U.S. Department of Transportation

Federal Highway Administration

Technical Advisory

Subject

PORTLAND CEMENT CONCRETE MIX DESIGN AND FIELD CONTROL

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1. PURPOSE. To set forth guidance and recommendations relating to portland cement concrete materials, covering the areas of material selection, mixture design, mixing, placement, and quality control.

2. BACKGROUND

a. Each year approximately 46 million cubic meters of concrete are used in all highway construction. The vast majority of States use a prescription type specification for portland cement concrete, often specifying minimum cement content, maximum water cement ratio, slump range, air content, and many times aggregate proportions. Admixtures such as fly ash are incorporated into mixes as a part of the prescription.

b. This system has worked fairly well in the past but may change as emphasis is placed on performance based specifications. States have begun to reduce or eliminate the amount of inspection at concrete plants as automation has increased productivity.

3. MATERIALS

a. Portland Cement. The proper type of portland cement should be specified for the conditions which exist.

OPI: HNG-23

(1) Types I, II, III, IP, and IS are typically used in highway construction. Type I is used when no special circumstances exist. Type II is used when sulfate exposure conditions are present. Type III is used when high early strengths are required. The use of Types IP and IS result in lower early strength gains and can be substituted for Type I cement when early strength is not a concern. In addition to the above mentioned types, Types IV and V are sometimes used in highway applications to meet special conditions. Further information about these cements can be found in the book Design and Control of Concrete Mixtures published by the Portland Cement Association (PCA).

(2) It is recommended that the acceptance of portland cement be based on certification by the supplier. The certification should contain the lot number of the cement. The supplier's test results should accompany the certification or be available to the State. Verification samples should be taken and used as part of the acceptance system.

(3) If alkali aggregate reactivity (AAR) is a concern, a maximum alkali content of 0.6 percent should be specified. Some State highway agencies consider this amount too high and recommend smaller amounts. If AAR is a problem in the State, a review of a States' Materials Manual is suggested. See Concrete Distress Conditions Section for other remedies.

b. Aggregates. Aggregates make up 60 to 70 percent of the volume of concrete mixes. A significant portion of poorly performing highway concrete can be traced to aggregate quality problems.

(1) The fine aggregate should meet the requirements of the American Association of State Highway and Transportation Officials (AASHTO) M 6.

(2) The range for the gradation of fine aggregate is quite broad. The fineness modulus (FM), calculated using AASHTO T 27, can be used as a tool for assessing the variability of the fine aggregate gradation. The specifications should limit the range of the FM between 2.3 and 3.1 according to AASHTO M6 and the variation of the FM should not be more than 0.20 from the value of the aggregate source.

(3) The FM is a means to control the influence that fine aggregate has on workability and the air content of the mix and is sometimes specified in the mix design. Further information regarding FM can be found in the Federal Highway Administration's manual FHWA-ED-89-006 (Portland Cement Concrete Materials Manual).

(4) It should also be noted that to provide good skid resistance, the PCA recommends that the siliceous particle content of the fine aggregate should be at least 25 percent. Consideration should be given, however, to the possibility of alkali-silica reactions when this is done.

(5) The coarse aggregate should meet the requirements stated in AASHTO M 80. For most parts of the country the severe exposure requirements should be used which means the use of class A aggregate for structural concrete and class B aggregate for pavements. The following table contains some of the more common information provided by Table 1 in AASHTO M 80.

	Class A Aggregate	Class B Aggregate
Clay lumps and friable particles	2%	3%
Chert	3%	3%
Sum of clay lumps, friable particles and chert	3%	5%
Material finer than No. 200	1%	1%
Coal and Lignite	0.5%	0.5%
Abrasion	50%	50%
Sodium Sulfate Soundness	12%	12%

c. Water

(1) The water serves as a key material in the hydration of the cement. In general, potable water is recommended although some non-potable water may also be acceptable for making concrete. Water of questionable quality should be examined since this can effect the strength and setting time. The following criteria is contained in Table 1 in AASHTO M 157 and is based on control tests made with distilled water:

Test	Limits
Compressive strength percent of control tests at 7 days	90
Time of set deviation from control	1 hour earlier to 1.5 hour later

(2) Wash water can be used to make concrete providing the resulting concrete mix water meets the following criteria in Table 2 in AASHTO M 157:

Chemical	Limits
Chloride as percent of weight of cement for the following uses:	
prestressed concrete	0.06
reinforced concrete in moist environment exposed to chlorides	0.10
reinforced concrete in moist environment not exposed to chlorides	0.15
sulfates	3000 ppm
alkalis	600 ppm
total solids	50,000 ppm

(3) If there is any question about the water, it should be tested using AASHTO T 26.

(4) It should be noted that the American Concrete Institute (ACI) provides more stringent tolerances for total chlorides in the mix. The chloride content for wash water in AASHTO M 157 is recommended for total chloride content in ACI 201.2R 22.

d. Admixtures. Admixtures are typically placed in mixes to improve the quality or performance. They can affect several properties and can have a adverse impact on the mix if not used properly. To avoid possible problems, it is suggested that trial batches be made to evaluate the mix.

(1) Air entraining admixtures should be specified when concrete will be exposed to freeze/thaw conditions, deicing salt applications, or sulfate attack. Recommendations for air content are contained in paragraph 4d.

(a) A vinsol resin type admixture should be added when fly ash having a variable loss on ignition (LOI) content (between 3 percent and 6 percent) is present. This is because of the effect that fly ash's fineness and carbon content has on the air entrainment system. Fly ashes not having a variable LOI do not have an adverse impact on entraining agents and therefore vinsol resin type admixtures may not be necessary.

(b) The specifications for air entraining admixtures are contained in AASHTO M 154.

(2) Chemical admixtures include water reducers, retarders, accelerators, high range water reducers (superplasticizers), corrosion inhibitors and combinations of the above. The specifications for chemical admixtures are contained in AASHTO M 194.

(a) Mixes containing admixtures are permitted an increase in shrinkage and a decrease in freeze thaw durability (as indicated in Table 1 AASHTO M 194) in comparison with mixes having no admixtures.

(b) Admixtures are usually accepted based on preapproval of the material and supplier certification. Verification tests should be performed on liquid admixtures to confirm that the material is the same as that which was approved. The identifying tests include chloride and solids content, pH, and infrared spectrometry.

(c) Water reducers and retarders may be used in bridge deck concrete to extend the time of set. This is especially important when the length of placement may result in flexural cracks created by dead load deflections during placement.

Often water reducers and retarders may increase the potential for shrinkage cracks and bleeding. Because of these concerns, increased attention needs to be placed on curing and protection.

(d) High range water reducers can be used to make high slump concretes at normal water cement (w/c) ratios or normal range slumps at low w/c ratios. The primary concern with the use of these admixtures is the loss of slump which occurs in 30 to 60 minutes. Redosing twice with additional admixture is allowed by ACI 212.4R; however, redosing typically reduces air entrainment. Type F and G high range water reducers may also be used. Type G has the added advantage of containing a retarding agent.

1 If transit mix trucks are used to mix high slump concrete, it is recommended that a 75mm slump concrete be used at a full mixing capacity to ensure uniform concrete properties. If transit mix trucks are used to mix low w/c ratio concrete, it is recommended that the load size be reduced to 1/2 to 2/3 the mixing capacity to ensure uniform concrete properties. Admixture companies are recommending additional mixing time with low w/c mixtures instead of decreasing the size of the load. This may have detrimental effects on some properties of the concrete such as the degradation of the aggregate resulting from over mixing.

2 High range water reducers may also affect the size and spacing of entrained air. If Freeze-Thaw

testing as described by ASTM C 666 indicates this to be a problem, it is recommended that the air content be increased by 1½ percent.

(e) Calcium chloride, the most commonly used accelerator, has been associated with corrosion of reinforcing steel and should not be used where reinforcing steel is present. In addition to the corrosion problem calcium chloride also reduces sulfate resistance, increases alkali-aggregate reaction, and increases shrinkage. Calcium chloride should not be used in hot weather conditions, prestressed concrete, or steam cured concrete. In applications using calcium chloride, the dosage rate should be limited to 2 percent by weight of cement.

(f) Non-Calcium Chloride accelerators are available and can be used where reinforcing steel is present. However, care must be taken in selecting these since some may be soluble salts which can also aggravate corrosion.

(g) Calcium Nitrate, which can be used as a corrosion inhibitor, also can function as an accelerator. There are no consensus standards available for the use of this material. Manufacturer specification sheets should be consulted for proper use.

(3) Mineral admixtures include fly ash, ground granulated blast furnace slag, natural pozzolans, lime, and microsilica (microsilica is also known as silica fume). Currently all of these materials are being used as additives or to reduce cement contents. Mineral admixtures are accepted based on approved sources with certifications and verification samples.

(a) According to the American Society of Testing and Materials (ASTM) C 618 and AASHTO M 295 there are two classes of fly ash, class C and class F. Since variability in fineness and carbon content can affect air content, the optional uniformity specifications in AASHTO M 295 should be specified when air entrained concrete is used. Fly ashes with LOI values less than 3 percent will typically not affect air content. Vinsol resin air entrainment admixtures should be specified when fly ash with LOI higher than 3 percent is used.

1 Fly ash may be used as a supplement or a replacement and is typically limited to 15 to 25 percent. If it is used as a replacement, it replaces cement on a 1.0 to 1.2:1 basis by weight.

2 Fly ash can be used to increase workability, reduce permeability, and mitigate alkali silica reaction (ASR); some Class C can make it worse. Class F fly ash with a calcium oxide content less than 10 percent can be used to mitigate ASR and sulfate attack. Fly ash with a calcium oxide content greater than 10 percent should be used in concrete which will be subjected to sulfate attack only with verification testing. This percentage and fly ash classification should only be used as a guide; further qualification should be based on ASTM C 452.

3 The cementing action with fly ash is pozzolanic in nature. The pozzolanic reaction with fly ash stops at approximately 4° Celsius.

Precautions need to be taken when using fly ash in concrete at lower temperatures. It should also be noted that fly ash can reduce early strength development and, therefore, should be monitored closely.

(b) Ground granulated blast furnace slag specifications are contained in AASHTO M 302.

1 Ground granulated blast furnace slag (GGBFS) is a cementitious material and can be substituted for cement on a 1:1 basis by weight for up to 50 percent of the cement in the mix.

2 For fresh concrete using GGBFS, the air entrainment agent dosage may need to be increased. The workability and finishability typically are improved but in mixes having high cementitious material content, mixes can be sticky and difficult to finish. Bleeding may be reduced and setting time may be longer.

3 Ground granulated blast furnace slag can reduce sulfate attack, alkali-aggregate reactions, and permeability. The rate of strength gain is usually decreased and sensitive to low temperature.

(c) Microsilica specifications are contained in AASHTO M 307. Microsilica can be used as an admixture or as a replacement for an equivalent amount of cement to produce high strength concrete. Microsilica will reduce permeability and help reduce alkali-aggregate reactions.

1 Microsilica has been used as an addition to concrete up to 15 percent by weight of cement, although the normal proportion is 10 percent. With an addition of 15 percent, the potential exists for very strong, brittle concrete. It increases the water demand in a concrete mix; however, dosage rates of less than 5 percent will not typically require a water reducer. High replacement rates will require the use of a high range water reducer.

2 Microsilica greatly increases the cohesion of a mix, virtually eliminating the potential for segregation. However, the cohesion may cause mixes to be sticky and difficult to finish. It may be necessary to specify a higher slump than normal to offset the increased cohesion and maintain workability. In addition, microsilica in the mix greatly reduces bleeding; therefore, mixes which contain microsilica tend to have a greater potential for plastic shrinkage cracking. It is imperative to use the proper curing methods to prevent the surface water from evaporating too quickly.

4. PROPORTIONING. Most of the concrete placed in highway facilities in the United States are under severe exposure conditions. State highway agencies specify a recipe for concrete mixes which includes minimum cement content, maximum water-cement ratio, air content range, and minimum strength. These requirements are necessary to achieve durability, as well as strength.

a. The maximum aggregate size should be as large as possible. This reduces total aggregate surface area and results in lower cement demand. The maximum aggregate size should be limited to 20 percent of the narrowest dimension of a concrete member, 75 percent of the clear spacing between reinforcing steel, or 33 percent of the depth of a slab for unreinforced concrete.

b. The minimum cement content refers to all cementitious and pozzolanic material in the concrete, including cement and any mineral admixtures that are being added to or substituted for cement. Replacement rates should be based on those contained in paragraph 3d(3).

(1) The PCA recommends a minimum cement content of 335 kg/m^3 for concrete placed in severe exposure conditions and ACI 316R recommends a minimum cement content of 335 kg/m^3 for concrete pavements in all locations unless local experience indicates satisfactory performance with lower cement contents. Even if strength requirements can be met with a lower cement content, a minimum cement content of 335 kg/m^3 should be used unless it can be demonstrated that the concrete will be durable.

(2) In cases where local experience allows a reduction in cement content below 335 kg/m^3 the cement content should not be reduced below the following minimum cement contents recommended by ACI 302.1R Table 5.2.4 for concrete slab and floor construction. The minimum cement contents listed below are based on the nominal maximum size of the aggregate. The cement content decreases as the nominal maximum aggregate size increases due to the decrease in aggregate surface area.

Nominal maximum size aggregate, mm	Cement content kg/m^3
37.5mm	280kg/m^3
25mm	310kg/m^3
19mm	320kg/m^3
12.5mm	350kg/m^3
9.5mm	365kg/m^3

(3) Low strength concrete in the field should not be addressed by arbitrarily increasing the cement content since an increase in cement content will increase the water demand leading to higher shrinkage and permeability. All changes in mix proportions should be evaluated with a trial batch.

c. The water-cement ratio in all cases should be as low as possible while maintaining workability. For freeze thaw resistance the following maximum water cement ratios are recommended in ACI 201.2R.

Thin sections (bridge decks, pavements and curbs) and sections with less than 25 mm cover and concrete exposed to deicing salts	0.45
all other structures	0.50

The water-cement ratio should include the weight of all cement, pozzolan, and other cementitious material.

d. The air content in the mortar fraction of the mix should contain approximately 9 percent air for concrete mixes exposed to severe conditions.

(1) The following recommendations are from ACI 201.2R Table 1.4.3.

Nominal maximum size aggregate, mm	Air content Percent
37.5mm	5-1/2
25mm	6
19mm	6
12.5mm	7
9.5mm	7-1/2

(2) The specified tolerance for air content should be ± 1½ percent.

5. PROPERTIES OF CONCRETE. Trial batches should be performed on all mixes at the expected placement temperatures. This is especially true for mixes containing multiple admixtures.

a. Workability. A concrete mix must be workable to ensure proper consolidation and finishing. The workability of a mix is a function of the gradation of the aggregate, amount and type of admixtures, water content, concrete temperature, and time. Once a workable mix is established during the trial batch process, slump can be used to monitor the consistency and uniformity of the mix. Slump, by itself, is not a measure of workability.

b. Durability

(1) Freeze-thaw durability depends on durable aggregates, proper air entrainment, low permeability, and a low water-cement ratio.

(2) D-cracking is strictly a pavement durability problem and is associated with aggregates. It should be addressed with the source approval of the aggregates.

(3) Alkali aggregate reactions are mostly the result of the alkali content of the cement in the concrete. The most common alkali aggregate reaction is associated with silicious aggregates although reactions have occurred with carbonate materials. If a reactive aggregate is encountered, several options are available: not using the source of aggregate, using a low alkali cement, using fly ash, or using microsilica. If alkali reactive aggregates are used, testing should be performed with the mix prior to its use to ensure a durable concrete.

(4) Resistance to or susceptibility to sulfate attack depends on the chemical composition of the cementitious portion of the concrete. Sulfate attack can occur from ground water, deicing salts, or sea water. Type II or Type V cement or some fly ashes, may be used to mitigate the problem.

c. Strength. The strength requirement is the compressive strength, f'_c, at 28 days. This must be equal to or exceed the average of any set of three consecutive strength tests. No individual test (average of two cylinders) can be more than 3.5 MPa below the strength requirements in the specification.

6. MIXING, AGITATION, AND TRANSPORTATION

a. In order to ensure proper operation, a concrete plant must be calibrated and inspected. Plant approval should include all the items covered in the Checklist for Portland Cement Concrete Plant Inspection (Attachment 1). This same checklist also discusses the inspection of truck mixers. The plant certification program operated by the National Ready Mix Concrete Association covers the same information contained in the attachment.

b. The mixing time for central mixers and approval of truck mixers should be determined by the uniformity test discussed in AASHTO M 157, Ready Mixed Concrete. The test is based on the comparison of tests on samples taken at the first and last 15 percent of the load. The following are maximum permissible differences to consider the mix properly mixed.

Test	Maximum Difference
Unit weight (air free basis)	15 kg/m^3,
Air content	1 percent
Slump	
less than 100mm	25mm
100 to 150mm	37.5mm
Coarse aggregate content	6.0 percent
Unit weight of air free mortar	1.6 percent
Compressive strength (7 day)	7.5 percent

c. Water added at the job site must be measured accurately. A water meter is the most accurate method for determining the amount of water added to the mix.

d. The recommendations for testing appear in paragraph 11, Quality Control and Testing, of this document.

e. The haul time should be limited to 90 minutes for truck mixers that agitate the mix and 30 minutes for trucks that do not agitate the mix. The maximum number of revolutions for truck mixers should be limited to 300.

f. No admixtures or water should be permitted to be added to the mix after the mixer has started unloading.

7. <u>PLACEMENT AND CONSOLIDATION</u>

a. Prior to placement of the concrete an inspection should occur covering the items in either the checklist for the placement of structural concrete (Attachment 2) or the checklist for the placement of concrete paving (Attachment 3).

b. Acceptance testing for pumped concrete should occur at the discharge end of the pump.

c. Aluminum pipe and chutes should not be used in concrete pumping operations.

d. Concrete can be conveyed to the location of placement by several commonly used methods including pumps, belt conveyors, buckets, chutes, and dropchutes. Care should be taken to ensure that there is no debris or blockages that will hinder or influence the properties or flow of the material. Concrete should not be allowed to free fall from distances greater than 1.2 meters to avoid segregation.

e. All concrete should be accompanied to the project with a delivery ticket. A sample delivery ticket appears as Attachment 4.

f. The proper consolidation of concrete is a significant factor in the ultimate performance of the concrete and it is achieved through vibration.

(1) The following are recommended frequencies for vibrators from ACI 309.

Diameter of head, mm	Frequency vibrations per minute
20 to 40 mm	10,000 - 15,000
30 to 65 mm	9,000 - 13,500
50 to 90 mm	8,000 - 12,000

8. CURING AND PROTECTION

a. Curing

(1) Curing is performed to maintain the presence of water in concrete and to provide a favorable temperature for cement hydration. Methods of curing include ponding, spraying, and fogging with water, wet covers such as burlap, plastic sheets, membranes, and the use of steam, electric forms, or insulation.

(2) The application rate of a particular curing compound should be based on the rate established during the approval process of the curing compound. The AASHTO M 148 indicates that a rate of application of $5m^2$/liter should be used for testing the material if no other rate is specified.

b. Protection

(1) Cold weather protection should be required when it is expected that the daily mean temperature for three consecutive days will fall below 4° Celsius. The following recommendations are for the minimum temperatures for delivered concrete as they appear in AASHTO M 157.

Air	Minimum Concrete Temperature	
Temperature	Thin	Thick
-1 to 7°C	16°C	10°C
-18° to -1°C	18°C	13°C
Below -18°C	21°C	16°C

Thin sections are defined as those less than 300 mm.

(2) Concrete should never be placed on a frozen subgrade. Care should be taken to assure that the subgrade is free from frost.

(3) Hot weather conditions can be defined as a condition of high temperature, low humidity, and high winds. The existence of these conditions can be determined by finding the evaporation rate described in ACI 305 and included in Attachment 5. An evaporation rate exceeding 1 $kg/m^2/hr$ has the potential of causing plastic shrinkage cracks. The evaporation rate is a function of concrete temperature, ambient temperature, relative humidity, and wind velocity. This chart has been incorporated into several State specifications. It may not completely apply in all cases, especially in mixes containing admixtures which reduce the amount of bleeding.

(4) In addition to the plastic shrinkage cracking problem, ultimate strength will decrease with higher temperatures. The ACI has not recommended a maximum concrete temperature since strength loss can be compensated for by other means.

However, significant strength loss occurs above 32°C. Due to the strength loss and increase in potential for plastic shrinkage cracking, many States have set a maximum ambient placement temperature of 32°C. In all cases, trial batches should be performed at the highest expected temperature to ensure that the concrete will have the desired properties.

9. CONCRETE DISTRESS CONDITIONS

a. Alkali aggregate reactivity can be one of two types, alkali-silica and alkali-carbonate. The most prominent problem is cracking of the concrete due to the alkali-silica reaction (ASR).

(1) A widely used test to determine ASR is ASTM C 227. The current test criteria allow a maximum expansion of 0.05 percent at 3 months and 0.1 percent at 6 months. Research by PCA indicates that the critical criteria is 0.1 percent ultimate expansion. Since some reactions take longer than others, testing should continue as long as expansion is occurring. Some aggregates may take several years to show expansion.

(a) Recently the Strategic Highway Research Program developed a test which can be used for rapid determination of ASR. It is called the Gel Fluorescence Test and can be performed easily and inexpensively by field personnel. With this test, a 5 percent solution of uranyl acetate is applied on the concrete surface. Ultraviolet light is then used to illuminate the surface and if ASR exists, a yellow-green fluorescent glow will appear. Some safety concerns may be associated with this test so proper precautions are recommended. It should also be noted that the test is limited to preexisting concrete and not to fresh concrete.

(b) Alkali-silica reaction can be mitigated by limiting the alkali content of portland cement to 0.6 percent, by using class F fly ash or microsilica admixtures, or by reducing the water to cement ratio. The success of this approach may be limited; therefore, laboratory testing should be conducted. Protecting the final structure from moisture also reduces ASR.

(c) Although PCA recommends 25 percent of the fine aggregate be siliceous material to improve skid resistance, the use of some siliceous material can promote the ASR reaction and requires care to ensure this will not occur.

(2) Alkali-carbonate reaction (ACR) may occur with dolomitic limestones which contain large amounts of calcite, clay, or silts. ASTM C 586 is used to screen dolomitic materials for alkali-carbonate reactions.

b. D-cracking occurs when freeze-thaw conditions combine with saturated concrete made from susceptible coarse aggregates. The problem is only associated with pavements. Some dolomites and limestones are susceptible due to their pore structure.

(1) The most common test for predicting D-cracking susceptible aggregates is AASHTO T 161. There are two methods contained in the procedure. In method A the specimens are immersed in water for freezing and thawing. In method B the specimens are frozen in air and thawed in water. The number of freeze thaw cycles varies between 300 to 350. The minimum durability factor specified by the States range between 80 and 95. Some States have also specified a maximum expansion criteria range between 0.025 percent and 0.06 percent. It should be noted that the test method allows a significant range of time for freezing and thawing cycles. This can account for the variation in the criteria used by the States. Care needs to be taken when establishing criteria so that it will correspond to the test equipment and the history of performance of the aggregates.

(2) The hydraulic fracture test developed under SHRP may be able to provide a determination of the D-cracking susceptibility of aggregates in only about 1 week compared with the 8 weeks for T 161. In this test, dry aggregates are submerged in a pressure chamber and the pressure is increased to force water into the pores. After releasing the pressure, D-cracking susceptible aggregate will fracture as the water is forced out of the pores.

10. MANUFACTURED CONCRETE PRODUCTS Concrete products consist of structural elements constructed at a plant and trucked to the jobsite. These precast products typically consist of beams, pipes, barriers, poles and other special elements. The criteria outlined within this document apply to these products as well. Additional information about prestressed products are contained in the Checklist for Prestressed Concrete Products in Attachment 6.

11. QUALITY CONTROL AND TESTING

a. All testing should be performed by certified technicians. The ACI and the National Institute for Certification in Engineering Technologies (NICET) administer a concrete technician certification program. Guidance for establishing a certification program for testing personnel appears in a FHWA paper titled "Laboratory Accreditation and Certification of Testing Personnel."

b. Process control testing should be performed on aggregate moisture content, aggregate gradation, air content, unit weight, and slump at the plant.

(1) The specifications should require that the contractor provide a process control plan. The State should also provide guidance on the minimum requirements for a process control plan. As a minimum, the process control plan should include the information contained in Attachment 7.

(2) All process control tests should be plotted on control charts. Control charts are a good visual tool for discovering trends quickly before major problems occur.

c. The acceptance procedures should include monitoring of the process control activities including aggregate gradation testing. In addition, acceptance testing at placement would include slump, strength, and air content. Close monitoring of the water-cement ratio is also required since this will ultimately affect the durability and strength of the concrete.

Additional information on acceptance procedures is provided in the Technical Advisory on Acceptance of Materials T 5080.11.

d. It is recommended that compressive strength be accepted using statistical criteria (based on average strength and standard deviation) to ensure that the strength, f'_c, at 28 days, is equal or exceeded by the average of any set of three consecutive strength tests. No individual test (average of two cylinders) can be more than 3.5 MPa below the specified strength. There are two strengths to be considered. One is the minimum specified strength (f'_c) which is a function of the structural requirements. The second is the average strength for mix design (f'_{cr}). The f'_{cr} must be higher than f'_c to ensure that the concrete will exceed the minimum specified strength. The following recommendations for f'_{cr} are from ACI 318.

(1) Unknown Standard Deviation

Specified compressive strength, MPa	Required average compressive. strength, MPa
f'_c	f'_{cr}
Less than 20MPa	$f'_c + 6.9$
20MPa to 35MPa	$f'_c + 8.3$
Over 35MPa	$f'_c + 9.6$

(2) Known Standard Deviation

For greater than 30 test results (one test result is the average of two cylinder breaks) f'_{cr} is the greater of the two values from the following equations.

MPa

$f'_{cr} = f'_c + 1.4s$
$f'_{cr} = f'_c + 2.4s - 3.5$

s = Standard deviation

(3) For 15 to 30 test results the standard deviation in the above formulas can be modified by the following factors.

No. of Tests	Modification factor for standard deviation
Less than 15	use table for unknown s
15	1.16
20	1.08
25	1.03
30	1.00

e. Air content and slump should be accepted based on an attribute system, i.e., pass/fail. The following is a recommended criteria.

Acceptance criteria	Air content deviation, %	Slump deviation, mm
Acceptable	< 1.5	< 25mm
Acceptable for trucks on the road	1.5 to 2	25 to 31.5mm
Reject	> 2	> 31.5mm

f. Testing procedures for resistance to freeze-thaw damage, deicing salt attack, and abrasion resistance are long and involved and do not lend themselves to testing on a routine basis. These tests are usually conducted to determine the durability of the concrete. It should also be noted that high strength concrete does not always insure durable concrete.

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for Program Development

Attachments

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CHECKLIST FOR PORTLAND CEMENT CONCRETE PLANT INSPECTION

1. Materials

A. Cements and Mineral Admixtures (cement, fly ash, etc.)

(1) Is evidence of cement or fly ash acceptability present (certification, test results)?

(2) Are bins or silos tight and provide for free movement to discharge opening?

(3) Are bins or silos periodically emptied to check for caking?

(4) Plants should provide separate storage for each type of cement or mineral admixture being used. Are the materials being isolated to prevent intermingling or contamination?

B. Aggregates

(1) Does the plant display evidence of source approval?

(2) Are aggregates stockpiled to prevent segregation and degradation? The preferred method of stockpiling is in layers. Cone shaped stockpiles will segregate.

(3) Are stockpiles adequately separated to prevent intermingling?

(4) Does the plant maintain separate storage bins or compartments for each size or type of aggregate? Are the aggregates tested for gradation and moisture content?

(5) What is the surface underneath stockpiles? Soil or paved? Are the stockpiles covered?

C. Water

(1) Does the plant have an adequate water supply with pressure sufficient to prevent interference with accuracy of measurement?

(2) Is there any evidence or history of contaminants in supply?

D. Liquid Admixtures

(1) Is there evidence of source approval?

(2) Is the admixture and dispensing equipment protected from freezing, contamination, or dilution?

(3) How often are the admixture metering and dispensing equipment periodically cleaned?

2. <u>Batching Equipment</u>

A. Scales

(1) Scales should indicate weight by means of a beam with balance indicator, full range dial, or digital display.

(2) For all types of batching systems the weighing devices must be readable by the batchman and the inspector from their normal stations.

(3) Scales should be certified or should be calibrated with a certified scale.

(4) Ten 25 kilogram test weights should be available at the plant at all times.

(5) Scale accuracy should generally be within plus or minus .4 percent of the scale capacity.

(6) Water meters will need to be calibrated to 1 percent of total added amount.

B. Batchers

(1) Cementitious material should be weighed on a scale that is separate and distinct from other materials.

(2) Bins with adequate separation should be provided for fine aggregate and each size coarse aggregate.

(3) Weigh hoppers should not allow the accumulation of tare materials and should fully discharge into the mixer.

(4) Batchers should be capable of completely stopping the flow of material and water batchers should be capable of leak free cut off.

(5) Separate dispensers will be provided for each admixture.

(6) Each volumetric admixture dispenser should be an accurately calibrated container that is visible to the batchman from his normal position.

(7) Aggregate should be measured to plus or minus 2 percent of the desired weight, cement to 1 percent, water to 1 percent and admixtures to 3 percent.

(8) Semi-automatic and automatic control mechanisms should be appropriately interlocked.

3. <u>Mixing</u>

A. Stationary Mixers

(1) Mixers should be equipped with a metal plate that indicates mixing speed and capacity.

(2) Mixers should be equipped with an acceptable timing device that will not permit discharge until the specified mixing time has elapsed.

(3) Mixers are to be examined periodically to detect changes in condition due to accumulation of hardened concrete or blade wear. A copy of the manufacturer's design, showing dimensions and arrangements of blades, should be available at the plant at all times.

B. Truck Mixers

(1) Mixers should be equipped with a metal plate that indicates mixing speed, capacity, mixing revolutions, agitating speed and agitating capacity.

(2) Mixers should be equipped with a revolution counter.

(3) Mixers are to be examined to determine satisfactory interior condition, that is, no appreciable accumulation of hardened concrete and no excessive blade wear. A copy of the manufacturer's design, showing dimensions and arrangements of blades, should be available at the plant at all times.

(4) Charging and discharge openings and chutes should be in good condition.

4. <u>Weather</u>

A. Hot Weather

(1) When concreting during hot weather, is plant equipped to cool ingredients? Is equipment available to produce acceptable ice?

(2) How are aggregates cooled? If by sprinkling, is provision made to account for excessive water?

B. Cold Weather

(1) When concreting during cold weather, is plant equipped to heat ingredients to produce concrete of applicable minimum temperature.

CHECKLIST FOR STRUCTURAL CONCRETE

1. TREATMENT OF FOUNDATION MATERIAL

   Has special care been taken not to disturb the bottom of any foundation excavation?

2. CURING

   Is the concrete being cured for 7 days, by one of the following methods?

   (a) Waterproof paper method

   (b) Polyethylene sheeting method

   (c) Wetted burlap method

   (d) Membrane curing method

3. REINFORCEMENT BAR STORAGE

   Are all delivered rebars being stored above the ground upon skids, platform, or other supports? A light coating of rust will not be considered objectionable.

   Are epoxy coated bars being stored on padded supports and handled to prevent damage to the bar coating?

4. FORMS

   Are the forms clean, braced, tight, and sufficiently rigid to prevent distortion?

   When wooden forms are used, are they dressed lumber or plywood and oiled prior to rebar placement?

   Are all sharp corners in forms being filleted with 20 millimeters molding, unless otherwise specified?

5. REINFORCEMENT BAR PLACEMENT

   Are all reinforcement bars tied securely in place? Are epoxy coated bars being tied with plastic or epoxy coated tie wire?

When epoxy coated bars are cut in the field, are they being sawed, sheared, or cut with a torch? Cutting with a torch is not acceptable. If cut in the field, the bars should be repainted at the cut ends with a similar type of epoxy paint.

Are at least 50 percent of the bar intersections being tied?

Are all rebar laps of the specified length?

Are all portions of metal bar supports in contact with any concrete surface galvanized or plastic coated? Are epoxy coated bars being supported with plastic, plastic coated, or epoxy wire chairs?

Are the reinforcement bar support in sufficient quantity and adequately spaced to rigidly support the reinforcement bars?

After epoxy coated bars are in place, are the bars inspected for damage to the coating and is the contractor repairing all scars and minor defects using the specified repair materials?

Is the finishing machine being used to detect high bars by making a "dry run" over the length of the deck prior to concrete placement? Is the proper coverage being maintained between the bars and any form work or surface, top, side, and bottom?

6. <u>PRE-POUR INSPECTION</u>

Prior to the placement of the concrete have the reinforcement bars, construction joints, and forms been cleaned of mortar, dirt, and debris?

Are the strike-off screeds set to crown, and other equipment on the job-site (such as vibrators) in good working condition?

7. <u>USE OF RETARDING ADMIXTURE (BRIDGE DECK)</u>

If the specified temperature is reached, is a retarding admixture being used in the bridge deck concrete?

8. TEMPERATURE CONTROL

Are proper precautions being taken for hot and cold weather concrete?

If outside temperatures warrant it, are temperature checks of the plastic concrete being taken?

9. TIME OF HAUL

Is all concrete that is being hauled in truck mixers being deposited within 90 minutes from the time stamped on the tickets?

If central-mixed concrete is hauled in nonagitor trucks, is the concrete being deposited within 30 minutes?

10. REVOLUTIONS

Have 70 to 100 mixing revolutions at mixing speed been put on the truck at the required speed (6-18 RPM)?

Have 30 mixing revolutions been placed on the truck at the required speed (6-18 RPM) after water has been added at the site?

Is the agitating speed between 2-6 RPM?

Are total number of revolutions being limited to 300?

11. CONCRETE DELIVERY TICKET

Are all truck tickets being properly completed, collected, and retained?

12. WATER CONTROL

Is all water that is being added to the mix accounted for and checked to ensure the w/c ratio is not exceeded?

13. AIR CONTENT DETERMINATION

Are air content tests being performed according to the required frequency?

14. SLUMP TEST

Are slump tests bring performed according to the required frequency?

15. STRENGTH TEST

Are concrete test specimens being cast at the site of work as per the required frequency?

16. PLACING CONCRETE

Is the concrete being deposited as near its final position as possible? (Moving concrete horizontally with vibrators is not permitted.)

Is the concrete being bucketed, belt conveyed, pumped, or otherwise placed in such a manner as to avoid segregation and is not being allowed to drop more than 1.2 meters?

17. CONSOLIDATION

Is all the concrete being consolidated with hand operated spud vibrators while it is being placed?

18. FINISHING (DECKS)

Is a finishing machine (having at least one reciprocating, nonvibratory screed operating on rails or other supports) being used to strike off and screed the bridge deck?

19. STRAIGHTEDGE TESTING AND SURFACE CORRECTION (DECK)

Is the plastic concrete being tested for trueness with a 3 meter straightedge held in contact with the slab in successive positions parallel to the centerline?

Are all depressions being immediately filled and all high areas being cut down and refinished?

20. SURFACE TEXTURING

Is the deck surface being textured with either a burlap drag or an artificial turf drag followed by tining with a flexible metal comb?

CHECKLIST FOR PORTLAND CEMENT CONCRETE PAVING

1. SUBBASE TRIMMING

   Has the subbase been trimmed prior to paving?

2. PAVING FORMS (IF USED)

   Are the forms: metal, not less than 3 meters in length, equipped with both pin locks and joint locks, within 2 millimeters along the length of its upper edge, within 7.5 millimeters along the length of its front face, and in sufficient supply.

   Is the height of form face at least the edge thickness of proposed pavement, the base width equal to or greater than the height, and are three steel pins being used to secure each section?

   Are the forms being set on a hard and true grade, built up in 12.5 millimeters maximum lifts of granular material in low areas (without using wooden shims) and oiled prior to the placing of concrete?

   When wooden forms are allowed, are they full depth, smooth, free of warp, not less than 50 millimeters thick when used on tangent, and securely fastened to line and grade?

   Are curved form of metal or wood being used on curves of 30 meters radius or less?

3. FORM ALIGNMENT

   Is the contractor checking the forms for line and grade and making necessary adjustments prior to concrete placement?

4. TEMPLATE

   Is the surface of the subbase being tested for crown and elevation by means of a template?

5. SUBBASE THICKNESS TEST

After trimming, is the thickness of the subbase being checked?

6. DRAINAGE

Is the subgrade being kept drained during all operations? Are all berms of earth deposited adjacent to the grade being kept drained by cutting lateral ditches through the berms?

7. LUG SYSTEMS (CONTINUOUSLY REINFORCED)

If concrete lug end anchorages are specified, are they staked and checked for dimensions and re-bar placement as shown in the plans?

Are they constructed of Structural Concrete at least 24 hours prior to pavement construction?

8. LONGITUDINAL JOINT KEYWAY AND BARS

Are the beginning and ending stations marked where adjacent curb, median, or pavement will necessitate the placement of keyway and/or bars in the edge of the proposed pavement?

9. SUPERELEVATION STAKING

Are the plan curb data examined for all curves to determine where to stake the beginning and ending stations for all superelevation transitions?

10. TEMPERATURE LIMITATIONS

Does the outside air temperature in the shade meet State specifications?

Does the temperature of the concrete meet State specifications at the time of placement?

11. REINFORCEMENT LAPPING

Are the locations and lengths of lap for bar or fabric reinforcement in conformance with the specifications.

Are all bar and fabric laps being tied?

12. <u>TRUCK REQUIREMENTS</u>

Is all concrete in a stationary mixer being deposited within 30 minutes when hauled in non-agitating trucks and within 90 minutes when hauled in agitator trucks?

Is transit mixed concrete being delivered and deposited within 90 minutes from the time stamped on the ticket?

If the contractor plans to use previously placed pavement as a haul road, are the truck weights checked to assure compliance with maximum weights permitted by State Law?

13. <u>REINFORCEMENT PLACEMENT</u>

Is the reinforcement being placed in accordance with one of the following methods?

<u>Method A</u> - After the full depth concrete is struck off the reinforcement should be placed into the concrete to the required depth by mechanical means.

<u>Method B</u> - The reinforcement should be supported on the prepared subbase by approved chairs having sand plates.

<u>Method C</u> - When the concrete is being placed in two layers the reinforcement should be laid full length on the struck-off bottom layer of concrete in its final position without further manipulation. (Cover within 30 minutes.) The depth of the first lift is 2/3 the depth of the pavement.

<u>Method D</u> - The reinforcement may be placed in the pavement using a method which does not require transverse steel or support chairs for support of the longitudinal steel. Tie bars at longitudinal joints are still required.

14. <u>SEQUENCES OF FORM TYPE PAVING</u>

Is all of the required concrete finishing equipment on the job and in acceptable working condition? Are the following sequences for form type paving being properly followed:

(a) Placing concrete. As little rehandling as possible. If equipment used can cause segregation, is the concrete being unloaded into an approved spreading device?

(b) Strike-off. Is the concrete being struck full width to the approximate cross section of the pavement?

(c) Consolidation. Is one pass of an approved surface vibrator or internal vibrator being made?

(d) Screeding. Are at least two passes with a machine having two oscillating screeds, and a finisher float being made?

(e) Straightedging - Are at least two 3 meter long shoulder operated or surface operated surface trueness testers (straightedges) being used?

(f) Surfacing Texturing - Are State specifications for texturing and tining being followed?

15. <u>SEQUENCES OF SLIPFORM PAVING</u>

When the contractor uses this optional method for the construction of the pavement are the following sequences being properly followed:

(a) Is the formless paver capable of spreading, consolidating internally, screeding and float finishing the newly placed concrete in one pass to the required line and grade?

(b) Is the pavement being straightedged, edged, and textured as required in the previous question 14?

(c) Does the contractor have available at all times metal or wooden sideforms and burlap or curing paper for the protection of the pavement in case of rain?

(d) Is the contractor immediately repairing all slumping edges in excess of 12.5 millimeters?

16. THICKNESS TEST

Is the thickness of the pavement being checked?

17. AIR CONTENT

Is the air content being tested as required by the frequency chart?

18. SLUMP

Is the slump being checked as required by the frequency chart?

19. REINFORCEMENT, DOWEL, AND TIE BAR DEPTH CHECKS

Is the concrete being probed to check the vertical and horizontal positioning of the pavement reinforcement, dowels, and tie bars?

20. STRENGTH

Are test specimens being cast at the site of work at the required frequency:

(a) at least one set per day
(b) one set for every 150 meters of two lane pavement (300 meters of one lane pavement)

21. LONGITUDINAL JOINT

(a) **Are tie bars placed properly?**

(b) **Are the joints sawed at the same time as the transverse joints with pavement widths greater than 7.3 meters? Are they cleaned and immediately filled with sealer?**

22. TRANSVERSE JOINTS

(a) **Are the smooth dowel bars positioned parallel to the grade at a depth of ½ t.**

Are the dowel bars coated with a thin bond breaker?

Are the capped ends of the bar coated with a debonding agent? (Expansion joints)

(b) Is a 1/3T deep groove being sawed over each assembly as soon as possible after concrete placement? Cleaned immediately?

(c) Are all joints being sealed after the curing period and before opening to traffic?

23. TRANSVERSE CONSTRUCTION JOINTS (CONTINUOUSLY REINFORCED CONCRETE)

(a) Are construction joints being placed at the end of each day's operation or after an interruption in the concreting operation of 30 minutes or more?

(b) Are construction joints being placed at least 1 meter from nearest bar lap?

(c) Are construction joints strengthened by supplementary 1.8 meter long bars of the same nominal diameter as the longitudinal steel so that the area of steel through the joint is increased by at least 1/3?

(d) Are construction joints formed by means of a clean (not oiled) split header board conforming to the cross section of the pavement?

(e) Is the concrete at construction joints being given supplemental internal vibration along the length of the joint both at the end of the day's operation and once again at the resumption on the next day? This is critical.

24. TRANSVERSE CONSTRUCTION JOINTS (JOINTED PAVEMENT)

(a) Are construction joints being placed at the end of each day's operation or after an interruption in the concreting operation of 30 minutes or more?

(b) Are construction joints being placed at least 3 meters from any transverse joint?

(c) Are construction joints being strengthened by epoxy coated dowel bars of the same size and positioning as specified for contraction joints?

Is a thin coating of bonding breaking agent applied to the dowels?

(d) Are construction joints being formed by means of a suitable header board conforming to the cross-section of the pavement?

25. <u>SURPLUS - DEFICIENCY DETERMINATION</u>

Is a daily check being made on the yield of produced concrete?

26. <u>CURING</u>

Are the pavement surface and edges being cured by one of the following methods:

(a) Waterproof Paper Method. Are the surfaces being covered as soon as possible with blankets or tear-free reinforced kraft paper, with 300 millimeter laps, properly weighted? Has the pavement been wetted with a fine spray first?

(b) Polyethylene Sheeting Method. Are surfaces covered as soon as possible with 30 meter long sheets of white polyethylene, with 300 millimeter laps, properly weighted? Has the pavement been wetted with a fine spray first?

(c) Wetted Burlap Method. Are surfaces covered as soon as possible with two layers of wet burlap, with 150 millimeter laps? Kept saturated by means of a mechanically operated sprinkling system or an impermeable covering? (Alternate: one burlap and one burlene blanket)

HAUL TICKET FOR TRUCK MIX CONCRETE

PROJECT NO. ____________ DATE:
BATCHED FROM (PLANT) ____________ TRUCK NO. ____________
NO. CUBIC METERS ____________ CLASS OF ____________
CONCRETE ____________

BATCH WEIGHTS

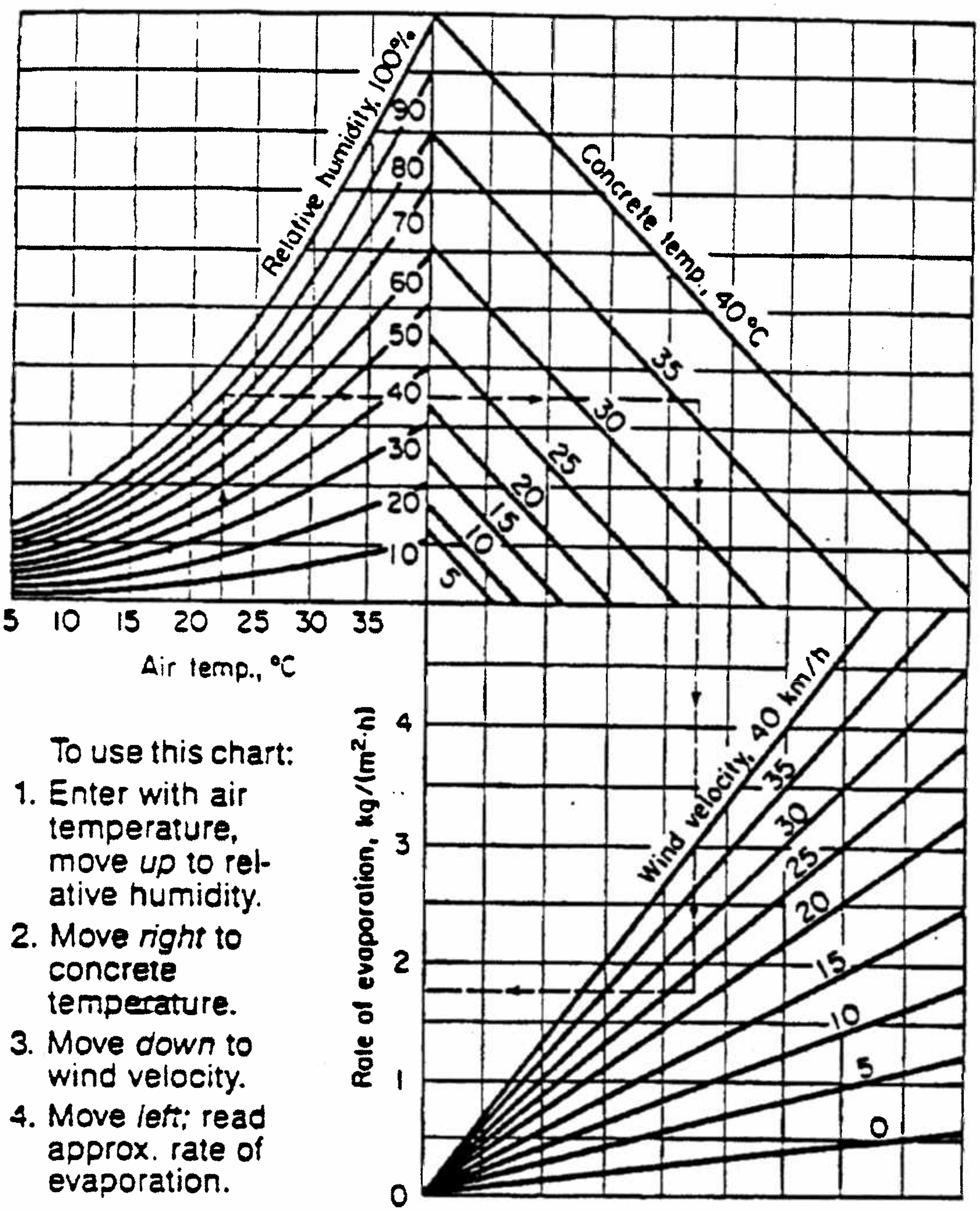
CEMENT BRAND ____________
kg ____________
FINE AGGR. SOURCE ____________
kg ____________
COARSE AGGR. SOURCE ____________
kg ____________
FLY ASH SOURCE ____________
kg ____________

AIR ENTRAINMENT BRAND ____________
grams ____________
RETARDER BRAND ____________
grams ____________
WATER REDUCER BRAND ____________
ml ____________

WATER
MAXIMUM WATER ALLOWED, Liter ____________
FREE MOISTURE
CA Liters ____________
FA Liters ____________
WATER ADDED AT PLANT Liters ____________
MAXIMUM WATER THAT CAN BE ADDED AT THE SITE Liters ____________

PLANT	SITE
TIME WATER ADDED TO MIX ______ AM PM	TIME DISCHARED COMPLETED ______ AM PM
	WATER ADDED AT JOBSITE Liters ______
	TOTAL WATER IN BATCH Liters ______
NUMBER OF MIXING	MIXING REVOLUTIONS AT SITE ______
	TOTAL NO. OF REVOLUTIONS ______
	SLUMP ______ AIR ______
	UNIT WEIGHT ______
	CONC. TEMP ______
	AIR TEMP ______
Signature ______	Signature ______

NOMOGRAPH USED TO
DETERMINE EVAPORATION RATE



To use this chart:

1. Enter with air temperature, move *up* to relative humidity.
2. Move *right* to concrete temperature.
3. Move *down* to wind velocity.
4. Move *left;* read approx. rate of evaporation.

CHECKLIST FOR QUALIFICATION OF FACILITIES FOR PRESTRESSED CONCRETE PRODUCTION

1. Items which require written approval: (check applicable blanks)

   (a) Plans and computations of facilities ________

   (b) Concrete mix design (should include curves for 28-day strength) vs W/C Ratio: ________

   (c) Curing method ________

   (d) Epoxy-sand mortar, if used ________

   (e) Coal tar epoxy, if used ________

   (f) Water reducer-retarder ________

   (g) Design Engineer should be approved by State DOT ________

   (h) Gauge calibration should be certified ________

   (i) Computations regarding beam tests (2 weeks prior to testing) ________

2. What is length and capacity of stressing bed(s)

   Bed No. ______ Length ______ Capacity ______
   Bed No. ______ Length ______ Capacity ______
   Bed No. ______ Length ______ Capacity ______

3. Procedure of prestressing (pretensioning) and stress release:

   (a) Jacks, carriages, and struts are adequate to attain and maintain design stress.
   Yes ________ No ________
   Comments:
   ____
   ____

(b) Stressing of straight strands: (check applicable blanks)
Single strand method ______
Multiple strand method ______
Comments:
______
______

(c) Stressing of draped strands (check applicable blanks)
Single strand method ______
Multiple strand method ______
Final draped position ______ both ends ______
Partial draped position ______ one end ______
Comments:
______
______

(d) Single strand jack available.
Yes ______ No ______

(e) Is an accurate dynamometer available for use in applying initial tension to the strands?
Yes ______ No ______

(f) What is proposed initial load to be applied
______ lbs.

(g) Is there a permanent, accurate linear gauge with which to measure elongation?
Yes ______ No ______

4. Forms: (Make comments in spaces provided)

(a) Metal
______
______

(b) True to shape and dimensions
______
______

(c) Adequate in number
______
______

(d) Condition and composition of bulkheads

____

____

(e) Type of hold-down device to be used

____

____

(f) Is provision being made to maintain 25 millimeter concrete cover over hold-down device?

____

____

(g) Are bulkheads and hold-down devices adequate to maintain dimensions of strand centers as shown on the plans?

____

____

5. Are facilities adequate for proper storage and handling of bridge members?
Yes ________ No ________

(a) Approximate available storage area ________________

(b) Condition of storage area ________________

6. Are facilities available for properly testing a member of the design type to be fabricated?
Yes ________ No________ (if No explain)

____

____

7. Are adequate lighting facilities available in the event that placing of concrete at night is necessary?
Yes ________ No ________

8. Vibrating equipment:

(a) Condition ________________

(b) Number to be used in placing ________________

(c) Two spaces available ____________________

9. Source of Materials:

(a) Steel Wire and Strand (manufacturer)

____

(b) Cement (type and brand name)

____

(c) Coarse Aggregate (producer and location)

____

(d) Sand (producer and location)

____

(e) Retarder (brand name)

____

(f) Form Oil (type and name)

____

(g) Reinforcing Steel (producer)

____

10. Type of concrete mixing facilities: mixed at plant ____________________
Ready Mix concrete ____________________

(a) Are concrete batching facilities adequate to ensure good quality and sufficient quantity to avoid delays under all working conditions?
Yes __________ No __________

11. Testing equipment available: (check applicable blanks)

(a) Plastic cylinder molds ____________________
No. Available ____________________

(b) Slump Cone ____________________

(c) Air content device ____________________
(pressure __________ volumetric __________)

(d) Facilities for testing cylinders available at (proposed location)

____

12. Requirements for steam cure method:

(a) Three (3) recording thermometers available

____

(b) Temperature record charts

____

(c) Adequate temperature control valves

____

(1) What are the increments of spacing of control valves?

____

13. Are facilities available for proper protection and handling of component materials in storage? (Rate "S" if satisfactory, "U" if unsatisfactory, and "NA" if not applicable)

(a) Wire and/or strand ________
(b) Reinforcing steel ________
(c) Structural steel ________
(d) Cement ________
(e) Coarse Aggregate ________
(f) Sand ________

14. Is there a suitable shelter (at least 14 square meters floor space, facilities for lights, heat, desk(s), etc.) available for the inspector's use?

____

15. Personnel present during inspection of plants:

Producers/Contractors	Highway Department

GUIDE FOR QUALITY CONTROL PLAN FOR PORTLAND CEMENT CONCRETE

REQUIREMENTS

1. General Requirements:

The contractor should provide and maintain a quality control system that will provide reasonable assurance that all materials and products submitted to the State for acceptance will conform to the contract requirements whether manufactured or processed by the contractor or procured from suppliers or subcontractors or vendors. The contractor should perform or have performed the inspections and tests required to substantiate product conformance to contract document requirements and should also perform or have performed all inspections and tests otherwise required by the contract. The quality control inspections and tests should be documented and should be available for review by the engineer throughout the life of the contract.

2. Quality Control Plan:

The contractor should prepare a Quality Control Plan detailing the type and frequency of inspection, sampling and testing deemed necessary to measure, and control the various properties of materials and construction governed by the Specifications. As a minimum, the sampling and testing plan should detail sampling location and techniques, and test frequency to be utilized. The Quality Control Plan should be submitted in writing to the engineer at the preconstruction conference.

The Plan should identify the personnel responsible for the contractor's quality control. This should include the company official who will act as liaison with State personnel, as well as the Certified Portland Cement Concrete Technician who will direct the inspection program.

The class or classes of concrete involved will be listed separately. If existing mix designs are to be utilized, the Mix Design Numbers should be listed.

Quality control sampling, testing, and inspection should be an integral part of the contractor's quality control system. In addition to the above requirements, the contractor's quality control system should document the quality control requirements shown in Table 1. The quality control activities shown in Table 1 are considered to be normal activities necessary to control the production and placing of a given product or material at an acceptable quality level. To facilitate the States' activities, all completed gradation samples should be retained by the contractor until further disposition is designated by the State.

It is intended that sampling and testing be in accordance with standard methods and procedures, and that measuring and testing equipment be properly calibrated. If alternative sampling methods, procedures and inspection equipment are to be used, they should be detailed in the Quality Control Plan.

3. Documentation:

The contractor should maintain adequate records of all inspections and tests. The records should indicate the nature and number of observations made, the number and type of deficiencies found, the quantities approved and rejected, and the nature of corrective action taken as appropriate. The contractor's documentation procedures will be subject to the review and approval of the State prior to the start of the work and to compliance checks during the progress of the work.

4. Charts and Forms:

All conforming and non-conforming inspections and tests results should be kept complete and should be available at all times to the State during the performance of the work. Batch tickets and gradation data will be submitted to the State as the work progresses. All test data will be plotted on control charts. It is normally expected that testing and charting will be completed within 48 hours after sampling.

All charts and records documenting the contractor's quality control inspections and tests should become property of the State upon completion of the work.

5. <u>Corrective Action</u>:

The contractor should take prompt action to correct conditions which have resulted, or could result, in the submission to the State of materials and products which do not conform to the requirements of the Contract documents.

6. <u>Non-Conforming Materials</u>:

The contractor should establish and maintain an effective and positive system for controlling non-conforming material, including procedures for its identification, isolation, and disposition. Reclaiming or reworking of non-conforming materials should be in accordance with procedures acceptable to the State.

All non-conforming materials and products should be positively identified to prevent use, shipment, and intermingling with conforming materials and products. Holding areas, mutually agreeable to the State and the contractor, should be provided by the contractor.

7. <u>Acceptance</u>:

The State will monitor the performance of the contractor's quality control plan and will perform verification testing to ensure that proper sampling and testing procedures are used by the contractor. The State may shut down the contractors operations for failing to follow the approved process control plan. All acceptance testing will be performed by State personnel.

TABLE 1

CONTRACTOR'S QUALITY CONTROL REQUIREMENTS

Minimum Quality Control Requirement	Frequency
A. PLANT AND TRUCKS	
1. Mixer Blades	Prior to Start of Job and weekly
2. Scales	Prior to Start of Job and weekly
a. Tared	Daily
b. Calibrate	Prior to Start of Job
c. Check Calibration	Weekly
3. Gauges and Meters - Plant and Truck	
a. Calibrate	Yearly
b. Check Calibration	Weekly
4. Admixture Dispenser	
a. Calibrate	Prior to Start of Job
b. Check Operation and Calibration	Daily
B. AGGREGATES	
1. Fine Aggregate	
a. Gradation	21 Days
b. Deleterious Substances	Daily
c. Moisture	Daily
2. Coarse Aggregates	
a. Gradation	21 Days
b. Percent Passing No. 200 Sieve	Daily
c. Moisture	Daily
C. PLASTIC CONCRETE	
1. Entrained Air Content	One Per 1/2 Day Operation
2. Consistency	One Per 1/2 Day of Operation
3. Temperature	One Per 1/2 Day of Operation
4. Yield	One Per 1/2 Day of Operation