Economic Considerations When Using Controlled Low-Strength Material (CLSM-CDF) as Backfill

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Controlled low-strength material (CLSM) is defined by the American Concrete Institute as having a 28-day compressive strength less than 1,200 psi. Its primary ingredients are portland cement, fly ash, and filler aggregate. Although CLSMs have been in use for a number of years, confusion about their construction benefits and economic savings remains. The principal use of CLSM has been as a controlled-density fill (CDF) in place of conventionally placed backfill. A method for determining the cost of CLSM-CDF and how it can affect a contractor's total construction costs is described. General technical information for the manufacture and testing of CLSM in the laboratory and in the field is cited. A small sample of ready-mixed concrete producers indicates the need for dissemination of information about CLSM.

The conventional backfilling technique for all types of excavations has supposedly been the placement of granular material into the excavation in layers with tamping to achieve the desired compaction (density). In many cases, the material was dumped into the trench but never tamped or adequately compacted.

In the early 1970s engineers started examining alternatives to conventional backfilling materials and methods (*1*). One alternative was a material designated as K-Krete (CDF) (CDF stood for controlled density fill), a low-strength material (in terms of concrete) with a 28-day compressive strength of about 100 psi. This was a patented material process developed by the Detroit Edison Co., Detroit, Michigan, and Kuhlman Corp., Toldeo, Ohio. The material is still sold under the name K-Krete through trademark holders. Because of the material's success, similar materials have been developed and sold under a variety of trade names: M-Crete, S-Crete, Flowable Fill, Flash Fill, Flowable Grout, Flowable Mortar, One-Sack Mix, and so on.

By 1980 it was evident to the early developers of low-strength materials that technical information about this product was not being properly developed or transferred to the public. Some information was being published in trade magazines, but not on a consistent basis. An American Concrete Institute (ACI) committee 229 was formed to correct these deficiencies. The ACI 229 committee is designated as Controlled Low-Strength Material (CLSM). The committee defined low strength to be a material with a 28-day compressive strength of less than 1,200 psi.

The creation of the ACI 229 committee gave publicity to CLSM. In recent years ready-mixed concrete trade associations have published numerous articles on CSLM uses (*2–4*). Even with this extended publicity, CLSM uses were confined because of misunderstandings about construction applications and a realistic pricing structure.

Although this paper primarily addresses backfilling with CLSM-CDF, CLSM is really a family of possible mixtures with a variety of uses: pavement base, structural fill, thermal fill, anticorrosion fill, high- or low-permeability fill, and so on. Each mixture is designated by a three-letter acronym, such as CPB (controlled pavement base), CSF (controlled structural fill), and CTF (controlled thermal fill).

OBJECTIVE AND SCOPE

One reason for using, or not using, CLSM-CDF has been its cost compared with that of conventional backfill. Construction costs for both conventional backfill and CLSM-CDF are investigated, and ways to reduce CLSM-CDF costs are suggested.

Information used in this paper has been gathered over the past 20 years and is the result of both laboratory and field research projects (*5–8*). Comparisons of conventional backfill and CLSM-CDF construction costs are reviewed. The review includes related topics for materials, manufacturing, transporting, placing, testing, OSHA regulations, and pricing.

CLSM AND RELATED BACKFILL PROPERTIES

Background

The basic components of CLSM are portland cement, fine aggregate, fly ash, and water. For backfilling operations the material must possess four properties: flowability, removability, strength, and a competitive price. Competitive price is the main theme of this paper. It is semidependent on the other three properties. To provide a better understanding of each property and its effect on price, each property is reviewed.

Flowability

The CLSM must be able to flow into the trench, thereby eliminating all labor requirements for placing. Several tests

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have been developed for laboratory determination of adequate flow. Early researchers developed the open-ended, 3-in.-diameter × 6-in.-long cylinder test. The open-ended cylinder is placed on a level surface, and the CLSM is poured into the cylinder. The cylinder is then lifted, vertically, to allow the material to flow out on the level surface. Good flowability requires no material segregation and a spread of approximately 8 in. in diameter.

Removability

Removability must be considered if the backfilled trench may be excavated in the future. In most projects removability is a property that is requested. To ensure removability, the unconfined compressive strength should be less than 100 psi. Concrete-oriented personnel have difficulty in understanding this low strength requirement, because they usually work in the range of 3,000 to 5,000 psi. Hardened CLSM is more directly related to soils than to concrete. For easy removability, the worst thing a manufacturer can do is to put extra cement into the mixture. In one case the material achieved a reported strength of 3,000 psi in 1 year.

Strength

Compressive strength testing of CLSM has been conducted using various size cylinders and 2-in. cubes. The resulting compressive strength depends on the materials used and their respective proportions in the mixture. For standard backfilling operations, considering flowability and removability, 100 psi or less is recommended. Different materials, types, and sources can drastically change the compressive strength. It is recommended that laboratory tests be run on initial mixtures and for any changes in the mixtures. Monitoring of materials during CLSM manufacture is strongly recommended. See Table 1 for referenced CLSM laboratory mixture.

These weights provide a starting point for laboratory determination of flowability and compressive strength. Type C fly ash is now being considered or used in several locations in the United States. Laboratory and field test comparisons are being conducted for Type F and Type C fly ashes. Initial tests indicate that higher strengths are being achieved with Type C fly ash. If removability is required, the use of Type C fly ash should be closely examined.

In most cases the fill aggregate has been concrete sand (ASTM C33). It provides an excellent CLSM backfill when properly designed and manufactured. Less expensive materials can also be used for the aggregate filler. In some cases bottom ash has been successfully used. Each geographic area contains inexpensive aggregate filler material that could be used in the manufacture of CLSM.

Yield of Mixture

There are two yield considerations for CLSM mixtures: the plastic, or wet, yield and the hardened, or subsided, yield. The absolute volume of the wet mixture is calculated in the same manner as for concrete. Because of the high water content, a significant amount of water bleeds off the placed CLSM mixture. Therefore, the hardened volume is less than the initial wet volume. A typical subsided yield would have volume reduced by approximately 6 to 8 percent. The reduced hardened volume must be reflected in both price and volume

TABLE 1 CLSM LABORATORY MIXTURE AND DETERMINATION OF WET ABSOLUTE VOLUME

CLSM LABORATORY MIXTURE

Material	Weight (lb)/Cubic Yard
Portland Cement, ASTM C150 (Type I)	100
Fly Ash, ASTM C618 (Type F)	300
Filler, ASTM C33 (Aggregate)	2560
Water	600

DETERMINATION WET ABSOLUTE VOLUME

Material	S.G.	Weight	Calculated Wet Abs. Volume
Cement	8.15	100	100/(62.4 * 3.15) = 0.51
Fly Ash	2.47	300	300/(62.4 * 2.47) = 1.95
Filler	2.65	2560	2560/(62.4 * 2.65) = 15.48
Water	1.00	600	600/62.4 = 9.62
			Total (cu.ft.) = 27.56

requirements. The specific gravity of the components will affect the final hardened volume. See Table 1 for an example of determining the wet absolute volume of a typical 1-yd^3 CLSM mixture.

The wet overyield (0.56 ft^3) could be adjusted by reducing the aggregate filler as long as proper flowability is maintained. Another consideration is that the higher wet yield increases the subsided volume. A volume reduction of 6 to 8 percent would result in a final subsided volume of 26.0 to 25.5 ft^3.

MATERIAL COSTS

To determine a proper pricing structure for a CLSM-CDF, a knowledge of material costs is required. Material costs generally vary with geographic locations. Time of year, competition, and the amount of work within the geographical area can affect costs. Costs for CLSM-CDF in a surveyed area of Ohio are shown in Table 2.

The cost of the fill material has the greatest significance in determining the cost of a CLSM-CDF mixture. Material for possible aggregate filler use should be investigated. It can be a nonstandard material that can satisfy CLSM mixture requirements. The Hatfield Station project (Pennsylvania) is one place where bottom ash was used as the filler material (*9*).

MANUFACTURING EQUIPMENT

Ready-mixed concrete equipment has generally been used to manufacture CLSM mixtures. This is not to say that other types of equipment and mixing procedures have not or could not be just as effective. Because the early CLSM concepts were developed by ready-mixed concrete producers, it was natural for ready-mixed concrete equipment to be used.

The important thing to remember is the proper mixing of the CLSM components. Flow, removability, and strength will not be controlled without proper mixing.

TRANSPORTATION AND PLACING COSTS

The usual method for transporting CLSM-CDF mixtures to the project has been by ready-mixed concrete trucks. With the advent of CLSM-CDF mixtures, the ready-mixed concrete trucks should now be referred to as material mixing and transporting trucks. The CLSM-CDF mixture is usually placed by pouring directly from the truck into the trench or excavation. For this paper, and in general, the transportation costs for concrete are used for the transportation costs of CLSM-CDF mixtures.

Technically, the CLSM-CDF supplier should consider less wear on equipment (blades) and faster placing times. Because most CLSM-CDF mixtures contain smaller-sized aggregate than concrete, blade wear is greatly reduced. Because CLSM requires no vibration or work after placing, placement time is reduced from the usual 10 min/yd^3 for concrete to 10 min or less for the entire CLSM-CDF load. Placement of CLSM-CDF mixtures can significantly decrease equipment turnaround time for trucks.

CONSTRUCTION CONSIDERATIONS AND BACKFILLING

When considering total CLSM-CDF costs, the contractor must consider related construction requirements. Related construction requirements include trench width, Occupational Safety and Health Administration (OSHA) requirements, and speed of backfill placement.

Trench widths can be reduced with the use of CLSM-CDF, because a wider trench is not required to achieve adequate compaction around the conduit. The reduction in trench width also reduces excavation costs and the amount of backfill material required.

OSHA requires sloping sides for trench excavations [29 CFR 1926.652 (7/1/89 ed.)]. For conduit placement, with a "steel box" and CLSM-CDF backfilling, sloping sides could be eliminated because no one is required to be in the trench during backfilling.

TABLE 2 CLSM CDF COST SURVEY, OHIO

COMPANY REFERENCE	MATERIAL REFERENCE	STRENGTH @ 28 DAYS PSI	COST ($/CY.YD.)
A	3 bag grout	?	52.00
B	K-Krete-CDF	100	29.50
C	Low Strength	500-1000	31.50
D	Fill Crete	?	36.75
E	Flowable Fill	500	30.00
F	U-Crete	500	30.00

? Means that producer had no information about the 28 day compressive strength.

All producers made claims about easy removability.

Backfilling is faster with the use of CLSM-CDF. There are no delays for compaction testing in the trench. Backfilling is as fast as the CLSM-CDF material can be poured into the trench, as long as conduit flotation can be controlled. A faster backfilling operation reduces total project construction time.

QUALITY CONTROL AND FIELD TESTING

The quality control and testing of CLSM-CDF mixtures are similar to construction controls for concrete and soils. The suggested controls and field-testing procedures apply to the end use of the mixture. The tests consist of the following ASTM standards and test procedures: ASTM C138, test for unit weight; ASTM C39, modified test for compressive strength; and flow test (no ASTM designation).

The cylinder size and rodding requirements of ASTM C39 have been modified. The cylinder size can be either 4 × 8 in. or 3 × 6 in. Naturally, 6 × 12 in. cylinders can be used, but smaller cylinders yield satisfactory results. To simulate field placement, no rodding should be done after placing the mix in the cylinder. The cylinders should be allowed to stand undisturbed for at least 48 hr.

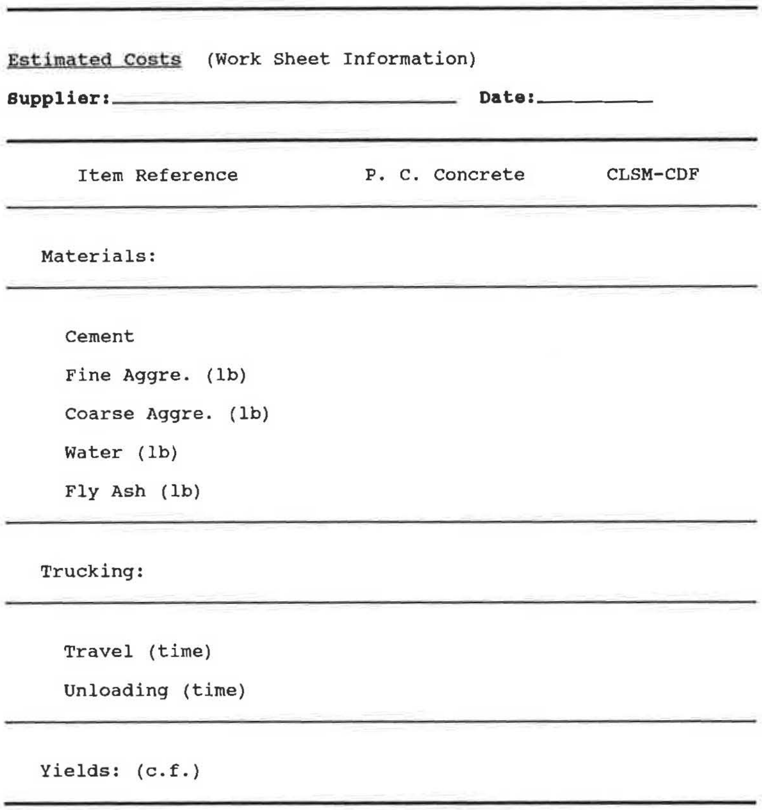
COMPETITIVE PRICE

The price per cubic yard of a CLSM-CDF mixture, as manufactured by the ready-mixed concrete producer, is governed by the cost of its components, the cost of competitive products, and the construction method. For this paper, material cost survey form sheets were developed along with a material cost determination procedure to be used by a ready-mixed concrete producer (see Figure 1 for cost form sheet). Five ready-mixed concrete producers in Ohio participated in the cost survey. Each producer was interviewed about possible uses of CLSM-CDF in its operation. Material cost and mix information received from the producers interviewed is given in Tables 3 and 4.

The material cost information was then used to calculate the cost of a standard CLSM-CDF mixture using ASTM C33 concrete sand as the filler. The CLSM-CDF costs include transportation and placement times. They were calculated using the same transportation and placement time costs as for concrete mixtures (see Table 5 for determination of CLSM-CDF mixture costs for material, transportation, and placement times).

The largest cost in a six-sack concrete mix is the cement (61 percent). Figure 2 shows a cost comparison for a six-sack concrete mix. The largest cost for CLSM-CDF, on the basis of average and minimum survey values, is the aggregate filler, 59 percent and 60 percent, respectively. See Figures 3 and 4 for cost comparisons for CLSM-CDF using average and minimum survey values. The filler material in a CLSM-CDF mixture greatly influences the final cost. On the average, for every 10-cent reduction in filler costs per ton, the resulting CLSM-CDF material cost reduction is 1 percent/yd^3.

Cost reductions for CLSM could be made to adjust for less equipment wear and faster placement times. The CLSM-CDF



Estimated Costs (Work Sheet Information)

Supplier: ______________________ **Date:** ________

Item Reference	P. C. Concrete	CLSM-CDF
Materials:		
Cement		
Fine Aggre. (lb)		
Coarse Aggre. (lb)		
Water (lb)		
Fly Ash (lb)		
Trucking:		
Travel (time)		
Unloading (time)		
Yields: (c.f.)		

FIGURE 1 Survey form for CLSM-CDF costs.

TABLE 3 CLSM-CDF COST INFORMATION, OHIO

MATERIAL REFERENCE	COMPANY SURVEY REFERENCE 1	 2	 3	 4	 5
			(Cost per Ton...$/T)		
Cement (Type 1)	60.00	57.00	57.00	62.00	60.00
Fine Aggr. (C33)	6.00	5.80	4.85	6.50	7.50
Coarse Aggr. (C33)	7.85	7.95	8.60	5.95	5.45
Fly Ash (F)	23.00	9.00	26.50	13.00	11.50
Unloading Time (con)	60 min.	60 min.	60 min.	10 min./ yd^3	10 min./ yd^3
Cost 6 Sack Mix	50.00	48.00	42.00	47.50	49.50

	Minimum	Maximum	Average
		(Cost per Ton...$/T.)	
Cement (Type 1)	57.00	62.00	59.20
Fine Aggr. (C33)	4.85	7.50	6.23
Coarse Aggr. (C33)	5.45	8.60	7.16
Fly Ash (F)	9.00	26.50	16.60
Cost 6 Sack Mix (con)	42.00	50.00	47.40

TABLE 4 CONCRETE MIX INFORMATION, OHIO

MATERIAL REFERENCE	COMPANY SURVEY REFERENCE 1	 2	 3	 4	 5
			(Pounds/Cubic Yard For 6 Sack Mix)		
Cement (Type 1)	564	564	564	564	564
Fine Aggr. (C33)	1320	1380	1380	1508	1500
Coarse Aggr. (C33)	1680	1765	1730	1735	1725
Cost 6 Sack Mix	50.00	48.00	42.00	47.50	49.50

	Minimum	Maximum	Average
		(Pounds/Cubic Yard For 6 Sack Mix)	
Cement (Type 1)	564	564	564
Fine Aggr. (C33)	1320	1380	1418
Coarse Aggr. (C33)	1680	1765	1727
Cost 6 Sack Mix (con)	42.00	50.00	47.40

TABLE 5 DETERMINATION OF CLSM-CDF COST

6 Sack Concrete Mix

Material Reference	Weight/ Cu.Yd.(lb)	Cost ($/T)	Matl.Cost ($/Cu.Yd.)	% Cost
Cement	564	59.20	16.69	61
Fine Aggr.	1418	6.23	4.42	16
Coar.Aggr.	1727	7.16	6.18	23
			27.29	100

Cost for 6 sack concrete mix including material, transportation and overhead...$ 47.40.

Therefore cost for transportation and overhead would equal...
$ 47.40 - 27.29 = **$ 20.11/cy.**

CLSM-CDF MIXTURE (Based on Average Values)

Material Reference	Weight/ Cu.Yd.(lb)	Cost ($/T)	Matl.Cost ($/Cu.Yd.)	% Cost
Cement	100	59.20	2.96	22
Fine Aggr.	2550	6.23	7.79	59
Fly Ash	300	16.60	2.49	19
			13.24	100

Add in transportation and overhead costs...
$ 20.11 + 13.24 = $ 33.35/cy.

Adjust for under yield...$ 33.35/1.06 = **$ 31.46/cy.**

CLSM-CDF MIXTURE (Based on Minimum Values)

Material Reference	Weight/ Cu.Yd.(lb)	Cost ($/T)	Matl.Cost ($/Cu.Yd.)	% Cost
Cement	100	57.00	2.85	27
Fine Aggr.	2550	4.85	6.18	60
Fly Ash	300	16.60	1.35	13
			10.38	100

Add in transportation and overhead costs...
$ 20.11 + 10.38 = $ 30.49/cy.

Adjust for under yield...$ 30.49/1.06 = **$ 28.76/cy.**

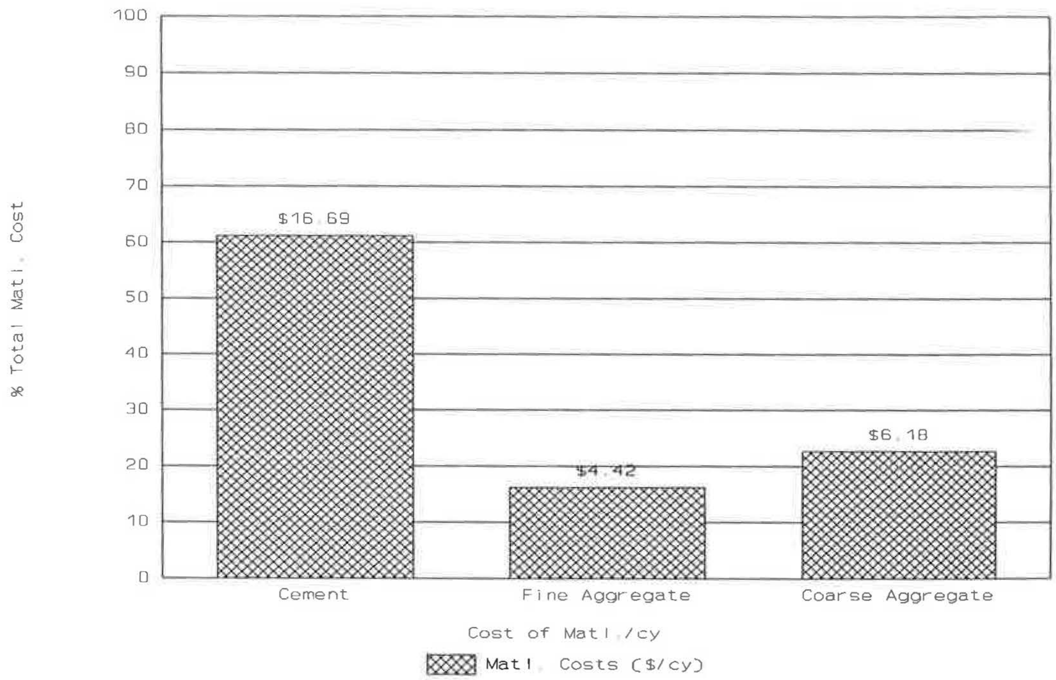


FIGURE 2 Concrete material cost comparisons.

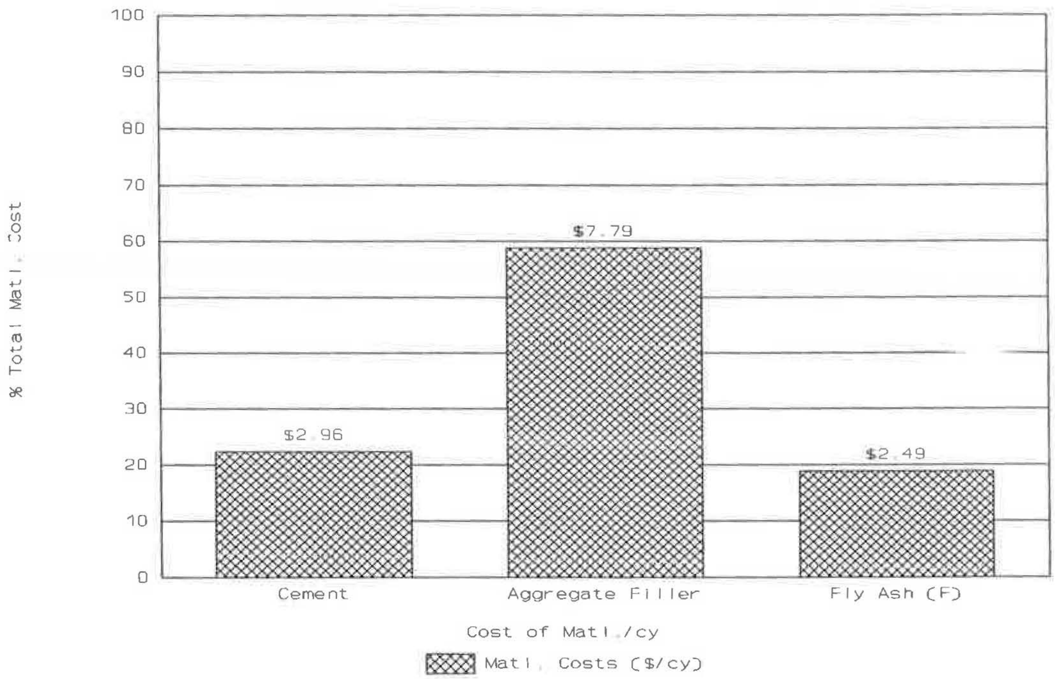


FIGURE 3 CLSM-CDF material cost comparisons (average).

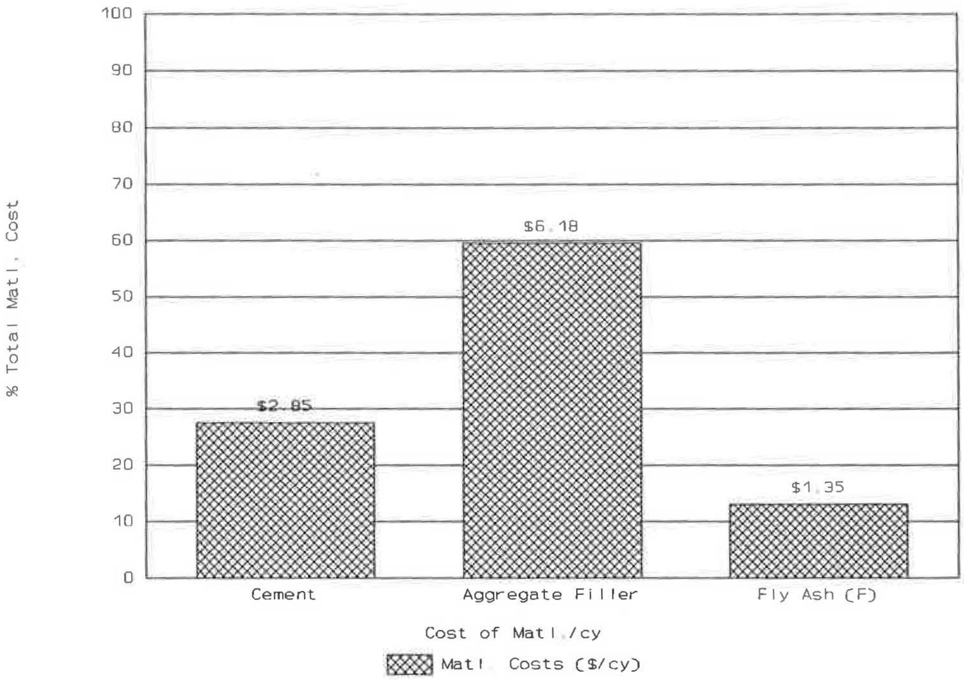


FIGURE 4 CLSM-CDF material cost comparisons (minimum).

TABLE 6 COST COMPARISONS—CLSM-CDF VERSUS CONVENTIONAL BACKFILL

Description	Quantity (Cu.Yd.)	Labor ($/Cu.Yd.)	Material ($/Cu.Yd.)	Total ($)
<u>Granular Backfill - Air Tamped</u>				
Material & Labor	26.67	14.00	8.00	586.74
Testing 6" lifts		($ 250/day...1 day)		250.00
Total Cost				836.74
<u>CLSM-CDF</u>				
Material	26.67	(no labor)	28.76	767.03
Testing		(Flat fee - 2 cylinders)		100.00
Total Cost				867.03

Note: Quantities based on a trench 3' wide, 6' deep, and 40' long.

Every 1' reduction in trench with, in this example, would represent a backfill cost reduction of $ 255.64 when using CLSM-CDF. The trench width reduction would be possible because conventional compaction requires additional access width around the conduit.

estimated costs shown in Table 5 do not reflect any adjustments for these reductions.

CLSM-CDF COSTS COMPARED WITH THOSE OF CONVENTIONAL BACKFILL

The cost of using CLSM-CDF in place of conventional backfill has been debated by many CLSM-CDF producers and contractors. The economy of using CLSM-CDF depends on the specification enforcement of the conventional backfill method and the cost of backfill materials. Using the costs for CLSM-CDF given in Table 5, an illustrative comparison between conventional backfill and CLSM-CDF will be made.

Consider a roadway trench with the following dimensions: width, 3 ft; depth, 6 ft; and length, 40 ft. The total backfill material requirement is 26.67 yd^3 less the pipe's displaced volume. Cost comparisons are given in Table 6, which indicates that CLSM-CDF is comparable with conventional backfill costs where compaction in lifts is required. Conventional backfill unit costs in Table 6 were supplied by the Area Paving Council, Toledo, Ohio. An additional cost advantage would be realized for CLSM-CDF if the contractor considered OSHA regulations and total construction project time. Naturally, any reduction in trench width due to backfilling around and under a conduit would also favor the use of CLSM-CDF. For example, every 1-ft reduction in trench width in this example represents a backfill cost reduction of $255.64 when using CLSM-CDF. The trench width reduction is possible because conventional compaction requires additional access width around the conduit.

RESPONSE TO TELEPHONE SURVEY

After the contact with the initial 5 ready-mixed concrete producers, who assisted in providing material costs information,

TABLE 7 CLSM-CDF SURVEY RESULTS

Company Reference	Survey Response
1	Company is now under new ownership and never heard of controlled low strength material.
2	Didn't know about controlled low strength material but recommended 3 bag grout. Had no idea about removability.
3	Didn't know about controlled low strength material, recommended using 4000 psi concrete.
4	Didn't have such a product.
5	"The product we sell is called K-Krete. Need strength of 100 psi or less for removability."
6	"Can sell you low strength fill. You'll need strengths of 500 to 1000 psi for removability."
7	"We have a product called Fill Crete. Can't tell you about strength, but you shouldn't drive on it."
8	"We don't have such a product." Suggested I call company referenced as "5".
9	"We have flowable fill but can't tell you anything about compressive strength...call back later."
10	"Yes, we can supply. You'll need at least 500 psi strength. Our product is called U-Crete."

Note: Same question asked of each ready mixed concrete producer.

"Do you have a product to backfill a washed out area under a floor? I've heard of a flowable, controlled low strength material that could be used. If so what would be the estimated 28 day compressive strength?"

another 10 ready-mixed concrete producers in Ohio were contacted. The second group was from a different area in Ohio. The 10 producers all sold to the same market area. The survey results are given in Table 7 and indicate the need for the dissemination of information about CLSM.

SUMMARY

The purpose of this paper was to furnish a cost determination method for CLSM mixtures. During its preparation, other problems were discovered:

- Lack of general knowledge about all CLSM mixtures by ready-mixed concrete producers,
- Misunderstanding by contractors about how a CLSM mixture could help reduce construction costs,
- Unrealistic pricing of CLSM mixtures by ready-mixed concrete producers, and
- Limited knowledge in the construction industry about the use of fly ash in various construction materials.

The cost determination method provided should help establish a realistic and competitive price for all CLSM mixtures. The major cost factor for CLSM is the aggregate filler. The finding of a suitable, less expensive, nonstandard aggregate filler material can result in a satisfactory product at a low cost while conserving other building materials.

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