SECTION 835 QMP – Concrete

835.1 Overview

This section addresses the standard specification for QMP Concrete Pavement, Cast-in-Place Barrier and Structures and the standard specification for QMP Ancillary Concrete.

The QMP for Class I concrete is detailed in standard spec 715.

The QMP for Class II and Class III concrete is detailed in standard spec 716.

835.1.1 Definitions

All personnel performing acceptance testing (QC and QV) must be certified through the WisDOT Highway Technician Certification Program (HTCP) administered by the University of Wisconsin – Platteville.

Certification requirements for each type of test are listed in standard spec table 701-1.

835.1.2 Concrete Grades

There are various types of concrete mixtures. By changing the proportions of the main ingredients, concrete mixtures are devised for specific applications. WisDOT defines these mixtures by concrete grade.

Grade A

- General use mix incorporated in paving, structures, and ancillary concrete. This is considered a standard concrete, which means it has a traditional unit weight of 145-160 pcf and traditional strength of 3,000-5,800 psi. Grade A concrete is the only grade of concrete that is allowed to reduce the cementitious content when using an optimized aggregate gradation (OAG). Admixture and supplementary cementitious material (SCM) requirements for this grade are found within the standard spec.

Grade B

- Concrete base mix that is specified when the concrete will be overlaid with either asphalt or concrete. This concrete is a structural component of the pavement and is not intended to be a wear surface for traffic. This grade has a lower cementitious content requirement than standard concrete and its ultimate strength will also be lower than a standard concrete. General strength for this mix will range between 2,000 psi and 4,000 psi.

Grade C

- General repair mixture for pavements and structures. It has a higher cement content for a rapid strength gain. This mixture is required in the contract when opening strength is needed sooner than a general use concrete.

Grade E

- Bridge deck overlay mixture that has a very high cementitious content. This mixture uses only No. 1 (AASHTO No. 67) coarse aggregates. These overlays are typically thin and are required to be open to traffic quickly due the nature of needing to construct the overlays on half of the bridge at a time. These mixes have a maximum w/cm ratio of 0.36. Specialized consolidation equipment is needed for this mixture grade.

In addition, listed below are some additional mixture types that are called out for specific purposes in the contract documents.

High Early Strength (HES) Concrete

- HES mixes are created by adding 95-280 lbs/cy of cement to an established mixture design. This modification can be applied to any concrete grade. The total amount of cement added to the mixture is dependent on a project's constraints. These constraints include, but are not limited to, project scheduling, opening to traffic or accelerated construction. When a concrete mix becomes HES, the HES is added after the grade. For example: Grade B mix design is submitted, when the additional cement is added, it becomes Grade B HES.

High Performance Concrete (HPC)

- HPC mixes are required to meet a higher performance standard for the constituent materials than a general use concrete. This mix generally has a higher durability than general concrete. These mixes are intended for use on high-capacity roadways and structures on the interstates. Designers consult with BTS/BOS when HPC concrete should be incorporated into a contract.

Modified High Performance Concrete (HPC)

- Modified HPC mixes are required to meet a higher standard for the constituent materials than a general use concrete. These mixes are intended for use on interstates. The modified HPC spec does not have as rigid delivery and discharge constraints as the HPC spec. Designers consult with BTS when the modified HPC concrete spec should be incorporated into a contract.

Lightweight Concrete

- This mixture has a concrete density less than 120 pcf and is made with lightweight aggregates or a combination of lightweight and normal weight aggregates. Lightweight concrete will require a longer drying time than normal weight concrete due to the porous aggregates. Some typical applications for lightweight concrete include lift structure grid decks and extremely long span bridge decks.

Special High Early Strength (SHES) Concrete

- SHES mixes are used when opening strength is needed within hours of being placed. These mixes contain very high cement contents. Typically, calcium chloride is added in either liquid or flake form on site to accelerate the hydration process to give faster strength gain. Rapid strength gaining cements like Portland cement Type III may also be used.

Self-Consolidating Concrete (SCC)

- SCC mixes flow easily and are compacted by their own weight. No vibration is applied to this mixture. These mixtures use chemical admixtures, called superplasticizers, to achieve the self-compacting property. Mixture designs containing superplasticizers need BTS approval prior to use. It is important to ensure that segregation of aggregates does not occur when placing SCC mixes. Typically, SCC is used in areas of extremely congested reinforcement where vibration methods cannot get in between the steel, deep placement of concrete where vibration cannot reach the bottom (ie: drilled shafts) and underwater pours where the seal cannot be broken.

Shotcrete

- This concrete mixture is placed using a pneumatic gun that sprays the concrete at a high velocity. Shotcrete may be required in areas that are difficult to reach, and require a thin, large surface area coverage. Typical applications of shotcrete are in overhead and vertical structure surface repair.

835.2 Quality Control (QC) Plan

The quality control plan must be produced and submitted according to standard spec 701.1.2.

The department is responsible for reviewing the QC plan and provide comments back to the contract. Once the contractor receives the departments comments, the contractor will need to review, revise, and resubmit the QC plan to project staff.

835.2.1 Contractor Concrete Mix Designs

The contractor is responsible for providing the design of the concrete mixture for use on the project and for any necessary adjustments during production. Each mix design must have the appropriate DT2220 or DT2221 form and all supporting documentation. Mix designs must conform to standard spec 710, 715, and 716. CMM 871 provides additional information regarding contractor concrete mix designs.

835.2.1.1 Class I Mix Designs

A PCC Technician II, hired or employed by the contractor, is required to develop and submit the mix design report to the engineer before the production of concrete for the project. The mix design must meet the conditions specified in standard spec 710.4 and 715.2.

A mix design may be used on multiple contracts. All supporting documentation is to be provided to each contract. Each project staff will review the documentation for the mix designs provided to the corresponding contract.

A copy of the mix design must be made available to all the interested project parties (i.e. engineer, contractor, QC technician, QA technician, and Independent Assurance technician) in the timeline defined in the standard spec. At a minimum, all parties should have a copy of the mix design packet prior to attending a pre-pour meeting.

835.2.1.2 Class II Mix Designs

The mix design for class II concrete must meet the conditions specified in standard spec 710.4 and 716.1.1.2.

A mix design may be used on multiple contracts. All supporting documentation is to be provided to each contract. Each project staff will review the documentation for the mix designs provided to the contract.

A copy of the mix design must be made available to all the interested project parties (i.e. engineer, contractor, QC technician, QA technician, and Independent Assurance technician) in the timeline defined in the standard specifications.

835.2.1.3 Department Review of Concrete Mix Design

The engineer’s signature is required on the certification page of the appropriate DT2220 or DT2221 form. The engineer should review the following prior to signing the certification page and confirm that the submitted mix design meets the specification requirements:

- Cement is on the APL?
- SCM’s have appropriate certified report of tests?
- Correct SCM amount?
- Admixtures are on the APL? ,or, Certified report of tests provided?

- Water source approved?
- Class I mix designs have trial batching? SAM number? Cylinder & beam break printouts? Box tests for optimized aggregate, slip-formed pavement?
- Aggregate sources are on the APL?

835.3 Concrete Plants

Plant start up includes calibration of the plant and testing equipment. Before production, the contractor should inspect the plant and test equipment. The engineer may choose to waive his inspection based on the results of the contractor's report.

In addition, the concrete producer is required to record the quantity of the materials used in each batch. The contractor is required to measure, monitor, and record the addition of materials to the mix after discharge from the plant.

835.4 Aggregate System

Aggregate gradation sampling and testing must be performed according to standard spec 710.5.

Mix designs will use one of two ways to evaluate aggregates. Either optimized gradation or combined gradation.

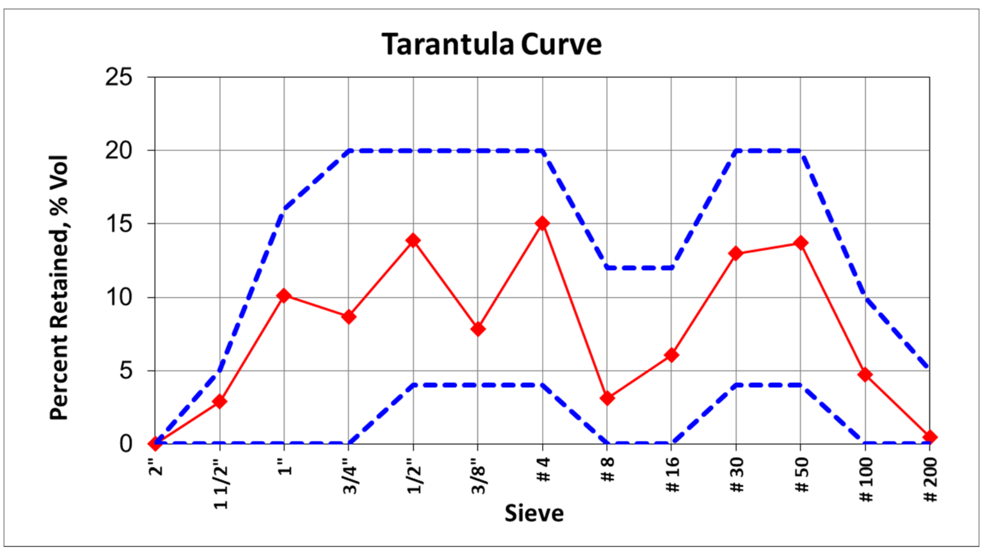
835.4.1 Optimized Aggregate Gradation

Optimized aggregate gradation (OAG) is required on pavement mix designs over the threshold stated in standard spec 501.2.7.4.2.1. OAG is encouraged on all projects, including Class II concrete.

OAG is taking the individual components of an aggregate sample and blending the individual sizes into a gradation that fits within the tarantula curve, refer Figure 835-1. Advantages of using the OAG include:

1. Contractor is allowed to reduce the cementitious content when using an OAG because the aggregate system of being in the tarantula curve has been tested and proven to increase workability and less paste is needed to achieve that property.
2. The durability of the concrete increases with this type of aggregate system provided the cement content is reduced. The amount of cement is directly related to the durability performance of the concrete.
3. Sustainability is increased provided the cement content is reduced.
4. Carbon footprint of concrete is decreased provided the cement content is reduced.

FIGURE 835-1 The Tarantula Curve



835.4.2 Combined Gradation

Aggregate systems are evaluated by using Combined Gradation for all mixtures not utilizing OAG.

The aggregates are blended together in the final product of the concrete and therefore are accepted per the blended combined gradation. Not all aggregates are conducive to optimization due to how they are produced. The combined gradation provides the state with a quality concrete that also accommodates the producer's products.

835.4.3 Structure Aggregate Moisture

During concrete production for class I structures, moisture content tests are required. Use department worksheet WS3010 "Worksheet for Calculating: Aggregate Moisture Content, Combined % Passing #200

Sieve, and Water/Cementitious Ratio" to calculate moisture content and combined P200. The quantities used must reflect a specific as-batched concrete moisture (not mix design quantities); therefore, as aggregate samples are collected the technician must also obtain current batch quantities.

Moisture of fine and coarse aggregates are tested when placing structure concrete as a measure to monitor the w/cm ratio. As the w/cm ratio increases, the strength of concrete decreases. Minimum structure strength is imperative to serviceability and safety.

835.5 Concrete Testing

835.5.1 Materials Reporting System

The contractor submits mix information and test results for concrete pavement, cast-in place barrier and concrete structures using the department's Materials Reporting System (MRS) software available on the department's web site at:

http://www.atwoodsystems.com/

835.5.2 Water Cementitious Ratio

Water to cementitious ratio (w/cm) is an indicator of concrete quality. High water contents result in lower strength and decreased durability.

The w/cm is calculated according to the formula below. Quantities used must reflect target batch weights (mix design) for production concrete; therefore, when an individual aggregate moisture content changes significantly, the technician must also obtain current target batch quantities and adjust the target batch weights to maintain the design w/cm. If using mobile transit mixer trucks, be sure that the technician includes the water added on-site to the mix drum.

$$\text{Water to Cementitious Ratio (w/cm)} = \frac{\text{Weight of Net Water}}{\text{Weight of Total Cementitious Material}}$$

$$\text{w/cm} = \frac{MW + \sum AFM}{C + \sum SCM}$$

Where:

w/cm = ratio of water to cementitious material

MW = the weight of mix water added to the batch (lbs)

$\sum AFM = AFM_1 + AFM_2 + AFM_3 + ... + AFM_n$

AFM_n = the weight of free moisture contributed by each aggregate (lbs)

C = weight of cement (lbs)

$\Sigma SCM = SCM_1 + SCM_2 + SCM_3 + ... + SCM_n$ (lbs)

SCM_n = weight of supplementary cementitious materials (lbs)

Conversion Factor for Water: 1 gallon = 8.34 lbs.

Free moisture contributed by each aggregate, AFM:

$$AFM = W_{Batch} \frac{TM - AC}{1 + TM}$$

Where:

W_{Batch} = the batch weight of the aggregate at field moisture;

TM = percent of total moisture of the aggregate expressed as a decimal fraction based on oven dry weight;

AC = percent absorption of the aggregate expressed as a decimal fraction based on oven dry weight.

In order to make this information useful to the batch operator, timely results are necessary. Work should begin immediately after the samples are collected and results should be shared as soon as they are available.

835.5.3 Concrete Lots and Sublots

835.5.3.1 Class I Pavement

The contractor must define lot and sublot locations before placing any concrete. Lots and sublots may contain concrete placed on more than one day of paving.

835.5.3.1.1 Lots by Lane Feet

A mainline sublot by lane feet is intended to be the length of a single paved lane. The sublot length can be divided in half if two lanes are paved simultaneously. For example: If the mainline sublot is 1000 lane feet in size, the sublot will be 500 linear feet for 2 lanes being paved simultaneously, or 1000 linear feet if the paving operation is one lane wide.

Lots will consist of a standard number of sublots and contain material from a single mix design. If a lot contains less than 3 sublots, there is not enough information to establish a meaningful percent within limits (PWL) statistic.

Create lots that logically correspond to construction operations. In order to transition into a new sublot, the previous sublot increment is required to be met. The only sublot that may have a different quantity is the last sublot of the mix design.

835.5.3.1.2 Lots by Cubic Yard

Lots and sublots by cubic yard are tested according to the amount of concrete placed. Sizes of lots and sublots are defined in the standard specification. Lots will consist of a standard number of sublots and contain material from a single mix design. If a lot contains less than 3 sublots, there is not enough information to establish a meaningful Percent Within Limits (PWL).

Create lots that logically correspond to construction operations. In order to transition into a new sublot, the previous sublot increment is required to be met. The only sublot that may have a different quantity is the last sublot of the mix design.

835.5.3.2 Class I Cast-In-Place Barrier

The contractor must define all lots on the project before placing any concrete. Lots and sublots may contain concrete placed on more than one day of placement.

Lots and sublots by cubic yard for barrier are tested according to the amount of concrete placed. Sizes of the lots and sublots are defined in the standard specifications. Lots will consist of a standard number of sublots and contain material from a single mix design. If a lot contains less than 3 sublots, there is not enough information to establish a meaningful PWL.

Create lots that logically correspond to construction operations. In order to transition into a new sublot, the previous sublot increment is required to be met. The only sublot that may have a different quantity is the last sublot of the mix design.

835.5.3.3 Class I Structures

The contractor must define all lots on the project before placing any concrete. Lots and sublots may contain concrete placed on more than one day of placement.

Lots and sublots by cubic yard for structure are tested according to the amount of concrete placed. Sizes of the lots and sublots are defined in the standard specification. Lots will consist of a standard number of sublots and contain material from a single mix design. If a lot contains less than 3 sublots, there is not enough information to establish a meaningful PWL statistic.

Create lots that logically correspond to construction operations. In order to transition into a new sublot, the previous sublot increment is required to be met. The only sublot that may have a different quantity is the last sublot of the mix design.

835.5.3.4 Class II Ancillary

Class II ancillary concrete testing frequencies are found in standard spec 716.

835.5.3.5 Class III Ancillary

Class III concrete is accepted based on a certification of compliance from the contractor. An example certification is shown in Figure 835-2.

FIGURE 835-2 Example Certificate of Compliance for Ancillary Concrete

(use company letterhead here)

Ready Mixed Concrete Producer Name______________________________________

Ready Mixed Concrete Producer Location___________________________________

This letter is to certify that the above ready-mixed concrete plant is supplying concrete in compliance with WisDOT specifications for project # (xxxx-xx-xx) and the ancillary concrete items listed below.

Ancillary Concrete Items (example: 504.0900 Concrete Masonry Endwalls)	
Item No.	Description

Signed: ____

Name: ____

Position: ____
(example: Plant Manager, QC Manager)

Phone: ____

E-mail: ____

Fax: ____

Date: ____

835.5.4 Slump

Slump test results must be documented with appropriate sample identification information. QC records slump test results in MRS. QV records slump test results in the strength report and report for the mix.

835.5.5 Temperature

High concrete temperatures result in fast hydration of the concrete which result in shrinkage cracking and low strengths.

Placing concrete in temperatures below 40 F impacts workability and set time of the concrete. In addition, it will slow the rate of strength gain. If the fresh concrete freezes before hardening, the ultimate strength is significantly reduced.

Temperatures need to be monitored as the time required before sawing will be altered in extreme temperature conditions. Hot weather will require sawing earlier and cold weather will require a delayed sawing.

835.5.6 Air Content

Air content in concrete is important to the freeze-thaw durability. Low air content will reduce the freeze-thaw durability of the concrete. High air content increases the freeze-thaw durability; however, it lowers the ultimate strength.

In addition, the air spacing factor is a more accurate indication of the freeze-thaw performance. This property is tested with a Super Air Meter (SAM) or hardened air void analysis.

The contractor plots air content data using the department's MRS software.

835.5.7 Strength Specimens

It is important to measure the concrete strength to ensure it can support the loads being applied to it; the department requires either compressive or flexural strength specimens to confirm minimum strength of the concrete is reached at 28-days. Strength requirements are defined in the spec and also may be indicated within the plans.

The contractor/department is responsible for fabrication, curing, and strength testing of their respective strength specimens. Strength requirements are found in standard spec 710.5, 715.3, and 716.2. Strength cylinders used for quality assurance must be independent of field-cured cylinders used to confirm strength prior to removing forms, falsework, or opening to service.

835.5.7.1 Fabricating and Curing Strength Specimens

The contractor QC staff fabricates, cures, and tests strength specimens to determine the 28-day strength for each sublot. A set of three strength specimens is required. The contractor selects 2 of the 3 specimens at random and breaks them. If the breaking strengths are close to the same, the average strength of those 2 specimens defines the sublot strength. If the 2 breaking strengths are significantly different, the contractor breaks the third specimen and determines the sublot strength as the average of the 2 highest strength specimens.

The contractor records strength specimen data using the department's MRS software.

The department records strength specimen data using the department's Material Tracking System (MTS) software.

Care should be taken during casting, curing, transporting, and breaking strength specimens to avoid anything that might bias the results. If vibrating strength specimens, the technician should take particular care to avoid over-vibration that can cause segregation and lower strength. Poor consolidation and careless sample handling techniques increase the variability of the strength results.

All HTCP certified technicians are trained to follow the same standard procedures. The department's independent assurance staff is charged with monitoring all project testing, whether by the contractor, the department, or a consultant, to make sure that those standard procedures are followed.

835.5.7.2 Strength Test Results

The 28-day strength is the benchmark strength the department uses for design, to measure the concrete quality, and to determine incentive/disincentive pay adjustment. The average strength of the 2 strength specimens from each sublot defines the 28-day concrete strength for that sublot.

835.5.7.3 Class I Pay Adjustment for Strength

The department determines a pay adjustment for 28-day concrete strength (compressive or flexural). For lots with less than 4 sublots, each sublot is evaluated individually. For lots with 4 or more sublots a statistical analysis is done to determine a lot-by-lot pay adjustment. After verifying the contractor's data, the department calculates pay adjustments using the department's MRS software. The contractor must submit the required strength test information electronically using the MRS software available at:

http://www.atwoodsystems.com/

The department administers incentives and disincentives under different items. The unit for both items is dollars. The engineer should always use these items for pay adjustment. On smaller jobs, there may be a single pay adjustment done for the entire project. On larger projects pay adjustments may be issued with progress payments.

The incentive items are included in the contract schedule of items as predetermined prices fixed at bidding. The estimated amount of incentive included in the incentive item is 60% of the maximum possible incentive. These items allow the engineer to pay incentives without a construction change order. Because a contractor can earn 0% to 100% of the maximum strength incentives attainable for the project and the contract bid items were at 60% of the maximum attainable, a project can result in more or less pay for the concrete strength incentives.

The disincentives are applied to the contract using an administrative item. A list of administrative items is provided in CMM 238. Administrative items need to be applied to the contract by change order.

835.5.7.3.1 Pay Adjustment for Partial Lots (less than 4 sublots)

Statistical analysis cannot be performed on lots containing less than 3 sublots. The department requires 4 sublots to determine the statistical analysis. The department calculates the pay adjustment for a lot with less than 4 sublots by treating each sublot individually. Sublots with average sublot strength greater than or equal to the specification limit receive no adjustment. Sublots with an average sublot strength less than the specification limit receive a disincentive.

835.5.7.3.2 Statistical Pay Adjustment (4 or more sublots)

The department calculates the pay adjustment for a lot with 4 or more sublots using a PWL analysis based on the lot's average strength and the lot's strength standard deviation. Only those lots with a standard deviation below a specified threshold are eligible for incentive payment. The lower quality index, how many standard deviations the lot mean is above the specification limit, is calculated and used to determine the PWL for a given sample size. The resultant PWL is applied to a pay equation to determine the appropriate pay adjustment for the lot.

The basis for the analysis is the sublot average strength which uses the average of 2 QC strength specimens for each sublot. Weighted lot statistics are developed from the set of sublot average strengths as follows:

LOT MEAN:

$$X = \frac{C_1 w_1 + C_2 w_2 + C_3 w_3 + \cdots + C_n w_n}{W}$$

Where:

X = lot mean
C = sublot average strength for each sublot
w = sublot weighting factor (sublot size)
W = Sum of weighting factors (lot size)

LOT STANDARD DEVIATION:

$$S_n = \sqrt{\frac{(C_1 - X)^2 w_1 + (C_2 - X)^2 w_2 + \cdots (C_n - X)^2 w_n}{(n-1)W \div n}}$$

Where:

Sn = lot standard deviation
C = sublot average strength for each sublot
X = lot mean
w = sublot weighting factor (sublot size)
W = Sum of weighting factors (lot size)
n = number of sublots in lot

LOWER QUALITY INDEX:

$$Q_L = \frac{X - L}{S_n}$$

Where:

QL = lower quality index
X = lot mean
L = specification limit
Sn = lot standard deviation

835.5.7.3.3 Additional Payment Considerations

Special circumstances may require the engineer to modify the pay adjustment using the MRS software. Material that is represented by out-of-spec test results is not eligible for incentive payment. The engineer must deduct the appropriate amount from the lot pay adjustment that the MRS calculates. Testing frequencies for those other properties (aggregate gradation, air content, slump, and concrete temperature) may not correspond to the strength sublots. The engineer should note what additional adjustments were made and how the quantity was determined in the remarks of the HQMS report.

835.6 Quality Assurance Testing

Quality assurance testing, including quality control, quality verification and independent assurance sampling and testing are required to be performed by HTCP certified technicians.

835.6.1 Verification Testing

A department representative performs quality verification testing when contractor quality control testing is used for acceptance of material. Quality verification samples are required to be collected per the frequencies stated in the standard spec and independently obtained from the quality control samples. Testing of quality verification samples is conducted utilizing separate equipment and qualified laboratory. Quality control and quality verification are required to follow the same testing procedures defined by standard spec.

835.6.2 Independent Assurance Review

Independent assurance reviews are required to be conducted by a department representative in accordance with CMM 820.

835.7 Documentation

Contractor is required to document all observations, sampling and testing results, mix adjustments, and other pertinent material information. Submit required test results in the MRS software. In addition, all original testing records need to be submitted to the engineer in a neat and orderly manner according to the timeframes defined in standard spec 710.1.2.7.

Department is required to document all observations, sampling and testing results and other pertinent material information. Department will utilize Material Information Tracking (MIT) software and MTS software for material reporting. The department compiles a material archive document at the end of the project. Additional guidance on the material archive is found in CMM 845.