Layers in New York City Overhead Tunnels

Project Name: CM005 and CM006
Project Location: Manhattan, NY
Shotcrete Contractor: Superior Gunite
General Contractor: MICHELS Corporation and Frontier Kemper
Architect/Engineer: New York Metropolitan Transportation Authority Capital Construction (MTACC)
Material Supplier/Manufacturers: Ferrara Brothers Building Material and Teccrete
Lab: Tectonic

The NYCT MTACC has several large scale projects throughout New York, including one major program, the East Side Access project. On many of these projects, Superior Gunite has been subcontracted to shotcrete the arch placements in lieu of cast in place due to construction form costs and time savings. These arches are from 12" to 30" (300 to 760 mm) thick encasing two layers of #9 (#29M) reinforcement at 6" (150 mm) on center spacing. The General Contractor, MICHELS Corporation, subcontracted Superior shotcrete this work, and due to the thickness and complexity of reinforcing we chose to place the shotcrete in layers. The NYCT MTACC requested that Superior Gunite prove our placement methods for these overhead placements in a mock up, where the structural performance could be verified by bond testing. The pull-off test was conducted using ASTM C1583/C1583M-13, *Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)*. The criteria we had to meet in the bond test was 100 PSI or greater.

Bond test panel unreinforced

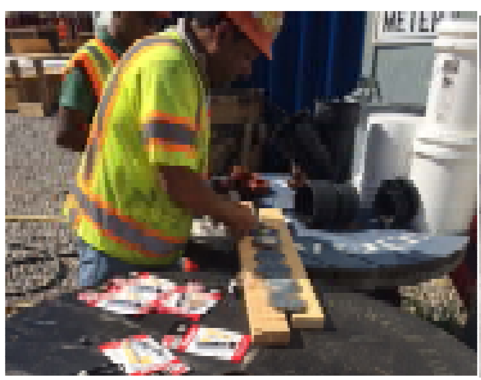
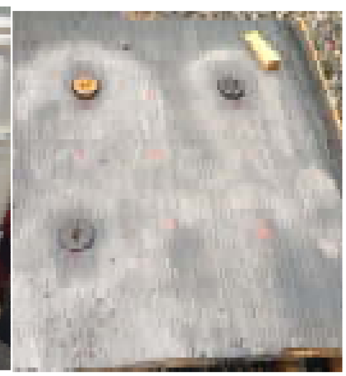
Bond test panel after two layers were shot

We took this opportunity to test two different surface preparations and configurations for layered, overhead shotcrete. Two boxes were made with a nozzle finish and the other two boxes were scratched, leaving an etched surface finish. No reinforcement was installed for any of the layers and all layers were prepared with a water hose cleaning between layers. Each layer has a minimum cure time of 24 hours prior to a subsequent layer being applied. With this, we also tested two-layer configurations; one being three-each 4″ (100 mm) lifts and the other two boxes were two-each 6″ (150 mm) lifts.


Nozzle finish panel

Scratch/Etched finished panel

The boxes were plywood 3′x3′ (0.9 x 0.9 m) with flared ends. All of the panels were identified and marked accordingly. Three 4″ (100 mm) cores in each box were done ¾″ (19 mm) beyond the layer interface into the second layer from the four panels. Surface preparation was done by the lab, Tectonic, the day prior to the bond test by cleaning the surface and using an epoxy adhesive (JB Weld 1/2 tube of each per puck) to adhere a steel puck to the concrete.

Epoxy Adhesive

Preparing each puck

Adhered pucks

The test apparatus was calibrated prior to the test and nine tests were performed at 11 days from the surface to the next layer down and 3 tests were performed at the 28-day mark from then intermediate layer to third layer. The test involves pulling on the steel plug (attached to the core face) using a hydraulic jack. The test equipment setup included: a hydraulic jack (cylinder and piston with a center hole); a manually operated hydraulic pump; hydraulic fluid pressure gage; valve; threaded rods/nuts; shackle; eyebolt; and steel U- frame.

Using the hand-operated hydraulic pump the hydraulic jack was actuated and a tensile load applied on the test area. The load applied by the jack on the specimen is related to the hydraulic fluid pressure, that is indicated by the pressure gauge included in the setup. Calibration charts of the hydraulic pressure to load relationship for the combination of jack and gauge were previously prepared by the testing lab during calibration of the jack.

Pressure being applied via hand jack

The load applied on the test area was obtained by reading from the calibration chart corresponding to the pressure shown by the pressure gage. The tensile load was gradually applied in four increments up to the required strength of 100 psi (0.69 MPa) and then load was gradually increased to failure. The maximum load applied and type of fracture was recorded. Test results (in psi) are shown below:

11 Day bond test				
	SPECIMEN	RESULT	FAILURE	AVERAGE
3 Layers, Prep Scratch Finish	1A	132	Glue plane	
4" Each lift	1B	185	Glue plane	164
	1C	174	Glue plane	
2 Layers, Prep Scratch Finish	2A	95	Glue plane	
6" each lift	2B	179	Glue plane	141
	2C	148	Glue plane	
3 Lifts, Prep Nozzle Finish	3A	95	Glue plane	
4" Each lift	3B	47	At Layer interface	76
	3C	84	At Layer interface	
2 Lifts, Prep Nozzle Finish	4A	99	Glue plane	
6" each lift	4B	32	At Layer interface	58
	4C	42	Glue plane	

BETWEEN 2ND AND 3RD LAYER				
3 Layers, Prep Scratch Finish	1D	248	Glue plane	
4" Each lift	1E	215	Glue plane	200
	1F	138	Glue plane	

The test data shows that the specimens where the surfaces between layers are scratched pass the bond test (box 1 and 2). In fact, the failure stress was not at the interface, but in the glue that adhered the steel puck to the concrete. In our testing the nozzle finish alone did not pass at an 11 day bond strength. However, the testing lab also noted that the unevenness of the rough, nozzle finished surface caused uneven stress with the test U-Frame that may have contributed to the lower tensile bond strength. The nozzle finish may have better bond in other situations. The procedures followed and criteria meets guidelines of ACI 506R-05 *Guide to Shotcrete*. With these full-scale tests we have proven that layers produce structurally monolithic sections when the surface is scratched, and we have proposed to do this on these MTACC projects.

Picture of glue plane failure

Picture of At layer interface failure

Following the pull test, Superior performed the mock up in layers. With all overhead work being performed in layers, each layer was prepared and shot with a 2 to 14-day time lapse between lifts.

Mock up

Arch Mock up in layers

Wall Mock up in single pass

After the mock up was performed, cuts were made through different locations. As you can see, the encapsulation of the rebar and water stop was excellent. Layering was not evident and with the pull test data this allowed Superior Gunite to proceed to the work.

Cut through the single pass wall Mock

Good encapsulation

A follow up test was performed for the East Side Access MTA project CM006 with another GC, Frontier Kemper. The same procedure was followed but only a scratch finish was prepared in the 2 boxes. More of the JB Weld adhesive for gluing on the steel pucks was used on this second test to try to obtain better results. Though the additional glue raised the test results, the failures were still in the glue, and not between the shotcreted layers. A table with the test results (in psi) is below:

CM006

11 Day bond test

First Layer	SPECIMEN	RESULT	FAILURE	AVERAGE
3 Layers, Prep Scratch Finish	1A	150	Glue plane	
4" Each lift	2A	264	Glue plane	216
	2C	233	Glue plane	
Second Layer				
3 Layers, Prep Scratch Finish	1B	267	Glue plane	
4" Each lift	1C	244	Glue plane	263
	2B	278	Glue plane	

A larger mockup was performed for this project and cuts were made through the shotcreted arch to evaluate the encapsulation.

Arch cut, single pass

Arch cut two layers

Cut mock up

In all the tests with a roughened, scratched surface preparation between layers we were never able to break the bond between layers with the test, since all the tests failed at the glue adhering the steel puck to the concrete surface. Conversely, our tests showed that shooting a subsequent layer on top of an unfinished, nozzle finished surface produced much lower test results. Though the tests were not overly complicated, we proved to the GC's and the MTACC that shotcrete sections shot out in layers with proper surface preparation between layers produces concrete sections that structurally act monolithically.

Today we are moving along through the MICHELS and Frontier Kempers projects. Below shows the arch done in a ~~hese tested~~ layers ~~above in its final application on the tunnel project.~~approach.

Written by Frank Townsend

Author Biography:

Frank E. Townsend III, is the East Coast Region Manager for Superior Gunite. He is a Civil Engineer graduate of Worcester Polytechnic Institute, in MA, and Master's Degree from the University of Missouri. Frank comes from the Army Corps of Engineers and has been running Superiors East Coast operations (Predominantly New York, New Jersey, Connecticut, and Boston) for 3 years now. Frank is an active member of ASA, and currently serves on the ASA Board of Directors.