

## Shotcrete Repair Saves Baltimore Bridges

by I. Leon Glassgold

*This "Shotcrete Classic" was selected for reader interest. While first published 23 years ago, most of the dry-mix shotcrete technology described for repair of bridges still remains relevant today. There are a few areas where things have changed. Small line wet-mix shotcrete equipment is now available with suitable start and stop characteristics for small volume wet-mix shotcrete repair of bridges and other structures and is now also widely used for this purpose. Also, with proper surface preparation and the incorporation of silca fume in shotcrete, bonding agents are now seldom used, or needed. Good guidance regarding current recommendations for shotcrete repair of bridges can be found in the AASHTO-AGC-ARTBA Task Force 37 Report "Guide Specification for Shotcrete Repair of Highway Bridges," published in 1998 by AASHTO in Washington, DC.*

The dry-mix fine-aggregate shotcrete process is still the most widely used shotcrete process for the repair of concrete structures and linings, especially for small patch and thin section repair. Shotcrete repair is extremely effective for variable depth repairs of bridge beams, caps, columns, abutments, wingwalls, and underdeck, whose deterioration has been accelerated by the introduction of continuous beam design, shallow depth deck slabs, asphalt surfacing, and the heavy use of deicers. The City of Baltimore has established an annual preventive maintenance shotcrete program to provide emergency repairs and upgrade bridges as the budget allows. The repair program consists of 3 basic steps: (1) preparation of disintegrated areas; (2) removing bad reinforcing steel and placing galvanized welded wire fabric; (3) shotcreting.

**Keywords:** bridges (structures); maintenance; repairs; shotcrete.



Figure 1: Deterioration of a bridge sidewalk due to freeze-thaw action coupled with liberal use of deicing salts.



Figure 2: Crack development of column base followed by rusting of the reinforcing steel causing aggravated decay of the concrete. Water and salt leaking from bridge deck plus freezing splash water from the roadway have combined to cause this distress.

One of the earliest and major uses of shotcrete, then known as "Gunite,"\* was the repair of concrete structures and linings. Prior to World War II, the dry-mix fine-aggregate shotcrete process was the only repair technique utilized, because it was the only successful method available. During the postwar years with the advent of wet-process and coarse-aggregate equipment, new alternatives were developed. While wet-mix and coarse-aggregate shotcrete have certain advantages and have found great utility in other applications, the dry-mix process using fine aggregate is still predominant, especially in small patch and thin section repair.

There are many reasons for this. Coarse-aggregate shotcrete requires a gradation not readily available, has higher rebound, is more difficult to finish, cannot be used for thin layers, and has little economic advantage over fine-aggregate shotcrete. On the other hand, wet-mix shotcrete cannot be readily placed in all positions, and water content cannot be instantaneously varied to meet field conditions. It has a higher water

\*"Gunite" is the fine or coarse aggregate product of the Allentown Cement Gun and conforms to the ACI definition of shotcrete—"mortar or concrete projected at high velocity onto a surface." In its early years "Gunite" was primarily a fine-aggregate product.

Reproduced with permission from the September 1980 edition of Concrete International—the magazine of the American Concrete Institute.

# Shotcrete Classics



Figure 3: Crack development in handrail post-penetration of moisture to the reinforcing with the subsequent rusting, cause the concrete to spall and break away.



Figure 4: Questionable quality of concrete with scaly finish and reinforcing bars too close to the surface. Reinforcing has developed heavy scale and lost considerable section.

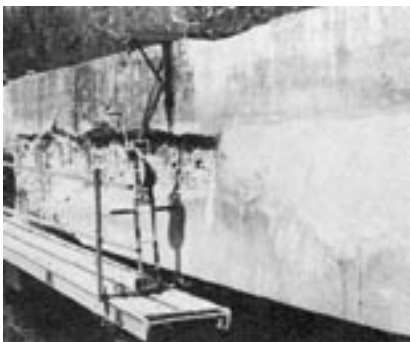


Figure 5: Fascia beam with advanced concrete decay at bridge deck level and below. Area to right of decay is hand patched or plastered and hollow sounding when struck with a hammer. Reinforcing is scaly.

content, does not have adequate start and stop placement characteristics, has lower strength and freeze-thaw durability, and generally is not as flexible a technique as the dry-mix process. All references to shotcrete in the balance of this article will be to dry-process fine-aggregate shotcrete.

## Causes of deterioration

While the causes of concrete deterioration are many and varied, it is not our purpose to define or analyze them in depth (Fig. 1, 2, and 3). Suffice to say that concrete not properly designed, prepared, installed, finished, or cured is more susceptible to those deleterious influences which cause the concrete to decay and spall and the reinforcing to rust and lose section (Fig. 4 and 5). This in turn reduces structural sufficiency, usually limits utility, and results in eventual failure (Fig. 6).

It should be noted that deterioration influences on reinforced concrete buildings, with the exception of air pollution, have through the years remained essentially the same. This is not true of concrete bridges. The introduction of continuous beam design, shallow depth deck slabs, black top surfacing, and the heavy use of deicers have continued to accelerate deterioration of the concrete in the many bridges of our highway systems (Fig. 7). In the frost belt where cyclic freeze-thaw action occurs, rapid disintegration occurs in the bridge decks with varying degrees of deterioration showing in the concrete and abutments.

## Bridge repair

While shotcrete repair can be used for deck rehabilitation, it has been found to be economically unfeasible for major full thickness repairs (Fig. 8). It is, however, extremely effective for variable depth repairs of beams, caps, columns, abutments, wingwalls, and underdeck from the standpoint of technique, cost, and other practical considerations. In many areas where a bridge has all the

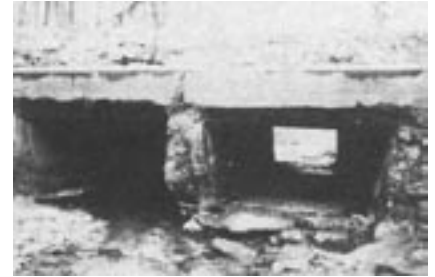


Figure 6: Culvert showing heavy disintegration and structural distress almost to the point of failure.



Figure 7: Bituminous surface breaking up exposing deck to corrosive influences. Even though surfacing has been patched, concrete underneath is severely deteriorated and ready to break through. Area in lower right hand corner is rubble from sidewalk deterioration.

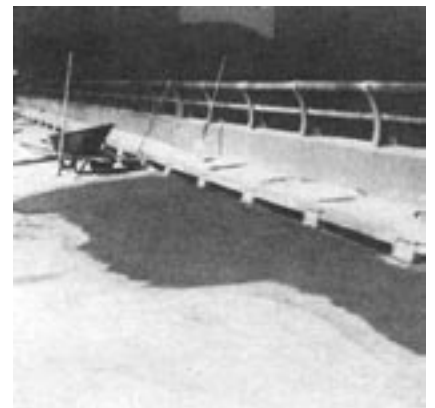


Figure 8: Shallow shotcrete repair of concrete deck to curb line. It is characteristic of bridge deck repair that the deepest areas of decay are usually found at the curb line.

# Shotcrete Classics

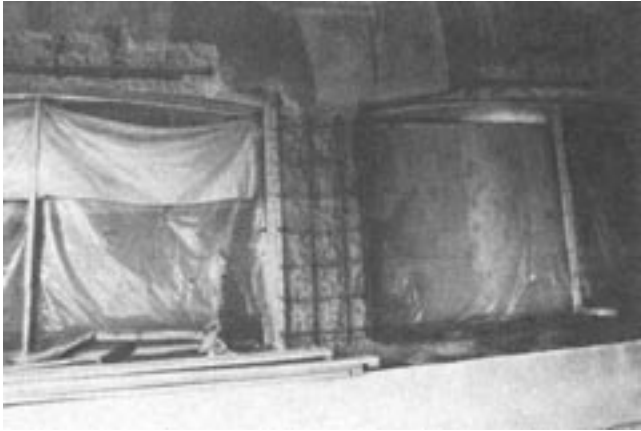


Figure 9: Column and cap repair showing chipped areas. The column steel has been sandblasted and welded wire fabric attached.



Figure 10: Same general view as Fig. 9. Areas have been shotcreted, finished, and a membrane curing compound applied.



Figure 11: Cantilever reinforced concrete beam support prior to repair. Note penetration of rust to areas adjacent to reinforcing.



Figure 12: Same cantilevered beam as shown in Fig. 11. The repair has been completed using the shotcrete process.



Figure 13: The deterioration of the concrete in this crash barrier and column base is primarily due to roadway splash adhering to the surface and going through many freeze-thaw cycles. Deicers accelerated the process.

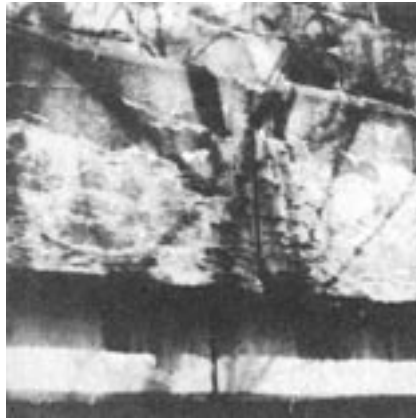


Figure 14: Fascia projection showing leaching of lime substances from the concrete due to wetting and drying. Once deterioration has started, freezing and thawing action during cold weather aggravates the problem.

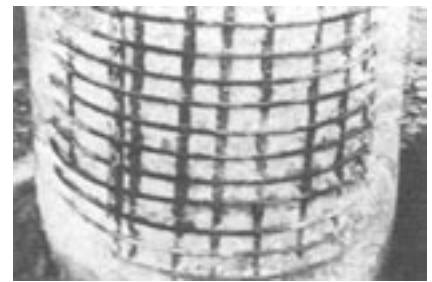


Figure 15: Circular column steel showing the effect of moisture and water infiltration on concrete of poor quality. Close spacing of reinforcing and overly dry concrete mixes can set the stage for this type of problem.

# Shotcrete Classics

requirements for future serviceability except for the deck impairment, the superstructure is replaced. This can involve both the deck and its supporting beams where the latter are not compatible with the new design or are beyond repair. A cost-effective shotcrete repair of the substructure can save precious tax dollars for other useful purposes.

A case in point is the City of Baltimore which has many types of bridges built between the two World Wars which have undergone severe deterioration. For the past 20 years the City has been salvaging many of these bridges by replacing the superstructure and salvaging the substructure. In addition, a yearly preventive maintenance shotcrete program has been established to provide emergency repairs when needed and to upgrade the condition of as many bridges as the budget will allow. Several photographs in this article represent shotcrete work on the bridge system of Baltimore City. Figures 9, 10, 11, and 12 show some typical before-and-after repair photographs.

## Basic procedure

Shotcrete repair involves three basic procedures:

1. preparation
2. reinforcing
3. shotcreting

**Preparation**— The most important phase of shotcrete repair of concrete structures is the preparation of the disintegrated areas. It is absolutely essential that all disintegrated, soft, spongy concrete be removed to a hard, sound base (Fig. 16). If any weak, unsound concrete is left, the shotcrete will not properly bond to the original material and a plane of weakness will remain which can result in future failure.

It is also imperative to remove any questionable material behind exposed reinforcing steel. Weak, fractured, or cracked concrete surrounding a reinforcing bar can provide internal access to seepage water recreating the conditions that are being corrected (Fig. 17).



Figure 16: Same fascia beam as shown in Fig. 14. Chipping concrete with a pneumatic chipping hammer. The concrete is soft, spongy, weak, and relatively easy to remove. Chipping must continue until a hard surface is exposed.

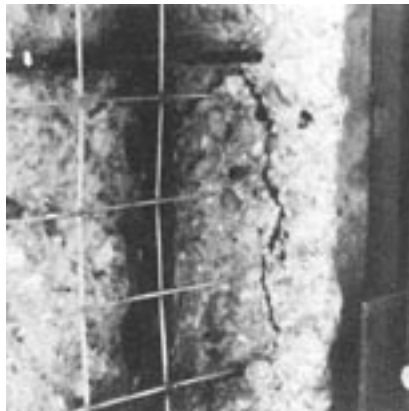


Figure 17: The dark crack in center of figure starts just behind the rusted reinforcing bar and represents dissolved rust. The crack is filled with rust which ends at the bottom of the figure.

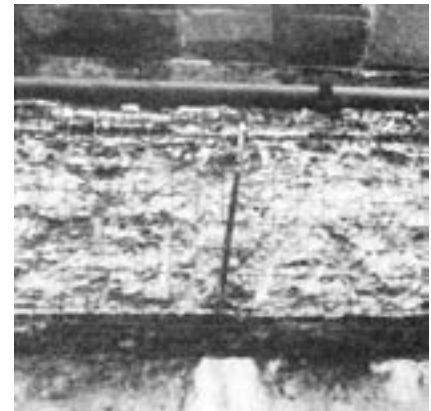


Figure 18: Fascia beam as shown in Fig. 14 and 16. Concrete chipped with welded wire fabric attached.



Figure 19: Wetting down an area prior to shotcreting with air-water blast. This procedure cuts down the absorption of mix and water and cleans the area prior to shotcreting.

# Shotcrete Classics



Figure 20: Shotcreting expansion dam that had become loose and had to be rewelded. Care must be taken by nozzleman to see that rebound does not build up in the inaccessible areas.



Figure 21: Shotcreting fascia beam. Area to right is over shot. Material will be wasted when surface is trimmed to wire fabric.

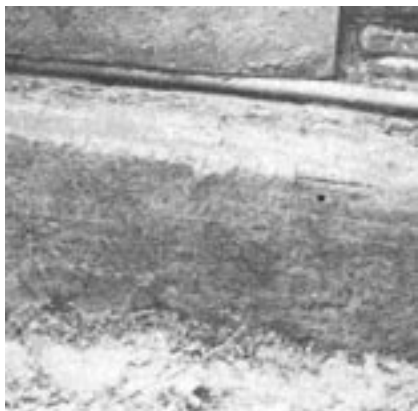


Figure 22: Fascia beam trimmed to welded wire fabric. A final coat of about 1 in. (25 mm) will be applied, finished to required texture, and cured.

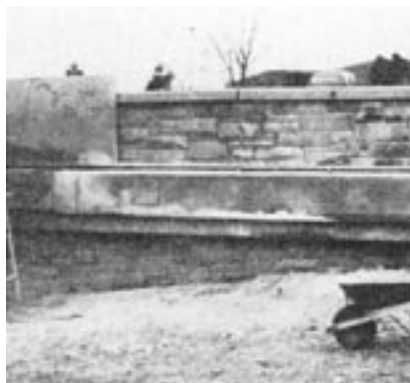


Figure 23: Fascia beam completed. Note that calcium deposits show on bottom of beam. Seepage water from roadway has made its way past the repair to the underside of the beam.

In those cases where seepage is deep-seated and beyond the depth of repair, the infiltrating water must be stopped at its source. This can be a difficult chore and if not effected, a new repair can exhibit cracks and staining at an early age.

**Reinforcing** — After preparation is completed, rusted reinforcing steel should be sand-blasted and steel of inadequate section replaced. Welded wire fabric usually galvanized, is then attached to the exposed reinforcing bars (Fig. 18). Plated anchor bolts at appropriate spacing are used where the bars are not sufficiently exposed. The mesh should be spaced in the repair so that  $\frac{3}{4}$ -1 in. (19-25 mm) of shotcrete coverage is provided.

**Shotcreting** — Except for unusual applications, forms are rarely used in shotcrete repair and then only as a backing material requiring minimal bracing. Guide and chamfer strips and piano wire provide means for maintaining adequate line and grade.

Bonding agents are used when there is a question of bond between the old and new material and/or a thin layer of unreinforced shotcrete is being applied.

The shotcrete mix requires various ratios of cement to sand depending on the application. The leaner mixes (1:4 to 1:5) have lower strength, are less impermeable, but exhibit lower shrinkage than do the richer mixes (1:3 to 1:4). A well graded concrete sand as specified in ACI 506-66 should be used with the proper moisture content. Admixtures should only be used after their compatibility with the other mix ingredients has been established.

Shotcrete of good quality requires well maintained equipment, a more than sufficient volume of air and water at required pressure, and an experienced nozzleman and crew. Careful attention to nozzle techniques is required for good bond, reduced rebound, elimination of sand pockets and voids, complete encasement of all reinforcing steel, and minimal

# Shotcrete Classics

overshooting (Fig. 19, 20, and 21). Finishing should be kept to a minimum to avoid breaking bond, hair crack development, and other surface distress (Fig. 22 and 23).

It should be noted that shotcrete practice varies from locale to locale. Climate, materials, and economics dictate procedures. A good understanding of the effect of these variables is required to insure a successful shotcrete installation. If proper attention has been paid to all details the end result should be a dense, high strength, impermeable, durable, and quality shotcrete repair (Fig. 24 and 25).

Received March, 1980 and reviewed under Institute publication policies.

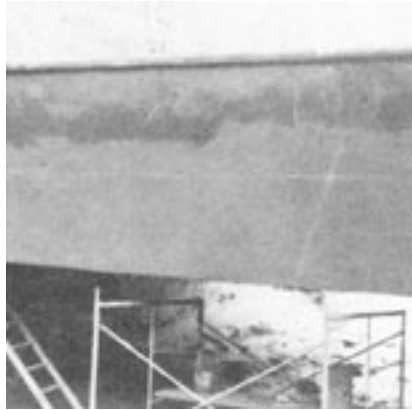


Figure 24: Outside beam and parapet of single span bridge showing completed shotcrete repair with fairly smooth brush finish.



Figure 25: Culvert from Fig. 6 partially restored with shotcrete. Finish is "natural" or "gun finish." Stone wingwall to right has been reintegrated with shotcrete.



ACI Fellow and former ACI President I. Leon Glassgold, P.E., is chief engineer at Masonry Resurfacing & Construction Co., Inc., Baltimore, MD, a firm specializing in applications

of shotcrete and refractory concrete for construction and repair. He served as President of the company for over 40 years. He is a former member of ACI's Board of Direction and Technical Activities Committee and a former chairman of TAC's Specifications Committee. Glassgold received ACI's Delmar L. Bloem Distinguished Service Award in 1979, the Henry C. Turner Medal in 1987, and the Chapter Activities Award in 1989. He is currently a member of several ACI technical committees including Committee 506, Shotcreting, and was Chair of the subcommittee that wrote "Guide to Shotcrete (ACI 506R.85)." Glassgold recently relinquished chairmanship of ASTM Subcommittee C09.46, Shotcreting, after 10 years. Under his leadership, the subcommittee has published many national standards for shotcrete.