

Shotcrete Supply: Dry or Wet?

A Shotcrete Supplier's Perspective

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Often, various clients request our firm's advice regarding the supply and application of shotcrete—be they owners, engineers, contractors, or private individuals. Just as shotcrete has evolved since its conception in the early 1900s, today the answer as to whether to use dry- or wet-mix shotcrete is at times simple yet sometimes complex. We thus refer this question to the “5 Ws” that help us determine a suitable choice of materials, mixture design, process, and often the construction method.

The “5 Ws” are:

- **What:** Relates to the type and scope of work.
- **Why:** Is shotcrete the correct and most cost-effective and sensible solution? If it isn't, what are the alternatives or how can we adapt or modify conditions to make shotcrete a viable solution?
- **Where:** Relates to location, accessibility, material availability, and environment.
- **When:** Relates to climatic and temperature concerns. Is shotcrete application done during the day or night? Are there shutdowns? What is the time of the year when the work must be done? What are the service conditions and how soon must the structure be put back into service?
- **Who:** Does the contractor have the experience and adequately qualified nozzle men, crews, and finishers to perform quality work? Does the contractor have the right equipment available?

The answers to all these questions will help in the selection of the most appropriate materials, mixture design(s), supply, and application methods.

What?

The type and scope of work and quantities of shotcrete required must be determined in order to properly evaluate the method and the factors that will influence the cost of the shotcrete application. The applications may vary from structural repairs of transportation structures, dams, marine structures, hydraulic or road or rail tunnels, seismic retrofits, landscapes, architectural and recreational buildings to new construction. Each application has its own specific requirements and limitations.

The quantity of shotcrete required is often the

most important factor in the selection of dry- or wet-mix shotcrete. Although shotcrete started initially as a dry-mix process in the early 1900s, the development of efficient small-line concrete pumps for wet-mix shotcrete has enhanced the production placement rates of shotcrete, and so the tendency today is to increasingly use wet-mix shotcrete on the majority of projects. The introduction of the shotcrete-placing boom has greatly improved production on large-volume applications and has doubled or tripled production on many mining and tunneling projects. The dry-mix shotcrete process, however, is still a well-known and proven procedure that is readily available and can be used economically for specific applications where logistics and accessibility are major concerns. Figures 1 to 3 illustrate dry-mix shotcrete applications where access and material availability were prime concerns.

In Quebec, the DOT (Transports Québec) and the city of Montréal have both developed a specification for both dry- and wet-mix shotcrete and let the contractor select which process is the most cost-effective for the proposed work to be performed. By contrast, Hydro-Québec specifies that a wet-mix shotcrete shall be used on its projects.



Fig. 1: Dry-mix prebagged shotcrete applied from marine installation for pier repairs on Champlain Bridge, Montréal, QC



Fig. 2: Dry-mix prebagged shotcrete used with predampener for repairs to Hydro-Québec Dam in Fort Coulonges, QC

Table 1

	Dry mix	Wet mix
Minimum compressive strength at 28 days	5075 psi (35 MPa)	5075 psi (35 MPa)
Cement content (blended)	760 lb/yd ³ * (450 kg/m ³)	690 lb/yd ³ * (410 kg/m ³)
Cement content (high early)	782 lb/yd ³ † (460 kg/m ³)	—
Water-cement ratio	0.40	0.40
Coarse aggregate size	3/8 in. to No. 8 (10 to 2.5 mm)	3/8 in. to No. 8 (10 to 2.5 mm)
Coarse aggregate: % of total weight of coarse and fine aggregates	10	25
Slump	N/A	4 ± 1.5 in.‡ (100 ± 30 mm)
% air entrained	3.5 to 7	10 to 15‡
Polypropylene fibers	1.5 lb/yd ³ (0.9 kg/m ³)	1.5 lb/yd ³ (0.9 kg/m ³)

* Hydraulic cement types permitted: CSA Type GUb-SF, GUb-S/SF, or GUb-F/SF.

† High early cement permitted in overhead applications only.

‡ Air entrainment and slump measured after addition of high-range water-reducing admixture at point of discharge from truck.

Typical specifications for the Quebec DOT for dry- and wet-mix shotcretes are shown in Table 1.

It is evident from Table 1 that the mixture design will vary between dry- and wet-mix shotcretes, and these variations will differ for different applications.

Why?

Again relating to the type and scope of work to be performed, it is necessary to use the most suitable material and method to be cost effective and compete with the alternative solutions. Often, shotcrete is presented as a viable alternative after preliminary field testing. Recent research on the durability of dry- or wet-mix shotcretes in different



Fig. 3: Dry-mix shotcrete supplied with concrete mobile mixer for pier repairs of bridge over Rivière-des-Prairies River, Montréal, QC

environments shows that both dry- and wet-mix shotcrete, when properly designed and applied, will withstand freezing-and-thawing cycles in cold climates. Site conditions will often dictate whether the use of dry- or wet-mix shotcrete is the most viable solution.

On a recently completed project for the rehabilitation of the roof of the NDG Tunnel on Autoroute 15 in Montréal, QC, a field trial was done using shotcrete and self-consolidating concrete (SCC) to ascertain which material would be most suitable to rehabilitate 107,600 ft² (10,000 m²) of the tunnel ceiling. The main difficulty was to properly encapsulate closely spaced No. 11 and No. 18 (35M and 60M) reinforcing bar located in each direction. Field trials performed with shotcrete showed that there was a large amount of shadowing and voids behind the large-diameter reinforcing bars whereas the SCC was able to properly encapsulate the closely spaced reinforcing steel. In this case, for structural considerations, the project was completed with SCC concrete. On the same Autoroute, however, 3.75 mi (6 km) of retaining walls were repaired at night over a 2-year period using dry-mix shotcrete with volumetric mixers and dry-mix prebagged material.

Each project has its limitations and must be evaluated on a case-by-case basis.

Where?

The geographic location and the environment have a great influence on the choice of shotcrete materials and placing methods. Among the factors

that influence the choice of dry- or wet-mix shotcrete are the availability of suitable materials in the vicinity of the project and climatic conditions. Rising fuel and transportation costs are becoming more critical in the material selection process, as they impact directly on the cost of a project made with imported, as opposed to locally available, materials. On-site batching with volumetric mixers using suitable local aggregates can offer a cost-effective alternative to prebagged materials, as a typical shotcrete mixture contains approximately 80% aggregates.

However, for remote sites such as hydroelectric sites, mines, or offshore marine projects, readily available suitable materials are often not available and material is supplied in prebagged “super sacks” and then either used as dry-mix shotcrete or mixed in volumetric or concrete trucks and applied as wet-mix shotcrete. The choice of dry- or wet-mix shotcrete in these remote projects is most often governed by scheduling so as to meet specific conditions such as the excavation cycle, ground support conditions, temporary or final lining in tunnels, access, and closure of roads, railways, runways, and tidal considerations. Material availability, project accessibility, and environment considerations are the most important factors to consider in determining whether to use dry- or wet-mix shotcrete on the project.

When?

This item covers a multitude of items that can influence the choice of shotcrete materials and process. The first consideration that must be dealt with is weather, as this severely affects the shotcrete quality and placing requirements. Cold weather can cause slower setting times and, hence, more rebound in overhead applications, while hot and dry weather will increase the potential for cracking and curling and require additional curing precautions.

Often, shotcrete work is carried during plant or road shutdowns. Consideration must be given to quantities to be used, mobilization and demobilization time, the time for opening of a facility or a structure to traffic, or availability when working with a tide. Sometimes both dry- and wet-mix shotcrete are used on the same project. For example, while excavating a tunnel in a soft shale rock formation for an effluent outfall in the St. Lawrence River, a Canadian contractor used prebagged dry-mix shotcrete after every blast prior to installing rockbolts to seal the shale from air slacking. Subsequently, once the tunnel excavation was completed, he used wet-mix shotcrete with a placing arm to provide a final lining for the tunnel. The wet-mix shotcrete for this 3000 ft (915 m) long tunnel was supplied with a volumetric mixer at the surface that was stationary over a drop



Fig. 4: Stationary concrete mobile mixer supplying wet-mix shotcrete for effluent outfall tunnel, Bécancour, QC



Fig. 5: Concrete mobile mixer supplying shotcrete for two pumps for access ramps on Grondines Tunnel under St. Lawrence River, Lotbinière, QC



Fig. 6: Shotcrete equipment platform with air-operated pump, mixing auger, and prebagged shotcrete for Grondines Tunnel under St. Lawrence River, Lotbinière, QC

hole, as shown in Fig. 4. The shotcrete was transported to the work area in a revolving drum mixer mounted on a front end loader. Wet-mix shotcrete was used, as the contractor was able to place up to 65 yd³ (50 m³) in a 10-hour shift for the final lining, while less than 2.6 yd³ (2 m³) of dry-mix shotcrete per day were required to be placed during the excavation cycle on a 24-hour continuous operation. On this project, the availability of small quantities of dry-mix shotcrete for the initial ground support on a 24-hour basis was critical in maintaining a safe and efficient tunneling operation. Ventilation and very limited access in this narrow tunnel were prime considerations in the selection of the shotcrete process to be used. This also is the case in mines where the shotcrete is often brought underground in dry-mix sacks and is then mixed underground and applied by either the dry- or wet-mix shotcrete processes, depending on specific needs.

In a recent development in the Agnico Eagle Laronde Gold Mine in northern Québec, SCC had been dropped from the surface down a drop pipe to transport the material underground to the work area. An accelerator was added at the nozzle to ensure adequate build-up and cohesion of the shotcrete. Until 2003, shotcrete was applied in this mine by the dry-mix method. However, as is common in mining operations, the transportation of the dry material from the surface to underground uses up valuable elevator time, and the production speed, rebound, and dust can be major drawbacks in using the dry-mix method in underground mines. This is yet another example of the ongoing changes and evolution of shotcrete technology.

Another example where a combination of dry-

and wet-mix shotcrete processes were used was in the construction of the Grondines tunnel under the St. Lawrence River for transmission of high-voltage 735 KV power lines from James Bay to U.S. markets. The access ramps were excavated in a soft shale rock formation and were shotcreted using wet-mix shotcrete supplied when required with a volumetric mixer, as shown in Fig. 5. The shotcrete was applied with a robotic arm. Up to 78 yd³ (60 m³) were placed in a 10-hour shift and the wet-mix shotcrete process was selected for rapidity and cost considerations. The tunnel was excavated with a tunnel-boring machine (TBM) and the contractor had to install 2 in. (50 mm) of shotcrete in the tunnel vault for safety and geological considerations while excavating and within 300 ft (90 m) of the face of the TBM. This operation could only be done for 5 hours during the middle of the shift while the TBM was in operation and could not interfere with the excavation cycle and the supply of materials and services to the TBM. In this case, shotcrete was supplied in 66 lb (30 kg) bags and was converted to a wet-mix by passing it through a mixing auger. It was pumped with a converted air-driven pump, as it was necessary to reduce diesel fumes in the tunnel and compressed air was readily available in the tunnel. Figure 6 illustrates the shotcrete equipment platform used behind the TBM. A liquid accelerator was used to ensure high early strengths and minimize rebound as the tunnel had to be cleaned out prior to placing a cast-in-place lining. The shotcreting operation was able to keep up with the TBM operation. Wet-mix accelerated shotcrete was used successfully to consolidate fractured rock in fault zones ahead of the TBM under the

St. Lawrence River when bad ground conditions were encountered.

Who?

For a client, engineer, or contractor to specify shotcrete, it is imperative that they verify that the shotcrete supplier can supply materials that meet the specifications. The specifications must be clear, concise, and definitive to remove ambiguity and enable the project to be estimated properly. Competent and knowledgeable QC/QA personnel must be available and a suitable QC testing program must be provided to assure the owner that the materials supplied and placed meet specifications. The shotcrete contractor must have certified nozzle men and competent shotcrete teams to apply material by the selected process.

The key to a successful shotcrete application is teamwork and cooperation of all parties involved.

The contractor must have the personnel, equipment, and know-how to place dry- or wet-mix shotcrete in a competent fashion and supply a quality product. Collaboration of all parties is essential for a successful project. An engineer or contractor should not hesitate to consult with shotcrete supply companies and personnel when considering a shotcrete solution.

Conclusions

Dry- or wet-mix shotcrete? It is evident that the selection of dry- or wet-mix shotcrete is dictated by a combination of different criteria. Answers to the 5 Ws will help lead to the most economical solution when using shotcrete. Each project must be considered on its own merit as each application is different. The question may be simple but often the answer may be complex, as it should take into consideration answers to all the 5 Ws. Each project must thus be evaluated on a project-by-project basis.

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