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Report on Controlled Low-Strength Materials

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Report on Controlled Low-Strength Materials

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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 anticorrosion 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 proportioning. 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 = modulus of elasticity, psi (MPa)
- f'_c = 28-day specified compressive strength of concrete, psi (kPa)
- k = coefficient of permeability, in./s (mm/s)
- RE = removability modulus
- W = dry mass density, lb/ft³ (kg/m³)

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)

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 generally 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. 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.
Strong and durable	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).
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 compacted 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 consolidation equipment.
Improves worker safety	Workers can place CLSM in a trench without entering the trench, reducing their exposure to 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 should be tested after each lift for sufficient compaction. CLSM self-consolidates consistently and does not need 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 by-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 by-product material.

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



Fig. 3.2a—Using CLSM to backfill adjacent to building foundation wall.

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 level surface. Compressive strengths vary depending on project requirements. Because



Fig 3.2b—Backfilling utility cut with CLSM.

of its strength, CLSM may reduce the required thickness or strength requirements of the slab. Near Boone, IA, 2800 yd³ (2141 m³) 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 back-fill 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. Isolation 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 during 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 spillage 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 (Flechsigt 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 MPa) were available within a few hours and a strength of 200 to 300 psi (1.38 to 2.07 MPa) 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. An 8 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). 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 Giovannitti 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 CLSM to prevent CLSM from flowing to the joints. These culverts

are set on granular backfill. CLSM is then placed until it is 6 in. (150 mm) from the lower surface of the deck. At least 72 hours is required before the CLSM is brought up to the deck bottom 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 (Larsen 1990; Buss 1989; Golbaum et al. 1997).

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 standardized 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

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 segrega-

tion, 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 additives, 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 μ m) 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 successfully include (Tansley and Deval 1981):