



DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

1 AUG 2011

FROM: HQ AFCESA/CEOA
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SUBJECT: Engineering Technical Letter (ETL) 11-15: Repairing and Backfilling Earthen Structures with Flowable Fill

1. Purpose. This letter provides guidance on the use of flowable fill for repairing or backfilling excavations in earthen structures. Direction is provided on the mix design, characterization, and usage of flowable fill. A brief review of the research efforts that led to the development of this ETL is also provided.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Application. All Department of Defense (DOD) organizations responsible for conducting construction and repair activities requiring the backfill of open excavations.

2.1. Authority: Air Force policy directive (AFPD) 32-10, *Air Force Installations and Facilities*

2.2. Coordination: Major command (MAJCOM) pavement engineers

2.3. Effective Date: Immediately

2.4. Intended Users:

- Air Force Prime BEEF and RED HORSE units
- Army Corps of Engineers
- Navy mobile construction battalions
- Marine Corps engineer battalions
- Organizations performing DOD pavement repairs or maintenance

3. Referenced Publications.

3.1. American Society for Testing and Materials (ASTM) (<http://www.astm.org>):

- ASTM C33/C33M, *Standard Specification for Concrete Aggregates*
- ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*
- ASTM C989, *Standard Specification for Slag Cement for Use in Concrete and Mortars*
- ASTM D4832, *Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders*

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- ASTM D6023, *Standard Test Method for Density (Unit Weight), Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM)*
- ASTM D6024, *Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to Determine Suitability for Load Application*
- ASTM D6103, *Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM)*
- ASTM D6951/D6951M, *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*
- Crouch, L. K. et al, "Long Term Study of 23 Excavatable Tennessee Flowable Fill Mixtures," *Journal of ASTM International*, Vol. 1 (6), 2004, 5 November 2007

3.2. Other Industry:

- American Concrete Institute (ACI) 229R-99, *Controlled Low-Strength Materials*, ACI Manual of Concrete Practice 2008, Part 2, <http://www.concrete.org/bookstorenet/ProductDetail.aspx?SACode=22999>
- Du, Lianxiang et al, "Effects of Constituent Materials and Quantities on Water Demand and Compressive Strength of Controlled Low-Strength Material," *Journal of Materials in Civil Engineering*, Vol. 14 (6), American Society of Civil Engineers, 2002, pp. 485-495
- Lade, Poul V., "Instability, Shear Banding, and Failure in Granular Materials," *International Journal of Solids and Structures*, Vol. 39(14), 2002, pp. 3337-3357
- National Cooperative Highway Research Program (NCHRP) Report 597, *Development of a Recommended Practice for Use of Controlled Low-Strength Material in Highway Construction*, Transportation Research Board, 2008, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_597.pdf
- Wu, Jason Y., "Soil-Based Flowable Fill for Pipeline Construction," *Pipelines Magazine*, 2005, 5 November 2007, <http://www.ascelibrary.org/>

4. Acronyms and Terms:

ACI	– American Concrete Institute
ASTM	– American Society for Testing and Materials
C'	– 30-day unconfined compressive strength
CLSM	– controlled low-strength material
DCP	– dynamic cone penetrometer
DOD	– Department of Defense
e	– exponential (mathematical function)
ERDC	– Engineer Research and Development Center
ETL	– Engineering Technical Letter
ft ³	– cubic feet
kg/m ³	– kilogram per cubic meter
lb	– pounds
lb/yd ³	– pound per cubic yard

LN	– natural logarithm (mathematical function)
NCHRP	– National Cooperative Highway Research Program
PCC	– portland cement concrete
pcf	– pounds per cubic foot (lb/ft ³)
psi	– pounds per square inch (lb/in ²)
R ²	– coefficient of determination
RE	– removability modulus
UCS	– unconfined compressive strength
w	– dry unit weight
w/c	– water to cement ratio
w/s	– water to solids ratio

5. Preface. The U.S. Army Engineer Research and Development Center (ERDC) was tasked to develop guidance on the use of flowable fill for backfilling excavations in earthen structures. The objective of this project was to determine the state of practice with respect to flowable fill technology and develop guidance for using flowable fills to repair patches and utility cuts in pavements. The objectives of the project were accomplished by: 1) reviewing current published research on the application and testing of flowable fill; 2) developing mix design specifications for excavatable and non-excavatable flowable fill using different aggregate blends; 3) conducting a laboratory investigation to characterize pre-blended commercially available materials, typical ready-mix blends, and developed mix design blends; 4) investigating standard and non-standard testing procedures for in situ material verification and quality assurance; 5) constructing a demonstration section composed of simulated utility trenches to validate field performance of flowable fill materials; and 6) establishing repair best practices. Although the focus of the supporting research was pavement applications of the technology, relevance to all earthen engineering structures is implicit.

6. Background. Flowable fill is a highly viscous, grout-like, cementitious blend commonly composed of portland cement, fine aggregate, and water. Other materials such as fly ash, slag, foundry sand, bottom ash, and chemical admixtures are also commonly employed in flowable fill blends (see NCHRP Report 597, *Development of a Recommended Practice for Use of Controlled Low-Strength Material in Highway Construction*). Flowable fill can also be referred to as controlled low-strength material (CLSM), controlled density fill, soil-cement slurry, soil-cement grout, flow fill, unshrinkable fill, and K-Krete[®]. Flowable fill blends fall into one of two categories: excavatable or non-excavatable, determined by the ability of the material to be removed, using standard effort (shovels and backhoes), after hardening has occurred. Flowable fills can also be designed for traditional and rapid setting times depending upon the type and amount of cementitious materials and chemical admixtures used.

6.1. Common Applications. The use of flowable fill as a substitute for traditional soil or aggregate in backfilling operations is gaining popularity in the engineering community. Flowable fill is self-leveling and self-compacting and possesses other desirable properties, including flow under gravity, rapid hardening, strength selectability, material uniformity, and reduced construction requirements. Flowable

fill presents a backfilling option which requires less facility downtime for construction and repair. It also provides a cost-effective backfill material with equivalent or greater strength, consistency, and reduced potential for settling as compared to traditional backfilling methods. Flowable fill technology has been successfully employed in a number of engineering applications, including use as backfill, structural fill, pavement base, void fill, pipe bedding, and in reclamation projects for abandoned bridges and culverts.

6.2. Composing Materials.

6.2.1. Aggregate. Fine aggregate constitutes the largest portion of common flowable fill blends and is typically concrete sand designated by ASTM C33/C33M, *Standard Specification for Concrete Aggregates*. Gravel, crushed stone, and sand not conforming to ASTM C33/C33M have also been successfully used in flowable fills. Waste materials such as foundry sand (a byproduct of metal casting), bottom ash (a byproduct of coal combustion), and boiler slag (a byproduct of iron and steel making), have also been successfully used in flowable fill blends. The use of waste materials in flowable fill is both economically and environmentally beneficial, reducing the volume of solid waste disposal while preserving virgin sands and high-quality aggregate.

6.2.2. Portland Cement. Portland cement is a finely powdered, hydraulic material composed of calcium silicates, aluminates, ferrites, and gypsum. Cement is primarily used to create the strength and consolidation of flowable fill, but can also be used to increase the fines fraction, resulting in a denser, well-graded blend. Type I or II portland cement is typically used; however, Type III portland cement has also been used to achieve higher early strengths and to reduce subsidence potential (see NCHRP Report 597).

6.2.3. Supplementary Materials. Other supplementary cementitious materials, such as fly ash and blast furnace slag, are commonly used in flowable fill blends. Fly ash is an extremely fine, spherical material composed of silicon dioxide, calcium oxide, ferric oxide, and aluminum oxide that is a waste product of the coal-combustion process. Slag is a byproduct of the ore-smelting process and contains similar oxides and sulfides as fly ash. Similarly to the use of foundry sand and bottom ash, the use of supplementary cementitious materials is beneficial both economically (typically having a lower cost than cement) and environmentally (reducing the volume of these materials stored in landfills).

6.2.4. Admixtures. Chemical admixtures which have been employed in flowable fill blends include air-entraining agents, foaming agents, and set accelerators. The use of air-entraining and foaming agents increases the air content of the flowable fill blend, reduces the unit weight, decreases the potential for segregation and bleeding, and minimizes the water content, while at the same time improving the freeze-thaw durability relative to non-entrained CLSM. Set

accelerators have been used to decrease hardening time and also to reduce subsidence.

7. Mix Design. A standardized mix design procedure for flowable fill does not currently exist. The wide variety of materials used in flowable fill blends, in addition to application-specific performance requirements, makes a general mix proportioning procedure very difficult to develop. Mixture proportioning of flowable fill blends is largely done by trial and error until a mixture with the required properties is designed (see ACI 229R-99, *Controlled Low-Strength Materials*). The NCHRP Report 597 study on flowable fill proportioning concluded that CLSM mixtures of similar proportions behave differently in field applications due to differences in raw materials, mixing action, and placement techniques when compared to laboratory proportioned mixes. An effective mix design yields a flowable fill blend that is sufficiently fluid, rapidly hardening, achieves the required bearing capacity without excessive long-term strength gain, and is excavatable if the application requires.

7.1. The properties of flowable fill are greatly influenced by the constituent materials and proportions used in the mixture. Generally, flowable fill blends are composed of portland cement, water, and fine aggregate. Typical cement contents range from 50 to 200 pounds per cubic yard (lb/yd^3) (30 to 120 kilograms per cubic meter [kg/m^3]) (see ACI 229R-99). Increasing cement content increases strength, flowability, and cost while reducing initial setting time, permeability, and bleeding and subsidence potential. Typical water contents range from 325 to 580 lb/yd^3 (193 to 344 kg/m^3) (see ACI 229R-99). Increasing water content increases flowability, initial setting time, and potential for bleeding, subsidence, and segregation. The aggregate proportion of the flowable fill blend is usually determined by the remaining volume after obtaining desired cement, water, air, and supplementary material contents (e.g., fly ash, slag). However, the type of aggregate used is the most important factor in proportioning a flowable fill blend due to the significant influence it has on water demand, flowability, air content, and potential for segregation and bleeding.

7.2. Supplementary materials such as fly ash, blast furnace and boiler slag, and chemical admixtures are commonly used in flowable fill mix designs. Other materials such as foundry sand, bottom ash, and foaming agents have been used but are much less common. Supplementary material contents can range from 0 to 2,000 lb/yd^3 (1,200 kg/m^3) (see ACI 229R-99). Some mixes do not employ the materials while others substitute it for portions of the portland cement content, aggregate content, or both. Both Types F and C fly ash have been employed in flowable fill to increase flowability while decreasing permeability, long-term strength gain, and cost. Type C fly ash contains pozzolans and can be substituted for portland cement or aggregate while Type F is generally only used to supplement the aggregate content. Slag usage is very similar to fly ash. Blast furnace slag contains pozzolans and is used similarly to Type C fly ash. Boiler slag is most commonly used as an aggregate substitute. Air-entraining admixtures and foams have been used to increase excavatability and permeability while reducing unit weight and cost. Set accelerating admixtures can be used to reduce hardening time, segregation, and subsidence

potential. Foundry sand and bottom ash are generally used exclusively to supplement the aggregate proportion.

7.3. Mix Design Methodology. The trial and error mix design procedure begins by determining the required performance properties of the flowable fill blend. Strength, flowability, hardening time, and excavatability are the critical properties of a flowable fill blend and are most directly controlled by adjusting the water-to-solids and water-to-cement ratios (see Wu, Jason Y., “Soil-Based Flowable Fill for Pipeline Construction”). Using experience or industry information, mix designers develop proportions that incorporate the required portland cement and water to ensure flowability and strength, then supplementary items such as fly ash, slag, chemical admixtures, or foams are added to the blend, and the remaining portion is composed of aggregate. The blends are first tested to ensure that the flowability requirements are met. Cylinders are poured and cured for 28 days to measure the unconfined compressive strength (UCS) which provides insight into the strength and long-term excavatability of the blend. Test strips are poured to verify the flowability and monitor the hardening time. The constituent material proportions are adjusted using an iterative process until a flowable fill blend which meets all of the performance requirements specified by the particular engineering application can be developed.

7.4. Recommended Procedure. The following mix design procedure has been developed using data obtained from published research, in addition to experience gained from the supporting research project. Typical mixture proportions are presented in Table 1 for reference.

7.4.1. Select the parent material for the blend. The ideal material is a well-graded, low-plasticity, granular material. Materials conforming to ASTM C33/C33M standards are commonly specified. Care should be taken to select a well-graded aggregate. Well- or dense-graded aggregate blends are defined as those with particle size distributions which plot on or near the 0.45 power curve. If a well-graded aggregate source is not available, supplementary materials such as fly ash, slag, or additional aggregates should be blended into the parent material. Soils containing clays and organic materials should not be used in flowable fill blends.

7.4.2. Select a water to cement (w/c) ratio. The ideal w/c ratio is that which will produce a mix with acceptable bearing capacity without excessive long-term strength gain. The relationship presented in Equation 1 can be used to select an initial w/c ratio. The relationship has a coefficient of determination (R^2) of 0.61 and is based on historical data obtained from published research and mix designs developed in the supporting research effort. The 28-day compressive strength of designed blends should be limited to 150 pounds per square inch (psi) if excavation at a later date is required.

$$(w / c) = e^{\frac{LN \left[\frac{(28\text{-day UCS (psi))}{2,035} \right]}{-1.85}} \quad (1)$$

7.4.3. Determine the desired amount of supplementary materials. Supplementary materials such as fly ash and slag are waste materials that have been found in previous studies to be effective substitutes for the portland cement and fine aggregate fractions of a flowable fill blend. High quality fly ash conforming to ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, and blast furnace slag conforming to ASTM Standard C989, *Standard Specification for Slag Cement for use in Concrete and Mortars*, can be used to supplement the portland cement proportion. Additionally, fly ash and boiler slag can be used to increase the fines fraction of the parent material. Due to the variability of locally available fly ash and slag, specific guidelines for the use of these materials are not presented herein.

7.4.4. Determine the use and concentration of admixtures. Performance-modifying agents such as air entrainers, set accelerators, and foams have been used successfully in flowable fill blends. These materials, like fly ash, slag, and other waste materials, should be proportioned using experience and engineering judgment and tested prior to field application.

7.4.5. Select water to solids (w/s) ratio. The ideal w/s ratio is one that will produce a mix with acceptable flowability without experiencing segregation. An initial water-to-solids ratio of 0.10 should be used to blend the mixture. Additional water should be added until the consistency of the blend resembles grout. Care should be taken not to over-saturate the blend and the volume of water used should be noted for future applications. If the blend experiences segregation before an acceptable flowability can be achieved, consider adjustments to the parent material gradation.

7.4.6. Assume an initial air content and fill remaining volume using aggregate / supplemental materials. Typical air contents for unmodified flowable fills range from 0.5 to 5 percent (see NCHRP Report 597). The air content of the mixture can be increased through the use of air-entraining admixtures. Increased air content results in reduced density, reduced compressive strength, reduced segregation and subsidence potential, increased flowability, and increased durability. Assume an air content of 3 percent unless using air-entraining admixtures or experience dictates otherwise. The remaining volume of the blend, the design volume minus portland cement, water, air, and supplementary cementitious material, should be composed of aggregate or aggregate supplementary materials.

7.4.7. Verify material properties. Material properties of the designed blend must be verified prior to placement. Upon completion of the mix design process, the performance characteristics of the blend should be determined, including flowability, UCS, hardening time, and excavatability. Using an iterative process, the proportions should be modified until a blend meeting all performance specifications is achieved.

Table 1. Material Proportions for Common Flowable Fill Blends

Mixture Constituents		Flowable Fill Blends			
		Cement + Fly Ash + Fine Aggregate	Cement + Fly Ash	Fly Ash + Fine Aggregate	Cement + Fine Aggregate
Fine aggregate (pcf)	Range	92.6 - 111.1	a	b	74.9 - 93.6
	Typical	96.3	a	93.6	84.3
Portland cement (pcf)	Range	1.9 - 7.4	2.9 - 4.6	a	1.9 - 3.7
	Typical	3.7	3.9	a	2.8
Water (pcf)	Range	12.4 - 30.8	13.6 - 23.2	b	8.1 - 18.7
	Typical	18.5	15.4	10.3	13.4
Fly ash (pcf)	Range	7.4 - 18.5	59.2 - 96.3	b	a
	Typical	11.1	77.0	17.2	a

^a Not included in mix

^b Data not available

7.5. Mix Design Example. A flowable fill blend is required for backfilling a utility trench on the shoulder of an airfield. The airfield manager indicates that the facility has a rehabilitation window for a maximum of 24 hours. Unearthing and repairing the utility will require six hours. The hot-mix asphalt surface can be placed and compacted in two hours, but also requires a 12-hour curing time. The specified performance requirements include 28-day UCS of 150 psi, flowability measure of 8 to 12 inches, complete initial hardening in four hours, and a removability modulus equal to or less than 1.0. Supplies of Type II portland cement are available for use.

7.5.1. Concrete sand conforming to the standards presented in ASTM C33/C33M is available from a local ready-mix plant and has been selected for use in the blend.

7.5.2. An initial w/c ratio of 4.09 was determined using Equation 1.

$$(w/c) = e^{\frac{LN\left[\frac{(28\text{-day UCS (psi))}{2,035}\right]}{-1.85}} = e^{\frac{LN\left[\frac{(150\text{psi})}{2,035}\right]}{-1.85}} = 4.09$$

7.5.3. Supplies of fly ash and slag that consistently conform to ASTM standards are not locally available and therefore will not be included in the mix design.

7.5.4. Due to a lack of experience with using air entrainers, set accelerators, and foams, no admixtures will be used in the mix design.

7.5.5. An initial w/s ratio of 0.1 will be used based on guidance provided in paragraph 7.4.5.

7.5.5.1. Typical densities of flowable fills not containing air entrainers or foams range from 115 to 145 pounds per cubic foot (pcf). A design density of 130 pcf will be assumed in this design.

7.5.5.2. Assuming a density of 130 pcf, the water content of the design is $0.10 \times 130 \text{ pcf} = \mathbf{13 \text{ pcf}}$.

7.5.5.3. Applying the calculated w/c ratio of 4.09, the portland cement content of the blend is $(13 \text{ pcf}) / 4.09 = \mathbf{3 \text{ pcf}}$.

7.5.5.4. Fine aggregate conforming to ASTM C33/C33M will make up the remaining portion of the blend. The volume of water, portland cement, and air must be calculated to determine the volume of fine aggregate required. Volume of water = $13 \text{ lb} / 62.4 \text{ pcf} = 0.21 \text{ ft}^3$. Volume of portland cement = $3 \text{ lb} / (3.15 \times 62.4) = 0.02 \text{ ft}^3$. Air content is assumed to be 3 percent or $0.03 \times 1 \text{ ft}^3 = 0.03 \text{ ft}^3$. The remaining volume in the mixture = $1 - (0.21 + 0.02 + 0.03) = 0.74 \text{ ft}^3$. The fine aggregate content is $0.74 \text{ ft}^3 \times 2.65 \times 62.4 = \mathbf{122 \text{ pcf}}$.

7.5.6. The design proportions should be thoroughly blended in the laboratory. Measured amounts of water should be added to the blend and recorded until a consistency resembling grout is obtained. The material characteristics of the blend, including flowability, UCS, hardening time, and excavatability, should be determined. Changes to the constituent material proportions should be made using an iterative approach until a design blend with the specified properties is obtained.

8. Material Characterization. The in situ performance of flowable fill is influenced by a number of factors, including the application, material properties, construction practices, and environmental conditions. Optimizing the contributing factors creates an optimal performance environment for the flowable fill material. Some factors, like application and construction practices, can be controlled regardless of the backfill media used, while others, like environmental conditions, can never be controlled. One attractive feature of flowable fill is the ability to adjust constituent material proportions to optimize performance properties for a particular engineering application. The properties of strength, flowability, hardening time, and excavatability are most commonly addressed by mix designers. However, other properties such as density, segregation and subsidence potential, permeability, and pumpability are also of great importance in certain engineering applications.

8.1. Strength.

8.1.1. The strength or bearing capacity of flowable fill is commonly quantified by measuring the UCS. Flowable fills are defined as having compressive strengths of 1,200 psi or less. Compressive strengths of 50 to 100 psi are equivalent to the bearing capacity of high quality compacted aggregate (see ACI 229R-99). Unlike portland cement concrete (PCC), higher compressive strength is not beneficial

for flowable fills. PCC requires a minimum strength to perform properly in structures. Flowable fill requires both a minimum and maximum strength to perform properly. Minimum-strength recommendations are to ensure that the flowable fill has adequate bearing capacity and does not deform excessively under load. Maximum-strength recommendations are required to ensure that the flowable fill can be excavated (see Crouch, L.K. et al, “Long Term Study of 23 Excavatable Tennessee Flowable Fill Mixtures”).

8.1.2. The UCS of flowable fill can be determined in accordance with ASTM D4832, *Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders*. In compliance with this method, 6-inch by 12-inch cylinders are poured from samples of representative material. The cylinders are allowed to cure for a period of 28 days and then capped with gypsum plaster. Each capped cylinder is then placed within the frame of a compression testing machine and axially loaded until the specimen reaches failure. Failure is defined as the point at which the specimen will no longer resist increases in load (see Lade, Poul V., “Instability, Shear Banding, and Failure in Granular Materials”). The ultimate load reached prior to failure is divided by the cross-sectional area to determine the UCS.

8.2. Flowability.

8.2.1. Defined as the measure of the fluidity of the flowable fill mixture, flowability quantifies the ability of flowable fill to be self-leveling, self-compacting, and to easily flow into confined areas to fill voids. Flowability is a property of flowable fill which separates it from traditional backfilling methods. Flowability is a critical parameter affecting performance and productivity when using flowable fills in engineering applications (see Du, Lianxiang et al, “Effects of Constituent Materials and Quantities on Water Demand and Compressive Strength of Controlled Low-Strength Material”) and should be designed for and monitored during construction activities.

8.2.2. The flowability of a representative sample of flowable fill can be determined in accordance with ASTM D6103, *Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM)*. According to this test method, a sample of freshly mixed flowable fill is poured into a 3-inch by 6-inch open-ended flow cylinder resting on a flat surface. The flow cylinder is lifted vertically, away from the sample, at a rate of 0.67 to 1 inch per second. Several measurements are taken of the diameters of the resulting pat and the average measurement is reported as the flow consistency. An ideal CLSM exhibits a flow consistency of 8 to 12 inches.

8.3. Hardening Time.

8.3.1. Hardening time is defined as the time required for a flowable fill mixture to transition from a plastic to a hardened state with sufficient bearing capacity to

support the weight of a person (see ACI 229R-99). Factors affecting the hardening time of a flowable fill mixture include type and quantity of cementitious material employed, permeability of confining material, water content of mixture, mixture proportions, mixture and ambient temperature, humidity, and depth of fill (see ACI 229R-99). Typical hardening times range from one to five hours, but can be accelerated by the use of set accelerator admixtures or the substitution of Type III for Type I/II portland cement.

8.3.2. The hardening time of flowable fill mixtures can be determined in accordance with ASTM D6024, *Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to Determine Suitability for Load Application*. The suitability of an in-place flowable fill for load application is determined according to this method by impacting the finished surface with a 30-pound (14-kilogram) Kelly Ball apparatus. The Kelly Ball is raised and dropped from a fixed height of 3.5 inches with four subsequent repetitions. At the conclusion of the final drop, several diameters of the resulting indentation are measured and the test location surface is inspected for free water. The flowable fill surface is ready for load application when the average impact diameter is 3 inches or less, with no free water rising to the surface.

8.4. Excavatability.

8.4.1. The ability to excavate flowable fill repairs is essential for certain engineering applications. Excavatability is the ability to remove flowable fill material using standard effort (shovels and backhoes). The excavatability of flowable fill mixes is determined by a number of factors, including maximum aggregate size, unit weight, compressive strength, and air content. UCS is commonly used as an indicator of excavatability, with maximum compressive strengths of 100 to 200 psi indicating excavatable blends (see ACI 229R-99).

8.4.2. A standard test method for directly measuring the excavatability of flowable fill does not currently exist. The Ohio Department of Transportation (ODOT) uses the theory of removability modulus (RE) to estimate if a flowable fill blend will maintain long-term excavatability. The RE is calculated using the dry unit weight (w) in pcf and 30-day UCS (C) in psi as shown in Equation 2. Within this research effort, the RE was calculated using the standard 28-day UCS and compared to field observations of excavatability. It was determined that materials with an RE equal to or less than 1.0 were excavatable using standard effort 56 days after placement of the material. The calculation of RE is an effective, non-destructive method for estimating the excavatability of a flowable fill blend.

$$RE = \frac{w^{1.5} \times 104 \times C^{0.5}}{10^6} \quad (2)$$

8.5. Density. The density or unit weight of flowable fill is determined by the proportioning of constituent materials in the blend. The density for typical flowable fill blends range from 115 to 145 pcf. However, when waste materials are used in place of aggregates, densities range from 85 to 110 pcf (see ACI 229R-99). Densities can be reduced by employing air-entraining or foaming agents. The density of flowable fill can be determined in accordance with ASTM D6023, *Standard Test Method for Density (Unit Weight), Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low-Strength Material (CLSM)*. Using this method, the density of a blend is determined by measuring the mass of freshly mixed flowable fill required to fill a known volume.

8.6. Segregation. Segregation refers to the separation of the liquid portion from the solids portion of a flowable fill blend. Segregation occurs as a result of the use of excessive water contents or a poorly graded aggregate structure. Segregation can be controlled by reducing the water content or through the use of well-graded aggregates, fly ash, air-entraining agents, or combinations of the previously mentioned methods. There is no standard test method for determining the segregation of solids from liquid in a flowable fill. A visual qualification can be made when conducting flowability testing in accordance with ASTM D6103.

8.7. Subsidence. Subsidence refers to the consolidation of a flowable fill blend after placement. Subsidence occurs when water in excess of what is required for hydration is released to the surface or absorbed into the confining material. Potential for subsidence increases with water content and typical subsidence measures for high water content blends range from 0.125 to 0.25 inch per foot of depth (see ACI 229R-99). The propensity for subsidence can be reduced by the use of sufficient fines, set accelerators, or Type III portland cement (see NCHRP Report 597). There is no standard test method for quantifying the consolidation experienced by a flowable fill during hardening. The level of subsidence was determined in this research effort by comparing the height of samples prepared for UCS testing in accordance with ASTM D4832 after being freshly poured and again before testing. The accuracy of this method for predicting the subsidence of flowable fill in field conditions has not been determined; however, this method does allow for a comparison of subsidence potential between flowable fill blends.

8.8. Permeability. The permeability, or ability to transmit gases and fluids, of flowable fill influences other properties such as drainage characteristics, durability, and leaching potential (see NCHRP Report 597). The permeability of typical flowable fill blends is similar to that of compacted granular fills (see ACI 229R-99). Permeability can be increased by reducing the cementitious materials content and/or increasing the air content or void space. There is no standard test method for determining the permeability of flowable fill. The development of a standardized testing method should be addressed in future research efforts.

8.9. Pumpability. Flowable fills can be delivered to installation points through the use of pumps. The ease with which a material can be pumped defines its pumpability.

The pumpability of a flowable fill blend can be increased by using well-graded aggregates with sufficient fines to reduce void space. Fly ash can also be used to provide adequate void filling. Care should be taken when pumping low-density, high-air-content mixes (see ACI 229R-99). There is no standard test method for determining the pumpability of flowable fill. The development of a standardized testing method should be addressed in future research efforts.

9. Construction. The construction of flowable fill structures is defined by the primary tasks of mixing, transporting, and placing the flowable fill blend. The performance properties of flowable fill are determined by a number of factors. One of the most influential factors is the construction practices employed during execution of a flowable fill repair. At the conclusion of construction, simple yet effective field testing methods are required to validate the specified material properties. The ability to effectively ensure the design properties of the flowable fill blend will guarantee a backfill with the required performance characteristics has been placed.

9.1. Mixing. The mixing process as it relates to flowable fill refers to the process of blending the material constituents, portland cement, fine aggregate, water, etc., to ensure even distribution of all of the materials to create a homogeneous blend of material. The majority of flowable fill produced in the United States is from ready-mix concrete plants; therefore, the most common method employed for mixing flowable fill is via transit mixing truck. However, many other methods—including mixing and batching from centralized plants, pugmills, and volumetric concrete mixers—can be employed for the process. Mixing using both a transit truck and a volumetric mixer was examined in the supporting research effort for this ETL. Many methods of mixing using these devices were examined and the following best practices are recommended:

9.1.1. Mixing in a Transit Truck:

- Add 75% of required water
- Add 50% of fine aggregate
- Add all specified cementitious materials (portland cement, fly ash, etc.)
- Add remaining fine aggregate
- Add balance of water
- If dry transit truck is being used, add additional 10% of required water to “butter” mixer
- Mix for 3 to 5 minutes before dispensing

9.1.2. Mixing Using a Volumetric Mixer:

- Calibrate mixer to produce blend with specified proportions by adjusting water flowrate, aggregate and cementitious material strike-off gates, and admixture flow or distribution rates, if used.
- Dispense small portion of mix, make visual observations of flowability and segregation, and make adjustments to calibration until mix resembling design blend is produced.

- Material constituents should remain in mixing auger for a minimum of 15 seconds to ensure uniform blending is achieved.

9.2. Transporting. Flowable fill can typically be transported using the same devices employed for transporting PCC. Documented successful transportation mechanisms include transit truck, volumetric mixing truck, and pump. Transporting using transit and volumetric trucks was examined in the supporting investigation. Additional guidance regarding pumping of flowable fill is available in ACI Manual of Practice 229R-99. Recommendations regarding the transportation of flowable fill include the following:

- Flowable fill is a cementitious material similar to PCC and should be transported using the same precautions.
- Constituent materials should not be allowed to come into contact except during mixing.
- Flowable fill sticks easily to the baffles of a transit truck or auger of a volumetric mixer.
- Contact time between mixing equipment and flowable fill should be limited and clean-up activities should begin immediately after dispensing material.
- The hardening of flowable fill can be retarded using citric acid.
- Guidance on dosage requirements does not currently exist and should be determined in future research efforts.

9.3. Placing. The placement method employed when using flowable fill is determined by the particular engineering application. Chutes, conveyors, buckets, and pumps have all been successfully employed. Placement using a chute was the only method investigated in the supporting research effort. Additional guidance on the use of conveyors, buckets, and pumps is available in ACI Manual of Practice 229R-99. Best practices developed include the following:

- Lightly saturate chute walls with water or a release agent to prevent buildup of cementitious materials.
- Place chute as low as possible to reduce spray and subsequent cleanup of excess flowable fill.
- When filling excavations, fill from higher elevations to lower to optimize flowability characteristics of backfill material.
- Flowable fill is similar in nature to PCC and should be placed using similar methods and safety precautions.

9.4. Quality Control and Acceptance Testing. The ability to determine the material properties of fresh flowable fill is essential to ensuring the successful long-term performance of the material. Determination of material properties using standard testing methods is expensive and time-consuming. Additionally, the UCS and long-term excavatability of blends cannot be determined until 28 days after placing the material. Testing approaches which are easier, faster, or produced results in a timelier manner were examined as part of the supporting investigation.

9.4.1. Strength. The strength or bearing capacity of flowable fill is commonly determined according to ASTM D4832. Although this method provides an accurate measure of the UCS of a flowable fill material, testing must be conducted in a laboratory using specialized equipment. Additionally, results indicating the long-term strength gain experienced by the material are not available until 28 days following placement of the material. Discovery of insufficient or excessive strength at this point results in an expensive removal, replacement, and repair operation. A model predicting the strength of a flowable fill blend was developed (see Du, Lianxiang et al) but was found to be highly material-dependent. Within the supporting research effort, a number of pre-blended commercial materials, two standard ready-mix blends, and 70 mix designs were tested according to ASTM D4832 after 7 and 28 days. The developed mix designs included straight blends using only portland cement, water, and aggregate, in addition to blends incorporating Types C and F fly ash, and an air-entraining admixture. A correlation between 7-day and 28-day strength was developed with a coefficient of determination (R^2) of 0.92 for mixes with w/c ratios between 1.0 and 5.0. The developed relationship is presented in Equation 3.

$$28 - \text{day UCS (psi)} = 1.6469 \times [7 - \text{day UCS (psi)}] \quad (3)$$

Employment of Equation 3 to predict the long-term strength of flowable fill blends prior to the standard 28-day curing period enables an estimation of mixture strength properties to be made at an earlier time, reducing the cost to replace material that is outside of design specifications. The development of a non-destructive in situ strength-testing method should be the focus of future research efforts.

9.4.2. Flowability. Flowability is an important performance measure because it affects the ease with which the material can be placed. The characteristics which separate flowable fill from traditional backfilling methods are the ability to be self-leveling, be self-compacting, flow into voids, encapsulate objects in the work area, and flow under gravity. Inadequate flowability prevents a flowable fill blend from satisfying the previously mentioned criteria. Optimum flowability has been observed to be 8 to 12 inches of spread, measured according to ASTM D6103. Several alternative methods of measuring the flowability of flowable fill were investigated, including the standard concrete slump cone and inverted slump cone methods. The standard method was determined to be as quickly and easily conducted as any other method and only requires a flat surface, measuring tool, and a 3-inch by 6-inch open-ended cylinder. ASTM D6103 is recommended for both field and laboratory measures of flowability.

9.4.3. Hardening Time. The time required for a flowable fill material to transition from a fluid to a rigid material capable of withstanding load is referred to as the hardening time. This material characteristic has direct effect on repair operations,

including staging of manpower and equipment, delivery schedules for capping material, and downtime for a facility. Hardening time is a customizable property of flowable fill, and periods ranging from 30 minutes to 24 hours have been recorded. Hardening time can be measured by ASTM D6024. This method requires the use of a 30-pound (14-kilogram) Kelly Ball, which is cumbersome to transport. The supporting research effort investigated the use of spring-loaded mortar and pocket penetrometers to determine the readiness of flowable fill materials to bear construction loads. This research found a direct correlation between a 3-inch indentation measured using the ASTM method, 130 psi measured using the mortar penetrometer, and 700 psi using the pocket penetrometer. Due to portability and ease of use, the pocket penetrometer is recommended for determining the hardening time for a flowable fill material in field environments.

9.4.4. Excavatability.

9.4.4.1. The ability to re-excavate a repair can be critical for particular engineering applications. When backfilling utilities, a material that requires significant effort to excavate (potentially damaging encased utilities) is not acceptable. Published research has shown that flowable fills with UCS ranging from 100 to 200 psi possess long-term excavatability. A flowable fill is considered to be excavatable if it can be removed using standard effort. Typically, indicators such as UCS or RE are used to predict if a flowable fill will be excavatable. A result of the supporting research effort was the development of a direct method for determining the excavatability of flowable fills.

9.4.4.2. A dynamic cone penetrometer (DCP) was employed to correlate California Bearing Ratio (CBR) to the UCS of flowable fill materials. As a result of this investigation, it was observed that mixes determined to be excavatable were also penetratable using the DCP. Repairs tested with the DCP and were not penetratable were subsequently found to be inexcavatable. Testing with the DCP in accordance with ASTM D6951/D6951M, *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*, is recommended to determine both the bearing capacity and excavatability of flowable fill in field environments.

10. Further Research. The development of guidance for the use of flowable fill to repair subsurface voids is of critical importance to the DOD. The guidance provided on the mix design, characterization, and construction using flowable fill reduces the lack of information with respect to employing the technology. However, a number of issues still remain and should be the focus of future research efforts. These issues include establishing a detailed mix design procedure which includes the use of marginal in situ aggregates, establishing a strength-testing procedure which can be employed immediately prior to operation of a facility, establishing standard testing methods for

segregation and subsidence potential, permeability, and pumpability, developing pavement design factors, and establishing a standard flowable fill specification. Such research will provide engineers with comprehensive guidance on the use of flowable fill for constructing and repairing earthen structures.

11. Point of Contact. Questions or comments regarding this ETL are encouraged and should be submitted to the Pavements Engineer, HQ AFCESA/CEOA, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, DSN 523-6439, commercial (850) 283-6439, e-mail AFCESAReachbackCenter@tyndall.af.mil

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