

# Shotcrete Repairs in Barbados— A Caribbean Experience

by Joe Hutter, Jean-François Dufour, and Nigel Fullam

**C**hallenges associated with the placement of concrete vary depending on the conditions in which the project is undertaken. Extreme climactic conditions can often be one of the most significant contributors to these challenges. For example, extremely cold temperatures will have a lengthening effect on the time required for concrete to reach its final set and delay its strength development at early age. In a case where the concrete freezes before reaching this point, the long-term effect on the hardened properties such as compressive strength and durability can be dramatic.

Conversely, precautions must also be taken when concrete is placed in conditions where extremely hot temperatures are prevalent. Hot temperatures will accelerate the setting time of concrete and contribute to rapid surface drying, a condition that promotes plastic shrinkage and surface cracking. Proper curing procedures, a critical step for any successful concrete placement application, take on an even more important role when temperatures rise at the job site.

Cold temperatures were definitely not a factor at the Reform & Expansion of Bridgetown Port project on the island of Barbados, but hot temperatures, experienced throughout the duration of the project, certainly were. The island of Barbados



*Shotcrete was supplied in special one-way bulk tote bags, lined with polyethylene, to prevent moisture from coming in contact with the cementitious material*

is the most easterly of the Caribbean Islands, lying east of the windward group of islands. It has a tropical maritime climate; and despite temperatures that are tempered by the northeast trade winds, daily, average highs vary between 83 and 89 °F (28.3 and 31.7 °C). These temperatures, in combination with warm Caribbean breezes, create less than optimum curing conditions for concrete placement and finishing.

## Reform and Expansion of Bridgetown Port—Background

The Bridgetown Port was originally constructed in the early 1960s and expanded in the mid-1970s to allow for increased growth in traffic from cruise and cargo ships. Further increases in forecasted growth required that the port again upgrade the existing berths and also upgrade and expand the cruise terminal facilities.

Delcan International of Markham, ON, Canada, undertook the planning, project management, and design of the project. Careful consideration was



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given to the construction materials specifications and the importance of curing—both extremely important factors considering the hot temperatures expected during the project.

Before embarking on the port expansion, attention would have to be given to the existing concrete structures. Continuous exposure to salt water had caused corrosion of the reinforcing steel and resulted in severe deterioration of the concrete throughout the facility. Removal of concrete from berths, wharves, and concrete dolphins sometimes exceeded 6 in. (150 mm) in depth. To replace this concrete, Delcan elected to specify shotcrete as a concrete repair method. Delcan engineers were familiar with this method of placing concrete from previous projects that involved similar challenges and were aware of the benefits offered by the shotcrete process.

The successful bidder, Lagan Holdings Limited of Belfast, Northern Ireland, was awarded the contract to conduct the work and moved on site in February 2005. Due to concerns with the consistency of local products and the quality of local aggregates, Delcan specified that the shotcrete material be prebagged and produced with aggregates from an approved source. Lagan then approached King Packaged Materials Company, which, in addition to having a wealth of experience designing shotcrete mixtures for varying site conditions, had extensive experience with the overseas shipment of materials.



*Prepared surface with timber side shutters*

## **Shotcrete Mixture Design and Packaging Requirements**

Shotcrete mixture designs require the use of well-graded aggregate size distribution. King Packaged Materials' engineers retained an aggregate gradation that would meet ACI 506R-05, "Guide to Shotcrete," gradation No. 2. This recommendation was based on the application thickness and concerns with drying shrinkage. Microsynthetic fibers were preblended with the other shotcrete mixture components to further reduce concerns about shrinkage cracking. The proposed shotcrete mixture also contained silica fume to reduce rebound, increase resistance to water washout, and decrease the permeability of the mixture. Concrete or shotcrete with low permeability values will reduce the potential for chlorides to migrate into the concrete, reducing corrosion potential of the reinforcing steel. The use of supplementary cementing materials such as silica fume also allowed the nozzleman to shoot the mixture at its wettest stable consistency, which contributes to proper reinforcing bar encapsulation and facilitates surface finishing.

To ensure that the shotcrete material remained in a dry, usable state during the 1800 mile (3000 km) voyage from the Brantford, Ontario, Canada, production facility to Bridgetown Port, King production personnel designed a special one-way bulk tote bag. These bags were lined with polyethylene to prevent moisture from coming in contact with the cementitious material and sized at 1653 lb (750 kg) each to maximize the amount of material that could be loaded into the 20 ft (6 m) containers.





*Access to the underside of the concrete wharf was difficult, especially at high tide*



*The shotcrete hoses ran from the shotcrete machine, which was stored with the prepackaged materials on the top side of the slab, to the nozzelman, positioned below*



*Large concrete dolphins, used to moor cargo ships, also required extensive rehabilitation*

## Concrete Removal and Shotcrete Placement

The shotcrete nozzelman, with years of experience on concrete rehabilitation projects, was brought in from the United Kingdom. Mock-up test panels, representative of the job site, were shot to qualify the shotcrete crew and to further assess in-place compressive strength of the shotcrete. This testing was completed under the supervision of both King and Metro Testing, shotcrete consultants appointed by Delcan. Test panels were then evaluated by Metro Testing quality control personnel and resulted in the nozzelman being approved to work on the project.

The concrete removal process commenced with a “bulk breakout” system using light-duty handheld CP9 chipping hammers. The areas of delaminated concrete were highlighted by the engineer, and the perimeter was sawcut to a depth of 1.2 in. (30 mm). Because the original concrete cover of the reinforcement was unknown and varied greatly, and to ensure preservation of the existing reinforcement, the depth of sawcut was limited to 1.2 in. (30 mm).

The main benefit of a bulk breakout process was to reduce the amount of hydrodemolition required, thus speeding up the removal and replacement process. After bulk breakout, hydrodemolition was used to remove the remaining delaminated concrete while preserving as much of the existing steel reinforcement as possible. Concrete removal continued until sound concrete was reached or until a minimum clearance of 0.8 in. (20 mm) around the steel reinforcing was achieved. The hydrodemolition process also provided an ideal substrate to which the shotcrete could bond.

The badly corroded steel reinforcement was marked for removal by the engineer and replacement steel was lapped or drilled and secured with epoxy. The exposed reinforcing steel was then blasted with glass grit to remove rust and scaling. This was completed a maximum of 24 hours before the shotcrete application to minimize further corrosion. Glass grit was chosen because it was an inert material and therefore had limited environmental impact.

On-site storage of large amounts of shotcrete allowed Lagan Holdings Inc. to easily schedule the placement of the shotcrete material. On the wharf rehabilitation section of the project, the nozzelman was able to access concrete beams and columns, located under the concrete slab, and the underside (soffit). The shotcrete hoses ran from the shotcrete machine, which was stored with the prepackaged materials on the top side of the slab, to the nozzelman, positioned below the slab on a specially designed floating platform, which allowed the nozzelman to stand slightly below the surface of the water. The anti-washout

characteristics, provided by the silica fume, would also allow the nozzelman to shoot material until the tidal actions prevented him from continuing.

After approval of the concrete removal and surface preparation by the engineer, temporary timber side shutters were placed to provide a side form on which the shotcrete could be applied. The entire area was then power-washed to provide saturated/surface dry conditions that reduced absorption of water from the plastic shotcrete mixture during the hot mid-day temperatures.

Large concrete dolphins, used to moor cargo ships, also required extensive rehabilitation. Spalling, caused by corroding reinforcing steel, was extensive and substantial amounts of concrete required removal. The flexibility offered by the prebagged shotcrete again allowed Lagan personnel to store all materials on the surface of the adjacent concrete slab and run hoses to the nozzelman, who stood on a large floating platform to access the vertical sides of the dolphins.

## Finishing and Curing

Finishing was completed using wood and rubber floats. It had to be completed quickly because of the effect of the hot temperatures on the plastic properties of the shotcrete mixture. Curing procedures were commenced as soon as possible after shooting to prevent surface cracking caused by plastic shrinkage. After the specified, continuous 7-day wet cure, Lagan was also required to apply a curing compound at twice the manufacturer's recommended coverage. The shotcrete process was delayed if outside temperatures were expected to reach 100 °F (38 °C), and the Lagan crew was required to maintain the temperature of the receiving surface and reinforcing steel below 100 °F (38 °C) whenever shotcrete was placed. All of these steps were taken to minimize the impact of the hot temperatures.

This attention to curing, while important in any shotcrete application, took on even more importance on the Bridgetown Port concrete repairs. Despite continuous hot, windy conditions, the shotcrete finishers were able to provide a smooth monolithic finish that blended well with the existing concrete structures.

During the project, King Packaged Materials' technical staff provided on-site technical assistance that provided an opportunity to exchange views with the European nozzelman, comparing the differences between the North American and European approach to dry-mix shotcreting. By the time the shotcrete portion of the project was completed, representatives of Delcan International and Barbados Port Inc. were in agreement that the quality of the shotcrete repairs met all expectations.



*The shotcrete nozzelman stood on a large floating platform to access the vertical sides of the concrete beams and columns*



*In areas with space restrictions, a specially designed floating platform allowed the nozzelman to stand slightly below the surface of the water*

## Meeting the Challenges

There are many reasons that shotcrete contributed to the success of the Bridgetown Port project. Access to the repaired areas was difficult because of the proximity of the beams and columns. The shotcrete nozzelman was able to easily place material in these confined areas without costly form work that would have been required throughout the structure had form and pump placement methods been used. The dry-mix method, supplied using preblended products, allowed the contractor to move from section to section without having to wait for ready-mix trucks or other batching systems. When required to stop, they were able to simply empty the machine and shut down.

The mixture design chosen provided improved durability over the original concrete and with the proper surface preparation (hydrodemolition) excellent bond strengths were achieved between the shotcrete and the existing concrete. The nozzelman's skill, combined with quality materials,



ensured that the quality of repairs exceeded the minimum, specified requirements outlined by the engineers.

The hot temperatures encountered during the project presented a challenge to the shotcrete crew but would have also have been a factor had the engineers and contractors elected to use a form and pump method of repair. In fact, the use of dry-mix shotcrete eliminated concerns about slump retention and mixture pumpability. These concerns would have been prevalent, especially in cases

where the repair areas were small and spread out on different areas of the structure.

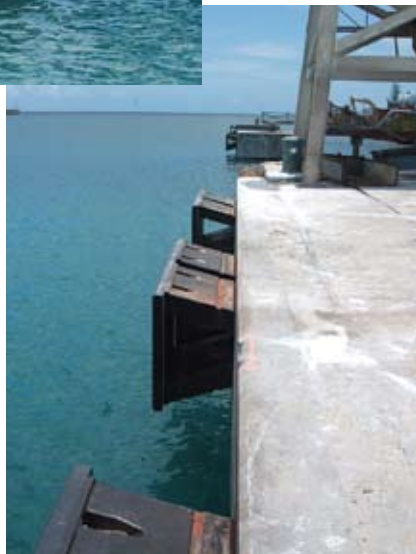
The flexibility offered by dry-mix shotcrete and the benefits offered through prepackaged products (manufactured in a controlled factory environment) allowed Lagan construction management personnel to focus on other aspects of the project. With the results of test panels available to them, it was only a short while after the shooting process began that Lagan management had full confidence in the excellent quality of the shotcrete work.



*Despite continuous hot, windy conditions, the shotcrete finishers were able to provide a smooth monolithic finish that blended well with the existing concrete structures*



*Completed repairs to concrete dolphins and wharf area*



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Most of his experience relates to the field of concrete and shotcrete technology in several disciplines such as new construction, rehabilitation, and mining industries. Dufour is Chair of ACI Committee C 660, Shotcrete Nozzleman Certification, and is certified as an ACI Certification Examiner. He is a graduate civil engineer with a master's degree in civil engineering from Laval University, with an emphasis on cement and concrete technology and shotcrete repairs.



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extensive experience with shotcrete in both tunneling and civil repair applications, and is currently project manager for the Reform & Expansion of Bridgetown Port project in Bridgetown, Barbados.