REINFORCED SHOTCRETE

Concrete Culvert Overview Flowchart
Structural Defects Flowchart (Concrete)
Bedding Deficiencies Flowchart (Concrete)
Hydraulic Capacity Flowchart (Concrete)

1.1. OVERVIEW

Shotcreting is the method in which cement mortar or concrete is pneumatically applied (jetted at high velocity) onto the surface of the structure being repaired. Shotcreting can be classified as a wet-mix process (all the ingredients including the water are mixed prior to introduction into the delivery equipment) or a dry-mix process, also known as gunite (all ingredients except the water are mixed and fed into the delivery equipment, and the water is added at the nozzle) as shown in Figure 1 (Hilton, 1990). The choice between gunite and the wet-mix process depends on various factors, e.g., project size (quantity of shotcrete required), application rate required (cubic yards per hour or shift), dust (could be an issue in a confined space and less is produced by wet-mix shotcrete), rebound (wet-mix shotcrete generally generates less material bouncing off the shooting surface), and required pumping length (Sulman, 2009).

Wire mesh reinforced cement mortar lining involves application of two layers of cement-mortar that are separated by a wire mesh (Figure 3). The first layer of cement-mortar (0.5 in. thick) is applied to the inner wall of the host pipe in the conventional manner (i.e., using gunite). A wire mesh is placed against the first coat of lining using overlapping joints, and the second layer of cement-mortar (0.5 in. thick) is applied by trowel over the wire mesh (AWWA, 2001).

Figure 1. Gunite application (REED, 2009)

Figure 2. Gunite lining inside the pipe (Queensland Gunite, 2009)

Figure 3. Wire mesh installed in the pipe; guniting will follow the mesh level and trowelling will complete the liner above it (Queensland Gunite, 2009)

1.2. SHOTCRETE MORTARS AND CONCRETES

Morgan et al. (1989) reviewed conventional and specialty shotcretes (steel fiber reinforced, polypropylene fiber reinforced, and wire mesh reinforced). ACI (1991) presented state of the art on fiber reinforced shotcrete. US Army Corps of Engineers (1993) provided guidance on the shotcrete selection and proportioning.

Conventional shotcrete concretes are made of Portland cement, aggregates and chemical admixtures. Gunite mixture is made from 1 part Portland cement and 4 parts sand (REED, 2009). Special concretes often employ admixtures (e.g., polymer modifiers) that inhibit corrosion and enhance chemical resistance. For producing a freeze-thaw durable shotcrete, aggregates susceptible to frost attack should not be used and the maximum size of the aggregate should be lowered to reduce susceptibility to freeze-thaw deterioration (Hilton, 1990).

US Army Corps of Engineers (1993) outlined benefits of adding fibers to the shotcrete mixture, i.e., the added ductility of the material (unreinforced shotcrete is a brittle material that experiences cracking and displacement when subjected to tensile stresses or strains), as well as added energy absorption capacity and impact resistance. Fibers used in shotcrete include steel fibers, glass fibers, and synthetic fibers.

Steel fiber reinforced shotcrete (SFRS) is a mortar or concrete containing discontinuous discrete steel fibers, which are pneumatically projected at high velocity onto a surface (Indian Concrete Journal, 2003). Typical fiber lengths for shotcrete range between 0.75 in. and 1.5 in., and the fibers are used in the amount of 2% by volume of shotcrete (US Army Corps of Engineers, 1993). Banthia et al. (1992) assessed the influence of fiber geometry in steel fiber reinforced dry-mix shotcrete on the rebound characteristics and hardened shotcrete properties. Properly designed, SFRS can reduce or even eliminate cracking, a common cause for concern in plain shotcrete (Indian Concrete Journal, 2003).

Glass fiber reinforced shotcrete (GFRS) is made by adding glass fibers to the cementitious mix to improve flexural, tensile and impact strength. Alkaline resistant glass fibers are used. For glass fiber reinforced concrete (GRFC) spray-up, the optimum fiber length is 1.5 in. to 2 in. The properties and proportional mixes are discussed in PCI (2001).

Girard (2006) provided an introduction to GFRS. The material is often used to make large, lightweight panels (considered lightweight because of the thinness of the material; GFRC concrete weighs on average about the same as ordinary concrete on a volume basis). When spray-applied, the fluid concrete mixture (minus fibers) is sprayed out of a gun-like nozzle that also chops and sprays a separate stream of long fibers. The concrete and fibers mix when they hit the form surface. Glass fiber is fed off of a spool in a continuous thread into the gun, where blades cut it just before it is sprayed. Chopped fiber lengths tend to be much longer (about 1.5 in.) than fibers that get mixed in, since long fibers would ball up if they were mixed into the concrete before spraying. Typically spray-up is applied in two layers. The first layer is the face coat, much like a gel-coat in fiberglass. This face coat usually has no fibers in it and is thin, often only about 0.125 in. thick. The second, or backer layer, has the fiber in it. The action of spraying on the fibers results in random orientation, much like the layers in plywood. Spray-up permits very high fiber loading using very long fiber length. GFRC made using the spray-up method yields the greatest strength. However, the equipment required to do spray-up is expensive, often costing more than $20,000.

Polypropylene fiber-reinforced shotcrete (FRS) is made by adding polypropylene fibers to the cementitious mix to improve strain capacity, toughness, impact resistance, and crack control. Collated fibrillated polypropylene (CFP) fibers with fiber lengths between 0.5 in. and 2.5 in. are used, having the primary benefit of control over thermal and drying shrinkage cracking when added in the amount of 1 to 2 lbs of fibers per cubic yard of shotcrete and increased shotcrete toughness when added up to 10 lbs of fibers per cubic yard (US Army Corps of Engineers, 1993). Loevlie (2008) stated that this kind of mortar develops a high compressive strength (6,000 psi in 7 days), and that is more acid and abrasion resistant and more impermeable than ordinary concrete. Fiber-reinforced shotcrete (FRS) proportional mixes are discussed in Morgan et al. (1989).

1.3. METHOD REVIEWS

Hilton (1990) prepared a brief state-of-the-art review of shotcrete covering material properties, applications, finishing, curing, durability, and failures in shotcrete installations. Most shotcrete failures are found to be related to poor preparation of the substrate surface, and the general consensus is that good quality shotcrete is a durable material even when used in severe environmental situations.

New York DOT recommends lining with shotcrete if the structural integrity of culvert is sufficient and corrosion on the entire circumference of culvert is minor, generally less than 20% total perforations. If signs of minor corrosion are limited to the bottom of culvert (i.e. less than 30% of the bottom one-fourth

of the pipe is perforated), paving the invert with Portland cement concrete (PCC) is the preferred method (NYDOT, 2001).

1.4. APPLICABILITY

Reinforced cement mortar lining is only applicable in many-entry pipes. Maximum installation length is about 50 to 60 ft in man-entry applications for practical reasons (this also depends on safety regulations) (Caltrans, 2003).

1.5. ADVANTAGES AND LIMITATIONS

The main advantages of this method is to provide structural repair (sufficient material thickness must be used) and the ability to provide protection against corrosion and abrasion, and restore flow capacity. No excavation is required.

The main limitations include the relatively long setting time and the relatively slow strength gain of the installed liner. The culvert must be completely free of water and flow bypass may be required. Extensive surface preparation is needed in most cases.

2. STANDARDS AND SPECIFICATIONS

Morgan (2000) listed shotcrete guides and specifications.

AWWA C602 covers cement-mortar lining of pipelines from 4 in. to 144 in. in diameter.

ACI 506.2 provides a useful basis (but only limited guidance) for the preparation of detailed specifications for a variety of different shotcrete constructions

ACI 506R provides detailed information on materials and properties of both dry-mix and wet-mix shotcrete. Most facets of the shotcrete process are covered, including application procedures, equipment requirements, and responsibilities of the shotcrete crew.

European Specification for Sprayed Concrete (EFNARC, 1996a) deals with concrete or mortar which is pneumatically placed onto a surface. Both wet and dry processes are covered. The appendix covers the admixtures for sprayed concrete: definitions, specifications, requirements, reference concrete mixes and test methods. EFNARC (1996b) covers the execution of spraying of concrete or mortar. EFNARC (1999) provide a commentary on the Specification by giving an explanation of the requirements.

3. REFERENCES

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