Report on Controlled Low-Strength Materials

Reported by ACI Committee 229
Report on Controlled Low-Strength Materials

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www.concrete.org
ISBN: 0-87031-816-0
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3.10— Nuclear facilities, p. 5
3.11— Bridge reclamation, p. 6

CHAPTER 4— MATERIALS, p. 6
4.1— General, p. 6
4.2— Portland cement, p. 6
4.3— Fly ash, p. 6
4.4— Admixtures, p. 6
4.5— Inorganic admixtures and other additives, p. 6
4.6— Water, p. 6
4.7— Aggregates, p. 6
4.8— Non-aggregates, p. 7
4.9— Ponded ash or basin ash, p. 7

CHAPTER 5— PROPERTIES, p. 7
5.1— Introduction, p. 7
5.2— Plastic properties, p. 7
5.3— In-service properties, p. 9

CHAPTER 6— PROPORTIONING, p. 11
6.1— Introduction, p. 11
6.2— Materials, p. 11
6.3— General formulation, p. 11
6.4— Proportioning methods, p. 11
6.5— Evaluation, p. 12
6.6— Adjustments to proportioning, p. 12

CHAPTER 7— MIXING, TRANSPORTING, AND PLACING, p. 12
7.1— General, p. 12
mixing} are discussed in Chapter 9.

**CHAPTER 8—QUALITY CONTROL, p. 13**
- 8.1—General, p. 13
- 8.2—Sampling of CLSM, p. 14
- 8.3—Consistency and unit weight, p. 14
- 8.4—Strength tests, p. 14

**CHAPTER 9—LOW-DENSITY CLSM USING PREFORMED FOAM, p. 14**
- 9.1—General, p. 14
- 9.2—Applications, p. 15
- 9.3—Materials, p. 16
- 9.4—Physical properties, p. 17
- 9.5—Proportioning, p. 18
- 9.6—Construction, p. 18
- 9.7—Quality control, p. 19

**CHAPTER 10—REFERENCES, p. 19**

**CHAPTER 1—INTRODUCTION**

Controlled low-strength material (CLSM) is a self-consolidating cementitious material used primarily as a backfill as an alternative to compacted fill. Terms used to describe this material include flowable fill, controlled density fill, flowable mortar, plastic soil-cement, and soil-cement slurry.

CLSM is a mixture intended to result in a compressive strength of 1200 psi (8.3 MPa) or less. Most CLSM applications require unconfined compressive strengths of 300 psi (2.1 MPa) or less. Long-term strengths (90 to 180 days) should be targeted to be less than 100 psi (0.7 MPa) for excavation with hand tools. Lower-strength requirements are necessary to allow for future excavation of CLSM.

The term “CLSM” is used to describe a family of mixtures for various applications. CLSM mixtures can also be developed as anti-corrosion fills, electrically conductive materials, low-permeability fills, thermal fills, and durable pavement bases. For example, the upper limit of 1200 psi (8.3 MPa) allows use of this material for applications where future excavation is unlikely, such as structural fill under buildings. CLSM is a self-consolidated backfill or fill material that is used in place of compacted earth fill and should not be considered as a type of low-strength concrete. Generally, CLSM mixtures are not designed to resist freezing and thawing, abrasive or erosive forces, or aggressive chemicals. Using recycled materials can maximize recycled material content for sustainable construction. Nonstandard materials that have been tested and found to satisfy the intended application can be used to produce CLSM. Chapter 9 describes low-density (LD) CLSM produced using preformed foam as part of the mixture portioning. Using preformed foam in LD-CLSM mixtures allows these materials to be produced having unit weights lower than those of typical CLSM. The distinctive properties of LD-CLSM and procedures for mixing it are discussed in Chapter 9.

CLSM typically requires no consolidation or special curing procedures to achieve desired strength and should not be confused with compacted soil-cement, as reported in ACI 230.1R. Long-term compressive strengths for compacted soil-cement often exceed the 1200 psi (8.3 MPa) maximum limit established for CLSM.

Long-term compressive strengths of 50 to 300 psi (0.3 to 2.1 MPa) are low when compared with conventional concrete. In terms of allowable bearing pressure, however—which is a common criterion for measuring the capacity of a soil to support a load—50 to 100 psi (0.3 to 0.7 MPa) strength is equivalent to a well-compacted fill.

Although CLSM generally costs more per cubic yard (cubic meter) than most soil or granular backfill materials, its many advantages often result in lower in-place costs. In fact, for some applications, CLSM is the only reasonable backfill method available (Adaska 1994, 1997; Ramme 1997). Table 1 lists a number of advantages to using CLSM (Smith 1991).

**CHAPTER 2—NOTATION AND DEFINITIONS**

2.1—Notation

\[
E = \text{modulus of elasticity, psi (MPa)} \\
f_c' = \text{28-day specified compressive strength of concrete, psi (kPa)} \\
k = \text{coefficient of permeability, in./s (mm/s)} \\
RE = \text{removability modulus} \\
W = \text{dry mass density, lb/ft}^3 (kg/m}^3) \\
\]

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology,” http://terminology.concrete.org.

**CHAPTER 3—APPLICATIONS**

3.1—General

The primary application of CLSM is as a structural fill or backfill in place of compacted soil. Because CLSM needs minimal consolidation and can be designed to be fluid, it is useful in areas where placing and compacting fill is difficult. If future excavation is anticipated, the maximum long-term compressive strength should generally not exceed 100 psi (0.7 MPa). The following applications present a range of uses for CLSM (Sullivan 1997).

3.2—Backfills

CLSM can be readily placed into a trench, hole, or other cavity (Fig. 3.2a and 3.2b). Compaction or consolidation equipment is not required; hence, trench width or excavation size can be reduced. Granular or site-excavated backfill, even if compacted or consolidated in the required layer thickness, cannot achieve the uniformity and density of CLSM (Sullivan 1997).

When backfilling against retaining walls, consideration should be given to lateral pressures exerted on the wall by flowable CLSM. Where lateral fluid pressure is a concern,
Table 1—Cited advantages of CLSM (Smith 1991)

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readily available</td>
<td>Using locally available materials, ready mixed concrete suppliers can produce CLSM to meet most project specifications.</td>
</tr>
<tr>
<td>Easy to deliver</td>
<td>Truck mixers can deliver specified quantities of CLSM to job site whenever material is needed.</td>
</tr>
<tr>
<td>Easy to place</td>
<td>Depending on type and location of void to be filled, CLSM can be placed by chute, conveyor, pump, or bucket. Because CLSM is generally self-leveling, it needs little or no spreading or compacting. This speeds construction and reduces labor requirements.</td>
</tr>
<tr>
<td>Versatile</td>
<td>CLSM mixtures can be adjusted to meet specific fill requirements. Mixtures can be adjusted to improve flowability. More cement or fly ash can be added to increase strength. Admixtures can be added to adjust setting times and other performance characteristics. Adding foaming agents to CLSM produces lightweight, insulating fill.</td>
</tr>
<tr>
<td>Strong and durable</td>
<td>Load-carrying capacities of CLSM are typically higher than those of compacted soil or granular fill. CLSM is also less permeable and is thus more resistant to erosion. For use as permanent structural fill, CLSM can be designed to achieve 28-day compressive strength as high as 8.3 MPa (1200 psi).</td>
</tr>
<tr>
<td>Allows fast return to traffic</td>
<td>Because many CLSMs can be placed quickly and support traffic loads within several hours, downtime for pavement repairs is minimal.</td>
</tr>
<tr>
<td>Will not settle</td>
<td>CLSM does not form voids during placement and will not settle or rut under loading. This advantage is especially significant if backfill is to be covered by pavement patch. Soil or granular fill, if not compacted properly, may settle after a pavement patch is placed and forms cracks or dips in the road.</td>
</tr>
<tr>
<td>Reduces excavation costs</td>
<td>CLSM allows narrower trenches because it eliminates having to widen trenches to accommodate consolidation equipment.</td>
</tr>
<tr>
<td>Improves worker safety</td>
<td>Workers can place CLSM in a trench without entering the trench, reducing their exposure to cave-ins.</td>
</tr>
<tr>
<td>Allows all-weather construction</td>
<td>CLSM will typically displace any standing water left in a trench from rain or melting snow, reducing need for dewatering pumps. To place CLSM in cold weather, materials can be heated using same methods for heating ready mixed concrete.</td>
</tr>
<tr>
<td>Can be excavated</td>
<td>CLSM having compressive strengths of 0.3 to 0.7 MPa (50 to 100 psi) is easily excavated with conventional digging equipment, yet is strong enough for most backfilling needs.</td>
</tr>
<tr>
<td>Requires less inspection</td>
<td>During placement, soil backfill should be tested after each lift for sufficient compaction. CLSM self-consolidates consistently and does not need extensive field testing.</td>
</tr>
<tr>
<td>Reduces equipment needs</td>
<td>Unlike soil or granular backfill, CLSM can be placed without loaders, rollers, or tampers.</td>
</tr>
<tr>
<td>Requires no storage</td>
<td>Because ready mixed concrete trucks deliver CLSM to job site in quantities needed, storing fill materials on site is unnecessary. Also, there is no leftover fill to haul away.</td>
</tr>
<tr>
<td>Makes use of coal combustion by-product</td>
<td>Fly ash is by-product produced by power plants that burn coal to generate electricity. CLSM containing fly ash benefits environment by making use of this industrial by-product material.</td>
</tr>
</tbody>
</table>

CLSM can be placed in layers. This allows each layer to harden before placing the next layer.

Following severe settlement problems of soil backfill in utility trenches, the city of Peoria, IL, in 1988, tried CLSM as backfill material (Smith 1991). CLSM was placed in trenches up to 9 ft (2.7 m) deep. Although fluid at time of placement, the CLSM hardened so that a person’s weight could be supported within 2 to 3 hours. Very few shrinkage cracks were observed. Further tests were conducted on patching the overlying pavement within 3 to 4 hours. In one test, a pavement patch was successfully placed over a sewer trench immediately after backfilling with CLSM. As a result of these initial tests, Peoria has changed its backfilling procedure to require using CLSM on all street openings (Smith 1991).

Some agencies backfill with CLSM that has a setting time of 20 to 35 minutes, after which time, a person can walk on it. After approximately 1 hour, the wearing surface consisting of either a rapid-setting concrete or asphalt pavement is placed, and the result is a total traffic-bearing repair in approximately 4 hours (Pons et al. 1998).

3.3—Structural fills

Depending on strength requirements, CLSM can be used for foundation support. Compressive strengths can vary from 100 to 1200 psi (0.7 to 8.3 MPa), depending on application. Where lightweight structural fills are required to reduce long-term settlement, a foaming agent may be used to provide lower unit weight. In weak soils, it can distribute the structure’s load over a greater area. For uneven or non-uniform subgrades under foundation footings and slabs, CLSM can provide a uniform and level surface. Compressive strengths vary depending on project requirements. Because...
of its strength, CLSM may reduce the required thickness or strength requirements of the slab. Near Boone, IA, 2800 yd$^3$ (2141 m$^3$) of CLSM was used to provide bearing capacity for a grain elevator footing (Larsen 1988).

3.4—Insulating and isolation fills
Low-density (LD) CLSM is generally used for insulating and isolation fills. Chapter 9 addresses LD-CLSM using preformed foam.

3.5—Thermal-insulation-conductivity fills
Using CLSM in place of granular backfills is common practice not only by utilities, but also by departments of transportation and local municipalities. These applications include backfilling trenches containing gas pipes, water and sewer mains, electrical cables and conduits (transmission as well as distribution), and as a general road base and subbase material. Engineered properties, ease of installation, and guaranteed performance are a few advantages (Ramme et al. 1995; Steinmanis 1981; Parmar 1991, 1992).

CLSM can be modified into thermal-insulation-conductivity fill, which is an engineered material with excellent thermal and mechanical properties (Ramme et al. 1995). Since 1989, thermal-insulation-conductivity fills have been used extensively by electric utilities as cable trench backfill replacing conventional granular backfill on high-voltage underground transmission line projects in North America and overseas. Projects of record lengths have used thousands of cubic meters of thermal-insulation-conductivity fills. These fills have proven to be cost effective (time and material) and resulted in improved cable rating.

In some special cases, thermal-insulation-conductivity fills have been modified to insulate rather than conduct. Insulation and insulation of chilled water pipes, steam mains in the vicinity of power cables, and hot-spot mitigation are examples of these applications.

3.6—Pavement bases
CLSM mixtures can be used for pavement bases, subbases, and subgrades. The mixture is placed directly from the mixer onto the subgrade between existing curbs. A range of coefficients should be established according to procedures in AASHTO (1986). For base course design under flexible pavements, structural coefficients differ depending on strength of the CLSM. Based on structural coefficient values for cement-treated bases derived from data obtained in several states, the structural coefficient of a CLSM layer can range from 0.16 to 0.28 for compressive strengths from 400 to 1200 psi (2.8 to 8.3 MPa).

Good drainage, including curb and gutter, storm sewers, and proper pavement grades, is required when using CLSM mixtures in pavement construction. Freezing-and-thawing damage can result in poor durability if the base material is frozen when saturated with water.

A wearing surface is required over CLSM because it has relatively poor wear-resistance properties unless specifically designed for this type of application.

3.7—Conduit bedding
CLSM is excellent bedding material for pipe, electrical, telephone, and other types of conduits. The flowable characteristic of the material allows CLSM to fill voids beneath conduit and provide uniform support.

The U.S. Bureau of Reclamation (USBR) began using CLSM in 1964 as bedding material for 15 to 96 in. (380 to 2400 mm) diameter concrete pipe along the entire Canadian River Aqueduct Project, which stretches 322 miles (518 km) from Amarillo to Lubbock, TX. Soil-cement slurry pipe bedding, as referred to by the USBR, was produced in central portable batching plants that were moved every 10 miles (16 km) along the route. Concrete trucks delivered the soil-cement slurry to the placement site. The soil was obtained from local blow sand deposits. It was estimated that soil-cement slurry reduced bedding costs 40 percent. Production increased from 400 to 1000 ft (120 to 300 m) of pipe placed per shift (Lowitz and Defroot 1968).

CLSM can be designed to provide erosion resistance beneath conduit. Since the mid-1970s, some county agencies in Iowa have been placing culverts on CLSM bedding. This not only provides solid, uniform pipe bedding, but prevents water from getting between the pipe and bedding, eroding the support (Larsen 1990).
Encasing the entire conduit in CLSM protects the conduit from future damage. If the area around the conduit is excavated at a later date, the obvious material change in CLSM versus the surrounding soil or conventional granular backfill would be recognized by the excavating crew, alerting them to the existence of the conduit. Coloring agents have been used in mixtures to help identify the presence of CLSM. Take care in this type of application to avoid floating and/or lifting pipes or conduits.

3.8—Erosion control

Laboratory studies and field performance have shown that CLSM resists erosion better than many other fill materials. Tests comparing CLSM with various sand and clay fill materials showed that CLSM, when exposed to a water velocity of 1.7 ft/s (0.52 m/s), was superior to the other materials in the amount of material loss and suspended solids from the material (Krell 1989).

CLSM is often used in riprap for embankment protection and in spilling basins below dam spillways to hold rock pieces in place and resist erosion. CLSM is used to fill flexible fabric mattresses placed along embankments for erosion protection, thereby increasing their strength and weight. In addition to providing erosion resistance under culverts, CLSM is used to fill voids under pavements, sidewalks, bridges, and other structures where natural soil or cohesionless granular fill has eroded away.

3.9—Void filling

3.9.1 Tunnel shafts and sewers—When filling abandoned tunnels and sewers, it is important to use a flowable mixture. A constant supply of CLSM will help keep material flowing and make it flow greater distances. CLSM was used to fill an abandoned tunnel under the Menomonee River in downtown Milwaukee, WI. The self-leveling material flowed over 235 ft (71.6 m). On another Milwaukee project, 831 yd³ (635 m³) were used to fill an abandoned sewer. The CLSM reportedly flowed up to 300 ft (90 m) (Naik et al. 1990).

Before constructing the Mount Baker Ridge Tunnel in Seattle, WA, an exploratory shaft 120 ft (37 m) deep and 12 ft (3.7 m) in diameter with 30 ft (9.1 m) long branch tunnels was excavated. After exploration, the shaft required filling before tunnel construction. Only 4 hours were needed to fill the shaft with 786 yd³ (601 m³) of CLSM (Flechsig 1990).

CLSM with a large constituent of kaolin clay was used to stabilize soil and lubricate a drilled 8 ft (2 m) diameter tunnel bore in Tampa, FL. It was also used for contact grouting behind tunnel liners. Compressive strengths of 30 to 40 psi (0.21 to 0.28 M Pa) were available within a few hours and a strength of 200 to 300 psi (1.38 to 2.07 M Pa) after 28 days.

3.9.2 Basements and underground structures—Abandoned basements are often filled in with CLSM by pumping or conveying the mixture through an open window or doorway. An industrial renovation project in LaSalle, IL, required filling an existing basement to accommodate expansion plans. Granular fill was considered, but access problems made CLSM a more attractive alternative. Approximately 400 yd³ (300 m³) were poured in 1 day. A 98 in. (200 mm) concrete floor was then placed directly on top of the CLSM mixture.

In Seattle, buses were to be routed off busy streets into a tunnel with pedestrian stations (Celis 1997). The tunnel was built by a cut-and-cover method, but stations had to be excavated from the surface to the station floor. After the station was built, there was a 25,000 yd³ (19,000 m³) void over each station to the street. So as not to disrupt traffic with construction equipment and materials, voids were filled with CLSM that required no layered placement, compaction, or consolidation.

CLSM has been used to fill abandoned underground storage tanks (USTs). Federal (EPA 40 CFR Part 280) and state (IDNR 2011; MDE 2010) regulations have been developed that address closure requirements for underground fuel and chemical tanks. USTs taken out of service permanently should either be removed from the ground or filled with an inert solid material. The Iowa Department of Natural Resources and the Maryland Department of the Environment (MDE) both specifically mention CLSM in their documents for underground storage tank closure guidance (IDNR 2011; MDE 2010).

3.9.3 Mines and sinkholes—Abandoned mines have been filled with CLSM to eliminate access, prevent subsidence, block trespasser entry, entrap hazardous gases, cut off oxygen supply for fires, and reduce or eliminate acid drainage. It is important that a flowable mixture be placed with a constant supply to facilitate spread and minimize the quantity of placement points. The western United States contains approximately 250,000 abandoned mines with various hazards (Celis 1997). A abandoned underground coal mines in the eastern United States have been filled using CLSM manufactured from coal combustion products (Gray et al. 1998; Celis 1997; Dolance and Giovanitti 1997).

On the west coast of Florida, CLSM has been used as compaction grout and to fill sinkhole voids. CLSM is also used to solidify sands over karst features.

3.10—Nuclear facilities

CLSM is used in nuclear facilities for conventional applications such as those described previously. It provides a significant advantage over conventional granular backfill in that remote placement decreases personnel exposure to radiation. CLSM can also be used in unique applications at nuclear facilities, such as waste stabilization, encapsulation of decommissioned pipelines and tanks, encapsulation of waste-disposal sites, and new landfill construction. CLSM can be used to address a wide range of chemical and radionuclide-stabilization requirements (Rajendran and Venkata 1997; Langton and Rajendran 1995; Langton et al. 2001).

3.11—Bridge reclamation

CLSM has been used in several states as part of a cost-effective process for bridge reclamation. The process requires putting enough culverts under the bridge to handle the hydrology requirements. A dam is placed over both ends of the culverts and the culverts are covered with fabric to prevent CLSM from flowing into the joints. These culverts
CHAPTER 4—MATERIALS

4.1—General

Conventional CLSM mixtures usually consist of water; portland cement; fly ash or other similar products; and fine aggregates, coarse aggregates, or both. Some mixtures consist of water, portland cement, and fly ash only. LD-CLSM mixtures, as described in Chapter 9 of this report, consist of portland cement, fly ash, or other cementitious or pozzolanic materials, water, and preformed foam.

Although materials used in CLSM mixtures normally meet ASTM or other standard requirements, the use of specialized materials is not always necessary. Materials selection should be based on availability; cost; specific application; and necessary mixture characteristics, including flowability, strength, excavatability, and density.

4.2—Portland cement

Cement provides cohesion and strength for CLSM mixtures. For most applications, Type I or Type II portland cement conforming to ASTM C150/C150M is normally used. Other types of cement, including blended cements conforming to ASTM C595/C595M or performance cements conforming to ASTM C1157/C1157M, can be used if prior testing indicates acceptable results.

4.3—Fly ash

Coal-combustion fly ash is sometimes used to improve flowability. Its use can also increase strength and reduce bleeding, shrinkage, and permeability. High-fly-ash-content mixtures result in lower-density CLSM when compared with mixtures having high aggregate contents. Fly ashes used in CLSM mixtures do not need to conform to either Class F or C as described in ASTM C618. For example, fly ashes containing carbon contents higher than traditionally used in concrete may be acceptable. Trial mixtures should be prepared to determine whether the mixture will meet the specified requirements. Refer to ACI 232.2R for further information (Naik et al. 1991; Landwermeyer and Rice 1997).

4.4—Admixtures

Airs-entraining admixtures and foaming agents can be valuable constituents for the manufacture of CLSM. The inclusion of air in CLSM can help provide improved workability, reduced shrinkage, little or no bleeding, minimal segregation, lower unit weights, and control of ultimate strength development. Higher air contents can also help enhance thermal insulation and resistance to freezing-and-thawing cycles. Water content can be reduced as much as 50 percent when using air-entraining admixtures. Using these materials may require modifications to typical CLSM mixtures. To prevent segregation when using high air contents, mixtures need to be proportioned with sufficient fines to promote cohesion. Most air-entrained CLSM mixtures are pumpable but can require higher pump pressures when piston pumps are used. To prevent extended setting times, extra cement or an accelerating admixture may be required. In all cases, pretesting should be performed to determine acceptability (Hoopes 1997; Nmai et al. 1997).

4.5—Mineral admixtures and other additives

In specialized applications such as waste stabilization, CLSM mixtures can be formulated to include chemical additives, mineral admixtures, or both, that serve purposes beyond backfilling. Some examples include using swelling clays such as bentonite to achieve CLSM with low permeability. The inclusion of zeolites, such as analcime or chabazite, can be used to absorb selected ions where water or sludge treatment is required. Magnetite or hematite fines can be added to CLSM to provide radiation shielding in applications at nuclear facilities (Rajendran and Venkata 1997; Langton and Rajendran 1995; Langton et al. 2001). Slag cement conforming to ASTM C989/C989M may be used as a substitute for, or in addition to, portland cement. As is the case with portland cement, higher slag cement contents can produce excessive strengths and should be tested before use. Silica fume may also be used in a CLSM formulation.

4.6—Water

Water that is acceptable for concrete mixtures is acceptable for CLSM mixtures. ASTM C94/C94M provides additional information on water-quality requirements.

4.7—Aggregates

Aggregates are often the major constituent of a CLSM mixture. The type, grading, and shape of aggregates can affect the physical properties, such as flowability and compressive strength. Aggregates complying with ASTM C33/C33M are generally used because concrete producers have these materials in stock.

Granular excavation materials with somewhat lower-quality properties than concrete aggregate are a potential source of CLSM, and should be considered. Variations of the physical properties of the mixture components, however, will have a significant effect on mixture performance. Silty sands with up to 20 percent fines passing through a No. 200 (75 μm) sieve have proven satisfactory. Soils with wide variations in grading have also shown to be effective. Soils with clay fines, however, have exhibited problems with incomplete mixing, mixture stickiness, excess water demand, shrinkage, and variable strength. These soil types are not usually considered for CLSM applications. Aggregates that have been used successfully include (Tansley and Bernard 1981):
4.8—Nonstandard materials

Nonstandard materials, which can be more available and economical, can also be used in CLSM mixtures, depending on project requirements. These materials, however, should be tested before use to determine their acceptability in CLSM mixtures.

There are numerous examples of nonstandard materials that can be substituted as aggregates (Naik et al. 1996; Naik and Singh 1997a,b). Such materials include various coal combustion products, crusher fines, discarded foundry sands (Tikalsky et al. 1998, 2000; Deng and Tikalsky 2008; Siddique and Noumowe 2008), glass cullet (Wang 2009), and reclaimed crushed concrete (Achtemichuk et al. 2009). In addition, nonstandard aggregate derived from stable organic sources, such as scrap tire rubber, can be used in CLSM mixtures (Pierce and Blackwell 2003).

Aggregates or mixtures that can swell in service due to expansive reactions or other mechanisms should be avoided. Wood chips, wood ash, or other organic materials may not be suitable for CLSM. Fly ashes with carbon contents up to 22 percent have been successfully used for CLSM (Ramme et al. 1995). Cement kiln dust, also a nonstandard material, may be used as a substitute for other cementitious materials (Pierce et al. 2003; Lachemi et al. 2010).

In all cases, nonstandard material characteristics should be determined, and the suitability of the material should be tested in a CLSM mixture to determine whether it meets specified requirements. Environmental regulations could require prequalification of the raw material, CLSM mixture, or both, before use.

4.9—Ponded ash or basin ash

Ponded ash—typically a mixture of fly ash and bottom ash slurried into a storage or disposal basin—can be used in CLSM. Proportioning of the ponded ash in the resulting mixtures depends on its particle size distribution. Typically, it can be substituted for all of the fly ash and a portion of the fine aggregate and water. Unless dried before mixing, ponded ash requires special mixing because it is usually wet. Basin ash is similar to ponded ash except it is not slurried and can be disposed of in dry basins or stockpiles (Rajendran and Venkata 1997; Langton and Rajendran 1995).

CHAPTER 5—PROPERTIES

5.1—Introduction

The properties of CLSM cross boundaries between soils and concrete. CLSM is manufactured from materials similar to those used to produce concrete, and is placed similarly to concrete. In-service CLSM, especially lower-strength CLSM, exhibits characteristic properties of soils. Characteristics of CLSM are affected by mixture constituents and proportions of the ingredients in the mixture. Because many factors can affect the characteristics of CLSM, a wide range of values can exist for the various properties discussed in the following sections (Glogowski and Kelly 1988).

5.2—Plastic properties

5.2.1 Flowability—Flowability distinguishes CLSM from other fill materials. It enables the materials to be self-leveling, to flow into and readily fill a void, and to self-consolidating. This property represents a major advantage of CLSM compared with conventional fill materials that must be mechanically placed and compacted. Because fresh CLSM is similar to fresh concrete and grout, its flowability is best viewed in terms of concrete and grout technology.

A major consideration in using highly flowable CLSM is the hydrostatic pressure it exerts. Where fluid pressure is a concern, CLSM can be placed in lifts, with each lift being allowed to harden before placement of the next lift. Examples where multiple lifts can be used are limited-strength forms used to contain the material or where buoyant items, such as pipes, are encapsulated in the CLSM.

Flowability can be varied from stiff to fluid, depending on requirements. Methods of expressing flowability include using a 3 x 6 in. (75 x 150 mm) open-ended cylinder modified flow test (ASTM D6103), the standard concrete slump cone (ASTM C143/C143M), and flow cone (ASTM C939).

Good flowability, using the ASTM D6103 method, is achieved where there is no noticeable segregation and the CLSM spread is at least 8 in. (200 mm) in diameter.

Flowability ranges associated with the slump cone can be expressed as follows:

- a) Low flowability: slump less than 6 in. (150 mm)
- b) Normal flowability: slump 6 to 8 in. (150 to 200 mm)
- c) High flowability: slump greater than 8 in. (200 mm) ASTM C939, for determining grout flow, has been used successfully with fluid mixtures containing aggregates not greater than 1/4 in. (6 mm). Chapter 8 briefly describes this method.

5.2.2 Segregation—Separation of materials in the CLSM mixture can occur when flowability is primarily produced by adding water. This situation is similar to segregation experienced with some high-slump concrete mixtures. With proper mixture proportioning and materials, a high degree of flowability can be attained without segregation. For highly flowable CLSM without segregation, adequate fines are required to provide suitable aggregate suspension and stability. Fly ash and other mineral admixtures generally account for these fines (refer to Table 5.2.2), although silty or other noncohesive fines up to 20% of total aggregate have been used. Using plastic fines, such as clay, should be avoided because they can produce deleterious results, such as increased shrinkage. Some CLSM mixtures have been designed without sand or gravel, using only mineral admixtures as filler material.

5.2.3 Subsidence—Subsidence deals with the reduction in volume of CLSM as it releases water and entrapped air...
Table 5.2.2—Examples of CLSM mixture proportions

<table>
<thead>
<tr>
<th>Source</th>
<th>Cement content, lb/yd³ (kg/m³)</th>
<th>Fly ash content, lb/yd³ (kg/m³)</th>
<th>Coarse aggregate, lb/yd³ (kg/m³)</th>
<th>Fine aggregate, lb/yd³ (kg/m³)</th>
<th>Approximate water content, lb/yd³ (kg/m³)</th>
<th>28-day compressive strength, psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO DOT 50 (30)*</td>
<td>1700 (1010)</td>
<td>1845 (1096)</td>
<td>325 (193)</td>
<td>60 (0.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IA DOT 100 (60)</td>
<td>—</td>
<td>2600 (1543)</td>
<td>585 (347)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL DOT 50 to 100 (30 to 60)</td>
<td>0 to 600 (0 to 356)†</td>
<td>—</td>
<td>2750 (1632)</td>
<td>500 (297) maximum</td>
<td>50 to 150 (0.3 to 1.0)</td>
<td></td>
</tr>
<tr>
<td>IL DOT</td>
<td>300 (178) Class F</td>
<td>2600 (1543)</td>
<td>500 (297) maximum</td>
<td>50 to 150 (0.3 to 1.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN DOT MIXTURE</td>
<td>185 (110)</td>
<td>—</td>
<td>2675 (1587)</td>
<td>500 (297)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK DOT</td>
<td>50 (30) minimum</td>
<td>250 (148)</td>
<td>2910 (1727)</td>
<td>500 (297) maximum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI DOT MIXTURE 1</td>
<td>100 (60)</td>
<td>2000 (1187) Class F</td>
<td>—</td>
<td>665 (395)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI DOT MIXTURE 2§</td>
<td>50 (30)</td>
<td>550 (326) Class F</td>
<td>—</td>
<td>1977 (1173)</td>
<td>257 (152)†† at 1 day</td>
<td></td>
</tr>
<tr>
<td>OH DOT MIXTURE 1</td>
<td>100 (60)</td>
<td>250 (148)</td>
<td>2850 (1691)</td>
<td>500 (297)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OH DOT MIXTURE 2</td>
<td>50 (30)</td>
<td>250 (148)</td>
<td>2910 (1727)</td>
<td>500 (297)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC DOT</td>
<td>50 (30)</td>
<td>600 (356)</td>
<td>2500 (1483)</td>
<td>460 to 540 (273 to 320)</td>
<td>80 (0.6)</td>
<td></td>
</tr>
<tr>
<td>DOE-SR#</td>
<td>50 (30)</td>
<td>600 (356) Class F</td>
<td>2515 (1492)</td>
<td>500 to 550 (297 to 326)</td>
<td>30 to 150 (0.2 to 1.0)</td>
<td></td>
</tr>
<tr>
<td>Unshrinkable fill**</td>
<td>60 (36)</td>
<td>—</td>
<td>1705 (1012) (3/4 in. [19 mm] maximum)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixture AF‡‡</td>
<td>165 (98)</td>
<td>810 (481)§§</td>
<td>2190 (1300)</td>
<td>—</td>
<td>700 (415)</td>
<td>65 (0.4)</td>
</tr>
<tr>
<td>Mixture D‡‡</td>
<td>100 (60)</td>
<td>550 (326) §§</td>
<td>2515 (1492)</td>
<td>—</td>
<td>507 (301)</td>
<td>65 (0.4)</td>
</tr>
</tbody>
</table>

Coarse aggregate CLSM #

| Non-air entrained‡‡‡‡ | 50 (30) | 250 (148) | 1900 (1127) (1 in. [25 mm] maximum) | 1454 (863) | 270 (160)††† | 100 (0.7) |
| Air entrained‡‡‡‡ | 50 (30) | 250 (148) | 1900 (1127) (1 in. [25 mm] maximum) | 1340 (795) | 255 (151)††† | — |

Flowable fly ash slurry

| Mixture S-2§§§ | 98 (58) | 1366 (810) Class F | — | — | 1068 (634) | 40 (0.3) at 56 days |
| Mixture S-3|| | 158 (94) | 1264 (749) Class F | — | — | 1052 (624) | 60 (0.4) (75 [0.5] at 56 days) |
| Mixture S-4### | 144 (85) | 1155 (685) Class F | — | — | 1146 (680) | 50 (0.3) (70 [0.5] at 56 days) |

Note: Table examples are based on experience and test results using local materials. Yields will vary from 27 ft³ (0.76 m³). This table is given as a guide and should not be used for design purposes without first testing with locally available materials.

*Cement quantity can be increased above these limits only when early strength is required and future removal is unlikely.
†Slag cement can be used in place of fly ash or used in combination with fly ash.
‡Adjust to yield 1 yd³ (0.76 m³) of CLSM.
§5 to 6 fl oz of air-entraining admixture produces 7 to 12 percent air contents.
‖Total granular material of 2850 lb/yd³ (1690 kg/m³) with 3/4 in. (19 mm) maximum aggregate size.
§§Department of Energy (DOE) Savannah River Site CLSM mixture.
**Emery and Johnston (1986).
††Produces 6 in. (150 mm) slump.
‡‡DOE Savannah River Site CLSM mixture using pond/basin ash.
§§Basin ash mixture.
||Pond ash mixture.
***Fox (1989).
†††Produces 5 percent air content.
§§§Produces modified flow of 8-1/4 in. (210 mm) diameter (Table 8.1a); air content of 0.8 percent; slurry density of 93.7 lb/ft³ (1500 kg/m³).
|||Produces modified flow of 10-1/2 in. (270 mm) diameter; air content of 1.1 percent; slurry density of 91.5 lb/ft³ (1470 kg/m³).
###Produces modified flow of 16-3/4 in. (430 mm) diameter; air content of 0.6 percent; slurry density of 90.6 lb/ft³ (1450 kg/m³).
through mixture consolidation. Water used for flowability in excess of that needed for hydration is generally absorbed by the surrounding soil or released to the surface as bleed water. Most subsidence occurs during placement, and the degree of subsidence is dependent on the quantity of free water released. Typically, subsidence of 1/8 to 1/4 in. (3 to 6 mm) per foot of depth has been reported (Mclaren and Balsamo 1986). This amount is generally found with mixtures of high water content. Mixtures of lower water contents may exhibit little or no subsidence.

5.2.4 Hardening time—Hardening time is the approximate time period required for CLSM to go from the plastic state to a hardened state with sufficient strength to support a person of average weight. This time is greatly influenced by the amount and rate of bleed water released. When excess water leaves the mixture, solid particles realign into intimate contact and the mixture becomes more rigid. Hardening time is greatly dependent on the type and quantity of cementitious material in the CLSM.

Normal factors affecting the hardening time are:
- a) Type and quantity of cementitious material
- b) Aggregate shape and absorption
- c) Permeability and degree of saturation of surrounding soil that is in contact with CLSM
- d) Moisture content of CLSM
- e) Proportioning of CLSM
- f) Mixture temperature and ambient placing temperature
- g) Humidity
- h) Depth of fill

Hardening time can be as short as 1 hour, but generally takes 3 to 5 hours under normal conditions (Smith 1991; Hoopes 1997; Mclaren and Balsamo 1986). Suitable tests for determining CLSM hardening time includes a penetration-resistance test according to ASTM C403/C403M and ASTM D6024. Depending on the application, the penetration numbers of 500 to 1500 are normally required to assure adequate bearing capacity (NRMCA 1989).

5.2.5 Pumping—CLSM can be delivered by conventional concrete pumping equipment. As with concrete, mixture proportioning is critical. Voids should be adequately filled with solid particles to provide cohesiveness and stability for transport through the pressurized pump line without segregation. The mixture should be statically stable so that it does not segregate and cause settling problems during pumping or in place. Also, it is important to maintain continuous flow through the pump line. Interrupted flow can cause segregation, which can restrict flow and result in line blockage.

In one example, CLSM using unwashed aggregate with high fines content was pumped through a 5 in. (127 mm) pump system at a rate of 60 yd³/h (46 m³/h) (Rocky Mountain Construction 1986). In another example, CLSM with a slump as low as 2 in. (50 mm) was successfully delivered by concrete pump without added consolidation effort (Glogowski and Kelly 1988).

CLSM with high entrained-air contents can be pumped, although care should be taken to maintain low pump pressures. Increased pump pressures can cause a loss in air content and reduced pumppability. Pumpability can be enhanced by careful proportioning to provide adequate void filling in the mixture. Fly ash and other mineral admixtures can aid pumppability by acting as microaggregate for void filling. Cement can also be added for this purpose. Whenever cementitious materials are added, however, take care to limit the maximum strength levels if later excavation is a consideration.

5.3—In-service properties

5.3.1 Strength (bearing capacity)—Unconfined compressive strength is a measure of the load-carrying ability of CLSM. Maintaining low strengths is a major objective for projects where later excavation is required. Some mixtures that are acceptable at early ages continue to gain strength with time, making future excavation difficult. Section 5.3.7 provides additional information on excavatability.

5.3.2 Density—Wet density of normal CLSM in place is in the range of 115 to 145 lb/ft³ (1840 to 2320 kg/m³), which is greater than most compacted materials. A CLSM mixture with only fly ash, cement, and water should have a density between 90 to 100 lb/ft³ (1300 and 1800 kg/m³) (Naik et al. 1990; Folliard et al. 2008). Ponded ash, basin ash, or bottom ash CLSM mixture densities are typically in the range of 85 to 110 lb/ft³ (1360 to 2000 kg/m³) (Langton and Rajendran 1995; Folliard et al. 2008). Dry density of CLSM can be expected to be substantially less than wet density due to water loss. Lower unit weights can be achieved by using lightweight aggregates, high entrained-air contents, and foamed mixtures, which are discussed in detail in Chapter 9.

5.3.3 Settlement—Compacted soil fills can settle even when specified compaction requirements have been met. In contrast, CLSM does not settle after hardening. Measurements taken months after placement of a large CLSM fill showed no measurable shrinkage or settlement (Flechsig 1990). For a project in Seattle, WA, 786 yd³ (601 m³) were used to fill a 120 ft (37 m) deep shaft. The placement took 4 hours and total settlement was reported as approximately 1/8 in. (3 mm).

5.3.4 Thermal insulation/conductivity—Conventional CLSM mixtures are not good insulating materials. Air-entrained conventional mixtures reduce density and increase insulating value. Lightweight aggregates, including bottom ash, can be used to reduce density. Foamed or cellular mixtures as described in Chapter 9 have low densities and exhibit good insulating properties.

Where high thermal conductivity is desired, such as in backfill for underground power cables, high density and low porosity are desirable. As moisture content and dry density increase, so does the thermal conductivity. Other, less important, parameters to consider include mineral composition, particle shape and size, gradation characteristics, organic content, and specific gravity (Ramme et al. 1995; Steinmanis 1981; Parmar 1991, 1992).

5.3.5 Permeability—Permeability of most excavatable CLSM is similar to compacted granular fills. Typical values are in the range of 10⁻⁴ to 10⁻⁵ in./s (or cm/s). CLSM mixtures with higher strength and higher fines content can achieve permeabilities as low as 10⁻⁷ in./s (or cm/s). Permeability increases as cementitious materials are reduced and...
Excavatability—The ability to excavate CLSM is an important consideration on many projects. In general, CLSM with a compressive strength of 100 psi (0.7 MPa) or less can be excavated manually. A removability modulus (RE) can be used to determine the excavatability of CLSM. The RE can be determined as follows:

\[
RE = \frac{W^{1.5} \times 0.619 \times C^{0.5}}{10^6} \tag{5.3.7}
\]

where \(W\) is the dry mass density (kg/m\(^3\)), and \(C\) is the 28-day unconfined compressive strength (kPa). If the RE is less than 1.0, the CLSM is removable. CLSM with RE values greater than 1.0 are not easily removed.

Mechanical equipment, such as backhoes, can remove materials with compressive strengths of 100 to 300 psi (0.7 to 2.1 MPa) (Fig. 5.3.7). Excavability limits are arbitrary guidelines and depend on the CLSM mixture constituents. Mixtures using high coarse aggregate quantities can be difficult to remove by hand, even at low strengths. Mixtures using fine sand or only mineral admixtures as aggregate filler have been excavated with a backhoe up to strengths of 300 psi (2.1 MPa) (Krell 1989).

When excavatability of CLSM is a concern, the type and quantity of cementitious materials is important. A acceptable long-term performance has been achieved with cement contents from 40 to 100 lb/yd\(^3\) (24 to 59 kg/m\(^3\)) and Class F fly ash contents up to 350 lb/yd\(^3\) (208 kg/m\(^3\)). Lime (CaO) contents of fly ash that exceed 10 percent by weight can be a concern where long-term strength increases are not desired (Tansley and Bernard 1981).

Because CLSM typically continues to gain strength beyond the conventional 28-day testing period, it is suggested, especially for CLSM with high cementitious content, that long-term strength tests be conducted to estimate the potential for excavatability. In addition to limiting the cementitious content, entrained air can be used to maintain low compressive strength.

5.3.8 Shear modulus—The shear modulus, which is the ratio of unit shearing stress to unit shearing strain, of normal-density CLSM typically ranges from 3400 to 7900 ksf (160 to 380 MPa) (Larsen 1988; Rajendran and Venkata 1997; Langton et al. 2001). Shear modulus is used to evaluate the expected shear strength and deformation of CLSM.

5.3.9 Potential for corrosion—The potential for corrosion on metals encased in CLSM has been quantified by a variety of methods specific to the material in contact with CLSM. Electrical resistivity tests can be performed on CLSM in the same manner that natural soils are compared for their corrosion potential on corrugated metal culvert pipes using California Test 643 (California Department of Transportation 1999). Moisture content of the sample is an important parameter for sample resistivity, and the samples should be tested at their expected long-term field moisture content. Unlike soil, high pH values characteristic of CLSM can be beneficial. The high pH of CLSM can provide a protective passive film for iron-based materials, thus reducing potential for corrosion.

The Ductile Iron Pipe Research Association (DIPRA) (Horn 2006; AWWA 2010) has a method for evaluating the corrosion potential of backfill materials. The evaluation procedure is based on information drawn from five tests and observations—soil resistivity, pH, oxidation-reduction (redox) potential, sulfides, and moisture. For a given sample, each parameter is evaluated and assigned points according to its contribution to corrosivity (Straud 1989; AWWA 2010; Hill and Sommers 1997). Although applicable for soils, this procedure in its entirety may not be applicable to CLSM. The DIPRA method indicates that high-pH soils are deleterious for corrosion protection. High pH associated with CLSM, as with concrete, is believed to be beneficial for corrosion protection. These procedures are guides for determining a soil’s potential corrosivity to ductile iron pipe and should be used only by qualified engineers and technicians experienced in soil analysis and evaluation.

A continuous metallic material that passes through soils of varying composition may exhibit galvanic corrosion due to differences in its corrosion potential in different soils. The uniformity of CLSM reduces the probability of galvanic corrosion due to dissimilarities in the surrounding environment, which may otherwise occur from the use of dissimilar backfill materials and non-uniform compaction of similar materials. Because of the high pH associated with CLSM and the more neutral pH of conventional soils, however, care must be taken when partially encasing iron-based products.
in CLSM. Research indicates that backfilling or bedding ductile iron pipes partially with CLSM and partially with conventional compacted backfill materials leads to accelerated corrosion of ductile iron pipes at the interface between the two fill materials (Halmen et al. 2006).

5.3.10 Compatibility with plastics—High-, medium-, and low-density polyethylene materials are commonly used as protection for underground utilities or as the conduits themselves. CLSM is compatible with these materials. As with any backfill, care must be exercised to avoid damaging the protective coating of buried utility lines. The fine gradation of many CLSMs can aid in minimizing scratching and nicking these polyethylene surfaces (Ramme et al. 1995).

CHAPTER 6—PROPORTIONING

6.1—Introduction

When proportioning CLSM mixtures, it is important to recognize that CLSM is typically designed to meet the requirements of compacted soil material and not that of structural concrete. Before initiating a mixture design investigation, the engineer needs to determine the intended purpose, identify necessary properties required, and recognize that not all CLSM mixtures are excavatable.

One unique characteristics of CLSM is the ability to use a wide variety of locally available materials to optimize design and provide economical engineered material for the intended purpose.

6.2—Materials

CLSM has been produced with fine aggregates ranging from ASTM C33/C33M quality concrete sand to bank run sand, dirty sands, and other non-ASTM C33/C33M-specified materials. CLSM offers the producer the flexibility of using locally available material in the regional marketplace to attain required performance, improve economics, sustainability, and potential environmental benefits. Quarry by-products, recycled foundry sand, crusher fines, and crushed (recycled) concrete are a few inexpensive fine aggregate materials used in CLSM. A well-graded fine aggregate will generally produce a more stable CLSM that resists segregation and excessive bleeding. Although mixtures designed with a high percentage of fine aggregate passing a 75 μm (No. 200) sieve (including silt and clay) will further stabilize the CLSM matrix, take care to avoid too much clay in the mixture, which could adversely affect mixing efficiency and in-place performance.

Cementitious materials used in CLSM vary as much as the fine aggregate. Portland cement, fly ash, bottom ash, slag cement, natural pozzolan, lime, cement kiln dust (CKD), and combinations of these materials have been used. Because CLSM is a low-strength material, one should be cautious about the strength potential of the mixture. A typical mixture will contain 25 to 100 lb/yd³ (30 to 60 kg/m³) of cement and up to 300 lb/yd³ (178 kg/m³) of fly ash that promote setting and long-term strength.

6.3—General formulation

The numerous formulations for CLSM can be summarized into three basic methodologies. The simplest form uses a combination of cementitious materials, fine aggregate, and water with little or no admixtures. A second design method uses a combination of cementitious materials, fine aggregate, water, and an air-entraining admixture resulting in a mixture with air contents ranging from 20 to 32 percent. The third design method is LD-CLSM and uses the typical combination of cementitious materials and water. This slurry is foamed to produce a mixture with an air content ranging from 50 to 80 percent. Foaming agent suppliers for these formulations usually provide designs for LD-CLSM mixes (refer to Chapter 9).

The wide variety of materials and performance requirements can present a challenge to the concrete practitioner when designing a CLSM mixture. Because strength requirements for CLSM are much less than conventional concrete, principles often used in developing concrete mixtures may not be applicable for many CLSM mixes. As a result, mixture proportioning for CLSM is an iterative process with adjustments made to an initial design until a mixture is developed that satisfies project requirements. Often, locally ready mixed concrete producers have a pretested CLSM that will meet most project requirements.

6.4—Proportioning methods

Proportioning methodology from ACI 211.1 may be used to establish initial mixture design. Basic CLSM mixtures typically contain 2500 to 3500 lb/yd³ (1483 to 2076 kg/m³) of fine aggregate, 400 to 500 lb/yd³ (237 to 297 kg/m³) of water, 25 to 200 lb/yd³ (15 to 119 kg/m³) of portland cement, and 0 to 700 lb/yd³ (0 to 415 kg/m³) of fly ash, as shown in Table 5.2.2. This combination of materials usually entraps 2 to 5 percent air, which should be included in the mixture volume calculations. Like most products sold by concrete producers, CLSM is batched by weight but sold by volume. One cubic yard of CLSM should yield 27 ft³ (0.76 m³). To calculate yield, the specific gravity of these materials should be known. The following example shows how to calculate the yield of a CLSM mixture using the absolute volume method.

Example: Initial assumptions to proportion a basic CLSM mixture: 450 lb/yd³ (267 kg/m³) of water, 94 lb/yd³ (56 kg/m³) of cement, 3 percent entrapped air, and fine aggregate to produce 1 yd³ (0.76 m³) of CLSM.

Sample calculations for 1 yd³ (or for 1 m³) of material are located in Table 6.4. The weight (mass) of sand required to achieve a volume of 1 yd³ (or 1 m³) is determined by calculating the absolute volume of the other constituents (cement, aggregate, water, and air) and subtracting that from 1 yd³ (or 1 m³). In this table, the sand is assumed to have a specific gravity of 2.65.

6.5—Evaluation

The next step to developing a basic CLSM mixture is to produce a test batch of the CLSM mixture design and evaluate its properties.
Typical evaluation should include, but may not be limited to, air content, yield, slump or flowability, stability, and strength. Yield and air content are used to establish the proper volume of material. Slump or flowability indicates relative workability and compactability. Stability refers to a homogeneous mixture, which is cohesive and does not have excessive segregation. Compressive strengths are typically low—25 to 150 psi (0.2 to 1.0 MPa) at 28 days—to allow for future excavation of CLSM. Test methods for determining these properties are given in Chapter 8.

If the required expectations of the CLSM are not met, the mixture should be adjusted, remixed, and retested.

### 6.6—Adjustments to proportioning

A djustments to the CLSM mixture can be accomplished by varying one or more of the constituents. Table 6.6 provides a simplistic approach for adjusting a basic mixture design.

A fter adjusting to the test batch of CLSM, batch the adjusted mixture and evaluate the properties using the guideline in 6.4.

Some examples of basic mixture proportions that have been used are given in Table 5.2.2.

### CHAPTER 7—MIXING, TRANSPORTING, AND PLACING

#### 7.1—General

M ixing, transporting, and placing CLSM generally follows methods and procedures given in ACI 304R. Other methods are acceptable if prior experience and performance data are available. Whatever methods and procedures are used, the main criteria are that the CLSM be homogeneous, consistent, and satisfy the requirements for the purpose intended.

#### 7.2—Mixing

CLSM can be mixed by several methods, including central-mixed concrete plants, ready mixed concrete trucks, pugmills, and volumetric mobile concrete mixers. For high-fly-ash mixtures where fly ash is delivered to the mixer from existing silos, batching operations can be slow.

Ready mixed concrete producers commonly use truck mixers to mix CLSM, but in-plant central mixers can be used as well. In truck-mixing operations, the following is one procedure that can be used for charging truck mixers with batch materials.

Load truck mixer at standard charging speed in the following sequence:

1. Add 70 to 80 percent of water required
2. Add 50 percent of the aggregate filler
3. Add all cement and fly ash required
4. Add balance of aggregate filler
5. Add balance of water

For CLSM mixtures consisting of fly ash, cement, water, and no aggregate filler, an effective mixing method consists of initially charging the truck mixer with cement then water. After thoroughly mixing these materials, fly ash is added. In

---

### Table 6.4—Sample calculations for 1 yd$^3$ (1 m$^3$) of material

<table>
<thead>
<tr>
<th>1 yd$^3$</th>
<th>1 m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>94 lb cement/(3.15 × 62.4 lb/ft$^3$) = 0.48 ft$^3$</td>
<td>56 kg cement/(3.15 × 1000 kg/m$^3$) = 0.018 m$^3$</td>
</tr>
<tr>
<td>450 lb water/(1.00 × 62.4 lb/ft$^3$) = 7.21 ft$^3$</td>
<td>267 kg water/(1.00 × 1000 kg/m$^3$) = 0.267 m$^3$</td>
</tr>
<tr>
<td>Assumed air vol (3% × 7 ft$^3$) = 0.81 ft$^3$</td>
<td>Assumed air volume (3% × 1 m$^3$) = 0.03 m$^3$</td>
</tr>
<tr>
<td>Volume, sand = 27 ft$^3$ – 0.48 ft$^3$ – 7.21 ft$^3$ – 0.81 ft$^3$ = 18.5 ft$^3$</td>
<td>Volume, sand = 1 m$^3$ – 0.018 m$^3$ – 0.267 m$^3$ – 0.03 m$^3$ = 0.685 m$^3$</td>
</tr>
<tr>
<td>Weight, sand = 18.5 ft$^3$ × (2.65 × 62.4 lb/ft$^3$) = 3060 lb</td>
<td>Mass, sand = 0.685 m$^3$ × (2.65 × 1000 kg/m$^3$) = 1815 kg</td>
</tr>
</tbody>
</table>

### Table 6.6—Adjustments to proportioning

<table>
<thead>
<tr>
<th>Property</th>
<th>Problem</th>
<th>Adjustment</th>
</tr>
</thead>
</table>
| Slump | Too high | a) Reduce water content  
b) Increase fines |
| | Too low | a) Increase water content  
b) Add water-reducing admixture |
| Stability | Mixture is segregating | a) Decrease water  
b) Increase fines  
c) Increase cementitious materials  
d) Add air entrainment  
e) Add viscosity-modifying admixture (VMA) |
| Yield | Too low | a) Confirm specific gravity used for constituents is correct  
b) Increase constituents |
| | Too high | a) Confirm specific gravity used for constituents is correct  
b) Decrease constituents |
| Strength | Too low | a) Increase cementitious materials  
b) Decrease air entrainment  
c) Decrease water in conjunction with use of water-reducing admixture |
| | Too high | a) Decrease cementitious materials  
b) Increase air entrainment |
one case, additional mixing for a minimum of 15 minutes was required to produce homogeneous slurry (Naik et al. 1990).

Pugmill mixing works for both high- and low-fly-ash mixtures and other high-fines-content mixtures. For high-fly-ash mixtures, fly ash is fed into a hopper with a front-end loader, which supplies a belt conveyor under the hopper. This method of feeding the mixer is much faster than silo feed. To prevent bridging within the fly ash, a mechanical agitator or vibrator is used in the hopper. Cement is usually added to the mixer by conveyor from silo storage. If bagged cement is used, it is added directly into the mixer.

7.3—Transporting

Most CLSM mixtures are transported in truck mixers. A gating of CLSM is required during transportation and waiting time to keep the material in suspension. Under certain on-site circumstances, CLSM has been transported in nonagitating equipment such as dump trucks. A gate truck, although providing some mixing action, may not provide enough action to prevent the solid materials from settling out.

CLSM has been transported effectively by pumps and other conveying equipment. When pumping CLSM, fly ash serves as a lubricant to reduce friction in the pipeline. The fine texture of fly ash requires that the pump be in excellent condition and properly cleaned and maintained.

CLSM can be transported effectively by volumetric-measuring and continuous-mixing concrete equipment (VMCM) (ACI 304.6R), particularly if it is desired to reduce waiting time. The major advantage of this equipment is its ability to mix at the job site and vary the water content to attain desired flowability. This is particularly true for fast-setting CLSM mixtures. VMCM equipment has separate bins for water, cementitious materials, and selected aggregates. The materials are transported to the job site where continuous mixing of water and dry materials make a good, easily regulated CLSM.

7.4—Placing

CLSM can be placed by chutes, conveyors, buckets, or pumps, depending on application and accessibility. Internal vibration, compaction, or consolidation is not required because CLSM consolidates under its own weight. Although it can be placed year round, CLSM should be protected from freezing until hard. Curing methods specified for concrete are not considered essential for CLSM (Tansley and Bernard 1981).

For trench backfill, CLSM is usually placed continuously. To contain CLSM when filling long, open trenches in stages or open-ended structures such as tunnels, the end points can be bulkheaded with sandbags, earth dams, or stiffer CLSM mixtures.

For pipe bedding, CLSM can be placed in lifts to prevent floating the pipe. Each lift should be allowed to harden before placement continues. Other methods of preventing flotation include sand bags placed over the pipe, straps around the pipe and anchored into the soil, or using faster-setting CLSM placed at strategic locations over the pipe.

In the plastic state, CLSM is not self-supporting and places a load on the pipe. For large, flexible wall pipes, CLSM should be placed in lifts so that lateral support develops along the side of the pipe before fresh CLSM is placed over the pipe (Smith 1991). Backfilling retaining walls can also require the CLSM be placed in lifts to prevent over stressing the wall due to hydrostatic pressure.

CLSM has been effectively placed by tremie under water (Krell 1989) without significant segregation. In confined areas, CLSM displaces water to the surface where it can easily be removed. CLSM can be designed to achieve a consistency so fluid that it can flow long distances to fill voids and cavities located in hard-to-reach places. Voids need not be cleaned, as the slurry will fill irregularities and encapsulate loose materials.

7.5—Cautions

7.5.1 Hydrostatic pressure—CLSM is often placed in a near-liquid state and thus exerts a hydrostatic pressure against basement walls and other structures until it hardens. On deep fills, it is often necessary to place CLSM in multiple lifts.

7.5.2 Quick condition—Liquid CLSM in deep excavations is a quicksand hazard and should be covered until hardening occurs.

7.5.3 Floating tanks, pipes, and cables—Underground utilities and tanks should be secured against floating during CLSM placement (Ramme and Naik 1997).

CHAPTER 8—QUALITY CONTROL

8.1—General

A quality control (QC) program for CLSM varies depending on previous experience, application, raw materials used, and level of quality desired. A QC program can be as simple as a visual check of completed work where standard, pretested mixtures are being used. Where the application is critical, materials are nonstandard, or where product uniformity is questionable, regular tests for consistency and strength may be appropriate.

Both as-mixed and in-service properties can be measured to evaluate mixture consistency and performance. For most projects, CLSM is pretested using the actual raw materials to develop a mixture having certain plastic (flowability, consistency, unit weight) and hardened (strength, durability, permeability) characteristics. Following the initial testing program, field testing can consist of simple visual checks, or can include consistency measurements or compressive strength tests.

Because the QC program can be simple or detailed, it is the responsibility of the specifier to determine an appropriate QC program that will assure that the product is adequate for its intended use. The procedures and test methods in Tables 8.1a and 8.1b have been used to evaluate CLSM mixtures.

8.2—Sampling of CLSM

Sampling CLSM that has been delivered to the project site should be performed in accordance with ASTM D5971.
8.3—Consistency and unit weight

Depending on application and placement requirements, flow characteristics can be important. CLSM consistency can vary considerably from plastic to fluid; therefore, several methods of measurement are available. Most CLSM mixtures perform well with various flow and unit weight properties. Table 8.1a describes methods that can be used to measure consistency and unit weight. CLSM generally exhibits large shrinkage. When CLSM is being placed in the ground, this may not be a problem. When used to backfill a pipe or other containment structure, shrinkage may be important to the designer. ASTM C157/C157M can be used for measuring CLSM shrinkage.

Table 8.1a—Test procedures for determining consistency and unit weight of CLSM mixtures

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Fluid mixtures</th>
<th>Plastic mixtures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASTM D6103—Procedure consists of placing 3 in. (75 mm) diameter by 6 in. (150 mm) long open-ended cylinder vertically on level surface and filling cylinder to top with CLSM. Cylinder is then lifted vertically to allow material to flow out onto level surface. Good flowability is achieved where there is no noticeable segregation and material spread is at least 8 in. (200 mm) in diameter.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM C399—Florida and Indiana DOT specifications require efflux time of 30 seconds ± 5 seconds. Procedure is not recommended for CLSM mixtures containing aggregates greater than 1/4 in. (6 mm).</td>
<td></td>
</tr>
<tr>
<td>Unit weight</td>
<td>ASTM C143/C143M</td>
<td>ASTM D6023</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D4380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D1556</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D2922</td>
</tr>
</tbody>
</table>

8.4—Strength tests

CLSM is used in a range of applications requiring different load-bearing characteristics. Maximum loads to be imposed on the CLSM should be identified to determine minimum strength requirements. In many cases, however, CLSM needs to be limited in its maximum strength. This is true where removal of the material at a later date is anticipated.

The strength of CLSM can be measured by several methods. Table 8.1b describes some of these methods. Unconfined compressive strength tests are the most common; however, other methods, such as penetrometer devices or plate load tests, can also be used. Compressive-strength specimens range in size from 2 x 2 in. (50 x 50 mm) cubes to 6 x 12 in. (150 x 300 mm) cylinders. Special care should be used when removing very-low-strength CLSM mixtures from test molds. Additional care in the handling, transporting, capping, and testing procedures should be taken because specimens are often fragile. Mold stripping techniques have included using a drill or hot probe to place a central hole in the bottom of standard watertight cylinder molds and adding a dry polyester fleece pad on the inside of the cylinder bottom for easy specimen release with or without air compression; splitting the molds with a hot knife; and presplitting molds and reattaching with duct tape for easier specimen removal.

When CLSM is used as subgrade for a pavement or slab, its in-place bearing strength may be important for the designer of the structural element. Bearing ratio tests may be performed in the laboratory or field and subgrade modulus may be determined from field plate load tests. In the field, a properly calibrated pocket penetrometer can be used to determine initial set.

CHAPTER 9—LOW-DENSITY CLSM USING PREFORMED FOAM

9.1—General

CLSM is a self-consolidating cementitious mixture that is intended to result in a compressive strength of 1200 psi (8.3 MPa) or less. Low-density (LD) CLSM not only meets this definition, but its final density is controllable from 20 to 120 lb/ft³ (320 to 1920 kg/m³). Because of its low density, LD-CLSM is preferred when reducing dead load is a critical requirement.

Generally, CLSM mixtures contain supplementary cementitious materials (SCM) with some portland cement and other fillers. LD-CLSM usually contains portland cement, possibly some SCM, and preformed foam for most of the volume. Most LD-CLSM applications are alternate solutions to conventional geotechnical solutions such as surcharging soils, bridging poor soils, removal and replacement of poor soils, pile support, and other foundation treatments. In addition, LD-CLSM is easily excavated, a requirement in some applications. The air void or cell structure inherent in LD-CLSM mixtures controls the final density of the mixture, provides thermal insulation, and adds shock mitigation properties to the fill material.
9.2—Applications

LD-CLSM has a very low density, which is a major advantage in most applications. All of the following applications can be constructed with LD-CLSM.

9.2.1 Backfill—LD-CLSM is placed against structures such as bridge abutments, retaining walls, and building walls to reduce dead load as much as 75 percent over poor soils. Once LD-CLSM sets, it does not exert active lateral pressure against the wall structure as standard granular backfill does. LD-CLSM is a cementitious material that is consolidated and does not require compaction like soil fills. Settlement is minimal because of its low density. Bridge approach applications are often 10 to 40 ft (3.0 to 12.2 m) or more in height. LD-CLSM is a low-density, self-consolidating fill that is a preferred alternative to standard compacted fill. Usually, LD-CLSM with a maximum in-service density of 30 lb/ft³ (480 kg/m³) is cast for most of the fill thickness. The top 2 to 3 ft (0.61 to 0.91 m) may be LD-CLSM with a maximum in-service density of 42 lb/ft³ (690 kg/m³), which has excellent resistance to freezing and thawing and provides a solid base for the approach slab or pavement structure.

9.2.2 Roadway bases—LD-CLSM is often used as a roadway base over poor soil. Using the material becomes even more important when raising or widening the roadway over poor soil, because added weight and settlement are design concerns (Fig. 9.2.2). These designs often involve load-balancing and buoyancy calculations. Specific site conditions may require special drainage details.

When constructing a roadway over poor soil, a geotextile fabric may be placed after the excavation is complete. The LD-CLSM is cast directly onto the geotextile fabric. This fabric acts as a tension skin and, in conjunction with LD-CLSM, can span most localized settlements.

9.2.3 Pipeline and culvert fills—LD-CLSM is often a supporting fill in pipeline applications over poor soils or a containment fill cast around these drainage structures to provide support and stability. Compaction is not necessary as it is with granular fill.

Culvert applications include concrete box culverts, segmented or pipe sections, and metal culvert systems including multi-plate culverts of significant size.

LD-CLSM reduces dead weight on the culvert. The cohesive nature of all CLSM mixtures provides erosion control, which is an advantage over standard granular fills that erode when subjected to moving water. CLSM mixtures may need to be evaluated for freezing-and-thawing resistance.

Placing LD-CLSM on both sides of the culvert simultaneously minimizes eccentric loading. In addition to supporting the culvert from below, LD-CLSM cast around these drainage structures provides lateral support of the culvert or pipeline.

9.2.4 Void fills—LD-CLSM is commonly used as a void fill when dead load reduction is critical. It is also applicable to mass structures where access may be limited and flowability is important. Void fill applications include pipeline abandonment, filling around excavations, annular space fills between slip-lined pipes, and structures that are to be abandoned rather than demolished (Fig. 9.2.4).

Because every void fill application is unique, each should be examined for special conditions. To contain LD-CLSM, the entire fill area should be sealed, including pipes, drains, and structural discontinuities such as holes in walls or under footings. Lift heights for void fills may be greater than normal if the LD-CLSM can be reasonably contained by earth, forms, or a structure.

9.2.5 Tank fills—An acceptable abandonment alternative to the excavation and removal of underground fuel- or oil-storage tanks required by many agencies is a LD-CLSM tank fill (Fig. 9.2.5). The 53 FR 37082-37247 regulations refer to LD-CLSM fills as an “inert substance.”

9.2.6 Insulation and isolation fills—The discrete air-cell structure within the cementitious matrix of LD-CLSM provides thermal-insulation and physical shock-mitigation properties to this material for applications such as walls (Fig. 9.2.6), roofs, and other similar structures. Giannakou and Jones (2004) describe using LD-CLSM to thermally insulate foundations and slabs.
9.3—Materials

The basic materials in LD-CLSM are cement, water, and preformed foam. Because the main ingredient by volume of a LD-CLSM mixture is preformed foam, it is critical that all admixtures are compatible with the preformed foam within the specific mixture. Trial mixture tests are needed to determine compatibility and the resulting physical properties. LD-CLSM mixtures may also include supplementary cementitious materials.

9.3.1 Portland cement—The cement should meet the requirements of ASTM C150/C150M (portland cement), ASTM C595/C595M (blended cement), or ASTM C1157/C1157M (hydraulic cement). Blended cements include cement containing combinations of portland cement, Pozzolans, slag, other hydraulic cement, or some combination of these. Blended cement may result in lower rates of early strength development, and should be tested for specific applications. High-early-strength (Type III or HE) cement produces LD-CLSM with higher rates of early strength development.

9.3.2 Water—Mixing water for LD-CLSM should be clean and free from detrimental amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement. Any nonpotable water should be tested for hardness, pH, suspended solids, total salt content, and other characteristics that might affect the preformed foam, the setting time, and the strength of LD-CLSM.

9.3.3 Preformed foam—Preformed foam is created by diluting a liquid foam concentrate with water in predetermined proportions (Fig. 9.3.3a) and passing this mixture through a foam generator. The preformed foam is metered directly into the cement-water slurry mixer at the job site (Fig. 9.3.3b). Preformed foam density is typically between 2.5 and 4.0 lb/ft³ (40 and 65 kg/m³).

Foam concentrate should have a chemical composition capable of producing and maintaining stable air cells within the LD-CLSM mixture. Air cells should be resistant to physical and chemical forces imposed during mixing, pumping, placing, and setting of LD-CLSM. When the cellular (air-cell) structure is not stable, it may break down under these forces, resulting in an increased LD-CLSM density and a loss of volume. Most common proprietary foam concentrate formulations contain protein hydrozylates or synthetic surfactants. ASTM C796/C796M provides a standard method for laboratory measurement of the performance of a foaming chemical to be used in producing foam (air cells) for making LD-CLSM. ASTM C869/C869M is a standard specification that covers foaming agents specifically formulated for making preformed foam for use in cellular concrete production. This specification provides the means for evaluating the performance of a specific foaming agent. Further information concerning these formulations and procedures for using them is available from foam manufacturers.

9.3.4 Supplementary cementitious materials—In the production of LD-CLSM, SCM such as fly ash, silica fume, high-reactivity metakaolin, or slag cement are included.
to reduce cement content and to maintain strength. Trial batches should be used to confirm the compatibility of the selected foam concentrate with other admixtures, and to help determine proper admixture dosages and resulting physical properties. SCM may differ considerably in composition, fineness, and other properties.

The user should review major SCM properties—loss on ignition (LOI), cementing activity, and water demand of the fly ash—before including fly ash in a LD-CLSM mixture. LOI is addressed in ASTM C618. Fly ash with a high LOI (carbon content) should be tested for acceptability in these mixtures to avoid an increase in density and loss of yield. Secondly, if the cementing activity is low, LD-CLSM may set too slowly and may not reach desired ultimate strength. Finally, high water demand results in weaker LD-CLSM and may require the water-cementitious material ratio (w/cm) be adjusted, the cast density increased, or the percentage of fly ash replacement of cement be reduced to achieve the desired strength.

**9.3.5 Aggregates**—Aggregates are not normally used in LD-CLSM mixtures with design densities below 50 lb/ft³ (800 kg/m³) where 100 percent cementitious material:water slurries are acceptable. If aggregates are used, they should be tested in trial mixtures for physical properties, pumpability, and compatibility.

**9.3.6 Nonstandard materials**—Such materials may include special cements, mineral admixtures, and aggregates. Some mine fill applications may use local materials as aggregates or fillers in LD-CLSM to extend the mixture when transportation of materials to remote areas is difficult. These nonstandard mixtures should be tested for compatibility and proper development of the desired fill properties.

**9.3.7 Admixtures**—Chemical admixtures, such as water-reducing admixtures (WRAs), high-range WRAs (HRWRAs), and set accelerators may be used with LD-CLSM. WRAs can improve compressive strength for special mixtures or applications. Hot water, high-early-strength (Type III or HE) cement, and chemical accelerators can be used singly or in combination to accelerate setting. Accelerators containing chloride ions should not be used in LD-CLSM that contacts steel. Chemical admixtures should conform to ASTM C494/C494M and be used at dosages recommended by the manufacturer or determined by trial mixtures.

Not all chemical admixtures are compatible for use in LD-CLSM. Individual manufacturers of foam concentrate should be contacted for information about the compatibility of specific admixtures with their foam concentrates, and trial batches should be used to determine the resulting mixture characteristics.

**9.4—Physical properties**

**9.4.1 As-cast density**—As-cast density at the point of placement should be determined by calculating the density of samples using a container of known volume and empty weight as prescribed in applicable sections of ASTM C796/C796M (Fig. 9.4.1). Monitoring as-cast density of LD-CLSM is an important job-site quality-assurance tool for controlling uniformity and density of the mixture at the point of placement. Procedures for sampling and testing hardened LD-CLSM are given in ASTM C513.

**9.4.2 Compressive strength**—The relationship between compressive strength and as-cast density is an important indicator of the quality of LD-CLSM (Kearsley and Wainwright 2001b). The compressive strength of LD-CLSM should be evaluated in accordance with ASTM C796/C796M and ASTM C495/C495M. Compressive-strength specimens should not be oven-dried.

For geotechnical applications, the cast density of LD-CLSM is usually the most significant property, and may be more critical than its bearing capacity (unconfined compressive strength). Specified densities and strength parameters must be met for these applications (Table 9.4.2). If standard materials are used, the density of LD-CLSM has properties that fall within ranges specified by the foam concentrate manufacturer. If nonstandard materials are used, test batches may be required to confirm specific properties. To define the general relationship between cast density and compressive strength for specific applications, one manufacturer has divided cast density into convenient ranges.

For specialized LD-CLSM geotechnical applications, other physical properties may be required.

LD-CLSM with a compressive strength below 70 psi (0.48 MPa) has proven satisfactory for applications such as pipe...
and wall insulation, tunnel and mine fills, energy absorption or shock mitigation, and backfills in sewer and highway construction per ACI SP-29 (ACI Committees 213 and 523 1971).

9.4.3 Permeability—Generally, LD-CLSM has a low coefficient of permeability (k) that is constant throughout the lower density ranges (Kearsley and Wainwright 2001a). The coefficient of permeability is inversely related to the effective confining pressure on the sample. Because LD-CLSM is a rigid material rather than a yielding soil, its permeability is measured using a modified triaxial test including a confining pressure to prevent direct water passage (short-circuiting) along the interface between specimen and confining membrane. A constant head should be maintained during the test. Reported k-values at a confining pressure of 2.0 psi (13.8 kPa) range from 5.5 × 10⁻⁴ to 4.3 × 10⁻⁷ in./s (1.4 × 10⁻³ to 1.1 × 10⁻⁶ cm/s) per ASTM D2434. Recent developments in LD-CLSM mixtures have resulted in greater permeability values due to changes in the preformed foam formulation and, therefore, in its properties. As a result, recently reported values range from 3.9 × 10⁻³ to 3.4 × 10⁻⁶ in./s (1.0 to 1.0 × 10⁻⁵ cm/s).

9.4.4 Freezing-and-thawing resistance—Freezing-and-thawing resistance of LD-CLSM is evaluated using Procedure B (rapid freezing and thawing) of ASTM C666/C666M, with a modified cycling protocol involving a longer thawing period. This modification is necessary because the insulating properties of LD-CLSM prevent rapid lowering and raising of temperatures at the interior of the specimen and prevent completion of a freezing-and-thawing cycle in the originally prescribed maximum 4-hour period. LD-CLSM intended for exterior exposure should have a relative dynamic modulus of elasticity (E) at least 70 percent of its original value after 120 cycles, when tested according to Procedure B of the modified ASTM C666/C666M. Because the freezing-and-thawing resistance of LD-CLSM increases with increasing density, LD-CLSM within 2 to 3 ft (0.6 to 1 m) of a surface subjected to freezing-and-thawing cycles while exposed to water should have a density of at least 36 lb/ft³ (575 kg/m³). MacDonald et al. (2004) provides an evaluation of the freezing and thawing performance and testing of LD-CLSM.

9.5—Proportioning

Mixture proportioning guidance is generally available from the foam concentrate manufacturers. The mixture proportion specifies the range of proportions of the ingredients needed to attain the desired physical properties (density and compressive strength). The user should test mixture proportions when nonstandard materials or special applications are involved.

### Table 9.4.2—Physical properties for geotechnical applications (ACI 523.1R-06, 3.11; Elastizell Corporation of America 2013)

<table>
<thead>
<tr>
<th>Maximum cast density, lb/ft³ (kg/m³)</th>
<th>Minimum compressive strength, psi (MPa)</th>
<th>Bearing capacity, ton/ft² (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 (385)</td>
<td>10 (0.07)</td>
<td>0.7 (0.07)</td>
</tr>
<tr>
<td>30 (480)</td>
<td>40 (0.28)</td>
<td>2.9 (0.28)</td>
</tr>
<tr>
<td>36 (575)</td>
<td>80 (0.55)</td>
<td>5.8 (0.56)</td>
</tr>
<tr>
<td>42 (675)</td>
<td>120 (0.83)</td>
<td>8.6 (0.82)</td>
</tr>
<tr>
<td>50 (800)</td>
<td>160 (1.10)</td>
<td>11.5 (1.10)</td>
</tr>
</tbody>
</table>

9.6—Construction

9.6.1 Batching—Materials for LD-CLSM are typically proportioned and batched on site directly into a specialized mixer. The cement, SCM, and other dry materials are weighed on a calibrated scale, and mixing water is metered. Preformed foam is metered into the mixture through a calibrated nozzle. The accuracy of each batching device is critical to the final mixture density and its subsequent reproducibility. Each batching device (scales, water meter, and foam-generating nozzle) should be calibrated before starting a project and during the project if necessary.

9.6.2 Mixing—Standard ready-mix equipment is normally not acceptable for LD-CLSM mixtures because the mixer does not combine ingredients with the correct speed and mixing action. A high-speed paddle mixer is preferable because it properly combines the ingredients and blends the preformed foam rapidly and efficiently to produce a uniformly consistent LD-CLSM mixture. Other mixers and processes that produce uniform mixtures include high-shear mixers and some continuous mixers.

In batch mixing, the mixer should be charged with mixture water and dry ingredients, followed by special admixtures and preformed foam. Acast density should be monitored at the point of placement every 30 to 60 minutes based on consistency of the density. Allowance should be made for any density changes that result from placing methods or conditions, such as pumping distances and extreme weather. Ingredients should be added in proper proportions and sequence during continuous mixing operations. This ensures reasonable uniformity and achieves the required as-cast density at the point of placement.

9.6.3 Placing—LD-CLSM should be placed by a progressive-cavity pump or a peristaltic pump. The pump hose should be large enough in diameter (usually 2 to 2-1/2 in. [51 to 64 mm]) to provide uniform delivery of LD-CLSM at the point of placement without damage to the structure or substrate. LD-CLSM can be pumped over 1500 ft (460 m), which is a major advantage over other materials and placing methods, and is important on large, congested projects with difficult access.

9.6.4 Forming and finishing—For geotechnical applications, lift thicknesses ranging from 2 to 4 ft (0.61 to 1.2 m) are typical. Lift thickness is job-specific and related to project layout and casting procedure. A greater lift thickness is acceptable for specific job conditions. The heat of hydration developed within the mass, material density, cement content, and the ambient temperature also influence lift thickness. Thinner castings reduce the heat buildup from cement hydra-
tion. It is desirable to cast material in a formed area within 1 or 2 hours to permit an undisturbed setting. In general, LD-CLSM should be cast to final grade with a tolerance of 0.1 ft (0.03 m). It is not necessary to scarify intermediate lift surfaces. A darby finish is acceptable for the final lift.

9.7—Quality control

9.7.1 Ingredient compatibility—Each ingredient that does not meet standard specifications for mixture compatibility should have their LD-CLSM physical properties checked in actual mixtures according to ASTM C796/C796M and ASTM C869/C869M. Cements may have significant strength variations within standard specification limits. Mill reports and test batches are useful for reviewing product differences between cement and SCM sources. Kearsley and Wainwright (2001b) demonstrate how to optimize SCM content for strength.

9.7.2 Sampling cast density—Measuring cast density at the point of placement is the simplest and most convenient test for monitoring the quality of the placed material. Cylinder specimens for compressive strength tests, usually measuring 3 x 6 in. (76 x 150 mm), should be cast at the same time that periodic density tests are performed. These samples should be covered and stored in a protected area for at least 24 hours before they are transported to the testing laboratory for testing in accordance with the applicable sections of ASTM C796/C796M.

9.7.3 Physical properties—For standard mixtures made from standard materials, cast density determines the physical properties of the LD-CLSM. It is not necessary to repeat the specialized tests of materials for each project. These specialized tests include permeability and freezing-and-thawing resistance; they may require up to 3 months to complete. Strength and density determinations are often sufficient. If unique applications or nonstandard materials are used, special tests may be required. A special test is one related to the performance of the material in the specialized application. Legatski (1994) provides a detailed review of testing the properties of LD-CLSM.

CHAPTER 10—REFERENCES

Committee documents are listed first by document number and year of publication followed by authored documents listed alphabetically.

American Concrete Institute

ACI 211.1-91—Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete (Reapproved 2009)
ACI 230.1R-09—Report on Soil Cement
ACI 232.2R-03—Use of Fly Ash in Concrete
ACI 304R-00—Guide for Measuring, Mixing, Transporting and Placing Concrete (Reapproved 2009)
ACI 304.6R-09—Guide for Use of Volumetric-Measuring and Continuous-Mixing Concrete Equipment
ACI 523.1R-06—Guide for Cast-in-Place Low Density Cellular Concrete

ASTM International

ASTM C33/C33M-13—Standard Specification for Concrete Aggregates
ASTM C94/C94M-12—Standard Specification for Ready-Mixed Concrete
ASTM C143/C143M-12—Standard Test Method for Slump of Hydraulic-Cement Concrete
ASTM C150/C150M-12—Standard Specification for Portland Cement
ASTM C403/C403M-08—Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
ASTM C494/C494M-12—Standard Specification for Chemical Admixtures for Concrete
ASTM C495/C495M-12—Standard Test Method for Compressive Strength of Lightweight Insulating Concrete
ASTM C513-11—Standard Test Method for Obtaining and Testing Specimens of Hardened Lightweight Insulating Concrete for Compressive Strength
ASTM C595/C595M-12—Standard Specification for Blended Hydraulic Cements
ASTM C618-12—Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
ASTM C666/C666M-03(2008)—Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
ASTM C796/C796M-12—Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam
ASTM C869/C869M-11—Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete
ASTM C939-10—Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)
ASTM C989/C989M-12—Standard Specification for Slag Cement for Use in Concrete and Mortars
ASTM D1556-07—Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
ASTM D2434-68(2006)—Standard Test Method for Permeability of Granular Soils (Constant Head)
ASTM D2922-01—Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)
ASTM D4380-12—Standard Test Method for Density of Bentonitic Slurries
ASTM D4429-09—Standard Test Method for CBR (California Bearing Ratio) of Soils in Place
ASTM D4832-10—Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders


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- Formal coordination with several international concrete related societies.

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As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level.

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The AMERICAN CONCRETE INSTITUTE

was founded in 1904 as a nonprofit membership organization dedicated to public service and representing the user interest in the field of concrete. ACI gathers and distributes information on the improvement of design, construction and maintenance of concrete products and structures. The work of ACI is conducted by individual ACI members and through volunteer committees composed of both members and non-members.

The committees, as well as ACI as a whole, operate under a consensus format, which assures all participants the right to have their views considered. Committee activities include the development of building codes and specifications; analysis of research and development results; presentation of construction and repair techniques; and education.

Individuals interested in the activities of ACI are encouraged to become a member. There are no educational or employment requirements. ACI’s membership is composed of engineers, architects, scientists, contractors, educators, and representatives from a variety of companies and organizations.

Members are encouraged to participate in committee activities that relate to their specific areas of interest. For more information, contact ACI.