



Guide Specification for Controlled Low Strength Materials (CLSM)

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1.0 SCOPE

1.1 This specification covers Controlled Low Strength Materials, CLSM, manufactured and delivered to a purchaser in a freshly mixed and unhardened state. Based on the application, the Engineer shall specify one or more of the performance properties and material parameters from tests listed in Table 1.1

R1.1 This specification is intended to serve as a guide to engineers, architects and specifiers that have interest in specifying controlled low strength materials (CLSM), commonly called flowable fill. It covers the selection of the raw materials and their proportions to produce the required performance properties, quality control and acceptance procedures, and procedures for measuring, batching, mixing and delivery, and placement.

Table 1.1: Performance & Material Test Properties

Performance Property	Test Property
Corrosive Resistance	pH, Resistivity, Permeability
Flowability	Flow
Excavatability	Unconfined Compressive Strength
Permeability	Water Permeability Air Content
In-Place Density	Plastic Unit Weight
Strength	Unconfined Compressive Strength California Bearing Ratio Penetration Resistance Ball Penetration
Thermal Conductivity	Plastic Unit Weight Moisture Conductivity Thermal Transmittance (U)
Thermal Insulating Value	Plastic unit Weight Moisture Content Thermal Resistance Value (R-Value)
Acidity/Alkalinity	pH

It is the responsibility of the specifying authority to identify performance characteristics required for the project. The material supplier should be permitted to design the CLSM mixture using readily available materials to meet the job performance requirements.

The guide is presented in a format similar to that used by the American Association of State Highway and Transportation Officials, AASHTO, for specifying materials of construction. The specifier may cite the guide in the contract documents or re-write the guide into contract documents using all or parts of the provisions. The specifier may supplement the guide provisions as needed. The specifiers' provisions will supercede the requirements of this guide specification.

The guide specification is not intended to address all applications of CLSM. Principal applications covered by this document include but are not limited to:

- General construction backfill and void filling
- Utility trench backfill and conduit bedding materials
- Road and highway subbase and base
- Structural fill

The desired engineering and performance properties of CLSM vary with the application. For example, it may be desirable for utility trench backfill material to be excavatable and permeable to ground water and utility gases. Designing for future excavation is assured by limiting the compressive strength as outlined in Section 6.3 of the guide. Applications such as a sub-base, base or structural fill generally require higher compressive strengths and thereby

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higher bearing capacity. Excavatability and permeability are generally not of great concern in structural fill applications.

Material properties such as shrinkage, subsidence and settlement are not considered as specification performance properties. These properties are considered as inherent to CLSM and as such, do not require the establishment of specification requirements. Where the application requires special consideration of properties not listed in Table 1.1, the specifier is advised to seek the recommendations of ACI Committee 229 or the National Ready Mixed Concrete Association.

1.2 Basis of Purchase - The basis of Purchase shall be the cubic yard or cubic meter of freshly mixed and unhardened material as discharged from the delivery mixer. The volume of freshly mixed and unhardened material in a given batch shall be determined from the total weight of the batch divided by the unit weight of the material.

R1.2 Basis of Purchase - The volume of hardened in-place CLSM may be, or appear to be, less than its volume as discharged from a delivery unit due to waste or spillage, over-excavation, underestimation, loss of entrained air, settlement, or subsidence. CLSM is often used in applications of uncertain or unknown volumes. The batched weights are available through batch recordation supplied by the ready mixed CLSM supplier. For CLSM mixtures without entrained air, verification of volume can be determined by comparing weights from the batch recordation to the theoretical mix design submitted and approved by the engineer. Unit weight of unhardened CLSM is not needed for verification of non air- entrained CLSM mixtures.

2.0 APPLICABLE DOCUMENTS

2.1 ASTM Standards

- C 403 Time of Setting of Concrete Mixtures by Penetration Resistance
- C 869 Foaming Agents Used in Making Performed Foam For Cellular Concrete
- D 1883 California Bearing Ratio
- D 4832 Preparation and Testing of Controlled Low Strength Material Test Cylinders
- D 508 Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
- D 5971 Sampling Freshly Mixed

R2.0 APPLICABLE DOCUMENTS

The intent of the guide is to use the most current version of each standard listed. Where the most current version is not listed the specifier should take caution before using the newer version. The equivalent ASTM or AASHTO standards may be interchanged. The specifier is encouraged to determine the possibility of differences between the equivalent standards and its impact on the acceptance criteria. Changes may conflict with cited references and the intent of its use.

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- Controlled Low Strength Material
- D 6103 Flow Consistency of Controlled Low Strength Material
- D 6023 Unit Weight, Yield, Cement Content and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM)
- D 6024 Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application

2.2 AASHTO Standards

- M 6 Fine Aggregate for Portland Cement Concrete
- M 80 Coarse Aggregate for Portland Cement Concrete
- M 85 Portland Cement
- M 195 Lightweight Aggregate for Structural Concrete
- M 154 Air Entraining Admixture Concrete
- M 157 Ready-Mixed Concrete
- M 194 Chemical Admixtures for Concrete
- M 240 Blended Hydraulic Concrete
- M 295 Fly Ash and Raw or Calcimined Natural Pozzolan for Use as Mineral Admixtures in Portland Cement Concrete.
- M 302 Ground Granulated Blast Furnace Slag for Use in Concrete and Mortars

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3.0 DEFINITIONS

3.1 Controlled Low Strength Material, (CLSM) - A self-leveling and self-compacting, cementitious material with an unconfined compressive strength of 1,200 psi or less.

3.2 Flowability - Material property which relates to the rheology of the material.

3.3 Excavatability - Material property which relates to the ease at which the material may be removed.

R3.0 DEFINITIONS

Controlled low strength materials have inherited many names that are commonly used in the industry. Some of the most common names include:

flowable fill, CDF or controlled density fill, flowcrete, liquid dirt, and other various trademark names. CLSM should not be considered, and in-turn tested, as a type of low strength concrete. Instead, CLSM should be considered as a self compacting and self leveling backfill material that is used in lieu of compacted fill. Additional explanation of the properties and characteristics listed in this guide specification may be found in the ACI Committee 229 report 'Controlled Low Strength Materials'.

R3.1 Controlled Low Strength Material, (CLSM)

While the upper limit on compressive strength is indicated as 1200psi, most CLSM applications require strengths less than 300psi.

R3.3 Excavatability-The excavatability Of hardened CLSM can generally be divided into two categories:

- 1) Unconfined compressive strength < 150 psi is considered to be EXCAVATABLE by hand tools and conventional machinery such as backhoes.
- 2) Unconfined compressive strength > 150 psi is considered to be NON-EXCAVATABLE.

Relating the ability to excavate CLSM to a measured compressive strength is an arbitrary guide to the engineer. Factors that influence excavatability will include: 1) the composition of the mixture - CLSM with coarse aggregate may be difficult to excavate even at low strengths, 2) the type and quantity of cementitious materials and their strength gaining characteristics, 3) the nature of the soil in contact with the CLSM mixture and its ability to drain water, 4) the method of excavation appropriate to the application, for example it may not be possible to use a backhoe near an embedded pipe. From this, it is recommended that long term strength

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characteristics of a CLSM mixture be correlated to excavatability. Strengths exceeding 150 psi have been known to be excavatable with mechanical equipment. However, prior tests indicating the ease of excavatability should be made prior to final placement.

3.4 Permeability - Material property which relates to the ease with which gases and liquids pass through the material.

3.5 Density - Material property which relates to the unit weight or mass of the materials.

3.6 Strength - Material property that relates to the ability of hardened material to support gravity loads or stresses at a given age.

3.7 Thermal Conductivity - Material property which relates to the ease at which the material transmits heat.

3.8 Thermal Insulating Value - Material property which relates to the resistance of the material to transmit heat.

3.9 CLSM Air Generating Admixture - A chemical admixture specially formulated to entrain air into CLSM.

R3.9 CLSM Air Generating Admixture – Dispensed and mixed into the CLSM, the admixture produces a stable air content between 15 and 30%. Some of the benefits of entraining air in CLSM is it controls strength development and reduces the water content, bleeding, shrinkage, and settlement.

3.10 Hardening Time - Period of time for CLSM mixtures to reach a state in which it will support a specified load.

R3.10 Hardening Time – The hardened state is when the in-place CLSM has attained sufficient strength to support the weight of a person.

3.11 Subsidence & Settlement - The reduction in initial in-place volume caused by the displacement of water and release of entrapped air as a result of consolidation.

R3.11 Subsidence & Settlement- CLSM - Will not experience settlement after hardening occurs. Subsidence and settlement are typically experienced during the initial 2-4 hours after placement. Hardened CLSM may exhibit shrinkage cracks, however, they do not effect the structural integrity of the material for most applications.

3.12 Corrosive Resistance - Material

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property that relates to the ability to inhibit the corrosion of embedded materials.

3.13 pH - CLSM property which is a measure of its acidity or alkalinity.

4.0 SUBMITTALS

4.1 Sources and proportions of CLSM ingredients: Prior to the start of CLSM placement, the CONTRACTOR shall submit a description of the proposed CLSM mixture design. Based on the application, the ENGINEER may require the CONTRACTOR to submit appropriate laboratory or field test data documenting compliance to specified material and or performance properties.

5.0 MATERIALS

CLSM shall be manufactured with materials conforming to the standards listed below. The ENGINEER shall approve the use of all non-conforming materials. Approval shall be based on documentation that controlled low strength material mixtures manufactured with the non-conforming materials meet the specified plastic and hardened properties and are suited for the intended application.

5.1 Hydraulic Cement
• AASHTO M 85 or M 240

5.2 Fly Ash
• AASHTO M 295

5.3 Granulated Blast Furnace Slag
• AASHTO M 302

5.4 Fine Aggregate
• AASHTO M 6

5.5 Coarse Aggregate
• AASHTO M 80

R4.0 SUBMITTALS

The listed requirements are intended to supplement submittal procedures listed elsewhere in the project documents.

R5.0 MATERIALS

Most of the materials listed are suitable for the production of structural hydraulic cement concrete. The use of materials not conforming to these standards may be more than suitable or adequate for CLSM mixtures. The specifier, however, is cautioned to review the performance characteristics of a CLSM mixture made with non-standard materials. Materials used successfully in CLSM include bottom ash, fly ash with high carbon content, spent foundry sand, crushed glass, kiln dust, in-situ excavated soil, fines from aggregate producing plants, non-conforming fly ash etc... The specifier is urged to obtain documentation from the ready mixed CLSM supplier that non-conforming materials are suitable for the intended use and that mixtures containing these materials meet specified performance properties.

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- 5.6 Lightweight Aggregate
 - AASHTO M 195
- 5.7 Water
 - AASHTO M 157
- 5.8 Chemical Admixtures
 - AASHTO M 194
- 5.9 Air Entrainment Admixtures
 - Approved by the ENGINEER.
- 5.10 Foaming Admixture
 - ASTM C 869

6.0 PROPERTIES OF CONTROLLED LOW STRENGTH MATERIAL

- 6.1 **Flowability** - Normal flowable material shall have a flow of 6 to 8 inches tested in accordance with ASTM D6103. Low flowable material shall have a maximum flow of 6 inches. High flowable material shall have a minimum flow of 8 inches.
- 6.2 **Unconfined Compressive Strength for Non-Excavatable CLSM** - Shall be specified by the Engineer.
- 6.3 **Unconfined Compressive Strength For Excavatable CLSM** - Excavatability shall be evaluated on

R6.0 PROPERTIES OF CONTROLLED LOW STRENGTH MATERIALS

This section provides specification criteria for desired performance properties. The specifier shall select performance properties and associated criteria that pertain to the intended application. The specifier is cautioned not to specify contradictory performance properties. For example, specifying a maximum compressive strength for excavatability and a high bearing strength may not be compatible.

R6.1 Flowability - CLSM is a self-leveling and self-compacting material and therefore does not require conventional placing and compacting equipment. The high flowability and self-leveling characteristics of CLSM mixtures allow the material to fill voids and spaces that prove to be difficult or impossible with granular compacted fill. If the application requires a stiffer consistency, the specifier may elect to specify a low flowable material. Material tested in accordance with ASTM D6103 resulting with a value less than 6 inches is considered to have a low flowability.

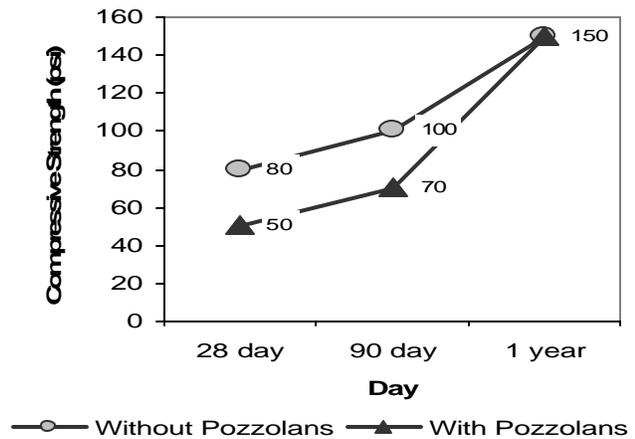
R6.2 and R6.3 Unconfined Compressive Strength for Non-Excavatable CLSM - Maximum unconfined compressive strength criteria are provided to assure excavatability for applications where future removal of the CLSM is desirable. Due to long term strength development when fly ash and ground granulated blast furnace slags are utilized, the maximum compressive strength with these materials is less than that when just Portland cement is utilized. If acceptance of the CLSM mixture is to be based on

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the basis of past performance and experience. When past performance records are not available, excavatability shall be evaluated on the basis of unconfined compressive strength tested in accordance with ASTM D4832. Excavatable CLSM shall have a minimum strength of 30 psi. The one-year strength shall not exceed 150 psi. In place of one year test data, the ENGINEER, may approve the CLSM mixture based on sufficient documentation, provided by the ready mix producer, that indicates the strength gain has ceased.

documentation in lieu of one year test data, the ENGINEER is suggested to require a testing schedule with sufficient frequency to indicate strength gain has ceased at any age beyond 180 days. The maximum compressive strength limit for excavatable CLSM may be waived by the engineer if evidence of strengths higher than 150psi being capable of being excavated is submitted. Graph R6.3 illustrates an example of compressive strength development for CLSM mixtures with and without pozzolans meeting ASTM and AASHTO standards. Different pozzolans may exhibit different strength development behavior.

Graph R6.3: An example of compressive strength development for CLSM mixtures.



The ability of a CLSM backfill to support foundations and pavements, and resist lateral forces without failures or undergoing excessive deformation or settlement is related to its mechanical strength. Unlike many granular compacted backfill materials, CLSM develops mechanical strength with time. The extent of the strength is controlled by proper selection and proportioning of the constituent materials.

6.4 Permeability - When required, the coefficient of permeability of CLSM shall be specified by the ENGINEER.

R6.4 Permeability - An important hydraulic property of a backfill material is permeability. The permeability affects the rate of seepage of water through a backfill material. The permeability of a soil is typically measured by Darcy's law

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(laminar flow) where the flow of water through a soil is:

$$Q = kIA,$$

where

Q = Water flow

k = Coefficient of Conductivity (permeability coefficient)

i = Hydraulic gradient, head or water pressure divided by length of flow path

A = Cross sectional area Perpendicular to flow path

A uniformly well graded coarse sand has a relatively high permeability with a coefficient of water conductivity of approximately 4.0×10^{-1} cm/sec. On the other hand, clay has relatively low permeability with a coefficient of water conductivity of 1.0×10^{-7} cm/sec. Typically coefficients of water conductivity for various backfill materials are provided in the following table, Table R6.4.

Table R6.4: Typical Water Conductivity Values

Soil Type	Permeability (cm/sec)
Uniform Coarse Sand	4.0×10^{-1}
Clean, Sand & Gravel	1.0×10^{-1}
Uniform Fine Sand	4.0×10^{-2}
Silty Sand & Gravel	4.0×10^{-2}
Silty Sand	1.0×10^{-2}
Sandy Clay	5.0×10^{-3}
Silty Clay	1.0×10^{-3}
Clay	1.0×10^{-7}

CLSM may be designed to be as permeable as a uniform coarse sand or as dense as clay. CLSM proportioned with a higher than normal fines content can achieve water conductivity as low as 10^{-1} cm/sec. Higher cement contents may cause a decrease in permeability. Increasing the aggregate content or adding special materials such as bentonite clay or diatomaceous earth or other fine materials may reduce permeability.

It is often desirable to have the permeability of a backfill material equal to or greater than the surrounding soil. This will reduce the potential for the backfill material to alter the hydrology of the area around the construction. Designing CLSM mixtures to have a minimum water conductivity coefficient equal to that of uniform fine sand (4.0×10^{-3} cm/sec) is recommended. Incorporating an air void system in the CLSM

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similar to that of uniform fine sand.

When a specific coefficient of permeability is required, laboratory data can be determined during the mix design submittal process to correlate the air content of the plastic CLSM with the permeability of the hardened CLSM. The Engineer may elect to specify a minimum and/or maximum total air content of the plastic CLSM in lieu of specifying a permeability test for the hardened CLSM. Verification and/or acceptance would be via field testing in accordance with ASTM D6023.

6.5 California Bearing Ratio - When required, the CBR value shall be specified by the ENGINEER. The ENGINEER may elect to specify a minimum 28-day compressive strength in place of specifying a CBR test.

R6.5 California Bearing Ratio - CLSM can be designed to significantly increase the bearing capacity of a subbase or base for pavements. The bearing capacity may be measured as subgrade modulus or California bearing ratio (CBR). CBR values generally increase proportionally with compressive strength. The ENGINEER may elect to approve compressive strength tests be used as a measure of bearing capacity with correlation to CBR values.

6.6 Penetration Resistance - The ENGINEER may elect to specify a minimum penetration resistance (ASTM C403), hardening time, proof rolling, drop ball test (ASTM D6024), or proof that the CLSM mixture will support an individual's weight.

R6.6 Penetration Resistance - The penetration test may be used as a measure of the hardening time and bearing strength. The California Department of Transportation requires a penetration number of 650 before allowing a pavement surface to be placed. Hardening time generally takes 3 to 5 hours. CLSM with high penetration resistance may develop 28-day compressive strengths in excess of 150 psi. This may impair excavatability. The maximum ball drop indentation diameter for controlled low strength material subject to vehicular traffic or pavement surfacing materials shall be 3 inches.

6.7 Unit Weight - When required, the unit weight shall be specified by the ENGINEER. The manufacturer shall be permitted to select and proportion the ingredients of the CLSM mixture to meet specified requirements.

R6.7 Unit Weight - CLSM can be proportioned to develop in-service unit weights in the range of 20 to 145 lbs/ft³. Low density CLSM made by preformed foam may be used as a lightweight fill. This fill reduces the load on buried structures and underlying soils or fills. Low Density CLSM provides insulating and isolation properties. ACI 523.3R-93, Table 5.3.4 provides typical thermal conductivity values.

Unit weights as low as 20 lbs/ft³ may be achieved by using lightweight aggregates and/or creating a stable air void or cell system throughout the CLSM mixture. This air void or cell system may be developed by using preformed foam.

Using normal weight aggregates and an ASTM C260 air

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entrainment admixture, air contents up to 30% and unit weights as low as 90 to 100 lbs/ft³ may be produced.

The use of CLSM air generating admixtures with normal weight aggregates may result in air contents up to 40% and unit weights as low as 80 to 90 lbs/ft³.

7.0 SELECTION OF INGREDIENTS

7.1 Proportioning - CLSM shall be proportioned by the ready mixed concrete supplier on the basis of field experience and/or laboratory trial mixtures to produce a cohesive and non-segregating mixture meeting the specified properties.

R7.0 SELECTION OF INGREDIENTS

Unless otherwise specified, the manufacturer shall select the proportions of the constituent materials to meet the specification requirements for performance and placement. CLSM is frequently proportioned with cementitious materials such as hydraulic cement, fly ash and slag, fine aggregates, water and chemical admixtures.

CLSM may be manufactured with any of the designated types of AASHTO M 85 portland cements or AASHTO M 240 blended hydraulic cements. The portland cement content for excavatable CLSM is typically in the range of 30 to 50 lbs/yd³. Class C fly ash or ground granulated blast furnace slag contents typically range from 20 to 300 lbs/yd³. Class F fly ash contents are typically in the range of 100 to 2000 lbs/yd³. CLSM is often proportioned with fly ash or slag to improve workability and pumpability, and reduce segregation, bleeding, shrinkage, or settlement.

Fly ash may be used in place of the fine aggregate. Mixtures containing high quantities of fly ash will typically have a higher water demand, displace more water during consolidation, and have a greater initial subsidence than the typical one eighth of an inch per vertical foot. CLSM mixtures with a flow of 6 inches or greater shall be used for all mixes containing fly ash.

Coarse aggregates have been used successfully; however, excavatability may be impaired.

Chemical admixtures are used to improve performance properties and lower material costs. ASTM C260 air entrainment admixtures produce a stable air void system in CLSM. Air contents as high as 30% may be developed.

Air contents up to approximately 40% can be developed by the addition of CLSM air generating admixtures. High air content lowers water demand which in-turn reduces bleeding, segregation, subsidence and drying shrinkage. Higher air contents will limit the ultimate strength and facilitate

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excavation.

Admixtures to accelerate the rate of hardening and early age strength development may be used for fast track construction. The ENGINEER should be cautioned that the use of these chemicals in conjunction with a improperly proportioned CLSM mixture may increase the ultimate compressive strength and impair excavatability.

Foaming agents or lightweight aggregates may be used to produce low density CLSM. Foaming agents produce a preformed foam that expands the CLSM forming a micro-bubbled, stable foam. The foam is formed using specialized equipment usually furnished by the manufacturer.

7.2 Pumpable CLSM - Shall be proportioned to allow transport by pumping methods without segregating or excessive bleeding.

R7.2 Pumpable CLSM - CLSM mixtures may be transported by conventional concrete pumping equipment. To reduce segregation and improve pumpability, the mixtures must be proportioned with sufficient fine materials, such as fly ash, to provide adequate void filling. High pump pressure may cause a loss in air content which increases the unity weight and reduces pumpability.

8.0 QUALITY CONTROL

- 8.1 Sampling - ASTM D 5971
- 8.2 Compressive Strength - ASTM D 4832
- 8.3 Unit Weight - ASTM D 6023
- 8.4 Flowability - ASTM D 6103
- 8.5 Air Content - ASTM D 6023
- 8.6 Permeability - ASTM D 5084
- 8.7 California Bearing Ratio - ASTM D 1883
- 8.8 Penetration Resistance - ASTM C 403

R8.0 QUALITY CONTROL

The scope of the quality control program will vary with the application and the required level of quality desired. The specifier shall select the appropriate test methods for the desired performance properties to assure that the material will be adequate for the intended use. Section 8, Quality Control, provides test methods appropriate for CLSM.

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9.0 ACCEPTANCE

9.1 Batch Records - Batch plant recordation or certified batch report should be used when a ready mixed truck is used and when it is not (ie., a volumetric mixer) then such other verification method as the supplier and customer can agree to. Acceptance shall be based on verification that the constituent materials were batched in accordance with the design. Verification shall be by inspection, automated batch plant recordation, or certified batch report. The method of verification shall be approved by the ENGINEER.

9.2 CLSM Properties - As required by the application, the ENGINEER shall specify acceptance tests for appropriate material properties. The testing frequency shall be specified by the ENGINEER.

10.0 MEASURING MATERIALS, BATCHING PLANT, MIXERS AND AGITATORS, MIXING AND DELIVERY

10.1 Batching And Delivery- Material shall be batched and delivered in accordance with AASHTO M 157-86 (1996), Sections 8, 9, 10 and 11 except the temperature requirements of 11.8 and 11.9 which shall be waived.

R9.0 ACCEPTANCE

Acceptance is based on verification that the CLSM material was batched within tolerance of the submitted and approved mix design. When the application requires special engineering properties, the Engineer may elect to specify additional acceptance tests related to the specified required properties.

R10.0 MEASURING MATERIALS, BATCHING PLANT, MIXERS AND AGITATORS, MIXING AND DELIVERY

The specified procedures and methods are appropriate for the production and delivery of structural hydraulic cement concrete. Quality CLSM may be fabricated and delivered with nonconforming procedures and methods. Use of non-conforming procedures requires the approval of the ENGINEER. Approval shall be based on the documentation that the non-conforming procedure will provide CLSM meeting the specified performance requirements similar to M157-87, Section 11.0.

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10.2 Water and Admixture Addition - The addition of water and admixtures on the jobsite is permitted. The amount of water and admixture added shall be recorded. The CLSM mixture shall be mixed for a minimum of 30 revolutions after the addition of the water or admixture.

11.0 PLACEMENT

11.1 Temperature - Material shall not be placed on frozen ground. The ambient temperature shall be 35 deg F and rising at the time of placement.

11.2 Standing Water - CLSM may be placed in confined spaces containing standing water.

R11.0 PLACEMENT

Placement considerations are discussed in ACI 229R-94, Section 6.4.

R11.1 Temperature - Requirements may Be waived by the ENGINEER if it is determined that freezing conditions will not be detrimental to the CLSM mixture.