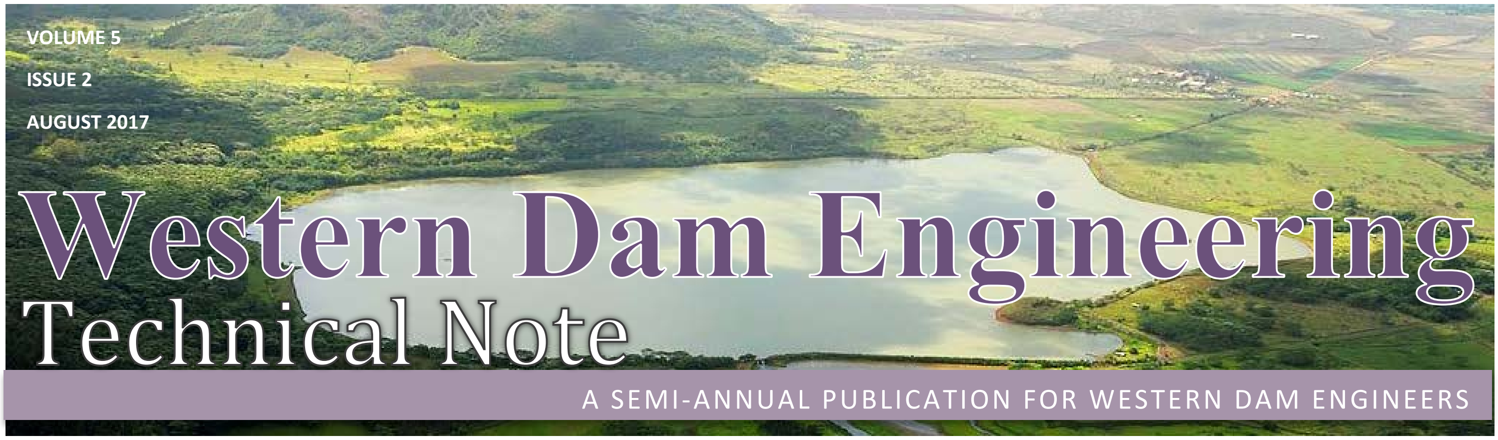

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In this issue of the ***Western Dam Engineering Technical Note,*** We present articles on **unmanned drones, overtopping protection methods for embankment dams, cellular grouting for conduit sliplining, and conduit repair with mechanical seals.** This semi-annual newsletter is meant as an educational resource for civil engineers who practice primarily in rural areas of the western United States. This publication focuses on technical articles specific to the design, inspection, safety and construction of small to medium sized dams. It provides general information. The reader is encouraged to use the references cited and engage other technical experts as appropriate.

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Cellular Grout Use in Conduit Sliplining

Nathan Walker, PE

Cellular grout has a long history of use in a variety of applications. It is a lightweight material composed of a uniform void cell structure prepared with a foaming agent. Cellular grout may contain common concrete admixtures, sand or coarse aggregates, or supplementary cementitious materials (pozzolans) such as fly ash or slag. Dam safety officials and regulators have seen an increased number of requests when sliplining conduits to utilize cellular grout for filling the annulus, which is the void space located between the two conduits. This article summarizes the current industry-specific considerations, the potential advantages and disadvantages, and case study comparing the use of cellular grout to traditional Portland cement grout. The March 2013 issue of Western Dam Engineering Technical Notes reviewed conduit rehabilitation including sliplining and annulus grouting: Low-Level Conduits – Rehab or Replace? [1]

Cellular Grout Background

The chief characteristic of cellular grout is the incorporation of a foaming agent, which creates a cellular matrix of small air bubbles as compared to the use of aggregate and sand in traditional cement grouts. The presence of air bubbles reduces the unit weight and increases grout mobility but also lowers the grout strength. The air bubbles in the cellular matrix survive the grout hydration period until the grout hardens, resulting in a homogeneous matrix of air voids. Similar to other grout materials, the period of time the grout remains fluid is key to proper use and cellular grouts can provide unique benefits for applications involving large volumes or long pumping distances.

Cellular grout has been successfully used for annular space grouting of various types of high density polyethylene (HDPE), fiberglass, concrete, steel, corrugated metal and ductile iron conduits ranging in size and length. Cellular grout typically involves proprietary equipment developed by specialized contractors who are trained and experienced in its use. Various agencies have developed specifications for cellular grout use. The U.S. Army Corp of Engineers' (USACE) *Grouting Technology Engineering Manual* provides technical criteria and guidance for annular space grouting of conduits. The USACE considers any application where low to moderate strength can be tolerated and lightweight grout is desirable as a candidate for cellular grout. [2]

Cellular Grout Mix Design

Cellular grout can be designed as either pervious or impervious with typical wet cast densities ranging from 20 pounds per cubic foot (PCF) up to 70 PCF and ranging in 28-day compressive strength from 50 pounds per square inch (psi) up to 1100 psi. Strength is directly correlated to density and desired strength is achieved through varying the ratio of cement slurry to foaming agent. If higher strengths are required, sanded mixes can be used; however sanded cellular grout is not as fluid and can require additional placement steps.

Impervious cellular grout with a permeability range of 10^{-5} to 10^{-6} cm/s has been successfully used in dam outlet conduit sliplining where control of water flow is desired. Pervious cellular grout is typically used to avoid disruption of water flow and is beyond the focus of this article.

The frequency of large diameter conduit rehabilitation has increased and sliplining has emerged as a preferred method of rehabilitation. In these cases large volumes of grout materials with suitable characteristics are needed. Large grout volume mix design often seeks to reduce material cost and heat of hydration through the use of pozzolans such as fly ash or slag, or other means. Testing has shown the addition of pozzolans reduces early-age compressive strength and elastic modulus, and affects the setting time of grout. These factors should be taken into consideration during selection of the mix design based on the application requirements.[3] If slower set time and reduced early-age compressive strength are not critical, use of pozzolans can be beneficial, as they tend to reduce shrinkage and improve pumpability.

Cellular Grout Specification

Specifications for traditional grouting of a conduit sliplining annulus typically include considerations for minimum contractor qualifications, mix design, low shrinkage or net positive expansion, set time, fluidity, trial testing, placement procedures, quality control, and contingency plan requirements. These same considerations should be developed for the use of cellular grout along with the following additional requirements:

1) Minimum specific gravity of 1.1. to ensure displacement of any water;
2) Minimum grout strength suitable for intended application; and
3) Testing to verify compressive strengths.

Natural Resources Conservation Service (NRCS) Specification 85[4] is a sample performance specification for conduit sliplining involving the use of cellular grout.

Cellular Grout Placement

Some cellular grout applications have utilized gravity placement; however, pumping is the recommended placement method for annulus grouting during conduit sliplining since this method better ensures uniform grouting and complete filling of the annulus.

Figure 1. Annular Space Slipline Grouting with Cellular Grout

Cellular grout is relatively fluidized and self-leveling and can be readily pumped long distances at low pressure and flows well through tight spaces and small openings. This characteristic allows for grouting of conduits without the need for frequent injection points associated with traditional cement grout. The homogenous structure of cellular grout reduces potential segregation during pumping compared to traditional cement grout and reduces the buoyancy of carrier pipes during annular space slipline grouting. As a result, there is an increased likelihood that annular spaces can be completely filled while reducing the chances of premature grout setting. Also, avoiding higher injection pressures can minimize the possibility of conduit damage.

Cellular Grout Advantages

There are a few unique advantages to using cellular grout for conduit sliplining compared to typical cement grouts. These can be summarized as (1) low injection pressures, (2) reduced unit weight and related pipe buoyancy, (3) economical use of cementitious materials, (4) decreased heat of hydration and associated decreases in temperature of grout and adjacent piping, and (5) increased pumping distances.

Reduced Unit Weight and Buoyancy

Typical traditional cement grouts are relatively dense, with unit weights of approximately 100 to 120 lb/ft^3. This results in significant buoyancy during grouting. Buoyancy and uplift of the carrier pipe during annulus grouting requires special provisions to avoid pipe movement and the structural damage that can result. This may include grouting in lifts, attaching centralizers or braces, or filling the carrier pipe with water to prevent movement during grouting.

Cellular grout density is typically less than half that of traditional neat cement grout. The lower density grout significantly reduces buoyancy forces on the carrier pipe and minimizes associated deflection during annulus grouting which may eliminate the need for mitigation in some applications.

With higher fluidity and self-leveling characteristics, cellular grout readily flows into irregular cavities, does not require consolidation, requires less pressure for injection, and can be pumped longer distances without concern for segregation of the mix. As a result, improved filling of annulus voids and reduced risk of collapsing the carrier pipe or damaging the existing pipe can be expected during slipline-grouting of large volumes over long distances.

Low Injection Pressures

Cellular grout injection pressures can typically be achieved below 10 lb/in^2 even for long pumping distances involving small annular spaces. Cellular grout pumping distances have exceeded 20,000 feet including the Arrowhead Tunnels Project in Southern California.[5] Reduced pumping pressure also reduces the risk of hydrofracturing the soil around the existing pipe, which is often in a deteriorated state prior to and during grouting.

Low Heat of Hydration

On large-diameter applications the heat of hydration of conventional Portland cement grout can be detrimental to both the host and carrier pipe materials. Cellular grout has a reduced volume of cementitious materials and therefore generates less heat during hydration. Depending on the size of the annular space being filled and the materials being utilized, this may provide a significant benefit to the project.

Economical Use of Cementitious Materials

Cellular grout can be economical for annular space grouting during conduit sliplining due to a reduction in the quantity of raw materials used such as the cement and sand required for the grout production, recognizing that a majority of the mix volume is composed of air.

Placement costs of cellular grout can also be reduced due to ease of pumping long distances and minimizing the number of grout injection points.

In addition, low-weight cellular grout mixes used for annulus grouting typically have expansion ratios greater than 5, which reduces the amount of grout mix required. This can minimize the overall footprint of the grouting operation and associated construction traffic, which may improve other jobsite logistics.

Cellular Grout Disadvantages

Despite the advantages, cellular grout use in conduit sliplining does have some distinct disadvantages that can be summarized as (1) specialized design and construction, and (2) application limitations.

Specialized Design and Construction

Traditional cement grouts are common and can be supplied from local ready mix suppliers or batch mixed on site. However, specialized equipment and experienced, licensed contractors are required for use of cellular grout. As a result, cement grout is generally used on smaller projects due to the cost of mobilizing a specialty contractor.

If the use of cellular grout is warranted for a particular conduit sliplining application, special design considerations must be evaluated. Best practice in these applications mandates use of a qualified engineer experienced in the design, specification, and use of cellular grouts. The engineer should work closely with the dam safety regulator to clearly identify the design, testing, and placement requirements that should be addressed in a performance specification for the work.

Application Limitations

According to the Federal Emergency Management Agency (FEMA), cellular grout should not be used in embankment conduit applications for significant or high hazard dams due to the grout's porous nature and lack of strength for structural encasement.[6] This highlights the need for proper impervious cellular grout mix design, specification, and performance testing including suitable strength, density, and similar considerations summarized in this article and detailed in the referenced USACE engineering manual and sample NRCS specification.

Large diameter conduits may require multiple lifts, since bubble collapse can occur under hydrostatic head greater than about 4 feet of grout. Collapse of bubbles will effectively provide a grout consistency similar to traditional cement grouts, which will negate the advantages of using cellular grout. This could also result in variable conditions around the pipe, with collapse of bubbles on the bottom and potential voids along the crown.

FEMA also recommends cellular grouts should not be used where exposed to flowing water or the environment since cellular grout is typically less durable.[6] Although not typically exposed to these conditions in conduit sliplining applications, these limitations should be considered for each application.

In general, if there is not a distinct advantage for a particular conduit sliplining application to use cellular grout, such as large volumes or long pumping distances, the use of conventional cement grout should remain the preferred approach.

Cellular Grout Case Study

The Montana Dam Safety Program is familiar with a couple of recent successful conduit sliplining projects involving cellular grout including the Estler Lake Dam Rehabilitation completed in 2015.

Figure 2. Conduit Sliplining with Relatively Large Annular Space Prior to Cellular Grout Placement at Estler Lake Dam

The 80-linear-foot, 24-inch by 36-inch concrete arch, outlet conduit constructed in 1903 had exceeded its useful life. This conduit was sliplined with a much smaller 18-inch-diameter HDPE conduit, leaving a large annular space to be grouted. Due to site access challenges (including location of the construction staging area being located over 1 mile downstream of the project site), and given the large volume of grout required to fill the annular space, cellular grout was utilized for the annulus grouting. The cellular grout provided a solution that was much lighter than cement grout, required significantly less raw material to be supplied to the site and produced a highly flowable mix, capable of filling the large annulus.[7]

Figure 3. Cellular Grout Placement at Estler Lake Dam

References

[1] Western Dam Engineering, *Low-Level Conduits – Rehab or Replace?,* Vol.1 Issue 1, March 2013.

[2] U.S. Army Corps of Engineers. 2017. *Grouting Technology, Engineering Manual,* (EM) 1110-2-3506. March 31, 2017.

[3] Vipulanandan, C. and Neelam Kumar, M. 2000. "Properties of Fly Ash-Cement Cellular Grouts for Sliplining and Backfililng Applications," Proceedings, Advances in Grouting and Ground Modification, ASCE, GSP 104, Denver, CO, pp. 200-214.

[4] Natural Resources Conservation Service (NRCS). 2015. *National Engineering Handbook (NEH), Part 642, Construction Specifications, Construction Specification 85—Conduit Sliplining*, February 2015.

[5] Tunnel Business Magazine. 2013. *Cellular Concrete: Filling the Void, Scott M. Taylor*, March 28.

[6] Federal Emergency Management Agency (FEMA). 2007. *Technical Manual: Plastic Pipe Used in Embankment Dams*, FEMA P-676, November.

[7] Montana Association of Dam and Canal Systems. 2016. *Estler Lake Dam Rehabilitation*, by Koy Holland and Paul Sanford, October 19.