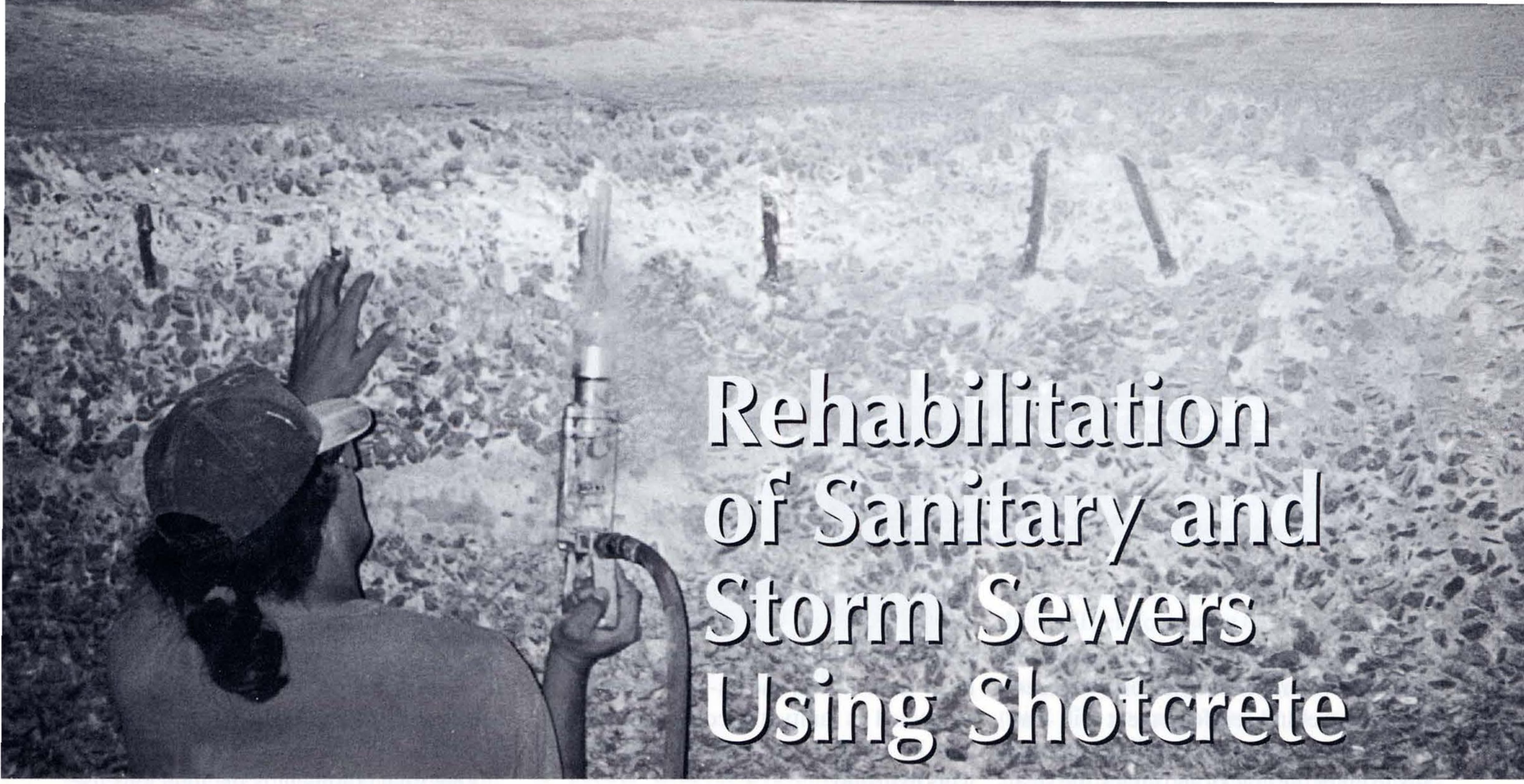


Rehabilitation of Sanitary and Storm Sewers Using Shotcrete

The infrastructure of the United States is crumbling above, below, and around us. A considerable segment of the public and private engineering community is currently engaged in solving a geometrically increasing problem with geometrically decreasing funds. The problem is often compounded since maintenance of public works facilities must be paid for using public funds. This article will introduce a process for solving these problems that has actually been around for many years—the process of using shotcrete or gunite to rehabilitate old, damaged, or otherwise substandard existing sewers.

by W. L. Snow

Shotcrete has been used for many years for repair of sewers in the midwest and northeastern United States and more recently in the southeast and other parts of the country. The more extensive experience in the midwest and northeast has more to do with the age of the infrastructure rather than regional economies or climates.

More infrastructure, such as buildings, bridges, and sewers, was built in the North between 1870 and 1930 than there was in the South. This means that these structures were turning 30 years old and older between 1900 and 1960. By and large, the southeastern United States' infrastructure was built from 1900 on, with a real push between 1930 and 1970. These structures are today, on a large scale, where the north was 30 to 60 years ago.

Since necessity is the mother of invention, folks up North found a long time ago that shotcrete repair is by far the fastest and cheapest way to solve the problem of deteriorating, collapsing, and thus dysfunctional storm and sanitary waste water sewer systems.

A recap of some of the problems causing the deterioration involve the following:

- Age
- Hostile Environment
- Poor Construction

The options for dealing with all of these problems are essentially the same: abandon the old and build new structures, or repair what is there.

The major problem with total replacement of existing sewers is obviously the disruptions caused by open cut digging in congested areas. There is no painless way for a municipal engineer to deal with problems associated with shutting down major thoroughfares while reconstruction or repairs take place. Problems such as relocating existing utilities, rerouting existing services during construction, and traffic detours, not to mention collateral business disruptions, are enough to make any public official

New reinforcement awaits a layer of shotcrete.

contemplate early retirement. There is simply no way to completely replace urban sewers without a cost both in dollars and in terms of public inconvenience. The use of shotcrete can, however, eliminate these headaches, due to the fact that nearly all repair and construction occurs within the sewer and out of sight. The minor inconvenience of the disruptions caused by access through existing manholes is universally more acceptable than total street closure. The use of shotcrete as a construction method can yield a virtually new sewer at tremendously lower cost than replacement alternatives.

Repair Procedures

The first stage of any repair procedure is preparation. Preparation can consist of cleaning, removal of debris, or even chipping to remove deteriorated concrete. Normally, the use of high-pressure waterblasters and/or sandblasting is necessary to complete the preparation process. This is usually followed by either the installation of reinforcement wire mesh or rebar. After all preparation is complete and reinforcement is in place the actual installation of shotcrete can commence.

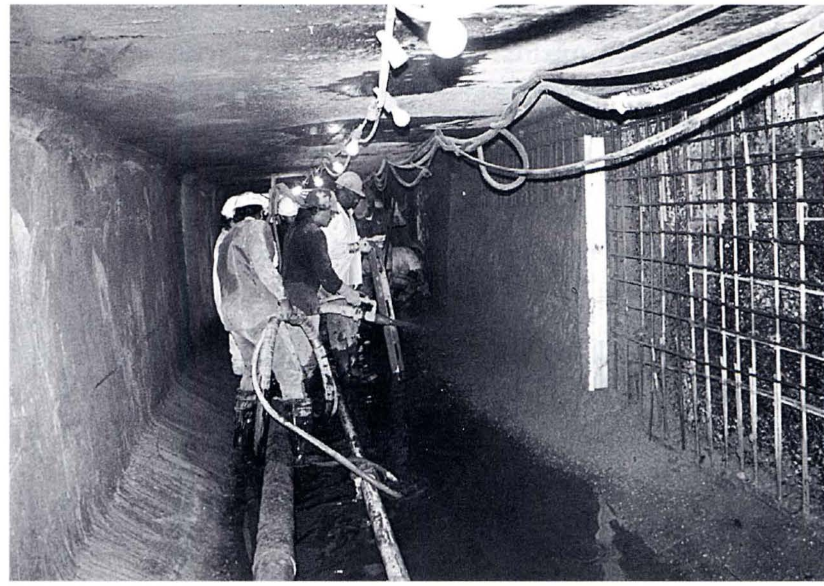
When proceeding with a sewer renovation, a contractor must consider many factors, not the least of which is the flow characteristics of sewage or stormwater in the structure. Attention to this particular site condition often makes the difference between a great project and a potential disaster. One commonly used method of controlling water and effluent includes damming and bypassing the liquids with flume pipes of various sizes and numbers. By-pass pumping is another option sometimes used.

The next step goes hand in hand with the first. The reason the water flow must be controlled is to protect the integrity of the shotcrete invert as it is installed. Not only will running water wash out the installed shotcrete, but mixing of excessive water into the shotcrete can yield a product with unacceptably high water/cement ratios.

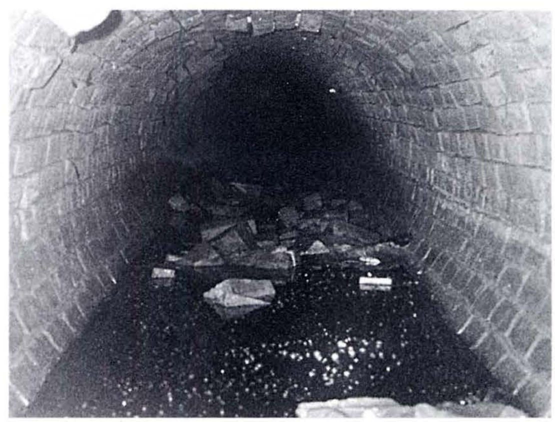
Proper installation of the invert that follows the controlling of water is, in my opinion, the most critical stage of any sewer repair. That is why most knowledgable contractors will usually complete installation of the invert before proceeding with the overhead stage of repair (if needed).

The critical nature of the invert in any repair is obvious, but is worthy of review:

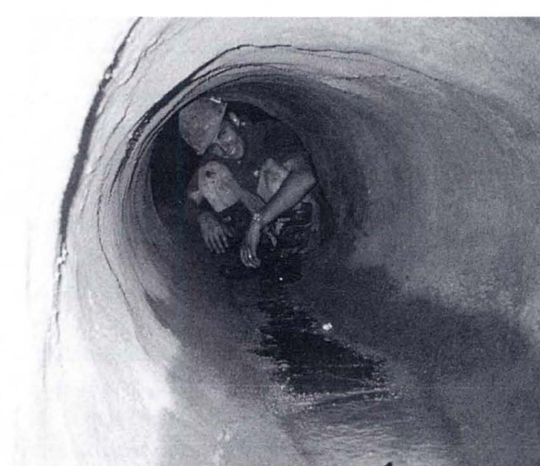
- Most of the wear and tear on a sewer is in the invert. Peak flows necessitate the sizing of the pipe, but the day in and day out sewage flow is usually at low volumes within the confines of the invert.
- Almost all voids over a pipe begin with soil loss through the invert.
- Most abrasives do damage in the invert for obvious reasons (i.e. gravity flow moving sand and other abrasive debris).



Shooting of a new sewer wall. Note the completed area at the left side of the tunnel.



A much smaller sewer pipe in need of rehabilitation.



Flow will often increase despite some lost surface area after shotcreting.

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Figure 1. Consider the following scenario:

Given: Existing brick sewer 60 in. (1.5 m) diameter

Grade: 0.02%

Age: 60 years

Depth from street to crown: 6 ft. (1.8 m)

Condition: Poor to failed, loose bricks, partially missing invert

Near term potential for total collapse: High

Proposed solution: Clean and repair using a 2 in. (50 mm) shotcrete lining reinforced with 2 in. x 2 in. galvanized welded wire fabric.

Ultimate flow capacity: (using Manning's equation)

$$Q = \frac{1.49}{n}(A)(R_H)^{2/3}(S)^{1/2} \qquad \text{Metric: } Q = \frac{1}{n}(A)(R_H)^{2/3}(S)^{1/2}$$

where Q = Ultimate flow
n = Manning's coefficient
A = Cross-sectional area of the pipe
S = Slope of the pipe
Pw = Wetted perimeter
R_H = Hydraulic radius = A/Pw

Existing: n= .016 (assuming no debris)
dia. = 60 in.

$$Q = \frac{1.49}{0.016}(19.625)\left(\frac{19.625}{15.7}\right)^{2/3}(0.0002)^{1/2} = 29.99 \text{ CFS}$$

Metric: dia. = 1.524 m

$$Q = \frac{1}{0.016}(1.824)\left(\frac{1.824}{4.788}\right)^{2/3}(0.0002)^{1/2} = .847\ m^3/s = 29.91 \text{ CFS}$$

After Repair: n = .013
dia. = 56 in.

$$Q = \frac{1.49}{0.013}(17.07)\left(\frac{17.07}{14.66}\right)^{2/3}(0.0002)^{1/2} = 30.62 \text{ CFS}$$

Metric: dia. = 1.422 m

$$Q = \frac{1}{0.013}(1.588)\left(\frac{1.588}{4.467}\right)^{2/3}(0.0002)^{1/2} = .867\ m^3/s = 30.62 \text{ CFS}$$

The geometry and condition of the invert also determine flow characteristics in all but peak flows; thus the efficiency and durability of the structure depends on the integrity of this part of the geometry of the sewer. The installation of the invert first also eliminates the following construction concerns in the shotcrete process:

1. Mixing rebound with freshly applied shotcrete.
2. Walking in, or disturbing freshly placed shotcrete while working on overhead placements.
3. Normal, light water flow ceases to be a concern to the final product during later construction.

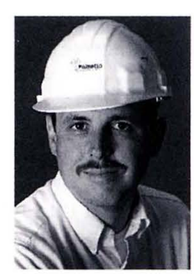
After the invert has been repaired, the walls and overhead parts of the sewer can be shot. In most structures of any size, the top of the pipe or tunnel nearly always requires two or more passes to obtain the desired shotcrete thickness. Barring contamination by flow or debris, shotcrete typically yields superb bonding between roughened shotcrete layers during this multi-layer repair process.

Sewers that are candidates for shotcrete generally range in size from 36 in. (1 m) in diameter to aqueducts as large as 16 to 20 ft. (5 to 6 m) in height and/or width. In every case, the designer must base his or her design on standard concrete design criteria for a given structure.

There is at least one potential drawback to lining an existing sewer with shotcrete versus replacement. That factor is a potentially reduced ultimate flow capacity due to a reduction in cross sectional area if the repaired shotcrete lining extends beyond the original sewer inner dimensions. At first glance, this appears a formidable concern until the designer calculates the actual impact. (See Figure 1.)

Even with the reduction of cross sectional area caused by the installation of a in shotcrete lining, the ultimate flow is usually comparable and often exceeds the existing flow condition. This is due to the relationship of a reduced "n" value versus the final diameter. Each structure must be similarly analyzed to compare existing conditions with the repaired structure when assessing this impact. The end result of the shotcrete repair is a like-new structure with wear characteristics vastly superior to the existing structure. If the life span of the existing structure is 30 to 50 years, the owner could reasonably expect an equivalent life span or even longer with the shotcrete-repaired structure.

In closing, it should be noted that changes in surrounding environmental and use criteria may affect the capabilities of existing sewers or make them obsolete. In the majority of existing structures, however, the alternative of using shotcrete as a repair method should at least be evaluated during the early planning and design phase. This is a tried and proven method of repair in large segments of the design community; its cost and convenience savings are simply too significant to be ignored.



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