb inlet shall be 6 ft in length ±½ in., from 17 to 19 in. in depth, 6 in. wide at the top and at least 6 in. wide at the bottom.

Curb inlets to be set on a radius of 160 ft or less shall be cut to the curve required. The joints of all curved curb inlets shall be cut on radial lines.

A gutter mouth at least 3 in. in depth and at least 2 ft in length shall be cut in the front face of the stone as shown on the plans.

Granite curb inlets shall match the adjacent curbing in color.

M9.04.6: Granite Curb Corners

The granite for curb corners shall conform to M9.04.0: Curb and Edging and shall have horizontal beds. They shall match the adjacent curbing in size, color and quality. The front arris lines shall extend through one-quarter of a circle having a radius of 2 ft or 3 ft respectively for Type A or Type B Curb Comer. The back arris line shall be straight. The plane of back shall be normal to top.

M9.04.8: Granite Bounds

Granite bounds shall be of sound granite, the top and bottom faces parallel and the front and back shall be straight split. The bounds shall be cut to the dimensions shown on the plans and shall be plain or lettered as indicated on the plans or as directed.

The stone shall be pointed on the top and on three sides and hammer dressed on the face for a distance of not less than 12 in. below the top. The top shall be 6 in. square and shall have a drill hole in the center 1.5 in. in depth and ½ in. in diameter, with the bottom somewhat flared.

M9.04.9: Dry Stone Masonry

Stone for dry stone masonry shall be hard and durable and free from seams or other imperfections and of an approved quality and shape. No stone shall be less than 6 in. in its least dimension. The stone shall be roughly square on joint beds and faces.

M9.05.0: Lumber and Wood Sheeting

Lumber and Wood Sheeting shall be sound Spruce, Douglas fir, white or yellow Lodgepole or Ponderosa pine, or western hemlock plank, planed on one side and either tongue and grooved or splined. Lumber sheeting shall not be less than nominal 4 in. thick. Wood sheeting shall not be less than nominal 2 in. thick.

M9.05.1: Wood Products

Timber shall conform to the requirements of AASHTO M 168, Wood Products, Structural Timber, Lumber, and Piling.

Preservative treatment shall meet the requirements of M9.05.5: Wood Preservatives.

M9.05.5: Wood Preservatives

Preservative treatment shall meet the requirements of AASHTO M 133 and AWPA U1, except that only preservative materials meeting current EPA or DEP regulations will be allowed.

Certificates of compliance and certificates of inspection bearing the independent inspection agencies verification for each lot of wood must be presented before installation and contain the species of wood, the type of preservative, the retention rate and penetration of the preservative.

M9.05.6: Timber Piles

M9.05.6.A: General Requirements

Timber piles shall conform to the requirements of ASTM D25 and shall be cut from sound and live trees, preferable during the winter season. Piles shall be free from any defects which will impair their strength or usefulness for the purpose intended or that will prevent proper driving.

Untreated timber piles shall have the bark unpeeled. Treated timber piles shall be clean-peeled so that all of the outer bark and at least 95% of the inner bark well distributed over the outer surface of the pile shall be removed.

All piles shall be cut above the ground swell, shall have a uniform taper from bun to tip end, and shall be free from short kinks. Knots or blemishes shall be trimmed off close and even with the body of the pile. A line from the center of the bun to the center of the tip must lie wholly within the body of the pile.

M9.05.6.B: Inspection

All piles will be subject to inspection before or after shipment to the site, or both, at the option of the Engineer. Any pile that does not conform to all the requirements will be rejected.

M9.05.6.C: Specific Requirements

All treated piles shall have not less than 1 in. of sapwood at any point on the butt end for Douglas-fir and not less than 2 in. of sapwood at any point on the butt end for Southern Pine.

Treated timber piles shall be Douglas-fir treated with ACZA or Southern Yellow Pine treated with CCA-C in accordance AWPA U1. Treated timber piles used in a marine environment shall be Southern Yellow Pine or Douglas-fir treated with creosote in accordance with AWPA U1 Certificates of compliance and certificates of inspection bearing the independent inspection agencies verification for each lot of wood must be presented before installation and contain the species of wood, the type of preservative, the retention rate and penetration of the preservative.

Butt and tip dimension for various lengths of piles shall be as set forth in the following table:

Table M9.05.6-1: Timber Pile Butt and Tip Dimensions

Length	Minimum Dimension 3 ft from Butt	Minimum Tip Dimension
Up to 40 ft	12 in.	8 in.
40 ft and up to 50 ft	12 in.	7 in.
50 ft and over	13 in.	6 in.

For all piles the maximum dimension 3 ft from the butt shall be 20 in. Measurements are under the bark in all cases. Where the piles are to support a concrete cap, the maximum butt dimensions shall be 6 in. less than the designated width of the concrete cap.

Where piles are to be in line in a bent, all piles in the bent shall be of uniform size to permit the proper fastening of the bracing. Cutting of piles to accommodate the bracing will not be permitted.

M9.06.0: Waterproof Paper Covers

Waterproof paper covers shall conform to the requirements of ASTM C171. The name of the manufacturer shall be marked or imprinted clearly on the paper for proper identification.

M9.06.1: Polyethylene Covers

M9.06.1.A: Black Polyethylene Sheeting

Black polyethylene sheeting suitable for use in covering storage piles of bulk or bag salt, or sand piles which have been blended with salt shall meet the requirements of NBS Product Standard PS-17.

The covers shall be 8 mils in thickness, black in color and contain suitable inhibitors to prevent deterioration due to sunlight and heat.

The sheeting shall be 40 ft in width and 100 ft in length. It shall be folded when packaged into rolls, so that the shipping width is not greater than 10 ft.

M9.06.1.B: White Polyethylene Sheeting

This material shall conform to the requirements of ASTM C171.

M9.06.1.C: Reinforced Polyethylene Sheeting

Reinforced Polyethylene Covers for stockpiles of salt and treated sand shall be reinforced with non-woven nylon or rayon cord, shall have a minimum tear strength of 110 lb in all directions, and shall weigh no less than 20 lb per 1,000 ft². They shall be black in color. The material shall be free from any additive which would reduce its resistance to water penetration or adversely affect the durability of the film. The covers shall contain suitable inhibitors to prevent deterioration due to sunlight and heat. They shall be 40 ft in width and 100 ft in length. They shall be folded when packaged into rolls, so that the shipping width is not greater than 10 ft.

M9.06.2: Tar Paper

Tar impregnated felted paper shall conform to the requirements of ASTM D227.

M9.06.3: Burlap

Burlap shall conform to the requirements of AASHTO M 182, Class 3. It shall not have been used as a container for sugar or other substances deleterious to concrete and shall be in good condition, free from holes, tears, or other defects that would render it unsuitable for curing concrete. It shall be furnished in strips not less than 3 ft nor more than 6 ft in width and not more than 2.5 ft longer than the width of the pavement slab.

M9.06.4: Polyethylene Coated Burlap

The material shall conform to the requirements of ASTM C171.

M9.06.5: Impervious Liquid Membrane

This material shall consist of an impervious liquid conforming to the requirements of ASTM C1315, Type 1 or 2. When tested in accordance with AASHTO T 155, the liquid membrane forming compound shall restrict the loss of water present in the test specimen at the time of application of the curing compound to not more than 0.055 g per cm² of surface after 3 days. When Type I is specified, it shall contain a fugitive dye.

M9.07.0: Plastic Waterstops

Waterstops shall be fabricated from a plastic compound, the basic resin of which shall be polyvinyl chloride. The compound shall contain any additional resins, plasticizers, inhibitors or other materials such that when compounded it shall meet the performance requirements hereinafter specified. No reclaimed polyvinyl chloride shall be used.

Waterstops shall be extruded in such a manner that any cross section shall be dense, homogenous and free from porosity or other imperfections. The cross section of waterstops shall be as shown on Department Standard Sketches.

M9.07.0.A: Physical Requirements

The waterstops shall meet the following requirements:

Description	Requirement
Tensile Strength, Die C, ASTM D412	Minimum 2,000 psi
Ultimate Elongation, Die C, ASTM D412	Minimum 250%
Cold Bend Test (See Appendix I)	No Cracking
Impact Resistance (See Appendix II)	No Cracking
Resistance to Alkalis (See Appendix III)	No Cracking
Increase in weight after 7 days	Maximum 0.25%
Increase in weight after 30 days	Maximum 0.40%
Decrease in weight after 7 days	Maximum 0.10%
Decrease in weight after 30 days	Maximum 0.30%
Change in dimensions after 30 days	Maximum 1.00%
Hardness Durometer (Shore A) ASTM D2240	75 ± 5
Water Absorption (48 hr) ASTM D570	Maximum 0.5% (by weight)

M9.07.0.B: General Requirements

The waterstops shall be spliced only at jointing made necessary by construction design.

Where joints are required, they shall be made in accordance with the manufacturer's instructions, without appreciable loss in strength, elasticity or permeability of the material.

The waterstop material shall be practically impervious to water and unaffected by most common acids, alkalis, sea water and mineral oils. The material shall be such that it will not engage in electrolytic action with steel, and will not discolor concrete.

The approved waterstop when properly installed, as in a concrete construction or expansion joint, shall be capable of maintaining a head of 75 ft of water without leakage.

M9.07.0.C: Qualification Samples

A manufacturer requesting approval of a waterstop shall furnish to RMS a 3-ft length of each type of waterstop they intend to supply and a COA shall be furnished with the samples. The certificate shall state that the material furnished conforms without exception to all the requirements specified herein; and shall also include all qualitative and quantitative test results.

M9.08.0: Waterproofing Membranes

M9.08.1: Spray-Applied Waterproofing Membrane

M9.08.1.A: General Requirements

Only products listed on the QCML will be accepted for use. The membrane waterproofing system shall consist of:

- Primer
- One or two coat rapid curing cold liquid spray applied seamless methyl methacrylate, polyurea, or polyurethane methyl methacrylate membrane
- Aggregate keycoat
- Polymer modified tack coat

M9.08.1.B: Material Requirements

The total minimum base thickness for the membrane shall be 80 mils measured over peaks. The membrane shall easily accommodate the need for day joints and patch repairs. The membrane shall be able to bridge live cracks up to ⅛ in. in width and meet the criteria specified in Table M9.08.1-2.

The membrane waterproofing system shall be asbestos-free. The chemical composition of the primer, membrane, aggregate keycoat and tack coat that make up the membrane waterproofing system shall conform to the manufacturer's specifications for the material. All components shall be approved by the manufacturer as being compatible for use with the specified membrane. Cleaning solvents shall also be approved by the manufacturer for use with the membrane.

M9.08.1.B.1: Primer for Spray-Applied Membrane

The primer shall promote adhesion of the membrane to the concrete surface.

Table M9.08.1-1: Primer Material Properties

Property	Test	Requirements
Gel Time		> 5 minutes
Tack Free Time		< 2.5 hours, max at 77°F
Adhesion to Concrete	ASTM D7234	≥ 100 psi minimum and failure in concrete

M9.08.1.B.2: Membrane

The membrane shall be meet the requirements in Table M9.08.1-2.

Table M9.08.1-2: Spray Applied Waterproofing Membrane Material Properties

Property	Test	Requirements
Solids Content		100%
Stability	ASTM C836	≥ 6 months
Crack Bridging		
(Neat Material + Aggregated Keycoat)	ASTM C1305 (see Note 1)	Pass, no cracking
Extensibility after Heat Aging	ASTM C1522	For information only
Percent Elongation at Break	ASTM D638	≥ 130%
Tensile Strength	ASTM D638	≥ 1,100 psi
Shore Hardness	ASTM D2240 (see Note 2)	≥ 50 Type 00
Minimum Thickness (Membrane only)	ASTM D6132 or other approved method	≥ 80 mils minimum measured over peaks; or ≥ thickness used to pass ASTM C1305 (Whichever thickness is greater)
Membrane Waterproofing System Adhesion to Concrete	ASTM D7234	≥ 100 psi minimum and failure in concrete
Permeance	ASTM E96	≤ 1.0 perms

Note 1: ASTM C1305 shall be modified to 25 cycles at -15°F no failure at ⅛ in. per hour.
Note 2: ASTM D2240 shall be modified per ASTM C836 section 6.5.

M9.08.1.B.4: Aggregate for Keycoat

The broadcast aggregate shall be durable and provide shear resistant to prevent the HMA from shoving. Aggregate shall have a minimum Mohs hardness rating of 7 and be approved by the manufacturer.

M9.08.1.B.4: Polymer Modified Tack Coat

The tack coat shall consist of either a polymer modified asphalt emulsion, or a polymer modified asphalt binder approved for use by the membrane waterproofing manufacturer and the Engineer. The tack coat shall be either supplied by the membrane waterproofing manufacturer or by a MassDOT approved asphalt emulsion Supplier.

M9.08.1.C: Material Qualification

A manufacturer requesting approval of a spray applied membrane system shall furnish to the Research and Materials Section the following:

- The membrane system material specifications including product performance data.
- Certified independent test reports demonstrating conformance to Table M9.08.1-2.
    - The independent lab shall be recognized by the National Cooperation for Laboratory Accreditation (NACLA) in Construction Materials Engineering and Testing (CMET) or an equal program approved by Research and Materials.
    - All testing shall be performed by one independent lab. Independent test reports must be dated within 2 years from the initial submission.

    - Samples for all required testing shall be fabricated at the same time. Test reports shall denote the lot of material as well as the sample fabrication and testing dates.
- MassDOT shall perform prequalification testing on the membrane.
    - Two 10 in. by 10-in. square samples of the proposed membrane with smooth surfaces (no primer or aggregate in the keycoat). The samples shall be a minimum of 80 mils thick or the thickness used to pass the crack bridging requirement found in Table M9.08-4.

All submittals shall be certified to be in conformance with the manufacturer's instructions. Systems qualified by MassDOT per the performance criteria shall be considered for placement on the QCML. Membrane waterproofing systems shall remain on the QCML for a period of 5 years at which time the manufacturer will be required to submit certified test reports demonstrating conformance to this specification.

M9.08.2: Sheet Membrane

M9.08.2.A: General Requirements

Only products listed on the QCML will be accepted for use. Chemical composition, physical properties and dimensional requirements of the sheet membrane shall conform to the manufacturer's specifications for the material.

Also, all accessory materials such as, flashing, primer, etc., used in the application of the sheet membrane will be considered a part of this specification and shall conform to the manufacturer's requirements. The membrane waterproofing system shall consist of:

- Primer
- Sheet Membrane
- Mastic

M9.08.2.B: Material Requirements

The primer shall meet the requirements of M9.09.1: Primer.

The membrane sheet shall meet the requirements in ASTM D6153 and Table M9.08.2-1.

The mastic for use with rubberized sheets shall be a rubberized asphalt cold-applied joint sealant. The mastic for use with modified bitumen sheet shall be a blend of bituminous and synthetic resins. The mastic shall be approved for use by the manufacturer.

Table M9.08.2-1: Sheet Membrane Material Properties

Property	Test	Requirements
Thickness	ASTM D3767	≥60 mils
Permeance	ASTM E96 Water Method, Procedure B	≤0.1 perms
Pliability	ASTM D146 (see Note 1)	No breaks

Note 1: The test temperature of the specimen shall be 0°F after 24 hours and 180° bend over a ¼ in. mandrel.

M9.08.2.C: Material Qualification

A manufacturer requesting approval of a preformed sheet membrane shall furnish to the Research and Materials Section the following:

- The membrane system material specifications including product performance data.
- The peel-off backing material shall be tear resistant to prevent portions of it from remaining after the membrane is applied.
- Certified independent test reports demonstrating conformance to ASTM D6153, Table M9.08.2-1, and the submitted product performance data.
    - The independent lab shall be recognized by the National Cooperation for Laboratory Accreditation (NACLA) in Construction Materials Engineering and Testing (CMET) or an equal program approved by Research & Materials. All testing shall be performed by the same independent lab.
    - Independent test reports must be dated within 2 years from the initial submission. Samples for all required testing shall be fabricated at the same time. Test reports shall denote the lot of material as well as the sample fabrication and testing dates.
- A detailed summary of successful installations that have occurred in the United States, including owner contact information, design and construction details (substrate type & condition, membrane system components, hot mix asphalt overlay thickness and mix details, etc.), year constructed, tests performed, performance monitoring and/or testing, and any other additional information requested by the Department.

All submittals shall be certified to be in conformance with the manufacturer's instructions. The Research & Materials Section shall review the manufacturer's submitted documentation. A demonstration of the product's installation and performance may be required to be qualified by MassDOT. Systems qualified by MassDOT shall be considered for placement on the QCML. Preformed sheet membrane systems shall remain on the QCML for a period of 5 years at which time the manufacturer will be required to submit certified test reports demonstrating conformance to this specification.

M9.08.3: Hot Applied Rubberized Asphalt Membrane

M9.08.3.A: General Requirements

Only products listed on the QCML will be accepted for use. Chemical composition, physical properties and dimensional requirements of the sheet membrane shall conform to the manufacturer's specifications for the material. The membrane waterproofing system shall consist of:

- Primer
- Hot poured rubberized asphalt membrane consisting of a single component hot applied asphalt
- Protective covering

M9.08.3.B: Material Requirements

The primer shall meet the requirements of M9.09.1: Primer.

The membrane shall be able to bridge live cracks up to ⅛ in. in width and meet the criteria specified in Table M9.08.3-1.

The protective covering shall be rolled asphalt sheets conforming to ASTM D6380, Type II.

Table M9.08.3-1: Hot Applied Rubberized Asphalt Membrane Material Properties

Property	Test	Requirements
Solids Content		100%
Flash Point	AASHTO T 48	≥ 500°F
Flexibility	ASTM D5329	No delamination or cracking
Penetration	ASTM D5329	at 77°F ≤ 110; at 122°F ≤ 200
Permeance	ASTM E96 Water Method, Procedure B	≤ 0.1 perms
Softening Point	ASTM D36	≥ 176°F

M9.08.3.C: Material Qualification

A manufacturer requesting approval of a hot applied rubberized asphalt membrane shall furnish to the Research and Materials Section the following:

- The membrane system material specifications including product performance data.
- Certified independent test reports demonstrating conformance to Table M9.08.3-1.
    - The independent lab shall be recognized by the National Cooperation for Laboratory Accreditation (NACLA) in Construction Materials Engineering and Testing (CMET) or an equal program approved by Research & Materials. All testing shall be performed by one independent lab.
    - Independent test reports must be dated within 2 years from the initial submission. Samples for all required testing shall be fabricated at the same time. Test reports shall denote the lot of material as well as the sample fabrication and testing dates.
- A detailed summary of successful installations that have occurred in the United States, including owner contact information, design and construction details (substrate type & condition, membrane system components, hot mix asphalt overlay thickness and mix details, etc.), year constructed, tests performed, performance monitoring and/or testing, and any other additional information requested by the Department.

All submittals shall be certified to be in conformance with the manufacturer's instructions. The Research & Materials Section shall review the manufacturer's submitted documentation. A demonstration of the product's installation and performance may be required to be qualified by MassDOT. Systems qualified by MassDOT shall be considered for placement on the QCML. Hot applied asphalt membrane systems shall remain on the QCML for a period of 5 years at which time the manufacturer will be required to submit certified test reports demonstrating conformance to this specification.

M9.09.0: Primer and Damp-Proofing

M9.09.1: Primer

This material shall be suitable for priming concrete and masonry surfaces prior to the application of waterproofing or damp-proofing and shall meet the requirements of ASTM D41. Only products listed on the QCML will be accepted for use.

M9.09.2: Damp-Proofing

This material shall meet one of the following requirements:

- ASTM D449, Type II.
- ASTM D1227, Type II – Class 1 or Type III – Class 1

Only products listed on the QCML will be accepted for use.

M9.11.0: Insulation and Waterproof Jackets

Where water pipe is installed or hung on structures, it shall be covered with insulation conforming to the following requirements:

The insulating material shall be fiberglass, cellular glass, expanded polystyrene, or urethane, and shall be covered with a waterproof jacket as specified. Section lengths and thickness shall depend on the pipe size and the recommendations of the insulation manufacturers. Under no conditions shall the minimum total thickness be less than 3 in., except when urethane is the insulating material and then the total thickness shall be no less than 2 in. Only one type of insulating material shall be used throughout an installation.

M9.11.1: Cellular Glass

Cellular glass insulation shall conform to the requirements of Federal Specification, HH-1-551, Insulation Block and Pipe Covering, Thermal Cellular Glass or revisions thereof.

The following installation accessories shall be part of this specification:

- Stainless steel strapping, ¾ in. x 0.015 in. and stainless steel clips.
- Asphalt coated glass fabric, 20 x 20 mesh conforming to M3.06.1: Coated Glass Fabric.

M9.11.2: Fiberglass

Fiberglass insulation shall conform to the requirements of Federal Specification, HH-1-562, Insulation, Thermal, Mineral Wool, Block or Board and Pipe Insulation (Molded Type) Type II, Class 2 and 3, or revisions thereof.

The following installation accessories shall be part of this specification:

- 1-in. galvanized wire netting.
- Corrugated aluminum jacket, 0.02 in. thick.

M9.11.3: Polystyrene

Expanded polystyrene insulation shall conform to the requirements of Federal Specification, HH-1-524, Insulation Board, Thermal, Type I, Class 2 or revision thereof.

The following installation accessories shall be part of this specification:

- Stainless steel strapping, ¾ in. x 0.015 in. and stainless steel clips.
- Corrugated aluminum jacket, 0.02 in. thick with integral vapor barrier.
- A suitable polystyrene adhesive.
- Asphalt coated-glass fabric, 20 x 20 mesh conforming to M3.06.1: Coated Glass Fabric.

M9.11.4: Urethane

Urethane insulation shall conform to the requirements of Federal Specification, HH-1-00530, Insulation Board, Thermal (Urethane), Type II, Class 2 or revisions thereof.

The following installation accessories shall be part of this specification:

- Stainless Steel Strapping ¾ in. x 0.015 in. and stainless steel clips.
- Corrugated aluminum jacket 0.02 in. thick with integral vapor barrier.
- A suitable urethane adhesive.
- Asphalt coated glass fabric, 20 x 20 mesh conforming to M3.06.1: Coated Glass Fabric.

M9.11.5: Waterproof Jackets

Waterproof jackets for covering insulation on water pipes shall be assembled as specified from any of the following materials or combinations thereof.

- Asphalt coated glass fabric, 20 x 20 mesh conforming to M3.06.1: Coated Glass Fabric.
- Stainless steel strapping, ¾ in. x 0.015 in. and stainless steel clips.
- 1-in. galvanized wire netting.
- Corrugated aluminum jacket, 0.02 in. thick.
- Corrugated aluminum jacket, 0.02 in. thick with integral vapor barrier.
- A polystyrene adhesive.
- A urethane adhesive.

M9.13.0: Hydrated Lime

Hydrated Lime shall consist of a minimum of 95% calcium and magnesium oxides, pulverized so that at least 99.5% will pass a No. 30 sieve and at least 85% pass a No. 200 sieve.

M9.14.0: Preformed Expansion Joint Filler

This specification covers non-extruding and resilient non-bituminous types of preformed expansion joint fillers and shall conform to AASHTO M 153.

M9.14.1: Preformed Compression Joint Seals (Bridges)

This specification covers the materials requirements for preformed polychloroprene elastomeric joint seals for bridges. The seal consists of a multiple-web design composed of polychloroprene and functions only by compression of the seal between the faces of the joint with the seal folding inward at the top to facilitate compression. The seal is installed with a lubricant adhesive and is designed to seal the joint and reject incompressibles. The compression seal and the lubricant-adhesive shall conform to AASHTO M 297.

M9.14.2: Closed Cell Foam Joint Filler

This specification covers the requirements for closed cell foam used as a joint filler between different components of bridges and walls. Closed Cell Foam Joint Filler shall have a compact closed cell structure composed of synthetic isomeric polymers and shall be gray in color. It shall offer sufficient heat resistance so that it is compatible with hot applied sealing compounds. Closed Cell Foam Joint Filler shall meet the requirements of Section 5.1 through 5.4 of ASTM D1752, with the compression requirement modified to 10 psi minimum to 25 psi maximum. Typical physical properties, as determined using test method ASTM D545, shall be as follows:

Property	Description
Compression, 50%	13 psi
Extrusion	0.1 in.
Recovery	99.21%
Water Absorption, Volume	0.246%

The Contractor shall provide certified test data which documents compliance with the required physical properties. The certified test data shall be submitted to the Engineer for approval.

M9.14.3: Polyurethane Joint Sealer

This specification covers the requirements for a cold applied, two component, elastomeric joint sealing compound suitable for use as a joint sealer and/or caulking compound on joints in Portland cement concrete or steel surfaces. This material shall meet ASTM C920.

M9.14.4: Polyurethane Joint Sealer, Non-Sag

This specification covers the requirements for a cold applied, single component elastomeric joint sealing compound for sealing, caulking vertical joints on bridges and other structures. This material shall meet ASTM C920.

M9.14.5: Elastomeric Bearing Pads

M9.14.5.A: General Requirements

Elastomeric bearing pads shall be plain or laminated. They shall meet the applicable requirements of AASHTO M 251, the MassDOT Bridge Manual, and the AASHTO *LRFD Bridge Design Specifications* and the AASHTO *LRFD Bridge Construction Specifications*. The type of bearing will be specified on the plans.

Laminated elastomeric bearing pads consist of layers of elastomers restrained at their interfaces by bonded metal laminates.

M9.14.5.B: Material Requirements

Plain elastomeric bearing pads shall consist of elastomer.

Laminated elastomeric bearing pad shall consist of:

- Elastomer
- Internal Steel Laminates
- Tapered Internal Load Plates (if used)

The components of the elastomeric bearing pad shall conform to AASHTO M 251 and the following:

- The elastomer compound shall be 100% virgin neoprene and classified as being of low-temperature grade 3.
- The steel laminates shall meet the requirements of ASTM A 1011 Grade 36 or higher.

M9.14.5.C: Material Qualification

Elastomeric bearing pads shall be approved on a project basis. The Contractor shall furnish to the Research and Materials Section certified independent test reports demonstrating conformance. All testing shall be performed by the same independent lab in accordance with M9.14.5.G: Testing Requirements.

M9.14.5.D: Fabricators

Bearing shall be fabricated by a fabricator listed on the QCML.

M9.14.5.E: Fabrication

Fabrication shall not begin until the shop drawings have been approved and the Department has an inspector at the fabricator's facility.

The shop drawings shall specify bearing dimensions as shown on the plans and, where applicable, shall include:

- Elastomer thickness and edge cover,
- Number and thickness of steel reinforcing laminates,
- Dimensions of load plates (if any),
- Design shear modulus of the elastomer shall be as shown on the Plans.

Plain elastomeric bearing pads shall be fabricated and tested in accordance with the "Method A" design outlined in the AASHTO *LRFD Bridge Design Specifications*.

Laminated elastomeric bearing pads shall be fabricated and tested in accordance with the "Method B" design outlined in the AASHTO *LRFD Bridge Design Specifications*.

The manufacturer shall designate the bearings in each Lot, as described in M9.14.5.G: Testing Requirements, and certify that each bearing in the Lot was manufactured in a reasonably continuous manner from the same batch of elastomer and cured under the same conditions. In addition, the manufacturer shall certify that each bearing in the Lot satisfies the requirements of this specification, AASHTO M 251, the AASHTO *LRFD Bridge Design Specifications*, and the contract plans and documents.

The tolerances on the overall dimensions for the bearings shall be according to Table 2 of AASHTO M 251, except that the tolerance on the overall vertical dimension shall be limited to 0, +⅛ in., regardless of the design thickness.

All steel included in the final bearing product must conform to Buy America Requirements.

M9.14.5.F: Packaging, Handling, & Storage

The bearing pads shall be packaged, handled, and stored as specified below:

- Prior to shipment from the point of manufacture, bearings shall be packaged in such a manner to ensure that during shipment and storage the bearings will be protected against damage from handling, weather, or any normal hazard. Each completed bearing shall have its components clearly identified, be securely bolted, strapped, or otherwise fastened to prevent any relative movement, and be marked on it top as to location and orientation in each structure in the project in conformity with the contract documents.
- Each elastomeric bearing shall be marked in indelible ink or flexible paint. The marking shall consist of the order number, lot number, bearing identification number, and elastomer type and grade per AASHTO M 251. For bearing pads fabricated with a tapered internal load plate, a $^{1}/_{32}$-in. deep direction arrow shall be inscribed into the bearing which will allow the bearing to be aligned with the up-station direction. All marks shall be permanent and be visible after the bearing is installed.

M9.14.5.G: Testing Requirements

M9.14.5.G.1: Quality Control System

Fabricators shall perform Quality Control (QC) testing in accordance with their quality system. QC test reports shall accompany the bearing pads when delivered to the project.

M9.14.5.G.2: Acceptance System

MassDOT will evaluate the fabricator's quality system and QC test reports. It will also perform its own testing and verify the independent laboratory's test reports, if applicable.

M9.14.5.G.3: Lot Sizes

Sampling of bearing pads for testing shall be random and performed on a Lot basis. A Lot of bearings shall be a group of 100 or fewer bearings that are:

- For a single contract,
- Cured under the same conditions,
- The same size and configuration,
- Manufactured in a reasonably continuous manner from the same batch of elastomer.

M9.14.5.G.4: Testing of Plain Bearings

M9.14.5.G.4.a: Testing Laboratory

Plain elastomeric bearing pads shall be tested by both an independent laboratory and MassDOT:

- Independent testing shall be performed by a nationally recognized third-party laboratory approved by the Research & Materials Section.
- Acceptance testing shall be performed by the Research and Materials.

M9.14.5.G.4.b: Sampling Frequency

Each Lot of plain bearings shall be randomly sampled for testing. The Contractor shall ensure that the fabricator produces the additional bearings required for testing.

Samples for independent testing shall be selected by the fabricator. The sampling rate for the independent testing shall be as follows:

- Lot sizes less than 10 bearings – One full-size bearing per Lot.
- Lot sizes greater than or equal to 10 bearings – Two full-size bearings per lot.

Samples for Acceptance testing shall be selected by the Engineer. The sampling rate for Acceptance testing shall be one bearing pad per lot.

M9.14.5.G.4.c: Testing Requirements

The laboratory shall test the bearings in accordance with Sections 8 and 9 of AASHTO M 251 as specified below:

- Dimensions per Section 8.4.
- Elastomer per Section 8.6.
    - The hardness, tensile strength, and ultimate elongation shall be in accordance with Table 1 of AASHTO M 251.
- Test procedures per Section 8.9.
    - Heat resistance per Section 8.9.3.

M9.14.5.G.5: Testing of Laminated Bearings

M9.14.5.G.5.a: Testing Laboratory

Laminated elastomeric bearing pads shall be tested by both an independent laboratory and MassDOT:

- Independent testing shall be performed by a nationally recognized third-party laboratory approved by the Research & Materials Section.
- Acceptance testing shall be performed by the Research and Materials.

M9.14.5.G.5.b: Sampling Frequency

Each Lot of laminated bearings shall be randomly sampled for testing. The Contractor shall ensure that the fabricator produces the additional bearings required for testing.

Samples for independent testing shall be selected by the fabricator. The sampling rate for the independent testing shall be as follows:

- Lot sizes less than 10 bearings – One full-size bearing per Lot.
- Lots sizes greater than or equal to 10 bearings:
    - One full-size bearing per every twenty per lot, or a minimum of two bearings.
    - The number of laminated bearings to sample shall be determined by taking the Lot size divided by 20. If the integer part of this calculation is 0 or 1, then two bearings shall be sampled. For example, if the lot size is 58 laminated bearings, two bearings shall be sampled; if the lot size is 65, three bearings shall be sampled; and if the lot size is 22, two bearings shall be sampled.

Samples for Acceptance testing shall be selected by the Engineer. The sampling rate for Acceptance testing shall be one bearing pad per lot.

M9.14.5.G.5.c: Testing Requirements

Testing of the bearings shall be in accordance with Sections 8 and 9 of AASHTO M 251 as specified below:

- Dimensions per Section 8.4.
- Elastomer per Section 8.6.
    - The hardness, tensile strength, and ultimate elongation shall be in accordance with Table 1 of AASHTO M 251.
- Compressive strain at the maximum design dead plus live service compressive load per Section 8.8.1.1.
    - The compressive deflection, as determined per Section 9.1., between the two loadings for each bearing tested shall not exceed 10%.
- Bond via Compressive Load per Section 8.8.2.2.
- Shear Modulus of the elastomer per Section 8.8.3.
    - Shear Modulus shall meet the requirements on the Plans.
- Test procedures per Section 8.9.
    - Additional Low Temperature Shear Modulus testing per Section 8.9.1.
    - Heat resistance per Section 8.9.3.
    - Compression set per Section 8.9.4.
    - Creep per Section 8.9.5.
        - The percent creep shall be less than 35%.
- Long Term Compression per Section 8.9.6.

Table M9.14.5-1: Test requirements for Elastomeric Bearings

Quality Characteristic	Test Method	Requirement
Hardness	ASTM D2240	From Independent Test Results ±5 Pts
Tensile Strength	ASTM D412	≥2250 psi
Ultimate Elongation	ASTM D412	Minimum Elongation Based on Durometer according to AASHTO M 251 Table 1
Shear Modulus (see Note 1)	ASTM D4014	Specified Value ±15%
After Heat Aging for 70 Hours at 100°C (Maximum Change from Unaged Testing)		
Hardness	ASTM D573	Hardness +15 Pts
Tensile Strength	ASTM D573	Tensile Strength -15%
Ultimate Elongation	ASTM D573	Ultimate Elongation -40%

Note 1: Test is only required for laminated elastomeric bearing pads.

M9.14.6: Bonded Closed Cell Joint System

The joint seal shall be composed of either closed cell cross linked ethylene vinyl acetate polyethylene copolymer or of closed cell polychloroprene (neoprene). The joint seal shall feature grooves or ribs which run the full length of the joint. The joint seal shall be bonded to the concrete surfaces on each side of the joint using a two-component epoxy-based adhesive.

The joint seal shall have the following typical physical properties:

Property	Description
Tensile Strength, (ASTM D412)	115 psi, Minimum
Elongation @ Break (ASTM D3575)	200%, Minimum
Water Absorption, Volume %	5%, Maximum

The two-component epoxy-based adhesive shall conform to ASTM C881, Type I & II, Grade 2, Class B & C, and shall have the following physical properties:

Property	Description
Tensile Strength, (ASTM D638)	3,500 psi, Minimum
Compressive Strength	7,000 psi, Minimum
Bond Strength	430 psi, Minimum

The Contractor shall provide certified test data which documents compliance with the required physical properties. The certified test data shall be submitted to the Engineer for approval.

M9.15.0: Liquid Penetrant/Sealant

Liquid penetrant/sealant for Portland cement concrete surfaces used to protect concrete surfaces from chloride intrusion shall be a material previously approved by the Department for the purpose intended and listed on the QCML.

M9.16.1: Rubber-Cotton Duck Bearing Pad

The bearing pads shall be manufactured of all new (unused) materials and composed of multiple layers of prestressed duck, 8.1 oz per net square yard, duck warp count 50 ±2 threads per inch and filling count 40 ± threads per inch, 64 plies per inch of finished pad thickness, impregnated and bound with a high quality rubber compound, containing rot and mildew inhibitors and anti-oxidants, compounded into resilient pads of uniform thickness.

The pads shall withstand compressive loads perpendicular to the plane of laminations of not less than 10,000 psi before breakdown. Load deflection properties in accordance with procedures of MIL-C-882 shall be the following maximum percentages of total pad thickness: 10% at 1,000 psi, 15% at 2,000 psi. When loaded to 1,500 psi, permanent set as load is removed in accordance with procedures of MIL-C-882 shall be a maximum of 2.5% of the original “zero point” thickness. Shore Durometer shall not be less than 85 nor more than 95. The ratio of lateral expansion to vertical deflection shall not exceed 0.25 when loaded to 1,500 psi. The material shall not lose effectiveness throughout a temperature range of -65°F to +200°F. No visual evidence of damage or deterioration by environmental effects of sunshine, humidity, salt spray, fungus, and dust in accordance with MIL-E-5272. Thickness shall be as shown on drawings within tolerances of ±5%.

M9.16.2: Molded Fabric Bearing Pad

The preformed pads shall consist of a fabric and rubber body.

The pad shall be made with new unvulcanized rubber and unused fabric fibers in proper proportion to maintain strength and stability.

The surface hardness expressed in standard rubber hardness figures shall be 80 Shore A Durometer ±10 durometer average, the ultimate breakdown limit of the pad under compression loading shall be no less than 7,000 psi for the specified thickness without extrusion or detrimental reduction in thickness.

The pads shall be furnished to specified dimensions with all bolt holes accurately located.

M9.17.0: Asphaltic Binder for Asphaltic Bridge Joint System

The thermoplastic polymeric modified asphalt binder shall conform to physical properties based on the designated ASTM testing methods found in Table M9.17.0-1.

Table M9.17.0-1: Physical Properties of Asphaltic Binder for Asphaltic Bridge Joint Systems

Test	Test Method	Required Properties
Softening Point	AASHTO T 53	180°F minimum
Tensile Adhesion	ASTM D5329	700% minimum
Ductility at 77°F	ASTM D113	400 mm minimum
Penetration at 77°F, 150 g, 5 sec.	ASTM D6690	7.0 mm maximum
Flow, 5 hours at 140°F	ASTM D6690	3.0 mm maximum
Resiliency at 77°F	ASTM D6690	70% maximum
Asphalt Compatibility	ASTM D6690	Pass
Low Temperature Penetration at 0°F, 200g, 60 sec.	ASTM D5 with cone*	1.0 mm minimum
Flexibility at -10°F	ASTM D5329	Pass
Bond 3 Cycles at -20°F, 50% Elongation	ASTM D3405	Pass
Bond 3 Cycles at 0°F, 100% Elongation	ASTM D3405	Pass
Recommend Installation Range		360°F to 390°F
Safe Heating Temperature Range		390°F to 420°F

* Use Method D5; however replace the standard penetration needle with a penetration cone conforming to the requirements given in Test Method D217, except the interior construction may be modified as desired. The total moving weight of the cone and attachments shall be 150.0 g ± 0.10.

M9.17.1: Aggregate for Asphaltic Bridge Joint System

The aggregate shall be granite, basalt or gabbro. The aggregate shall be selected, crushed, processed, double-washed and dried at the source. It shall be delivered to job site in prepackaged waterproof containers. The supplier shall certify the above requirements are met.

The aggregate shall be made available in ¾-in., ½-in. and ⅜-in. sizes and shall meet gradation requirements specified by the manufacturer for the joint system.

M9.17.2: Backer Rod

The backer rod shall be closed cell foam expansion joint filler, compatible with polymeric binder and the elevated temperatures of the polymeric binder application. The size of the backer rod shall be in accordance with the manufacturer's recommendations for the gap width.

The backer rod shall meet ASTM D1752 and have the following typical physical properties using a ½ in. specimen and the test method ASTM D545:

Property	Description
Compression, 50%	13.3 psi
Extrusion	0.1 in.
Recovery	99.21%
Water Absorption, Volume	0.246%

M9.17.3 Bridge Plate for Asphaltic Bridge Joint System

The bridge plate shall be AASHTO M 270 Grade 36 steel, minimum width and thickness of 8 in. x 0.25 in. and shall be galvanized in accordance with AASHTO M 111. Holes for the locating pins shall be 12 in. on center. Locating pins shall be 16d common nails or larger, hot dipped galvanized.

M9.17.4: Neoprene Seals

Neoprene seals shall be composed of flexible, non-reinforced, extruded neoprene compound exhibiting the physical properties listed in Table M9.17.4-1. All neoprene seals shall incorporate a matching locking lug that mechanically snaps into the corresponding extrusion shape cavity to ensure watertightness and proper joint performance. All mitering and/or splicing of the neoprene seal shall be performed under controlled conditions at the place of manufacturer. The neoprene seal shall be supplied and installed in one continuous length without field splices.

Table M9.17.4-1: Physical Properties of Neoprene Seals

Property	Test Method	Requirement
Tensile Strength	ASTM D412	2,000 psi
Tensile Strength, Elongation at Break	ASTM D412	250%, minimum
Hardness, Durometer Type A	ASTM D2240 Modified	50 to 60
Oven Aging, 70 hours at 212°F:		
Loss of Tensile Strength	ASTM D573	20% loss maximum
Loss of Elongation	ASTM D573	20% loss maximum
Maximum Change in Hardness	ASTM D573	-0 to +10 points
Oil Swell, ASTM Oil #3, 70 hours at 212°F	ASTM D471	45% maximum weight increase
Low Temperature	ASTM D746	Not Brittle
Ozone Resistance, 70 hours at 104°F, 20% elongation, 300 pphm, in air, Wipe Surfaces to Remove Contamination	ASTM D1149	No Cracks
Low Temperature Stiffening, 7 days at 14°F, Hardness, Durometer Type A	ASTM D2240	0 to +15 points change

Compression Set, 70 hours at 212°F	ASTM D395 Method B	40% maximum

M9.18.0: Impact Attenuators

All Impact Attenuators shall be tested to MASH crash testing standards.

M9.18.1: Redirective Impact Attenuators

To be classified as a Redirective Impact Attenuator, the results of the following crash test designations must fall within the acceptable impact tolerances and evaluation criteria show in Table 2-3 of MASH (n = Test Level): n-30, n-31, n-32, n-33, n-34, n-35, n-36, n-37 (2270P Pickup Truck, only), and n-38.

Redirective Impact Attenuators will be designated as such on the QTCE.

M9.18.2: Non-Redirective Impact Attenuators

To be classified as a Non-Redirective Impact Attenuator, the results of the following crash test designations must fall within the acceptable impact tolerances and evaluation criteria show in Table 2-3 of MASH (n = Test Level): n-40, n-41, n-42, n-43, n-44, and n-45.

Non-Redirective Impact Attenuators will be designated as such on the QTCE.

M9.18.3: Low-Maintenance Impact Attenuators

To be classified as a Low-Maintenance Impact Attenuator, the device must:

- Meet the criteria of M9.18.1: Redirective Impact Attenuators.
- Meet the Department's minimum requirements for the evaluation of Low-Maintenance Impact Attenuators.

Low-Maintenance Impact Attenuators will be designated as such on the QTCE. A single product may be listed as both a Redirective Impact Attenuator and a Low-Maintenance Impact Attenuator.

M9.30.0: Retroreflective Sheeting

This specification covers retroreflective sheeting designed to reflectorize traffic control signs, delineators, barricades, and other devices. All retroreflective sheeting shall meet the requirements of ASTM D4956 and AASHTO M 268, and as listed below:

Table M9.30.0-1: Retroreflective Sheeting Requirements

Retroreflective Sheeting Application	Allowable Retroreflective Sheeting Classification(s) per ASTM D4956
Type A Permanent Sign Panels (per Subsection 828.42: Panels)	Type IV, Type XIII, Type IX
Temporary Rigid Sign Panels (flat panel aluminum or plywood substrate)	Type IV, Type VIII, Type IX
Temporary Roll-Up Signs	Type VI
Type B Sign Panels (per Subsection 828.42: Panels)	Type VII, Type IX, Type XI
Traffic Cones	Type VI
Reflectorized Drums	Type IV, Type VIII, Type IX
Portable Breakaway Barricades Type III	Type IV, Type VIII, Type IX
Flexible Delineator Posts	Type IV, Type V, Type VIII, Type IX
Guardrail End Treatments	Type VIII, Type IX
Guardrail Terminal Delineators	Type IV, Type VIII, Type IX
Demountable Reflectorized Delineator, Guard Rail	Type VIII, Type IX
Impact Attenuator Delineators	Type IV, Type VIII, Type IX

Sheeting shall only be applied to a substrate that is recommended by the sheeting manufacturer.

M9.30.4: Acrylic Plastic 3.25 Inch Diameter Center-Mount Reflectors

Acrylic plastic 3.25 in. diameter center-mount reflectors shall be a material previously approved by the Department for the purpose intended and listed on the QTCE.

M9.30.6: Temporary Raised Pavement Markers

Temporary raised pavement markers shall consist of a durable plastic or another type of durable material and have the following characteristics.

- Color: (ASTM D1535) White or Yellow.
- Dimensions are to be at least 4 in. wide and a minimum reflective area of 1.5 in.^{2} of retroreflective sheeting meeting M9.30.0, Type C.
- Markers shall contain one-way or two-way retro reflective faces as required by the Engineer.

Markers shall provide daytime delineation and shall adhere to HMA or PCC surfaces using adhesives and/or methods recommended by the manufacturer. Markers shall be removable from HMA and PCC pavements without the use of heat, solvents, grinding or blasting. After removal, permanent marks, scars or damage to the pavement surface shall be minimal, free from dirt or any other contaminants.

M9.30.7: Guardrail Delineator

Guardrail delineators shall be fabricated from galvanized steel having a minimum coating thickness of 0.9 oz per square foot, polycarbonate plastic or thermoplastic and shall allow a minimum of 8 $in.^2$ of retroreflective sheeting per face, conforming to M9.30.0: Retroreflective Sheeting.

Guardrail delineators shall be shaped to fit in the valley of the W shape. Circular holes shall be used for the bolt connecting the delineator to the W beam. Adhesive connections shall not be allowed.

M9.30.8: Reflectorized Flexible Delineator Post

Reflectorized Flexible Delineator Posts shall be used as directed for delineation of roadways and ramps. Only those products previously approved for the purpose intended and listed on the QTCE may be used.

M9.30.9: Reflectorized Drum

Reflectorized drums shall be plastic and shall meet the requirements of the MUTCD.

Retroreflective sheeting for drums shall meet the requirements of M9.30.0: Retroreflective Sheeting and be 6 in. wide.

Reflectorized drums are listed on the QTCE.

M9.30.10: Guardrail Termini Delineator

Guardrail termini delineators shall be fabricated in accordance with the Plans. The panel shall consist of Type A aluminum sign panel. Retroreflectorized sheeting shall conform to M9.30.0: Retroreflective Sheeting.

M9.30.11: Traffic Cones

Traffic cones shall be orange in color, 36 in. tall and with retroreflective sheeting collars that conform to M9.30.0: Retroreflective Sheeting.

Traffic cones are listed on the QTCE.

M9.31.0: Non-motorized Traffic Counting Stations (NTCS)

NTCS shall have a count accuracy of 85% or greater, by direction of travel. When located on a facility that has both pedestrian and bicycle traffic, such as a multi-use path, the minimum count accuracy shall apply to both user types. When located on a facility that is limited to pedestrians, such as a sidewalk, the minimum count accuracy shall only apply to pedestrian counts. When located on a facility that is limited to bicyclists, such as a bike lane, the minimum count accuracy shall only apply to bicyclist counts.

NTCS shall have the capability to collect counts by direction and log the data for pedestrians and bicyclists separately.

The data collected shall be in predefined time interval bins. These bins shall, at a minimum, include options for 1-minute, 5-minute, 15-minute, 1-hour, and 24-hour intervals. 24-hour counts shall be formatted with intervals that start at midnight (0:00 a.m.). Data shall be exportable in a Department-defined .csv, .xlsx, and/or .xml format.

NTCS shall have an independent, battery-operated power source and shall not require a hard-wired service connection, with exceptions to Permanent NTCS for Intersections as described below. Batteries shall be sized to allow uninterrupted operation of the NTCS for a minimum of 1 year. Solar panels, if required, may be used to keep the batteries at a sufficient charge. All batteries shall carry a minimum 1-year warranty. Replacement batteries shall be industry standard, commercially available, and not proprietary to device.

As an exception to the independent power source requirement, a traffic signal cabinet may be used to leverage the installation of a Permanent NTCS for Intersections by providing Power over Ethernet (PoE) from the cabinet to the proposed device.

All NTCS shall offer free, manufacturer support available during typical business hours, Monday through Friday. Permanent devices shall be furnished with a manufacturer's warranty for all materials for at least one year following acceptance.

Firmware, software, and security updates shall be included at no cost for the life of the product.

M9.31.1: NTCS for Intersections

Items classified for use at Intersections shall have the capability of uniquely identifying, classifying, and discretely counting pedestrians and/or bicyclists passing through one or more user-defined zones, traveling in both directions along multiple axes.

The accuracy of Intersection Devices shall not be influenced by the presence of motor vehicles adjacent to the user-defined detection zones, if separate, or within the detection zone if the space is shared between motorized and non-motorized traffic, such as a shared lane or crosswalk.

M9.31.2: NTCS for Trails

Items classified for use on Trails shall have the capability of uniquely identifying, classifying, and discretely counting pedestrians and/or bicyclists passing a user-defined point or zone in both directions on a single axis.

The accuracy of Trail Devices shall not be influenced by the presence of motor vehicles that are offset a minimum of 6 ft from the edge of the detection point or zone.

M9.40.0: Drilling Slurry

Drilling slurry shall conform to one of the following specifications. Reports of all required tests shall be furnished to the Engineer upon completion of each drilled shaft.

Mineral Slurry

Mineral slurry shall be premixed thoroughly with water and adequate time, as prescribed by the manufacturer, shall be allotted for hydration prior to introduction into the shaft hole. Slurry tanks of adequate capacity are required for slurry circulation, storage, and treatment. Control tests shall be performed on the mineral slurry by the Contractor to determine density, viscosity, sand content and pH. Properties of mineral slurry (Bentonite or Attapulgite) in water shall meet the range of values found in Table M9.40.0-1.

Table M9.40.0-1: Physical Properties of Mineral Slurry

Property	Value Required	Test Method
Density*	64 to 75 pcf	Mud Density API 13B-1 Section 1
Viscosity	26 to 50 s per qt	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	8 to 11	Glass Electrode, pH Meter, or pH Paper
Sand Content	4.0% by volume maximum	Sand Content API 13B-1 Section 5

* To be increased by 2 pcf in salt water or brackish water.

Tests to determine density, viscosity and pH shall be performed during shaft excavation to establish a consistent working pattern. Four sets of tests shall be made during the first 8 hr of slurry use. When the results show consistent behavior, one set of testing shall be made every 4 hr of slurry use thereafter.

Water Slurry

The use of water slurry without full length steel casings will only be allowed if approved in writing by the Engineer. In that case, all of the properties of mineral slurry shall be met, except that the maximum density shall not exceed 70 pcf. Mixtures of water and on-site soils shall not be allowed for use as a drilling slurry, since particulate matter falls out of suspension easily and can contaminate the concrete.

Polymer Slurry

Natural or synthetic slurry shall have specific properties at the time of mixing and of concreting that are in conformance with the written recommendations of the manufacturer and the Contractor's Drilled Shaft Installation Plan. The Contractor shall perform the required tests at the specified frequency and shall provide slurry that complies with the maximum and/or minimum property requirements for the subsurface conditions at the site and with the construction methods that are used. Whatever product is used, the sand content at the base of the shaft excavation shall not exceed 1% when measured by the API sand content test, immediately prior to concreting.

M9.40.1: Well Casing Pipe

Well casing pipe shall conform to the requirements for welded and seamless steel pipe, ASTM A53.

M9.40.2: Water Pumps

Water pumps (jet, submersible or shallow well) shall be of a standard commercial quality. The capacity of the pump shall be such that it will be capable of discharging water at the rate and pressure for the pumping depth specified for the installation.

The motor voltage of the pump shall be compatible with the voltage available at the electrical source.

The Contractor shall submit for approval to the Engineer five days before placing any purchase orders for the water pump, accessories and electrical equipment, the name of the manufacturer, the specifications for the pump, accessories and electrical equipment that they propose to furnish.

M9.40.3: Chlorine Solution

Chlorine solution used for disinfecting springs, wells and other water systems, shall consist of a solution of water and liquid chlorine, sodium hypochlorite, calcium hypochlorite or chloride of lime.

Liquid forms of chlorine or sodium hypochlorite and powder forms of calcium hypochlorite or chloride of lime shall be used according to the instructions supplied by the manufacturer and as recommended by the DEP.

If sodium hypochlorite is already in solution as a laundry bleach containing 5.25% sodium hypochlorite, it shall be used at the rate of 1 qt per 3,000 gallons of water to be disinfected. The dosage should be sufficient to produce a chlorine taste in the water.

M9.40.4: Plastic Water Pipe, Flexible

Flexible plastic pipe shall be polyethylene plastic pipe schedule 40 or 80 suitable for the transportation of potable water and conform with the requirements of AASHTO M 258. The material grade selected shall be capable of withstanding a minimum sustained water pressure of 160 psi at 73.4°F. The pipe shall be inside diameter controlled. Fittings may be either nylon, copper or bronze. Clamps shall be stainless steel.

M9.40.5: Plastic Water Pipe, Rigid (PVC)

Rigid polyvinyl chloride (PVC) plastic pipe shall be suitable for transportation of potable water and conform. with the requirements of AASHTO M 258. The material grade and standard pipe dimension ratio (SDR) shall be capable of withstanding a minimum sustained water pressure of 160 psi at 73.4°F. Fittings shall be PVC plastic conforming with AASHTO M 258. The burst strength of the fittings shall be not less than that of the pipe being furnished.

M9.40.6: Plastic Water Pipe, Rigid (ABS)

Rigid Acrylontrile-Butadiene-Styrene (ABS) plastic pipe shall be suitable for the transportation of potable water and conform with the requirements of AASHTO M 258. The material grade and SDR shall be capable of withstanding a minimum sustained water pressure of 160 psi at 73.4°F. Fittings shall be ABS plastic conforming with AASHTO M 258. The burst strength of the fittings shall be not less than that of the pipe being furnished.

M9.40.7: Copper Water Tube, Seamless

Seamless copper water tube suitable for general plumbing shall conform to the requirements of AASHTO M 258. Tube material shall conform to ANSI/ASTM 888, Type k.

M9.40.8: Steel Water Pipe, Galvanized

Galvanized steel water pipe shall be the standard weight class conforming to the requirements of AASHTO M 258. Pipe material shall conform with the ASTM A120 option.

M9.50.0: Geotextile Fabrics

Geotextile fabric used for subsurface drainage, separation, stabilization, permanent erosion control, temporary silt fences, or paving fabric shall conform to requirements of AASHTO M 288 for the intended application and be listed on the QCML.

SECTION M10: TRAFFIC CONTROL DEVICES

M10.00.0: General

All Traffic Control Devices shall be designed, manufactured and tested in accordance with the applicable standards of the ANSI, IMSA, ITE, NEMA, UL and these Specifications.

Inclusion on the Qualified Traffic Control Equipment (QTCE) List is contingent upon meeting these Specifications.

M10.01.0: Advanced Transportation Controller Cabinets (General)

M10.01.0.A: Definitions

All Advanced Transportation Controller (ATC) Cabinets shall conform to the requirements defined in the Advanced Transportation Controller Cabinet (ATCC) 5301 v02 Standard.

ATC Cabinet types are classified in Table M10.01.0-1:

Table M10.01.0-1: ATC Cabinet Types

Type	Description	Doors	Nominal Dimensions (Height x Width x Depth)	Material Specification
P4	Ground-mount NEMA "P"	4 (2 front, 2 rear)	67 in. x 44 in. x 26 in.	M10.01.1
P1	Ground-mount NEMA "P"	1	67 in. x 44 in. x 26 in.	M10.01.2
352	Ground-mount Caltrans 352	2 (1 front, 1 rear)	67 in. x 30 in. x 24 in.	M10.01.3
336S	Side-of-pole-mount Caltrans 336S	1	46 to 48 in. x 24 to 26 in. x 22 to 24 in.	M10.01.4

M10.01.0.B: Cabinet Fabrication

All ATC Cabinets shall be fabricated from a minimum of ⅛-in. thick 5052-H32 sheet aluminum alloy and be of all-weather construction. All internal and external hardware shall be fabricated from non-corrosive material. Finish and surface preparation of the cabinet shall conform to Section 7.7 of the NEMA TS2-2016 Standard. The door hinge shall be a continuous type with a stainless-steel hinge pin. The door handle and all external fasteners used in the cabinet construction shall be stainless steel. All unwelded cabinet seams shall be sealed with clear RTV silicone sealant to prevent dust intrusion.

M10.01.0.C: Cabinet Rack Cage

Standard rack cages shall be installed inside the cabinet. The EIA rack portion of the cage shall consist of four continuous, adjustable equipment mounting angles. The mounting angle nominal thickness shall be 11-gauge plated steel. The mounting angles shall be tapped with 10-32 threads with Electronic Industries Association (EIA) universal spacing. The mounting angle shall comply with EIA-310-B and shall be supported at the top and bottom be either welded or bolted support angle to form the cage. The mounting angles shall provide holes to mount the side panels. Clearance between the rails for mounting assemblies shall be 17.75 in. The cage shall be bolted to the cabinet at four points via the housing cage supports and four points via associated spacer brackets and the top and bottom. The cage shall be centered within the cabinet door opening.

M10.01.0.D: Cabinet Power

The main cabinet circuit breaker shall be rated at 30 amps. Circuit breakers shall be approved and listed by the UL. All circuit breakers shall be quick-make, quick-break on either automatic or manual operation and shall conform to UL 489. Contacts shall be silver alloy enclosed in an arc quenching chamber.

M10.01.0.E: Back of Door Documentation

All ground-mount ATC Cabinets shall be supplied with a 6-in. high riser aluminum base that elevates the cabinet above the cabinet foundation. The color and finish of the base shall match the color and finish of the cabinet it supports.

ATC Cabinets shall be supplied with a laminated door sticker. This sticker shall be permanently affixed to the inside front control side of the cabinet door. At a minimum, the sticker shall contain the following information:

- Vehicle detection information including all detector channel assignments, phases assigned, approaches, and cabinet termination points.
- Per approach preemption information including channel, approach/direction, and termination points.
- Field termination chart showing per approach/per phase numbering of all signal circuits.
- Signal phasing and signal plan with intersection geometry and signal head designations.

The back of the main front door shall contain a resealable, heavy-duty opaque plastic envelope with two grommets that provide mounting to two integrated hooks installed on the back side of the front cabinet door. The heavy-duty plastic envelope shall be used to store cabinet wiring diagrams and operations manuals that cannot be accommodated in the pull-out drawer storage tray.

M10.01.0.F: Electric Meter Trim

The cabinet shall be supplied and installed with an electric service meter socket trim and electrical service disconnect switch mounted on the exterior of the cabinet. The meter and disconnect switch shall be installed centered on the side of the cabinet without doors such that it is not less than 48 in. nor more than 60 in. above final grade.

The Contractor shall coordinate with the local electric utility company to determine the appropriate type of electric service meter socket trim and electrical conductors to be used.

The line side cable shall be routed external to the cabinet from the ground to a 50A disconnect switch, then continuing to the bottom of the electric service meter socket trim, all through rigid steel conduit furnished and installed by the Contractor. The load side cable shall be routed through the cabinet and terminated on the line side of the main cabinet circuit breaker.

The cable shall be routed through the interior of the cabinet such that it does not block or enter into available rack space preventing that space from being used either by equipment supplied as part of the project, or future equipment that would be installed in the rack system. The cable shall be routed between the edge of the rack system and the cabinet side wall, along the bottom of the cabinet and below the bottom opening of the doors.

Care shall be taken by the Contractor when installing the electric service meter socket trim and electrical service disconnect switch so that there is no damage inflicted on installed devices or the rack system during the installation. All metal shavings produced during the drilling of the access hole for the electric service shall be removed from the cabinet interior by the Contractor. The Contractor shall install appropriate bushings to all cabinet penetrations.

All wiring shall comply with all applicable local electrical codes and the MEC.

M10.01.0.G: Detector Test Switch Panel

The cabinet shall be supplied with a detector test switch panel. There shall be a total of 48 switches to allow for the manual placement of detector calls into the controller. Each switch shall be clearly labelled as to input channel. Each switch position shall correspond to the same controller input; switch 1 is for controller input channel 1, switch 2 is for controller input channel 2, etc. The detector switch panel shall be comprised of switches that are wired directly to the corresponding input channels on the rack assemblies. Each switch shall be supplied with a red LED indicator to be illuminated whenever a channel input is active via the three-position detector switch. The use of an SIU internal to the detector test switch panel to provide this capability is not allowed. The switches shall be three position type and function as follows:

- Up Position: provides a constant call
- Center Position: normal operation (phase receives call from detectors)
- Down Position: provides a momentary call

M10.01.0.H: Standard Cabinet Devices

A Cabinet Monitor Unit (CMU) and Auxiliary Display Unit (ADU) shall be supplied and installed in each cabinet. The CMU and ADU shall conform to requirements defined in the Advanced Transportation Controller Cabinet (ATCC) 5301 v02 standard. The CMU/ADU units supplied and installed as part of this project shall support 32 channels. All configuration programming shall be resident in a non-volatile Datakey device. Each CMU shall be supplied with a Datakey programmer and associated software. The Datakey programming software shall include a set-up wizard which shall assist the user with the initial set up of the device. The Contractor shall program the Datakey with data entries appropriate for each intersection. All programing resident on the Datakey shall be included in the hardcopy.

A cabinet power supply shall be supplied with each cabinet. The cabinet power supply shall comply with ATCC 5301 v02. A full complement of switch packs shall be supplied with each cabinet, switch packs shall comply with ATCC 5301 v02.

A full complement of flashers shall be supplied with each cabinet, flashers shall comply with ATCC 5301 v02.

A full complement of SIUs shall be supplied with each cabinet, the Serial Interface Units (SIU) shall comply with ATCC 5301 v02.

A full complement of flash transfer relays shall be supplied with each cabinet, flash transfer relays shall comply with ATCC 5301 v02.

The Contractor shall reconfigure the default username and passwords on all communications/control equipment within the ATC Controller and Cabinet. This includes but is not

limited to the ATC traffic controller, ATC ancillary equipment, video detection equipment, Ethernet switches, and routers. The new username and passwords shall be created in accordance with the Department Information Technology (IT) standards; no manufacture default level passwords shall be allowed.

All SDLC cables used to interconnect devices within the cabinet shall be supplied with factory installed protective wire covers to protect the connector side of the cables. The use of Contractor supplied/installed cable protector covers shall not be allowed.

The Contractor shall utilize network communications encryption settings on all forms of wired Ethernet data paths. No "in the clear" communications shall be allowed. At a minimum all wired Ethernet connections shall meet 802.1AE standards. The Contractor shall supply and configure a Cyber Intrusion and Prevention Device (CIPD) in each ATC cabinet. The CIPD shall prevent any unauthorized access/connections to the traffic control system. Upon detection of unauthorized attempts, the CIPD shall notify the Department via SMS message and/or email and log the event. The CIPD shall be installed prior to any remote access device.

The Contractor shall coordinate with the Engineer for final configuration of the CIPD. No direct access to the traffic system shall be allowed without the installation of a CIPD and/or Router/Firewall.

M10.01.0.I: Surge Suppression

Electrical filtering/surge protection shall be supplied and installed in each cabinet in accordance with ATCC 5301 v02 requirements and the manufacturer's recommendations. At a minimum, surge suppression shall be provided for incoming electric utility power conductors, all signal control circuits, vehicle detection, pedestrian detection, communications, and preemption system terminations. The use of a single fuse for surge suppression shall not be allowed.

The cabinet shall be electrically bonded and grounded to comply with Section 643, the National Electrical Code (NEC) and the National Electrical Safety Code (NESC), latest versions of each document.

Each in-cabinet current interrupting device (controller unit, flasher, and all other devices) shall be equipped with a suitable radio interference suppressor installed at the input power point. Interference suppressors shall be designed to minimize interference in both broadcast and aircraft frequencies. Suppressors shall be designed for 125 percent of the total connected load and shall meet standards of the UL and the EIA.

M10.01.0.J: External GFCI Outlet

The cabinet shall be supplied with a GFCI outlet to be installed on the upper left, exterior of the control side wall of the ground-mount cabinet and the upper left side of the pole-mount cabinet. The electrical outlet will be GFCI protected, house in a locked access enclosure. The GFCI outlet shall be supplied via its own 15-amp circuit breaker. The GFI outlet assembly shall be housed in a heavy-duty vandal resistant, weatherproof, dustproof enclosure designed for exterior applications. The GFCI enclosure door shall contain a weatherproof seal and supplied with a lock accessed with a skeleton style (#1) key.

M10.01.0.H: Generator Transfer Switch

The cabinet shall be supplied with a generator panel. The generator panel shall consist of a manual transfer switch and a twist-lock connector for generator hookup. The manual generator transfer switch shall be Reliance Controls model CSR302 or approved equivalent. The transfer switch and twist-lock connector shall be located inside a surface mounted generator access enclosure with a separate lockable door mounted on the lower left, exterior wall of the cabinet.

The door shall be equipped with a tamper resistant hinge. The generator panel assembly shall be housed in a heavy-duty, vandal resistant, weatherproof, dustproof enclosure designed for exterior applications. The connection to an external generator shall be via a waterproof, secure connection. The connection shall allow authorized personnel to access, connect, and secure an external electrical source to the cabinet for power restoration. The generator panel door shall be constructed with a weatherproof seal and supplied with a lock accessed with a J201 key.

M10.01.0.I: Output Channel Assignments

The cabinet shall be configured to provide output channel assignments per Table M10.01.0-2:

Table M10.01.0-2: Output Channel Assignments

Channels	Outputs (16 Channel Cabinet)	Outputs (32 Channel Cabinet)
1-8	Phases 1-8	Phases 1-8
9-12	Flashing Yellow Arrow, Overlaps, As Needed	Flashing Yellow Arrow
13-16	Pedestrians	Pedestrians
17-20	n/a	Overlaps
21+	n/a	As Needed

M10.01.1: P4 ATC Cabinet

M10.01.1.A: Cabinet Enclosure

The cabinet size and functional requirements shall conform to the NEMA TS2-2016 Standard, Section 7.

The cabinet enclosure shall be a dust and moisture-proof aluminum housing with an auxiliary door in door feature. The cabinet shall be configured to eliminate arc flash. All electrical equipment shall be dead front, no open terminals, busbars, breakers, or exposed terminal strips. All cabinet switches and circuit breakers shall be permanently labeled as to function. The cabinet shall be designed, constructed, and installed with all necessary provisions to comply with the latest NFPA 70E requirements. All electrically live contact points over 50V shall be covered with Lexan or a suitable physical barrier to eliminate the possibility of arc flash.

The lock for the police door switch compartment shall unlock with a skeleton style (#1) key. The lock for the main door(s) of the cabinet shall unlock with a Corbin #2 key. Two sets of two keys (main door/police door) shall be furnished with each cabinet.

The cabinet shall be supplied with a permanent label mounted on the upper portion of the inside front main door that shall contain the name of the cabinet manufacturer, controller manufacturer, model/part number and year/month of assembly.

The cabinet shall be supplied with a GFCI duplex outlet and a rack mounted multi-outlet strip.

The quantity, size and location of the equipment shall correspond to the contract drawings for the ATC Cabinet. All equipment shall be installed with the correct number of mounting screws/mounting support devices. All internal cabinet wiring shall be routed such that there is no conflict for access to cabinet devices or interference with door mechanisms.

The cabinet shall be provided with two removable lifting eyes for placing the cabinet on its foundation. Each eye opening shall have a minimum diameter of ¾ in. Each lifting eye shall be able to support a weight limit of 1,000 lbs.

The cabinet shall be equipped by the with an internal cable management system. The cable management system shall be comprised of nonconductive channels designed to facilitate wire and cable routing within an electrical enclosure.

All shelving used on the Power and Auxiliary side of the cabinet shall be constructed of .125-gauge aircraft grade aluminum or mold steel and designed to support a minimum of 250 lbs. The shelves shall be securely attached to the 19-in. cage.

M10.01.1.B: Cabinet Configuration

The cabinet shall be supplied with two side-by-side, 19-in. rack cages which shall extend from the bottom to the top of the cabinet. The cabinet front shall provide for user interface to the in-cabinet equipment including the front panel of the controller, the cabinet status displays and detection system control interfaces. The cabinet rear shall provide access for termination of field cables and shall only be accessed for installation and for cabinet troubleshooting. The left-side rack of the cabinet relative to facing the cabinet from the front, to be referred to as the “Control” side, shall house the control devices such as the Controller, Cabinet Monitor Unit (CMU) and Auxiliary Display Unit (ADU), switch packs, and the power distribution panel. As such, this rack shall be referred to as the “Control” side of the cabinet. The right-side rack of the cabinet relative to facing the cabinet from the front, to be referred to as the “Power and Auxiliary” side, shall house the spare card cage assembly, battery back-up devices (if required), communications elements and future ancillary devices.

M10.01.1.C: Cabinet Doors

The cabinet shall be supplied with four main doors: two on the front face and two on the back face. Each door shall open independently with an independent center post latching for each of the four doors. The front control door shall be defined as the “primary” door; the remaining three main doors shall be defined as “secondary” doors.

The cabinet main doors shall be provided with a stop to limit door opening to both 90° and 180° ±10°. The door stop bars shall be a captive-type mechanism that serves to keep the bars in contact with the cabinet at both stop bar ends and provided with a catch that can be operated when the doors reach these two positions and shall hold the doors open securely until released. The cabinet shall be supplied with a three-point draw roller latching system consisting of the following latching points:

- Center of the cabinet (lock)
- Top of the cabinet – controlled by door handle
- Bottom of the cabinet – controlled by door handle

The latching points on the top and bottom of the cabinet doors shall remain in the locked position until the door locks are disengaged. The locking mechanism shall be equipped with nylon rollers to secure the top and bottom of the doors.

The cabinet shall be supplied with a ¾-in. diameter shank, stainless steel latching handle for each door. The latching handle shall have a provision for padlocking the door in a closed position. The cabinet shall have a pliable seal composed of caulking compound or mastic installed between the cabinet base and the concrete foundation and in between the riser base and the cabinet to prevent dust and dirt from entering the cabinet.

M10.01.1.D: Internal Cabinet Lighting

The cabinet shall be supplied with white LED light panels which shall automatically illuminate via a door open switch whenever any one of the four main cabinet doors are opened. The LED panels shall produce a minimum of 1,000 lumens on the Control side of the cabinet and 1,000 lumens on the Power/Auxiliary side of the cabinet and be protected by a clear shatterproof shield. The cabinet shall contain four light panels: two at the top of each rack assembly and two at the bottom portion of each rack assembly. There shall be two switches on each of the four main doors. LED light panel mounting brackets shall be installed such that they do not interfere with the unused rack mounting holes which could potentially conflict with the installation of future rack mounted devices. The second door switch shall be used to monitor when the door has been opened. The front control side door monitoring switch shall be connected to one of the door status inputs of the controller. The door monitoring switches for the remaining doors shall be connected to the second door status input to the controller. The door status inputs shall log a report event that one of the doors was opened.

M10.01.1.E: Cabinet Fans

The cabinet shall be provided with thermostatically controlled ventilating fans and throwaway glass fiber air filters. The electric fans shall have ball or roller bearings and shall have a capacity of 100 ft^3 per minute. The fans shall be rated for continuous duty with a minimum service life of 3 years. The fan blades shall be supplied with a safety screen to prevent accident contact with the blades. The ventilating system shall be designed to prevent the entrance of rain, snow, dust, and insects. The fans and vents shall be arranged in such a manner that the air intake is at the cabinet bottom and the exhaust is at the cabinet top. The air intake shall be rain tight and covered with a removable glass fiber air filter. The removable air filter shall be firmly held in place with aluminum louvered backing plate such that cracks, and openings are eliminated to ensure that all air is filtered. The cabinet shall contain two fans. The thermostat panel shall be mounted to the top, rear of the cabinet's 19-in. equipment rack and oriented to be clearly visible allowing user adjustable temperature settings from a minimum of 70°F to 140°F and capable of activating the fans within plus or minus five degrees of the set temperature; the thermostat shall be initially set to 100°F. Any exposed terminals shall be covered to protect a technician's hand. There shall be two intake vents provided with the cabinet, one in each front door.

M10.01.1.F: Cabinet Switches/Manual Control

The cabinet shall be supplied with a police door panel located in the middle area of the front door on the Power and Auxiliary side. The switches shall be mounted in the police panel and labelled as to function. The three switches shall be supplied as follows:

- Signal On/Off
- Signal/Flash
- Manual/Auto with cord

The manual control cord shall be a coiled type, sealed weatherproof covered hand switch extending to 6 ft when fully stretched. The cord shall be fastened to the cabinet via a compression type connector to provide strain relief for the cord's electrical connections. The police door panel shall be of sufficient size so as to store the manual control cord when panel door is closed.

The cabinet shall be supplied with a technician's panel mounted integral to the front of the input/output rack assemblies. This panel shall be supplied with the following switches:

- Flash/Auto (Allows the controller to cycle while flashing)
- Signals On/Off (Allows the controller to cycle with signal displays being dark)
- Stop Time Normal/On (Provides the ability to manually activate a controller stop time input)

M10.01.1.G: Slide Out Tray

The cabinet shall contain a pull-out drawer, 19-in. wide with sufficient strength to hold a laptop computer. The top of the drawer shall be covered with a non-conductive, non-skid material and hinged such that a storage space is available to store cabinet documentation or small parts. The pull-out drawer shall be located in the Power and Auxiliary side below the first top unused empty shelf.

M10.01.1.H: Spare Devices

The cabinet shall be supplied with a Spare Lateral Rack (SLR) assembly. This rack assembly shall not be wired to any cabinet device, but rather used to store spare rack mounted cabinet devices such as switch packs, isolators, serial interface units (SIUs), CMUs and phase selectors. This spare rack assembly shall be located at the top of the Power and Auxiliary rack.

In addition to the full complement of switch packs, flashers, SIU's and flash transfers relays, 2 additional SIU's, 32 additional Phoenix connectors, and 1 additional CMU USB datakey programmer tool with software shall be supplied. All spare equipment required to be supplied with the cabinet shall be stored in the SLR and any additional spare equipment shall be placed on the Power and Auxiliary side shelves. No spare equipment shall be placed on the interior cabinet foundation.

M10.01.1.I: Input and Output Channels

The cabinet shall be supplied with one of the following Input and Output Channel configurations, as called for in the Plans or Special Provisions:

- 32 Output Channels and 48 Input Channels
- 32 Output Channels and 24 Input Channels

- 16 Output Channels and 24 Input Channels

M10.01.2: P1 ATC Cabinet

M10.01.2.A: Cabinet Enclosure

The cabinet size and functional requirements shall conform to the NEMA TS2-2016 Standard, Section 7.

The cabinet enclosure shall be a dust and moisture-proof aluminum housing with an auxiliary door in door feature. The cabinet shall be configured to eliminate arc flash. All electrical equipment shall be dead front, no open terminals, busbars, breakers, or exposed terminal strips. All cabinet switches and circuit breakers shall be permanently labeled as to function. The cabinet shall be designed, constructed, and installed with all necessary provisions to comply with the latest NFPA 70E requirements. All electrically live contact points over 50V shall be covered with Lexan or a suitable physical barrier to eliminate the possibility of arc flash.

The lock for the police door switch compartment shall unlock with a skeleton style (#1) key. The lock for the main door(s) of the cabinet shall unlock with a Corbin #2 key. Two sets of two keys (main door/police door) shall be furnished with each cabinet.

The cabinet shall be supplied with a permanent label mounted on the upper portion of the inside front main door that shall contain the name of the cabinet manufacturer, controller manufacturer, model/part number and year/month of assembly.

The cabinet shall be supplied with a GFCI duplex outlet and a rack mounted multi-outlet strip.

The quantity, size and location of the equipment shall correspond to the contract drawings for the ATC Cabinet. All equipment shall be installed with the correct number of mounting screws/mounting support devices. All internal cabinet wiring shall be routed such that there is no conflict for access to cabinet devices or interference with door mechanisms.

The cabinet shall be provided with two removable lifting eyes for placing the cabinet on its foundation. Each eye opening shall have a minimum diameter of ¾ in. Each lifting eye shall be able to support a weight limit of 1,000 lbs.

M10.01.2.B: Cabinet Configuration

The cabinet shall be supplied with three shelves. The top two shelves shall be supplied with two side by side 19” rack support systems. The cabinet front shall provide for user interface to the in-cabinet equipment including the front panel of the controller, the cabinet status displays and detection system control interfaces as well as provide access to the field cable terminations.

M10.01.2.C: Cabinet Doors

The cabinet shall be supplied with one main door. The main door shall be defined as the “primary” door The cabinet main door shall be provided with a stop to limit door opening to both 90° and 180° ±10°. The door stop bars shall be a captive type mechanism that serves to keep the bars in contact with the cabinet at both stop bar ends and provided with a catch that can be operated when the doors reaches these 2 positions and shall hold the doors open securely until released. The cabinet shall be supplied with a three-point draw roller latching system consisting of the following latching points:

- Center of the cabinet (lock)
- Top of the cabinet – controlled by door handle
- Bottom of the cabinet – controlled by door handle

The latching points on the top and bottom of the cabinet doors shall remain in the locked position until the door locks are disengaged. The locking mechanism shall be equipped with nylon rollers to secure the top and bottom of the doors.

The cabinet shall be supplied with a ¾-in. diameter shank, stainless steel latching handle for each door. The latching handle shall have a provision for padlocking the door in a closed position. The cabinet shall have a pliable seal composed of caulking compound or mastic installed between the cabinet base and the concrete foundation and in between the riser base and the cabinet to prevent dust and dirt from entering the cabinet.

M10.01.2.D: Internal Cabinet Lighting

The cabinet shall be supplied with white LED light panels which shall automatically illuminate via a door open switch whenever the main cabinet door is opened. The LED panels shall produce a minimum of 1,000 lumens and be protected by a clear shatterproof shield. The cabinet shall contain two light panels: one at the top of the cabinet and one at the bottom portion of the cabinet. There shall be two switches on the main door. LED light panel mounting brackets shall be installed such that they do not interfere with the installation of any in cabinet devices. A second door open status switch shall activate a controller input to log a report event that one of the doors was opened.

M10.01.2.E: Cabinet Fans

The cabinet shall be provided with thermostatically controlled ventilating fans and throwaway glass fiber air filters. The electric fans shall have ball or roller bearings and shall have a capacity of 100 ft^3 per minute. The fans shall be rated for continuous duty with a minimum service life of 3 years. The fan blades shall be supplied with a safety screen to prevent accident contact with the blades. The ventilating system shall be designed to prevent the entrance of rain, snow, dust, and insects. The fans and vents shall be arranged in such a manner that the air intake is at the cabinet bottom and the exhaust is at the cabinet top. The air intake shall be rain tight and covered with a removable glass fiber air filter. The removable air filter shall be firmly held in place with aluminum louvered backing plate such that cracks, and openings are eliminated to ensure that all air is filtered. The cabinet shall contain two fans. The thermostat shall be mounted on the top interior of the cabinet and user adjustable to allow for temperature settings from a minimum of 70°F to 140°F and capable of activating the fans within plus or minus five degrees of the set temperature; the thermostat shall be initially set to 100°F. Any exposed terminals shall be covered to protect a technician's hand. There shall be one intake vent provided with the cabinet in the front door.

M10.01.2.F: Cabinet Switches/Manual Control

The cabinet shall be supplied with a police door panel located in the middle area of the front door. The switches shall be mounted in the police panel and labelled as to function. The three switches shall be supplied as follows:

- Signal On/Off
- Signal/Flash
- Manual/Auto with cord

The manual control cord shall be a coiled type, sealed weatherproof covered hand switch extending to six ft when fully stretched. The cord shall be fastened to the cabinet via a compression type connector to provide strain relief for the cord's electrical connections. The police door panel shall be of sufficient size so as to store the manual control cord when panel door is closed.

The cabinet shall be supplied with a technician's panel mounted integral to the front of the input/output rack assemblies. This panel shall be supplied with the following switches:

- Flash/Auto (Allows the controller to cycle while flashing)
- Signals On/Off (Allows the controller to cycle with signal displays being dark)
- Stop Time Normal/On (Provides the ability to manually activate a controller stop time input)

M10.01.2.G: Slide Out Tray

The cabinet shall contain a pull-out drawer, 19-in. wide with sufficient strength to hold a laptop computer. The top of the drawer shall be covered with a non-conductive, non-skid material and hinged such that a storage space is available to store cabinet documentation or small parts. The pull-out drawer shall be located under the top shelf on the left-hand side.

M10.01.2.H: Spare Devices

In addition to the full complement of switch packs, flashers, SIU's and flash transfers relays; 2 additional SIU's, 32 additional Phoenix connectors, and 1 additional CMU USB datakey programmer tool with software shall be supplied. All spare equipment required to be supplied with the cabinet shall be stored on the lower shelf. No spare equipment shall be placed on the interior cabinet foundation.

M10.01.2.I: Input and Output Channels

The cabinet shall be supplied with one of the following Input and Output Channel configurations, as called for in the Plans or Special Provisions:

- 32 Output Channels and 48 Input Channels
- 32 Output Channels and 24 Input Channels
- 16 Output Channels and 24 Input Channels

M10.01.3: 352 ATC Cabinet

M10.01.3.A: Cabinet Enclosure

The cabinet size and functional requirements shall conform to the Caltrans Transportation Electrical Equipment Specifications (TEES), 2020 for cabinet size 352.

The traffic signal control equipment shall be enclosed within a dust and moisture-proof aluminum housing with an auxiliary door in door feature. The cabinet shall be configured to eliminate arc flash. All electrical equipment shall be dead front, no open terminals, busbars, breakers, or exposed terminal strips. All cabinet switches and circuit breakers shall be permanently labeled as to function. The cabinet shall be designed, constructed, and installed with all necessary provisions to comply with the latest NFPA 70E requirements. All electrically live contact points over 50V shall be covered with Lexan or a suitable physical barrier to eliminate the possibility of arc flash.

The lock for the police door switch compartment shall unlock with a skeleton style (#1) key. The lock for the main door(s) of the cabinet shall unlock with a Corbin #2 key. Two sets of two keys (main door/police door) shall be furnished with each cabinet.

The cabinet shall be supplied with a permanent label mounted on the upper portion of the inside front main door that shall contain the name of the cabinet manufacturer, controller manufacturer, model/part number and year/month of assembly.

The cabinet shall be supplied with a GFCI duplex outlet, as well as a cabinet mounted multi-outlet strip.

The quantity, size and location of the equipment shall correspond to the contract drawings for the ATC cabinet. All equipment shall be installed with the correct number of mounting screws/mounting support devices. All internal cabinet wiring shall be routed such that there is no conflict for access to cabinet devices or interference with door mechanisms.

The cabinet shall be provided with two lifting eyes for placing the cabinet on its foundation. Each eye opening shall have a minimum diameter of ¾ in. Each lifting eye shall be able to support a weight limit of 1,000 lb.

M10.01.3.B: Cabinet Configuration

The cabinet shall be supplied with a single 19-in. rack cage which shall extend from the bottom to the top of the cabinet. The cabinet front shall provide for user interface to the in-cabinet equipment including the front panel of the controller, the cabinet status displays and detection system control interfaces as well as provide access to the field cable terminations.

M10.01.3.C: Cabinet Doors

The cabinet shall be supplied with two main doors: one on the front face and one on the back face. The front control door shall be defined as the “primary” door; the rear door shall be defined as “secondary” door.

The cabinet main doors shall be provided with a stop to limit door opening to both 90° and 180° ±10°. The door stop bars shall be a captive-type mechanism that serves to keep the bars in contact with the cabinet at both stop bar ends and provided with a catch that can be operated when the doors reach these 2 positions and shall hold the doors open securely until released. The cabinet shall be supplied with a three-point draw roller latching system consisting of the following latching points:

- Center of the cabinet (lock)
- Top of the cabinet – controlled by door handle
- Bottom of the cabinet – controlled by door handle

The latching points on the top and bottom of the cabinet doors shall remain in the locked position until the door locks are disengaged. The locking mechanism shall be equipped with nylon rollers to secure the top and bottom of the doors.

The cabinet shall be supplied with a ¾-in. diameter shank, stainless steel latching handle for each door. The latching handle shall have a provision for padlocking the door in a closed position. The cabinet shall have a pliable seal composed of caulking compound or mastic installed between the

cabinet base and the concrete foundation and in between the riser base and the cabinet to prevent dust and dirt from entering the cabinet.

M10.01.3.D: Internal Cabinet Lighting

The cabinet shall be supplied with white LED light panels which shall automatically illuminate via a door open switch whenever any one of the two main cabinet doors are opened. The LED panels shall produce a minimum of 1,000 lumens and be protected by a clear shatterproof shield. The cabinet shall contain two light panels: one at the top of the rack assembly and one at the bottom portion of the rack assembly. There shall be two switches on each of the two main doors. LED light panel mounting brackets shall be installed such that they do not interfere with the unused rack mounting holes which could potentially conflict with the installation of future rack mounted devices. A second door open status switch per door shall activate a controller input to log a report event that one of the doors was opened. The door open status switches shall be connected to separate controller inputs.

M10.01.3.E: Cabinet Fans

The cabinet shall be provided with a thermostatically controlled ventilating fan and throwaway glass fiber air filter. The electric fan shall have ball or roller bearings and shall have a capacity of 100 ft^3 per minute. The fan shall be rated for continuous duty with a minimum service life of 3 years. The fan blades shall be supplied with a safety screen to prevent accident contact with the blades. The ventilating system shall be designed to prevent the entrance of rain, snow, dust, and insects. The fan and vent shall be arranged in such a manner that the air intake is at the cabinet bottom and the exhaust is at the cabinet top. The air intake shall be rain tight and covered with a removable glass fiber air filter. The removable air filter shall be firmly held in place with aluminum louvered backing plate such that cracks, and openings are eliminated to ensure that all air is filtered. The cabinet shall contain one fan. The thermostat panel shall be mounted to the top, rear of the cabinet's 19-in. equipment rack and oriented to be clearly visible allowing user adjustable temperature settings from a minimum of 70°F to 140°F and capable of activating the fans within plus or minus five degrees of the set temperature; the thermostat shall be initially set to 100°F. Any exposed terminals shall be covered to protect a technician's hand. There shall be one intake vent provided with the cabinet in the front door.

M10.01.3.F: Cabinet Switches/Manual Control

The cabinet shall be supplied with a police door panel located in the middle area of the front door. The switches shall be mounted in the police panel and labelled as to function. The three switches shall be supplied as follows:

- Signal On/Off
- Signal/Flash
- Manual/Auto with cord

The manual control cord shall be a coiled type, sealed weatherproof covered hand switch extending to six ft when fully stretched. The cord shall be fastened to the cabinet via a compression type connector to provide strain relief for the cord's electrical connections. The police door panel shall be of sufficient size so as to store the manual control cord when panel door is closed.

The cabinet shall be supplied with a technician's panel mounted integral to the front of the input/output rack assemblies. This panel shall be supplied with the following switches:

- Flash/Auto (Allows the controller to cycle while flashing)
- Signals On/Off (Allows the controller to cycle with signal displays being dark)
- Stop Time Normal/On (Provides the ability to manually activate a controller stop time input)

M10.01.3.G: Slide Out Tray

The cabinet shall contain a pull-out drawer, 19-in. wide with sufficient strength to hold a laptop computer. The top of the drawer shall be covered with a non-conductive, non-skid material and hinged such that a storage space is available to store cabinet documentation or small parts. The pull-out drawer shall be located in the rack directly under the 24 channel input assembly.

M10.01.3.H: Spare Devices

In addition to the full complement of switch packs, flashers, SIU's and flash transfers relays; 2 additional SIU's, 32 additional Phoenix connectors, and 1 additional CMU USB datakey programmer tool with software shall be supplied. All spare equipment required to be supplied with the cabinet shall be delivered to the Department.

M10.01.3.I: Input and Output Channels

The cabinet shall be supplied with 16 output channels and 24 input channels.

M10.01.4: 336S ATC Cabinet

M10.01.4.A: Cabinet Enclosure

The cabinet size and functional requirements shall conform to the Caltrans Transportation Electrical Equipment Specifications (TEES), 2020 for cabinet size 332.

The traffic signal control equipment shall be enclosed within a dust and moisture-proof aluminum housing with an auxiliary door in door feature. All cabinets shall be configured to eliminate arc flash. All electrical equipment will be dead front, no open terminals, busbars, breakers, or exposed terminal strips. All cabinet switches and circuit breakers shall be permanently labeled as to function. The cabinet shall be designed, constructed, and installed with all necessary provisions to comply with the latest NFPA 70E requirements. All electrically live contact points over 50 volts shall be covered with Lexan or a suitable physical barrier to eliminate the possibility of an arc flash.

The lock for the police door switch compartment shall unlock with a skeleton style (#1) key. The lock for the main door(s) of the cabinet shall unlock with a Corbin #2 key. Two sets of two keys (main door/police door) shall be furnished with each cabinet.

The cabinet shall be supplied with a permanent label mounted on the upper portion of the inside front main door that shall contain the name of the cabinet manufacturer, controller manufacturer, model/part number and year/month of assembly.

The cabinet shall be supplied with a GFCI duplex outlet, as well as a rack mounted multi-outlet strip.

The quantity, size and location of the equipment shall correspond to the contract drawings for the ATC cabinet. All equipment shall be installed with the correct number of mounting screws/mounting support devices. All internal cabinet wiring shall be routed such that there is no conflict for access to cabinet devices or interference with door mechanisms.

The cabinet shall be provided with two lifting eyes for placing the cabinet on its mount. Each eye opening shall have a minimum diameter of ¾ in. Each lifting eye shall be able to support a weight limit of 1,000 lb.

The cabinet shall be equipped by the with an internal cable management system. Comprised of nonconductive channels designed to facilitate wire and cable routing within an electrical enclosure.

M10.01.4.B: Cabinet Configuration

The cabinet shall be supplied with a single 19-in. rack cage which shall extend from the bottom to the top of the cabinet. The cabinet front shall provide for user interface to the in-cabinet equipment including the front panel of the controller, the cabinet status displays and detection system control interfaces. The cabinet rear shall provide access for field cable termination and shall only be accessed for installation and for cabinet troubleshooting.

M10.01.4.C: Cabinet Doors

The cabinet shall be supplied with two doors: one on the front face and one on the back face. The front main door shall be defined as the "primary" door; the rear main door shall be defined as the "secondary" door.

The cabinet main doors shall be provided with a stop to limit door opening to both 90° and 180° ±10°. The door stop bars shall be a captive type mechanism that serves to keep the bar in contact with the cabinet at both stop bar ends and provided with a catch that can be operated when the doors reaches these 2 positions and will hold the doors open securely until released. The cabinet shall be supplied with a three-point draw roller latching system consisting of the following latching points:

- Center of the cabinet (lock)
- Top of the cabinet – controlled by door handle
- Bottom of the cabinet – controlled by door handle

The latching points on the top and bottom of the cabinet doors shall remain in the locked position until the door locks are disengaged. The locking mechanism shall be equipped with nylon rollers to secure the top and bottom of the doors.

The cabinet shall be supplied with a ¾-in. diameter shank, stainless steel latching handle for each door. The latching handle shall have a provision for padlocking the door in a closed position. The cabinet shall have a pliable seal composed of caulking compound or mastic installed between the cabinet base and the concrete foundation and in between the riser base and the cabinet to prevent dust and dirt from entering the cabinet.

M10.01.4.D: Internal Cabinet Lighting

The cabinet shall be supplied with white LED light panels which shall automatically illuminate via a door open switch whenever any one of the two main cabinet doors are opened. The LED panels

shall produce a minimum of 1,000 lumens and be protected by a clear shatterproof shield. The cabinet shall contain two light panels: one at the top of the rack assembly and one at the bottom portion of the rack assembly. There shall be two switches on each of the two main doors. LED light panel mounting brackets shall be installed such that they do not interfere with the unused rack mounting holes which could potentially conflict with the installation of future rack mounted devices. A second door open status switch per door shall activate a controller input to log a report event that one of the doors was opened. The door open status switches shall be connected to separate controller inputs.

M10.01.4.E: Cabinet Fans

The cabinet shall be provided with a thermostatically controlled ventilating fan and throwaway glass fiber air filter. The electric fan shall have ball or roller bearings and shall have a capacity of 100 ft^3 per minute. The fan shall be rated for continuous duty with a minimum service life of 3 years. The fan blades shall be supplied with a safety screen to prevent accident contact with the blades. The ventilating system shall be designed to prevent the entrance of rain, snow, dust, and insects. The fan and vent shall be arranged in such a manner that the air intake is at the cabinet bottom and the exhaust is at the cabinet top. The air intake shall be rain tight and covered with a removable glass fiber air filter. The removable air filter shall be firmly held in place with aluminum louvered backing plate such that cracks, and openings are eliminated to ensure that all air is filtered. The cabinet shall contain one fan. The thermostat panel shall be mounted to the top, rear of the cabinet's 19-in. equipment rack and oriented to be clearly visible allowing user adjustable temperature settings from a minimum of 70°F to 140°F and capable of activating the fans within plus or minus five degrees of the set temperature; the thermostat shall be initially set to 100°F. Any exposed terminals shall be covered to protect a technician's hand. There shall be one intake vent provided with the cabinet in the front door.

M10.01.4.F: Cabinet Switches/Manual Control

The cabinet shall be supplied with a police door panel located in the middle area of the front door. The switches shall be mounted in the police panel and labelled as to function. The three switches shall be supplied as follows:

- Signal On/Off
- Signal/Flash
- Manual/Auto with cord

The manual control cord shall be a coiled type, sealed weatherproof covered hand switch extending to six ft when fully stretched. The cord shall be fastened to the cabinet via a compression type connector to provide strain relief for the cord's electrical connections. The police door panel shall be of sufficient size so as to store the manual control cord when panel door is closed.

The cabinet shall be supplied with a technician's panel mounted integral to the front of the input/output rack assemblies. This panel shall be supplied with the following switches:

- Flash/Auto (Allows the controller to cycle while flashing)
- Signals On/Off (Allows the controller to cycle with signal displays being dark)
- Stop Time Normal/On (Provides the ability to manually activate a controller stop time input)

M10.01.4.G: Slide Out Tray

The cabinet shall contain a pull-out drawer, 19-in. wide with sufficient strength to hold a laptop computer. The top of the drawer shall be covered with a non-conductive, non-skid material and hinged such that a storage space is available to store cabinet documentation or small parts. The pull-out drawer shall be located in the rack directly under the controller.

M10.01.4.H: Spare Devices

In addition to the full complement of switch packs, flashers, SIU's and flash transfers relays; 2 additional SIU's, 32 additional Phoenix connectors, and 1 additional CMU USB datakey programmer tool with software shall be supplied. All spare equipment required to be supplied with the cabinet shall be delivered to the Department.

M10.01.4.I: Input and Output Channels

The cabinet shall be supplied with 16 output channels and 24 input channels.

M10.02.0: Advanced Transportation Controller

All Advanced Transportation Controllers (ATC) shall be solid state, menu driven, keyboard units.

The Contractor shall supply a rack-mounted ATC unless otherwise indicated in the Plans or Special Provisions.

The ATC shall be supplied with the latest firmware. The ATC firmware shall be upgradeable via a USB connection at the front of the controller. No additional software shall be required to perform this function. The ATC shall be supplied with a manufacture's Software Development Kit (SDK) for the supplied firmware version to allow for future system modifications/expansions.

The ATC shall be able to backup and restore programing data via a USB connection at the front of the controller. No additional software shall be required to perform this function.

No additional hardware, software items, licenses, and/or subscription fees/costs shall be needed or allowed to satisfy the ATC requirements as defined in these specifications.

The ATC shall be supplied with all necessary interfaces needed to support Advanced Transportation Controller Cabinet (ATCC) / Serial Interface Unit (SIU) communications.

M10.02.0.A: Compliance with Standards

The ATC conform to or be compliant with the following standards:

- ATC 5201 Standard v06.25
- NTCIP 1201 and 1202
- NEMA TS2-2016, including all amendments

The ATC shall contain Application Programming Interface (API) software conforming to ATC 5401 Standard v02.

M10.02.0.B: Operating Environment

The ATC shall be configured to operate in an ATCC 5301 v02 cabinet platform conforming to M10.01.0: Advanced Transportation Controller Cabinets (General) unless otherwise indicated in the Plans or Special Provisions.

M10.02.0.C: Operating System

The ATC shall be supplied with the appropriate version of the Linux operating system, Board Support Package (BSP) and internal processing levels necessary to support connected vehicle (CV) as well as local and system operations.

The ATC shall be supplied with programming documentation fully defining the coding (compiler and C libraries) used to create the ATC controller applications residing in the unit.

The ATC shall be supplied with the source code used to produce and support the Linux kernel environment.

M10.02.0.D: Serial Interface Ports

The ATC shall have a minimum of two SDLC ports.

The ATC shall have a minimum of three Universal Serial Bus (USB) ports. The ports shall conform to USB v2.0 or later.

The ATC shall have a minimum of three 10/100BaseT, RJ45 ethernet connector ports.

All data communication connectors shall be supplied and installed with an outer boot molded cover designed specifically for the connector to ensure physical protection for the connector wire terminations. There shall be no exposed wires visible between the connector and the cable insulated jacket.

M10.02.0.E: User Interface

The ATC shall contain the ability to alter the controller unit's internal database using a built-in front panel keyboard, using a computer connected to the controller unit with a USB cable or an Ethernet cable, and remotely using a central management system application. In addition, a remote access system shall be provided using HTTPS.

The ATC shall contain real-time context sensitive Help screens.

The Real-Time Clock (RTC) shall be capable of daily, weekly, and yearly event time programming via a scheduler.

A user shall have the ability to alter the controller unit's internal database using a built-in front panel keyboard, using a computer connected to the controller unit with a USB cable or an Ethernet cable, and remotely using the central management system application.

M10.02.0.F: Functional Requirements

The ATC shall support the following:

- A minimum of 8 vehicle/pedestrian phases and 8 overlaps.
- The ability to provide 12 unique preemption/priority inputs.
- Dedicated phase detection inputs, pedestrian detection inputs, and system detection inputs.
- Flashing Yellow Arrow (FYA) and Flashing Red Arrow (FRA) operation with the ability to provide a minimum of 6 flashing pairs.
- An internal database which stores all configurable parameters, including but not limited to phase timings, phase sequencing, overlaps, coordination parameters, preemption and priority parameters, time base parameters, communications parameters, detection parameters, flashing operation parameters, and security parameters.
- The ability to generate user defined alarms and alerts.
- Detector failure algorithms that initiate user defined actions when user defined criteria are met.

The ATC shall not utilize internal logic processing or script programming to directly control conditional timing or operation of vehicle or pedestrian field signal circuits.

M10.02.0.G: Transit Signal Priority

The ATC shall support Transit Signal Priority (TSP) without the need for additional software, hardware, data key device or any recurring licensing fees. TSP shall be available during both coordinated and free operation and shall include the following:

- TSP shall support a minimum of six priority routines.
- The TSP program shall be capable of extending the priority phase green time and truncating the non-priority phase(s) green when a priority call is received by the ATC unit.
- TSP operation shall not cause the ATC unit to skip any phases that have active vehicle/pedestrian demand.
- Emergency vehicle preemption (EVP) shall override TSP operation.
- The TSP program shall have the ability to delay and/or extend priority calls.
- The TSP program shall have the ability to support user defined time periods between servicing valid priority calls.
- All TSP events shall be logged (time/date stamped) in the ATC unit.
- The TSP algorithm shall allow for non-TSP phases to be conditionally truncated based on the absence of a concurrent pedestrian service of the non-TSP phase.
- It shall be possible to user define in the traffic controller a minimum time between responses to priority calls.

Under coordinated operation, the controller shall modify existing signal operation to accommodate a priority call. This may include modification to per phase termination points established under normal coordinated control. During a priority event, per phase coordination modes shall remain in effect. Priority and non-priority phase duration shall be user programmable per coordination pattern.

Under free operation, upon receipt of a valid priority call, the controller shall either extend the priority phase or reduce the non-priority(s). These settings for the adjusted green times shall be user defined, on a per phase basis, and adjustable on a time-of-day basis.

M10.02.0.H: Reporting

The ATC shall be supplied with all necessary hardware, software elements and instruction procedures needed to facilitate the extraction and processing of Automated Traffic Signal Performance Measures (ATSPM) data.

The ATC shall collect and process all 255 high resolution enumerations as defined in the report "Indiana Traffic Signal Hi Resolution Data Logger Enumerations." This data will be processed in the controller and available via download from the controller USB Ethernet port or, if available, via system communications.

At a minimum, the ATC shall be configured to provide the following performance reports:

- Approach delay
- Preemption events
- Transit Priority Events
- Split Monitor
- Approach Volumes
- Purdue Coordination Diagrams
- Arrivals on Red
- Arrivals on Green
- Phase Termination
- Pedestrian Delay

M10.05.0: Traffic Signal Structures (General)

The bases of all Traffic Signal Structures shall be supplied with a bonding lug.

M10.05.1: Signal Posts and Bases

All Signal Posts shall be one-piece 4-in. diameter, Schedule 40 or Schedule 80, and machine-threaded.

Signal Posts may be fabricated from aluminum with a brushed or spun finish or from steel with a galvanized finish.

The interior of Signal Posts shall be coated as specified in Underwriters Laboratories UL-6 for enameled conduit, or aluminum conduit conforming to M5.07.1: Electrical Conduit-Rigid Metallic (Type RM).

Signal Posts Bases shall be fabricated to accept the threads from the Signal Post and locked into place with set screws.

Signal Post Bases shall be fabricated from aluminum with a natural or anodized finish or galvanized cast iron.

Signal Post Bases shall be square or octagonal.

Signal Posts and Bases conform to Table M10.05.1-1.

Table M10.05.1-1: Signal Post and Base Material Requirements

Component	Material	Specification
Signal Post	Aluminum	6063-T6 (ASTM B221, B429 or B241)
Signal Post	Steel	ASTM A53, Grade A or B
Signal Post Base	Aluminum	356.0-T6 (ASTM B26, B108)
Signal Post Base	Cast Iron	AASHTO M 105

M10.11.0: RRFB Assemblies

Rectangular Rapid Flashing Beacon (RRFB) Assemblies shall consist of a Light Bar and an enclosure for the Controller and Activation Unit.

M10.11.0.A: Light Bar

The Light Bar shall consist of two rapidly-flashed rectangular-shaped yellow indications, each with an LED-array based pulsing light source. The size of each RRFB indication shall conform to the Construction Standard Details.

The light intensity of the yellow indications during daytime conditions shall meet the minimum specifications for Class 1 yellow peak luminous intensity in the publication "Directional Flashing Optical Warning Devices for Authorized Emergency, Maintenance, and Service Vehicles J595," 2005, Society of Automotive Engineers (SAE). A photocell or equivalent device shall be included to reduce the brilliance of the LED beacons during nighttime conditions.

M10.11.0.B: Controller and Activation Unit

The enclosure for the Controller and Activation Unit shall be NEMA rated for outdoor use and protection against rain and sleet.

The Controller and Activation Unit shall be powered by a DC battery/solar array system or a 120 VAC service connection.

The Controller and Activation Unit shall be actuated by a pedestrian pushbutton, a passive pedestrian detection device, or both.

Communications between multiple units within the same system shall be via a 900MHz or 2.4 GHz frequency hopping spread spectrum with a minimum range of 200 ft. Multiple channels shall be available to prevent cross-communication between multiple systems located close to each other.

The Controller shall be programmable via an on-board user interface or a no-fee wireless (Wi-Fi, Bluetooth®, etc.) connection and application.

M10.16.0: Temporary Barrier

All Temporary Barrier shall be tested to MASH crash testing standards, and the results of the following crash test designations must fall within the acceptable impact tolerances and evaluation criteria shown in Table 2-2A of MASH:

- Test Level 2: 2-10, 2-11
- Test Level 3: 3-10, 3-11

M10.16.1: Limited Deflection Temporary Barrier

To be classified as a Limited Deflection Temporary Barrier, the results of MASH Test Designation 3-11 must result in a measured dynamic deflection of 24 in. or less.

M10.16.2: Delineators for Temporary Barrier

Delineators for Temporary Barrier shall consist of a housing, retroreflective material, and an adhesive or mechanical fastener.

Housings for Delineators for Temporary Barrier shall be fabricated from a lightweight polymer material. Metal housings shall not be permitted.

Retroreflection shall be achieved using an acrylic reflector or retroreflective sheeting directly applied to the housing. If used, retroreflective sheeting shall be factory applied and conform to ASTM D4956 Type IV, Type V, or Type IX. A minimum of 8 $in.^2$ of reflective material shall be visible on any traffic-facing portion of the delineator.

Delineators shall be attached to temporary barriers using a manufacturer-approved adhesive or mechanical fastener.