Repair of Bridge Elements Using Shotcrete

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By Steve Gebler

This article presents the essential elements necessary for successful remediation of bridge elements. It should be noted that all structural elements whether from bridges or other structures can have certain commonality. However, with bridges, there are certain environmental characteristics that enhance the potential for distress. Bridge elements have a certain sensitivity to damage caused by freezing and thawing of inadequately air-entrained concrete, chloride induced corrosion, alkali-silica reactivity (ASR), and possibly load-related conditions.

D. Morgan and J. Neil (1) discussed the performance of shotcrete repairs made on bridge elements (2), and prepared for the Canadian Strategic Highway Research Program (C-SHRP) the "Recommended Practice for Shotcrete Repairs of Highway Bridges." ACI Committee 506 has several documents, including a specification that addresses the use of shotcrete. In a paper by S. Gebler, et al. (3), important elements are presented that should be considered when using shotcrete.

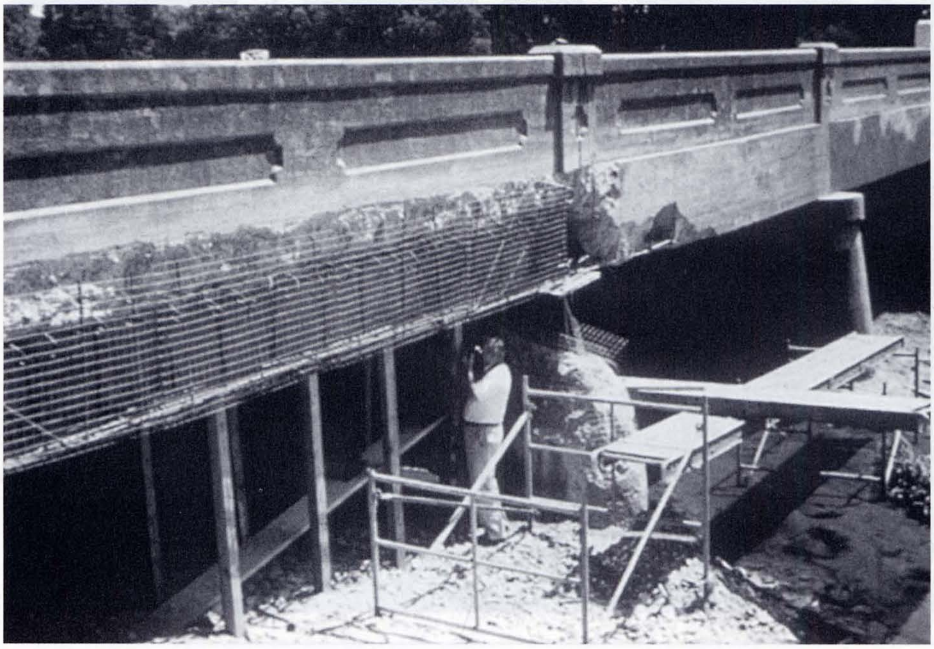
Removal of deteriorated concrete and surface preparation are discussed, along with specific application techniques of shotcrete and key elements in the specification. The need for a Quality Assurance/Quality Control (QA/QC) plan is set forth.

Removal of Distressed Concrete

Before embarking upon any repair, the engineer must first identify the limits of distress and determine the cause of the distress. To address just the symptoms (spalling, cracking, etc.) it is important to establish the cause for distress so that appropriate repairs can be affected. The repair design and restoration should incorporate measures that mitigate the damage. For example, if improper drainage caused the damage, then adequate measures to correct the drainage should be employed in the repair. In identifying damage due to corrosion related problems, the chloride-ion content should be determined at various levels, especially at the steel reinforcement. Knowing how deep the chloride contamination penetrates the original concrete will enable the designer to determine the extent to which distressed concrete must be removed. Further, if tests show that alkali aggregate reactivity (AAR) is pervasive throughout the original concrete, the engi-

Figure 1. (Below left) Greensboro Bridge in North Carolina. Preparation before shotcreting.

Figure 2. (Below right) Removal of deteriorated concrete, I-695 Baltimore Beltway over U.S. 1 in Maryland.



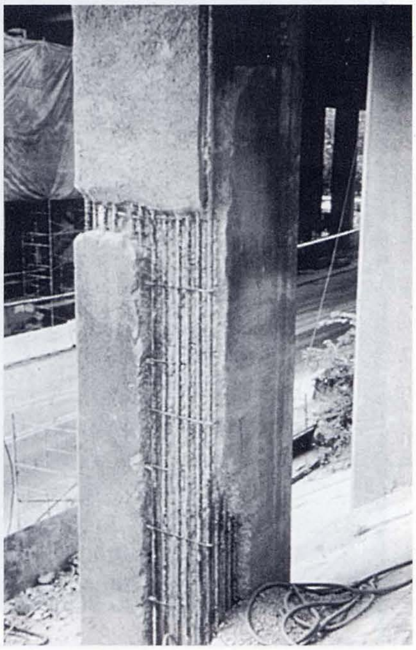


Figure 3. Use of blowpipe to remove rebound for cooling tower shell repair.

neer can obtain greater insight regarding possible future damage and know how to handle it. For example, anchors may be necessary to prevent delamination in the newly applied shotcrete. In other repairs, a full jacket may be required (see Ref. 2). This situation is discussed below under Shotcrete Applications.

Deteriorated concrete should be removed down to sound concrete. The surface should be cleaned; that means no dust or loose particles on the surface that can interfere with shotcrete bonding.

For corrosion-related damage, steel reinforcement should be cleaned using dry sandblasting methods. For areas on the backside of the reinforcement, the sandblast should ricochet off the concrete to clean this part of the steel. All rust and pitted steel should be repaired using appropriate techniques discussed by IACRS, now ICRI (4). If more than 20% of cross-sectional area of the steel reinforcement is lost, the engineer should be notified for appropriate resolution. The clearance behind reinforcement, and the concrete substrate should be at least 20 mm (3/4 in.). The outer edges of the repair area should be sawcut to a minimum depth of 20 mm (3/4 in.) and tapered to sound concrete at approximately a 45-degree angle to reduce entrapping rebound at edges. Regardless of the type of material used for repair, featheredges should be avoided. Featheredging leads to peeling and delamination of repairs. Figures 1 and 2 show bridge elements being prepared for shotcreting.

Very porous concrete should be kept moist for at least 24 hours before shotcrete application. For denser concrete, the surfaces should be kept moist for at least one hour before shotcrete application. In any event, the substrate surfaces should be in a saturated-surface dry (SSD) condition at the time of shotcrete application.

Shotcrete Materials

Shotcrete repairs on bridges are most commonly made using the dry-mix process. The wet-mix process can be used but is generally more applicable to larger volume repairs. Wet-mix shotcrete for repairs should have a water-cementitious materials ratio (W/Cm) not exceeding 0.40 by mass. Silica fume is recommended as a constituent of the shotcrete for most repairs, especially when low permeability of the repair is required. Incorporation of silica fume in shotcrete increases adhesion, enables greater thickness to be applied in a single application, and reduces rebound. For wet-mix shotcrete containing silica fume, a superplasticizer is strongly recommended. The amount of silica fume is generally between 8 and 15% by mass of cement. For wet-mix shotcrete, air-entraining admixtures should be used. The air content for the as-mixed material should be at least 6%. It is normal to lose air during shotcreting, but studies have shown that the freeze-thaw durability is not affected by some loss of air (5). In my opinion, and as shown in laboratory and field studies (6), dry-mix shotcrete does not require purposely entrained air to develop adequate freeze-thaw resistance.

Choose the proper type of cement and minerals admixture consistent with the environmental conditions. Type II or V portland cement should be used in sulfate environments. Shotcrete incorporating fly ash, silica fume, and slag can inhibit ASR and provide resistance to sulfate attack and chloride intrusion. Shotcrete made with rapid set accelerators can lose significant strength and be vulnerable to deterioration from freeze/thaw action (7).

Steel fiber can be incorporated into shotcrete mixes to increase toughness and strengthen load-bearing elements. Reference 2 and ACI 506.1R (8) address the use of fibers in shotcrete.

Shotcrete Application

Whenever possible, shotcrete should be applied as a single full thickness layer. Application of shotcrete in discrete layers can result in delaminations if surface preparation between layers is inadequate. During

Figure 4. Repair of circular bridge pier.

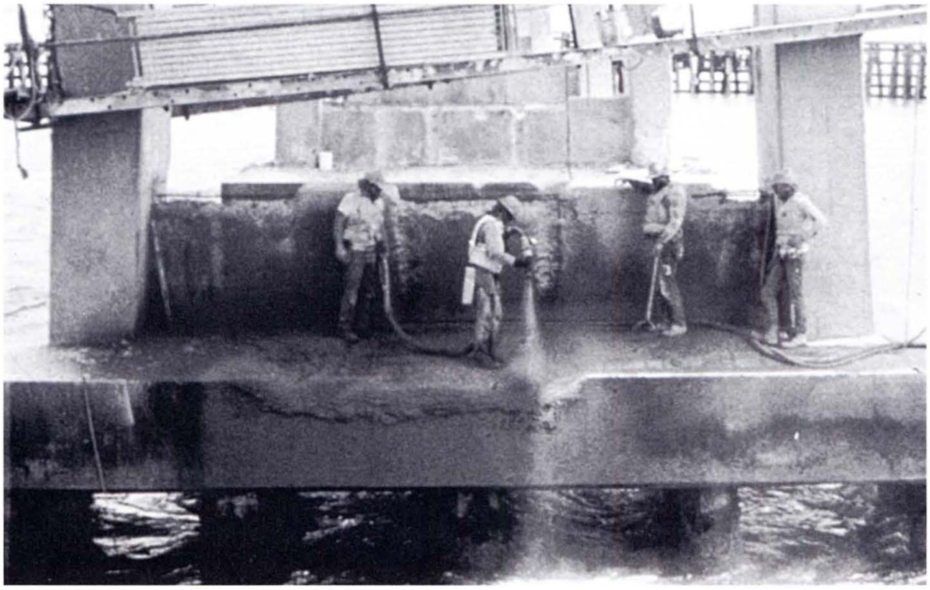


Figure 5. Pier cap being shot for Herbert C. Bonner Bridge in Nags Head, North Carolina.

shotcrete application of an area, protection of adjacent previously prepared areas should be provided to prevent contamination due to overspray. This can be especially critical with shotcrete containing latex.

To prevent accumulation of rebound within the repair area, a blowpipe should be used. Generally, the assistant nozzleman operates the blowpipe. This is extra insurance against incorporating unwanted rebound into the repair which can result in weakened zones of porous material, which generally initiates cracks. Figure 3 depicts the use of a blowpipe.

Reference 2 cautions against using rotary drum transit mixer for dry-mix shotcrete. There is a tendency for "balls" or "pellets" to develop resulting in non-homogeneous and non-free flowing material within the mixer.

Encapsulation of elements is strongly recommended as discussed in References 1 and 2. The C-SHRP study (2) found:

"In encapsulating elements such as pier caps, buttress, parapets, etc., it is important that the shotcrete be designed to completely cap the elements. The C-SHRP study found that there was a danger of the shotcrete repair acting as a 'dam' to promote saturation of the original concrete with water and salts, if the shotcrete repair did not completely cap the original concrete. All caps should be designed with a minimum 3 percent slope, to prevent ponding and facilitate drainage."

Figures 4 through 8 shows shotcrete application and the finished sections of various bridges.

Quality Assurance/Quality Control

Among important elements in the shotcrete process, QA/QC is essential. Department of transportation officials and bridge engineers are vitally concerned with proper application of repairs. They want and expect repairs be performed correctly the first time in order to avoid a future failure and not lose any additional service life of the structure. This is important since taking a bridge out of service leads to inconvenience to the public and embarrassment to the authority. Therefore, strict QC, inspection and enforcement by knowledgeable inspectors are crucial for high-quality shotcrete repairs. The specifications must provide for removal details, performance requirements such as strength, permeability, freeze-thaw resistance, and tensile bond strength. In addition, pre-construction test panels for substantial projects should be made unless proof of adequate workmanship of similar materials and processes can be shown. Each nozzleman should be qualified for each specific project unless proof of suitable, previous qualification can be shown. Test panels should be shot with the same amount and configuration of the steel reinforcement that is to be encased. In addition, panels should be made for all anticipated shooting positions. Figure 9 shows a preconstruction test panel being fabricated for a cooling tower repair. Cores should be drilled at intersections of steel to insure that the reinforcement is adequately encased.

Figure 6. Restoration of hammerhead pier to original lines.

Figure 7. Shotcreting provides an efficient means of rebuilding bridge curbing.

Figure 8. Completed bent.

Figure 9. Shooting of preconstruction panel for cooling tower shell repair.

The next question is "What constitutes proper and improper encasement?" Excessive voids behind reinforcement will lead to cracks and pathways for moisture and salts to enter the cracks and attack the steel reinforcement. The core grade system, a quantitative method of measuring the quality of shotcrete, originally developed by T. Crom (9), should be used for acceptance/rejection of nozzleman workmanship. This system is incorporated into the new ACI 506.2 specification. Generally, for structural grade quality an average core grade exceeding 2 should be considered unacceptable. This system can be used when checking in-place shotcrete quality. However, the specification should address this system if it is to be used for acceptance/rejection, e.g., incorporate the criteria so the contractor knows what is expected.

ACI 506.2 and C-SHRP (2) provide the details for an adequate specification. However, the C-SHRP document is not in mandatory specification language. There is an AASHTO Task Force 37 publication available which provides good guidance to the design engineer writing specifications for shotcrete repair of highway bridges.

There is considerable discussion within the industry on the use of use the core grade system. Use of the core grade system by knowledgeable shotcrete technologists is a valuable tool. Specifying the core grade system also alerts the contractor as to the quality of shotcrete that is expected. Using the core grade system is a fair method to assess quality by the owner, contractor, and engineer. Many current specifications do not adequately address what constitutes causes for rejection of defective shotcrete. The core grade system provides for quantification of quality for the specifications. If an area within the as-shot material is suspected as faulty, the core grade system can be used to assess the quality of workmanship.

Tensile bond tests (see Figure 10) (3) provide a useful tool to measure the bond between the shotcrete and substrate. However, if this test is used, the engineer should understand the meaning of the values obtained. Preliminary tests may be required before drafting the specification to determine minimum acceptable values. If the tensile bond test is used, careful interpretation of the test results is required, depending upon obtained test values and location of failure, i.e., in the substrate, at the bond line, or in the shotcrete. Outright rejection of low values may be inappropriate without consideration of the location of the failure and the properties of the substrate material.

One final comment is the judicious use of tolerances and aesthetics. Engineers need to be cognizant that closer tolerances and aesthetics require more money. For repairs where the public may not observe the repair or the structure is in a rural area, greater tolerances or less appealing aesthetics may be satisfactory. In developing aesthetic and tolerance requirements, the engineer should keep in mind the costs associated with those requirements.

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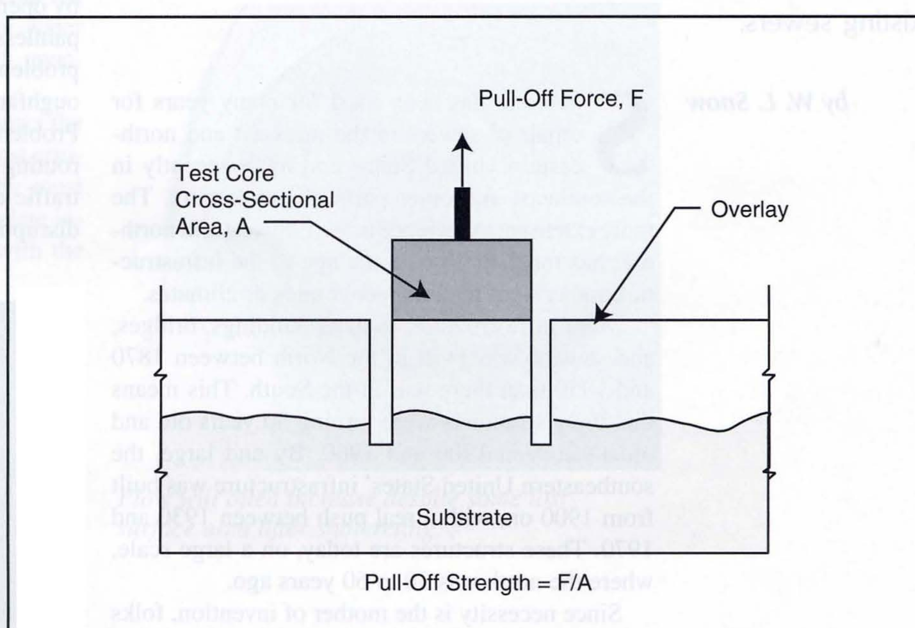

Figure 10. Schematic of tensile bond pull-off strength test.

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Summary

This paper discusses the importance of proper application of shotcrete for repairs to bridges. Suitable removal and surface preparation of the deteriorated concrete is critical. Proper mix constituents, as well as application, are critical to satisfactory in-place shotcrete. The specifications should address pre-construction qualification of nozzleman and materials. Where applicable, the core grade system should be used to determine acceptance/rejection criteria.

References

1. Morgan, D. R. and Neill, J., "Durability of Shotcrete Rehabilitation Treatments of Highway Bridges in Canada" Transportation Association of Canada Annual Conference, Winnipeg, Manitoba, September 17, 1991, pp. 36.
2. "Recommended Practice for Shotcrete Repair of Highway Bridges," Canadian Strategic Highway Research Program, HBT AGRA Limited, Burnaby, B.C., June 1992.
3. Gebler, S., Kolf, P., Seegebrecht, G., Litvin, A., and Vincent, J., "Shotcrete: Surveillance for Durable Structure—Case Histories," Proceedings of the Second CANMET/ACI International Conference on Durability of Concrete, Montreal, Canada, ACI SP-126, Vol. 11, August 1991, pp. 869-900.
4. International Concrete Repair Insitute, Technical Guideline No. 03730—*Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion*, Sterling, Virginia , October, 1989.
5. Litvin, A. and Shideler, J.J., "Laboratory Study of Shotcrete," Shotcreting, SP-14, American Concrete Institute, Detroit, Michigan, pp. 165-184.
6. Seegebrecht, G., Litvin, A., and Gebler, S., "Durability of Dry-Mix Shotcrete," *Concrete International: Design and Construction*, American Concrete Institute, Vol. 11, No. 10, October 1989, Detroit, Michigan. pp. 47-55.
7. Gebler, S., Litvin, A., McLean, W.J., and Schutz, R., "Durability of Dry-Mix Shotcrete Containing Accelerators," *ACI Materials Journal*, Vol. 89, No 3; May-June, 1992, pp. 259-262.
8. ACI 506.1R-84, "State-of-the-Art Report on Fiber Reinforced Shotcrete," American Concrete Institute, *ACI Manual of Concrete Practice—Part 5*, 1985, Detroit, Michigan.
9. Crom, T.R., "Dry Mix Shotcrete Nozzling," The Crom Corporation, 1985, Gainsville, Florida. p. 39.
10. AASHTO-AGC-ARTBA Task Force Report, "Guide Specifications for Shotcrete Repair of Highway Bridges," AASHTO, Washington D.C., February, 1998, pp. 117.

For core grades see ACI 506.2-95

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Figures 2 and 5: Coastal Gunite Construction Company.

Figures 4, 6, 7, and 8: Engineering Branch, Alberta Transportation and Utilities.

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