## 11.50 CONCRETE
## (STRUCTURAL, CLASS X, AND FLOWABLE MORTAR)

### 11.51 PCC PLANT PAGE (FORMS 800240E and 800240M)

The project engineer shall report weekly all concrete placed for each project on "PCC Plant Page" (Form 800240). This form will record concrete placements, all results of sieve analysis tests, and all data on test beams made and tested. The week covered by each report shall begin on Sunday morning and end on Saturday evening. A separate Form 800240 is required for each bridge design, including bridge deck surfacing and resurfacing, and each group of culverts. Refer to *Materials I.M. 527* for instructions on preparing this form.

### 11.52 USE OF READY MIXED STRUCTURAL CONCRETE

**Prepour Meeting**
It is very important to use the prepour meeting to discuss the specifics of placement, establish communication, and resolve potential "sticky" issues prior to placement. Generally it is recommended to discuss:

- Chain-of-command. Who is in charge for contractor? Who needs to be notified if material tests do not comply with specifications? Establish prior to placement how test results are reported (i.e., does the contractor want to be notified verbally, or in writing each time?).

- Material requirements and admixtures needed for the placement (Examples: Single cement source, concrete temperature and methods used to cool the mix, source and amount of any admixtures, specific mixes required for bridge decks, etc.).

- Procedures for introducing admixtures during mixing operations need to be discussed and formalized. For example: How and where will the air entraining agent be introduced? There is a growing concern that placement location of admixtures is causing significant variability in mixes. The plant monitor must watch and document how admixtures are introduced during mixing.

- Method and frequency of acceptance testing during placement. Inform the contractor what is expected if non-acceptable material is found during placement. Recommend to the contractor that they arrange to have a representative from the ready mix plant on site to coordinate concrete delivery, adjustments to concrete mix, and provide direct communication with the ready mix plant during concrete placements.

- Scheduling, truck availability, placement method, and required placement rates.

- Establish an acceptable source of preplacement weather forecasting. Agree on weather parameters which will be used for "go" or "no-go" decisions both "prior to" and "during" the placement activity.

- Review & discuss items under "Concrete Bridge Floors" in Section 11.62.

**Inspector's Checklist**
A. Specifications regarding plant inspection, equipment approval, and batching operations should be reviewed for familiarity. In addition to proper plant calibration, the inspector should verify that each truck mixer used on the job has a current certification as

required by *Specification 2001.21, Paragraph B* and *Materials I.M. 528*. It is good practice to inspect a random sample of ready mix trucks that will be used on the job, verifying that the certification accurately reflects the truck's condition. Truck certification numbers should be recorded in the inspector's diary and will need to be reverified at least every 30 days. Required information to be recorded on ready mixed concrete truck batch tickets shall be according to Construction Manual Section 9.03.

B. Batching and mixing should be limited to the lead truck until slump and air content have been tested for conformance with specifications. Contractors may make preliminary tests at the plant, but project acceptance is based on job site tests. It is intended that the ready mix plant supply concrete to the construction site that conforms to all applicable specifications at the point where the acceptance sample is taken.

*Specification 2403.03, Paragraph A* states for Structural Concrete: "Concrete shall be placed with a slump between 25 mm and 75 mm (1 and 3 inches) as a target range, allowing a maximum of 100 mm (4 inches) ..."

*Specification 2403.03, Paragraph B* states for Structural Concrete:
"... unvibrated structural concrete shall be 6.5 percent, as a target value, with a maximum variation of plus 1.5% or minus 1.0%." Note: As stated in I.M. 318, an adjustment to the target air content called an aggregate correction factor may be required for some aggregates obtained from quarries in ~~east central~~ Iowa that have highly absorptive aggregates (refer to related list of aggregate sources in Materials I.M. 318). The aggregate correction factor may be obtained from the District ~~6~~ Materials Engineer ~~Office~~. The target air content for structural concrete utilizing these aggregates would be the specified target for the application plus the aggregate correction factor (see example below). Applying the aggregate correction factor when using aggregates from these quarries helps ensure that proper air content is achieved in the hardened concrete and also reduces excessive bleeding.

Example: For structural concrete specified air content is 6.5% plus 1.5% or minus 1.0%. For an aggregate correction factor of 1.0%, the target would be 7.5% (7.5% equals a specified target of 6.5% plus aggregate correction factor of 1.0%) plus 1.5% or minus 1.0%.

If concrete is being delivered which deviates much from these target values, the contractor is responsible for taking corrective action to bring the mix to within target values. Even if the current mix is within specified limits. The intent of the tolerance is to provide latitude during placement for unforeseen changes in materials, mixes, and placement methods. Placing concrete "consistently" near a tolerance limit is not desirable and warrants additional sampling.

What is important, is the contractor's response to test results approaching tolerance limits. Continually having to add water and/or air agent to each load at the site will not be permitted. If such practice is occurring, the inspector shall notify the contractor (or whomever was designated as "the" responsible individual in charge of the concrete at the site). Ultimately, it is the contractor's responsibility to initiate immediate corrective action.

Non-responsiveness on the contractor's part is reason to initiate sampling and testing of each truck or halt placement. The purpose for additional testing is to ensure that no noncomplying materials are incorporated into the project.

In some cases admixtures, such as water reducers, are required to be added in split doses or sometimes totally at the site.

C. All Structural Concrete

- At the start of each day's placement, no concrete is to be placed in the forms or on the deck until the first truck has been sampled, tested, and approved. Incorporation of materials from this truck will not be permitted unless desired slump and air content are within specified limits. Continuous placement shall not begin until after test results indicate the material meets specified requirements.

  If the first load is close to a limit value, it is recommended to sample and test the second load unless site experience indicates it is not necessary.

- Initial start up test results (if taken from the truck chute) must account for method of placement. For example, if placement will be through a pump, air values should be on the high side of target to account for loss during pumping. Again, site/project experience should be factored in this decision.

- Routine acceptance testing will be at a minimum frequency of one sample per 25 cubic meters (30 cubic yards). This frequency may be changed for large, continuous placement where placement rates warrant a lesser frequency. Minimum *quantity* placed between routine acceptance tests is 25 cubic meters (30 cubic yards). This rate of testing may be ***increased*** (made more frequent) if the inspector has a concern that target values are not being met.

  NOTE: Only the District Materials Engineer has authority to approve ***decreasing*** (less frequent) testing frequencies from those listed in *Materials I.M. 204*. PLAN AHEAD and obtain approval for those cases where a variance would be reasonable.

- For routine acceptance testing, obtain a representative sample *at the last practical point* before incorporation, but prior to consolidation. The intent here is to obtain a sample that will most accurately represent the values of slump and air content of the concrete placed. There have been some questions regarding what is considered the *last practical point* before incorporation. This is an area for good judgment relative to the particular placement. As a guideline, if an inspector has access to the point of discharge of the concrete and will be in this location for other inspection being performed it would seem reasonable that a sample could be obtained for testing. The testing of the sample should be able to be conducted in a reasonably close proximity to the point of sampling.

  **NOTE:**
  ***When concrete is placed by means other than directly from the back of the truck, the sample shall be taken, if possible, after the concrete has passed through the conveyance method being used. (This includes placement by bucket, belt, pumps, power buggies, etc.)***

- Routine acceptance sampling and testing does not require holding a truck until results are available. However, if there are obvious deficiencies, the inspector has the authority to hold that truck until test results are available.

- Inspectors should be alert to obvious visual changes in consistency, with routine acceptance air and slump tests being made as noted above. Any load having questionable consistency should be checked for slump.

- If noncomplying test results are found during routine acceptance sampling, no more material (from that truck or others) shall be incorporated until complying test results are obtained. When test results indicate noncomplying material:

  1. The rest of that load shall be rejected and not incorporated, unless adjustments can be made to bring it back into compliance *(Specification 1106.04).*

  In an attempt to bring noncomplying concrete into compliance, the supplier may make field adjustments (i.e., add air entraining agent, add portland cement, or rotate the drum). Such "field" adjustments shall be an **EXCEPTION** and not the general rule and the 90 minute time restriction shall not be waived for any situation.

  2. For all noncomplying test results the inspector shall immediately notify the contractor or their representative in charge of the concrete. This notification shall also inform the Contractor if noncomplying materials have been incorporated into the structure.

  3. If test results indicated noncomplying materials have been incorporated, the inspector shall make a note in the diary indicating the test results, approximate volume incorporated, location the material was placed, and to whom the notification was given. The inspector should also note a noncomplying event on that particular truck's delivery ticket.

  At the end of each day or each placement event (whichever is sooner) the inspector shall prepare a Noncompliance Notice (Form 830245) for all noncomplying material incorporated and not removed/replaced during that day or placement event. This notice shall be given to the Contractor yet that day *(Materials I.M. 204).*

  4. When noncomplying materials are found, the inspector will a) hold each truck, and b) initiate sampling and testing of each truck until two consecutive loads meet specifications. At this point, sampling and testing may return to normal project acceptance frequency.

D. *Specifications* and *Materials I.M.s* spell out requirements that materials must meet to be acceptable. Further, *Materials I.M. 204* identifies a frequency for sampling/testing and whether the test is an acceptance or assurance test.

Authority for initially rejecting noncomplying materials and poor quality work performance is given to the inspector in *Specification 1105.07*. This rejection authority is only superseded by the project engineer. There is an old saying to the effect, *"We shall not knowingly incorporate noncomplying material into a project."* This means exactly what it says and there is ample support in the specifications for this position.

E. During placements, the inspector should alternate sampling among the various trucks involved in the operation.

F. If there is a specific truck which is identified as causing a problem with consistency, that truck shall be rejected from further use. (Refer to *Specification 2001.21, Paragraph B.*)

G. Transit mixers shall be completely emptied of wash water before reloading. If the truck's top fill hopper is washed after loading, no wash water shall be allowed to enter the mixer.

H. When it is not practical to sample at the last point prior to incorporation, then a method of correlation between point of placement and the actual point of sampling must be developed. While such cases should be the **EXCEPTION and NOT THE GENERAL RULE**, one approved method is as outlined below:

When concrete reaches a stable consistency and is within target ranges, correlation tests can be run between the last practical sampling location and the place of deposition. If differences are consistent, then correlated tests can be taken at the last practical sampling location.

The following is a guideline if tests are not consistent:

Test a minimum of three loads of concrete sampled from the "last practical sampling location" and at the point of discharge. Average the difference between the test results. This average (correction factor) is used until another correlation is determined. Correlation tests should be determined, as a minimum, at the beginning, middle, and toward the end of a pour. The inspector needs to factor in situations such as size of pour, changing weather conditions, changes in conveyor length, changes in pumping configuration or pipe angles, and changes in batch proportions when determining frequency of correlation tests.

All subsequent "acceptance" tests are taken at the last practical sampling location and are adjusted using the correlation factor.

All correlation tests and correction factors are to be documented in the field books and noted on the "PCC Plant Page" (Forms 800240E and 800240M) or on a sheet attached to the form. Results reported using correction factors shall be identified with an asterisk (*) or written note.

I. The inspectors will need to satisfy themselves regarding compliance with the specifications for the number of drum revolutions at mixing speed.

J. If water, air entrainment, or other admixtures are added at the project site, acceptance testing will not be performed until all additions have been made AND 30 revolutions at mixing speed have been completed following the change.

## 11.53 ADMIXTURES

Admixtures are those ingredients in concrete other than portland cement, water, and aggregates, that are added to the mixture immediately before or during mixing. Admixtures typically encountered on our jobs can be classified by function as follows:

- Air entraining admixtures
- Water reducing admixtures
- Set retarding admixtures
- Set accelerating admixtures
- Corrosion inhibiting admixtures
- Finely divided and permeability mineral admixtures (Fly Ash, Ground Granulated Blast Furnace Slag & Silica Fume)
- Coloring agents (normally not used for Iowa DOT work)

The amount of any admixture used in a mix should be as recommended by the manufacturer and verified through laboratory testing or trial mixes. Effectiveness of an admixture depends upon such factors as type, brand, and amount of cement; water content; aggregate shape; gradation and proportions; mixing time; slump; and temperatures of concrete and air.

**Air Entraining Admixtures**
Air entraining admixtures are used to purposely entrain microscopic air bubbles in concrete. Air entrainment will dramatically improve the durability of concrete exposed to moisture during cycles of freezing and thawing. Entrained air greatly improves concrete's resistance to surface scaling caused by chemical deicers.

***Rules-of-Thumb***

- As cement content increases, air agent must increase to maintain equal entrained air.
- As cement fineness increases, the amount of air agent must increase to maintain equal entrained air.
- As coarse aggregate size decreases, the air content increases for a given amount of air agent.
- As fine aggregate volume increases, the air content increases for a given amount of air agent.
- As mixing water increases, the air content increases for a given amount of air agent.
- Air entraining admixtures should be introduced into mix at the plant, but additional may be added at the site to adjust mix for correct air content.
- Air entraining admixtures should (usually) be added to the front of the truck at the plant. If corrosion inhibiting admixture is used, air entraining agents should be added to the back of the truck.

**Water Reducing Admixtures - Regular**
Water reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump or reduce the water-cement ratio. Regular water reducers reduce water content by about 5% to 10%.

Adding a water reducing admixture to a mix without reducing water content can produce a mixture with a much higher slump.

***Rules-of-Thumb***

- Typically, water reducing admixtures do not reduce the rate of slump loss; in most cases, it is increased. Rapid slump loss results in reduced workability and less time to place concrete at the higher slump.
- Typically, water reducing admixtures have no effect on bleed water.

- Certain types of sulfate starved portland cements may cause false-set with certain brands of water reducers. Typically, water reducers contain lignosulfonates and these sulfates are easily attracted by sulfate starved cements. This action may cause early false-set.
- Despite reduction in water content, water reducing admixtures can cause a significant increase in drying shrinkage.

**Water Reducing Admixtures - Super Plasticizers**

Super plasticizers are simply "high-range water reducers." They are added to concrete with low-to-normal slump and water content to make high slump "flowable" concrete. Flowable concrete is a highly fluid, but workable concrete that can be placed with little or no vibration and can still be free of excessive bleeding or segregation. Flowable concrete has applications:

1. In areas of closely spaced and congested reinforcing steel
2. In tremied concrete where "self consolidation" is desirable
3. In pumped concrete to reduce pump pressure
4. To produce low water-cement ratio - high strength concrete. High-range "super plasticizers" can reduce water content by about 12% to 30%.

***Rules-of-Thumb***

- The effect of most super plasticizers in increasing workability or flowable concrete is short lived. Typically, maximum is 30 to 60 minutes followed by a very rapid loss in workability.
- Typically, super plasticizers are added as split treatments (part at the plant, part at the site). Sometimes the addition is totally at the site.
- Setting time may be affected depending on the brand used, dosage rate, and interaction with other admixtures.
- Excessively high slumps of 250 mm (10 inches) or more may cause segregation.
- High-slump, low water/cement super plasticized concrete has less dry-shrinkage than does high-slump high water/cement conventional concrete.
- Effectiveness of super plasticizer is increased with an increased amount of cement, and/or increased fineness of cement.
- Effectiveness of water reducers on concrete is a function of their chemical composition, cement composition and fineness, cement content, concrete temperature, and other admixtures being used.
- Some water reducing admixtures, such as lignosulfonates, may also entrain some air in the mix.

**Retarding Admixtures**

Retarding admixtures (retarders) are used to delay the initial set of concrete. High temperatures of fresh concrete 30°C (85°F) and up often cause an increased rate of hardening. Since retarders do not decrease the initial temperature of concrete, other methods of counteracting the effect of temperature must be used.

***Rules-of-Thumb***

- Retarders are sometimes used to delay initial set of concrete when difficult, long placement times, or unusual placement conditions exist.

NOTE: Retarders are not to be used when the anticipated temperature of the mix is below 13°C (55°F); however, placement requirements must be met within the initial set time indicated for the non-retarded concrete.

Retarding admixtures require a concrete temperature of 13°C (55°F) or greater in order to activate and effectively retard the set of concrete. If the proposed placement cannot be accomplished within the initial set time for non-retarded concrete, the concrete mix temperature will have to be increased through the use of heated materials. When heated materials are used, it is recommended that a concrete mix temperature of 18°C (65°F) be targeted for effective activation of retarding admixtures.

- Retarders offset the set acceleration effect of hot weather.
- Retarders can be added at the site.
- In general, some reduction in strength at early ages (one to two days) accompanies the use of retarders.
- Use of retarders must be closely monitored, because there is probably no single admixture which has caused more field problems.
- If too much retarder has been used in a mix:

    1. Time will usually counter the effects.
    2. "Be sure" to maintain the cure during the added time.

**Accelerating Admixtures**
Accelerating admixtures (accelerators) are used to accelerate the setting time and strength development of concrete at an early age. Strength development can also be accelerated by using:

- Type III "high-early" cement
- Lowering water/cement ratio
- Curing at controlled higher temperatures

Calcium Chloride ($CaCl_2$) is the material most commonly used in accelerating admixtures. Besides accelerating strength gain, calcium chloride also causes an increase in drying shrinkage, potential reinforcement corrosion, discoloration, and potential scaling.

***Rules-of-Thumb***

- Always add calcium chloride in solution form as part of the mixing water.
- Calcium chloride is not an antifreeze agent. When used in allowable amounts, it will only reduce the freezing point of concrete by a few degrees.

**Corrosion Inhibiting Admixtures**
Concrete protects embedded steel from corrosion through its highly alkaline nature (12.5 pH). This causes a passive and non-corroding protective oxide film to form on steel. However, carbonation or the presence of chloride ions from deicers, can destroy or penetrate the protective film. Once this happens, an electronic cell (very small battery) is formed and an electro-chemical process of corrosion begins. This process ultimately forms rust. Rust is expansive (up to 4 times original volume). This induces internal stress and eventually causes spalling to occur.

Corrosion inhibiting admixtures chemically inhibit the corrosion reaction.  Calcium nitrite, the most commonly used inhibitor, blocks a corrosion reaction by chemically reinforcing the concrete's passive film.

***Rules-of-Thumb***

- Corrosion inhibitors should be added at the plant.
- Experience indicates corrosion inhibitors should be placed in the front of the truck (first-in) and air entrainment agent should be placed at the back (last-in).
- Corrosion inhibitors are accelerators and will affect set times. It is recommended to consider adding about a one-half dose of retarder to extend working times.
- Air content of mixes using corrosion inhibitors is often difficult to stabilize. Watch the target air closely.
- A certain amount of calcium nitrite can protect up to a certain threshold level of chloride.  Therefore, the amount of corrosion inhibitor added to a mix must be developed for an assumed maximum level of chloride ingress expected.

**Finely Divided Mineral Admixtures**
These admixtures are powdered or pulverized materials added to concrete to improve or change the properties (plastic or hardened) of concrete. Based on the mineral's chemical or physical properties, they are classified as: (1) Cementitious, (2) Pozzolans, (3) Pozzolanic and Cementitious, and (4) Nominally inert. Typical PCC mix designs use #3 above.

**Pozzolanic Materials**
A pozzolan is a siliceous or aluminosiliceous material that in itself possesses little or no cementitious value but will, in finely divided form and in the presence of water, chemically react with the calcium hydroxide released by the hydration of portland cement to form compounds possessing cementitious properties.  Pozzolans include fly ash and silica fume.

**Fly Ash (Class C & F)**
Fly ash is a finely divided residue that results from the combustion of pulverized coal in electric power plants.

**Silica Fume**
Silica fume, also referred to as micro-silica or condensed silica fume, is another material that is used as a pozzolanic admixture. This light to dark gray powdery product is a result of the reduction of high-purity quartz with coal in an electric arc furnace.

Fly ash and silica fume have a spherical shape.  Silica fume has an extremely small particle size (about 100 times smaller than the average cement particle).  Although silica fume is normally in powder form, because of its small size and increased ease of handling the product is commonly available in liquid form.

**Cementitious Materials**
Cementitious materials are substances that alone have hydraulic cementing properties (set and harden in the presense of water). Cementitious materials include ground granulated blast furnace slag.

**Ground Granulated Blast Furnace Slag (GGBFS)**
GGBFS made from iron blast-furnace slag is a non-metallic product consisting essentially of silicates and aluminosilicates of calcium and other bases developed in a molten condition simultaneously with iron in a blast furnace. The molten slag is rapidly chilled in water to form a glassy sandlike material which is ground to a particle size similar to fly ash. Unlike fly ash and silica fume which have a spherical shape, GGBFS is rough and angular-shaped.

***Rules-of-Thumb***

- Mixes containing fly ash or GGBFS will generally require less water (about 1% to 10%) for a given slump. Silica fume concrete requires more water for a given slump.
- The amount of air-entraining admixture required to obtain a specified air content is normally greater when fly ash or silica fume is used. Ground slags have variable effects on the required dosage rate of air-entraining admixtures. The amount of air-entraining admixture for a certain air content is a function of the fineness, carbon content, and alkali content.
- Fly ash and ground slag will generally improve the workability of concretes of equal slump. However, fly ash in low slump concrete will tend to tear and have reduced workability. Silica fume tends to reduce workability, thus high-range water reducers are usually added to maintain workability.
- Concrete using fly ash or silica fume generally shows less segregation and bleeding than plain concrete. Concrete using some ground slags tend to have slightly higher bleeding than plain concretes, but have no adverse effect on segregation.
- Use of fly ash and ground slag will reduce the amount of heat build-up in concrete. Silica fume most likely will not reduce the heat of hydration, because typically high-range water reducers are used and they increase mass temperatures.
- Use of fly ash and ground slag will tend to generally retard the setting time of concrete. Silica fume alone will accelerate the setting time, however, high-range water reducers tend to offset this.
- Use of fly ash and ground slag generally aids the pumpability of concrete.
- With adequate and correct curing, fly ash and ground slag generally reduce the permeability. Silica fume is especially effective in this regard.

## 11.54 USE OF INSULATED FORMS FOR PROTECTION

Commercial insulation may be used for protecting concrete during cold weather, or when the contract documents require controlling the heat of hydration. This technique is the contractor's option and could be used in lieu of housing and heating. It will then be the contractor's responsibility to furnish insulation of sufficient quality and thickness to maintain concrete at a temperature of not less than 10$^{o}$C (50$^{o}$F) for the first 48 hours after placing, if air temperatures will be less than 5$^{o}$C (40$^{o}$F). (Refer to *Specification 2403.08, Paragraph H.*)

Concrete must be between 7$^{o}$C and 27$^{o}$C (45$^{o}$F and 80$^{o}$F) when placed. To ensure a concrete temperature of at least 10$^{o}$C (50$^{o}$F) for 48 hours after placement, the concrete for thin sections such as culvert walls, end posts, piling encasements, etc. should be 18$^{o}$C (65$^{o}$F) or higher, since the only additional heat source is the heat of hydration. Concrete for massive sections such as stub abutments, heavy piers, and footings should be in the 13$^{o}$ to 18$^{o}$C (55$^{o}$ to 65$^{o}$F) range.

Since only dry insulation is effective, any insulation that has a propensity to adsorb water or become saturated must be protected with a waterproof membrane. The insulation system must provide complete coverage and be secured to provide maximum protection during the full curing period.

For typical protection applications, insulated forms must be left undisturbed for 96 hours before being removed. (Refer to *Specification 2403.11.*)

**Checking Temperature of Concrete**
For checking compliance with minimum temperature requirements during the 48-hour period after placement, thermometer wells should be cast in the concrete during the pour. The following procedure for checking temperature is suggested:

1. Drill an 8 mm (5/16 inch) hole through the form at one or more locations where temperature checks will be made.
2. Grease the thermometer probe and insert it through the hole about 100 mm (4 inches) into the plastic concrete.
3. Remove probe after the concrete is set and cover hole with insulating material.
4. Further checks can be made by inserting the thermometer through the insulation into the well developed in step 2. Leave thermometer in place if desired, but protect from damage or theft.

NOTE: The thermometer stem should be inserted about 75 mm (3 inches) into the concrete because the sensitive portion of stem is about 70 mm (2 3/4 inches) below the groove.

Other acceptable methods for monitoring concrete temperature are the use of maturity meter with temperature probe wires embedded in the concrete or use of thermal ‘iButtons’ embedded in the concrete with exposed wires for data collection and recording.

Record temperature daily for 48 hours following the pour. Temperature readings below $10^{o}$C ($50^{o}$F) during the first 48 hours should be reported to the Office of Construction for evaluation of possible damage or price adjustment.

## 11.55 DECK PLACEMENT AND HEAT OF HYDRATION

Cracking of concrete in bridge deck placements and large concrete elements (ie: bridge footings, columns, pier caps, etc.) can occur unless the placements are properly controlled. The following provides information on measures that are used in the effort to control cracking of concrete in bridge decks and large concrete element placements.

**Deck Placement**
Sometime ago the Office of Bridges and Structures, Office of Materials, and Office of Construction began evaluating the phenomena of bridge deck cracking. Measures have been implemented to manage bridge deck placement and prevent cracking through the use of Evaporation Rate Controls.

Research continues in the management of quality bridge deck placements and deck cracking control. To provide needed site specific data for this research, Forms E122, E139, M122 and M139 were developed. These reporting forms were initiated during 1991. Since that time, the information provided from the field has been compiled into a database for evaluation. The evaluation of this data is ongoing and includes review of the effectiveness of Evaporation Rate Controls and possible trends which may lead to a better understanding of crack development.

Forms E122, E139, M122 and M139 are included in *Appendix 11-16*. Since they are not available in Office Supplies, please photocopy as needed. Submit completed forms to the Office of Construction.

**Deck Concrete Temperature and Curing**
*Specification 2412* identifies requirements for placing and curing concrete bridge floors. Of importance for this section are:

- Plastic concrete, when placed, shall not exceed 32°C (90°F).
- Concrete floors will not be placed if the theoretical rate of evaporation exceeds 1 $kg/m^2$ /hr (0.2 lbs./sq.ft./hr.).

NOTE: A theoretical evaporation chart is included in *Specification 2412.05*. As an alternative, a computer program has been developed for calculation of theoretical rate of evaporation using Excel. This program incorporates the charts from the specifications in a formula table included on report Forms E122 and M122. The program simplifies the determination of the theoretical rate of evaporation and enables the user to perform trial evaluations for possible changes in air temperature, relative humidity, plastic concrete temperature, and wind velocity. A copy of the Excel program for theoretical rate of evaporation is available at

English - http://www.iowa.dot.gov/construction/structures/theoretical_evaporation_rate.xls
or
Metric -
http://www.iowa.dot.gov/construction/structures/theoretical_evaporation_rate_metric.xls

- The curing method requires prewetted burlap to be placed within 10 minutes of final finishing and followed by a "wet" burlap cure for four (4) days. A continuous sprinkling system is required to keep the burlap wet during this time.
- Plastic, in addition to wet burlap, may only be used between October 1 and April 1. The plastic provides a moisture proof barrier above the wet burlap and replaces the sprinkling system after 20 hours of the application of water during cold weather.

The placing of concrete will require close monitoring to comply with the specification. The contractor or ready mix plant should determine temperature of previously placed concrete to project a mix temperature prior to a deck pour. Further, they should obtain a weather report to determine predicted air temperature, wind velocity, and relative humidity for the pour day. Based on this information, you will be able to reasonably predict an evaporation rate.

The above information should be discussed by the inspector, contractor, and ready mix plant operator before a deck pour. The pour should not be attempted if concrete temperature is predicted at 29° C (85°F) or higher and predicted air temperature is above 32°C (90°F). Also, the pour should not be attempted if an evaporation rate would exceed 1 $kg/m^2$/hr. (0.2 lbs./sq.ft./hr.).

District Materials Office has sling psychrometers and wind gauges available for usage the day of the pour. A sling psychrometer is used to determine the relative humidity by finding "wet" and "dry" bulb temperatures. (Refer to Charts in *Appendix 11-17*.) With these values, compute temperature difference and locate the "Difference Between Readings..." column. Then locate the row labeled with appropriate dry bulb temperature. The value at the intersection of "Difference" column and "Dry" bulb temperature is the relative humidity.

**EXAMPLE:** (English units only)
If the dry bulb temperature is 71$^{o}$F and the wet bulb temperature is 64$^{o}$F, the difference is 7$^{o}$F. At the top of the chart, locate the column headed 7. Follow this column down to the dry bulb temperature row of 71$^{o}$F. The intersection indicates a relative humidity of 68%.

There are also electronic pocket weather meter/station devices (ie: Ketsrel) which is a hand-held instrument for air temperature, wind speed, and relative humidity determination which can be used for evaluation of the theoretical evaporation rate.

**Placement Considerations**
A. If there is any doubt about the concrete temperature exceeding 29$^{o}$C (85$^{o}$F), the contractor needs to identify measures which will be implemented to keep mix temperatures within specifications. If the contractor is not prepared to maintain a mix temperature below specifications, the pour should be postponed.

There are several ways concrete temperatures may be kept within specifications. They are:

- Scheduling placements during cooler times of the day
- Wetting the aggregate stockpiles
- Covering/shading the aggregate stockpiles
- Maintaining a supply of portland cement on hand to preclude getting hot material from the supplier
- Chilling the mixing water is one of the most effective ways to lower mix temperatures.
- Shaved ice can be used, however, the ready mix operator must submit a proposal for this to the project engineer for review by the Office of Construction.

NOTE:
1. No payment will be made for methods taken to keep concrete temperatures and evaporation rates within specifications.
2. If pour has to be delayed because of temperature, and pouring is the controlling operation, no working days will be charged.

B. Location of permissible headers should be discussed with the contractor. If during the pour, it appears:

- The temperature may exceed 32$^{o}$C (90$^{o}$F)
- And/or the theoretical evaporation rate would exceed 1 kg/m$^{2}$/hr. (0.2 lbs./sq.ft./hr.)

and these deficiencies cannot be corrected by immediate action, the placement shall be halted at the first permissible joint. On slab bridges, any joint location listed on the plans can be used. For girder beam bridges (steel or concrete), placement may be stopped, in an emergency, at locations as follows:
Case A. (Continuous or noncontinuous beams, positive section)
If the positive section has not been completed:
Complete the positive section and stop at the header location shown on the plans.

Case B. (Noncontinuous beams, negative section)

If placement has not proceeded beyond the pier:
Do not place concrete in the pier diaphragm, and stop just short of the beam end.

Case C. (Noncontinuous beams, negative section)

If placement has progressed beyond centerline of the pier:
Placement must continue through that negative section and stop at the header shown on the plans.

Case D. (Continuous beams, negative section)

If problem occurs after starting the negative section:
Placement must continue through the negative section, and stop at the header shown on the plans.

See *Appendix 11-24* for case illustration.

In every case listed above, contact the Office of Construction for curing times and beam break strengths before allowing the contractor to resume deck placement.

**Field Documentation**
The temperature of concrete should be taken as soon as concrete is placed. It should be taken when the first load is placed and at intervals shown on Forms E122 and M122, Appendix 11-16. Additional checking is warranted if temperature is running at or near maximum. Air temperature should also be taken about the same time as the concrete temperature.

**Heat of Hydration**
Occasionally, projects will require placement of large volumes of concrete for individual concrete elements (ie: bridge footings, columns, pier caps, etc.). Controlling the temperature of this large volume is important to reduce cracks and potential premature deterioration from thermal cracking that can result from a large temperature difference between the center of the concrete element and its surface. In these cases the contract documents may require monitoring the "heat of hydration." There will also be requirements for the differences between specified monitoring locations. For example: "The temperature difference between the edge of the concrete and the center shall not exceed 10$^{o}$C (35$^{o}$F)."

The cooling of large volumes of concrete can take considerable time, and during that time monitoring is required. A form to record these temperatures has been developed. (Refer to "Heat of Hydration" form in *Appendix 11-18*.) Since this form is not included in Office Supplies, please photocopy as needed. Submit completed forms to the Office of Construction.

## 11.56 PLACEMENT METHODS (PUMPING, BELTING, AND CRANE BUCKET)

Much concern has been expressed about the method of concrete placement because of lost entrained air. Rough handling of plastic concrete during placement has, at times, reduced entrained air to less than 2% not to mention potential segregation problems. While testing at the point of placement "should" identify such problems, varying placement conditions during the pour can affect concrete conditions significantly.

General conditions which must be avoided, or at least severely minimized, are as follows. If one of the following cannot be avoided, *at least* be aware of the condition, and *be sure* to conduct additional testing should any of the conditions present themselves.

**Crane and Bucket**
In the past it was felt the crane and bucket placement method did not adversely affect concrete. This is now in question when viewed from loss of air and potential segregation. Therefore, this method will now also require testing at the placement location, if practical.

**Points-to-Watch For**

- Free fall of unrestrained concrete shall not exceed 2 m (6 feet) for vertical placement and 1 m (3 feet) for floors and slabs. (Refer to *Specification 2403.08, Paragraph C.*) If the distance is exceeded: (1) reduce the pour depth, (2) remove a section of form work for intermediate placement, (3) or use a tremie.
- Discharge from the bucket must be controllable.
- Cross section of the drop-chute should permit inserting into the form work without interfering with reinforcing steel.

**Belt Placement**
Belt equipment is typically used to convey concrete to a (1) lower, (2) horizontal, or (3) somewhat higher level.

**Points-to-Watch For**

- Keep the number and distance of drops between belts to an absolute minimum. Drops tend to encourage segregation and reduce entrained air.
- As belt conveyors are removed from the line (i.e., as on deck pours), recheck the "as placed" air content.
- Be sure all mortar is being removed at the discharge. (No mortar should be on the return belt.)
- Check discharge for potential segregation problems.
- In adverse weather (hot and/or windy conditions), long belt runs need to be covered.

**Pump Placement**
The modern mobile pump with hydraulic placing boom is economical to use in placing both large and small quantities of concrete. These units are used to convey concrete directly from a truck unloading point to the concrete placement area.

**Points-to-Watch For**

- Typically, pumps are initially flushed with a thin water/cement paste mixture to coat the lines. This slurry must be wasted and the lines charged with the project mix before beginning. Observe, and be sure initial pump charge is thoroughly removed from the pipelines.
- Always pump at a constant rate and keep pipelines full of concrete. High air loss can occur when concrete is allowed to free-fall inside pump lines.
- Avoid, if at all possible, having steep angles in the pump pipelines. Steep angles and slow placement rates are probably the worst conditions for minimizing air loss and segregation. If this condition occurs:

1. Attempt to relocate the pumper, thereby minimizing lift angle.
2. If discharge is not maintaining a constant flow with partial concrete head in the pipe, request pump operator to place a reducer and short section of hose at the discharge end. The purpose is to avoid free falling concrete from impacting the epoxy coated reinforcing steel, deck or forms at high velocity. High velocity impact of concrete aggregate on epoxy coated bars can potentially damage the epoxy coating.
3. If above condition is unavoidable, watch and test the discharge frequently for loss in air and potential segregation.

***Rules-of-Thumb for Pumping***

- Pump concrete with pipelines as flat as possible (or at least with minimal down angle)
- Minimize (or eliminate) free falling concrete in the pipelines. To do this, maintain some amount of concrete head in the pipelines
- Pump concrete through as few elbows and restrictions as possible
- Pump concrete at "some" constant rate
- Watch for, and test frequently, when situations are not optimized

## 11.57 FORM REMOVAL

### Setting Beams

The following should be used as a guide in conjunction with *Specification 2403.19:*

A. On diaphragm piers, beams may be set as soon as doing so will not mar or chip the concrete. It is recommended that 24 hours be considered a minimum cure time. (In cooler weather, ambient temperatures below 5°C (40°F), the minimum time indicated should be increased to 48 hours.)

B. No beams may be set on pedestal (T or P10A) piers until the cap concrete is 7 days old and modulus of rupture is at least 3,800 kPa (550 psi) or more. The contractor has the option under *Specification 2403.03* to substitute Class M concrete mix for Class C except in bridge floors. When Class M concrete mix is used, beams may be set when the cap concrete is 3 days old and the modulus of rupture is at least 3,800 kPa (550 psi) or more. (Refer to *Specification 2403.19* .) If no test beams are made, the time must be extended to 14 days. (Refer to *Specification 2403.18*.)

There have been special situations where the contractor has been allowed to set beams on piers that have not attained the above strengths. In these cases, the bottom forms have remained in place for an extended period of time. Before approving any variance, contact the Office of Construction for approval.

C.On stub abutments or integral abutments, steel beams and girders may be set as under A above. Concrete beams on stub abutments or integral abutments, same as A above. (Stub abutments are abutments with battered piling, sliding bearings, and the abutment does not move. Integral abutments have vertical piling in prebored holes, beams are rigidly connected to the abutment, and the abutment moves.) On full abutments (solid and continuous from spread footing), same as A above.

## 11.58 CLASS 3 CONCRETE SURFACE FINISH (RAIL AND BEAMS)

### Approval of Materials

*Materials I.M. 491.10* lists the approved materials and proportions for use in obtaining a Class 3 finish required by *Specification 2403.21*. Any one of the listed materials may be used. However, for uniformity, only one type should be used on any one structure.

Approvals of this material will be on the basis of legible brand markings on the containers. Periodic sampling and testing will be the responsibility of the Office of Materials. The type used on any structure should be included in the project documentation.

### Application of Finish

Surfaces to be given a Class 3 finish must first be given a Class 2 strip down finish immediately after removal of forms. Successful application and adhesion of any type of finish to concrete surfaces is dependent on concrete condition and concrete surface preparation. Factors such as pH of the concrete, concrete moisture content, cleanliness of the concrete surface, and concrete surface profile are all critical to ensuring any coating being applied will securely adhere. For additional information and guidance contact the Office of Construction.

Materials for a special surface finish should be mixed to a uniform condition, preferably with a power mixer. When using a power mixer, add dry ingredients to the liquid. One worker should place the material with a steel trowel, making sure it is pressed firmly into all voids and leveled. When the surface is set so it will not roll or lift, a second worker should smooth the surface uniformly with a rubber float.

### Concrete Railings

Surfaces of concrete for barrier rails placed against fixed forms, either on site or in precasting, shall be given a surface finish described for exterior beams in *Specification 2407.14* before application of curing. This should be done as the forms are removed. The contractor may opt to broom (brush) finish the slipform barrier rail.

## 11.59 FLOWABLE MORTAR

Flowable mortar is being used for four separate purposes according to the current specification:

- **Backfilling culverts** with flowable mortar is specified for the purpose of preventing settlement in the excavation area. Flowable mortar backfill of open trench culverts is typically used when the excavation is in an existing roadway embankment and the excavation area is too small to facilitate normal soil backfill and compaction methods. In this case, flowable mortar fluidity, as discussed in the specifications, is considered non-critical.

- **Backfilling culverts constructed under bridges** with flowable mortar is specified when existing bridge structures are being converted into roadway embankment sections. This involves constructing a drainage structure under the bridge and converting the existing bridge superstructure into a fully supported roadway section. Flowable mortar backfill is used under the bridge superstructure to fill the embankment area under the bridge up to the bottom of the existing bridge deck. The flowable mortar method is specified since normal soil backfill and compaction methods are not practical and would not achieve the required embankment support for the converted bridge deck. In this case, flowable mortar fluidity is considered non-critical in the area placed below the bridge beams, but would be considered critical between the beams. Flowable mortar for this case is typically specified to be placed in two or more stages.

- **Filling void between culvert and culvert liner** with flowable mortar is specified to provide support between the culvert liner and existing culvert to prevent future culvert collapse. Flowable mortar is used since normal soil backfilling and compaction methods are not possible. In this case, flowable mortar fluidity is critical and flow distance is limited which may require incremental placement points.

- **Plugging culverts** with flowable mortar is specified when it is either not possible or practical to remove existing culverts, therefore these culverts are being abandoned in place. In this case, flowable mortar fluidity is critical and flow distance is limited which may require incremental placement points.

Depending on the application, samples of sand, cement, and fly ash may need to be submitted to the Office of Materials for a mix design. (Refer to *Specification 2506.02* for information as to when material will meet the required flow time as measured with a flow cone.) Free water in the sand pile must be considered as mix water because a mix design uses oven dried sand.

Refer to *Appendix of Materials I.M. 491.17* for approved fly ash sources and classes.

The success of all flowable mortar projects depends on establishing uniform under-drainage.

Where flowable mortar is to be placed against joints, the joints should be: (1) wrapped with a fabric as per *Specification 4196.01, Paragraph B*, or (2) sealed with a gasket, or (3) sealed with roofing cement.

If the contractor uses crushed limestone for granular backfill, it shall meet the requirements for Granular Backfill. (Refer to *Specification 4133.01*.)

Remember flowable mortar is a liquid which has a density of about 2,136 $kg/m^3$ (3,600 lbs./cu yd.) until the water has dissipated. Bulkheads should be strong enough to withstand those pressures.

Under normal conditions, flowable mortar should be set-up sufficiently within 24 to 48 hours for placement of the final lift of either earthfill or special backfill. If "set-up" does not occur or if it seems slow, typically the problem relates directly to drainage of the granular backfill. Often contamination or "dirty" granular backfill is the culprit. Check to be sure it is draining. If not, additional time will help. If time is critical, you may have to physically cut trenches (drainage paths) into the flowable mortar.

**Backfilling Culverts - Typical Grading**
For backfilling culverts, flowable mortar is used above the granular backfill elevation

identified on the plans. There should be a 100 mm (4 inch) subdrain typically located at the culverts flow line elevation. This subdrain is placed to facilitate draining water from the flowable mortar. Therefore, for culverts with buried flow lines, the subdrain will need to be placed in the granular backfill at the lowest elevation possible and yet allow drainage.

Flowable mortar will nominally be placed 0.6 m (2 feet) thick over the entire culvert excavation. Plans, or typicals, define the area used to calculate plan quantities for flowable mortar and granular backfill. (Flowable mortar plan quantities should include 30% additional for anticipated consolidation of the granular backfill and shrink due to loss of water.) If the Contractor opts to excavate a larger area than assumed for plan quantity, additional excavation, backfill, and flowable mortar will not be considered for pay. We will however, require additional excavation to be backfilled in a manner as identified by the plans or typicals.

Placement of flowable mortar shall always be computed from "top down." This means allow for:

1. Pavement thickness
2. 0.3 m (1 foot) of special backfill, if required
3. Variable thickness of earth fill where cover heights are over 2.5 m (8 feet)
4. Placement of 0.6 m (2 feet) of flowable mortar

There are two general installation situations.

Situation 1:
Distance between the top of culvert and bottom of pavement is greater than 0.9 m (3 feet), but less than or equal to 2.5 m (8 feet). In this situation, the top of granular backfill will *vary* from 0.6 m (2 feet) below top of culvert to 1.5 m (5 feet) above the culvert top.

Example:

Assume:
1. Bottom of slab is elevation 30 m (100 feet) and top of culvert is 28.65 m (94 feet).
2. There is 0.3 m (1 foot) of Special Backfill. Elevation 29.7 m (99 feet)
3. 0.6 m (2 feet) of flowable mortar is required. Elevation 29.1 m (97 feet)

In this example, cover is less than 2.5 m (8 feet), granular backfill is placed from bottom of excavation up to elevation 29.1 m (97 feet).

Note: There will be consolidation in both the granular backfill and flowable mortar. It is recommended to place:

- Granular backfill to the required calculated elevation
- Flowable mortar to its calculated elevation
- Make up any final elevation difference due to total consolidation by additional thickness of special backfill

Situation 2:
Distance between "top of culvert and bottom of pavement" is greater than 2.5 m (8 feet). In this situation: A) the top of granular backfill will be fixed at the elevation of culvert top, B) 0.6 m (2 feet) of flowable mortar will be placed directly on top of the granular

backfill, and C) compacted earthfill will be placed between flowable mortar and special backfill. In this example, the earthfill will have a minimum thickness of 1.5 m (5 feet) and no theoretical maximum thickness.

Example (Using English units only)

Assume:
1. Bottom of slab is Elevation 100.
2. There is 1 foot of Special Backfill (Elevation 99).
3. Earthfill is required, but thickness cannot be calculated yet. (Elevation ???)

At this point you must now calculate from the culvert top, up to the bottom of the earthfill.
4. Top of culvert, for this example, is assumed to be Elevation 86.
5. Granular backfill is fixed at the culvert top (Elevation 86).
6. 2 feet of flowable mortar is required. (Elevation is 86 + 2 = 88.)

In this situation, earthfill is placed from the top of flowable mortar (Elevation 88) to bottom of special backfill (Elevation 99). Specifically, 11 feet of earthfill is required. (Elevation 99 - 88 = 11 feet)

**Plugging Culverts**
For culverts 20 m (60 feet) or less in length, flowable mortar may be placed into the outlet first, then the inlet. For culverts more than 20 m (60 feet) long, the desirable spacing for placing flowable mortar should be 20 m (60 feet). The optimum travel of flowable mortar is 10 m (30 feet) with approximately 75 mm (3 inches) of fall in the surface. To avoid drilling through pavement, the spacing can be increased to 25 m (80 feet) if necessary.

**Backfilling Culverts - Under Bridges**
Prior to installing flowable mortar, the culvert must be backfilled with granular backfill to at least 75 mm (3 inches) over the culvert or 1.5 m (5 feet) below the lowest bridge elevation. As this granular backfill is placed, the outside fill should be brought up at the same time with soil.

Flowable mortar used for backfilling culverts under bridges is placed in two stages.

In the first stage, flowable mortar is placed to an elevation about 150 mm (6 inches) below the bottom of bridge deck or the beams whichever is lower. Bridge beams should be fitted with Styrofoam filler to full width of the flanges. Refer to illustration in *Appendix 11-25*. This will prevent adding dead load to the beams with flowable mortar.

In the second stage, flowable mortar is placed through holes drilled in the deck at spacings identified in the plans or specifications. Typically, begin at one abutment and continue longitudinally down the bridge until the other abutment has been reached, filling all holes on one side of the centerline. Then begin on the other side of the bridge and work holes nearest the centerline and proceed to the outside.

After flowable mortar has been placed, the contractor is required to saw a minimum of 75 mm (3 inches) deep cut into the original deck before any sidewalk, curb, or handrail is removed. It is important that this 75 mm (3 inch) saw cut be done prior to any curb removal, thereby preventing damage to the deck.

Placing flowable mortar under a bridge can be accomplished during staged construction. The specification requires a 72-hour delay between stage 1 and stage 2 placement of flowable mortar to allow for settlement of the granular backfill.

**Filling Voids Between Culverts**
If there is room to place granular backfill between culverts, do so to one-half the new culvert height. In situations such as multiple barrels, or a new pipe inside a box, the granular backfill will adequately maintain pipe location during flowable mortar placement.

If granular backfill cannot be used, culvert(s) should be blocked at 3 m (10 foot) intervals or less and flowable mortar placed as usual. If a pipe inside a culvert has to be blocked in place, the blocking must be situated in a manner to prevent damming and causing voids in the mortar. All blocking placed on the top of the inside culvert must be saddle shaped to fit the culvert. This distributes the buoyant forces over a larger area and reduces chance of pipe buckling. To further reduce buoyant forces:

- Place about one-half of the total flowable mortar
- Delay about four hours before placing the remainder

In all cases, a drainage system must be established on each side of the culvert(s). The drainage system should be a 100 mm (4 inch) slotted drain with a minimum of 150 mm (6 inches) of granular backfill cover. The drainage system reduces buoyancy effects and allows for dewatering of the flowable mortar.

Inspect all pipe joints and lifting holes for looseness and voids. Two approved repair methods are:

- Wrap joints with fabric approved per *Specification 4196.01, Paragraph B*
- Seal joints with sealant material such as roofing cement or gaskets