Controlled Low Strength Material (CLSM): Practical Solutions to Backfilling Challenges in Construction

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Abstract

Controlled Low Strength Material (CLSM) is a self-compacting, low strength cementitious material that can be used as backfill in lieu of compacted soil. Its benefits include increased productivity, improved worker safety, and reduced labor and equipment cost. It has significant applications if used in projects; for example, subgrade support, locations of limited access, or on an accelerated schedule. In many times, the lack of knowledge and experience among construction contractors and concrete suppliers limits CLSM usage. This paper provides case studies, practical field guidance, and recommendations for contractors on CLSM batching, transporting, placement, and quality control.

Keywords: CLSM (controlled low strength material), backfilling, compacted soil, cementitious material

INTRODUCTION

Controlled low strength materials (CLSM) is a cementitious material used as a replacement of compacted soil in cases where the application of the latter is difficult or impossible. It is defined as materials that result in a compressive strength of 8.3MPa (1200 psi) or less. [1]; and typically composed of water, cement, fine aggregates, and, possibly other by-product materials [5]. However, it should not be considered as a type of low-strength concrete. It can be used as replacement for soil and structural fillings like bridge abutment, pipeline bedding, tilt-up construction, foundation backfill, , under slab voids, and sequential excavations in contaminated soil [6]. Several terms are currently used to describe it such as flowable fill, unshrinkable fill, flowable mortar, soil-cement slurry, and plastic soil–cement [6].

APPLICATIONS

There are several applications of CLSM, these include

- *Backfilling:* the material can be readily placed into trenches[1], limited spaces, holes or other cavity without need of compaction [2] or curing. Therefore, trench width or size of excavation can be reduced. In addition, CLSM can be placed in trenches up to 2.7 m (9 ft) deep and it sets (a person can walk on it) within 20 to 35 min, with very few shrinkage cracks. Besides, settlement problems with compact fills can be avoided. In addition, CLSM backfilling rate (by volume) is approximately 50 times that of manual compaction, and can be placed at 60 m^3/h; this improves productivity and decreases construction costs. Moreover, the relatively low strength of CLSM allows for future excavation, if required [5].
- *Utility bedding:* The material is an excellent bedding for pipe and utility conduits [3]. It provides a uniform support, protects the conduit from future damage or water ingress, reduces trench preparation time, and it can be recognized during excavation from the surrounding soil which alerts the excavating crew to the existence of the conduit. [8]
- *Subgrade Support*: CLSM can be used to create a stable base layer or pavement subbase on sabkha to allow construction activities to proceed. In addition, compaction operations in saturated soils or in areas with elevation near the groundwater level brings water to the surface, which creates a quicksand condition. In general, a 300 mm layer of CLSM is sufficient to create a stable base. After 24 hours of hardening, the CLSM can receive subsequent soil fill layers.
- *Erosion control:* CLSM may resist erosion better than many other fill materials (e.g. sand and clay fill materials. It is often used in riprap for embankment protection. [1]
- *Other applications:* CLSM is utilized in various applications such as structural fill, insulation and isolation fill, construction of bridge approaches, and pavement bases. Also, it can be used for non-uniform subgrades under foundation footings or slabs to provide a uniform level surface.

CASE STUDIES

Here two case studies are presented to demonstrate the advantages (and the required precautions) in using CLSM. These cases are from applications in hydrocarbon facilities.

- ❑ *CASE I: Headers Filling at Pump Station (abandoned utilities)*

In a pump station (for crude oil), and underneath foundations of the pipe supports, there are two main abounded pipes found thinning due to corrosion. The loss is up to 20% and the diameter of each pipe is 48-inch. Collapse of the empty header pipes could jeopardize the stability of the overlaying pipe support foundations which in turn can result in disruptive and costly repairs and potentially temporary shut-down of the pump line. The headers are located in an area of limited and restricted access which represents a challenge to construction work, and the location of the pump station is secluded from urban areas where material production plants are readily available (the shortest concrete mixer haul would take approximately 4 hours). In addition, the headers

[1] When used in street openings it can support traffic load within hours of placement [5].

must be filled with a non-compressible material, the material must has free flow that assures filling the complete length of the header, and formation of voids should be prevented. CLSM presents a solution for this problem, as it provides high flow to advance large distances from limited access ports. The preparatory work for the filling operations includes:

- Cleaning the headers from hydrocarbon residue, cutting and capping on one end.
- Excavation of two areas for each of the headers to expose sections large enough to permit the installation of an entry port on one end, and an air-release / inspection port on the other end
- Installation of entry ports risers with a height of 1000mm, and the top of the riser includes a fitting to which a hose can be connected for the delivery of the material.
- Opening of one air-release / inspection port for each header. These ports are openings on the top of the header pipe that allow trapped air to escape, facilitating the complete filling of the pipe.
- CLSM selection based on the properties needed
- CLSM injection

In this case, CLSM provided consistency and density similar to well compacted soil.

- ❑ *CASE II: Repair of Brine Reject 42" Line in a Pretreatment Plant*

The pipeline leakage created a cavity that needs to be filled, and prevent cave-in of surrounding pipe supports and tank foundation. The cavity is apparent from opening on the asphalt pavement and its extension under pavement is unknown. CLSM is selected as an emergency measure to stabilize and fill the cavity. This is because the material is self-compact and highly flowable; and can provide a platform (after hardening) to the inaccessible underground areas. Another reason for its usage is that the material can be excavatable since the pipe repair would be done after the stabilization (cavity fill).

MATERIALS

Conventional CLSM mixtures consist of water, Portland cement, fine aggregates, coarse aggregates, and other products such as fly ash and admixtures. By-product and waste materials can also be used [4]. Materials selection should be based on availability, cost, specific application, and the desired characteristics of the mixture (e.g., flowability, strength, excavatability, and density) [9]. Materials should be in conformance to ACI 229R Chapter 3.

While cement, fly ash, and water for CLSM must follow the same requirements of concrete, fine aggregate may consist of concrete sand (ASTM C 143), sand with fines, crushed sand as a byproduct of quarry crushing operations, and silty sandy soils with up to 20% fines passing through a 75 µm (No. 200) sieve.

BATCHING, MIXING, TRANSPORTING, PLACING AND CURING

There is no standard mixture proportioning method for CLSM (such as ACI 211 for conventional concrete); proportioning for CLSM has generally been performed empirically. Tables 1 through 3 present mix proportions that have been successfully batched and tested for compressive strength, segregation and flowability properties. These proportions should be used as a baseline in producing CLSM mixes; noting that since changing the aggregate type and source is the most significant factor affecting the water demand of CLSM, adjustments of water content should be anticipated. Regardless of the approach to mixture proportioning, the key properties sought are fluidity with minimal segregation, acceptable setting times, and adequate strength gain.

Sample Mix (Compressive Strength: 50 to 100 psi)	**A**	**B**	**C**
Cement (type I/II or II/V), kg/m^3	50	50	70
Fly ash, kg/m^3	--	150	--
Coarse Aggregate (5 mm nominal size, max.), kg/m^3	1,000	--	--
Fine Aggregate (concrete sand), kg/m^3	1,100	1,800	--
Crushed Sand/ Quarry Sand, kg/m^3	--	--	1,710
Silty Soil/ Sand, kg/m^3	--	--	--
Water [1], kg/m^3	330	400	292
Admixture (Superplasticizer), L	5	4	--
Compressive Strength – ASTM D 4832, psi	50-100	50-100	50-100
Flowability – ASTM D 6103, mm	200-250	200-250	200-250
Density - wet, kg/m^3	2,480	2,400	2,070

Table 1: Excavatable CLSM – Manual

Sample Mix (Compressive Strength: 100 to 300 psi)	**D**	**E**
Cement (type I/II or II/V), kg/m^3	100	100
Fly ash, kg/m^3	85	85
Coarse Aggregate (3/8" nominal size, max.), kg/m^3	410	410
Fine Aggregate (concrete sand), kg/m^3	1,230	--
Crushed Sand/ Quarry Sand, kg/m^3	--	1,230
Water [1]., kg/m^3	265	260
Admixture (Superplasticizer), L	4	
Compressive Strength – ASTM D 4832, psi	100-300 psi	100-300 psi
Flowability – ASTM D 6103, mm	200-250	200-250
Density - wet, kg/m^3	2,095	2,085

Table 2: Excavatable CLSM – Equipment

Sample Mix (Compressive Strength: 300+ psi)-	F	G
Cement (type I/II or II/V), kg/m^3	150	150
Fly ash, kg/m^3	85	85
Coarse Aggregate (3/8" nominal size, max.), kg/m^3	410	410
Fine Aggregate (concrete sand), kg/m^3	1,230	--
Crushed Sand/ Quarry Sand, kg/m^3	--	1,230
Water 1., kg/m^3	275	260
Admixture (Superplasticizer), L	4	--
Compressive Strength – ASTM D 4832, psi	300+ psi	300+ psi
Flowability – ASTM D 6103, mm	200-250	200-250
Density - wet, kg/m^3	2,150	2,140

Table 3: Non-Excavatable CLSM

CLSM may be produced on site or at a batch plant and transported to the site[2]. The preferred method of mixing is at a concrete ready-mix batch plant. Transportation of the batched CLSM should be in transit-mix trucks; however, in view of the high flowability of the material, and precautions should be taken to avoid spilling during transportation. Use of end plugs, lower transportation volumes, and transporting with partial water content are typical precautions.

Before production of CLSM for the actual project, the supplier must demonstrate that a satisfactory mix can be produced. A trial batch should be performed by the proposed batching facility and testing results of Compression Strength in accordance with ASTM D 4832 and flowability in accordance with ASTM D 6103 should be requested.

CLSM can be placed by chutes, buckets, or pumps. Internal vibration or compaction is not required. Curing methods specified for concrete are not considered essential for CLSM. [1] The material may be placed using chutes, conveyors, buckets, pumps. Internal vibration or consolidation is not required. Conventional concrete pumping equipment can deliver CLSM; however, mix proportioning should be targeted to provide adequate void filling in the mixture providing adequate cohesiveness for transport through the pump line without segregation.

Hardening is the time required for CLSM to go from a plastic state to a hardened state sufficient to support the weight of a person. Under normal conditions, this time is around 5 hours; however, it is recommended that the CLSM remain undisturbed for 24 hours after placement. See ASTM C 403 for methods to test readiness, particularly in areas that will receive additional structures over the CLSM (i.e., pavement placement). Curing procedures specified for concrete are not necessary for CLSM.

[2] CLSM is typically batched, mixed, transported, and placed similar to concrete (see ACI 304).

QUALITY CONTROL

Quality control of CLSM in the field is often done by visual inspection alone. It is recommended to verify flowability on site before CLSM pouring (see ASTM D 6103). It is also recommended to test the suitability for load application before paving operations over CLSM (see ASTM D 6024).

Test Procedure		
Sampling	ASTM D 5971	Practice for Sampling Freshly Mixed Controlled Low Strength Material
Consistency, fluid mixtures	ASTM D 6103	Test Method for Flow Consistency of Controlled Low Strength Material
Consistency, plastic mixtures	ASTM C 143	Slump of Portland Cement Concrete
Compressive strength	ASTM D 4832	Test Method for Preparation and Testing of Soil- Cement Slurry Test Cylinders
Suitability for load application	ASTM D 6024	Standard Test Method for Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application

Table 4: CLSM Testing Procedures

CONCLUSION

CLSM has its benefits as backfilling materials in terms of productivity, safety, and wide range of applications. The procedure of choosing and proportioning the constituents is based on criteria such as unconfined compressive strength, flowability, excavatability, and subsidence. By-product and waste materials can also be used as part of its constituents; thus, successful and environment-friendly utilization of CLSM is important to sustainable construction.

Contractors are recommended to consider the use of CLSM for structural fill or as a replacement of compacted soil. It would have positive impacts on project schedule, safety, and efficiency. Its quality and testing requirements is low compared with concrete, and CLSM is also a proper solution for applications where normal backfilling can be difficult or challenging. Currently the limitation for the material usage is the lack of experience among contractors that makes batch plants not receiving sufficient orders for producing CLSM with competitive prices. This paper provides contractors and concrete suppliers with the necessary guidance to production, quality control, and field applications on CLSM.

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