# MassDOT Cement Concrete Pavement Project

**N**orth**E**astern **S**tates **M**aterials **E**ngineers' **A**ssociation

100th Annual Meeting

Springfield, MA

October 15, 2024

massDOT Massachusetts Department of Transportation Highway Division

**N**orth**E**astern **S**tates **M**aterials **E**ngineers' **A**ssociation

HNTB

# Presenters

Richard Mulcahy, P.E.
Materials Research and Evaluation Engineer
MassDOT Research and Materials Section
Richard.Mulcahy@dot.state.ma.us

James Barnack, P.E.
Project Manager/Roadway Section Manager
HNTB
jbarnack@HNTB.com

# Learning Outcomes

- ❑The Long Road Back
- ❑Proposed Design
- ❑Mix Design Formulation and Verification Testing
- ❑Construction Methods
- ❑Lessons Learned and Future Considerations


# The Long Road Back

MassDOT Cement Concrete Pavement Project

NESMEA 100th Annual Meeting

# The Long Road Back

CHARLTON
ROUTE 20

| STATE | FED. AID PROJ. NO. | FISCAL YEAR | SHEET NO. | TOTAL SHEETS |
|---|---|---|---|---|
| MASS. | NFA | 1998 | 1 | 331 |
| RECORD KEY NO. 601617 | | | | |

TITLE SHEET

## THE COMMONWEALTH OF MASSACHUSETTS
## MASSACHUSETTS HIGHWAY DEPARTMENT

PLAN OF

**ROUTE 20**

IN THE TOWN OF

**CHARLTON**

**WORCESTER COUNTY**

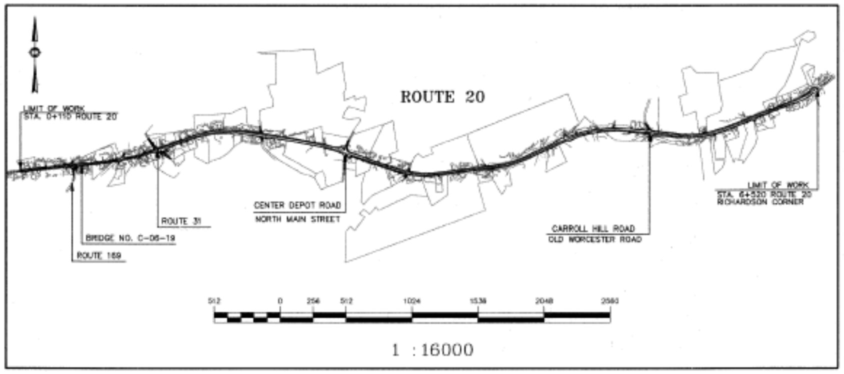
NON-FEDERAL AID PROJECT

### INDEX

| SHEET NO. | DESCRIPTION |
|---|---|
| 1 | TITLE & INDEX |
| 2 | LEGEND, ABBREVIATIONS & GENERAL NOTES |
| 3-4 | GENERAL KEY AND BORING PLANS |
| 5-18 | BORING LOGS |
| 19-25 | TYPICAL SECTIONS |
| 26-43 | TYPICAL DETAILS |
| 44 | MISCELLANEOUS DETAILS |
| 45-85 | GENERAL CONSTRUCTION PLANS |
| 86-107 | PROFILES |
| 108-125 | CURB TIE AND GRADING PLANS |
| 127-139 | RETAINING WALL PLANS |
| 140-174 | DRAINAGE AND EROSION CONTROL PLANS |
| 175-192 | PAVEMENT MARKINGS AND SIGNAGE PLANS |
| 193-199 | TRAFFIC SIGN SUMMARY |
| 200-206a | TRAFFIC SIGNAL PLANS |
| 207-213 | TRAFFIC SIGNAL DETAILS |
| 214-234 | TRAFFIC MANAGEMENT PLANS |
| 235 | CONSTRUCTION SIGN SUMMARY |
| 236-252 | LANDSCAPE PLANS |
| 254-256 | LANDSCAPE DETAILS |
| 257-331 | CROSS SECTIONS |

Note: Sheets 126 & 253 not used.

THE 1995 MASSACHUSETTS STANDARD SPECIFICATIONS FOR HIGHWAYS AND BRIDGES, THE 1994 SUPPLEMENTAL SPECIFICATIONS DATED NOVEMBER 30, 1994, THE 1996 MASSACHUSETTS CONSTRUCTION AND TRAFFIC STANDARD DETAILS, THE 1997 MASSACHUSETTS HIGHWAY DESIGN MANUAL, THE 1988 "MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES FOR STREETS AND HIGHWAYS", THE 1990 "STANDARD DRAWING FOR SIGNS AND SUPPORTS" AND THE AMERICAN STANDARD FOR NURSERY STOCK (ANSU Z-60.1-1986) WILL GOVERN.




### DESIGN DESIGNATION

| | |
|---|---|
| DESIGN SPEED | 80 KM.P.H. |
| ADT (1997) | 21,200 |
| ADT (2017) | 27,000 |
| K | 9% |
| D | 69% |
| T (PEAK HOUR) | 5.0% |
| T (AVERAGE DAY) | 10.0% |
| DHV | 2,420 |
| DDHV | 1,670 |

### CONVENTIONAL SIGNS

EXISTING STATE, OR COUNTY LAYOUT
PROPOSED STATE LAYOUT
SLOPE WORK LIMIT
WETLAND DELINEATION
CONSTRUCTION BASELINE
PROPOSED WALL
EDGE OF PROPOSED ROADWAY
PROPOSED SURFACE
PRESENT SURFACE
ELEVATIONS
POLE

SCALES – AS NOTED

LENGTH OF PROJECT = 6.410 KM

MASS HIGHWAY

MASSACHUSETTS HIGHWAY DEPARTMENT

RECOMMENDED FOR APPROVAL

CHIEF ENGINEER — Date 7/1/98

APPROVED

COMMISSIONER — Date 7/1/98

ASSOCIATE COMMISSIONERS — Date 7/1/98, 7/1/98

The Long Road Back

# 2002: U.S. Route 20, Charlton, MA


# Proposed Design

MassDOT Cement Concrete Pavement Project

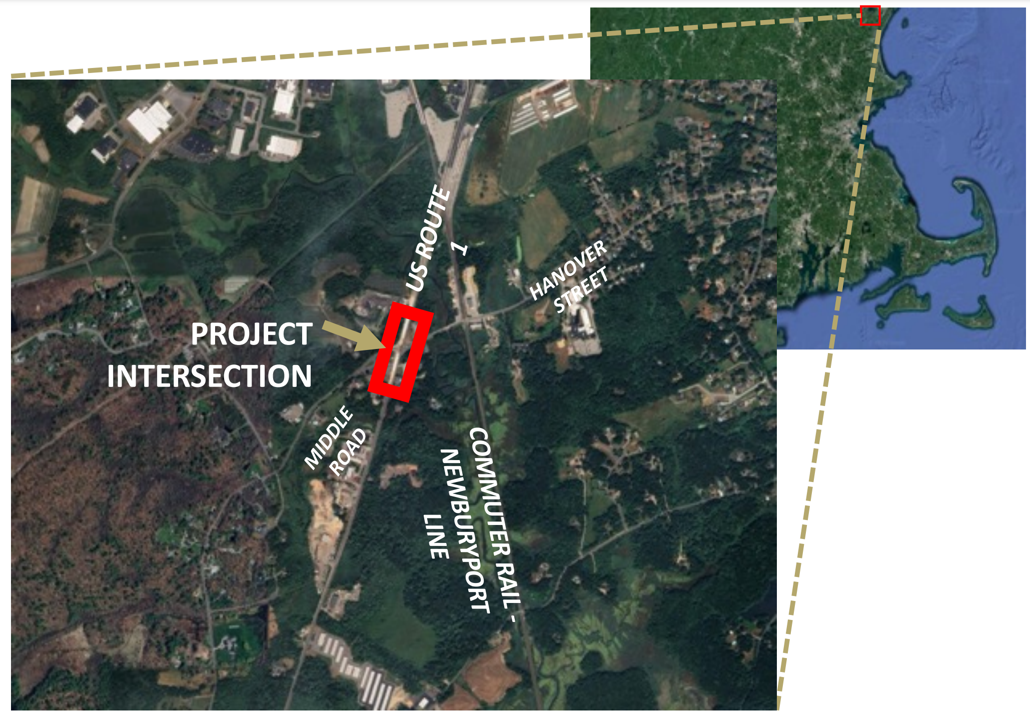
massDOT
Massachusetts Department of Transportation
Highway Division

HNTB

Proposed Design

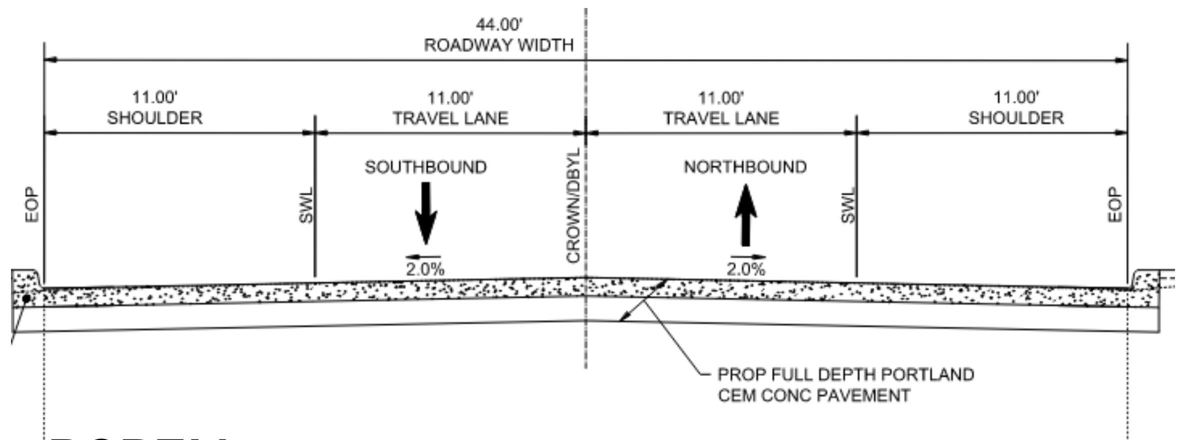
# Project Information

- Newburyport, MA, Route 1 at Middle Rd. / Hanover St. Intersection
- Concrete placed Mid July to Early September 2024
- Low bid estimate $17.1M
- Concrete Intersection ~$2M
- 1st Performance Engineered Mix (PEM) Design
- Heavy truck volumes/minimal underground utilities



Proposed Design

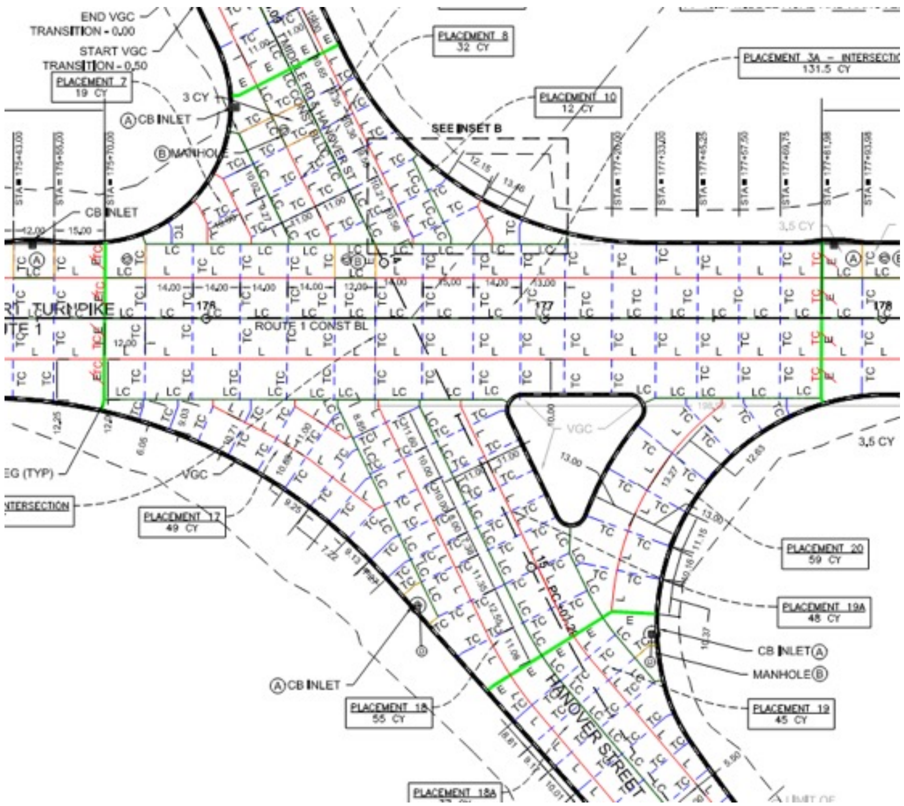
# Cross Section




- 9 Inches PCPEM
- 12 Inch Gravel Borrow Subbase
- 4-foot aggregate shoulder to lock in free edge
- 22-foot wide pours, length varied 12-15 feet

# Proposed Design

# Jointing Layout




- Transverse Contraction (TC) Joints

  18” long-1¼” dia. - 12” o.c.

- Longitudinal (L) Contraction Joints

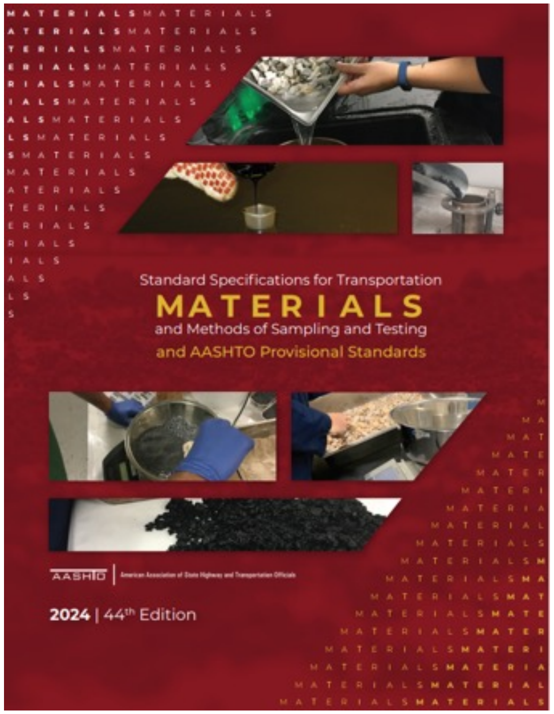
  24” long-¾” dia. - 36” o.c.

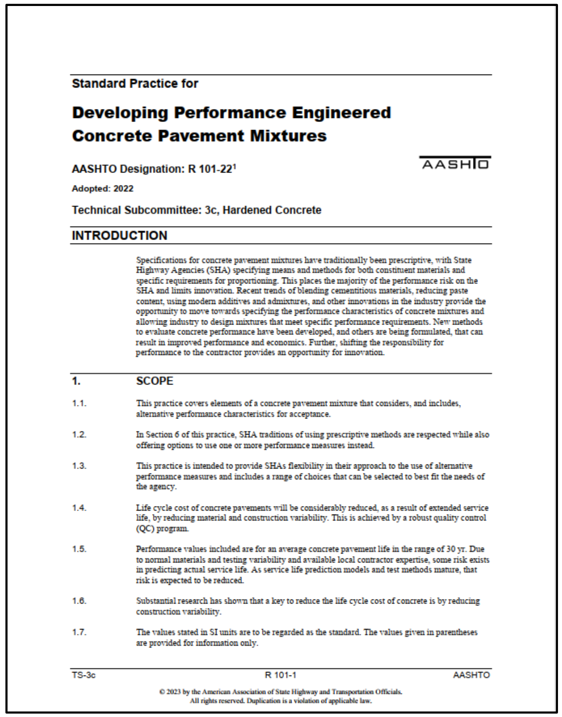
- Longitudinal Construction (LC) Joints
  24” long-#6 bar - 36” o.c.

- Expansion Joints (E)

  18” long 1¼” dia. Grade 60 smooth

  dowel



Standard Practice for

**Developing Performance Engineered Concrete Pavement Mixtures**

AASHTO Designation: R 101-22[1]

AASHTO

Adopted: 2022

Technical Subcommittee: 3c, Hardened Concrete

**INTRODUCTION**

Specifications for concrete pavement mixtures have traditionally been prescriptive, with State Highway Agencies (SHA) specifying means and methods for both constituent materials and specific requirements for proportioning. This places the majority of the performance risk on the SHA and limits innovation. Recent trends of blending cementitious materials, reducing paste content, using modern additives and admixtures, and other innovations in the industry provide the opportunity to move towards specifying the performance characteristics of concrete mixtures and allowing industry to design mixtures that meet specific performance requirements. New methods to evaluate concrete performance have been developed, and others are being formulated, that can result in improved performance and economics. Further, shifting the responsibility for performance to the contractor provides an opportunity for innovation.

**1. SCOPE**

1.1. This practice covers elements of a concrete pavement mixture that considers, and includes, alternative performance characteristics for acceptance.

1.2. In Section 6 of this practice, SHA traditions of using prescriptive methods are respected while also offering options to use one or more performance measures instead.

1.3. This practice is intended to provide SHAs flexibility in their approach to the use of alternative performance measures and includes a range of choices that can be selected to best fit the needs of the agency.

1.4. Life cycle cost of concrete pavements will be considerably reduced, as a result of extended service life, by reducing material and construction variability. This is achieved by a robust quality control (QC) program.

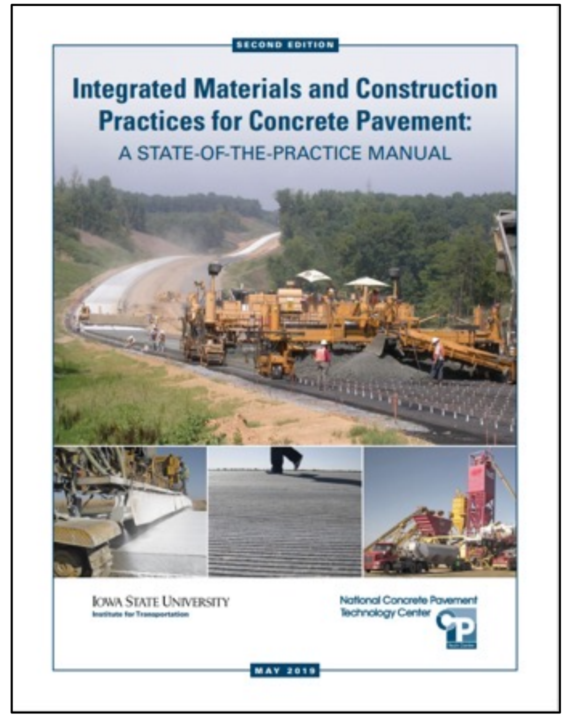
1.5. Performance values included are for an average concrete pavement life in the range of 30 yr. Due to normal materials and testing variability and available local contractor expertise, some risk exists in predicting actual service life. As service life prediction models and test methods mature, that risk is expected to be reduced.

1.6. Substantial research has shown that a key to reduce the life cycle cost of concrete is by reducing construction variability.

1.7. The values stated in SI units are to be regarded as the standard. The values given in parentheses are provided for information only.

TS-3c R 101-1 AASHTO





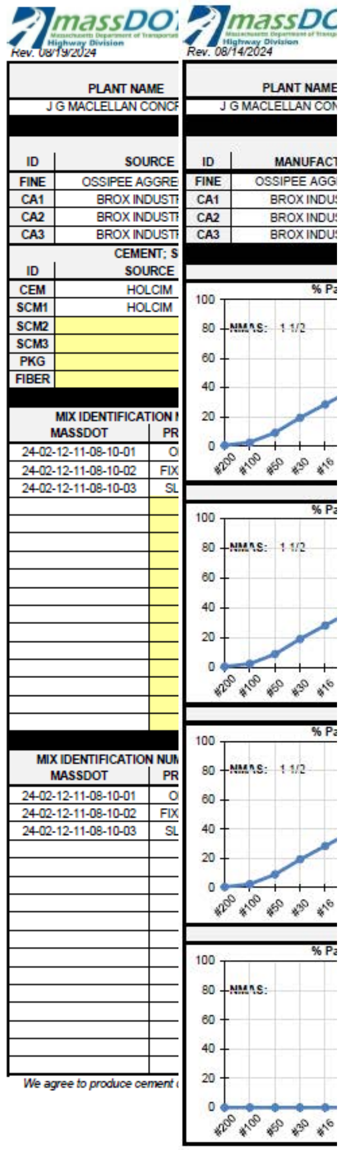

# Mix Design Formulation and Verification Testing

MassDOT Cement Concrete Pavement Project

massDOT Massachusetts Department of Transportation Highway Division

HNTB

# Mix Design Formulation




massDOT Highway Division
Rev. 08/14/2024

## 2024 CEMENT CONCRETE MIX DESIGN AIR VOID AND PASTE SYSTEM ANALYSIS

| PLANT INFORMATION | | MAILING ADDRESS | | | MIX SHEET IDENTIFICATION | |
|---|---|---|---|---|---|---|
| PLANT NAME | LOCATION | STREET NO. & ADDRESS | CITY/TOWN | EMAIL ADDRESS | CONTRACT | SHEET IDENTIFICATION NO. |
| J G MACLELLAN CONCRETE | AMESBURY, MA | 180 Phoenix Ave. | Lowell, MA 01852 | alexm@jgmaclellan.com | | 24-02-12-11-08-10 |

**DESIGN PARAMETERS FOR WORKABILITY AND RESISTANCE TO FREEZING, THAWING, DE-ICING, SHRINKAGE, CRACKING, SULFATE REACTION, CORROSION OF STEEL REINFORCEMENT**

| MIX IDENTIFICATION NO. MASSDOT | PRODUCER | MIX DESIGN TYPE | F'C (PSI) | NMAS (IN.) | S (IN.) | AC (%) | W / CM | PC (%) | $PC_A$ (%) | $VC_{CM}$ (%) | $PC_E$ (%) | $PC_A$ / $VC_{CM}$ | SCM1 (%) | SCM2 (%) | SCM3 (%) | $UW_M$ (PCF) | YIELD (CF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24-02-12-11-08-10-01 | ORIGINAL | PAVEMENT | 7000 | 1 1/2 | 6 | 6.5 | 0.39 | 28.0 | 34.5 | 23.8 | 17.2 | 2.01 | 25.2 | 0.0 | 0.0 | 148.1 | 27.0 |
| 24-02-12-11-08-10-02 | FIXED FORM | PAVEMENT | 5000 | 1 1/2 | 6 | 6.5 | 0.39 | 24.8 | 31.3 | 25.0 | 18.1 | 1.73 | 25.0 | 0.0 | 0.0 | 149.8 | 27.0 |
| 24-02-12-11-08-10-03 | SLIP FORM | PAVEMENT | 4000 | 1 1/2 | 2 | 6.5 | 0.40 | 20.8 | 27.3 | 26.5 | 19.1 | 1.43 | 25.0 | 0.0 | 0.0 | 151.8 | 27.0 |
| 24-02-12-11-08-10-01 | ORIGINAL | PAVEMENT | 7000 | 1 1/2 | 6 | 6.5 | 0.39 | 28.0 | 34.5 | 23.8 | 17.2 | 2.01 | 25.2 | 0.0 | 0.0 | 148.1 | 27.0 |

*Optimized air void systems promote quality concrete properties, including enhanced workability, cohesion, strength, and resistance to freezing, thawing, de-icing, and sulfate reaction. Air-Entraining chemical admixtures or air-entraining materials interground into the cement clinker are used to achieve these quality properties by providing the air void system with sufficient air content and stabilized air bubble distribution. Optimized paste systems promote quality concrete properties, including enhanced workability, bleed rate, setting time, strength, aggregate bonding, concrete reinforcement bonding, and resistance to freezing, thawing, de-icing, sulfate reaction, alkali silica reaction, corrosion of steel reinforcement, drying shrinkage, cracking, and volume change from wetting and drying.*

**Freezing, Thawing, and De-icing Resistance**

| Class | Severity | Condition | Maximum W/CM Ratio: Reinforced | Maximum W/CM Ratio: Non-Reinforced | NMAS (in.) | Minimum Air Content (%): Reinforced < 5000 psi | Reinforced ≥ 5000 psi | Non-Reinforced |
|---|---|---|---|---|---|---|---|---|
| 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 | 0.55 | 3/8 | 6.0 | 5.0 | 7.0 |
| | | | | | 1/2 | 5.5 | 4.5 | 7.0 |
| | | | | | 3/4 | 5.0 | 4.0 | 6.5 |
| | | | | | 1 | 4.5 | 3.5 | 6.5 |
| | | | | | 1 1/2 | 4.5 | 3.5 | 6.0 |
| 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 | 0.45 | 3/8 | SAME MIMIMUM AIR CONTENT REQUIREMENTS AS CLASS F3 | | |
| | | | | | 1/2 | | | |
| | | | | | 3/4 | | | |
| | | | | | 1 | | | |
| | | | | | 1 1/2 | | | |
| 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 | 3/8 | 7.5 | 6.5 | 7.5 |
| | | | | | 1/2 | 7.0 | 6.0 | 7.0 |
| | | | | | 3/4 | 6.0 | 5.0 | 7.0 |
| | | | | | 1 | 6.0 | 5.0 | 6.5 |
| | | | | | 1 1/2 | 5.0 | 4.5 | 6.5 |

**Corrosion Resistance of Steel Reinforcement [1]**

| Class | Severity | Condition | Maximum W/CM Ratio |
|---|---|---|---|
| C2 | Severe | Exposed to moisture and external sources of chlorides including de-icing chemicals, salt, brackish water, and seawater | 0.40 |
| PS | All | All prestressed concrete structures exposed to any condition | |

[1] High performance concrete shall also be formulated with 384 fl. oz. / cy (3.0 gal. / cy) of corrosion inhibiting admixture.

**Sulfate Reaction Resistance**

| Class | Severity | Condition: C1580 (% by mass) | Condition: D516 or D4130 (ppm) | Maximum W/CM Ratio | Cement or SCM Type |
|---|---|---|---|---|---|
| S1 | Moderate | $0.10 < SO_4 < 0.20$ | $150 < SO_4 < 1500$ | 0.50 | Type MS and SCM |
| S2 | Severe | $0.20 < SO_4 < 2.00$ | $1500 < SO_4 < 10{,}000$ | 0.45 | Type HS and SCM |
| S3 | Very Severe | $SO_4 > 2.00$ | $SO_4 > 10{,}000$ | 0.40 | |

**Shrinkage and Cracking Resistance [1]**

| Concrete | Paste Content (PC) (%) |
|---|---|
| Pavement Concrete (Slip Formed) | ≤ 25.0 |
| Pavement Concrete (Fixed Formed) | ≤ 28.0 |
| High Performance Concrete | ≤ 30.0 |
| Exterior Slab Concrete | |

[1] Not applicable to self-consolidating concrete or concrete with Type S-SRA shrinkage reducing admixtures at a dosage ≥ 128.0 oz./cy (or per Manufacturer's recommendations), Type S-CRA crack reducing admixtures at a dosage per Manufacturer's recommendations, fibers that inhibit shrinkage (dosage per Manufacturer's recommendations) or test results within the shrinkage limits specified in standard specifications.

**Workability [1]**

| Condition | $PC_A/VC_{CM}$ Ratio |
|---|---|
| Decreased Workability | < 1.25 |
| Pavement Concrete | 1.25 – 1.75 |
| High Performance Concrete | |
| Exterior Slab Concrete | |
| Segregation, | > 1.75 |

[1] Only applicable to pavement concrete, high performance concrete, and exterior slab concrete. Not applicable to self-consolidating concrete or concrete with Type S chemical admixtures that enhance the workability of the concrete.

**Durability and Environmental**

| Supplementary Cementitious Materials | SCM (%) |
|---|---|
| Fly Ash (Class C) | 20 – 50 |
| Fly Ash (Class F) | 15 – 30 |
| Slag | 20 – 50 |
| Silica Fume | 5 – 15 |
| Metakaolin (Class N) | 10 – 20 |
| Calcined Clay or Shale (Class N) | 20 – 35 |
| Total Fly Ash and Silica Fume | ≤ 35 |
| Total SCM | ≤ 50 |

**Durability and Environmental**

| Alternative Supplementary Cementitious Materials | SCM (%) |
|---|---|
| Blended Hydraulic Cement | [1] |
| Rapid Hardening Hydraulic Cement | [1] |
| Performance Based Hydraulic Cement | [1] |
| Pozzolanic Performance Based Hydraulic Cement | [2] |
| Ground-Glass Pozzolan | [3] |
| High Reactivity Pozzolan | [3] |

[1] Target shall meet the requirements specified in the previous Durability and Environmental table.
[2] Target requirements are not applicable to pozzolanic performance based hydraulic cement.
[3] Per Manufacturer's recommendations.

Mix Design Formulation

# Sources of Constituent Materials

## *J. G. MacLellan Concrete – Amesbury, MA Plant*

| Material | Type | Source | Specification |
|---|---|---|---|
| Fine Aggregate | – | Ossipee Aggregates – Ossipee, NH | AASHTO M 6 |
| Coarse Aggregate | 1-1/2 in. (No. 4)<br>3/4 in. (No. 6)<br>3/8 in. (No. 8) | Brox Industries – Dracut, MA | AASHTO M 80 |
| Cement (Original) | I / II | Holcim – St. Constant, QC | AASHTO M 85 |
| Cement (Final) | IL(11)MS | Holcim – St. Constant, QC | AASHTO M 240 |
| Slag | Grade 120 | Holcim – Baltimore, MD | AASHTO M 302 |
| Air Entrainer | AEA | GCP – Darex II AEA | AASHTO M 154 |
| HR Water Reducer | F | GCP – Mira 95 | AASHTO M 194 |
| HR Water Reducer | F | GCP – Adva 190 | AASHTO M 194 |
| Water Reducer / Retarder | D | GCP – Recover | AASHTO M 194 |

Mix Design Formulation

# Quantity of Constituent Materials

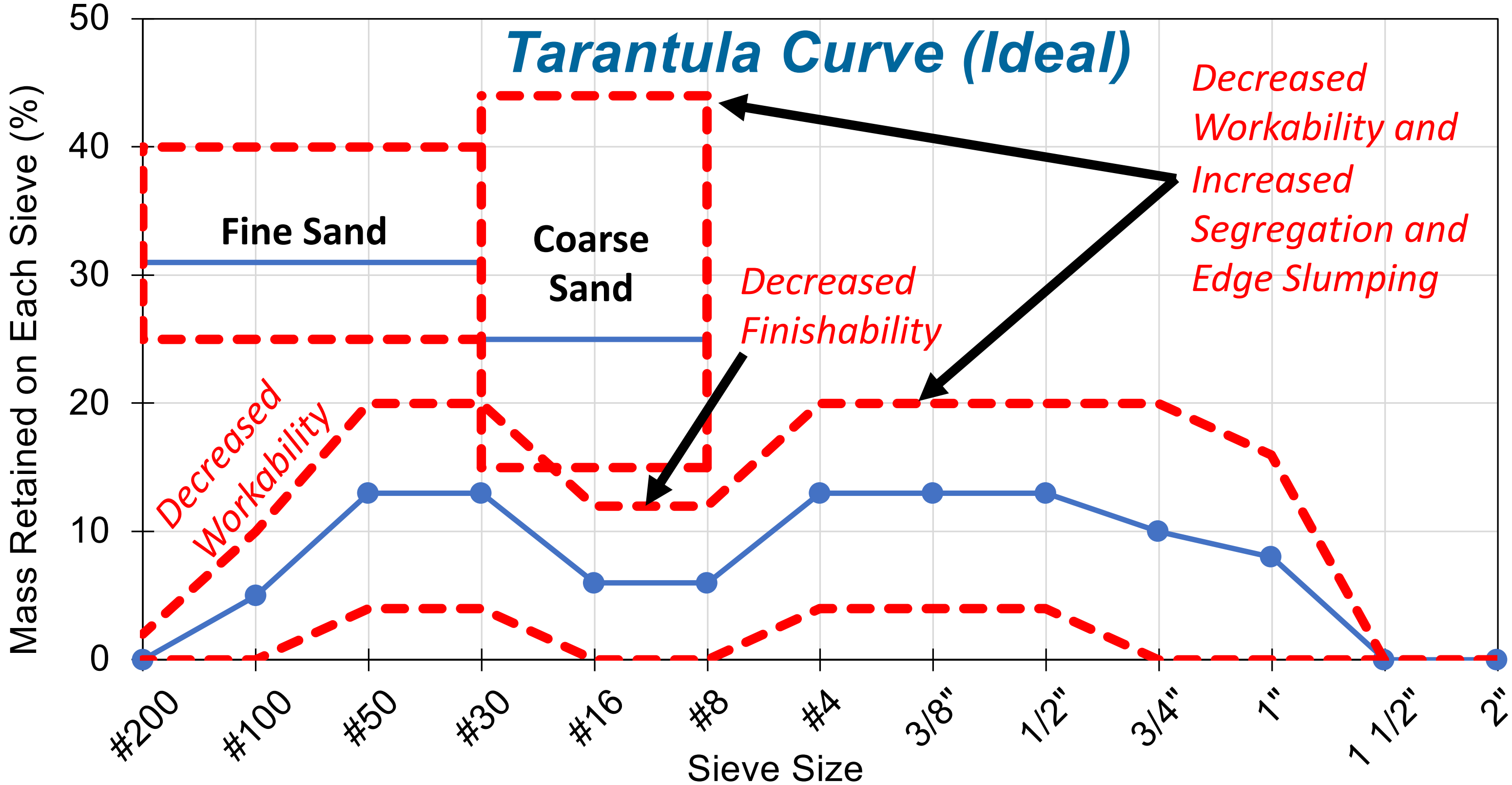
## *J. G. MacLellan Concrete – Amesbury, MA Plant*

| Material | Type | Qty. |
|---|---|---|
| Fine Aggregate (lb.) | – | 1225 |
| Coarse Aggregate (lb.) | 1-1/2 in. | 650 |
| | 3/4 in. | 685 |
| | 3/8 in. | 525 |
| Cement (lb.) | IL(11)MS | 489 |
| Slag (lb.) | Grade 120 | 165 |
| Total Water (gal.) | – | 30.5 |
| Air Entrainer (fl. oz.) | AEA | 3.8 |
| HRWR (fl. oz.) | F | 39.2 |
| HRWR (fl. oz.) | F | 26.1 |
| WR / Retarder (fl. oz.) | D | 13.1 |

| Parameter | Target | Actual |
|---|---|---|
| Compression (psi) | ≥ 4,000 | 7,000 |
| Slag (%) | 20 – 50 | 25.2 |
| w/cm Ratio | ≤ 0.40 | 0.39 |
| Slump (in.) | 6 | 6 |
| Air Content (%) | 6.5 | 6.5 |
| Paste Content (%) | ≤ 28.0 | 28.0 |
| Void Content (%) | – | 17.2 |
| (PC + AC) / VC Ratio | 1.25 – 1.75 | 2.01 |
| Tarantula Curve | Meets | Meets |
| Shilstone | Zone II | Zone II |

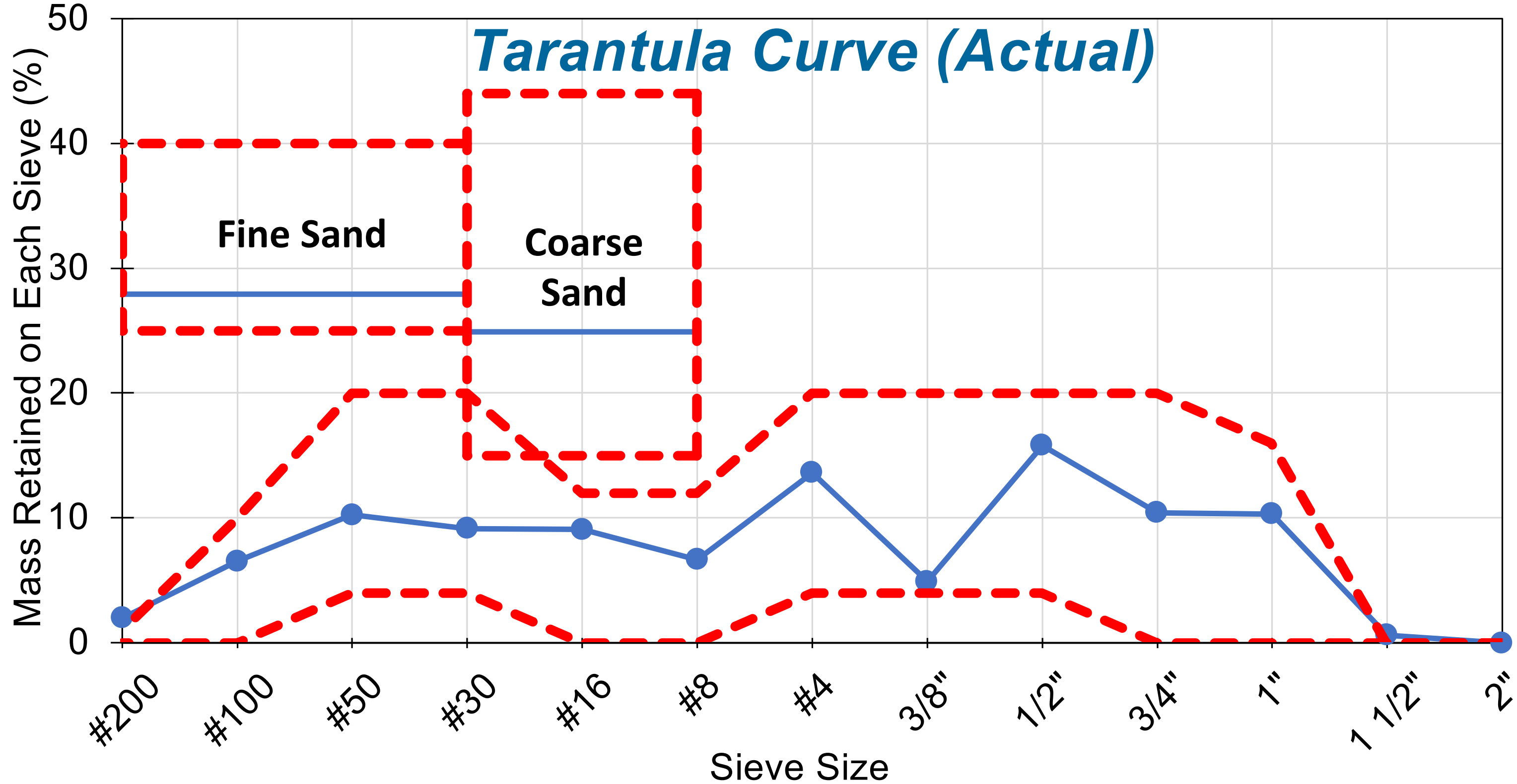
[1] Verification test results allowed for this value to be exceeded. However, it is best practice to design for the 1.25 – 1.75 target. Next time!

# Combined Aggregate System



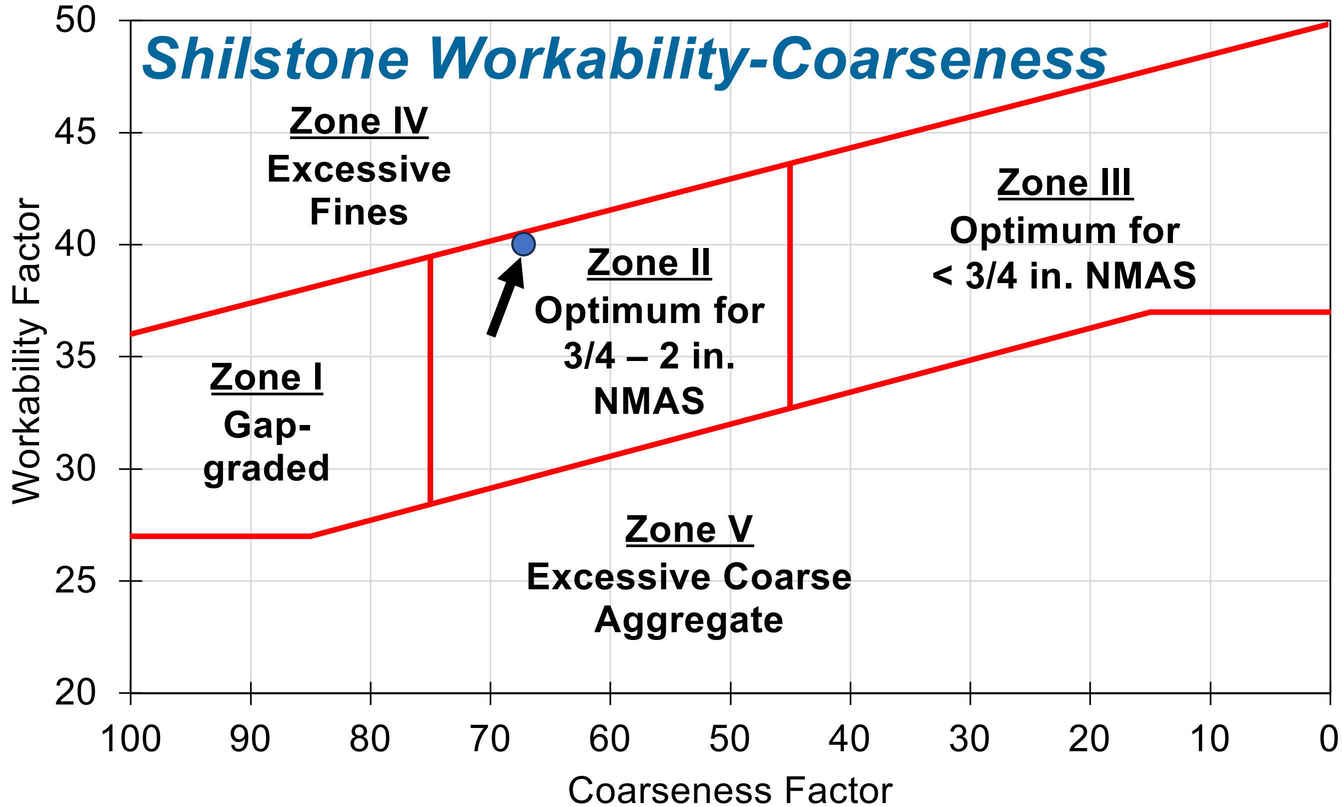
Mix Design Formulation

# Combined Aggregate System



Mix Design Formulation

# Combined Aggregate System



Mix Design Formulation

# Combined Aggregate System

## *Shilstone Workability-Coarseness*

| 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 |

# Combined Aggregate System

### *Void Content*

- ❑AASHTO T 19 Standard Method of Test for Bulk Density ("Unit Weight") and Voids in Aggregate
- ❑Mix design proportioning tool used to determine how much paste and air content is needed to fill the voids and ensure acceptable workability

Mix Design Formulation

# Freezing, Thawing, De-icing

| Exposure Class | Severity | Condition |
| --- | --- | --- |
| F1 | Moderate | Exposed to freezing and thawing cycles; Not exposed to accumulation of snow, ice, and de-icing chemicals; Limited exposure to water |
| 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 |
| F3 | Very Severe | Exposed to freezing and thawing cycles and accumulation of snow, ice, and de-icing chemicals; Frequent exposure to water |

Mix Design Formulation

# Air Content and w/cm Ratio

| Exposure Class | Severity | Maximum w/cm Ratio | NMAS (in.) | Reinforced Concrete Air Content (%) | Plain Concrete Air Content (%) |
|---|---|---|---|---|---|
| F1 | Moderate | 0.55 | 3/8 | 6.0 | 7.0 |
| | | | 1/2 | 5.5 | 7.0 |
| | | | 3/4 | 5.0 | 6.5 |
| | | | 1 | 4.5 | 6.5 |
| | | | 1-1/2 | 4.5 | 6.0 |
| F2 | Severe | 0.45 | Same Air Content Requirements as Class F3 | | |
| F3 | Very Severe | 0.40 | 3/8 | 7.5 | 7.5 |
| | | | 1/2 | 7.0 | 7.0 |
| | | | 3/4 | 6.0 | 7.0 |
| | | | 1 | 6.0 | 6.5 |
| | | | 1-1/2 | 5.5 | 6.5 |

[1] A 1.0% reduction from the air content target is permitted for 28-day compressive strength ≥ 5000 psi.