The Use of Shotcrete as a Repair Process for Marine Structures

By Liam Ireland

Concrete marine structures include dams, canals, docks, piers, and seawalls that are regularly exposed to either fresh or salt water. Marine structures are normally exposed to harsh environmental conditions and require periodic maintenance to meet their expected service life. In normal service they may be exposed to more aggressive deterioration processes such as freezing and thawing, wetting and drying, chloride intrusion from salt or brackish water, erosion, and abrasion impact from ice flows. Maintenance and repairs of marine structures are generally more challenging than those on land due to site access, tides, winds, waves, and other related issues. The impact of repairs on the adjacent land and marine life must also be considered. This requires planning and proper execution of measures to mitigate contamination of the surrounding water and land. This article illustrates how shotcrete provides a more versatile and cost-effective solution for repairing concrete marine structures than traditional form-and-pour concrete.

CHALLENGES

The combined effect of gravitational forces exerted by the sun and moon along with the rotation of the earth results in the rise and fall of sea levels known as tides. The ocean is constantly moving from high tide to low tide, providing an approximately 12-hour window between high tides. This phenomenon poses a challenge for both the designer and the contractor to maximize productivity and efficiency while timing a work schedule between high tides.

Access to the repair locations on concrete marine structures can also be quite challenging. To be a successful bidder, contractors must be creative and come up with innovative methods to execute the repair work in a cost-efficient and timely manner. When there's no road access to the repair locations, boats and barges are required to transport materials and equipment from the shore (Fig. 1). The reduction or elimination of formwork associated with the shotcrete process results in reduced barge size and frequency of trips required. An accelerated construction schedule and reduced material handling costs are only two of the resulting benefits. The use of shotcrete may also eliminate the need for dive crews to set up formwork underwater, and then return later for removal.

For submerged concrete repairs on dam structures with little or no tidal effects, mobile cofferdam systems can be set up to provide a work area for the shotcrete crews (Fig. 2), as was done on the McCormick Dam in Sept-Iles, QC, Canada, in 2014 (as reported by Côté et al.[1]).

Fig. 1: Shotcrete material and equipment transported by barge

Fig. 2: Mobile cofferdam system on dam repair project

When the shotcrete process is chosen for the repair of dams and other marine structures, wet-mix shotcrete pumps, dry-mix shotcrete guns, compressors, and materials can be set up on land, and the material conveyed through small-diameter delivery hoses over long distances to the repair areas if required. This eliminates the need for cranes, concrete buckets, and other lifting equipment required for form-and-pour concrete applications, making shotcrete a much more efficient and sustainable repair solution.

DRY OR WET?

The decision of opting for a wet-mix process or dry-mix process shotcrete should be left up to the contractor. An experienced shotcrete contractor is able to gather the necessary information about the project and determine which process will be most suitable. The project specifications prepared by the design professional should be strictly performance-based and must include key properties such as strength and durability of the final in-place concrete. Once the material is in place, there is no difference between dry-mix and wet-mix, as both produce high-strength, low-permeability concrete when applied correctly.

When using the dry-mix process, shotcrete material (often supplied in a prepackaged form) is conveyed through the hose by a high-velocity air stream from a compressor, and water for hydration is added at the nozzle. The distance that the dry material can be conveyed is dependent on the volume of air from the compressor. Dry-mix shotcrete can be conveyed over 400 ft (121 m), allowing the nozzleman to access repair locations even when they are well away from the equipment and operator setup.

Dry-mix hoses are lighter weight than wet-mix hoses, making them easier to set up and manipulate when pumping material over long distances. When placing dry-mix shotcrete, the nozzleman has the ability to start and stop material flow without cleaning out the hoses. This provides flexibility on projects where repair patches are spaced far apart. Dry-mix shotcrete also allows the nozzleman to manually provide the required material consistency and to build thicker passes overhead without accelerator.

In the presence of tides, set accelerators are often required to prevent the fresh shotcrete from being washed away by rising tides and splashing waves. For dry-mix shotcrete, powdered set accelerator is typically added to the dry prepackaged material; however, it can also be added at the nozzle through a dosing pump.

Another advantage of dry-mix shotcrete is the ability to use ultra-rapid strength gain mixtures capable of reaching compressive strengths of 3000 psi (21 MPa) after 3 hours. This technology is practical for concrete structures exposed to vibration, or for structures that need to be put rapidly back into service. Ultra-rapid strength gain mixtures are typically not compatible with wet-process shotcrete due to the limited working time once the powder comes in contact with water. Whether placing concrete using the dry-mix or wet-mix process, quality ready mix supply might not be available on marine structure repair projects in remote locations. In cases such as these, prepackaged shotcrete products are always preferred.

When using wet-mix shotcrete, freshly mixed concrete is pumped through a hose and air is added at the nozzle to increase velocity and maximize compaction. The benefits of wet-mix in terms of access are similar to those of the dry-mix system because material can be pumped over long distances to hard-to-access repair areas. Pumping distance is dependent on the size of concrete pump, the size and type of delivery line, as well as the shotcrete mixture design. To pump over long distances, the mixture design must be optimized with high-range water-reducing admixtures (HRWRAs) to increase the slump without increasing the water-cementitious materials ratio (*w/cm*). When using set accelerators in wet-mix shotcrete, they must be added at the nozzle with a properly calibrated dosage pump. Under-dosage of accelerator will result in slower set times. Over-dosage of accelerator will reduce the quality of in-place shotcrete and can result in lower strengths. The wet-mix process allows for concrete volumetric placement at a rate approximately three to four times faster than dry-mix. This faster production rate favors wet-mix shotcrete for high-volume applications most of the time, such as new construction and large-scale repair projects.

ENVIRONMENT

When shotcreting on or near waterways, it's critical to consider the effect on the nearby environment and take necessary measures to reduce water contamination and protect marine life. Owners or government code requirements will often impose strict measures requiring use of enclosed work sections, protective barriers, and floating booms (Fig. 3) to prevent rebound and dust from entering the water.

Fig. 3: Protective barrier and floating boom

SPECIFICATION

Concrete marine structures are subjected to harsher environmental conditions than concrete structures on land. The correct shotcrete repair material must be specified to ensure a long lasting, durable repair solution. The in-place shotcrete material must be able to withstand the applicable exposure conditions such as freezing and thawing, wetting and drying, chloride intrusion from salt or brackish water, erosion, and abrasion impact from ice flows.

In structures located in climates that experience extensive freezing-and-thawing cycles, it is imperative that the shotcrete material contains properly dosed air-entraining admixtures creating a consistent, quality air-void system.

Concrete structures located in saltwater or exposed deicing salts must be able to resist chlorides that will penetrate into the concrete and attack the embedded reinforcing steel. To increase resistance to chloride penetration, the shotcrete material must have a lower permeability. Supplementary cementitious materials such as silica fume, fly ash, or slag are often used to lower the concrete's porosity by creating a denser binder matrix.

In climates with extended freezing weather, dams and bridge piers may be exposed to impact from ice flows. A common technique for preventing abrasion and impact damage caused by ice movement is to protect the concrete element with a steel plate. This method can be extremely costly and is often less effective than alternative methods available using the shotcrete process. Increased abrasion and impact resistance can be achieved by incorporating granite-based aggregates and steel fiber reinforcement with the shotcrete mixture design. The shotcrete material manufacturer should be able to provide data on impact and abrasion resistance as well as examples of successful projects that have been completed on structures with similar exposure conditions. For example, shotcrete has been proven to be an effective repair method for lighthouse foundations (Fig. 4), as reported by Gendreau et al.[2] and Giroux and Reny.[3]

When new shotcrete placement is exposed to tides, preventive measures must be taken to ensure the freshly placed shotcrete doesn't wash away before it sets. High-early-strength cement and set accelerators are commonly used for shotcrete repairs in tidal zones to speed up set times and reduce the potential for washout from the rising tides. Some dry-mix shotcrete material suppliers provide precise set times at various accelerator dosages, making it easy for the design professional to specify the required dosage for the project. Specifiers should also ask for examples of successful projects that have been completed in similar exposure conditions with the process, equipment, and material being proposed for a project.

Fig. 4: Lighthouse foundation repair with abrasion-resistant shotcrete

Some concrete marine structures must be rapidly returned to service. Others may be exposed at an early age to vibrations or abrasion from heavy water flow. Tunnel sluices in lock structures may require maintenance and may need to be put back into service rapidly to minimize closure of the seaway and allow boats to pass through. When traditional accelerated shotcrete cannot provide sufficient early strength to resist vibration or heavy water flow through the tunnel sluices, ultra-rapid-strength-gain shotcrete can provide an optimal solution. The ability to reach compressive strengths of 3000 psi (21 MPa) after 3 hours allows the structure to be put back into service quickly, resulting in a shorter construction schedule and a more rapid return to service.

CONCLUSIONS

The flexibility of the shotcrete process provides a practical, cost-effective competitive advantage for contractors that face the challenge of repairing dams and other water structures. It also provides owners and specifiers with a long-term, effective solution for repairing those same structures. The reduction or elimination of formwork and a dramatic reduction in the need for cranes and lifting equipment makes shotcrete a more versatile, cost-effective and sustainable repair solution with considerable advantages over concrete placed using traditional cast-in-place methods.

References

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