# Shotcrete in Qatar

*By Lars Balck, Robert (Bobby) Oyenarte, Buddy Williams, and T. J. Williams*

Crom International LLC (Crom), a subsidiary of The Crom Corporation, recently completed two large shotcrete storage tank projects in Qatar totaling over 144 million gal. (545,000 $m^3$) of usable potable water storage. In both projects, Crom was responsible for constructing four large-diameter cast concrete membrane floors and cylindrical composite walls of shotcrete with embedded galvanized corrugated steel diaphragm, and circumferential single wire-wrapped prestressing with shotcrete cover. Throughout the course of both projects, Crom placed over 21,000 $yd^3$ (16,000 $m^3$) of shotcrete and 2165 miles (4012 km) of galvanized high-tensile-strength prestressing wire for the walls of the storage tanks.

Qatar, a sovereign Arab emirate, shares its only land border with Saudi Arabia to the south, with the rest of its territory surrounded by the Persian Gulf. Doha, Qatar's capital and only major city, has approximately 1.6 million residents. Qatar is estimated to have 1% of the world's oil and the third-largest natural gas reserve, which has helped the nation to become the world's richest country per capita in the last decade. Since Qatar gained independence from the British in 1971, it has embarked on a remarkable transformation recently labeled the "National Vision 2030," where the nation will continue to invest billions of dollars in infrastructure to promote tourism and develop a diverse economy not solely reliant on petrochemicals and hydrocarbons.

Fig. 1: Night finishing exterior

In 2012, nearly all the available potable water was being supplied from desalination facilities with no peak demand production capabilities, which reduced reserves to less-than-desirable levels. As of December 31, 2013, Qatar had a total population of 2.05 million people, of which approximately 300,000 are Qatari nationals. This total far exceeds the originally projected population for 2016. With low reserves and actual population growth rate exceeding the projected rate, the government instituted aggressive measures to boost their potable water storage capacity by building out a number of reservoir pump stations.

## Challenges

The combination of weather, silica fume, high-cement content mixture, water availability, and high levels of traffic congestion all presented challenges to having an efficient shotcrete operation.

## Weather

Working around the weather was a constant and significant struggle. Sandstorms and fog would occur unexpectedly and would completely "whiteout" the site and access roads, causing a complete shutdown of work. Because of the inherent dangers and recorded incidents in sandstorms and fog, all truck traffic, by law, must pull off the road until the event has passed or face steep traffic violations and even jail time. With the concrete delivery trucks having an average commute of 45 minutes, even a short event would result in the load of concrete being rejected. After a sandstorm, the crew would often need an entire shift to remove the dust, clean up, and start over. Even welcomed fog during the spring months caused delivery delay problems, which resulted in many loads being rejected.

In the summer, nearly all concrete was placed at night due to constant daily high temperatures that often reach 106°F (41°C) and sometimes exceeding 112°F (44.5°C). For the workers' protection, all work was restricted if the ambient temperature exceeded 113°F (45°C).

## Inconsistent Shotcrete Mixture

The concrete mixture used for the wet-mix shotcrete presented the greatest challenge for two reasons. First, although shotcrete mixtures are typically cement rich and, consequently, sticky, adding silica fume caused the mixture to become extremely sticky. The second challenge was that the concrete delivered to the site was rarely delivered with a consistent slump. With over 40 concrete suppliers covering the construction boom in Doha and most concrete placement occurring at night, many people consider the concrete truck Doha's summer nocturnal creature.

Throughout the nation, older concrete structures are crumbling due to corrosion of internal reinforcement caused by the high internal chloride content in the original concrete mixtures. As a result, Qatar has established strict requirements in the national building code called the Qatar Construction Standards (referenced locally as QCS 2010). Local limestone aggregates are only to be used on a limited basis due to their substantial nonuniform qualities, uncontrolled water absorption, and abrasion quality. Imported limestone and Gabbro aggregates (igneous rock) from the United Arab Emirates and Saudi Arabia are widely employed for nearly all construction activities. Although most aggregates are imported with low chloride levels, mixtures are continually checked to ensure the chlorides are kept below allowable levels. Cement, which is produced locally by the government, and chloride-contaminated potable water also contribute to chlorides in mixtures and must be closely monitored.

For both RPS projects, the QCS 2010 required the use of QCS 2010 C40 for the shotcrete mixture. C40 refers to a concrete cube 6 x 6 x 6 in. (150 x 150 x 150 mm) sample that must break higher than 40 $N/mm^2$

40 $N/mm^2$ (cube) = 32 MPa (cylinder) = 4600 psi (cylinder)*

Low breaks were never a concern because the mixture design consistently outperformed the C40 requirements with an average 28-day strength exceeding 6700 psi (46.2 MPa).

*QCS 2010 C40 requirements for cylinder strength and durability:*

| | **Requirements** |
|---|---|
| **Strength (28-day)** | 4600 psi (32 MPa) |
| **Chloride content ASTM C1281** | 0.06% |
| **Durability (56-day)** | |
| Water penetration BS 12390-8 | 15 mm (0.6 in.) |
| Water absorption BS 1881 | 2 |
| Chloride migration | $5 \times 10^{-12}$ |
| RCP ASTM C1202 | 2000 coulombs |

*refer to Shotcrete Corner on pg. 22 for a more detailed explanation.

Following is the approved shotcrete mixture design that met the QCS 2010 requirements for C40 strength and durability. To meet the strict durability requirements, silica fume was added to the shotcrete mixture and to provide workability, the maximum allowable plasticizer was added. The high-range water reducer (HRWR), in addition to providing workability, also retarded the set.

| | **lb/yd³** | **kg/m³** |
|---|---|---|
| Cement | 660 | 390 |
| Micro silica | 50 | 30 |
| Fly ash | 304 | 180 |
| 0-1/4 aggregate | 2395 | 1420 |
| Water | 262 | 155 |
| Glenium 183 (HRWR) | 7 | 4.2 |
| Fiber | 1.1 | 0.7 |
| Total | 3679 | 2180 |

Acceptance of a concrete mixture design was a lengthy, involved process.

- The first step was submittal of a proposed mixture design along with the concrete supplier qualification, yearly government approval, and current batching equipment certifications.
- After initial acceptance, a trial mixture was arranged in the presence of the owner's inspector, general contractor, and requesting contractor. The trial mixture was batched into a truck. Every 30 minutes, concrete samples, along with slump and temperature measurement, are taken until 90 minutes elapse. Samples were taken for strength, chloride, and durability tests.
- Samples obtained at the trial batch were sent for laboratory testing. It took over 56 days to receive all the results.

Due to the extremely hot weather conditions and the silica fume in the mixture, a maximum dosage of HRWR was required by the supplier to attain workability. With the significant temperature changes throughout the day, the concrete supplier needed to vary the amount of HRWR, which led to constant slump inconsistencies at the time of delivery. Poor equipment maintenance, driver inexperience, and delivery delays all ensured that no two trucks arrived with the same slump. To compound inconsistent deliveries, the inspectors enforced a rule that "not one drop of water can be added on-site." This rule was required because it was not possible to ensure that the water carried onboard the trucks was clean and free of chlorides. At times, adding additional HRWR to the mixture on site led to a false sense that the mixture was acceptable, when in fact flash-setting was experienced while attempting to shoot out of the truck.

To combat the inconsistent slumps of the mixture and flash setting, only 8 yd³ (7 m³) loads were ordered, and a concrete triage was set up. When trucks arrived on site, they were either sent immediately to a pump (delivered at just the right slump) or held so the slump could be adjusted. Many times, a small addition of plasticizer would make a drastic change in slump only to be followed by a flash set. With as many as four crews shooting at one time, the triage required significant resources to ensure that the trucks were released as soon as possible. Many trucks, because of frequent traffic problems or weather delays, were rejected, causing the delivery loop to break down and resulting in long days to meet the production schedule. To deal with the delays, shooting was kept to relatively small areas and completed in vertical layers, which minimized moving the pumps and made curing easier. To minimize plugs, the entire pump/shotcrete system would be cleaned out as soon as each truck was emptied. Finishers would begin their work almost as soon as the nozzleman began placing shotcrete and oftentimes, extra finishers were placed on each lift to speed up the finishing operation ahead of the quick set caused by sudden loss of the retarding.

## Equipment

A desert environment is particularly hard on equipment. The ultrafine wind-blown sand that causes the "white-outs" penetrates every pore of the equipment, requiring air filters to be changed daily. To prevent overheating, water was run over the radiators of pumps and compressors during high-temperature months. Sticky concrete required that extra time needed to be spent cleaning and maintaining equipment. Although pumps were rotated and the maintenance program was stepped up, pumps would still break down almost every other day due to the sand, heat, and sticky concrete. The number of spare parts ordered more than tripled our normal experience in the United States.

## Curing

The availability of a continuous water supply impacted both curing and cleanup. Water was delivered by truck and stored in tanks on site. Truck delivery of water, however, was inconsistent. In addition, electrical power for the water pumps was also intermittent. This combination of factors often meant that there were times the crew ran out of water while shooting, making cleanup a challenge. Curing was accomplished using a variety of methods: evaporation retarder, plastic sheets, and soaked burlap.

## Testing

The amount of testing required was substantial. Concrete/shotcrete samples were taken in accordance with the British Standards and rodded into metal cube molds 6 x 6 x 6 in. (150 x 150 x 150 mm), which weighed about 20 lb (9 kg) before adding concrete samples. Every truck was sampled and measured for slump and temperature. Shooting just 100 yd (91.44 m) required taking nearly 60 samples. Samples were kept on site in a special temperature-controlled environment large enough to hold several hundred samples because samples had to be kept on site for 7 days. A chain of custody had to be maintained until the samples were received by the testing laboratory. Over the course of the job, about 5000 samples were taken, stored, and handled.

*Fig. 2: Exterior shotcreting from the ground*

## Summary

Placement of 21,000 yd$^3$ (16,000 m$^3$) of shotcrete was completed in just 10 months, although temperatures at times reached 115°F (46°C) in the day. Weather in the form of sandstorms and fog forced a halt to the shotcrete operation and forced the crew to regroup and set up for the following evening. Heat, silica fume, maximum dosage of HRWR, and inconsistent wet-mix concrete delivered to the job caused many loads to flash-set.

Ingenuity, determination, and teamwork enabled our crews to work through the problems and meet the aggressive construction time frames. All eight tanks were leak tested and passed on the first try—a feat we understand is unique for the region.


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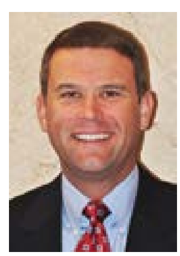

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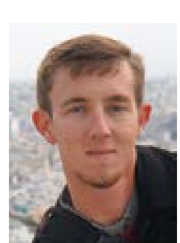

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