Flowable Fly Ash

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This paper identifies many of those features that distinguish flowable fly ash from other backfill materials, both conventional and controlled low-strength materials (CLSM). The physical properties of the flowable fly ash (using Type F ash) that are discussed are also provided with physical units that define these same properties. These characteristics include its resistance in both a fresh plastic and a hardened state to erosion from flowing water; this resistance to erosion from water normally allows the material to be placed directly into water without the need for tremies. Flowable fly ash, using either dry or conditioned fly ash, can be mixed in ready-mix trucks, pug mills, or turbine mixers. Flowable fly ash can be placed by chutes from ready-mix trucks, by end-dumping from conventional trucks or conveyors, or by pumping. The material can be competitive in cost and has been used in many applications in which its advantages in properties, scheduling, and elimination of hazards to manual labor have far outweighed those of other conventional backfill materials.

Detroit Edison, Detroit, Mich., was the first utility to burn pulverized coal. The company also used electronic precipitators to capture the fine fly ash particles from the stack gases. To capitalize on this by-product, Detroit Edison looked for ways to commercially use this new material. They introduced use of this by-product into the production of concrete, becoming pioneers in the specification that became ASTM C-618. Then, along with Kuhlman Ready-Mix as co-sponsors, they developed K-Krete, the forerunner of the "controlled low-strength materials" (CLSM), now considered under American Concrete Institute's Committee 229. Detroit Edison then developed "flowable fly ash," which has all the properties of a CLSM, but also has additional unique characteristics of its own, and which uses a Type *F* fly ash (*1*).

Flowable fly ash was first developed to use as a backfill material to be placed into deep flowing water. Local granular backfill materials have become harder to obtain, and the cost has been rising. The use of fly ash for a backfill material resulted in two big advantages: it used a by-product that had been wasted, thus helping the environment, and provided a low-cost construction material. The material not only serves as conventional backfill material but also has some additional desirable characteristics. A trial program began in 1979 and consisted of an embankment constructed in flowing water 20 ft deep. Flowable fly ash has been used both on land and in water with excellent succcss. In this discussion, only Type *F* fly ash is considered.

BACKGROUND

Fly ash is available in quantity from coal-burning utilities. It is a very fine material (similar to portland cement) that is captured from the stack gas stream with emissions control equipment. It ranks sixth by weight of minerals produced yearly in the United States, following stone, sand, gravel, coal, iron ore, and Portland Cement. Flowable fly ash is placed at a stiff plastic to a fluid consistency. It consists of Type *F* fly ash, water, and a small amount of Portland Cement. The design mix is as follows:

1,800 lb of dry fly ash,

90 lb of portland cement,

±80 gal of water,

±7-in. slump.

YIELD

Many ready-mix companies prefer to deal in quantities of yield and cubic yards of material delivered. The total weight of the flowable fly ash mixture given above is 2,556 lb. The net weight of the material varies from plant to plant but generally ranges from about 100 to 105 lb/ft^3. With a unit weight of 102 lb/ft^3, as an example, this mixture would yield about 25 ft^3.

Most conventional backfill materials are charged to a project based on the number of tons delivered. Once the wet unit weight has been established, flowable dry ash can be delivered and costed to a project by similar units. Flowable fly ash eliminates the constant quarrel about price that exists with other conventional backfill materials when they have been delivered to a project either too dry, too wet, or of questionable gradation. The following is also true about fly ash:

1. Flowable fly ash can be used as a fill material in place of compacted soils or granular materials. In addition, it can be placed directly into water or wet conditions and it can be placed by pumping or conventional methods.
2. Dry fly ash obtained directly from ready-mix hoppers has been used, but fly ash conditioned with water to control dusting can be obtained directly from power plants at a fraction of this cost.
3. Flowable fly ash can normally support the weight of a loaded truck within the first 24 hr. In hot weather, it has supported trucks and construction loads in a matter of a few hours.

PRELIMINARY INVESTIGATION

Fly ashes vary because of the type of coal burned and the type of furnace used to burn the coal. Detroit Edison has conducted numerous tests on their own fly ash and also managed a program for the Electric Power Research Institute, which was concerned with a wide base of fly ashes, both

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geographically and with respect to physical qualities. All of the tests indicate a general similarity in the performance of Type *F* fly ash when used as flowable fly ash.

Producers should test local materials before supplying a project. A common-sense program can be done at a minimum cost. Experience has shown that the engineer and contractor both need to develop a feel for the material to take full advantage of its properties. The following are some particular cautions:

- Moist, conditioned ash can hang up in hoppers, which is not a problem unless it is not anticipated.
- Pumping flowable fly ash requires that the concrete pump be in top shape. Leaky gates just do not work.
- The finish surface is not a wearing surface. It will tend to abrade and eventually dust under traffic conditions.
- Droppings on roadways should be avoided as this may also result in dusting.
- Contractors should be aware that when it is wet, the surface will be slippery, similar to a clay. Any coarse-grained material can be spread on top to control this condition.

MANUFACTURE OF FLOWABLE FLY ASH

Flowable fly ash has been successfully produced in pug mills, concrete ready-mix trucks, concrete central mix, and pan turbine mixers.

Quality Control

The burden of ensuring the proper cement content and mixing should be the producer's. Field controls should include compressive tests on 2-in. cubes and the performance requirement that it support the weight of construction equipment. Tests on various-sized samples in this strength range indicate that the 2-in. cube strength is comparable to a standard concrete cylinder of 6-in. diameter by 12-in. length and does not require any correction factor as in the case of concrete testing.

Testing

Flowable fly ash should be tested. First, 2-in. standard cubes should be taken to determine the 28-day strength. Various-sized specimens have been used and, in this strength range, the results have been found to be comparable. Although the standard 6-in. cylinder has been used on projects, it has been determined that the standard 2-in. cube is virtually trouble free. The 2-in. cube requires little storage space and often can be tested on simple soil compression machines.

It should be noted that a typical mix using 5 percent Portland Cement of the dry weight of the fly ash was established for the convenience of the contractor. Most soil procedures use the percent of cement as that of the total weight of all the material. This means that a flowable fly ash using 5 percent Portland Cement by dry weight of fly ash is approximately equal to 2.3 percent Portland Cement based on the total weight of all materials as would normally be reported by a soils laboratory. The point made here is that if the designer compares either costs or materials all elements must be compared on a basis of equal units.

Slump

Slump is measured with a standard slump cone. Its use is limited to the start of a project where it serves to help the contractor get a feel for the proper consistency of the flowable fly ash. After the proper consistency is determined, the slump becomes self-policing, and seldom is it necessary to use it as a field control.

Strength

Unconfined compression tests of flowable fly ash using Type *F* fly ash at 28 days containing 5 percent Portland Cement (by dry weight of fly ash) will show values of about 100 psi. This value is better than 7 tons/ft^2, which is considered superior to a good backfill material that would have a bearing strength from 3,000 to 4,000 lb/ft^2. Flowable fly ash also ensures uniform placement of the material, which is not always the case with conventional compacted materials.

Flexural tests of flowable fly ash indicate that the modulus of rupture (tensile value) is high and is often equal to its compressive strength. This characteristic is not unusual in low-strength cementitious materials. The strength varies with the moisture and the cement content, and for that reason, no value is offered. The tests indicate, however, the slab action provided by the material and the reason it can bridge over soft spongy soil areas.

The subgrade modulus for the design of paving is 50 times the unconfined compressive strength, which is superior to most other sub-base materials (*2*). Its high value indicates that it is better than any backfill that it would replace. The subgrade modulus of a good base course is often assumed to be 500 lb/in.^{3}, and flowable fly ash is 5,000 lb/in.^{3} or over.

Erosion Properties

Field placement has shown that flowable fly ash resists erosion in both its plastic and hardened state. No test (either physical or environmental) could be found that identified the loss of materials when placing backfill in water. A tank was constructed with water being pumped continuously pasts a sample of material being tested. This test was developed to compare materials and determine how they would affect water quality. The flowable fly ash proved to be better than the other backfill materials (Table 1). Clean rock fill is probably the only other material that could achieve these results. This property of flowable fly ash when used as a backfill placed under water should eliminate the need for silt curtains, containment by weirs, and other environmental concerns.

The fly ash and the cement particles are approximately the same size. For this reason, segregation does not occur even when the flowable fly ash is placed through water. In deep flowing water, it would not be difficult to use a tremie for placement of the material if it is required.

Corrosion

Most fly ashes are alkaline. In addition, the 28-day compressive strength is dependent on the action of the Portland Cement,

TABLE 1 TEST FOR EROSION OF VARIOUS FILL MATERIALS

	EROSION TEST	
Material*	% of Sample In Suspension	% Total Sample Loss
Silica Sand	1.6	10.0
Coarse Sand & Gravel	2.7	11.4
Fill Sand	8.3	44.9
Clay	8.9	22.6
Flowable Fly Ash (Fresh Plastic)	0.7	1.3

Obtained from local construction sites

which is also alkaline. The basic alkalinity of the fly ash, along with the enhancement effect of Portland Cement, provides the same beneficial properties as concrete. The flowable fly ash is an ideal environment to inhibit the rusting of iron and steel.

Compaction and Density

Compaction tests were run in accordance with the ASTM D-1557 modified proctor test on individual mixes using 5 percent Portland Cement. It was found that the flowable fly ash attained a density equivalent to 85 percent of that obtained by using the full compactive effort of the test. This property allows the flowable fly ash to be loaded by construction equipment soon after placement. The continuance of the pozzolanic cementing action, along with the hydration of the Portland Cement, provides additional strength. The user should be aware of the following rule of thumb when comparing costs on a given project: 1 ton of fly ash is equivalent to about 1 yd^3, and this volume requires about 1.5 tons of granular material.

TRANSPORTATION AND PLACEMENT

Flowable fly ash has been placed by end-dumping and chuting from ready-mix trucks. The material also has been placed from conveyor lines and by pumping. In its first application, flowable fly ash was end-dumped and then bulldozed into water depths up to 20 ft. Its placement method is limited only by one's imagination.

Freeze-Thaw Resistance

The material has been used with success in several waterfront installations on the Detroit River. When placed in a zone of total water saturation and subject to severe winter freezing at well below 0°F, flowable fly ash broke into pieces about the size of a hand. Sacrificial thickness was provided to allow for this loss, and the projects were successful. Without water saturation, flowable fly ash (Type *F*) at 5 percent cement content appears to perform well under freeze-and-thaw conditions in the field.

Laboratory freeze-thaw tests in water indicate that a cement content of about 10 percent should be used. However, vacuum saturation tests that were suggested by the Michigan Department of Transportation, indicated that the typical 5 percent Portland Cement mixture would perform well in a freeze-thaw environment. It is hoped that a field test that would provide practical proof of this will be done. All the evidence seen in the field to date indicates that the 5 percent Portland Cement mixture should perform as a road base under severe winter conditions.

Permeability

Although the permeability of Type *F* fly ash used in flowable fly ash varies depending on the source of the fly ash, tests on a number of ashes indicate that permeability ranges from 1.9×10^{-6} to 3.3×10^{-7}. This type of permeability places the material in the region of a poor clay soil. Although the use of the material in any environmental application should be checked at that site, laboratory tests indicate that at a 15 percent Portland Cement content (by dry weight of fly ash) can be considered suitable as a lining for landfill applications.

Vibration

Initially, it was felt that this Type *F* fly ash had great potential for use in atomic power plants. Today, economics indicate that this future market is dead. Consideration of cross-hole shear and column resonance tests to determine vibration characteristics of the flowable fly ash were abandoned because of the high cost of conducting such programs.

The initial application of the material was to support railroad tracks that would supply coal to a power plant. A simple test was recommended by the Construction Testing Laboratories. The test was to apply the load found at the bottom of the railroad ties under the full loading of a moving coal train.

No consideration was given to the beneficial effects of the ballast stone. This test concluded that a railroad embankment constructed with a fly ash stabilized with 5 percent cement could carry 620,000 wheel load applications. Loads were applied through a 6-in.-diameter steel plate. The block of hardened flowable fly ash was 12 in. deep and rested on a steel plate support with the lower 2 in. immersed in water. Loads were applied at a rate of 2.5 cycles per second. This test provided sufficient confidence that the material could be used under this vibration condition and would perform satisfactorily.

Ability to Be Dug

Flowable fly ash gains strength with age. Material having a 28-day strength in excess of 100 psi has been dug by a small backhoe at the end of a year's time. At this age, its strength was in excess of 300 psi. No consideration was given to hand excavation because the local construction people emphasized that this simply was not done in today's labor market.

Subsidence

Subsidence does occur with flowable fly ash, and in tests of a 12-in. depth, subsidence appears to be about 0.25 in. This drop or settlement occurs in a matter of minutes. Where the material has been placed in deep fills (12 to 15 ft), this effect is not noticed since time and pressure from new material being placed offset this decrease.

A check of the filling of tunnels and sewers and under slabs indicates that subsidence is not a problem and that tight contact for support can be easily accommodated during construction.

Segregation

Mixtures with slumps up to 10 in. have been placed without segregation. With the addition of more water, the mixture will release free water. Since most mixtures are workable below this slump range, segregation is not a problem.

When free water flows from a mixture, it does not appear to segregate. Most probably the reason segregation does not occur is because the fly ash and Portland Cement are close in size and generally do not contain a larger aggregate.

CASE HISTORIES

In selection of any construction material for use on a job, the effect of the material on costs should be considered. Although its costs vary with availability and the market, flowable fly ash offers many properties that cannot be found in other materials, such as erosion resistance, ability to be placed in water, minimum testing costs, elimination of compaction, and other advantages. The following case histories (*3*) are offered to suggest some of the cost items, beside those of direct material costs that should be considered.

The first case history is that of a six-story apartment building that was found to have pockets of soft material under the foundations. The contractor simply excavated these pockets; then at the end of his working day, he had flowable fly ash (Type *F*) chuted into these voids from a ready-mix truck. The next morning, his carpenters set forms and the footings were cast. Had he resorted to conventional material that required compaction, it would have taken days of manual labor and testing to get the correct material in place. In addition, this work would have seriously disrupted his construction activity. In this case, schedule alone had sufficient cost advantage to support the use of flowable fly ash as a backfill material.

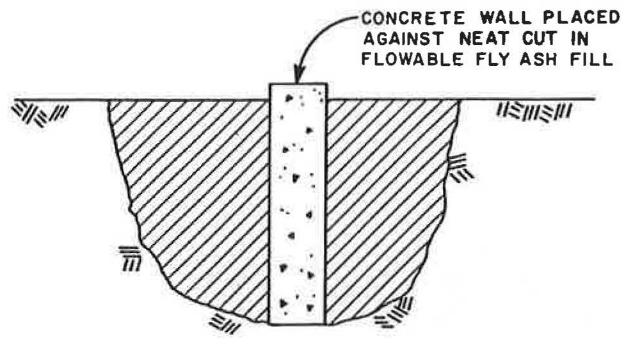

FIGURE 1 Use as formwork and support in caving soils.

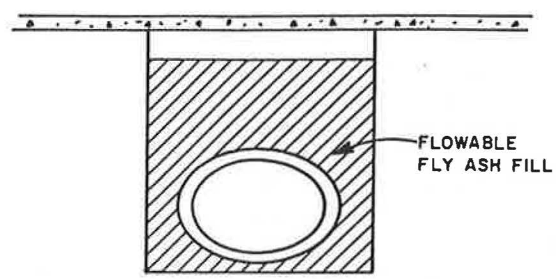

FIGURE 2 Settlement-free backfill around buried pipes.

The second case is that of a multistory office, hotel, and parking structure constructed on a site that consisted of old basements filled with loose materials including bricks, broken concrete, and timber. During excavation, this material was collapsing, creating a wide irregular trench that required form work to cast concrete foundation walls. Flowable fly ash was rapidly placed in these oversized trenches. On the following day, the neat excavation for concrete placement was accomplished (Figure 1). This procedure saved both schedule and money and allowed the walls to be constructed by the subcontractor without change in the original contract.

The third case shows a common use of flowable fly ash in the filling of various utility cuts (Figure 2). When conventional backfill materials are used, the trench must be wide and sloped back to allow room for equipment to compact the material, and to provide for the testing that should be done. In spite of these precautions, dips and cracks often show up in cuts made through roadways. Here, as long as the material can be seen to flow under the pipe, good bedding is provided. The use of flowable fly ash does away with future settlement, minimizing both the amount of excavation and the amount of backfill material required. Inspection costs are also reduced.

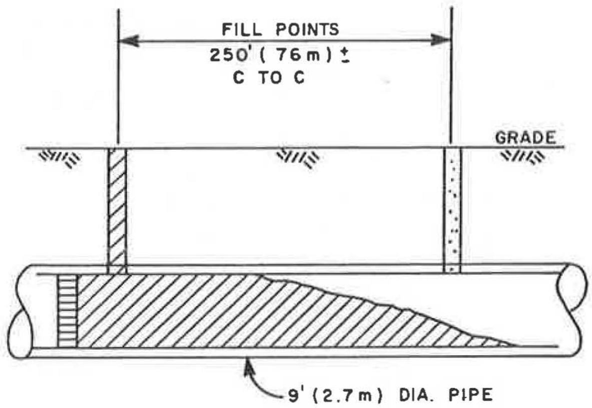

FIGURE 3 Structural fill of underground enclosures.

The last case history is illustrated by Figure 3. Flowable fly ash has been used to fill abandoned gasoline tanks, tunnels, pits, and sewers. In this instance, the material was used to fill an abandoned sewer under a new automotive plant. The fill points were drilled about 250 ft apart. After flowable fly ash was placed in one point, the air was vented at the next point 250 ft away. That point, in turn, became the next fill point. Drilling after placement of the flowable fly ash served to check that the method was successful.

CONCLUSION

This paper was prepared for the Transportation Research Board's annual meeting held in January 1989. This particular session was concerned with "Controlled Low-Strength Concrete," now represented by the American Concrete Institute's Committee 229.

The author has strived to present sufficient technical information that can be used in the design of a fly ash backfill or other installation. The information presented should serve to provide a sound background to design most proposed projects. Other testing has been done for specific projects. Only a few of the available case histories have been presented in this paper (*3*). Much has been learned on each new application of the material.

The use of flowable fly ash is not limited once it is used on a project. The imagination and creativity of the persons involved with it has propelled flowable fly ash into new and various uses. Its unique properties indicate that flowable fly ash has potential to perform well in many unusual applications. The state of the art is that the material can be used by the engineer for new projects, and in most instances only a limited amount of testing is necessary.

It would be appreciated if any new use, test, or other information on the application of flowable fly ash would be sent to the author, so this information can be made available to others.

REFERENCES

1. J. J. Funston, W. C. Krell, and F. V. Zimmer. Flowable Fly Ash: A New Cement Stabilized Backfill. *Civil Engineering—ASCE*, Vol. 53, No. 5, March 1984, pp. 48–51.
2. D. W. Bird. *Modulus of Subgrade Reaction Tests.* Internal Report. Detroit Edison, Detroit, Mich., January 1985.
3. J. J. Funston and W. C. Krell. Need a Dependable Backfill—Try Flowable Fly Ash. *Advanced Cementitious Products.* Presented at the Fall 1985 Convention of the American Society of Civil Engineers, Detroit, Mich., 1985.

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