Top Ten Sustainability Benefits of Shotcrete

The United States Green Concrete Council's (USGCC) book, *The Sustainable Concrete Guide—Applications*, includes a list of the top 10 sustainability benefits of shotcrete in its chapter on shotcrete. Over the next 10 issues of *Shotcrete* magazine, this Sustainability column will elaborate on each one of the listed advantages. Previous discussion of advantages from past issues can be viewed on the ASA website at **www.shotcrete.org/sustainability**.

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1. Formwork savings of 50 to 100% over conventional cast-in-place construction.
2. Formwork does not have to be designed for internal pressures.
3. Complex shapes require very little—if any—formwork.
4. Crane and other equipment savings or elimination.
5. Labor savings of at least 50% in repair applications.
6. New construction speed savings of 33 to 50%.
7. Speed of repair reduces or eliminates downtime.
8. Better bonding to the substrate enhances durability.
9. Adaptability to repair surfaces that are not cost-effective with other processes.
10. **Ability to access restricted space and difficult-to-reach areas, including overhead and underground** (see below).

Ability to Access Restricted Space and Difficult-to-Reach Areas, Including Overhead and Underground

Accessing the site of a concrete pour can often be one of the biggest challenges faced by contractors. Good quality, pumpable concrete mixtures will help minimize the extent of the challenge. But, in the case of form-and-pump placement, forming crews will still be required to install forms and remove them after placement. The extent of the challenges can be magnified when accessing difficult-to-reach locations, such as an elevated bridge structure or a location deep underground in a mine or tunnel. These challenges can often be minimized when shotcrete is the placement method chosen.

The reduction or elimination of formwork minimizes movement of materials, a key benefit provided by the shotcrete process. In difficult-to-access locations, a shotcrete nozzleman can place concrete thousands of feet (1000 ft = 300 m) away from the material source, and is limited only by the amount of available air required to move the material for dry-mix applications and the pump selection in wet-mix applications.

When faced with the challenge of difficult access, it is important for specifiers to have a strong understanding of the capabilities and limitations of the shotcrete placement process. Understanding these capabilities and limitations will allow them to specify shotcrete for applications where conventional form-and-pump placement methods are difficult and costly to undertake.

Dry-Mix Shotcrete Process

When placing dry-mix shotcrete, the concrete mixture is pneumatically conveyed through a shotcrete hose or other conveying pipe until it reaches the nozzle, where the water required for hydration is added by the nozzleman. The benefits in terms of access are obvious. The distance that a dry concrete mixture can be conveyed is dependent on a number of factors—the most important being volume of air. A minimum of 185 ft^3/m (5.25 m^3/m) is usually required to convey a dry shotcrete mixture a distance of 100 ft (30 m), allowing the shotcrete nozzleman to access elevated locations such as a bridge deck or confined spaces such as a sewer pipe, while the remainder of the crew's material and equipment are staged at an easier-to-access location. If higher volumes of air (and longer hose lengths) are available, the distance over which the shotcrete can be conveyed can be much greater.

Wet-Mix Shotcrete Process

When placing wet-mix shotcrete, the concrete mixture (with water already added) is pumped through a hose and air is added at the nozzle to increase the speed of the mixture to achieve a high velocity. Benefits in terms of access are the same as those experienced when using dry-mix shotcrete. The distance that wet-mix shotcrete can be pumped is dependent on the capabilities of the concrete pump and, of course, the available length of the hose. One important difference between the two placement methods is the weight of the hose. In the dry-mix shotcrete process, much of the material composition (as it travels through the hose) consists of air. In the wet-mix shotcrete process, the material composition also contains admixtures and the water required for hydration. The result is a much heavier material hose that is more difficult to maneuver.

Access in Underground Environments

Difficult access is a common challenge when placing concrete in an underground environment. In mining environments, concrete placement is often required in locations that are extremely difficult to reach (refer to Fig. 1). One example would be ore bins that often require concrete lining; or shafts and raises that require stabilization. A nozzleman can usually access a raise (often from a working platform) hundreds of feet (100 ft = 30 m) above the access point where concrete can be placed using either the dry or wet shotcrete process. Both processes have challenges that are common to many underground environments—the most common being communication between the nozzleman and the gun/pump operator.

It is imperative from a safety standpoint that communication between the nozzleman and the gun/pump operator always be maintained. A constant line of communication is critical to ensure that the material flow is cut off in the event of a plug or an injury. It should be noted, however, that in the case of underground environments, visible contact is not always possible and must be substituted with verbal communication, usually through the use of voice-activated headsets.

For an application in which dry-mix shotcrete material is conveyed vertically over significant distances, consideration should also be given to the available water pressure. Although the volume of air may be sufficient to convey the material to a waiting nozzleman, the water pressure must also be sufficient to ensure the mixing water also reaches the nozzle. This can be of particular concern in a confined space where lack of water at the nozzle would result in dry, cementitious material filling the space. This provides another example of the importance of communication between the nozzleman and the gun operator.

When shotcrete equipment is located above the placement site and the shotcrete material is conveyed down hundreds of feet (100 ft = 30 m) into a raise or ore bin, the increased velocity of the material can often lead to inconsistent material flow and hose blockages. Depending on the process (wet or dry), there are a number of steps that can be taken to minimize the effect of gravity on the material conveyed down to the point of placement. First, the hose can be "looped" to decrease the velocity of the material prior to it exiting the nozzle and to help balance the speed of the material. This is especially true in the dry-mix process when combined with a decrease in conveyance air, as required.

Although the effect of gravity must be monitored closely in the dry-mix process, the wet-mix process is more susceptible to hose blockages and nozzle pulsation due to the force of gravity on the material within the pipeline. As the conveying hose or pipe is filled, segregation can occur as the material enters free-fall, and a plug can arise before shooting begins. The use of a sponge ball or "Go Devil" can eliminate plugs caused by segregation, as this ball restricts material flow and forces the concrete pump to naturally convey material through the line. As with the dry-mix process, a "loop" in the hose or the addition of an elbow (configured similarly to a "P Trap" under a sink) can help to regulate material flow and allow the pump to convey material, instead of gravity conveying the material. For this reason, it is often easier to convey concrete up, rather than down, especially when the conveying distance is in excess of 100 ft (30 m).

Access in Elevated Environments

The rehabilitation of elevated bridge structures is a common example of an application where the shotcrete process can minimize the problems related to access (refer to Fig. 2). Once deteriorated concrete is removed, it must be replaced to ensure structural integrity. On elevated structures, especially over water, railways, or heavy traffic areas, it can be extremely challenging to access the areas where concrete placement is required (refer to Fig. 3). In a form-and-pump application, forms and form hardware must be lifted into place and removed several days later, after the concrete reaches sufficient strength. This can be an arduous task,

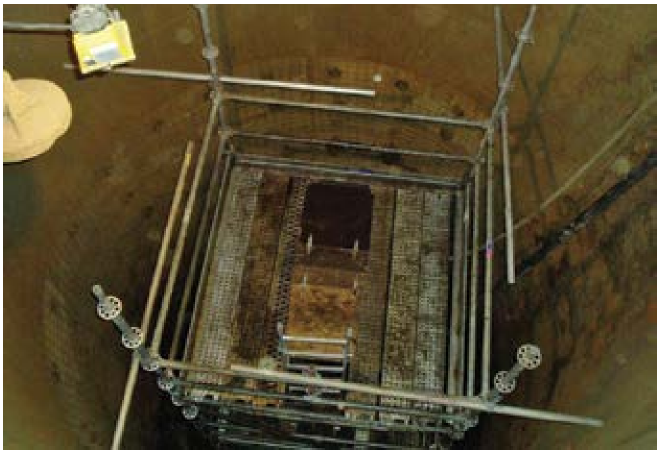

Fig. 1: In mining environments, concrete placement is often required in locations that are extremely difficult to reach, such as ore bins

especially when several patches throughout the structure require repair. Through the use of the shotcrete process, a nozzleman and finisher can shoot, cut, finish, and cure several patches in succession, without having to return to the same location on the structure. This results in lower labor costs and a reduced construction schedule. The shotcrete process also allows the contractor to stage materials and equipment from one central location, accessing several repair areas from that location, thereby minimizing movement, planning, and time necessary to shift operations.

Access in Remote or Isolated Environments

Concrete placement challenges can also come from projects where access to the project itself is the biggest challenge. Repairs to an isolated lighthouse and construction of a remote dam are two examples. For these types of projects, a lack of proximity to a batch plant, cement supply, and aggregate source generally makes pre-blended, pre-bagged materials the best choice for material supply. As with other projects where access is a challenge, the less formwork required, the more efficient the concrete placement process will be. When the Haut-fond Prince Lighthouse rehabilitation was tendered in 1996, shotcrete was specified as the placement method and a highly accelerated, durable, steel-fiber shotcrete mixture, supplied in lined marine tote bags, was specified for the material supply (refer to Fig. 4). The site was located in the middle of the St. Lawrence River, 5 miles (8 km) from the coast of Tadoussac, QC, Canada, and was only accessible by barge and only when the weather was cooperative. Shotcrete nozzlemen worked from an inflatable zodiac, with all material, equipment, potable water, and other personnel located on the main barge. The shotcrete was placed ahead of the rising tides through a 490 ft (149 m) long hose that ran from the barge to the zodiac. The shotcrete process allowed easier access to the site and eliminated any need for forms. It played a significant role in the successful completion of this project.

Access in Challenging Terrains

Whether selecting a wet or dry shotcrete process, it is much easier for a nozzleman to reach a difficult-to-access placement site while the crew, material, and equipment are stationed in an accessible location. Difficult access, however, can mean different things to different people. The location of a backyard swimming pool, for example, can be considered a difficult-to-access location for the pumps and other materials supply equipment. Other examples of difficult access can be much more extreme and include projects that require skilled nozzlemen who are also skilled rock climbers.

An example of the latter occurred in 2003, when New Jersey Transit was faced with the challenge of stabilizing the rock

Fig. 2: The rehabilitation of elevated bridge structures is a common example of an application where the shotcrete process can minimize the problems related to access

Fig. 3: On elevated structures, forms and form hardware must be lifted into place and removed several days later

face of the King's Bluff Slope and Weehawken Tunnel East Portal along the Hudson-Bergen Light Rail Transit Line (refer to Fig. 5). Shotcrete crews from Atlantic Underground Services Ltd. (AUSL) of Riverview, NB, Canada, were contracted to place up to 4 in. (101 mm) of steel fiber-reinforced, dry-mix shotcrete over a rock face situated up to 200 ft (61 m) above the rail line. In addition to being skilled in the art of dry-mix shotcrete placement, the AUSL nozzlemen had also mastered the skill of rappelling down rock faces (refer to Fig. 6). This skill allowed the AUSL nozzlemen to place over 236 yd^3 (181 m^3) of material over a period of several weeks, while the remainder of the crew handled the material delivery and equipment operation at the base of the bluff.

Accessibility is a key factor when choosing which concrete placement method is best suited for a specific application. On projects where access is difficult, the traditional form-and-pour school of thought will often leave contractors with challenges that are difficult and costly to overcome. The benefits offered by shotcrete will provide specifiers with an effective alternative that is less labor-intensive, more sustainable, and less costly.

Fig. 4: Shotcrete was specified as the concrete placement method for the rehabilitation of the Haut-fond Prince Lighthouse in the St. Lawrence River

Fig. 5: New Jersey Transit was faced with the challenge of stabilizing the rock face of the King's Bluff Slope

Fig. 6: In addition to being skilled in the art of dry-mix shotcrete placement, the AUSL nozzlemen had also mastered the skill of rappelling down rock faces