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Viability and Durability of Shotcrete for Repairing Bridges

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16. Abstract Several construction projects were reviewed that had used shotcrete for unformed repair work on bridge superstructures and substructures. These repairs, usually overhead or vertical repairs, are normally done by using rapid set cement mix and the manual lay-up method. In the past contractors have asked to substitute shotcrete. There now is a Bridge Special Provision sometimes used to specify shotcrete for a particular job. The main problems seen in the field with shotcrete were shrinkage cracking and lack of bond to the existing bridge. Through observation of four projects and checking literature on best practices from other states and the AASHTO-AGC-ARTBA Task Force 37 - 1999 report on Shotcrete Repair, several conclusions were reached. If the special provisions are followed closely shotcrete is a viable repair method for highway bridges. Good surface preparation and pre-wetting before shotcreting are critical to getting a good bond. Contractors quite often use the dry-mix shotcrete method, especially for small repairs. MoDOT should require pre-bagged mixes for dry-mix shotcrete because it makes a more consistent mix. The pre-bagged mix should include silica fume in order to make the mix stickier and provide better bond strength. Testing showed a good air structure in the hardened concrete and an air entraining agent should be required in a pre-bagged mix. A 7-day moist cure is needed for shotcrete, and curing compound use should be secondary to specifying wet curing to decrease shrinkage cracks. Changes to the Bridge Special Provision incorporating these conclusions have been presented in this report.			
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Final Report

RI03-011

**Viability and Durability of Shotcrete for
Repairing Bridges**

Prepared for the

Missouri Department of Transportation
Organizational Results

By

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Missouri Department of Transportation

June 2007

The opinions, findings, and conclusions expressed in this publication are those of the principal investigators and the Missouri Department of Transportation, Organizational Results. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard or regulation.

Abstract

After an inquiry by the Bridge Division in 2003, Organizational Results, reviewed several construction projects that had used shotcrete for unformed repair work on bridge superstructures and substructures. These repairs are usually overhead or vertical repairs normally done by using rapid set cement mix and the manual lay-up method for application of the patching material. In the past contractors have substituted shotcrete instead of using a qualified special mortar as called for in the specifications. There now is a Bridge Special Provision sometimes used to specify shotcrete for a particular job. The main problems seen in the field with shotcrete were shrinkage cracking and lack of bond to the existing bridge.

Through OR's observation of the four projects mentioned and from checking literature on best practices from other states and the AASHTO-AGC-ARTBA Task Force 37 1999 report on Shotcrete Repair we have reached several conclusions. If the special provisions are followed closely shotcrete is a viable repair method for highway bridges. Good surface preparation and pre-wetting before shotcreting are critical to getting a good bond. Contractors quite often use the dry-mix shotcrete method, especially for small repairs. MoDOT should require pre-bagged mixes for dry-mix shotcrete because it makes a more consistent mix. The pre-bagged mix should include silica fume in order to make the mix stickier and provide better bond strength. Usually not included in a dry mix, an air entraining agent was incorporated in the pre-bagged mix. In testing done by OR it showed a good air structure in the hardened concrete and it should be required in a pre-bagged mix. A 7-day moist cure is needed for shotcrete, and using curing compound should be secondary to specified wet curing to decrease shrinkage cracks. Changes to the Bridge Special Provision incorporating these conclusions have been presented in this report.

Costs of normal unformed repairs and shotcrete repairs were compared for 2004 – 2006 and were actually a little lower but the average price was close to \$120/sq.ft. Some savings could be expected by more use of shotcrete in superstructure and substructure repair.

It is recommended that MoDOT continue to specify the shotcrete method by the use of the modified Bridge Special Provisions on recommended bridges. As more positive experiences are gained a move towards including shotcrete in the Standard Specifications as an equal alternate to hand lay up materials should be pursued.

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Present Conditions:

Very few contractors use shotcrete. MoDOT has no standard specification for its use. Its use most often comes up when a contractor asks to use it in place of Rapid Set Concrete Patching Material for vertical or overhead patching of bridge superstructures and substructures.

Shotcrete has been used on only a handful of bridge repairs in the past. This report is to present follow up information from the shotcrete repaired bridges. The objective is to document the condition of the few bridges with shotcrete repairs and decide whether MoDOT should allow the use of shotcrete for bridge repairs. In addition to documenting the durability of shotcrete repairs made on MoDOT structures it will investigate and suggest what construction specification should be used.

Investigation:

If done strictly according to procedures as found in American Concrete Institute, ACI 506, and the special provisions set up, using shotcrete is an acceptable repair method.

I. One job done as an Experimental Project in 1998 is still in service and in good condition. It is located on Mo. 210 on Bridge A2175. Shotcrete was allowed by change order as a substitute for hand patching using Rapid Set Concrete Patching Material. This change order made several key conditions necessary. These conditions or best practices were set up by a team of District 4, Bridge, Construction and Materials Division personnel and agreed upon by Progressive Contractors Inc. the applicator. The requirements were:

- All surfaces adjacent to the area to be shot shall be covered to protect them from overspray.
- The drip strip, if used originally, must be satisfactorily constructed.
- Certain areas may need some hand finish work at the Engineer's discretion to provide satisfactory appearance.
- The work on J4I1241 shall conform to all requirements of ACI 506.2-95 Standard Specification for Shotcrete, except as modified
- Design Strength shall be a minimum of 4000 psi. Mix design shall be submitted for approval.
- Surface Preparation:
The surface shall be rough, sand blast cleaned, and in a saturated surface dry condition prior to application. If successive Shotcrete layers are to be applied, the surface shall be blast cleaned and in a saturated surface dry condition prior to application.
- Tolerances for line and grade shall be 2 times the tolerance of ACI 117.
- ACI Specification 506.2-95, section 1.6 states that all the preconstruction and construction testing shall be followed. Test specimens shall represent a days placement or 50 yard increments and shall be taken from the in-place shotcrete at the intervals specified. All samples shall be tested for compressive strength at the

contractors expense by a certified testing laboratory and a copy of the results delivered to the Engineer.

- All core samples should be at least Grade 2.
- A set of 3 cores which fail to meet the strength requirements of Section 1.6.2.4 or any individual core that does not meet the grade requirement shall be subject to rejection and the shotcrete in the affected repair area removed and replaced at the contractors expense. Any areas, which show evidence of delamination or have unsatisfactory finish, shall also be subject to rejection.

II. Jen Harper and J.D. Wenzlick of the Organizational Results division looked at Bridge A2175 in 2006, eight years after the shotcrete was applied, and the patching is still in good condition. We could only visually inspect and sound the patches that were in reaching distance but in the small area tested the patches were not debonding. The surface finish was smooth and there was no cracking noticed.



Figure 1 - Br. A2175, shotcrete patches around drains now 8 years old.

If done strictly according to procedures and special provisions set up as the repair on Bridge A2175, using shotcrete is an acceptable repair method.

III. J. D. Wenzlick observed shotcrete repairs being performed on another project done in 2004. Although constructed after the above job, by the same contractor and also the same gunman the project done at I-435 and I-70 did not turn out as well. This project was again done by the dry method. The work was done in August on Bridge A0991 and because of equipment problems the first attempt at overhead repairs had to be removed and redone. The evaporation rate was high and the ready mix truck with the mixed sand and cement was allowed to sit for 1½ hours before being unloaded (twice the time

recommend by the ACI specifications). The shotcrete had to be removed and re-applied the next day. The repair is now in good condition and shown below.



Figure 2 - Bridge A0991 – overhang near NE corner of abutment.

A vertical patch on the abutment of the same bridge was repaired, however, and inspected a couple of weeks later and already it had large shrinkage cracks (see photo).



Figure 3 - Bridge A0991 – NW abutment wing wall.

IV. A project let in July 2006, J4I1699, contains a bridge, which is specified by Bridge Special Provision to have 500 sq. ft. of Shotcrete repair. Progressive Concrete Inc. was again the applicator. Because of a recent project on Rt. 54, Cole Co. and a test slab made there, the test slab requirement in the special provision for this job in Jackson Co. was waived. The contractor used pre-bagged mix material and the dry shotcrete method, which makes the difficulty of finding the correct amount of water to use at the spraying nozzle much easier. Once calibrated the amount of water at the nozzle doesn't require changing because with the pre-bagged mix moisture content is low and stable. The water at the nozzle doesn't need corrections between loads or parts of loads like it does when using a bulk amount in a ready mix truck. The mix used also had 7% silica fume, which makes the mix stickier to adhere better to the concrete, rebar, or lower layers of shotcrete. The pre-bagged mix also contains air-entraining agent that cannot be added to dry mix easily as it is in the wet method, thus adding more resistance to freeze-thaw damage to the patch.



Figure 4



Figure 5 - Repairs on the underside joint of the roof of a tunnel bridge on Project J4I1699, NB I-35 in Kansas City. The dry method using pre-bagged mix did a good job here.



Figure 6 - Close up shows no cracking. Curing compound allowed on this job, but it should be noted that it was done in very mild October weather and was not exposed to sun as it was inside a tunnel.

V. As a follow up to the above project the qualification test panels from the Rt. 54 project J5P0786 mentioned above were inspected at the Jefferson City Project Office. A specimen was taken to do a Linear Traverse to look at the air entrainment in the pre-bagged mix shotcrete. The test showed that the shotcrete had good air bubble size and good spacing. The entrained air was only 4.8% but this is as good as is expected for shotcrete. (See Appendix 2 for report.) It shows that the pre-bagged mix with an air additive will give more acceptable freeze thaw resistance than a regular dry mix.

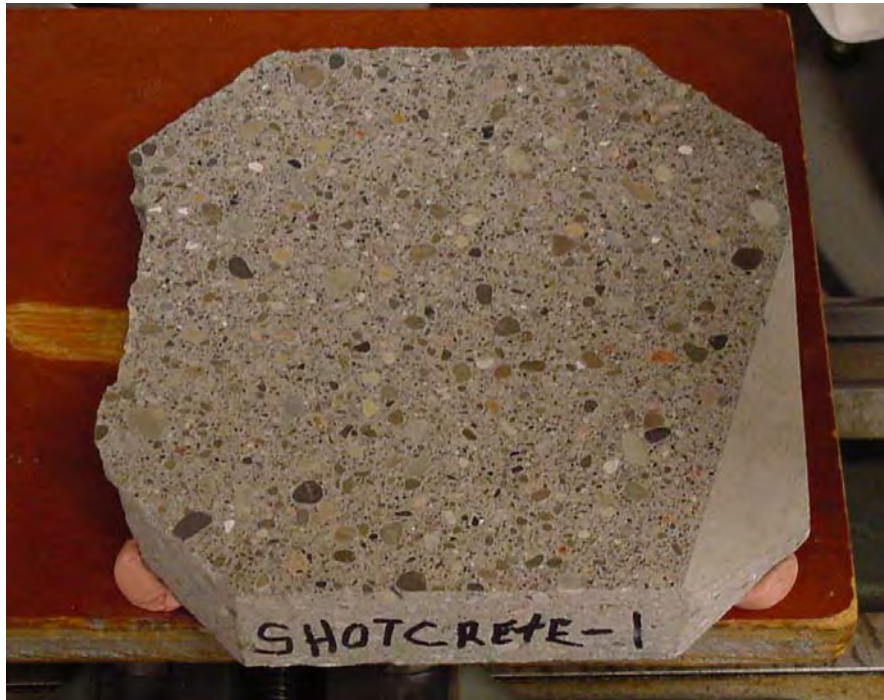


Figure 7 - Linear Traverse specimen from qualification test panel shows homogeneous mix, no sand pockets or air voids.

Current State of Practice:

Today almost no one uses the wet mix method (also called Guniting) for bridge repairs because equipment is expensive; it is messy and subject to equipment plug ups. The dry method is not prone to plug ups but is very sensitive to any changes in moisture content of the dry mix mortar (Sand and cement).

New High Performance mixes show some advances but are expensive. These mixes contain steel or synthetic fibers and silica fume in the cementitious material. Illinois DOT specifies this as Class A shotcrete and also allows a Class B which allows substitution of Portland cement with up to 20% fly ash, 50% slag or 7% silica fume. IDOT requires shotcrete subject to freezing and thawing using the wet process to have an air content of $7.0\% \pm 1.5\%$.

As stated in the IDOT/FHWA Joint Process Review Program: Substructure Repair Quality Improvement Team (QIT) 2002 Statewide Closeout⁴ report, "Economics is an important consideration in the selection of repair alternatives." Illinois DOT's statewide

average cost in 2002 for formed repair was \$76/sq.ft. while the statewide average for shotcrete was \$64/sq.ft. (They noted however that unit bid prices for shotcrete on major river structures was often two or three times as much.)

In Missouri the 2004 and 2005 unit bid price statewide for Superstructure Repair (Unformed) was \$128.54/sq.ft. and \$128.82/sq.ft. respectively. The costs for the three MoDOT shotcrete projects reviewed, built from 2004 – 2006, ranged from \$92.70/sq.ft. to \$140.00/sq.ft. In 2005 the statewide unit bid price for Substructure Repair (Unformed) was \$172.83/sq.ft. compared to two of the shotcrete projects bid at \$92.70/sq.ft. and \$108.15/sq.ft. Some savings could be expected by more use of shotcrete in superstructure and substructure repair.

Cost is one of the reasons cited in the IDOT/FHWA report⁴ that lead to the recommendation that, “The use of shotcrete should be continued in Illinois as an alternate method of substructure repair.”

Conclusions:

Shotcrete is a viable option for doing superstructure repair (unformed) and substructure repair (unformed) if done strictly according to specifications and best practices. It is a good substitute for the manual lay-up method for vertical and overhead applications using rapid set mortar. Out of four projects observed there were cracking problems and bonding problems observed but there were also some quality applications from projects as much as eight years old.

Problems involved with shotcrete that were observed during this review were equipment problems, mix problems, application problems and curing problems. However, these problems can be overcome if there is strict adherence to specifications and procedures. Some of the materials problems have been eliminated, especially when using the dry mix applications, by using pre-bagged mixes. The pre-bagged mixes solve fluctuating demands of mixing water at the nozzle because of constant moisture content and may incorporate silica fume to make the mix stickier and easier to get good adhesion between the substrate and the shotcrete mix itself. The pre-bagged mixes also allow the addition of an air agent so that entrained air is introduced to the mix, not just large entrapped air bubbles, and freeze/thaw protection can be attained in the dry mix applied shotcrete. This was shown by the good values found in the linear traverse of the mix that showed 4.8% entrapped air size bubbles and a good spacing factor and specific surface.

Recommendations:

1. It is recommended that MoDOT continue to specify the shotcrete method by the use of the Bridge Special Provisions on recommended bridges. As more positive experiences are gained a move towards including shotcrete in the Standard Specifications as an equal alternate to hand lay up materials should be pursued.

Good air entrainment must be specified for the dry method as well as the wet in any standard specification adopted.

2. Strict enforcement of the specifications is vital to getting a good application. It is important to stress:
 - a.) Good surface preparation - Sandblasting before application and between layers if a curing compound is used.
 - b.) Pre-wetting - the surface should be saturated surface dry when shotcrete applied.
 - c.) Good ambient conditions when applied. The pre-mix can lose moisture in the mixer and also after shot by the dry method causing shrinkage cracking. Evaporation rates should be checked and if $>0.2 \text{ lb/ft}^2/\text{hr}$ application should be halted unless steps such as misting are taken to bring the evaporation rate down in the area of the work.
 - d.) Curing needs to be started as soon as possible after the surface is finished.
3. On badly deteriorated deck edges and curb drains formed superstructure repair is the most desirable repair in order to get the best patch including air-entrained concrete. Air entraining is needed even if an epoxy coating is applied over the repair afterwards.

Usually forming because of deck drains is difficult, so if not formed repair, a laid up rapid set patching material could be utilized. Also, regular shotcrete using the wet method or the dry method using pre-bagged mix as recommended below could also be used.

A regular dry mix shotcrete should never be allowed since it isn't possible to ensure good air entrainment and proper adhesion.
4. If the contractor is using the dry method, pre-bagged shotcrete mix should be required. This mix has the advantage of providing a consistently low moisture content and a consistent amount of water needed at the nozzle, it is a stickier mix especially if it contains some silica fume. The pre-bagged mix must have an air entraining agent. to cut down freeze/thaw damage, and 5%-8% silica fume added, to give better bond strength to the substrate concrete.
5. These modifications have been made to the Bridge Special Provisions used on project J4I1699 observed in this study and are attached in the appendix. It is recommended that the changes be used in the special provisions for future projects.
6. It is also recommended that inspectors for shotcrete projects should obtain training on proper shotcrete application. This training should follow the Inspectors' Guide for Shotcrete Repair of Bridges - Task Force 37 Report, December 1999 by the AASHTO-AGC-ARTBA Joint Committee. (see Bibliography for purchase information)

Additional Research and Implementation:

1. Construction Inspectors who will be working on shotcrete repair jobs should be required to take a course on shotcrete principles and the Inspector's Guide for Shotcrete Repair of Bridges. This course could be set up with In-House instructors or through an outside source that Organizational Results would find.
2. It is recommended that on a future repair project three methods of repair, as stated in no. 3 in Conclusions, be compared for best performance. This would include the recommended procedures for deck edge repair: 1. Formed, 2. Manually laid up rapid set concrete patching material, and 3. Pre-bagged dry mix (containing air-entraining agent and silica fume).

Bibliography:

1. ACI Manual of Concrete Practice, 1997, Part 5 – Section 506R-90, Guide to Shotcrete
2. Guide Specifications for Shotcrete Repair of Highway Bridges – February 1998 - AASHTO-AGC-ARTBA Joint Committee Task Force 37 Report
3. Inspectors’ Guide for Shotcrete Repair of Bridges - Task Force 37 Report, December 1999” by the AASHTO-AGC-ARTBA Joint Committee (Can be purchased from AASHTO for \$68, member price, Item code: 3-IGSRB-1, Online <http://bookstore.transportation.org>)
4. IDOT/FHWA Joint Process Review Program: Substructure Repair Quality Improvement Team (QIT) 2002 Statewide Closeout report – Illinois Department of Transportation and US Department of Transportation Federal Highway Administration, Illinois Division
5. Section 412 – Widening, Repairing, and Reconstructing Existing Structures – Virginia Department of Transportation, 9/25/2003

APPENDICES

JOB SPECIAL PROVISIONS (BRIDGE)

D. SHOTCRETE FOR SUPERSTRUCTURE REPAIR (UNFORMED)

1.0 Description. Superstructure repair (unformed) shall be in accordance with [Sec 704](#) and as shown on the plans. Shotcrete shall be used instead of qualified special mortar.

1.1 Shotcrete shall be accordance with the current requirements of American Concrete Institute (ACI) 506.2-95, "Materials, Proportioning and Application of Shotcrete", except as otherwise specified. Shotcrete shall consist of an application of one or more layers of mortar or concrete conveyed through a hose and pneumatically projected at a high velocity against a prepared surface.

1.2 Shotcrete may be produced by either dry-mix or a wet-mix process. The wet-mix process shall consist of thoroughly mixing all the ingredients except accelerating admixtures, introducing the mixture into the delivery equipment and delivering the shotcrete by positive displacement to the nozzle. The wet-mix concrete shall be air jetted from the nozzle at high velocity onto the surface. The dry-mix process shall consist of thoroughly mixing all the ingredients except accelerating admixtures and mixing water and conveying the mixture through the hose pneumatically and the mixing water is introduced at the nozzle. For additional descriptive information, the contractor's attention shall be directed to the ACI 506R-90, "Guide to Shotcrete".

2.0 Contractor Experience Requirements.

2.1 Workers, including foremen, nozzle men and delivery equipment operators, shall be fully experienced to perform the work. All shotcrete nozzle men on this project shall have experience on at least 3 projects in the past 3 years in similar shotcrete application work and shall demonstrate ability to satisfactorily place the shotcrete.

2.2 Initial qualification of nozzle men will be based ACI certification. The nozzle men shall submit documented proof they have been certified in accordance with the ACI 506.3R-91 "Certification of Shotcrete Nozzle men". The certification shall have been done by an ACI recognized shotcrete testing lab and/or recognized shotcreting consultant and have covered the type of shotcrete to be used (plain wet-mix, plain dry-mix).

3.0 Construction Submittals.

3.1 At least 15 days before the planned start of unformed superstructure repair, copy of the following information shall be submitted in writing to the engineer for review:

- (a) Written documentation of the nozzlemen's qualifications including proof of ACI certification.
- (b) Proposed methods of shotcrete placement and of controlling and maintaining facing alignment.
- (c) Shotcrete mix design including:
 - 1) Type of Portland Cement.
 - 2) Aggregate source and gradation.
 - 3) Proportions of mix by weight and water-cement ratio.
 - 4) Proposed admixtures, manufacturer, dosage and technical literature.
 - 5) Previous strength test results for the proposed shotcrete mix completed within one year of start of shotcreting may be submitted for initial verification of the required compressive strengths at start of production work.

3.2 The engineer will approve or reject the contractor's submittals within 10 days after the receipt of a complete submission. The contractor will not be permitted to begin unformed superstructure repair until the submittal requirements are satisfied and found acceptable to the engineer. Changes or deviations from the approved submittals shall be re-submitted for approval. No adjustment in contract time will be allowed due to incomplete submittals.

3.3 A pre-construction meeting scheduled by the engineer will be held prior to the start of work on **the structure**. Attendance shall be mandatory. The shotcrete contractor shall attend.

4.0 Shotcrete Materials.

4.1 All shotcrete materials shall meet the requirements in accordance with [Sec 501](#), except that the aggregate gradation will not apply. Coarse aggregate shall meet the quality requirements for concrete pavement. Reinforcing bars and welded wire fabric, etc., shall be in accordance with the Missouri Standard Specifications for Highway Construction.

4.2 Material shall be delivered, stored and handled to prevent contamination, segregation, corrosion or damage. Liquid admixtures shall be stored to prevent evaporation and freezing.

5.0 Shotcrete Mix Design. The contractor will receive notification from the engineer that the proposed mix design and method of placement of the shotcrete are acceptable before unformed superstructure repair placement can begin.

5.1 Aggregate. Aggregate for shotcrete shall meet the following gradation requirements:

Sieve	Percent by weight (Mass)
Passing 1/2 inch (12.5 mm)	100.00
Passing 3/8 inch (9.50 mm)	90-100
Passing No. 4 (4.75 mm)	70-85
Passing No. 8 (2.36 mm)	50-70
Passing No. 16 (1.18 mm)	35-55
Passing No. 30 (600 μm)	20-35
Passing No. 50 (300 μm)	8-20
Passing No. 100 (150 μm)	2-10

5.2 Proportioning and Use of Admixtures. The shotcrete shall be proportioned to be pumpable with the concrete pump furnished for the work, with a cementing materials content of at least 1125 pounds per cubic yard (390 kg/m³) and a water to cement ratio not greater than 0.45. Admixtures will not be permitted unless approved by the engineer. The admixtures shall be mixed thoroughly at the manufacturer’s recommended rate. Accelerators, if used, shall be compatible with the cement, be non-corrosive to steel and not promote other detrimental effects such as cracking or excessive shrinkage.

5.3 Air Entrainment. Air entrainment shall be required for wet-mix shotcrete. The air content measured at the truck shall be between 7 to 10 percent when tested in accordance with AASHTO T 152/ASTM C 231. Air entrainment will be required in pre-bagged dry-mix shotcrete.

5.4 Strength and Durability Requirements. The shotcrete mix shall be capable of attaining compressive strength of 2000 psi (14 MPa) in 3 days and 4000 psi (28 MPa) in 28 days. The average compressive strength of each set of three cores extracted from the test panels shall equal or exceed the specified compressive strength, with no individual core less than 75 percent of the specified compressive strength, in accordance with ACI 506.2R-95. The boiled absorption of shotcrete when tested in accordance with ASTM C 642 at 7 days, shall not exceed 8.0 percent.

5.5 Mixing and Batching. Aggregate and cement may be batched by weight or by volume in accordance with the requirements of ASTM C 94 or AASHTO M 241/ASTM C 685. Mixing equipment shall thoroughly blend the materials in sufficient quantity to maintain placing continuity. Ready mix concrete shall be in accordance with Sec 501. Shotcrete shall be batched, delivered and placed within 90 minutes of mixing. Premixed and packaged shotcrete mix may be provided for on-site mixing. The packages shall contain materials in accordance with the material section of this specification. In addition

the packaged shotcrete mix shall contain 5%-8% silica fume and an air entraining agent. Placing time limit after mixing shall be per the manufacturer's recommendations.

5.6 Field Quality Control.

5.6.1 Production test panels shall be required. Qualified personnel shall perform shotcreting and coring of the test panels with the engineer present. The contractor shall provide equipment, materials and personnel as necessary to obtain shotcrete cores for testing including construction of test panel boxes, field curing requirements and coring. The engineer will perform compressive strength testing. Shotcrete final acceptance will be based on obtaining the specified 28 day compressive strength.

5.6.2 Unformed superstructure repair may commence upon initial approval of the design mix and nozzle men. If the test result for their work does not satisfy the strength requirements, the contractor shall performed the repair work again at the contractor's expense. The contractor shall change all or some of the following: the mix, the crew, the equipment or the procedures. Before re-performing the work, the crew shall shoot additional test panels and demonstrate that the shotcrete in the panels satisfies the specified strength requirements. The cost of all work required to obtain satisfactory test shall be borne by the contractor.

5.7 Production Test Panels. At least one production test panel shall be furnished during each production application of shotcrete placed. The production test panels shall be constructed simultaneously with the shotcrete facing installation at times designated by the engineer. Production test panels shall be made with the minimum full thickness and dimension of 18 x 18 inch (450 x 450 mm) and at least 8 inch (200 mm) thick.

5.8 Test Panel Curing, Test Specimen Extraction and Testing. Immediately after shooting, the test panels shall be field moist cured by covering and tightly wrapping with a sheet of material meeting the requirements of ASTM C 171 until delivered to the testing lab or test specimens are extracted. The test panels shall not be immersed in water. The test panels for the first 24 hours after shooting shall not be disturbed.

5.8.1 At least nine 3 inch (75 mm) diameter core samples shall be cut from each unreinforced production test panel for absorption and compressive strength testing. Contractor has the option of extracting the test specimens from test panels in the field or transporting to another location for extraction. The panels shall be kept in their forms when transported. Cores shall not be taken from the outer 6 inch (150 mm) of test panels measured in from the top outside edges of the panel form. The compressive strength cores ends shall be trimmed to provide test cylinders at least 3 inches (75 mm) long. The cores to be tested for boiled absorption shall not have the ends trimmed.

5.8.2 The cores and container shall be clearly marked to identify the core locations. For production testing, the production section of the unformed superstructure repair represented by the production test panel cores shall be marked on the cores and the container. Immediately wrap cores in wet burlap or material in accordance with the requirements of ASTM C 171 and seal in a plastic bag. Deliver cores to the engineer or

testing lab, as approved by the engineer, within 48 hours of shooting the panels. The remainder of the panels shall become the property of the contractor. The engineer will perform the boiled absorption and compressive strength testing.

5.8.3 Upon delivery to the testing lab, samples will be placed in the moist room until the time of test. When the test length of a core is less than twice the diameter, the correction factors given in AASHTO T 24/ASTM C 42 will be applied to obtain the compressive strength of individual cores. Three cores will be tested at 3 days and three cores will be tested at 28 days for compressive strength per AASHTO T 24/ASTM C 42. Three cores will be tested at 7 days for boiled absorption per ASTM C 642.

6.0 Shotcrete Facing Requirements.

6.1 Shotcrete Alignment Control. The final surface of the shotcrete shall maintain the existing concrete plane surface. Shooting wires, ground wires, or other devices acceptable to the Engineer shall be used to control the line, grade, and thickness of the shotcrete.

6.2 Surface Preparation. The surfaces to be shotcreted shall be cleaned of loose materials, mud, rebound, overspray or other foreign matter that could prevent or reduce shotcrete bond. Adjacent surfaces shall be protected from overspray during shooting. Shotcrete shall not be placed on frozen surfaces.

6.3 Delivery and Application. A clean, dry, oil free supply of compressed air sufficient for maintaining adequate nozzle velocity shall be maintain at all times and for simultaneous operation of a blow pipe for cleaning away rebound. The equipment shall be capable of delivering the premixed material accurately, uniformly and continuously through the delivery hose. Shotcrete application thickness, nozzle technique, air pressure and rate of shotcrete placement shall be controlled to prevent sagging or sloughing of freshly applied shotcrete.

6.3.1 The shotcrete shall be applied from the lower part of the area upwards to prevent accumulation of rebound. The nozzle shall be oriented at a distance and approximately perpendicular to the working face so that rebound will be minimal and compaction shall be maximized. Special attention shall be pay to encapsulating reinforcement. Care shall be taken while encasing reinforcing steel and mesh to keep the front face of the reinforcement clean during shooting operations, so that the shotcrete builds up from behind, to encase the reinforcement and prevent voids and sand pockets from forming. A blow pipe shall be used to remove rebound and overspray immediately ahead of the nozzle. Rebound shall not be worked back into the construction. Rebound that does not fall clear of the working area shall be removed. Hardened rebound and hardened overspray shall be removed prior to the application of additional shotcrete using abrasive blast cleaning, chipping hammers, high pressure water blasting or other suitable techniques.

6.3.2 When the thickness of an individual shotcrete layer is 6 inch (150 mm) or greater or when shotcreting is conducted through two curtains of reinforcement, shotcrete shall

be placed by the bench gunning method. The bench gunning method shall consist of building a thick layer of shotcrete from the bottom of the lift and maintaining the top surface at approximately a 45 degree slope.

6.3.3 A clearly defined pattern of continuous horizontal or vertical ridges or depressions at the reinforcing elements after covered with shotcrete will be considered an indication of insufficient reinforcing cover or poor nozzle techniques. In this case the application of shotcrete shall be immediately suspended and the contractor shall implement corrective measures before resuming the shotcrete operations. The shotcreting procedure may be corrected by adjusting the nozzle distance and orientation, by insuring adequate cover over the reinforcement, by adjusting the water content of the shotcrete mix or other means. Adjustment in water content of wet-mix shall require requalifying the shotcrete mix.

6.3.4 When using multiple layer shotcrete construction, the surface of the receiving layer shall be prepared before application of a subsequent layer, by either:

- (a) Brooming the stiffened layer with a stiff bristle broom to remove all loose material, rebound, overspray or glaze, prior to the shotcrete attaining initial set.
- (b) If the shotcrete has set, surface preparation shall be delayed 24 hours, at which time the surface shall be prepared by sandblasting or high pressure water blasting to remove all loose material, rebound, hardened overspray, glaze or other material that may prevent adequate bond.

6.4 Defective Shotcrete. The engineer will have authority to accept or reject the shotcrete work. Shotcrete that is not in accordance to the project specifications may be rejected either during the shotcrete application process, on the basis of tests done on the test panels or completed work. Shotcrete surface defects shall be repaired as soon as possible after placement. Shotcrete that exhibits segregation, honeycombing, laminations, voids or sand pockets shall be removed and replaced. In-place shotcrete determined not meeting the specified strength requirement will subject to remediation as approved by the engineer. Possible remediation option includes removal and replacement at the contractor's expense.

6.5 Construction Joints. Construction joints shall be tapered uniformly toward the excavation face over a minimum distance equal to the thickness of the shotcrete layer. Square joints will not be permitted except at the expansion joint. The surface of the joints shall be rough, clean and sound. A minimum reinforcement overlap at reinforcement splice joints shall be provided. The surface of a joint shall be clean and wet before adjacent shotcrete is applied.

6.6 Final Face Finish. After grade and alignment of the shotcrete is attained per section 6.1, Shotcrete finish shall be either an wood float, rubber float, steel trowel or smooth screeded finish.

6.7 Weather Limitations.

6.7.1 The shotcrete shall be protected if placed when the ambient temperature is below 40°F (5°C) and falling or when likely to be subject to freezing temperatures before gaining sufficient strength. Cold weather protection shall be maintained until the compressive strength of the shotcrete is greater than 725 psi (5 MPa). Cold weather protection includes blankets, heating under tents or other means acceptable to the engineer. The temperature of the shotcrete mix, when deposited, shall be not less than 50°F (10°C) or more than 85°F (29°C). The air in contact with the shotcrete surfaces shall be maintained at temperatures above 32°F (0°C) for a minimum of 7 days.

6.7.2 If the prevailing ambient temperature conditions (relative humidity, wind speed, air temperature and direct exposure to sunlight) are such that the shotcrete develops plastic shrinkage and/or early drying shrinkage cracking, shotcrete application shall be suspended. The contractor shall reschedule the work to a time when more favorable ambient conditions prevail or adopt corrective measures, such as installation of sun screens, wind breaks or fogging devices to protect the work. Newly placed shotcrete exposed to rain that washes out cement or otherwise make the shotcrete unacceptable shall be removed and replaced at the contractor's expense.

6.8 Curing. Permanent shotcrete shall be protected from loss of moisture for at least 7 days after placement while maintaining a temperature over 40°F (5°C). Cure shotcrete by methods that shall keep the shotcrete surfaces adequately wet and protected during the specified curing period. Curing shall commence within one hour of shotcrete application. When the ambient temperature exceeds 80°F (27°C), the work shall be planned such that curing can commence immediately after finishing. Curing shall be in accordance with the following requirements.

(a) Silica-fume shotcrete provides better bond strength and corrosion resistance properties but must always be continuously moist-cured to prevent plastic shrinkage cracking and assure proper strength gain and surface durability. Dry-mix Shotcrete using pre-bagged mixes with silica-fume shall be moist cured for 7 days. The use of fogging nozzles can be very helpful in maintaining a moist condition on all new surfaces. Sprinklers and soaker hoses can also provide adequate curing so long as it can be assured that all the surface area is maintained in a moist condition. The use of water-saturated burlap covered with plastic sheets or plastic-coated water-saturated geotextile fabrics can also be appropriate for certain structures.

(b) Membrane Curing. Curing compounds are satisfactory for curing if drying conditions are not severe. If the evaporation rate is $>0.2 \text{ lb/ft}^2/\text{hr}$ steps shall be taken as described in (a) above to augment or in lieu of using curing compounds. Curing compounds will not be permitted on any surface against which additional shotcrete or other cementitious finishing materials are to be bonded unless the surface is thoroughly sandblasted in a manner acceptable to the engineer. Membrane curing compounds shall be spray applied as quickly as practical after

the initial shotcrete set at rate of coverage of not less than 7.1 square feet per gallon (2.5 m²/L).

6.9 Safety Requirements. Nozzlemen and helpers shall be equipped with gloves, eye protection and adequate protective clothing during the application of shotcrete. The contractor shall be responsible for meeting all federal, state and local safety requirements.

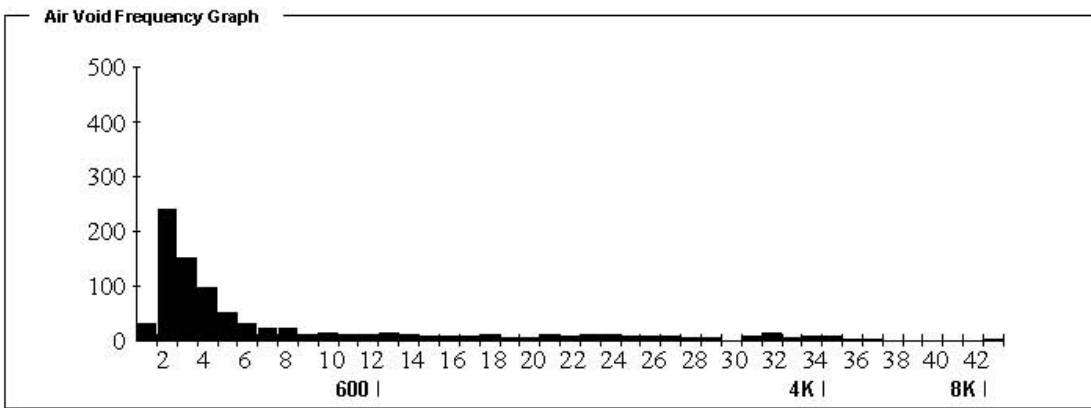
7.0 Method of Measurement. Measurement of superstructure repair (unformed) shall be in accordance with [Sec 704](#).

8.0 Basis of Payment. Payment for superstructure repair (unformed) shall be in accordance with [Sec 704](#).

APPENDIX 2

MoDOT Linear Traverse Summary SHOTCRETE-1.cho				12/5/2006	
Traverse Length	102.018	Percent Air	4.754	Average Air Void	0.00536
Void/Paste Ratio	0.126	Percent Paste	37.82	Paste/Void Ratio	7.96
Air Void Std Dev	0.010	Percent Mortar	75.55	Voids Per Inch	8.86
Spacing Factor	0.00722			Specific Surface	745.66
Spec. Range: 0.004 - 0.008			Spec. Range: 600 - 1100		

Air Void Frequency Distribution (in Distance Pulse Counts)														
Bin	Lower	Upper	No.	Pct.	Bin	Lower	Upper	No.	Pct.	Bin	Lower	Upper	No.	Pct.
1	0-	49	32	3.54	2	50-	99	241	30.20	3	100-	149	152	47.01
4	150-	199	96	57.63	5	200-	249	52	63.38	6	250-	299	32	66.92
7	300-	349	24	69.58	8	350-	399	21	71.90	9	400-	449	12	73.23
10	450-	499	14	74.78	11	500-	549	13	76.22	12	550-	599	12	77.54
13	600-	649	14	79.09	14	650-	699	11	80.31	15	700-	749	8	81.19
16	750-	799	7	81.97	17	800-	849	9	82.96	18	850-	899	12	84.29
19	900-	949	5	84.85	20	950-	999	4	85.29	21	1000-	1099	13	86.73
22	1100-	1199	9	87.72	23	1200-	1299	12	89.05	24	1300-	1399	11	90.27
25	1400-	1499	7	91.04	26	1500-	1599	7	91.81	27	1600-	1699	7	92.59
28	1700-	1799	5	93.14	29	1800-	1899	6	93.81	30	1900-	1999	1	93.92
31	2000-	2499	9	94.91	32	2500-	2999	14	96.46	33	3000-	3499	6	97.12
34	3500-	3999	7	97.90	35	4000-	4499	8	98.78	36	4500-	4999	2	99.00
37	5000-	5499	3	99.34	38	5500-	5999	1	99.45	39	6000-	6499	1	99.56
40	6500-	6999	0	99.56	41	7000-	7499	1	99.67	42	7500-	7999	1	99.78
43	>=	8000	2	100.00										



Air Void Summary by Size			
	Concrete	Mortar	
Total Air	4.754	6.292	
< 600			
Percent Air	1.132	1.498	
Tot Pct	77.54		
Tot No	701		
600 - 4K (1mm)			
Percent Air	2.596	3.436	
Tot Pct	20.35		
Tot No	184		
4K-8K (1-2mm)			
Percent Air	0.852	1.127	
Tot Pct	1.88		
Tot No	17		
> 8K (2mm)			
Percent Air	0.174	0.230	
Tot Pct	0.22		
Tot No	2		



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