

Controlled Low-Strength Materials

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Controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill in place of compacted fill. Many terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, flowable fly ash, fly ash slurry, plastic soil-cement, soil-cement slurry and other various names. This report contains information on applications, material properties, mix proportioning, construction, and quality-control procedures. The intent of this report is to provide basic information on CLSM technology, with emphasis on CLSM material characteristics and advantages over conventional compacted fill.

Keywords: aggregates; backfill; compacted fill; controlled density fill; controlled low-strength material; flowable fill; flowable mortar; fly ash; foundation stabilization; low-density material; pipe bedding; plastic soil-cement; preformed foam; soil-cement slurry; trench backfill; unshrinkable fill; void filling.

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CHAPTER 1—INTRODUCTION

Controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill as an alternative to compacted fill. Several terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, soil-cement slurry, and other various names.

Controlled low-strength materials are defined by ACI 116R as materials that result in a compressive strength of 8.3 MPa (1200 psi) or less. Most current CLSM applications require unconfined compressive strengths of 2.1 MPa (300 psi) or less. This lower-strength requirement is necessary to allow for future excavation of CLSM.

The term CLSM can be used to describe a family of mixtures for a variety of applications. For example, the upper limit of 8.3 MPa (1200 psi) allows use of this material for applications where future excavation is unlikely, such as structural fill under buildings. Chapter 8 of this report describes low-density (LD) CLSM produced using preformed foam as part of the mixture proportioning. The use of preformed foam in LD-CLSM mixtures allow these materials to be produced having unit weights lower than those of typical CLSM. The distinctive properties and mixing procedures for LD-CLSM are discussed in the chapter. Future CLSM mixtures can be developed as anticorrosion fills, thermal fills, and durable pavement bases.

CLSM should not be considered as a type of low-strength concrete, but rather a self-compacted backfill material that is used in place of compacted fill. Generally, CLSM mixtures are not designed to resist freezing and thawing, abrasive or erosive forces, or aggressive chemicals. Nonstandard materials can be used to produce CLSM as long as the materials have been tested and found to satisfy the intended application.

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

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

Although CLSM generally costs more per yd^3 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.^{1–3} Table 1 lists a number of advantages to using CLSM.⁴

CHAPTER 2—APPLICATIONS

2.1—General

As stated earlier, the primary application of CLSM is as a structural fill or backfill in lieu of compacted soil. Because CLSM needs no compaction and can be designed to be fluid, it is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. If future excavation is anticipated, the maximum long-term compressive strength should generally not exceed 2.1 MPa (300 psi). The following applications are intended to present a range of uses for CLSM.⁵

2.2—Backfills

CLSM can be readily placed into a trench, hole or other cavity (Fig. 2.1 and 2.2). Compaction is not required; hence, the trench width or size of excavation can be reduced. Granular or site-excavated backfill, even if compacted properly in the required layer thickness, can not achieve the uniformity and density of CLSM.⁵

When backfilling against retaining walls, consideration should be given to the lateral pressures exerted on the wall by flowable CLSM. Where the lateral fluid pressure is a concern, CLSM can be placed in layers, allowing each layer to harden prior to placing the next layer.

Following severe settlement problems of soil backfill in utility trenches, the city of Peoria, Ill., in 1988, tried CLSM as an alternative backfill material. The CLSM was placed in trenches up to 2.7 m (9 ft) deep. Although fluid at time of placement, the CLSM hardened to the extent that a person's weight could be supported within 2 to 3 hr. Very few shrinkage cracks were observed. Further tests were conducted on patching the overlying pavement within 3 to 4 hr. In one test, a pavement patch was successfully placed over a sewer trench

Table 1—Cited advantages of controlled low-strength materials⁴

Readily available	Using locally available materials, ready-mixed concrete suppliers can produce CLSM to meet most project specifications.
Easy to deliver	Truck mixers can deliver specified quantities of CLSM to job site whenever material is needed.
Easy to place	Depending on type and location of void to be filled, CLSM can be placed by chute, conveyor, pump, or bucket. Because CLSM is self-leveling, it needs little or no spreading or compacting. This speeds construction and reduces labor requirements.
Versatile	CLSM mixtures can be adjusted to meet specific fill requirements. Mixes 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.
Strong and durable	Load-carrying capacities of CLSM are typically higher than those of compacted soil or granular fill. CLSM is also less permeable, 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).
Allows fast return to traffic	Because many CLSMs can be placed quickly and support traffic loads within several hours, downtime for pavement repairs is minimal.
Will not settle	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 consolidated properly, may settle after a pavement patch is placed and forms cracks or dips in the road.
Reduces excavation costs	CLSM allows narrower trenches because it eliminates having to widen trenches to accommodate compaction equipment.
Improves worker safety	Workers can place CLSM in a trench without entering the trench, reducing their exposure to possible cave-ins.
Allows all-weather construction	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.
Can be excavated	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.
Requires less inspection	During placement, soil backfill must be tested after each lift for sufficient compaction. CLSM self-compacts consistently and does not need this extensive field testing.
Reduces equipment needs	Unlike soil or granular backfill, CLSM can be placed without loaders, rollers, or tampers.
Requires no storage	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.
Makes use of coal combustion product	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 product material.

immediately after backfilling with CLSM. As a result of these initial tests, the city of Peoria has changed its backfilling procedure to require the use of CLSM on all street openings.⁴

Some agencies backfill with a CLSM that has a setting time of 20 to 35 min. (after which time a person can walk on it). After approximately 1 hr, the wearing surface consisting of either a rapid-setting concrete or asphalt pavement is placed, resulting in a total traffic-bearing repair in about 4 hr.⁶

2.3—Structural fills

Depending upon the strength requirements, CLSM can be used for foundation support. Compressive strengths can vary from 0.7 to 8.3 MPa (100 to 1200 psi) depending upon application. In the case of weak soils, it can distribute the structure's load over a greater area. For uneven or nonuniform subgrades under foundation footings and slabs, CLSM can provide a uniform and level surface. Compressive strengths will vary depending upon project requirements. Because of its strength, CLSM may reduce the required thickness or strength requirements of the slab. Near Boone, Iowa, 2141 m³ (2800 yd³) of CLSM was used to provide proper bearing capacity for the footing of a grain elevator.⁷

2.4—Insulating and isolation fills

LD-CLSM material is generally used for these applications. Chapter 8 addresses LD-CLSM material using preformed foam.

2.5—Pavement bases

CLSM mixtures can be used for pavement bases, subbases, and subgrades. The mixture would be placed directly from the mixer onto the subgrade between existing curbs. For base course design under flexible pavements, structural coefficients differ depending upon the 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 be estimated to range from 0.16 to 0.28 for compressive strengths from 2.8 to 8.3 MPa (400 to 1200 psi).⁸

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 could 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. Further information regarding pavement base materials is found in ACI 325.3R.



Fig. 2.1—Using CLSM to backfill adjacent to building foundation wall.

2.6—Conduit bedding

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

The U.S. Bureau of Reclamation (USBR) began using CLSM in 1964 as a bedding material for 380 to 2400 mm (15 to 96 in.) diameter concrete pipe along the entire Canadian River Aqueduct Project, which stretches 518 km (322 miles) from Amarillo to Lubbock, Tex. Soil-cement slurry pipe bedding, as referred to by the USBR, was produced in central portable batching plants that were moved every 16 km (10 miles) along the route. Ready-mixed concrete trucks then delivered the soil-cement slurry to the placement site. The soil was obtained from local blow sand deposits. It was estimated that the soil-cement slurry reduced bedding costs 40%. Production increased from 120 to 300 m (400 to 1000 linear ft) of pipe placed per shift.⁹

CLSM can be designed to provide erosion resistance beneath the conduit. Since the mid-1970s, some county agencies in Iowa have been placing culverts on a CLSM bedding. This not only provides a solid, uniform pipe bedding, but prevents water from getting between the pipe and bedding, eroding the support.¹⁰

Encasing the entire conduit in CLSM also serves to protect the conduit from future damage. If the area around the conduit is being 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 also been used in mixtures to help identify the presence of CLSM.

2.7—Erosion control

Laboratory studies, as well as 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 0.52 m/sec (1.7 ft/sec), was superior to the other materials, both in the amount of material loss and suspended solids from the material.¹¹



Fig. 2.2—Backfilling utility cut with CLSM.

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 an erosion resistance under culverts, CLSM is used to fill voids under pavements, sidewalks, bridges and other structures where natural soil or noncohesive granular fill has eroded away.

2.8—Void filling

2.8.1 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 the material flowing and make it flow greater distances. CLSM was used to fill an abandoned tunnel that passed under the Menomonee River in downtown Milwaukee, Wis. The self-leveling material flowed over 71.6 m (235 ft). On another Milwaukee project, 635 m³ (831 yd³) were used to fill an abandoned sewer. The CLSM reportedly flowed up to 90 m (300 linear ft).¹²

Before constructing the Mount Baker Ridge Tunnel in Seattle, Wash., an exploratory shaft 37 m (120 ft) deep, 3.7 m (12 ft) in diameter with 9.1 m (30 ft) long branch tunnels was excavated. After exploration, the shaft had to be filled before

construction of the tunnel. Only 4 hr were needed to fill the shaft with 601 m³ (786 yd³) of CLSM.¹³

2.8.2 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, Ill., required the filling of an existing basement to accommodate expansion plans. Granular fill was considered, but access problems made CLSM a more attractive alternative. About 300 m³ (400 yd³) of material were poured in one day. A 200 mm (8 in.) concrete floor was then placed directly on top of the CLSM mixture.¹⁴

In Seattle, buses were to be routed off busy streets into a tunnel with pedestrian stations.¹³ The tunnel was built by a conventional method, but the stations had to be excavated from the surface to the station floor. After the station was built, there was a 19,000 m³ (25,000 yd³) void over each station to the street. So as not to disrupt traffic with construction equipment and materials, the voids were filled with CLSM, which required no layered placement or compaction.

CLSM has been used to fill abandoned underground storage tanks (USTs). Federal and State regulations have been developed that address closure requirements for underground fuel and chemical tanks. USTs taken out of service permanently must either be removed from the ground or filled with an inert solid material. The Iowa Department of Natural Resources has developed a guidance document for storage tank closures, which specifically mentions flowable fill.

2.8.3 Mines—Abandoned mines have been filled with CLSM to eliminate access, prevent subsidence, bottle up hazardous gases, cut off the 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 the spread and minimize the quantity of injection/placement points. The western U.S. alone contains approximately 250,000 abandoned mines with various hazards.¹⁵ CLSM can be used to fill mine voids completely, or in areas of particular concern, to prevent subsidence, block trespasser entry, and eliminate or reduce acid or other harmful drainage. Abandoned underground coal mines in the eastern U.S. have been filled using CLSM that was manufactured from various coal combustion products for this purpose.^{6,15-17}

2.9—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 radio-nuclide-stabilization requirements.¹⁸⁻²⁰

2.10—Bridge reclamation

CLSM has been used in several states as part of a cost-effective process for bridge rehabilitation. The process requires putting enough culverts under the bridge to handle

the hydrology requirements. A dam is placed over both ends of the culvert(s) and the culvert(s) are covered with fabric to keep the CLSM from flowing into the joints. These culvert(s) are set on granular backfill. The CLSM is then placed until it is 150 mm (6 in.) from the lower surface of the deck. A period of at least 72 hr is required before the CLSM is brought up to the bottom of the deck through holes cored in the deck. Later, the railing is removed and the deck is widened. The same procedure is then completed on the opposite side of the bridge. The work is done under traffic conditions. The camber of the roadway over the culvert(s) is the only clue that a bridge had ever been present. Iowa DOT officials estimate that the cost of four reclamations is equivalent to one replacement when this technology can be employed.^{10,21,22}

CHAPTER 3—MATERIALS

3.1—General

Conventional CLSM mixtures usually consist of water, portland cement, fly ash or other similar products, and fine or coarse aggregates or both. Some mixtures consist of water, portland cement, and fly ash only. Special low-density CLSM (LD-CLSM) mixtures, as described in Chapter 8 of this report, consist of portland cement, water, and preformed foam.

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

3.2—Cement

Cement provides the cohesion and strength for CLSM mixtures. For most applications, Type I or Type II portland cement conforming to ASTM C 150 is normally used. Other types of cement, including blended cements conforming to ASTM C 595, can be used if prior testing indicates acceptable results.

3.3—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 with high aggregate contents. Fly ashes used in CLSM mixtures do not need to conform to either Class F or C as described in ASTM C 618. Trial mixtures should be prepared to determine whether the mixture will meet the specified requirements. Refer to ACI 232.2R for further information.^{23,24}

3.4—Admixtures

Air-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 CLSM's thermal insulation and freeze-thaw properties. Water content can be

reduced as much as 50% when using air-entraining admixtures. The use of these materials may require modifications to typical CLSM mixtures. To prevent segregation when utilizing high air contents, the 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 the use of an accelerating admixture may be required. In all cases, pretesting should be performed to determine acceptability.^{6,25,26}

3.5—Other additives

In specialized applications such as waste stabilization, CLSM mixtures can be formulated to include chemical and/or mineral additives that serve purposes beyond that of simple backfilling. Some examples include the use of 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.¹⁸⁻²⁰

3.6—Water

Water that is acceptable for concrete mixtures is acceptable for CLSM mixtures. ASTM C 94 provides additional information on water-quality requirements.

3.7—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 C 33 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 materials, and should be considered. Variations of the physical properties of the mixture components, however, will have a significant effect on the mixture's performance. Silty sands with up to 20% fines passing through a 75 µm (No. 200) sieve have proven satisfactory. Also, soils with wide variations in grading have shown to be effective. Soils with clay fines, however, have exhibited problems with incomplete mixing, stickiness of the mixtures, excess water demand, shrinkage, and variable strength. These types of soils are not usually considered for CLSM applications. Aggregates that have been used successfully include:²⁷

- ASTM C 33 specification aggregates within specified gradations;
- Pea gravel with sand;
- 19 mm (3/4 in.) minus aggregate with sand;
- Native sandy soils, with more than 10% passing a 75 µm (No. 200) sieve;
- Quarry waste products, generally 10 mm (3/8 in.) minus aggregates.

3.8—Nonstandard materials

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

Examples of nonstandard materials that can be substituted as aggregates for CLSM include various coal combustion products, discarded foundry sand, glass cullet, and reclaimed crushed concrete.²⁸⁻³⁰

Aggregates or mixtures that might swell in service due to expansive reactions or other mechanisms should be avoided. Also, wood chips, wood ash, or other organic materials may not be suitable for CLSM. Fly ashes with carbon contents up to 22% have been successfully used for CLSM.³¹

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

3.9—Ponded ash or basin ash

Ponded ash, typically a mixture of fly ash and bottom ash slurried into a storage/disposal basin, can also be used in CLSM. The 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 prior to 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.¹⁸⁻²⁰

CHAPTER 4—PROPERTIES

4.1—Introduction

The properties of CLSM cross the boundaries between soils and concrete. CLSM is manufactured from materials similar to those used to produce concrete, and is placed from equipment in a fashion similar to that of concrete. In-service CLSM, however, exhibits characteristic properties of soils. The properties of CLSM are affected by the constituents of the mixture and the proportions of the ingredients in the mixture. Because of the many factors that can affect CLSM, a wide range of values may exist for the various properties discussed in following sections.³²

4.2—Plastic properties

4.2.1 Flowability—Flowability is the property that distinguishes CLSM from other fill materials. It enables the materials to be self-leveling; to flow into and readily fill a void; and be self-compacting without the need for conventional placing and compacting equipment. This property represents a major advantage of CLSM compared with conventional fill materials that must be mechanically placed and compacted. Because plastic CLSM is similar to plastic 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 in the case of limited-strength forms that are 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 upon requirements. Methods of expressing flowability include the use of a 75 x 150 mm (3 x 6 in.) open-ended cylinder modified flow test (ASTM D 6103), the standard concrete slump cone (ASTM C 143), and flow cone (ASTM C 939).

Good flowability, using the ASTM D 6103 method, is achieved where there is no noticeable segregation and the CLSM material spread is at least 200 mm (8 in.) in diameter. Flowability ranges associated with the slump cone can be expressed as follows:³³

- Low flowability: less than 150 mm (6 in.);
- Normal flowability: 150 to 200 mm (6 to 8 in.);
- High flowability: greater than 200 mm (8 in.).

ASTM C 939, for determining flow of grout, has been used successfully with fluid mixtures containing aggregates not greater than 6 mm (1/4 in.) The method is briefly described in Chapter 7 on Quality Control. The Florida and Indiana Departments of Transportation (DOT) require an efflux time of 30 ± 5 sec, as measured by this method.

4.2.2 Segregation—Separation of constituents in the mixture can occur at high levels of flowability when the flowability is primarily produced by the addition of 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 cohesiveness. Fly ash generally accounts for these fines, although silty or other noncohesive fines up to 20% of total aggregate have been used. The use of plastic fines, such as clay, should be avoided because they can produce deleterious results, such as increased shrinkage. In flowable mixtures, satisfactory performance of CLSM has been obtained with Class F fly ash contents as high as 415 kg/m³ (700 lb/yd³) in combination with cement, sand, and water. Some CLSM mixtures have been designed without sand or gravel, using only fly ash as filler material. These mixtures require much higher water content, but produce no noticeable segregation.

4.2.3 Subsidence—Subsidence deals with the reduction in volume of CLSM as it releases its water and entrapped air through consolidation of the mixture. 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 of the subsidence occurs during placement and the degree of subsidence is dependent upon the quantity of free water released. Typically, subsidence of 3 to 6 mm (1/8 to 1/4 in.) per ft of depth has been reported.³⁴ This amount is generally found with mixtures of high water content. Mixtures of lower water content undergo little or no subsidence, and cylinder specimens taken for strength evaluation exhibited no measurable change in height from the time of filling the cylinders to the time of testing.

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

Normal factors affecting the hardening time are:

- Type and quantity of cementitious material;
- Permeability and degree of saturation of surrounding soil that is in contact with CLSM;
- Moisture content of CLSM;
- Proportioning of CLSM;
- Mixture and ambient temperature;
- Humidity; and
- Depth of fill.

Hardening time can be as short as 1 hr, but generally takes 3 to 5 hr under normal conditions.^{4,25,34} A penetration-resistance test according to ASTM C 403 can be used to measure the hardening time or approximate bearing capacity of CLSM. Depending upon the application, penetration numbers of 500 to 1500 are normally required to assure adequate bearing capacity.³⁵

4.2.5 Pumping—CLSM can be successfully delivered by conventional concrete pumping equipment. As with concrete, proportioning of the mixture is critical. Voids must be adequately filled with solid particles to provide adequate cohesiveness for transport through the pump line under pressure without segregation. Inadequate void filling results in mixtures that can segregate in the pump and cause line blockage. Also, it is important to maintain a continuous flow through the pump line. Interrupted flow can cause segregation, which also could restrict flow and could result in line blockage.

In one example, CLSM using unwashed aggregate with a high fines content was pumped through a 127 mm (5 in.) pump system at a rate of 46 m³/hr (60 yd³/hr).³⁶ In another example, CLSM with a slump as low as 51 mm (2 in.) was successfully delivered by concrete pump without the need for added consolidation effort.³⁷

CLSM with high entrained-air contents can be pumped, although care should be taken to keep pump pressures low. Increased pump pressures can cause a loss in air content and reduce pumpability.

Pumpability can be enhanced by careful proportioning to provide adequate void filling in the mixture. Fly ash can aid pumpability by acting as microaggregate for void filling. Cement can also be added for this purpose. Whenever cementitious materials are added, however, care must be taken to limit the maximum strength levels if later excavation is a consideration.

4.3—In-service properties

4.3.1 Strength (bearing capacity)—Unconfined compressive strength is a measure of the load-carrying ability of CLSM. A CLSM compressive strength of 0.3 to 0.7 MPa (50



Fig. 4.1—Excavating CLSM with backhoe.

to 100 psi) equates to an allowable bearing capacity of a well-compacted soil.

Maintaining strengths at a low level 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 4.3.7 provides additional information on excavatability.

4.3.2 Density—Wet density of normal CLSM in place is in the range of 1840 to 2320 kg/m³ (115 to 145 lb/ft³), which is greater than most compacted materials. A CLSM mixture with only fly ash, cement, and water should have a density between 1440 to 1600 kg/m³ (90 to 100 lb/ft³).¹² Ponded ash or basin ash CLSM mixture densities are typically in the range of 1360 to 1760 kg/m³ (85 to 110 lb/ft³).¹⁹ Dry density of CLSM can be expected to be substantially less than that of the 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 8.

4.3.3 Settlement—Compacted fills can settle even when 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.¹³ For a project in Seattle, Wash., 601 m³ (786 yd³) were used to fill a 37 m (120 ft) deep shaft. The placement took 4 hr and the total settlement was reported to be about 3 mm (1/8 in.).³⁷

4.3.4 Thermal insulation/conductivity—Conventional CLSM mixtures are not considered good insulating materials. Air-entrained conventional mixtures reduce the density and increase the insulating value. Lightweight aggregates, including bottom ash, can be used to reduce density. Foamed or cellular mixtures as described in Chapter 8 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 (maximum surface contact area between solid particles) are desirable. As the moisture content and dry density increase, so does the thermal conductivity. Other parameters to consider (but of lesser importance) include mineral com-

position, particle shape and size, gradation characteristics, organic content and specific gravity.^{31,38-40}

4.3.5 Permeability—Permeability of most excavatable CLSM is similar to compacted granular fills. Typical values are in the range of 10⁻⁴ to 10⁻⁵ cm/sec. Mixtures of CLSM with higher strength and higher fines-content can achieve permeabilities as low as 10⁻⁷ cm/sec. Permeability is increased as cementitious materials are reduced and aggregate contents are increased.⁴ However, materials normally used for reducing permeability, such as bentonite clay and diatomaceous soil, can affect other properties and should be tested prior to use.

4.3.6 Shrinkage (cracking)—Shrinkage and shrinkage cracks do not affect the performance of CLSM. Several reports have indicated that minute shrinkage occurs with CLSM. Ultimate linear shrinkage is in the range of 0.02 to 0.05%.^{12,27,34}

4.3.7 Excavatability—The ability to excavate CLSM is an important consideration on many projects. In general, CLSM with a compressive strength of 0.3 MPa (50 psi) or less can be excavated manually. Mechanical equipment, such as backhoes, are used for compressive strengths of 0.7 to 1.4 MPa (100 to 200 psi) (Fig. 4.1). The limits for excavatability are somewhat arbitrary, depending upon the CLSM mixture. Mixtures using high quantities of coarse aggregate can be difficult to remove by hand, even at low strengths. Mixtures using fine sand or only fly ash as the aggregate filler have been excavated with a backhoe up to strengths of 2.1 MPa (300 psi).¹¹

When the re-excavatability of the CLSM is of concern, the type and quantity of cementitious materials is important. Acceptable long-term performance has been achieved with cement contents from 24 to 59 kg/m³ (40 to 100 lb/yd³) and Class F fly ash contents up to 208 kg/m³ (350 lb/yd³). Lime (CaO) contents of fly ash that exceed 10% by weight can be a concern where long-term strength increases are not desired.²⁷

Because CLSM will typically continue to gain strength beyond the conventional 28-day testing period, it is suggested, especially for high cementitious-content CLSM, that long-term strength tests be conducted to estimate the potential for re-excavatability.

In addition to limiting the cementitious content, entrained air can be used to keep compressive strengths low.

4.3.8 Shear modulus—The shear modulus, which is the ratio of unit shearing stress to unit shearing strain, of normal density CLSM is typically in the range of 160 to 380 MPa (3400 to 7900 ksf).^{7,18,20} The shear modulus is used to evaluate the expected shear strength and deformation of CLSM material.

4.3.9 Potential for corrosion—The potential for corrosion on metals encased in CLSM has been quantified by a variety of methods specific to the material that is 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 (California Test 643). The moisture content of the sample is an important parameter for the resistivity of a sample, and the samples should be tested at their expected long-term field moisture content.

The Ductile Iron Pipe Research Association has a method for evaluating the corrosion potential of backfill materials. The evaluation procedure is based upon 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.⁴¹⁻⁴³

These procedures are intended as guides in 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.

One cause of galvanic corrosion is the differences in potential from backfill soils of varying composition. The uniformity of CLSM reduces the chance for corrosion caused by the use of dissimilar backfill materials and their varying moisture contents.

4.3.10 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.³¹

CHAPTER 5—MIXTURE PROPORTIONING

Proportioning for CLSM has been done largely by trial and error until mixtures with suitable properties are achieved. Most specifications require proportioning of ingredients; some specifications call for performance features and leave proportioning up to the supplier. ACI 211 has been used; however, much work remains to be done in establishing consistent reliability when using this method.³⁷

Where proportions are not specified, trial mixtures are evaluated to determine how well they meet certain goals for strength, flowability, and density. Adjustments are then made to achieve the desired properties.

Table 5.1 presents a number of mixture proportions that have been used by state DOTs and others; however, requirements and available materials can vary considerably from project to project. Therefore, the information in Table 5.1 is provided as a guide and should not be used for design purposes without first testing with locally available materials.

The following summary can be made regarding the materials used to manufacture CLSM:

Cement—Cement contents generally range from 30 to 120 kg/m³ (50 to 200 lb/yd³), depending upon strength and hardening-time requirements. Increasing cement content while maintaining all other factors equal (that is, water, fly ash, aggregate, and ambient temperature) will normally increase strength and reduce hardening time.

Fly ash—Class F fly ash contents range from none to as high as 1200 kg/m³ (2000 lb/yd³) where fly ash serves as the aggregate filler. Class C fly ash is used in quantities of up to 210 kg/m³ (350 lb/yd³). The quantity of fly ash used will be determined by availability and flowability needs of the project.

Ponded ash/basin ash—Ponded ash/basin ash contents range from 300 to 500 kg/m³ (500 to 950 lb/yd³), depending upon the fineness of ash.¹⁸⁻²⁰

Aggregate—The majority of specifications call for the use of fine aggregate. The amount of fine aggregate varies with the quantity needed to fill the volume of the CLSM after considering cement, fly ash, water, and air contents. In general, the quantities range from 1500 to 1800 kg/m³ (2600 to 3100 lb/yd³). Coarse aggregate is generally not used in CLSM mixtures as often as fine aggregates. When used, however, the coarse aggregate content is approximately equal to the fine aggregate content.

Water—More water is used in CLSM than in concrete. Water provides high fluidity and promotes consolidation of the materials. Water contents typically range from 193 to 344 kg/m³ (325 to 580 lb/yd³) for most CLSM mixtures containing aggregate. Water content for Class F fly ash and cement-only mixtures can be as high as 590 kg/m³ (1000 lb/yd³) to achieve good flowability. This wide range is due primarily to the characteristics of the materials used in CLSM and the degree of flowability desired. Water contents will be higher with mixtures using finer aggregates.

Admixtures—High doses of air-entraining admixtures and specifically formulated or packaged air-entraining admixtures, or both, can be used to lower the density or unit weight of CLSM. Accelerating admixtures can be used to accelerate the hardening of CLSM. When these products are used, the manufacturer's recommendations for use with CLSM should be followed.

Other additives—Additives such as zeolites, heavy minerals, and clays can be added to typical CLSM mixes in the range of 2 to 10% of the total mixture. Fly ash and cement can be adjusted accordingly while maintaining all other factors.¹⁸⁻²⁰

CHAPTER 6—MIXING, TRANSPORTING, AND PLACING

6.1—General

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

6.2—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.

Truck mixers are commonly used by ready-mixed concrete producers to mix CLSM; however, 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.

Table 5.1—Examples of CLSM mixture proportions*

Source	CO DOT	IA DOT	FL DOT	IL DOT	IN DOT		OK DOT	MI DOT		OH DOT	
					Mix 1	Mix 2 ⁴		Mix 1	Mix 2 ⁴	Mix 1	Mix 2
Cement content, kg/m ³	30 (50)	60 (100)	30 to 60 (50 to 100)	30 (50)	36 (60)	110 (185)	30 (50) min	60 (100)	30 (50)	60 (100)	30 (50)
Fly ash, kg/m ³ (lb/yd ³)	—	178 (300)	0 to 356 (0 to 600) ²	178 (300) Class F or 119 (200) Class C	196 (330)	—	148 (250)	1187 (2000) Class F	326 (550) Class F	148 (250)	148 (250)
Coarse aggregate, kg/m ³ (lb/yd ³)	1010 (1700) ¹	—	—	—	—	—	—	—	Footnote no. 5	—	—
Fine aggregate, kg/m ³ (lb/yd ³)	1096 (1845)	1543 (2600)	1632 (2750) ³	1720 (2900)	1697 (2860)	1587 (2675)	1727 (2910)	—	Footnote no. 5	1691 (2850)	1727 (2910)
Approximate water content, kg/m ³ (lb/yd ³)	193 (325)	347 (585)	297 (500) maximum	222 to 320 (375 to 540)	303 (510)	297 (500)	297 (500) maximum	395 (665)	196 (330)	297 (500)	297 (500)
Compressive strength at 28 days, MPa (psi)	0.4 (60)	—	0.3 to 1.0 (50 to 150)	—	—	—	—	—	—	—	—

Table 5.1(continued)—Examples of CLSM mixture proportions*

Source	SC DOT	DOE-SR ¹⁶	Unshrinkable fill ⁶	Pond ash/basin ash mix ¹⁷		Coarse aggregate CLSM ⁸		Flowable fly ash slurry ¹²		
				Mix AF	Mix D	Non-air entrainment ⁹	Air entrainment ¹¹	Mix S-2 ¹³	Mix S-3 ¹⁴	Mix S-4 ¹⁵
Cement content, kg/m ³	30 (50)	30 (50)	36 (60)	98 (165)	60 (100)	30 (50)	30 (50)	58 (98)	94 (158)	85 (144)
Fly ash, kg/m ³ (lb/yd ³)	356 (600) Class F	—	—	481 (810) ¹⁸	326 (550) ¹⁹	148 (250)	148 (250)	810 (1366) Class F	749 (1262) Class F	685 (1155) Class F
Coarse aggregate, kg/m ³ (lb/yd ³)	—	—	1012 (1705) (3/4-in. maximum)	1300 (2190)	1492 (2515)	1127 (1900) (1-in. maximum)	1127 (1900) (1-in. maximum)	—	—	—
Fine aggregate, kg/m ³ (lb/yd ³)	1483 (2500)	1492 (2515)	1173 (1977)	—	—	863 (1454)	795 (1340)	—	—	—
Approximate water content, kg/m ³ (lb/yd ³)	273 to 320 (460 to 540)	397 to 326 (500 to 550)	152 (257) ⁷	415 (700)	301 (507)	160 (270) ¹⁰	151 (255) ¹⁰	634 (1068)	624 (1052)	680 (1146)
Compressive strength at 28 days, MPa (psi)	0.6 (80)	0.2 to 1.0 (30 to 150)	0.1 (17) at 1 day	0.4 (65)	0.4 (65)	0.7 (100)	—	0.3 (40) (40 at 56 days)	0.4 (60) [0.5 (75) at 56 days]	0.3 (50) [0.5 (70) at 56 days]

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

¹Quantity of cement can be increased above these limits only when early strength is required and future removal is unlikely.

²Granulated blast-furnace slag can be used in place of fly ash.

³Adjust to yield 1 yd³ of CLSM.

⁴5 to 6 fl oz of air-entraining admixture produces 7 to 12% air contents.

⁵Total granular material of 1690 kg/m³ (2850 lb/yd³) with 19 mm (3/4 in.) maximum aggregate size.

⁶Reference 44.

⁷Produces 150 mm (6 in.) slump.

⁸Reference 37.

⁹Produces approximately 1.5% air content.

¹⁰Produces 150 to 200 mm (6 to 8 in.) slump.

¹¹Produces 5% air content.

¹²Reference 6.

¹³Produces modified flow of 210 mm (8-1/4 in.) diameter (Table 7.1); air content of 0.8%; slurry density of 1500 kg/m³ (93.7 lb/ft³).

¹⁴Produces modified flow of 270 mm (10-1/2 in.) diameter; air content of 1.1%; slurry density of 1470 kg/m³ (91.5 lb/ft³).

¹⁵Produces modified flow of 430 mm (16-3/4 in.) diameter; air content of 0.6%; slurry density of 1450 kg/m³ (90.6 lb/ft³).

¹⁶Department of Energy (DOE) Savannah River Site CLSM mix.

¹⁷DOE Savannah River Site CLSM mix using pond/basin ash.

¹⁸Basin ash mix.

¹⁹Pond ash mix.

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

- Add 70 to 80% of water required.
- Add 50% of the aggregate filler.
- Add all cement and fly ash required.
- Add balance of aggregate filler.
- 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, the fly ash is added. Additional mixing for a minimum of 15 min was required in one case to produce a homogeneous slurry.¹²

Pugmill mixing works efficiently for both high and low fly ash mixtures and other high fines-content mixtures. For high fly ash mixtures, the 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. The measurement for payment of CLSM mixed through a pugmill is generally based on weight rather than volume, which is typically used for concrete.

6.3—Transporting

Most CLSM mixtures are transported in truck mixers. Agitation 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. Agitator trucks, 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 types of conveying equipment. In pumping CLSM, the fly ash serves as a lubricant to reduce the friction in the pipeline. However, the fine texture of the fly ash requires that the pump be in excellent condition and properly cleaned and maintained.

CLSM has also been 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. VMCMs are equipped with 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.

6.4—Placing

CLSM can be placed by chutes, conveyors, buckets, or pumps, depending upon the application and its accessibility. Internal vibration or compaction is not required because the CLSM consolidates under its own weight. Although it can be placed year round, CLSM should be protected from freezing until it has hardened. Curing methods specified for concrete are not considered essential for CLSM.²⁷

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 mixtures of CLSM.

For pipe bedding, CLSM can be placed in lifts to prevent floating the pipe. Each lift should be allowed to harden before continued placement. Other methods of preventing flotation include sand bags placed over the pipe, straps around the pipe anchored into the soil, or use of 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 can develop along the side of the pipe before fresh CLSM is placed over

the pipe.⁴ Backfilling retaining walls can also require the CLSM be placed in lifts to prevent overstressing the wall.

CLSM has been effectively placed by tremie under water¹¹ without significant segregation. In confined areas, the CLSM displaces the water to the surface where it can easily be removed. Because of its very fluid consistency, CLSM 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 in irregularities and encapsulate any loose materials.

6.5—Cautions

6.5.1 Hydrostatic pressure—CLSM is often placed in a practically liquid condition and thus will exert a hydrostatic pressure against basement walls and other structures until it hardens. On deep fills, it is often necessary to place the CLSM in multiple lifts.

6.5.2 Quick condition—Liquid CLSM in deep excavations is essentially a quick-sand hazard and therefore should be covered until hardening occurs.

6.5.3 Floating tanks, pipes, and cables—Underground utilities and tanks must be secured against floating during CLSM placement.⁴⁵

CHAPTER 7—QUALITY CONTROL

7.1—General

The extent of a quality-control (QC) program for CLSM can vary depending upon previous experience, application, raw materials used, and level of quality desired. A QC program can be as simple as a visual check of the completed work where standard, pretested mixtures are being used. Where the application is critical, the 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 the 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.

As stated above, 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 will be adequate for its intended use. The following procedures and test methods have been used to evaluate CLSM mixtures.

7.2 Sampling

Sampling CLSM that has been delivered to the project site should be performed in accordance with ASTM D 5971.

7.3—Consistency and unit weight

Depending upon 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 proper-

Table 7.1—Test procedures for determining consistency and unit weight of CLSM mixtures

Consistency	
Fluid mixtures	
ASTM D 6103	"Standard Test Method for Flow Consistency of Controlled Low Strength Material." Procedure consists of placing 75 mm diameter x 150 mm long (3 in. diameter x 6 in. 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 200 mm (8 in.) in diameter.
ASTM C 939	"Flow of Grout for Preplaced-Aggregate Concrete." Florida Department of Transportation and Indiana Department of Transportation specifications require efflux time of 30 sec \pm 5 sec. Procedure is not recommended for CLSM mixtures containing aggregates greater than 6 mm (1/4 in.).
Plastic mixtures	
ASTM C 143	"Slump of Portland Cement Concrete."
Unit weight	
ASTM D 6023	"Standard Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Controlled Low Strength Material." Ohio Ready Mixed Concrete Association has similar test method [FF3(94)].
ASTM C 1152	"Acid Soluble Chloride in Mortar and Concrete."
ASTM D 4380	"Density of Bentonitic Slurries." Not recommended for CLSM containing aggregate greater than 1/4 in.
ASTM D 1556	"Density of Soil In-Place by Sand-Cone Method."
ASTM D 2922	"Density of Soil and Soil Aggregate In-Place by Nuclear Method (Shallow Depth)."

Table 7.2—Test procedures for determining in-place density and strength of CLSM mixtures

ASTM D 6024	"Standard Test Method for Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application." This specification covers determination of ability of CLSM to withstand loading by repeatedly dropping metal weight onto in-place material.
ASTM C 403	"Time of Setting of Concrete Mixtures by Penetration Resistance." This test measures degree of hardness of CLSM. California Department of Transportation requires penetration number of 650 before allowing pavement surface to be placed.
ASTM D 4832	"Preparation and Testing of Soil-Cement Slurry Test Cylinders." This test is used for molding cylinders and determining compressive strength of hardened CLSM.
ASTM D 1196	"Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements." This test is used to determine modulus of subgrade reaction (K values).
ASTM D 4429	"Bearing Ratio of Soils in Place." This test is used to determine relative strength of CLSM in place.

ties. Table 7.1 describes methods that can be used to measure consistency and unit weight.

7.4—Strength tests

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

The strength of CLSM can be measured by several methods (Table 7.2). 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 can vary in size from 50 x 50 mm (2 x 2 in.) cubes to 150 x 300 mm (6 x 12 in.) cylinders. Special care may be needed removing very low-strength CLSM mixtures from test molds. Additional care in the handling, transporting, capping, and testing procedures shall be taken because the specimens are often very fragile. Mold stripping techniques

have included: placement of a hole on the center of the bottom of standard watertight cylinder molds by drilling or use of a hot probe, and addition of a dry polyester fleece pad on the inside bottom of the cylinder; for easy release of the specimen with or without air compression, splitting of the molds with a hot knife, and presplitting the molds and reattachment with duct tape for easy removal later. The use of grout molds has also been employed for testing CLSM. In this method, four 150 x 150 x 200 mm (6 x 6 x 8 in.) high concrete masonry units are arranged to provide a nominal 100 mm (4 in.) square space in the center. The four sides and bottom of the inside of the molds are lined with blotting paper to serve as a bond breaker for easy removal.

CHAPTER 8—LOW-DENSITY CLSM USING PREFORMED FOAM

8.1—General

This chapter is limited to low-density CLSM mixtures (LD-CLSM) produced using preformed foam as part of the mixture proportioning. Preformed foam is made up of air cells generated from foam concentrates or gas-forming

chemicals. The use of preformed foam in LD-CLSM mixtures allows mixture proportionings to be developed having lower unit weights than those typical of standard CLSM mixtures. Preformed foam is used in LD-CLSM proportions to attain stable air void or cell structures within the paste of the mix. LD-CLSM mixtures can be batched at ready-mix plants or in specially designed job site batch plants. The preformed foam can be added to LD-CLSM mixtures during batching at the ready-mix plant, into the mixers of transit-mix trucks at the job site, or directly into the mixer during the batching operations of specially designed job site batch plants.

8.2—Applications

LD-CLSM mixtures can be alternatively considered in situations where standard CLSM mixtures have been determined applicable. LD-CLSMs are typically designed by unit weight. The ability to proportion mixtures having low unit weights is especially advantageous where weak soil conditions are encountered and the weight of the fill must be minimized. LD-CLSM is also effective as an insulating and isolation fill. The air void or cell structure inherent in LD-CLSM mixtures provides thermal insulation and can add some shock mitigation properties to the fill material.

8.3—Materials

Portland cement is a typical binder component used to produce most LD-CLSM mixtures. Neat cement paste LD-CLSMs can be produced by adding preformed foam to the paste during mixing. The encapsulated air within the preformed foam is often the primary volume-producing component in the LD-CLSM mixtures. LD-CLSMs can also be designed to include mineral fillers such as fly ash or sand. When considering the use of nonstandard binders or mineral filler materials in LD-CLSM mixture proportioning, pretesting is recommended.

Generally all preformed foams are pregenerated by the use of devices known as foam generators. These foam-generating devices, however, can be configured specifically to be used with a particular foaming agent. The manufacturer of the foaming agent to be used should be consulted to obtain specific foam-generating recommendations.

Foaming agents used to produce the preformed foam must have a chemical composition capable of producing stable air cells that resist the physical and chemical forces imposed during the mixing, placing, and setting of the LD-CLSM mixture. If the air void or cellular structure within the mixture is not stable, a nonuniform increase in density will result. Procedures for the evaluation of foaming agents are specified in ASTM C 796 and ASTM C 869. Additional information can be found in ACI 523.1R.

8.4—Properties

The properties of LD-CLSM are primarily density-related. When batched using standard component materials, LD-CLSM can be produced having properties that fall within ranges described by the manufacturer of the foaming agent. When nonstandard component materials are used, trial

Table 8.1—Typical strength properties of low-density CLSM based on density

Class	In-service density, kg/m ³ (lb/ft ³)	Minimum compressive strength, MPa (psi)
I	290 to 380 (18 to 24)	0.1 (10)
II	380 to 480 (24 to 30)	0.3 (40)
III	480 to 580 (30 to 36)	0.6 (80)
IV	580 to 670 (36 to 42)	0.8 (120)
V	670 to 800 (42 to 50)	1.1 (160)
VI	800 to 1300 (50 to 80)	2.2 (320)
VII	1300 to 1900 (80 to 120)	3.4 (500)

batches should be produced and tested to confirm theoretical predictions.

The most significant property of LD-CLSM is the in-service density. Table 8.1 divides the in-service density into convenient ranges relating density with typical minimum compressive-strength values. Classes VI and VII may be subdivided into smaller ranges for specific applications.

8.5—Proportioning

Mixture proportioning of LD-CLSM typically begins with the designation of the desired in-place dry density and minimum compressive strength. Within these parameters, the mixture constituents are designed on a rational basis. Basic LD-CLSM mixtures consist of portland cement as a binder, water, and preformed foam. In addition to this base proportioning, fly ash can be included as a pozzolan or a densifying mineral filler. Sand aggregate is also often used to achieve density in mixture proportionings having unit weights more than 800 kg/m³ (50 lb/ft³). The manufacturer of the foam concentrate is generally responsible for the mixture proportioning, which is based on desired physical properties (density, compressive strength, etc.) of the in-place material.

8.6—Construction

8.6.1 Batching—The batching sequence used to produce most LD-CLSM mixtures begins by metering the required water into a mechanical mixer. The portland cement binder, fly ash, or aggregates (if used) are individually weighed before entering the mixer. After the components are mixed to a uniform consistency, the required amount of preformed foam is added. The preformed foam is measured into the mixture through calibrated nozzle or by filling and weighing a mixing vessel of known volume. The accuracy of the foam-generating device and the batching apparatus is critical to the final mixture's density and its subsequent reproducibility.

8.6.2 Mixing—All LD-CLSM component materials should be mechanically mixed to a uniform consistency prior to the addition of the preformed foam. To properly combine the mixture ingredients (including the foam) sufficient mixing action and speeds are required. When producing neat cement or cement/fly ash pastes for LD-CLSM mixtures, mixers that provide vigorous mixing action, such as high-speed paddle mixers, are preferred. Truck mixers readily blend LD-CLSM mixtures to the consistency required for the addition of preformed foam. When truck mixers are used to produce neat

cement or cement/fly paste mixtures, slightly longer mixing times are required. Other mixing processes, such as volumetric mixing, that produce uniformly consistent mixtures are also acceptable. The manufacturer of the foaming agent to be used should be consulted for specific recommendations on mixing procedures and approved mixing equipment.

8.6.3 Placing—LD-CLSM can be placed by chutes, buckets, or pumps. The method of placement must not cause a change in density by loss of air content beyond predictable ranges. Often, site-produced LD-CLSMs are delivered to the point of placement through pumplines. Progressing cavity pumps can be used, which provide nonpulsating and constant flow, minimizing air volume losses between the mixer and the point of deposit. By this method, LD-CLSMs can be pumped over 300 m (1000 ft).

CONVERSION FACTORS

1 ft	=	0.305 m
1 in.	=	25.4 mm
1 lb	=	0.454 kg
1 yd ³	=	0.7646 m ³
1 psi	=	6.895 kPa
1 lb/ft ³	=	16.02 kg/m ³
1 lb/yd ³	=	0.5933 kg/m ³
1 ft/sec	=	0.305 m/sec

CHAPTER 9—REFERENCES

9.1—Specified references

The documents of the various standard-producing organizations referred to in this document are listed below with their serial designation.

American Concrete Institute

- 116R Cement and Concrete Terminology
- 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete
- 230.1R State-of-the-Art Report on Soil Cement
- 232.2R Use of Fly Ash in Concrete
- 304.6R Guide for Measuring, Mixing, Transporting and Placing Concrete
- 325.3R Guide for Design of Foundations and Shoulders for Concrete Pavements
- 523.1R Guide for Cast-in-Place Low Density Concrete

American Society for Testing and Materials (ASTM)

- C 33 Specification for Concrete Aggregates
- C 94 Specifications for Ready-Mixed Concrete
- C 138 Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Concrete
- C 143 Test Method for Slump of Hydraulic Cement Concrete
- C 150 Specification for Portland Cement
- C 403 Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
- C 595 Specification for Blended Hydraulic Cements
- C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
- C 796 Test Method of Testing Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam

- C 869 Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete
- C 939 Test Method for Flow of Grout for Preplaced-Aggregate Concrete
- C 1152 Acid-Soluble Chloride in Mortar and Concrete
- C 1556 Density of Soil in-place by Sand-cone Method
- C 2922 Density of Soil and Soil Aggregate in-place by Nuclear Method (Shallow Depth)
- D 1196 Test Methods for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements
- D 4380 Test Method for Density of Bentonitic Slurries
- D 4429 Test Method for Bearing Ratio of Soils in Place
- D 4832 Test Method for Preparation and Testing of Soil-Cement Slurry Test Cylinders
- D 5971 Practice for Sampling Freshly Mixed Controlled Low Strength Material
- D 6023 Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Controlled Low Strength Material
- D 6024 Test Method of Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application
- D 6103 Test Method for Flow Consistency of Controlled Low Strength Material

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

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