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TECH NOTE
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FLOWABLE FILL USING IN-SITU SOILS

SUMMARY

Flowable fill for pipeline installation can use the native soils excavated from the trench as the aggregate in the mix. The flowable fill can be mixed using trench-side mixing equipment that move along with the pipe installation or with a portable batch plant. Using the soil excavated from the trench reduces spoil pile waste, spoil pile handling, importing aggregate materials, soil export related truck traffic and other neighborhood transit mixer traffic from ready-mix plants.

Traditionally, flowable fill is obtained from a ready-mix plant and is a mixture of Portland cement, concrete sand, sometimes flyash, and water. Flowable fill is typically used as a replacement for compacted earth backfill.

Several contractors and competitors to ready-mix have found ways to reduce the cost and improve overall efficiency through the use of on-site highly modified volumetric mixers using native trench spoils as aggregates. These contractors have been successfully using the native soils excavated from the trench to make flowable fill. In-situ soils that are sands or a mixture of sand and silt are ideal for flowable fill. The soil is easily processed and mixed. Clayey soils require more processing, including moisture conditioning with lime, but have been successfully used. (Finney et al 2009) A photo of a chunk of hardened flowable fill made using insitu clay soil and Portland cement is shown in Figure 1.

Figure 1 Chunk of Flowable Fill made from Insitu Clay Soil

Two different equipment set-ups have been used for mixing the material. Each set-up is specifically designed to handle soils as opposed to the traditional sand only. "Trench Side Mixing" is used to refer to machines that travel beside the trench, mix the soil, cement, and water, and then discharge the flowable fill directly into the trench. "Portable Batch Plants" are mobile units and can be set up near the job site and used to produce high volumes of native slurry for placement using ready mix trucks. Soil from the trench is stockpiled next to the batch plant, screened if necessary, and batched on a weight basis similar to ready-mix concrete.

Trench Side Mixing

A trench side mixer is shown in Figure 2. This is a volumetric mixing operation. Soil from the hopper goes onto a conveyor belt to a mixing chamber at the beginning of a screw auger. Concurrently, cement and water are added to the mixing chamber. The material continues to mix as the screw auger moves the material down the chute. The flowable fill goes directly into the trench and around the pipe. This technique has been in use since the mid 1990's.

Figure 2 Volumetric Concrete Mixer used for Flowable Fill

The mixer has a hopper for soil, a cement bin, and a water tank. All are mixed with the screw auger as shown in Figure 2.

Figure 3 Mixing and Screw Auger on Volumetric Mixer

Figure 4 Fresh Flowable Fill

The resulting flowable fill is shown in Figure 4.
All of these trench side mixing operations can produce flowable fill with a 28 day compressive strength of as low as 10 to as much as 1400 psi. Typically, the mix design should have a psi window of 50 psi to 200 psi. Lower 28-day strengths are sometimes desirable to allow ease of future excavation if ever required. The insitu soils are examined ahead of the mixing operation so that any changes to the percent cement can be adjusted as the rig moves ahead. Compressive strength cylinders are usually cast every day to monitor the strength of the soil-cement-water mixtures. The fluidity (spread diameter) of the mixture is typically in the 6 to 10 inch range as prescribed in ASTM D 6103 "Flow Consistency of Controlled Low Strength Material."

Shredding

Use of native soil requires processing to make the soil the proper size and consistency. The mixing of the flowable fill is more effective if the clod size is about 2-inch or less and if the soil moisture is about at the Plastic Limit (PL) or less.

For cohesionless sands and fine gravels, a preliminary screening to remove oversize particles is all that is required. Moisture content is not a concern. Many times this step is incorporated into the mixing operation. Soils with a Plasticity Index (PI) below 25 can also be screened as part of the mixing operation if they are not too wet. Such soils can be spread out and let to dry for a day or more to obtain a workable moisture.

For the more cohesive soils, shredding is necessary to make the appropriate clod size. While some soil shredders can manipulate wet, sticky clays, the resulting material is usually too wet to mix. For soils that are too wet, the excavated material can be spread out and moisture conditioned, including the possible use of quicklime. Since the excavators are usually a day or so ahead of the mixing and placing equipment, this does not significantly affect the overall installation time. The critical part of re-using in-situ clays is the shredding of the soil into 0.25 to 1 inch clods. There are commercially available shredders that can handle most materials as shown below.

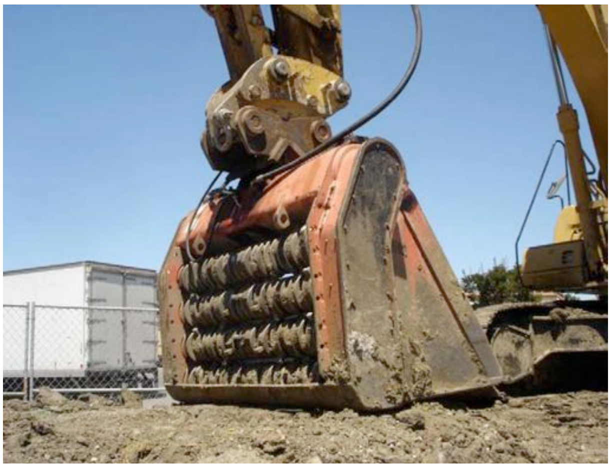

Figure 5. An Allu shredder

Figure 5. Remu Shredder Bucket

The typical operation is to excavate the soil with an excavator and put into a spoil pile. About a day later, a backhoe with a shredder bucket picks up the material, shreds it, and dumps into the flowable fill processor, as shown in Figure 6.

Figure 6 Allu Shredder on Excavator Loading Soil Hopper on Volumetric Mixer

Figure 6 Remu Shredder bucket on excavator loading material

Portable Batch Plants

Portable Batch Plants have also been used. One such plant is shown in Figure 7.

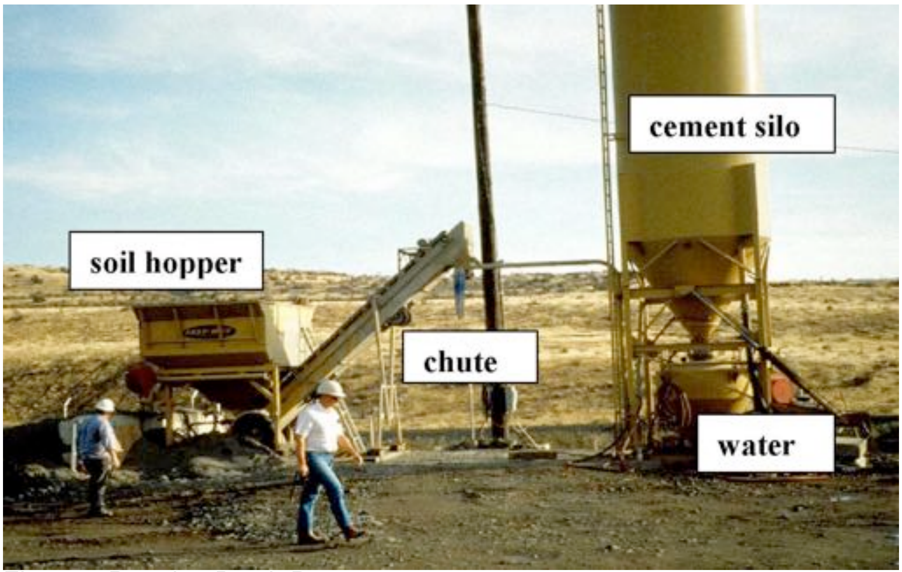

Figure 7 Portable Batch Plant

The soil hopper was charged with soil from the trench excavation. The soil, cement, and water were all added to a transit-mix truck that mixes the flowable fill on the way to the trench site.

On the CAP project, shown in Figure 8, flowable fill was used in the haunch area of a 21-ft diameter steel pipe (Randolph and Howard 2010) (Sayer and Howard 2010). The excavated soil was taken to a portable batch plant, screened, batched, and transported back to the pipe using transit-mix trucks. The soil was a Clayey Sand/Clayey Gravel (SC, GC) with minus 3/8-inch particles and about 10-15% fines.

Figure 8 Flowable Fill on the CAP 21-ft Steel Pipe

Flowable Fill Pipe Design Considerations

Flowable fill reduces or eliminates problems such as uneven bedding, ring deflection, non-uniform embedment support, and voids under the haunches. If ring deflection is less than 5%, crack widths caused by elliptical ring deflection are less than 1/16 inch. When the pipe is pressurized and re-rounded, deflection cracks in the mortar close. However, small cracks remain due to expansion of the steel pipe when it is subjected to internal pressure. These are longitudinal hair cracks distributed fairly uniformly around the circumference. But for worst- case analysis it is assumed that cracks open only where initiated by ring deflection during installation at crown and invert in the lining, and at springline in the coating.

The width of these cracks is $w = (jt/2)D(S/E)$.

For steel, if $S = 21$ ksi, and $E = 30,000$ ksi, then $w = D/910$.

$w = 0.05$ inch (1.34 mm) in a 48-inch diameter pipe $w = 0.10$ inch (2.7 mm) in a 96 inch diameter pipe

Pressure cracks occur in high-pressure pipes, over 140 psi (970 kPa) internal pressure, for which wall thickness is based on hoop stress. For lower pressure pipes, wall thickness is based on the requirements of fabrication rather than hoop stress. Pressure cracks are usually not an issue.

Figure 9. Transverse section of a mortar-lined-and-coated steel pipe wall, showing the maximum possible crack width, w, in the coating at spring- line caused by a change in radius from circular, r, to measured rx. Measured rx can be calculated from the middle ordinate from a short chord of known length to the inside surface of the pipe. Two parallel cracks would each be half as wide as the single crack shown.

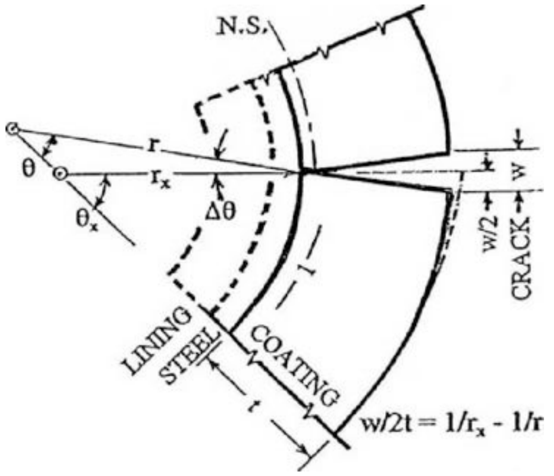

Figure 10 is ”impermissible" Class D bedding. The maximum bending moment is at the invert, B, and is 0.15 PD2. Ring deflection is d = 0.015 PD3/EI. Figure 11 shows an alternative bedding, "flowable fill" — a full-contact bedding. The bending moment at B is 0.06 PD2, which is only 40% of the maximum bending moment in Class D bedding. The ring deflection is d = 0.002 PD3/EI, which is only one-seventh of the ring deflection in Class D bedding. Flowable fill can be used as embedment at the sides, and even over the top of the pipe.

Buried pipe technology lives with a chronic urge to use native soil as embedment. Therefore, processing of native soils into a slurry of soil, water, Portland cement and enough fine particles to make it "flowable" is the logical solution for a high performing backfill.

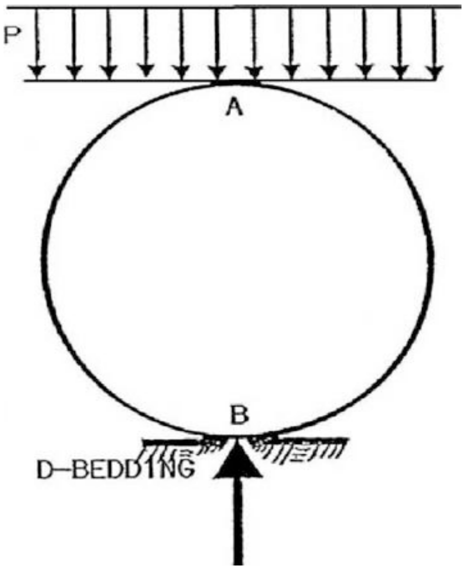

Figure 10 D-Bedding (impermissible bedding). Maximum bending moment, MB = 0.15PD2. Ring deflection is d = 0.015 PD/EI

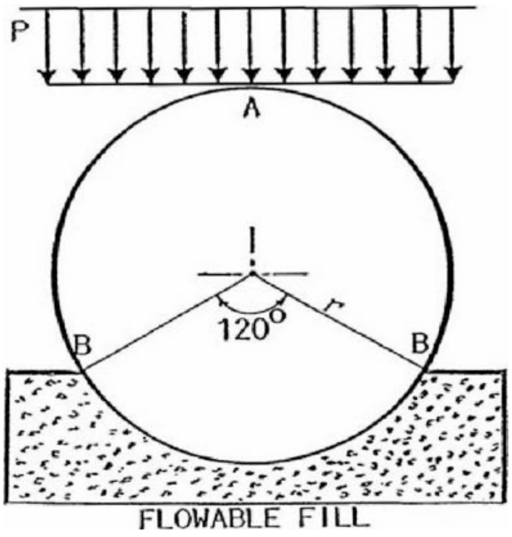

Figure 11 Flowable fill bedding. Critical moment at B is, Mb - 0.06 PD2. Ring deflection is d = 0.002 PD/EI. Values may vary somewhat in field installations.

The slurry must be fluid enough to flow under the pipe in full contact with the pipe. To be flowable, fines are required. The fines may include Portland cement or fly ash, but may also include silt and even some clay. A typical slump test of the slurry is 6-10 inches of spread. Fines are also beneficial to keep the slurry particles in suspension longer and avoid excessive bleed water formation. This improves pumpability (if used) and flowability of the slurry for optimal placement.

Vertical Compressibility

Ring deflection is roughly equal to vertical compression (vertical strain) of the sidefill soil. If the flowable fill is placed as sidefill, vertical strain must be within limits of ring deflection.

Bearing Capacity

Flowable fill must have enough bearing capacity to support backfill. It must also hold the pipe in shape. High strength is not a primary requirement. Theoretically, because embedment is in compression, it needs no cement. However, some cement is recommended for flowability. Unconfined compression strength should be kept low — no more than 100 psi (689.5 kPa), or it might be argued, compression strength should be no greater than internal pressure in the pipe. Some designers suggest a minimum of 40 psi (275.8 kPa). High strength should be limited for the following reasons:

1. Embedment cannot be excavated easily in case the pipe must be uncovered or serviced.
2. If the embedment cracks due to soil movement (differential subsidence, sidehill slip, etc.) stresses are concentrated on the pipe, and the potential for pipe fracture increases.

Inspection

Large rocks must be screened out of flowable fill. The flowable fill must be fluid enough to flow under the pipe. If used as sidefill, it must not shrink excessively or compress vertically more than allowable ring deflection. It must support the pipe and backfill. A good test is the penetrometer. Bearing capacity and the time of set can be found onsite without delay of installation. Penetrometers are available commercially at a reasonable cost.

Test Results

Field tests show that flowable fill embedments can be of good quality with as little as one sack of cement per cubic yard of native soil with more than 50% silt. This is a much greater percent of fines than the maximum of 10% typically allowed for select embedment.

Sustainability

Sustainability is achieved through less time and energy consumption for excavation, handling of soil excavated from trench, hauling of materials (both to and from construction sites), compaction of soil in 6 to 12-inch lifts, reworking compaction due to density test failures, hauling water for compaction, transportation to landfills, personnel for inspection of the construction, for testing, detours and traffic delays. In most cases, sustainable methods using insitu soils result in flowable fill that can be cost competitive with compacted earth fill.

Conclusions

Designers and constructors should be aware of the "best practices" approach for flowable fill beddings and embedments. While there are some pipeline constructors that are experienced and equipped to recycle native soil as flowable fill, the process is best served with specialty subcontractors that have more than 5 years experience. Techniques are being "fine-tuned" in all aspects of flowable fill and require specific equipment and experience for a successful project.

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