

Considerations for Underground Training

By William T. Drakeley Jr.

The growing demand for increasingly complex and adaptable urban infrastructure has caused developers to turn an eye to shotcrete as the most economically viable, technically flexible, and structurally sound construction method.

Shotcrete—or sprayed concrete—is the natural option for the underground tunnel or mining environment. It intrinsically allows for the stabilization of existing structures and accommodates tight construction schedules through quick application without the need for forming. Furthermore, shotcrete can be applied to variable-grade substrates such as ore, existing rock, or ledge without requiring extensive demolition because as a material, it binds quickly and bears its own weight.

Shotcrete has increased in popularity as the preferred method of stabilizing blasted rock and covering exposed earth in underground construction. Because tunnel construction is a multi-phase process wherein excavation may take place in stages depending on the load-bearing capacities and stability of the substrate, shotcrete ideally allows for flexibility in the concrete application without compromising strength.

Relative ease of application notwithstanding, underground shotcrete requires a precise set of skills that are responsive to the underground setting. Incorrectly placed materials can lead to disaster, especially in high-risk environments such as tunnels or mines.

For those familiar with the aboveground shotcrete process, shotcrete in the underground environment will sound virtually the same. For instance, following production of the shotcrete material, the material is transported to the site and conveyed to the equipment. The material is then sprayed at high velocity onto the receiving surface. Given the force of compaction and the immediate commencement of the hydration process, material may also be placed vertically and overhead. The shooting direction should be at a right angle to the receiving surface, whether placed manually or robotically.

However, in the tunnel environment, it is the substrate—the existing rock or ground conditions—that should be viewed as the primary construction material. Shotcrete is a key support component. Crews must have the ability to perceive the reinforcement needs of individual sections of

rock, following joints and fractures in the substrate and placing the material accordingly.

Key ingredients that are a must for any applicator, subcontractor, or company in the underground shotcrete world include complete familiarity with the following:

1. Underground excavation;
2. Geologic conditions of ground or rock formations;
3. All aspects of the shotcrete process as it relates to underground support systems; and
4. Installation techniques, geologic reinforcement, and all alignment controls (such as rock bolts, lattice girders, welded wire, ground wire, pencil rods, and mining straps).

With many tunnels or underground infrastructure projects, determining the weight-bearing properties and stability of the rock or ground will determine shotcrete techniques (Fig. 1). Shotcrete installation comprises a key support component to the substrate, following the process of identification. A typical shotcrete crew needs to understand this basic premise. Shotcrete applicators need to know how a site is excavated, what the different phases of tunnel rock removal are, and at what time drift wall support is needed.

Jürg Schlumpf and Jürgen Höfler, in their handbook *Shotcrete in Tunnel Construction*,¹ identify six factors that are of prime importance to the mixture requirements for both dry- and wet-mix shotcrete processes relating to the workability and durability of the mixture: high early strength, the correct set concrete characteristics, user-friendly workability (long open times), good pumpability (dense flow delivery), good sprayability (pliability), and minimum rebound.

Regarding placement, crews must be able to identify the factors that will determine the amount of material that can be placed in a single sitting. These include the adhesive strength of the concrete, the characteristics of the receiving surface, and the direction of placement. For instance, when shooting a ground or floor surface, the depth of placed material can be as thick as desired, as long as rebound and overspray are removed. When shooting walls, it is preferable to build thickness through a number of thinner applications or through the systematic layering of

the full thickness from the lower elevation to the higher elevation (benching), while still removing rebound. By contrast, when shooting overhead, thinner applications are preferable to allow for less rebound and maximum adhesion and reducing the potential for dropouts. Alignment control is another key factor in producing a precise application. Devices to establish line and grade include ground wires (piano wire), pencil rods for curved profiles, lattice girders, depth gauges, rock bolt extensions, and guide strips/formwork.

Qualification to shoot in an underground environment is based on both individual and group crew training for underground environment. Not every crew will qualify for every job. For instance, ACI certification does not, by virtue of content covered, constitute qualification for underground shotcrete construction. To be considered competent in the underground environment, a nozzleman must be familiar with all the following: the process of underground excavation and underground support; the condition of ground/rock surfaces (that is, hard rock, frozen ground, soft ground conditions, and sacrificial layering); and the aspects of the shotcrete process as it relates to the ground support system.

Many shotcrete crews seeking to enter the underground shotcrete market adopt a “learn-on-the-job” mentality. Not only does this present significant safety concerns but it also can lead to longer project timelines, greater costs, and quality differentials between early-project shotcrete and late-project shotcrete. A proper training program will call out methods of advanced placement. Make no mistake, shooting in the underground environment constitutes advanced shotcrete placement. Each job should have its own training and qualification program specifically designed for its substrate characteristics. This type of pinpoint training with regard to quality control and quality assurance allows the owner and/or general contractor to be confident in the applicator, and more generally, in the shotcrete process. Many of us would be surprised to find out that most underground shotcrete applicators and those trying to enter that market have little experience with the actual environment or can successfully identify advancement protocol in a simple crown, bench, or base of a tunnel cross section (Fig. 2).

The underground environment is vast and greatly varied. For this reason, current ACI nozzleman certification does not make one automatically capable of properly executing a complex job. The ACI certification covers the basic facets of shotcrete production and application, and is not intended to fully encompass the complex aspects of most underground or heavy structural work. Our

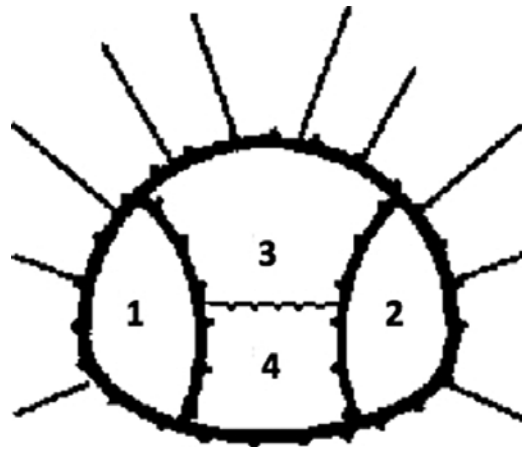


Fig. 1: Drift wall advance: Preceding drift walls (1 and 2), followed by excavation of the crown (3) then the bench and invert (4), including safe support in each case!

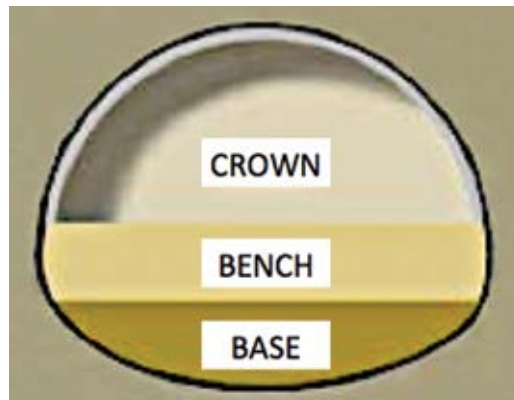


Fig. 2: Methods of advance!



Fig. 3: Preliminary training and shotcrete scope review with team members

current nozzleman training is limited and is not designed as “one size fits all.” Many specifiers, engineers, and even shotcrete contractors are confused on this point. The New Austrian Tunneling Method (NATM) currently states that training programs should be developed specific to job parameters. Appropriate application methods, as identified in a quality control and quality assurance submission, would include nozzleman qualification pre-mockup testing and specific pumping and shooting techniques needed to place material on and around blasted rock, unstable soils, lattice girder, or ring steel. These components can be adapted and qualified prior to actual job commencement.

In addition to job-tailored training, crews should be supported by around-the-clock trainers and quality monitors—at least in the early phases of the job—to help crews to make the transition from an aboveground shotcrete skill set (and mind set) to an underground one. The ultimate quality of the project—and the safety of all those involved—depends on it (Fig. 3).

References

1. Schlumpf, J., and Höfler, J., *Shotcrete in Tunnel Construction: Introduction to the Basic Technology of Sprayed Concrete*, Putzmeister AG, Aichtal, Germany, 2004, 70 pp.



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