# Designing and Installing a Shotcrete Strengthening Application on the Spokane Street Bridge

**By Basil Kattula and Roger Runacres**

In 1999, the Spokane Street Viaduct in Seattle was strengthened for live load by the application of a composite shotcrete layer to concrete girders and cross beams. This use of shotcrete was the first ever for the City of Seattle to strengthen any of its bridge structures. Although in general the project went well, the real testament to the effectiveness of the strengthening design and application process was the bridge's ability to survive the area's recent earthquake. Occurring on February 28, 2001, the Nisqually earthquake had a magnitude of 6.8 Richter and was centered approximately 35 miles from the bridge. In a post-quake inspection of the structure, no damage to the composite shotcrete application was found. This article discusses the viaduct's strengthening for live load through the use of shotcrete.

## Introduction

The Spokane Street Bridge connects the community of west Seattle to downtown Seattle via Highway 99 and Interstate 5 south of the city center. The bridge was not originally designed and constructed to handle its present-day usage and loading; consequently, the bridge structure has experienced severe loading. Deemed a critical roadway by the city of Seattle, it was determined, after structural review in 1994, that strengthening the structure for both live and seismic-event loading was necessary. Based on structural analysis, increased capacity in shear and bending in the majority of longitudinal girders and transverse beams were required.

The strengthening design involved adding a steel-reinforced composite concrete layer to the existing concrete girders and cross beams. After review of constructibility issues, the design team approached the owner about the use of structural shotcrete. Although the city of Seattle was not experienced in the proposed installation method, they accepted the shotcrete option, provided the design team could adequately ensure the project would give the owner a high-quality, long-lasting finished product.

Co-authored by the structural engineer and the shotcrete contractor of the project, this article addresses many challenges and considerations encountered while designing and completing this shotcrete application. The article further examines what lessons can be learned from the completed project and what changes may be warranted to improve the process regarding applicable testing.

*Underside of bridge prior to shooting*

## Project Description

The South Spokane Street Viaduct was built in 1941 and consists of both steel and concrete spans and columns. Its total length is approximately 4000 ft (1219 m). The viaduct connects the community of west Seattle to downtown Seattle via Highway 99 and Interstate 5 south of the City Center. Over the structure's life, its railing has been updated and its east and west termini have been modified to connect it directly to I-5 and the West Seattle Bridge. These direct connections to the two major traffic routes have made today's viaduct a heavily traveled east-west arterial.

The South Spokane Street Viaduct encompasses a total of 67 spans. Roadway width varies from 45 to 67 ft (13.7 to 20.4 m). The 4th Avenue South and 1st Avenue South ramp widths are 24 and 22 ft (7.3 and 6.7 m), respectively.

*Shooting in progress on south side of bridge*

*Shooting in progress on crossbeam*

Concrete spans consist of cast-in-place, reinforced concrete with five, six, or seven T-beams. The decks are 7 inches (178 mm) thick and have a 1-1/2 inches (38 mm) asphaltic overlay. Steel spans have a cast-in-place reinforced concrete deck slab overlaying the steel girders. The 1-1/2 inches (38 mm) overlay was removed, and the deck spalls were patched in 1998.

PBQ&D Engineers (formerly with Tudor Engineering Co.) assembled the PS&E documents for the superstructure concrete elements to be strengthened. They were also responsible for a seismic retrofit of the total bridge structure to a No Collapse Concept, per the 1996 AASHTO code seismic requirements.

PS&E documents were prepared in 1997, with two proposed alternatives for the strengthening of the superstructure concrete elements. The city of Seattle and the consultant agreed that allowing the bidders two alternatives for strengthening would result in a more competitive bid.

## Evaluation of Documents for Construction

The contract documents were released for bidding in early March of 1998. The original project included 630 net $yd^3$ (481.7 net $m^3$) of overhead concrete strengthening installation, averaging approximately 4 inches (102 mm) in thickness. The PS&E documents allowed the use of either a formed-and-pumped mortar or a shotcrete installation procedure to achieve strengthening of the existing concrete girders and cross beams. It was clear when reviewing the specification that a substantial bond of the new shotcrete or pumped mortar to the concrete substrate was essential to the success of the installation. This was evident in the specification details concerning surface preparation, final washdown of the prepared surface, tensile bond strength requirements, and the related testing (ACI 506.4) frequency of one in-place pulloff test for every day of installation. Based on these bond-related issues and the belief that a shotcrete installation could provide a cost savings over a formed-and-pumped alternative, the decision was made to pursue the subcontract work utilizing a dry-mix shotcrete application.

### Surface Preparation Considerations

Work discussions prior to the bid opening made it clear that the bidding prime contractor would take responsibility for the surface preparation. The reasons for this were primarily schedule and access conflicts that could only be resolved if the general contractor accomplished the surface preparation work item with their own crew. The shotcrete specification included the requirement to achieve a tensile bond value of 325 psi (2.25 MPa) in 28 days. Proper surface preparation on the part of the general contractor would be essential in order to develop a tensile bond value near the originally specified number. The specification allowed the use of bush hammering or hydroblasting to achieve a sound concrete substrate with a surface amplitude of 1/4 in. (6.4 mm). The initial surface preparation was complemented by a final washdown with a minimum 5000-psi (35 MPa) pressure wash.

Generally, bush hammering does not provide a well-prepared substrate on which to bond shotcrete. This is primarily a result of the substrate surface weakening that bush hammering can produce. In the greater Seattle area, waterblasting in the 20,000-psi (140 MPa) range is not widely used as a normal means of concrete surface preparation. There are limited subcontractors providing this service to general contractors, and there are requirements to capture and treat the water runoff prior to release into the storm sewer system. A high-pressure hydroblasted substrate could have provided a superior tensile bond for the finished shotcrete. Sandblasting can also provide a good substrate onto which shotcrete will bond. Noncaptured sandblasting, however, is no longer allowed by various government agencies due to the potential health hazard it poses to workers and the public near the work site. Confinement of the blasting process was cost-prohibitive due to the specifics of the work site.

The general contractor explored the hydroblasting option, but ultimately selected a hand-held shotblasting setup. This equipment shoots steel shot against the substrate and through an integrated vacuum system, captures the dust, and recycles the steel shot. In general, this equipment can provide a surface similar to sandblasting, provided that the equipment operator is patient, as the process can be slower than sandblasting. After a test was completed, the owner accepted this surface preparation method. As the specification and good shotcreting practices require, the final prepared surfaces were kept saturated with potable water for at least 24 hours before the shotcrete placement.

### Preconstruction Testing

The project specifications included requirements specific to quality control, quality assurance, and crew experience. All installation was to be performed by nozzlemen certified in accordance with ACI 506.3R. Crew certifications were part of the submittal package. Additionally, an in-place test shoot would be completed to evaluate surface preparation, steel installation, shotcrete application, nozzlemen qualifications, and test strengths.

*Table 1: Initial test shoot mixture and properties*

| Mixture 1 description (meeting ACI gradation #2) | 1 yd³ dry weights | |
|---|---|---|
| Pea gravel | 728 lb (330 kg) | |
| Sand | 2184 lb (991 kg) | |
| Type I II cement | 658 lb (298.5 kg) | |
| Silica fume | 90 lb (41 kg) | |
| **Test performed** | **Specified value, psi (MPa) min.** | **Average test value, psi (MPa)** |
| Average test value, psi Compressive strength (ASTM C 42; C 1140) | 4500 (31) | 7750 (53.4) |
| Tensile bond strength (ACI 506.4R) | 325 (2.25) | 178 (1.2) |

*Table 2: Production testing and values*

| Test performed | Specified value | Average test value |
|---|---|---|
| Compressive strength (ASTM C 42; C 1140) | 4500 psi (31 MPa) min. | 5280 psi (36.4 MPa) |
| Boiled absorption (ASTM C 642) | less than 7% max. | 6.23% |
| Tensile bond strength (ACI 506.4R) | 150 psi (1 MPa) min. | 160 psi (1.1 MPa) |

This preconstruction test shooting was an excellent way to make a final evaluation of surface preparation, materials, and installation techniques prior to production shooting.

The in-place test shoot was completed on four longitudinal girders after the surface preparation and after the reinforcing steel was installed. A float finish was provided on the test shotcrete. In addition to the in-place test shoot, two test panels were shot. Four cores were then cut into the girder concrete substrate to qualify the two test-shooting nozzlemen. These cores were tensile bond-tested and removed, then visually examined per the requirements of ACI 506.3R. The nozzlemen were approved for shooting based on the visual examination of these same core samples. Three core samples were taken from each of the two test panels to test for the specified physical properties (see Table 1).

## Production Testing

The shotcrete installation required 70 days of actual shooting to complete. For every day of shotcrete application, three cores were taken from the one daily test panel. These cores were tested for compressive strength and boiled absorption. In addition to these test panel cores, a core hole was drilled through the shotcrete into the existing concrete in the strengthened girders and cross beams, and was tested for tensile bond. Figure 1 shows the tensile bond test set-up. Tests and results are presented in Table 2.

The 70 tensile bond tests revealed a wide variance in test values, even after procedural changes were made in the test to help yield more consistent results. As mentioned earlier, the original specification required 28-day bond to be 325 psi (2.25 MPa) minimum. After much exploration of this isssue, the owner determined that a more realistic goal for the direct tensile value was 150 psi (1 MPa) minimum. Although a bond strength of 150 psi (1 MPa) of the new shotcrete to the existing concrete surface was significantly more than the repair design required, it was decided that this value was a good benchmark for determining the adequacy of the long-term composite bond of the shotcrete to the old surface. Figure 2 shows some of the bond tensile-tested cores.

### Evaluation of Tests

Preconstruction and production testing were an extremely important part of the Spokane Street Bridge Strengthening project. The relevant testing allowed for all parties involved in the work to ensure that the application met the standard of quality required by the contract documents.

In this case, it was prudent to evaluate not only the test value, but also the method. There were difficulties with providing a reliable, repeatable direct tensile bond test. These difficulties were related to:

*Figure 1: Tensile bond test setup*

*Figure 2: Tensile-tested cores*

- The initial coring into the old concrete substrate to leave an undamaged core, perpendicular to the face of the shotcrete;
- The adequate bonding of a steel plate to the surface of the core, at the face of the shotcrete; and
- The loading of the bonded interface without introducing any eccentricity.

The owner, at its expense, ultimately cored and tested 12 additional tensile bond areas in the completed work. The additional tests were performed in previously tested areas exhibiting low tensile bond values. The average of these additional tests was 240-psi (1.66 MPa) tensile bond. The predominant mode of failure for this series of tests was the failure of the steel plate-bonding adhesive, indicating that the actual tensile bond strength of the shotcrete to the substrate is greater than the 240-psi (1.66 MPa) average value. This may indicate that the tensile bond test should provide an indication of shotcrete bond to the substrate, but may not always give a purely objective measurement of bond strength.

## Evaluation of Completed Work

In reviewing the completed work that has now been in service for over 18 months, no distress in the shotcrete has been observed. A small percentage of concrete cracks originating in the existing girders and cross beams have telegraphed through the new shotcrete. This can be expected when applying a relatively thin bonded shotcrete layer over a cracked substrate. Due to budget constraints, the cracks were not epoxy-injected prior to the shotcrete application. No spalling, leaching, or delaminating has been observed in the new shotcrete. This can be expected when applying a relatively thin bonded shotcrete layer over a cracked substrate. Due to budget constraints, the cracks were not epoxy-injected prior to the shotcrete application. No spalling, leaching, or delaminating has been observed in the new shotcrete.

## Summary

In conclusion, the South Spokane Street Bridge Strengthening project was an excellent use of the dry-mix shotcrete process. The placement technique saved the owner over $100,000 over alternate systems, and provided a high-quality finished product. The project was not without some challenges, however, and the following lessons were learned:

- The success of the shotcrete application is contingent upon the owner's commitment to pursue this application technology;
- Contract documents and test requirements should reflect realistic standards appropriate for the desired finished quality of the project;
- Preconstruction surface preparation tests are essential; and
- Preconstruction shotcrete test applications are essential.

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***Basil Kattula*** *is a Supervising Structural Engineer with the Seattle, Wash., office of PBQ&D, where he has been responsible for managing projects involving seismic retrofit and strengthening of existing old bridges. He is a graduate of the University of Kansas with an MSc degree in structural engineering.*

***Roger Runacres*** *is a Principal with ConTech Services, Inc. in their Seattle, Wash., office, where he is responsible for both wet and dry shotcrete applications. He is a graduate of the University of Washington with a Bachelor of Science in Construction Management.*