Modified Concrete Mixes and Optimized Aggregate Gradations

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MDOT’s Statewide Concrete Construction Engineer
Modified Concrete Mixtures (High Performance)

12SP-604A-09 and 12SP-604B-10
Modified Concrete Mixtures:

- **What Is a Modified Concrete Mixture?**
  - Incorporates a Supplementary Cementitious Material
  - Uses an Optimized Aggregate Gradation

- **What Does a Modified Concrete Mixture Provide?**
  - Densify the mix
  - Reduce the paste content
  - Reduced the Portland Cement Content
  - Can Increased workability

- **What Does this Mean?**
  - Increased Durability
  - Increased Service Life
Modified Concrete Mixtures: Location

- [https://mdotcf.state.mi.us/public/dessssp/spss/gotoview.cfm?ds=27](https://mdotcf.state.mi.us/public/dessssp/spss/gotoview.cfm?ds=27)
- Google MDOT Supplemental Specifications
- Click on the link: MDOT - Plans & Specifications - State of Michigan
- Click Supplemental Specs/Special Provisions
- Select Special Provision - Frequently Used (2012)
- Click View/Print Documents
- Scroll down to find 604A or B
Modified Concrete Mixtures: Major Changes

- Optimized aggregate is required when using a pump:
  - Except tremies and drilled shafts
    - Outlined on the 2nd to last paragraph on page 6
- QC testing performed for Air lost will now be tested according to the QC Plan
  - Outlined in the middle of page 12
- When testing for air loss do not interrupt or alter the pumping operation
  - Outlined in the middle of page 12
- Suspension limit for air is now <5.0 or >9.0
  - Outlined in Table 2 on the top of page 13
Modified Concrete Mixtures: Major Changes

- Test Correlation must be performed prior to placement
  - Outlined in the last paragraph on page 14
- Samples for acceptance will be taken at the point of discharge from the haul unit
  - Outlined in the 2nd paragraph on page 16
- QA sampling and testing for air loss using a slipform or pump:
  - At least once per production day,
  - Whenever the pump is relocated, or
  - Significant change in pumping operations
    - Outlined 2/3 of the way down on page 16
Modified Concrete Mixtures: QA vs QC

- **Quality Control (QC):**
  - Administered by the Contractor
  - Monitor, assess, and adjust production and placement processes
  - Ensure final product meets specifications

- **Quality Assurance (QA):**
  - Administered by the Agency/Owner
  - Deals with acceptance of the product:
    - Materials Selection
    - Sampling and Testing
    - Construction Inspection
    - Review of Contractor QC Documentation
  - Procedures that will be used for acceptance of and payment for all Portland cement concrete
Modified Concrete Mixtures: Material Requirements

- Supplementary cementitious materials (25 to 40% replacement):
  - Do not exceed 40% total replacement
  - Do not remove supplementary materials
  - MDOT approved manufacture
- Do not use set accelerating admixtures
  - Unless otherwise specified by the contract
- Use the combine weight of portland cement and supplementary cementitious materials to determine the water-cementitious ratio (w/c)
- Alkali-Silica Reaction (ASR):
  - Current test methods:
    - ASTM C 1293 (Concrete Prism Test)
    - ASTM C 1567 (Mortar Bar Test)
    - ASTM C 1260 (Rapid Mortar Bar Test)
<table>
<thead>
<tr>
<th>Mix Design Parameter</th>
<th>Grade of Concrete</th>
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<tbody>
<tr>
<td><strong>PWL Applications</strong></td>
<td></td>
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<tr>
<td>Lower Specification Limit (LSL) (28-day compressive, psi)</td>
<td>3500</td>
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<tr>
<td>Rejection Limit for an Individual Strength Sample Test Result</td>
<td>2500</td>
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<tr>
<td><strong>Non-PWL Applications</strong></td>
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<tr>
<td>Lower Specification Limit (LSL) (28-day compressive, psi)</td>
<td>3500</td>
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<tr>
<td>Rejection Limit for an Individual Strength Sample Test Result</td>
<td>3000</td>
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<td><strong>All Concrete Applications</strong></td>
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<tr>
<td>Maximum Water/Cementitious Ratio (lb/ft³) (c)</td>
<td>0.45</td>
</tr>
<tr>
<td>Cementitious Material Content (lb/ft³) (d)</td>
<td>470-504</td>
</tr>
<tr>
<td>Air Content (percent) (f)</td>
<td>5.5±0.5</td>
</tr>
</tbody>
</table>

a. If the local average minimum temperature in the next 10 consecutive days is forecast to be below 40 degrees F, submit a revised QC plan, for the Engineer’s approval, addressing, in detail, changes in materials, construction methods, curing, and protection of the in situ concrete to ensure that the necessary quality characteristics of the hardened concrete product will not be compromised as a result of the cold weather. The revised QC plan must be approved by the Engineer prior to cold weather concrete placement. Do not remove supplementary cementitious material from the concrete mixture.

b. Use aggregates from only geologically natural sources for pavement, shoulder, miscellaneous pavement (including ramps), concrete pavement overlay, bridge approach slab, structural concrete, drilled shaft, bridge railing, and bridge sidewalk applications.

c. Use admixtures as listed in the Qualified Products List to reduce mixing water. Ensure concrete in concrete diaphragms contains a water-reducing admixture, or a water-reducing retarding admixture.

d. Type III cement is not permitted.

e. For grades of concrete requiring optimized graduation, aggregates must meet the physical requirements specified in subsection 902.3.C of the Standard Specifications for Construction. Optimized aggregate gradation is required for pumped concrete.

f. For action, suspension, and specification limits, see Tables 2, 3 and 4, where applicable.

g. The maximum slump for Grades P1, P1M, and F2 concrete is 3 inches or as documented on the approved JMF. All other grades of concrete will be according to Table 701-1 of the Standard Specifications for Construction.

h. Section Number Reference:
   - 401 Pipe Culverts
   - 403 Drainage Structures
   - 603 Concrete Pavement Restoration
   - 706 Structural Concrete Construction
   - 712 Bridge Rehabilitation-Concrete
   - 715 Drilled Shafts
   - 802 Concrete Curb, Gutter and Dividers
   - 804 Concrete Barriers and Smoke Screens
   - 805 Fencing
   - 813 Site Protection
   - 819 Electrical and Lighting

   402 Storm Sewers
   602 Concrete Pavement Construction
   705 Foundation Paving
   711 Bridge Railings
   713 Bridge Rehabilitation-Steel
   801 Concrete Driveways
   803 Concrete Sidewalk, Sidewalk Ramps, and Steps
   805 Shared Use Paths
   810 Permanent Traffic Signs and Supports
   814 Paved Ditches
Modified Concrete Mixtures: Job Mix Formula

- **Job Mix Formula (JMF):**
  - Contractor Provides, except:
    - Structural concrete patching mixtures, mortars, and grouts
    - Bridge deck overlay concrete mixtures
    - Project-specific concrete grades not defined in Table 1
  - 4 methods of verification:
    - Trial Batches
    - Same Mix
    - Similar Mix
    - Annual Verification

- **Mix Design Review Checklist:**
  - Form 2000
  - Concrete Job Mix Formula (JMF) Yield Calculator
# MIX DESIGN REVIEW CHECKLIST

<table>
<thead>
<tr>
<th>CS-JN</th>
<th>JMF #</th>
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<tbody>
<tr>
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<tr>
<td>REVIEWER</td>
<td>APPROVED</td>
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</table>

**THE SUBMITTAL MUST INCLUDE THE FOLLOWING:**

- Form 1976 – Job Mix Formula (JMF) Concrete Field Communication
- Source of Materials
- Batch Weights of Constituent Materials (Dry)
- For Optimized Gradations Only – Individual Aggregate Gradations
- Specific Gravity of Constituent Materials

**Typical Ranges:**

- Type I Portland Cement: 3.15 (approximate)
- Class F Fly Ash: 2.20 – 2.70
- Class C Fly Ash: 2.55 – 2.80
- Slag Cement: 2.85 – 2.95
- Coarse Aggregate: 2.55 – 2.85
- Intermediate Aggregate: 2.55 – 2.85
- Fine Aggregate: 2.60 – 2.80

**Dry Loose or Dry Rodded Unit Weight of Coarse Aggregate**

- Water/Cementitious Ratio (w/cm) – 0.45 max
- Workability factor (b/v) coarse aggregate per unit volume concrete – 65 – 75% (inclusive)

**Aggregate Absorptions and Correction Factors**

- Typical Absorptions
  - Coarse Aggregate: ≤ 2.5%
  - Intermediate Aggregate: ≤ 2.5%
  - Fine Aggregate: ≤ 2.0%

**Alkali-Silica Reactivity (ASR) testing results for fine aggregate**

- Date of completion within the last 2 years
- Conforms with one of the methods in c.5.A of 12SP004B

**STRENGTH, COMPRESSION**

- The Lower Specification Limit (LSL) at 28 days, or
  - 70% of the Lower Specification Limit (LSL) at 7 days (Method 1 verification only)

**SUPPLEMENTAL CEMENTITIOUS MATERIALS (SCM)**

- If Used, Maximum Slag Cement Replacement is 40% (Minimum replacement 25% for P1M and DM)
- If Used, Maximum Fly Ash Replacement is 30% (Minimum replacement 25% for P1M and DM)
- If Both Are Used, They Must Not Exceed 40% of Cementitious Material
DOCUMENTATION

Air Content (%) 
Slump Inch 
Compressive Strength Psi 
Concrete Age at Time of Test Days 
Verification Method Use (ref. c.5.B.2 of 12SP804B) 1 2 3 4 

GPL/APPROVED SOURCE CHECK

Coarse Aggregate YES NO N/A 
Intermediate Aggregate YES NO N/A 
Fine Aggregate YES NO N/A 
Cement YES NO N/A 
Fly Ash YES NO N/A 
Slag Cement YES NO N/A 
Admixtures YES NO N/A 
Specified Dosage Greater Than Minimum or Within Dosage Range YES NO N/A 

CEMENTITIOUS CONTENT

Meets or Exceeds Minimum Required (ref. Table 1 of 12SP804B) YES NO 

YIELD AND OPTIMIZED GRADATION CHECK

Mix Design Yields (Use Concrete Job Mix Formula Yield Calculator) YES NO 
If Used, Optimized Aggregate Gradation Meets Appendix 1 of 12SP804B YES NO N/A 

NOTES/COMMENTS
Concrete Job Mix Formula (JMF) Yield Calculator

<table>
<thead>
<tr>
<th>Component</th>
<th>Input</th>
<th>Absolute Volume</th>
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<tbody>
<tr>
<td>Air</td>
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<td>0.00</td>
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<tr>
<td>Water</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Net</strong> Water Weight (lbs)</td>
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<td>0.00</td>
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<tr>
<td>Cementitious</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portland Cement Weight (lbs)</td>
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</tr>
<tr>
<td>Cement Density (Specific Gravity)</td>
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<tr>
<td>Fly Ash Weight (lbs)</td>
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<td>0.00</td>
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<tr>
<td>Fly Ash Density (Specific Gravity)</td>
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<td>0.00</td>
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<tr>
<td>Slag Cement Weight (lbs)</td>
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<tr>
<td>Slag Cement Density (Specific Gravity)</td>
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<tr>
<td>Other (Pozz) (lbs)</td>
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<tr>
<td>Other (Pozz) Density (Specific Gravity)</td>
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<tr>
<td><strong>Aggregates</strong></td>
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<tr>
<td>Coarse Aggregate Weight (Dry or SSD) (lbs)</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Coarse Aggregate Specific Gravity (Bulk Dry or Bulk SSD)</td>
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<tr>
<td>Intermediate Aggregate Weight (Dry or SSD) (lbs)</td>
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<td>0.00</td>
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<tr>
<td>Intermediate Aggregate Specific Gravity (Bulk Dry or Bulk SSD)</td>
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<tr>
<td>Fine Aggregate Weight (Dry or SSD) (lbs)</td>
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<tr>
<td>Fine Aggregate Specific Gravity (Bulk Dry or Bulk SSD)</td>
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<tr>
<td><strong>Total Volume</strong></td>
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<tr>
<td>Water/Cementitious Ratio</td>
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<td>#DIV/0!</td>
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</table>

Note: If you use 'Dry' weights for the aggregates then you must use the 'Bulk Dry' specific gravities. If you use 'SSD' weights for the aggregates then you must use the 'Bulk SSD' specific gravities.
Modified Concrete Mixtures:
Sampling and Testing

- QC Startup sampling and Testing:
  - Temperature, slump, density (unit weight), and air content
  - Ensure concrete tests do not exceed QC action limits
  - QC sampling and testing must be independent from QA

- QC Sampling and testing for air content loss will be performed according to the QC Plan
  - Do not interruption or alteration to the pump operation

- Concrete exceeding the maximum specification limits for slump or temperature must be rejected
- Work Progress Test Specimens must be cured in the same manner as the in-situ concrete
Modified Concrete Mixtures: Sampling and Testing

- Contractor provides initial curing facilities
- QA and QC must use the same size strength test specimens for 28 day strengths
- QA and QC conduct side by side testing of the same concrete from the first load:
  - Temperature: 2 degrees F
  - Air: 0.8 % by volume
- Agency will verify the Contractor’s daily startup sampling and testing
Modified Concrete Mixtures: Sampling and Testing

- QA Sampling:
  - Random number method
  - Taken at the point of discharge from the haul unit
  - Engineer will test for air loss when either slipforming or pumping is used
    - 1.5% difference

- QA Testing:
  - Two QA concrete strength specimens cast for 28-day breaks
  - Engineer provides the padlock
  - Engineer will transport QA cylinders within 48 hours of casting but not less than 8 hours
  - Transportation of QA cylinders will not exceed 4 hours
Modified Concrete Mixtures: QA Stop Production

- QA Stop Production Criteria:
  - Six causes
    - QA testing shows that one or more of the suspension limits are in non-compliance
    - QC Plan is not being followed
    - Segregation, excessive slumping of unsupported slipformed edges, etc.
    - Required curing system is not being applied in a timely manner
    - Measured air content loss between to locations is greater than 1.5%
    - Air content of fresh concrete is <5.0 or >9.0% after the pump or paver
Rejectable Concrete
Rejectable Concrete:

- The Engineer will require additional evaluation to determine if further action is warranted.
- If 28-day compressive strength results show that the rejection limit has been exceeded the Engineer will reject the concrete.
- Propose an evaluation plan to the Engineer and submit for approval.

Engineer may allow non-destructive testing:
- Done by the Contractor
- In the Presence of the Engineer
- Within 45 days of concrete placement
- All cost are borne by the Contractor
- Minimum of 3 randomly selected locations
Rejectable Concrete:

- Results from NDT will only be used by the Engineer for deciding what further action is required, as follows:
  - All Results are passing 28 day strength:
    - Non-structural:
      - Concrete will remain in place and PF will equal 1.00
    - Structural:
      - Concrete will remain in place and PF will equal 0.85
  - If one or more NDT results fall below the lower specification for 28 day strength:
    - Require removal and replacement
    - Allow the Contractor to submit a plan for corrective action
    - Allow the concrete to remain in place with a PF of 0.50
Optimized Aggregate Gradation

4.13 of the Materials Quality Assurance Procedure Manual (pg. 123)
Optimized Aggregates:

- What Is an Optimized Aggregate Gradation?
  - Combination of Coarse, Intermediate and Fine Aggregates
  - Obtain a “Well Graded” Gradation
    - Provide Aggregates of All Sizes
    - Optimize Particle Packing
    - Provide a Workable Mix
Optimized Aggregates:

- What Does Optimized Aggregates Provide?
  - Densify the mix
  - Reduce the paste content
  - Increased workability

- What Does this Mean?
  - Increased Durability
  - Increased Service Life
Optimized Aggregates:

- When are Optimized Aggregates Required:
  - 12SP-604A and 12SP-604B
    - All MDOT Trunk-line Projects:
      - Pavements
      - Bridge Decks
      - Any High Performance Concretes (Modified (M))
  - All Pumped Concrete:
    - Except for Drilled Shafts
    - Except for Tremies
Optimized Aggregates:

Where are the Optimized Aggregate Gradation Procedures located?

- 4.13 of the Materials Quality Assurance Procedure Manual (pg. 123)
  - [https://www.michigan.gov/mdot/0,4616,7-151-9622_11044_11367-207980--,00.html](https://www.michigan.gov/mdot/0,4616,7-151-9622_11044_11367-207980--,00.html)
  - Google MDOT MQAP Manual (click on first link)
Optimized Aggregates:

- **Materials:**
  - 902.03 in the Standard Specifications for Construction
  - No more than 15% of aggregates from a quarried carbonate source may pass the #4 sieve
  - Freeze-thaw dilation greater than 0.04% retained on the ½ sieve cannot constitute more than 5% of the total combined aggregate

- Exception: Non-High Performance Concrete
Optimized Aggregates:

- Sampling:
  - Obtain 3 samples of each individual coarse, intermediate, and fine aggregate
  - Use mini-stockpile method in accordance to MTM 107
  - All sampling must be performed by a Michigan Certified Aggregate Technician (MCAT Level I/II)

- Mechanical Analysis:
  - Requirements and procedures are listed
  - Must be MCAT Level II to perform mechanical analysis
Optimized Aggregates:

- Determination of optimized aggregate proportions:
  - Combining aggregate gradations
  - Coarseness Factor
  - Workability Factor
  - CF vs. WF Chart
  - Loss by Wash
  - Finalized Gradation Report
- MDOT’s Optimized Aggregate Spreadsheet
Optimized Aggregates:

- Google “MDOT Manuals and Guides”
- Select the First Link
- Select Concrete Resources
  - Located Under Construction Field Services
Optimized Aggregates:

- **Corrective Action Limits:**
  - Determined and documented by the Contractor in the Quality Control Plan

- **Suspension of Work Limits:**
  - Contractor must stop production and perform all necessary corrective actions
  - Occurs when aggregate gradation exceeds Operating Zone Boundary on the CF vs WF graph
  - Resume production only when the Engineer provides a Notice to Resume Work (Form 1165)
Optimized Aggregates:

▲ Sampling Rate for Acceptance:

▲ All aggregate will be tested at the same time as the coarse aggregate and tested concurrently:

▲ On-site Batch Plant: 1 per 5,000 tons of coarse aggregate

▲ Commercial Batch Plant: determined by the Engineer at the preproduction meeting:

▲ Prequalified: 1 per 5,000 tons

▲ Non-prequalified: 1 per 1,000 tons

▲ Volume of concrete produced: 1 per 2,000 cubic yards for each grade of concrete
Optimized Aggregates:

- Sampling for Acceptance:
  - Conducted at the Concrete batching facility
  - Samples will be taken from the production face of each aggregate stockpile
  - Agency will perform mechanical analysis for each individual aggregate according to MTM 109
- Verify Loss by Washing
Optimized Aggregates:

- Acceptance of the combined aggregate gradation will be based on the ability of the combined aggregate gradation to plot within the Operating Zone Boundary.
Questions?

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