Use of Coarse Aggregate in Controlled Low-Strength Materials

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Controlled low-strength materials (CLSM) have evolved using only sand as aggregate filler. CLSM in the Pacific Northwest has evolved differently in that many mixtures use gravel up to 1 in. top size. The reasons for the use of gravel center around economy and performance. Concrete technology teaches that the largest top-size aggregate that can be used yields the lowest voids in the combined aggregates. Reduced voids result in a lower paste requirement, which reduces the cost for cementitious materials.

Controlled low-strength materials (CLSM) have gained appreciable recognition as fill materials because of their many inherent advantages. These advantages include flowing placement without segregation, self-consolidation, controlled density, controlled strength, ease of excavation, and economy. In recognition of the increasing use of CLSM, The American Concrete Institute (ACI) has enforced committee 229 to develop a state-of-the-art document of CLSM.

Development of CLSM has centered around mixtures using a sand filler. The interparticle voids are then slightly overfilled with a fluid paste composed of cement, fly ash, water, and occasionally additives. Components of the paste are varied in quantity to achieve the required performance in terms of strength development, self-consolidation, flow behavior characteristics, durability, economy, and ease of removal (*1*). Gravel generally has not been a component of the aggregate filler probably because of economical reasons. Throughout the country, gravel is usually at a premium while sand is generally in surplus. K-Krete, Flowable Mortar, and earlier cement-sand slurries are typical of CLSMs that use only sand as a filler.

Sand filler mixtures have performed well, giving all the properties desired. It may be difficult to achieve satisfactory flowability and there may be severe bleeding in cement-sand slurries. Bernard and Tansley reported that fly ash can be of assistance in obtaining properties of flowability with reduced bleeding (*1*).

Exceptions to sand-filled CLSM are foamed mixtures, flowable fly ash, lean concrete mixtures, and sand-gravel–filled mixtures. Foamed CLSM, rich in cementitious material fines, do not need or want aggregate fillers. Flowable fly ash capitalizes on abundant, inexpensive fly ash to act as a paste component and as a filler. Lean concrete mixtures are typically specified at fairly low slump and are not expected to have good flowability. Gravel-sand–filled CLSM can be proportioned to achieve all the necessary performance features, in which suitable gravel economy exists.

Economy, given satisfactory performance, is the key factor to the viability of CLSM. The greater the economy, the greater the applications for its use. Mother nature blessed many areas of the west with equivalent or greater supplies of gravel compared with sands. The use of gravel in CLSM can assist in gaining economy where sands are premium or equivalent in cost. Initial economy is achieved through the use of a lower-cost material, whereas secondary economy can be achieved because of lowered paste requirements from reduced voids with increasing maximum aggregate size.

PRODUCTION, PERFORMANCE, AND ECONOMY CONSIDERATIONS

Production of CLSM usually must fit within the confines of normal concrete production operations. Normal concrete operations contain bunker and silo space only for specification materials used routinely in the production of concrete. The use of materials not normal to the concrete production operation requires either additional bunker and or silo space or a plant dedicated to the production of CLSM. Consequently, nonstandard aggregates that could well be used in CLSM, generally are not used because of a lack of plant capacity.

Since concrete plants usually use standard concrete materials, the objective is to proportion CLSM of suitable performance at lowest cost using available materials. With cement costing \$50 to \$80 per ton and fly ash costing \$30 to \$45 per ton, it is economically important to minimize their use while maintaining product quality. Premium prices for sand or surplus of gravel make it advisable to use as much gravel as possible.

PROPORTIONING

When proportioning CLSM with gravel, standard concrete porportioning techniques apply since the material so closely resembles weak concrete. The steps taken for proportioning can basically be taken from ACI 211, section 5 (*2*), modified for CLSM: (a) selection of slump range; (b) selection of maximum aggregate size; (c) selection of cement content; (d) selection of fly ash content; (e) estimating water content; (f) selection of entrained air content; and (g) determination of aggregate content.

Selection of Slumps

As in concrete, slump provides a measure of consistency defined in ACI 116 (*3*) as, "the relative mobility or ability of freshly

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mixed concrete or mortar to flow." CLSM generally will be more flowable than concrete at the same slump primarily because of the lubricating action of the high volume of fly ash spheres. General fill applications require a slump range of 6 to 8 in. Where greater flow is required, care should be taken to ensure that adequate fines (generally fly ash) are present to accept the flow without segregation. CLSM of low slump (2 in.) has been successfully delivered by concrete pump without the need for added consolidation effort (sub-footing fill, Valley General Hospital, Kent, Washington).

Selection of Maximum Aggregate Size

Similar to concrete, selections should allow for the largest practical size commensurate with the intended application. Most work with gravel in CLSM has been done in the sizes from ⅜ in. to 1 in., although larger sizes could be used under permissible conditions.

Selection of Cement Content

Selection of cement content is based on required compressive strength and unfortunately does not follow the water to cement (w/c) law. Actual requirements must be determined by trial. The following table has given good results in determining the requirements:

Cement Content (lb/yd³)	*CLSM 28-day Compressive Strength (psi)*
40–50	100
70–80	200
90–110	400
110–150	500

Where excavation is required, CLSM strength should be limited to 150 psi maximum.

Selection of Fly Ash Content

Fly ash is used in CLSM as a void filler and fluidifying agent more than for strength production. Fly ash contents as low as 100 lb/yd³ have been used with an equivalent amount of cement for placement directly from the truck chute when flowability was not required. Where average flowability is required, 250 lb of fly ash is generally used with at least 40 lb of cement. Where great flowability or pumpability is required, fly ash contents may reach 1,000 lb/yd³.

Class C fly ash may produce strengths higher than is wanted. Thorough testing should be done to determine the advisability of using class C fly ash.

Estimating Water Content

The high fly ash-low cement contents of these mixtures provide for high slump with low water contents relative to what can be expected from concrete. We have found that switching a plain cement 5-sack concrete mix at a 4-in. slump to a mixture using 50 lb of cement and 250 lb of fly ash with the same aggregates and water gives a CLSM with a 7- to 8-in. slump. Less water is required for a change of slump with CLSM than can be expected for concrete. Where 1 gal of water changes concrete slump 1 in., consider about 0.5 gal for CLSM.

Increasing the fly ash content has a dramatic effect on reducing water demand for a given slump. Trials run by Pozzolanic on a mixture with 50 lb of cement and equal portions of pea gravel and building sand showed an 11-lb reduction in water for each 100 lb of fly ash added. This value held true in the fly ash range of 100 to 500 lb/yd³.

The use of entrained air can be expected to have a water-reducing effect similar to that in concrete.

Water demand prediction techniques, such as the loose fine aggregate voids method by Willis (*4*), may be useful in determining initial starting points.

Selection of Entrained Air Content

The use of entrained air is not mandatory and is not recommended when using variable, high-carbon fly ash because of the technical control effort required. At the low compressive strength levels used in CLSM, it is doubtful that entrained air would contribute significantly to durability; however, it may have a beneficial place. Because it occupies volume, entrained air replaces more costly aggregates to provide additional economy. Unit weight is reduced, which may be an important factor in certain fill situations. Entrained air also has the capacity to promote cohesion and reduce water content as it does in concrete mixtures.

Entrapped air contents in CLSM are similar to those of concrete.

Selection of Aggregate Content

Selection of aggregates should follow conventional practice for concrete proportioning. The *b/bo* technique proposed by Goldberg and Gray (*5*) first published in 1942 and adopted by ACI 211 (Section 5.3.6) provides a good basis for gravel content determination. With the high fly ash contents used, *b/bo* values can be increased to accommodate larger gravel contents without adversely affecting performance. Sand can then be calculated as the volume remaining after cement, fly ash, gravel, water, and air.

EXAMPLE OF CLSM PROPORTIONS WITH GRAVEL

The following data give a representation of CLSM with and without entrained air in which gravel content water and demand are approximated from an existing 5-sack plain concrete mix. These data could be obtained from other methods as well as from practical experience.

Required

- Compressive strength ≤ 150 psi at 28 days (excavatable);

TABLE 1 EXAMPLE OF CSLM WITH AND WITHOUT ENTRAINED AIR

			CLSM			
	Plain Concrete		Non-Air Entrained		Air Entrained	
	Weight SSD (lb)	Volume (ft^3)	Weight SSD (lb)	Volume (ft^3)	Weight SSD (lb)	Volume (ft^3)
Cement: Type I/II	470	2.39	50	0.25	50	0.25
Fly Ash: class F	—	—	250	1.82	250	1.82
1″–4# Gravel	1,900	11.36	1,900	11.36	1,900	11.36
4#–0 Sand	1,400	8.51	1,454	8.83	1,340	8.13
Water	270	4.33	270	4.33	255	4.09
Air (%)	1.5	0.41	1.5	0.41	5	1.35
Total	4,040	27.00	3,924	27.00	3,795	27.00

- Slump range 6–8 in.;
- General flowability;
- With and without entrained air.

Materials

- 1-in. No. 4 gravel, specific gravity, 2.68;
- No. 4–0 sand; specific gravity, 2.64; fineness modulus (FM) 2.80;
- Fly ash (class F), specific gravity, 2.20; loss on ignition (LOI), 0.2 percent;
- Cement (Types I or II).

Procedure

- Water demand from concrete shown with a normal slump of 4 in.;
- Fly ash content for general flowability, 250 lb/yd³;
- Cement content, 50 lb/yd³ for ≤ 150 psi;
- Gravel 1,900 lb/yd³ as in the concrete;
- Entrained air, none and total air, 5 percent.

The following example gives a representation of CLSM with and without entrained air (see Table 1). Water demand and gravel content are approximated from an existing 5-sack concrete mix. Data for water demand and gravel content could be obtained by other methods and practical experience.

Required

- A flowable, cohesive, nonsegregated CLSM for street-cut backfill, placed directly from the concrete truck chute. Must be excavatable.
- General flowability;
- Slump range, 6–8 in.;
- Strength ≤ 150 psi, therefore ~100 psi @ 28 days;
- With and without entrained air.

Materials

- 1-in. No. 4 gravel; $G_s = 2.68$;
- No. 4–0 sand; $G_s = 2.64$; FM = 2.80;
- Fly ash (class *F*); $G_s = 2.20$; LOI = 0.2;
- Cement (type I or II).

Procedure

- Water demand for 6- to 8-in. slump from reference concrete;
- Gravel content from reference concrete;
- Fly ash content = 250 lb/yd³ (general flowability);
- Cement content = 50 lb/yd³ (~100 psi @ 28 days);
- Entrained air, none and total air, 5 percent.

ENGINEERING PROPERTIES

CLSM with gravel behaves similarly to mixtures that use only a sand filler in terms of compressive strength, erosion, flow, permeability, and excavatability. Subsidence may be one area in which gravel mixtures perform better than those with sand only. This better performance is probably because of the reduced water contents of the gravel mixtures, as consolidation occurs by water leaving the mass.

Filling the 12-ft-diameter by 120-ft-deep exploratory shaft and 10-ft-diameter by 30-ft-long subsurface tunnels for the Mount Baker Ridge Tunnel in Seattle, Washington, was accomplished by using a CLSM with ⅞-in. top-size gravel. The calculated fill volume was approximately 800 yd³ with filling to refusal reached at 786 yd³ of CLSM, discharged directly into the shaft from concrete truck chutes in 4 hr. Oliver Harding, project engineer for the Washington Department of Transportation, reported a subsidence of ⅛ in. in the 120-ft depth (personal communication, 1984). Subsequent excavation operations resulted in a subsidence of several inches in the hill through which the tunnel passes. The subsidence of the hill occurred without subsidence of the CLSM-filled shaft, which now extends several inches above ground level.

SUMMARY

Whereas CLSM historically has used only sand as a filler, gravel is indeed a viable material for use as a filler. Economics will likely determine whether gravel will be used. Proportioning of gravel CLSM can be accommodated by current concrete proportioning practices such as those in ACI 211. Performance of the gravel mixtures can be expected to be similar to those made with sand only. Subsidence may be reduced as a result of low-mix water requirement.

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