2011 Honorable Mention

Shotcrete Saves the Day—Restoring a Crumbling Rock Face

By Mark K. Seel

An exposed section of bedrock that supports a playground adjacent to a city school was in desperate need of intervention. Upon arrival at the site, the adjacent sidewalk had been blocked off with a cyclone fence to keep pedestrians away from the rock mass, which showed signs of movement as evidenced by individual blocks of fallen rock (refer to Fig. 1). Subsequent investigation and analyses were initiated by Langan Engineering and Environmental Services, Inc. (Langan); and recommendations were made that included using a combination of steel rock anchors and high-strength steel netting to restrain the rock mass. Shotcrete was suggested to provide cohesion to the blocky rock mass. Supplemental sculpted and tinted shotcrete would provide the rock mass with the appearance of being restored to a near-original visual condition.

Investigation and Design Intent

Langan investigated the rock exposure using: 1) a combination of shallow test pits to verify foundation conditions; and 2) discontinuity mapping to verify observed potential modes of block failure along joints in the rock mass. All available information and measurements were then used to characterize the rock mass and determine block stability. The observed conditions indicated that the adjacent roadway and sidewalks were cut into the rock mass during initial site development. It is believed that to achieve the desired site and road grades, the rock cut was made as steep as possible. This condition left no space for rock-fall catchment. As with any rock exposure, time and the elements took their toll on the rock mass. Our analyses indicated that plane sliding and general ravel-type failures had recently occurred and were likely to continue without intervention. Because of the adverse orientation of select discontinuities in the exposure and the lack of adequate space for rock-fall catchment, significant active restraint and rock-fall protection were required.

Fig. 1: Initial condition—fallen rock

A combination of steel rock anchors and high-strength steel netting was needed to provide the required restraint and rock-fall protection; however, steel fiber-reinforced shotcrete was also needed to provide supplemental durable structural support of the rock. In addition, shotcrete was also expected to architecturally conceal the stabilizing elements from view. Langan subsequently designed a four-part system for the rehabilitation of the rock mass that included installation of rock anchors; base/dental shotcrete; and high-strength steel netting and a drainage mat integrated into a strong, cohesive decorative shotcrete façade.

The base shotcrete was an important element that would provide supplemental structural support to the rock mass. In addition, the base/dental shotcrete would mitigate the potential to leave voids in the stabilized mass. Primary structural support was provided by the high-strength steel netting and steel rock bolts. The base shotcrete was also expected to facilitate the rock bolt installation through potentially unstable rock blocks (refer to Fig. 2). Shotcrete also insulates the rock mass from the effects of seasonal weathering. The decorative shotcrete façade provided a new durable face with several decades of reliable service life.

Construction

All work had to be performed at the site, which essentially consisted of a 15 ft (5 m) wide

Fig. 2: Unstable rock

sidewalk approximately 300 ft (91 m) long. All work was coordinated through the project architect and the school's administration. The hours of operation had to be controlled to prevent impacting normal school activities. Occasional night work was required to accommodate the schedule. Quality control and quality assurance were performed on all aspects of the work. The work was supervised by a licensed professional engineer. Shotcrete test panels were made and cores were removed from them. Grout cubes were cast during the rock anchor testing. Samples of the shotcrete and grout were tested to verify that their unconfined compressive strengths exceeded the 28-day design strengths required in the contract documents.

The contractor cleared the site of debris, soil cover, and vegetation. The rock face was cleaned with a high-pressure water blast. The stabilization work then proceeded in two parallel paths. Three inch (75 mm) diameter holes were drilled in stable sections of the rock mass using a track-mounted hydraulic drill equipped with a carbide-tipped hammer drill (refer to Fig. 3). Cuttings were blown out and the borehole was flushed with fresh water. Concurrently, but in areas where the rock was potentially unstable, the first 3 to 4 in. (75 to 100 mm) of base wet-mix shotcrete (steel fiber-reinforced) was applied in "dental" fashion to secure blocks of rock and create a stable smooth substrate. This base shotcrete layer was applied to deep crevasses and joints to provide structural support to the generally weakened rock mass. Additionally, shotcrete was applied in greater thickness to areas where deep and/or steep transitions occurred. The idea here was to "soften" edges so the overlying steel netting would make full contact with the substrate when placed. This provides uniform stress distribution and eliminates the formation of cavities behind the netting, thus ensuring full continuity of the section within the shotcrete. Once the rock mass was sufficiently stable, holes for the remaining rock anchors were drilled and cleaned. Steel dowels were drilled and grouted locally into the rock where greater thicknesses of shotcrete were required to achieve the project objective. Weep holes were then drilled into the rock mass to facilitate drainage, and a drainage mat was affixed to the rock and base shotcrete surface to drain water away from the rock mass.

One inch (25 mm) diameter Grade 97 (670 MPa) corrosion-protected rock anchors were placed in the clean boreholes, and a neat cement grout with a 28-day design compressive strength of 5000 psi (37 MPa) was tremied into the boreholes and allowed to cure. Ten percent of the anchors were performance-tested. High-strength steel netting was then stretched over the rock mass and pulled tight over the anchors. Plates and nuts were secured on the anchors, which were restressed and locked off. The remaining anchors were tightened with a calibrated torque wrench and locked off. The anchor head assemblies were

Fig. 3: Drilling rock anchor borehole

Fig. 4: Applying and sculpting shotcrete

Fig. 5: Sculpting shotcrete

fabricated with protruding pins to engage the overlying shotcrete cover.

After installing the high-strength steel netting, one to two layers of wet-mix shotcrete with a total thickness of 6 to 8 in. (150 to 200 mm) was applied and finished (refer to Fig. 4 and 5). The final face surface was sculpted and tinted to match the rock's original appearance. "Jointing" was carved in the final surface to replicate the natural appearance of the rock. After an initial curing period of 24 hours, the shotcrete was stained to match the original rock surface (refer to Fig. 6). Final site work consisted of removing and replacing the site sidewalk and curb.

The entire project took approximately a) 3 weeks to complete; b) 1 week to mobilize, clear, and restore the site; c) 6 days to install the rock anchors and netting; and d) 4 days to complete the shotcrete work. Roughly 95 yd^3 (73 m^3) of shotcrete was used in this project.

Benefits

Stabilizing the rock mass eliminated the public safety concern of pedestrian traffic in the vicinity of a potentially unstable rock exposure. The use of shotcrete virtually eliminates the need for future maintenance that would involve the use of trucks and heavy construction equipment, which congests roads and creates noise and air pollution. In addition, there will be no further need for additional material, processing, or rock, which can cause dust nuisance and would use additional energy resources. The result is a sustainable, safe, aesthetically pleasing, durable façade.

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Project Name
PS #6 - Rock Stabilization

Project Location
Bronx, NY

Shotcrete Contractor
Moretrench American Corporation &
Boulderscape Incorporation*

General Contractor
CM&E Con Inc.

Architect/Engineer
Langan Engineering and Environmental Services

Material Supplier/Manufacturer
Jenna Concrete

Project Owner
New York City School Construction Authority

*Corporate Member of the
American Shotcrete Association

Fig. 6: Final stabilized rock mass

Mark K. Seel *is Vice President of Langan Engineering and Environmental Services, Inc., a full-service engineering, environmental, and construction services firm headquartered in Elmwood Park, NJ. He is a Senior Geotechnical Engineer involved in the assessment and stabilization of rock exposures. Seel is a member of several associations, including the Transportation Research Board, the American Rock Mechanics Association, the Deep Foundations Institute, and the American Society of Civil Engineers. His research interests include the advancement of technical excellence within the geotechnical and rock mechanics fields. Seel received his BS in geological engineering from the Colorado School of Mines, Golden, CO, and his MS in civil/environmental engineering from the Stevens Institute of Technology, Hoboken, NJ. He is both a licensed professional engineer and geologist in several states.*