Layers in New York City Overhead Tunnels

By Frank E. Townsend III

The New York City Transit (NYCT) Metropolitan Transportation Authority Capital Construction (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 concrete due to construction form costs and time savings. These arches range from 12 to 30 in. (300 to 760 mm) thick, encasing two layers of No. 9 (No. 29M) reinforcement at 6 in. (150 mm) on-center spacing. The general contractor, MICHELS Corporation, subcontracted Superior to shotcrete this work, and due to the thickness and complexity of reinforcement, 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 mockup, where the structural performance could be verified by bond testing. The pulloff 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 (0.69 MPa) or greater.

We took this opportunity to test two different surface preparations and configurations for lay-


Fig. 1(a): Bond test panel, unreinforced


Fig. 2(a): Nozzle-finished panel


Fig. 1(b): Bond test panel after two layers were shot


Fig. 2(b): Scratch/etched finished panel, unreinforced

ered, 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 had a minimum cure time of 24 hours prior to the placement of the subsequent layer. Two layer configurations were also tested on each of the finishes mentioned previously: for one set, three layers were placed, each with 4 in. (100 mm) lifts; and the second set of boxes were placed in two layers, each with 6 in. (150 mm) lifts.

The boxes were 3 x 3 ft (0.9 x 0.9 m) plywood with flared ends. All of the panels were identified and marked accordingly. Three 4 in. (100 mm) cores in each box were taken 0.75 in. (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 (J-B Weld, one-half tube of each per puck) to adhere a steel puck to the concrete.

Fig. 3(a): Epoxy adhesive

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 three tests were performed at the 28-day mark from the intermediate layer to third layer. The test involved 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 gauge; 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.

The load applied on the test area was obtained by reading from the calibration chart corresponding to the pressure shown by the pressure gauge. 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 in Table 1.

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 an 11-day bond strength test. However, the testing lab also noted that the unevenness of the rough, nozzle-finished

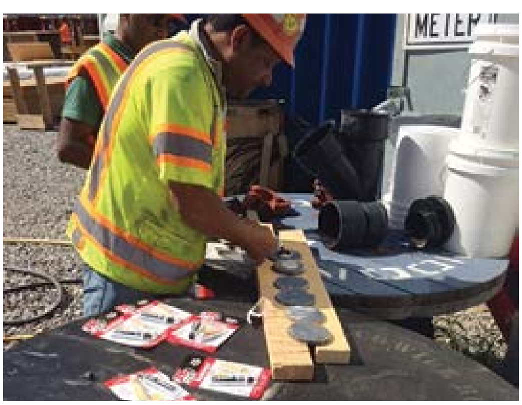


Fig. 3(b): Preparing each puck

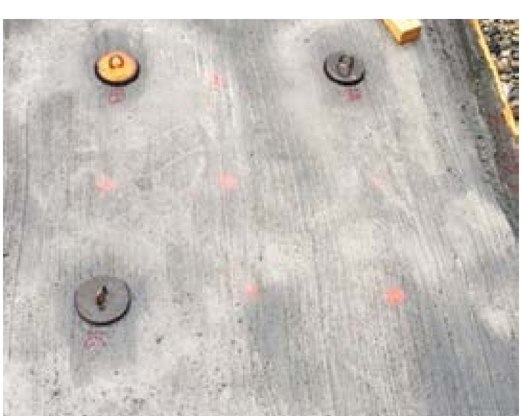


Fig. 3(c): Adhered pucks

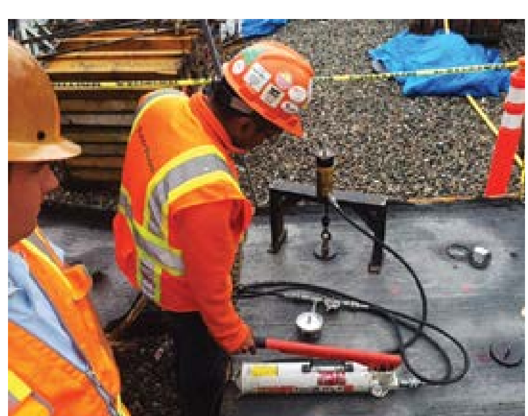


Fig. 4: Pressure being applied via hand jack

Table 1: 11-Day Tensile Strength of Bond Test (First test: MICHELS Corporation)

	Specimen	Result	Failure	Average
Three layers, prep scratch finish 4 in. (100 mm) each lift	1A	132	Glue plane	164
	1B	185	Glue plane	
	1C	174	Glue plane	
Two layers, prep scratch finish 6 in. (150 mm) each lift	2A	95	Glue plane	141
	2B	179	Glue plane	
	2C	148	Glue plane	
Three lifts, prep nozzle finish 4 in. (100 mm) each lift	3A	95	Glue plane	76
	3B	47	At layer interface	
	3C	84	At layer interface	
Two lifts, prep nozzle finish 6 in. (150 mm) each lift	4A	99	Glue plane	58
	4B	32	At layer interface	
	4C	42	Glue plane	
Between second and third layer				
Three layers, prep scratch finish 4 in. (100 mm) each lift	1D	248	Glue plane	200
	1E	215	Glue plane	
	1F	138	Glue plane	

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 the criteria met the 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.


Fig. 5(a): Picture of glue plane failure


Fig. 5(b): Picture of layer interface failure

Following the pull test, Superior performed the mockup 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.

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

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

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

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 because 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

Fig. 6(a): Mockup

Fig. 6(b): Arch mockup in layers

Fig. 6(c): Wall mockup in single pass

Fig. 7(a): Cut through the single pass wall mockup in layers

Fig. 7(b): Good encapsulation

Table 2: 11-Day Tensile Strength of Bond Test (Second test: Frontier Kemper)

	Specimen	Result	Failure	Average
First layer				
Three layers, prep scratch finish 4 in. (100 mm) each lift	1A	150	Glue plane	216
	2A	264	Glue plane	
	2C	233	Glue plane	
Second layer				
Three layers, prep scratch finish 4 in. (100 mm) each lift	1B	267	Glue plane	263
	1C	244	Glue plane	
	2B	278	Glue plane	

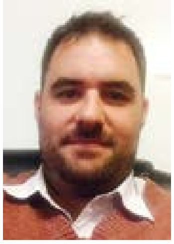
Fig. 8(a): Arch cut, single pass

Fig. 8(b): Arch cut, two layers

Fig. 8(c): Cut mockup

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

produced much lower test results. Although the tests were not overly complicated, we proved to the general contractors and the MTACC that shotcrete sections shot out in layers with proper surface preparation between layers produces concrete sections that structurally act monolithically.



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