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Design and application of controlled low strength materials as a structural fill

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HIGHLIGHTS

- CLSM mixtures were developed as structural fill for bridge abutments.
- Performance criteria were compressive strength and flowability.
- Higher temperatures promote early strength gain in CLSM mixtures.
- Higher temperatures lower the rate of later-age strength gain in CLSM mixtures.
- Bond strength performance of the CLSM to steel anchors was investigated.

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ABSTRACT

Controlled low strength materials (CLSM) are flowable and self-compacting construction materials that have been used in a wide variety of applications. This paper describes design of an optimized CLSM mixture that was used as a structural fill for construction of a bridge abutment. The main performance criteria for selection of a potential CLSM mixture were compressive strength to support the bridge loads, excavatability and flowability to fill the entire abutment in one continuous pour. Several CLSM mixtures were developed and tested in the laboratory for engineering properties including flowability, density, compressive strength and stress–strain behavior.

Since it was a critical area of concern in design of the CLSM bridge abutment, the bond strength performance of the CLSM to steel anchors was also investigated. In pullout tests, a CLSM mixture with higher compressive strength resulted in higher bond strength and more brittle slippage. A numerical simulation of pullout tests indicated that the bond strength decreases with increase in bar size and embedment length.

1. Introduction

Recently, the use of controlled low strength materials (CLSM) as a cost and time efficient substitute of compacted fills has grown considerably. CLSM is a mixture of soil or aggregate, cementitious materials, fly ash, water and sometimes chemical admixtures that hardens into a material with a higher strength than the soil. CLSM, also known as flowable fill, is defined by the ACI 229R-99 [1] as a flowable self-compacting cementitious material that has a specified 28-day compressive strength of 8.3 MPa (1200 psi) or less. CLSM can be used as a replacement for compacted backfill and is defined as excavatable if the 28-day compressive strength is 2.1 MPa (300 psi) or less.

Compared with conventional earthfill materials that require controlled compaction in layers, CLSM has several inherent advantages for use in construction, including: ease of mixing and placement, ability to flow into hard-to-reach places, self-leveling characteristics, rapid curing, incompressibility after curing, which reduce equipment needs, labor costs, and associated inspections. Moreover, environment-friendly utilization of by-product materials such as fly ash or foundry sand in CLSM translates into greater economy and the potential for a sustainable construction [2,3].

The challenge in the application of CLSM is that it behaves like a compacted soil. Therefore, much of the available knowledge and publications on its applications have fallen between concrete materials engineering and geotechnical engineering, and it often does not receive the level of attention it deserves by either group [4].

CLSM is a multipurpose construction material that has been used in a wide variety of applications that are well documented in the literature. Among the many applications of CLSM, the following are the most important [1]: backfill for building excavations, utility trench, and retaining walls; structural fill for footings, road bases and utility bedding; and void-filling for underground

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structures. It has recently been implemented in bridge approaches to minimize the bump at the end of the bridge. This study looks at the new application of CLSM in rapid construction of bridge abutments. As illustrated in Fig. 1, CLSM as a structural fill can be placed behind full-height precast concrete panels that are attached to the CLSM backfill via steel anchors [5].

Required engineering and performance properties of CLSM vary depending upon application. For example, it might be desirable for utility trench backfill material to be excavatable and permeable to ground water. For the CLSM abutment application in this study, the main performance requirements included sufficient compressive strength to support the bridge loads and flowability to fill the entire abutment in one continuous pour by pumping. The density and stress–strain response were also parameters used for the finite element analysis. The bond between the steel rebar and CLSM has an important role in the design for internal stability of the CLSM bridge abutment (Fig. 1). The existence of this bond is a basic condition for these materials to work together as a kind of composite material by transferring load between the rebar and surrounding CLSM.

In this paper, several CLSM mixtures were developed and tested for the required engineering properties in order to design an optimum CLSM mixture as a structural fill for the bridge abutment (Fig. 1). Experimental pullout tests and numerical simulations were performed to evaluate the bond performance of the CLSM and steel anchors.

2. Materials

Selection of materials for CLSM should be based on availability, cost, specific application and the necessary characteristics of the mixture including flowability, strength, excavatability, density, etc. [1]. Selected materials for CLSM mixtures in this study included type I Portland cement, class F fly ash, fine aggregates and water.

Commercial type I Portland cement was manufactured by Lafarge Cement and had the following compound composition: C_3S – 55%, C_2S – 17.6%, C_3A – 8.0%, C_4AF – 8.2% and contained 3.4% of limestone filler. Locally available class F fly ash for this research was sourced from We Energies, Elm Road Generating Station, Wisconsin. Fly ash is a by-product of coal combustion in electric power generating plants. Chemical and physical properties of the Portland cement and fly ash used in this study are shown in Table 1 and compared with the requirements of ASTM C150 and ASTM C618 specifications, respectively. The particle size distribution of the

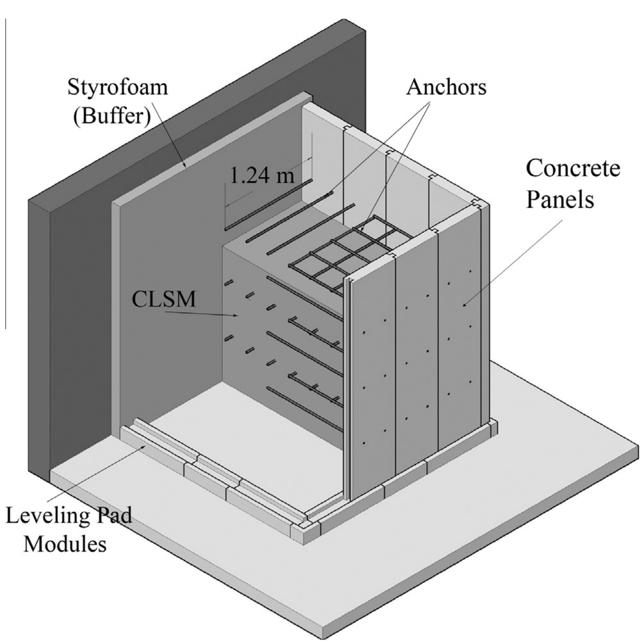

Fig. 1. Design of a CLSM bridge abutment and location of embedded steel rebars.

Table 1
Chemical and physical properties of Portland cement and fly ash type F.

Property	Cement	ASTM C150	Fly ash	ASTM C618
Chemical properties				
Silicon dioxide, SiO_2, %	20.6		49.9	70 min
Aluminum oxide, Al_2O_3, %	4.7		24.0	
Iron oxide, Fe_2O_3, %	2.7		14.4	
Calcium oxide, CaO, %	63.9		3.23	
Magnesium oxide, MgO, %	2.3	6.0 max	0.98	
Sodium oxide, Na_2O, %	0.55	0.6 max		
Sulfur trioxide, SO_3, %	2.4	3.0 max	0.88	5.0 max
Loss on ignition (LOI), %	2.1	3.0 max	3.50	6.0 max
Physical properties				
Moisture content, %			0.11	3.0 max
Blaine fineness, m^2/kg	380	260 min		
Autoclave expansion, %	0.02	0.8 max	0.08	0.8 max
Compressive strength, MPa				
3-day	21.7	12.0 min		
7-day	27.6	19.0 min		
28-day	37.9	28.0 min		
Time of setting, minutes				
Initial	110	45 min		
Final	225	375 max		
Specific gravity	3.15		2.30	

quartz sand which was used as the fine aggregate complies with the ASTM C33 that classifies the fine aggregates for use in concrete. The fine aggregate had a specific gravity of 2.65, moisture content of 1.16% and water absorption of 0.5%.

3. Mixture proportioning

Proportions of the constituent materials in CLSM are based on requirements for performance and placement. Development of compressive strength is an important design parameter for many CLSM applications. In some applications, it is not only required to meet the minimal strengths to maintain the structural support, but also the ultimate strength must be limited to allow for future excavation [6]. Due to the sensitivity of compressive strength and other properties, trial and error process has been recommended for proportioning of CLSM mixtures [7].

In this study, several CLSM mixtures were tested for compressive strength and flow consistency. To evaluate and select a potential CLSM mixture for the specified structural fill application, the following criteria were considered:

1. Preliminary finite elements analysis of the CLSM bridge abutment showed that a backfill with a minimum compressive strength of 0.21 MPa (30 psi) provides sufficient load-carrying capacity for a typical span type bridge. This is actually equivalent to the bearing capacity of a well-compacted soil. Therefore, the selection criteria favored the mixture with relatively high early compressive strength (minimum of 0.21 MPa (30 psi) in 1–3 days) with respect to rapid construction of the bridge abutments and with 28-day strength not exceeding 8.3 MPa (1200 psi). For the laboratory construction it was required to develop some mixture proportions with lower ultimate strength to assure excavatability (with 28-day strength not exceeding 1.4 MPa (200 psi)).
2. According to the ACI 229R-99 [1], high flowable material must have a flow of at least 200 mm (8 in.) using the ASTM D6103 method. A flow of 300 mm (12 in.) or more was desired to prevent blockage of pumping equipment.

Properties of the fresh mixtures, flowability and unit weight were tested after mixing in a drum mixer. Then the specimens were cast in 100 × 200 mm (4 × 8 in.) cylindrical molds and cured for varying periods, 1-day, 7-day and 28-day, before the compressive strength testing. Because of the self-leveling characteristics of