FLOWABLE FILL FOR STREET AND HIGHWAY APPLICATIONS

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WHAT IS FLOWABLE FILL?

Flowable Fill is one of many names given to a class of materials now called Controlled Low Strength Materials (CLSM) by the American Concrete Institute. CLSM is any combination of granular material, cementitious material and water which will acquire a 28-day compressive strength of 1,200 psi or less. Other names used sometimes are flowable mortar, controlled density fill, K-Crete, or plastic soil-cement. It is most often a fluid mixture that will flow into excavations and cavities, around conduits and under overhangs, and level itself; hence the name, Flowable Fill. Once in place, it will consolidate itself and then slowly gain strength that is low compared to concrete mixtures, but high compared to compacted soils. Its fluid, self-leveling characteristics make it ideal for backfilling excavations, bedding utility conduits, filling abandoned tanks or mines; and its adjustable strength makes it useful for structural fills, mud slabs and pavement base repairs.

COMMON APPLICATIONS

The most common applications for Flowable Fill are backfilling excavations where normal consolidation of the backfill is unacceptable, such as utility excavations within a roadway. It has been used when sewer or water main construction is within a pavement, and it is ideal for rapid repair of maintenance excavations. It is also used for service line trenches that cross pavements. It is also used successfully for backfilling bridge abutments in order to avoid the usual subsidence of approach slabs.

Other ideal applications are in inaccessible places where compaction is difficult or impossible. Multiple culvert installations have voids between them that cannot be compacted, and excavations that undercut pavements or foundations present backfill problems.

In Iowa, the state DOT has developed a procedure for replacing old, narrow bridges without interrupting traffic, using what they call flowable mortar. A large culvert of adequate hydraulic capacity and proper length is placed under the bridge, and then flowable mortar placed through holes in the bridge deck fills then voids between culvert and bridge and flows out on each end until stopped by temporary dams of sandbags. When the culvert is stable, the side rails of the bridge are removed, and the roadway is widened to standard width with pavement and shoulders on top of the hardened flowable mortar.

A use that has become popular recently is the filling of potholes in asphalt pavement to provide a smoother surface before constructing a concrete overlay.

Flowable Fill is also used for stabilizing abandoned mines, filling abandoned sewers and manholes, and neutralizing abandoned underground storage tanks. It is used as structural fill where unstable earth is encountered at building sites. The poor material can be removed and replaced with Flowable Fill to provide foundation support.

ADVANTAGES / COST EFFECTIVENESS

Flowable Fill's primary advantages are that it completely fills voids, levels itself, and will not consolidate after it stabilizes. It can be placed very quickly without compaction and without inspection, and it can be paved over in just a few hours. Its strength can be adjusted to make it strong enough to carry structural loads, or to make it weak enough to allow easy removal for utility repair. Because it does not require men and equipment in trenches to compact it, the cost of shoring and bracing excavations is reduced significantly. Because it stays where it is placed, the costs of call backs, complaints and settlement repairs are eliminated; and liability exposure is much less.

Some of these costs savings can be accurately estimated, such as increased production, reduced inspection and testing costs, and elimination of shoring during compacting. Other savings, such as those realized by reduced liability exposure, extended pavement life, and reduced numbers of complaints and call backs are real but difficult to determine.

CONTROLLING PROPERTIES & COSTS

The abilities of Flowable Fill to flow and gain strength depend on the combinations and amounts of aggregates and cementitious materials used. The cost is affected by these factors, market acceptance, and competition. Aggregates and flyash used in Flowable Fill do not have to meet the same standards as materials used in concrete, but unless there is a consistent demand for the materials, producers cannot economically justify equipping themselves to utilize low cost materials. Cement content is a cost factor, but the amount used is usually very low. Concrete, sand and water make up most of the volume and are relatively cheap in most places. The cost factors for Flowable Fill are the same as for concrete are truck and driver time and plant operation. The cost of Flowable Fill is usually less than that for lean concrete if concrete producers understand the material and recognize the advantages to themselves in encouraging its use. In areas where the material is not widely used, the cost may be close to that of lean concrete. Nevertheless, if its many advantages are fully evaluated, it will be a cost effective material for many applications.

FRESH MIX PROPERTIES OF CLSM

Workability/Flowability

Flowability is one of the properties of CLSM that make it very suitable as a fill material. It enables the material to flow and fill voids, self-compact, and self-level. In fact, the ability of CLSM to flow is more important than the strength development. The total amount of water required to reach a certain flowability depends on some properties of the mix components. These are gradation of both fly ash and sand, shape and texture of sand particles, and size of fly ash and sand particles. However, the most important to design the CLSM mix is the compatibility between the sand and fly ash particles. Sand with high fineness modulus will have a tendency to form a mix with more bleeding water and particle segregation.

A very fluid mixture of CLSM has a major problem with hydrostatic pressure. However, this material can be placed in lifts and allowed to harden before placement of the next lift. For pipe bedding, placing CLSM in lift prevents floating the pipe. Sandbags or other weights can be used to ballast the pipe until the CLSM sets. Another solution is to design the proper mix of CLSM so that minimum water content and high flowability can be achieved and the CLSM can be placed in lifts.

Flowability of CLSM can be measured using standard slump cone (ASTM C-143), flow cone (Corps of Engineers Specification CRD-C611), and 3" x 6" open ended cylinder spread test. Flowability for a stiff CLSM mix can be measured easily with the standard slump cone; very fluid CLSM can be measured with the flow cone, and CLSM mix with sand as primary filler can be measured with the open ended cylinder spread test. The spread for normal use CLSM is 8 inches. It is flowable enough to fill the voids, self-leveling, and self-consolidating.

Segregation

In slurry-like materials, separation of particles based on their sizes in the mix can occur in a very flowable mix, especially if the flow is enhanced by adding more water to reach a certain flowability. However, proper proportioning of the components in the CLSM can improve the concentration of particles in the fluid and segregation can be minimized. In slurry, when concentration is raised to a value where the interparticle distance between the coarser particles is less than the diameter of the smaller ones, then no segregation takes place. When this occurs, the large particle matrix mechanically holds the finer particles within its structure.

In CLSM, the amount of fly ash should be increased because if the distance between the coarser particles is less than the diameter of the smaller ones, then the coarser particles might be in contact with each other. This is a disadvantage for flowability of CLSM. To have a good proportion with less segregation and high flowability, the amount of fly ash should be in a certain level where very minimum segregation will occur among the fly ash particles only. As in the requirement for flowability, the compatibility of sand and fly ash should be reviewed before use.

Subsidence/Bleeding

Decreasing volume of CLSM when water and air are released because of consolidation of CLSM can commonly occur. Especially a mix with high water content, subsidence of 1/8 to 1/4 inch per foot of depth have been reported. A mix with good proportion and low segregation has negligible subsidence. Some attempts have been made to decrease the subsidence and bleeding by using air voids (air entrainment). However, a mix design with high water content cannot decrease the bleeding and subsidence by adding air bubbles, rather it increases the bleeding and subsidence.

Set Time (Hardening Time)

There are two different stages in early strength development of CLSM. Stiffening Stage, which indicates that the CLSM is beginning to develop cohesion; and Hardening Stage, which indicates that the CLSM has hardened to the point at which it can sustain some load. Presently, only the hardening stage is recognized. This is two to three hours after the cement is in contact with the water, when the CLSM can sustain foot traffic without surface depression. The time from the start of mixing to the stiffening stage is greatly influenced by the rate excess water leaves the mixture and the hydration of cement. The time to reach the hardening stage depends primarily on the hydration of cement and a small influence from particle friction because of the departure of the water.

Increasing the amount of cement can decrease the time to reach both stages, especially the hardening stage, but it will increase the strength. If low strength is a major concern, the cement content should be kept low by creating a harsher mix. A mix low in fly ash and cement can keep the strength low and can make the hardening time a little bit shorter. However, that certain mix will make the flowability low, and increase bleeding.

HARDENED PROPERTIES OF CLSM

Strength

Fly ash, sand, and in some cases, coarse aggregates are selected for their ability to flow, rather than for their contribution to strength. The major contribution to the strength are cement content, type of the fly ash, and degree of saturation of the hardened product. Higher cement content can easily increase the strength. Various strength criteria for CLSM have been developed.

For backfilling purposes that require future removability, strength lower than 100 psi is suggested. A major problem with CLSM strength has been the development of higher strength than required. Class C fly ash can give strength far higher than expected. Class F fly ash with high reactivity and smaller prticle sizes can also increase the strength. Degree of saturation also influences the strength. Highly saturated CLSM can have a strength of 75% less than expected.

Long term strength development for CLSM depends on the type of fly ash used. Highly reactive fly ash will develop strength immediately after mixing it with cement and water. The strength in 28 days for highly reactive fly ash will not be much different than the strength in one year. Slowly reactive fly ash barely develops higher strength after 28 days. This is because the cement is already hydrated almost completely and later on fly ash class F alone can not develop strength.

Durability

Most CLSM applications are not designed to resist freezing and thawing conditions. However, in some applications, the CLSM is susceptible to freeze and thaw deterioration. Some previous works stated that CLSM can perform effectively as granular fill in freezing and thawing conditions. At least one application in water front structure using CLSM as a granular fill has been rated successful. The CLSM does not disintegrate to particles but into pieces the size of a hand. Stronger CLSM can perform perfectly well in freezing and thawing conditions. CLSM with a strength higher than 150 psi performs excellently in freezing and thawing tests in saturated condition. Air bubbles also help protect the CLSM from deterioration of freezing and thawing. For CLSM with a strength lower than 100 psi, there is no problem with cracking and disintegration. The deterioration of lower strength CLSM is mostly scalling on the surface. Even if scalling occurs, the particles are already compacted during placement. Settlement caused by deterioration is not likely to occur even for lower strength CLSM.

PROPORTIONING CLSM

Properties of the sand and fly ash fillers are the most important in order to design a mix for CLSM. Table 1 shows an example of CLSM mix for general purposes. It has Stout class F fly ash, type I cement, and sand with fineness modulus of 2.67. That particular mix has a spread of 5 inches using the 3" x 6" open ended cylinder spread test. It has been tested for freeze and thaw and it performs excellently.

Figure 1 shows the relationship of water content and fly ash content to design higher flowability CLSM with minimal bleeding and segregation. There are three types of sand, based on the fineness modulus. Concrete lab sand with fineness modulus of 2.67, Elkhart sand with 2.69, and Washington sand with 2.74. Stout fly ash has a commonly found particle distribution based on sizes. Figure 1 shows that the higher the fineness modulus (coarser) the sand the more difficult it is to create a good mix design. Washington sand with higher fineness modulus has more bleeding water and segregation compared to the other sands. The flowability was measured using the 3" x 6" open ended cylinder spread test.

Figure 2 shows all three types of sand with Schahfer fly ash. The average particle size of Schahfer fly ash is very small; 100% of the particles are smaller than 45 microns. It shows that smaller fly ash is more compatible with different types of sand even with higher fineness modulus. However, fly ash of this kind is not commonly found in the market. Most of the fly ashes have the gradation of that of Stout fly ash.

HOW TO SPECIFY

At the present time there is no standardized approach to specifying Flowable Fill. The most important characteristic to control in many instances is maximum strength, to assure easy, future removal of the material; so simple performance specifications are sometimes written. Prescription specifications spelling out estimated amounts of cement, flyash, aggregate and water; along with quality requirements for the materials; and some control on the flowability are also common with governmental agencies. In some markets where the material is used routinely, producers offer a selection of mixtures with different properties. For example, in Lincoln, Nebraska, a ready mixed concrete producer offers five standard mixtures with 28-day compressive strengths ranging from 100 to 1,200 psi. In Indiana, anyone who wants to use Flowable Fill but is not familiar with it can be confident of success if the material is ordered to conform to INDOT's Standard Specification Section 213. Later, adjustments and modifications to the proportions can be made if they are advantageous.

Table 1. -- Mix Design of Typical CLSM

MIX TYPE	1
DESIGN STRENGTH	80 psi.
ACTUAL STRENGTH	80 psi.
FLY ASH	F (Stout)
NOTE	Control

MIX (per cubic yard)	**Weight (lbs)**
CEMENT (C)	63.00
FLY ASH (P)	321.00
SAND (FA)	2774.00
WATER (W)	494.00
TOTAL	3652.00

RATIO	
W/C	7.84
W/(C+P)	1.29
W/(C+P+FA)	0.1564
P/FA	0.1157

BLEEDING	
Time (minutes)	**Bleeding (%)**
10	7.21
20	5.71
30	1.69
40	0.53
70	0.42
100	
130	
160	
190	
Total	15.56

UNIT WEIGHT	
Unit weight (lbs/cu.ft)	134.00

STRENGTH			
Cylinder No.	**3 days (psi)**	**7 days (psi)**	**28 days (psi)**
1	19	29	75
2	21	31	81
3	21	30	83
Average	20	30	80

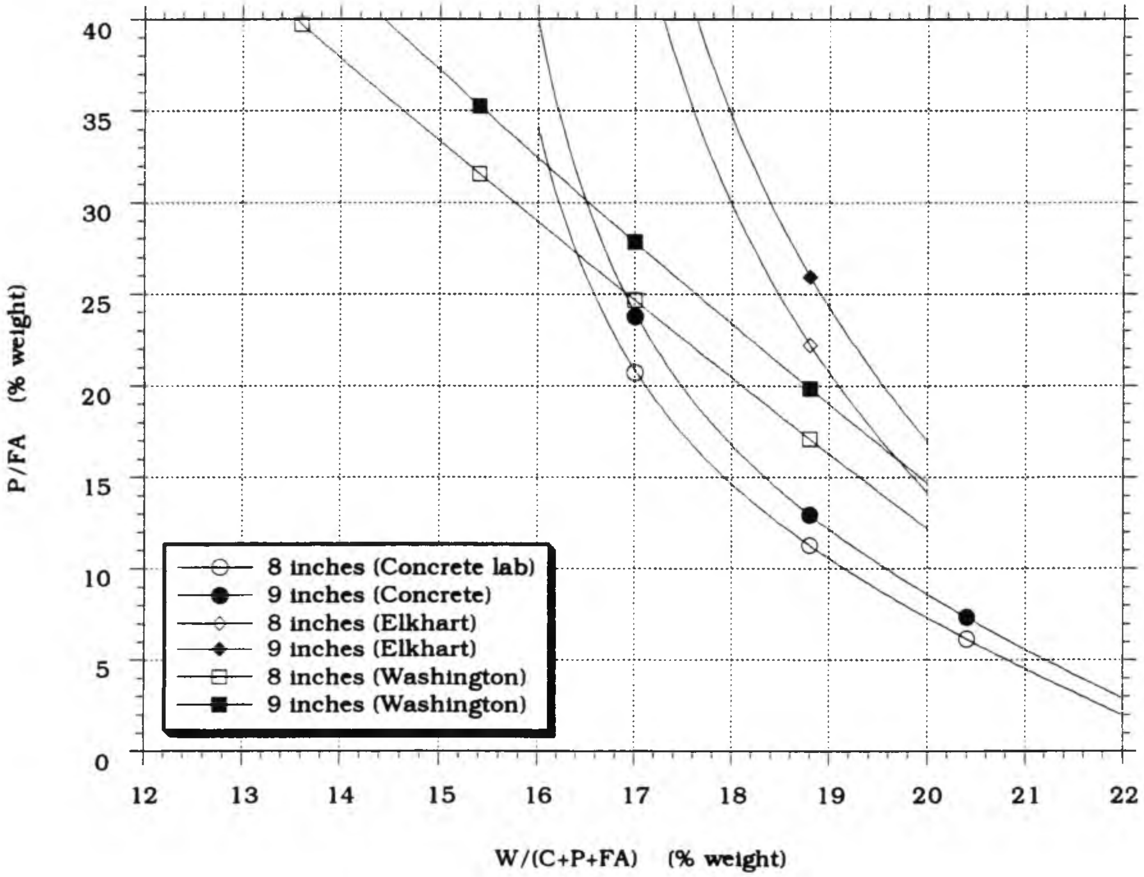

Figure 1 -- Flowability of all sands + Stout fly ash

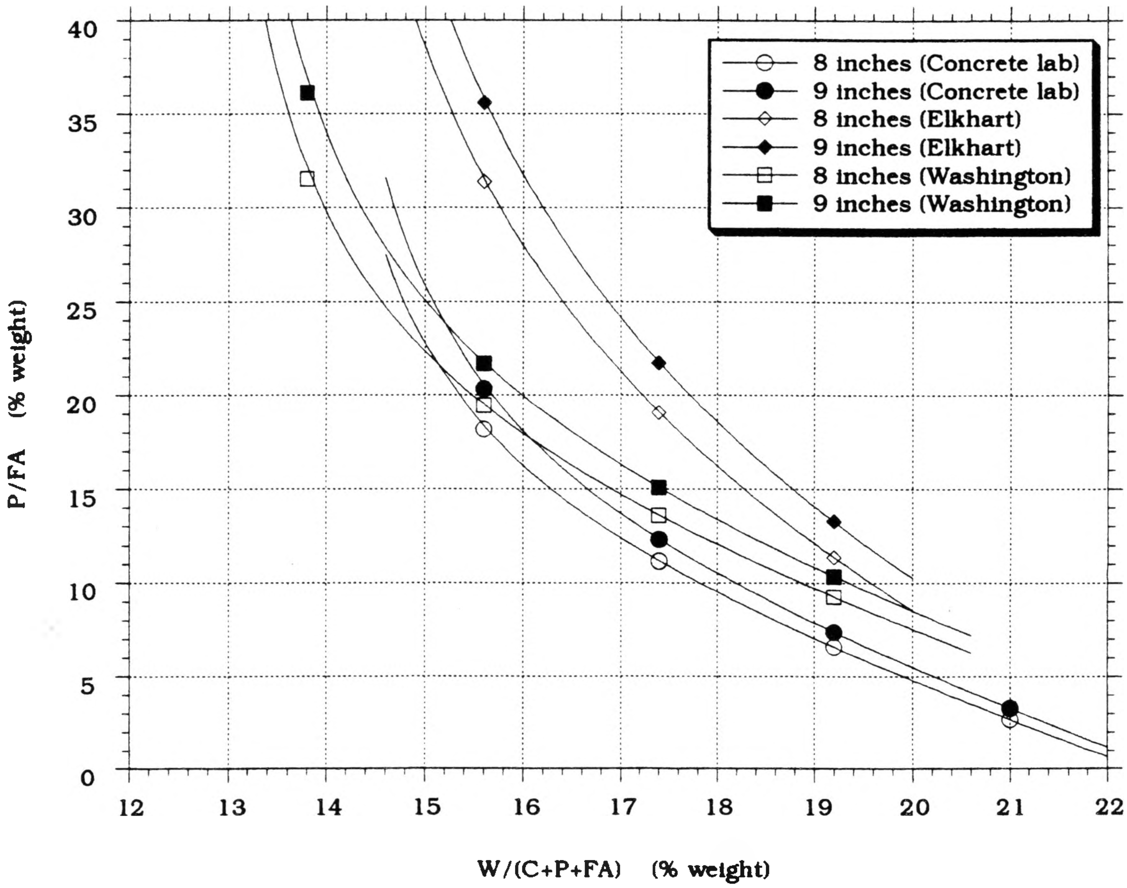

Figure 2 -- Flowability of all sands + Schahfer fly ash