Relieving Water Pressure on Shotcrete Lining by Integrating a Drainage Mesh

By Johnny Poulsen & Sergii Tabachnikov

Since the first shotcreting patent issued in the United States in 1911 to Carl E. Akeley, the technique and equipment have undergone substantial advancements, leading to its widespread adoption in construction practices around the world. Nowadays it is a well-proven technique for applying one or more layers of concrete onto a prepared surface, which enables use of conventional reinforcement or metallic and non-metallic fibers as structural reinforcement components.

Even with all the technical and efficiency advantages of shotcreting, a major challenge remains in constructing underground and soil retaining structures: The presence of free and capillary water in fissures of rock formations and the non-rocky soil base, which impacts the structure during construction and maintenance. Water pressure on tunnel structures, whether shotcreted or cast-in-place, is a leading design challenge that often requires creative solutions to mitigate water flow and potential damage.

WATER PRESSURE ISSUES

Water seeping through cracks in the rock can hinder the effective application of the initial layer.

The creation of voids in rock masses or saturated soil during tunnel construction can prevent the drainage of water, leading to increased hydrostatic pressure on portions of the tunnel lining. Hydrostatic pressure can force water through cracks or defects in concrete, causing dripping onto trains, vehicles, and tunnel components below (Fig. 1a). Dripping onto roads can pose a risk to traffic — especially with the formation of ice on the road or icicles falling from the ceiling (Fig. 1b) — and water saturating the concrete can create damage from frequent freeze/thaw cycles.

In the worst case, excessive water pressure, when combined with inadequate design or poor quality construction, can lead to the collapse of the underground structures during construction or operation (Fig. 2).

Repairs and maintenance of damaged tunnel structures are complicated, expensive, and carry socio-economic costs. Closing the tunnel, locating all areas of damage, and fully repairing the tunnel with today's solutions can take substantial time. The repair work may require multiple steps, including additional shotcrete layers, new anchors, and grout injection

Fig. 1: Some of examples of water pressure effects:
a) Leaking tunnel in waterproofing process (ABOVE);
b) Icicles causing damage to a concrete structure (BELOW)
(photo: Washington State Dept. of Transportation).

Fig. 2: Collapsed tunnel

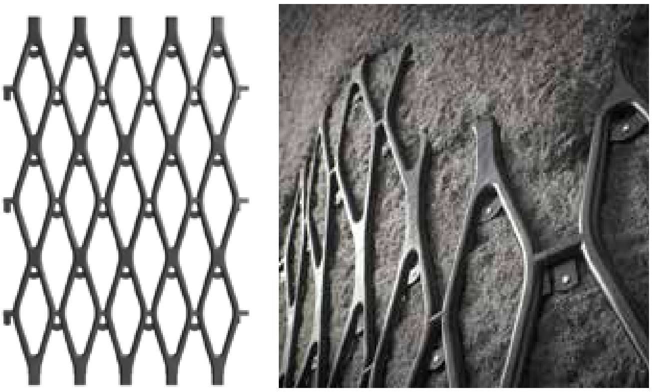

Fig. 3: View of Dolenco Drain network drainage module

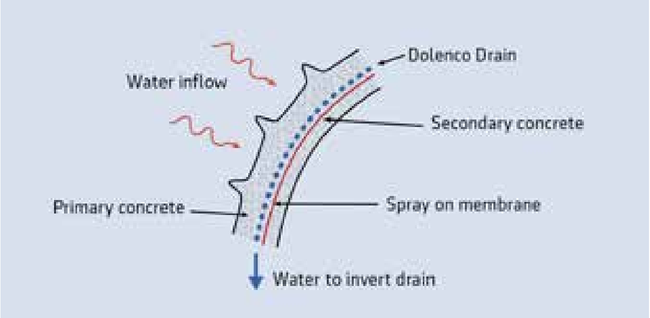

Fig. 4a: Application of Dolenco Drain: Basic approach of Dolenco Drain for preventing the build-up of water and resultant pressure in the concrete sections.

Fig. 4b: Application of Dolenco Drain: Cross section of shotcreted sample showing a network of channels that lead water away, alleviating pressure.

work under difficult working conditions. With planning and design efforts to systematically drain the external water pressure against the structure, repairs can be accomplished safely and within a much shorter time frame.

NEW APPLICABLE CONCEPT FOR MANAGING WATER IN UNDERGROUND CONSTRUCTION

One of the key technical conditions for applying shotcrete in underground retaining structures is the absence of water seepage at the receiving surface. If flowing water is likely to form at the receiving surface, measures must be taken to divert it away to allow for the planned shotcrete placement. Creating a drainage path is a method that can help provide drainage away from the receiving surface.

Because a tunnel lining, as with most underground structures, is often exposed to ground water pressure and requires some form of ground water management, an integrated drain mesh solution (IDMS) behind the tunnel lining of a shotcrete layer or sprayed membrane can safely and efficiently reduce water buildup.

Dolenco Drain (Fig. 3) is a patented network drainage module for tunnels that prevents the accumulation of water and the resulting hydrostatic pressure behind structural tunnel walls. It measures 32 x 48 x 0.6 in. (800 x 1200 x 14 mm) and can drain 2100 gal (8000 l) of water per 3 ft (0.9 m) of wall width per hour. The modules are made from low-density or high-density polyethylene (LDPE/HDPE), which are 100% recyclable and CO_2-neutral. The system also has additional benefits including easy installation, a long design life, and lower maintenance. The life expectancy of the system in normal conditions is estimated at up to 120 years. Dolenco Drain is currently made with 100% recyclable material and we are working on further improvements with a focus on saving the earth's resources. Not only in product development, but also in supporting the reduced need for construction materials and construction time, via design optimization and maintenance/ repair reduction.

The network drain module is embedded in concrete, so the lining remains monolithic, creating a thinner concrete section with a network of embedded drain channels (Figs. 4a, 4b).

The installed modules connect and overlap one another with a simple anchoring system nailed to the surface (Fig. 5) to fully cover all surfaces. Then, an initial layer of shotcrete protects it before another layer of reinforced shotcrete is applied for structural integrity. The final structural thickness may be fiber or conventionally reinforced.


Fig. 5: Installing Dolenco Drain to tunnel crown and next covering with another layer of shotcrete.

As installation does not need drilled anchors, it reduces the initial and life cycle cost (LCC), extends the life span, and in the event of physical damage, allows quick and safe repair with minimal downtime in the tunnel. This solution can also reduce fire damage potential giving water vapor a channel to exit rather than spalling the concrete.

CURRENT CONSTRUCTION METHODS, THEIR CHALLENGES, AND THE TECHNICAL AND ECONOMICAL ADVANTAGES OF AN IDMS

To manage water in tunnels, the solutions available today are complicated, costly, time-consuming, and can cause significant disturbances to traffic. We can clearly use additional options.

Let's review some of today's solutions with their respective challenges. Several key technical solutions to the challenges related to accommodations for water and the required drainage can be identified. Then we will explore how these solutions might be optimized by combining them with an IDMS.

The appropriate design method for temporary or permanent shotcrete linings depends on the structural role the shotcrete is fulfilling. Table 1 summarizes common construction methods and how implementation of an IDMS is applicable. The design thicknesses of shotcrete are impacted not only by external water pressure, but also by soil or rock loads, overburden, or other external loadings. The values in Table 1 are provided as a comparison, but design thicknesses must be determined by the design engineer with the site-specific loadings and requirements.

Whether for new projects or the repair and renovation

Construction methods	Application area	Challenges	Constructing with IDMS	Technical and economical advantages of IDMS
Solution 1a - Shotcrete only It is a widely used technique in tunnel construction for stabilizing and reinforcing the exposed soil or rock surface after excavation.	**Tunnels:** • Blasting • Boring • Digging **Construction approach:** • Pre-injection grout; • Stabilizing shotcrete layer ≈1 in. (25 mm); • Final shotcrete layer ≈3 to 4 in. (75 to 100 mm).	• Higher risk of water pressure damaging the structure; • Water pressure can build up over time; • Absence of possibility of water pressure reducing.	• Pre-injection grout; • Stabilizing shotcrete layer ≈1 in. (25 mm); • Application of IDMS • Covering IDMS with shotcrete up to ≈1 in. (25 mm); • Final shotcrete layer ≈3 to 4 in. (75 to 100 mm).	• Drains the water away from the structure without damage to the concrete; • Prevents water pressure buildup on the structure; • Reduces risk of medium to long-term deterioration, damage, and repair related to water pressure.
Solution 1b - Shotcrete with sprayed waterproofing membrane This technique involves a process of tunnel excavation and support, where shotcrete is applied in two stages along with the installation of a sprayed waterproofing membrane to prevent water ingress.	**Tunnels:** • Blasting • Boring • Digging **Construction approach:** • Pre-injection grout; • Stabilizing shotcrete layer ≈1 in. (25 mm); • Covering initial layer with a waterproofing membrane; • Final shotcrete layer ≈3 to 4 in. (75 to 100 mm).	• Waterproofing membrane doesn't ensure water pressure can't build up over time creating a higher risk of water pressure damaging the structure.	• Pre-injection grout; • Stabilizing shotcrete layer ≈1 in. (25 mm); • Application of IDMS • Covering IDMS with shotcrete up to ≈1 in. (25 mm); • Spraying waterproofing membrane; • Final shotcrete layer ≈3 to 4 in. (75 to 100 mm).	• Drains the water away from the structure without damaging the concrete; • Prevents water pressure buildup on the structure; • Reduces risk of medium to long-term deterioration, damage, and repair related to water pressure.
Solution 2 - Shotcrete with sheet waterproofing membrane This technique uses a similar approach to Solution 1b but with differences in the type of waterproofing membrane. A thicker layer of shotcrete is applied over the membrane. This final layer is usually reinforced for added structural integrity.	**Tunnels:** • Blasting • Boring • Digging **Construction approach:** • Pre-injection grouting; • Anchors installed • Stabilizing shotcrete layer ≈1 in. (25 mm); • Fastening waterproofing membrane sheets to initial layer surface with; • Final shotcrete layer ≈3 to 12 in. (75 to 300 mm).	• Sheet often made of flammable material that can cause spalling and scaling damage from fire; • Waterproofing membrane doesn't ensure water pressure can't build up over time making higher risk of water pressure damaging the structure.	• Pre-injection grout; • Stabilizing shotcrete layer ≈1 in. (25 mm); • Application of IDMS; • Covering IDMS with shotcrete up to ≈1 in. (25 mm); • Fastening to initial layer surface with waterproofing membrane sheets (if required to minimize the risk of damages to the structure); • Final shotcrete layer ≈3 to 4 in. (75 to 300 mm).	• Drains the water away from the structure without damage to the concrete; • Prevents water pressure build-up on the structure; • Reduces risk of medium to long-term deterioration, damage, and repair related to water pressure; • Possible reduction in the total volume of concrete due to a reduction in the thickness of the final layer and; • Construction time reduction.

Table 1: Construction methods and how implementation of an IDMS is applicable. Continued next page.

Construction methods	Application area	Challenges	Constructing with IDMS	Technical and economical advantages of IDMS
Solution 3 - Shotcrete only for temporary water protection This technique focuses on managing groundwater ingress that occurs unexpectedly during tunnel boring machine (TBM) operations. To manage this, shotcrete is used as an immediate solution to reduce water flow and create safer working conditions.	**Tunnels:** • With a tunnel boring machine (TBM). **Construction approach:** • Pre-injection grout; • Temporary stabilizing and water protection shotcrete layer ≈1 in. (25 mm).	• Water pressure can build up over time creating a higher risk of water pressure damaging the temporary shotcrete layer; • Challenging underground working conditions; • Difficult or impossible to manage the water seeping and flowing into the tunnel during construction.	• Pre-injection grout; • Nailing of IDMS directly onto the rock; • Covering IDMS and stabilizing shotcrete layer ≈1 in. (25 mm).	• Drains the water away from the rock; • Prevents water pressure build-up on the shotcrete layer; • Allows construction work to continue.
Solution 4 - Shotcrete for sealing the gaps between the secant piles Shotcrete is often used to seal gaps between the secant piles, adding an additional layer of water resistance. However, while shotcrete is functionally watertight, this technique doesn't allow for the dissipation of groundwater pressure behind the piles and shotcrete, which can lead to problems.	**Underground stations:** • Secant piling for shafts; • Retaining walls for stations. **Construction approach:** • Pre-injection grout; • Filling the surface and water protection shotcrete layer up to 12 in. (300 mm) in gap.	• Surface preparation on the piles may be poor; • Water pressure can build up over time making a higher risk of water pressure damaging the temporary shotcrete layer; • Challenging soil support working conditions; • Difficult or impossible to manage the water seeping and flowing into underground space during construction; • Requires some type of difficult, time-consuming, technically challenging and costly injection.	**Variant 1:** • Pre-injection grout; • Nailing of IDMS directly onto the piled wall; • Final shotcrete layer ≈2 to 3 in. (50 to 75 mm). **Variant 2:** • Pre-injection grout; • Leveling the surface shotcrete layer up to 12 in. (300 mm) in gap; • Nailing of IDMS; • Final shotcrete layer ≈2 to 3 in. (50 to 75 mm).	• Drains the water away from the pile wall; • Prevents water pressure build-up on the shotcrete layer; • Allows construction work to be continued.

Table 1 Continued: Construction methods and how implementation of an IDMS is applicable.

of existing structures, Dolenco Drain is an innovative and versatile IDMS solution specifically designed for drainage of water in underground construction. Its effectiveness stems from its adaptability to various construction methods, particularly in shotcrete placement for linings commonly used for stabilizing underground surfaces.

PROJECT EXAMPLES USING DOLENCO DRAIN

SOLUTION 1A

Built in 1968, the Tuscarora Mountain Tunnel is one of the key highway tunnels located on the Pennsylvania Turnpike in the United States. It is part of the infrastructure that allows vehicles to traverse through the Tuscarora Mountain, a part of the Appalachian Mountain Range, and is a significant engineering achievement due to the mountainous terrain it penetrates.

During refurbishment, water ingress challenged the repair method for a permanent, sustainable solution. Removing the outer layer of concrete and mounting Dolenco Drain before finishing with shotcrete made the repair possible and sustainable (Fig. 6a).

A similar solution was used to renovate a road tunnel in Switzerland. The problem was water seeping through the existing shotcrete layer. After removing a layer of shotcrete, a new layer of shotcrete was applied. The thin structure severely limited what could be done to address the leaking water, the solution was to mount Dolenco Drain onto the surface and

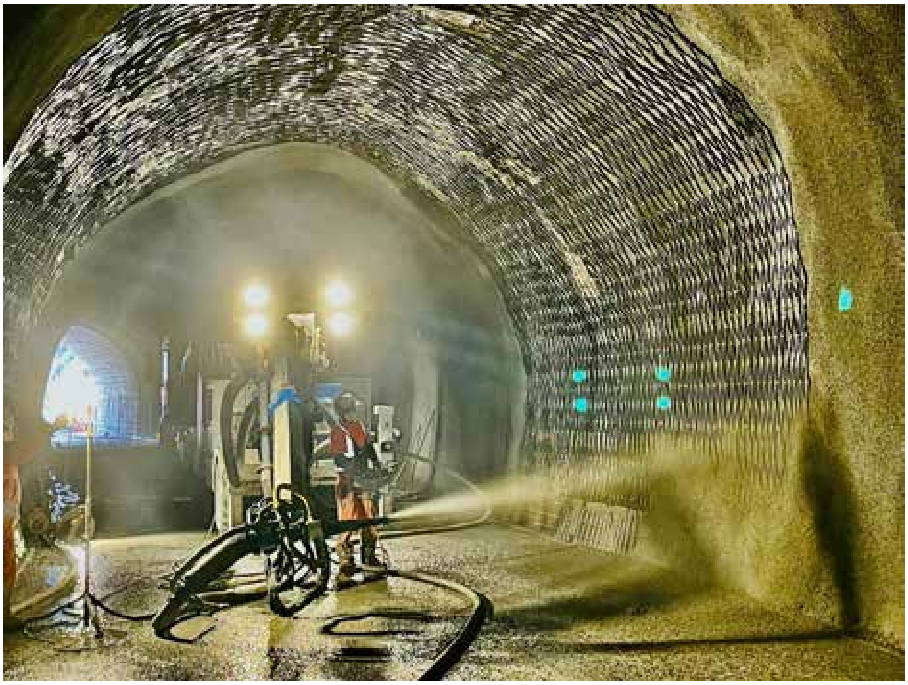

Fig. 6: Solution 1a application: a - LEFT) Dolenco Drain is covering the entire surface of the repaired area and secures permanently against water pressure (Tuscarora Mountain Tunnel); b - ABOVE) Renovating seeping road tunnel (La Tzoumaz, Switzerland)

cover with a thin layer of shotcrete (Fig. 6b). At the bottom of the wall, a detail for collecting the draining water was added.

SOLUTION 1B

The Réseau Express Métropolitain is an electric and fully-automated light-rail transit network designed to facilitate mobility across the Greater Montreal Region, Canada. It is the largest public transit project undertaken in Québec in the last 50 years. With an overall length of 42 miles (67 km) and 26 stations, it connects with the Montreal metro with initial excavation started in 2021. The original design with a spray membrane incountered problems with water ingress. Dolenco Drain was installed to control the water behind the shotcrete smoothening layer (Fig. 7a). This prevented water pressure buildup on the shotcrete and resultant leakage, thus facilitating the application of the spray-on membrane. The design required: 12 in. (300 mm) of shotcrete (for safety) placed directly onto rock, installation of the Dolenco Drain, then a 1 to 2 in. (25-50 mm) smoothening layer, sprayed membrane, and finally 5 in. (125 mm) of reinforced shotcrete on each umbrella section.

Also, depending on specific field conditions, project requirements, and designer decisions, it is possible to use Dolenco Drain in combination with sprayed membrane, as was the case during the Canfranc, Spain railway tunnel repair (Fig. 7b).

SOLUTION 3

Dolenco Drain was used at a project in Toronto, Canada, where the drainage system was installed directly onto the rock surface. Afterward, a steel wire reinforcement net was mounted, followed by the application of a stabilizing shotcrete layer (Fig. 8).

Fig. 7: Solution 1b application: a - ABOVE) Dolenco Drain was used to control the water by installing behind the shotcrete smoothening layer (Réseau Express Métropolitain); b - BELOW) Repair of railway tunnel (Canfranc, Spain).

Fig. 8 (LEFT): Allowing shotcrete placement with water inflow using Dolenco Drain directly on the rock surface, with anchored wire mesh. Toronto, Canada

Fig. 9: Dolenco Drain applied to secant pile wall: a - ABOVE) Basement. Copenhagen, Denmark; b - RIGHT) Underground Railway Station, Montreal, Canada

SOLUTION 4

A project in Copenhagen, Denmark (Fig. 9a) and the Réseau Express Métropolitain Railway Station 40 ft (12 m) underground (Fig. 9b) in Montreal, Canada, both used Solution 4.

Work on the station started in 2020. To address seeping water and water pressure behind the secant pile walls of the station and ramp, the design included Dolenco Drain between the secant piles and the final shotcrete layer. To permanently prevent pressure on the shotcrete and to ease the application of the spray membrane, Dolenco Drain was mounted behind the sprayed membrane.

TECHNICAL, ECONOMIC, AND ENVIRONMENTAL ADVANTAGES

Preventing or minimizing post-construction injections and repairs, Dolenco Drain is a quick, simple, safe, and permanent solution. It prevents pressure and leaking, keeping the tunnels dry. Once installed, the Dolenco Drain improves the tunnel durability with an estimated lifespan of 120 years.

Used for both new and existing structures, the thin and monolithic design of Dolenco Drain can be installed with little space required. The solution requires minimal downtime of the tunnel and is a quick and safe repair of concrete after physical damage.

Comparing a Dolenco Drain solution with conventional drainage systems is complicated, because it is not a direct substitute for the solutions available today. It is often used to complement existing solutions, because it improves the overall tunnel design. However, a comparison has shown significant reduction in repair and maintenance, which saves on time and cost. Using an IMDS to prevent water ingress facilitates surface preparation before applying the first layer of shotcrete and the membrane or second layer.

Summarizing the overall comparison for tunnels, the use of IMDS leads to savings in construction cost and time savings to the scheduled repair. With design changes recognizing control or elimination of external water pressure, reduced concrete thicknesses may be needed, resulting in a significant reduction in the carbon footprint of the tunnel construction.

If we consider cases where the installation of anchors is necessary (incurring possible problems with membrane damage during installation, subsequent expenditure of time and effort to eliminate the problems, subsequent maintenance of the finished structure, and care for the final layer of shotcrete), then the difference becomes even greater and the advantages more pronounced.

CONCLUSIONS

Finding a solution to alleviate water pressure and subsequent through section leakage is important. Today's solutions can be complicated, costly, and exhibit limited success in channeling water away from the exterior of the tunnel. Most common damage in tunnels includes water inflow, accumulation of water, and cracking and spalling of the surface. The solutions available today do not address all the challenges of removing water pushed into and through cracks in the concrete by the accumulated water pressure.

Dolenco Drain provides a solution that is tailored to the specific project. It is suitable for both new and existing structures, and the thin and monolithic design can be installed with little available space — even on wet and seeping structures. Once installed, Dolenco Drain improves the tunnel serviceability and durability. The solution requires minimal downtime when repairing tunnels and provides a quick and safe repair of a tunnel after physical damage.

Underground construction, especially a tunnel, is one of the most complex challenges in the field of civil engineering. Dolenco Drain is an innovative solution which addresses many of the difficulties with controlling or eliminating water pressure in an easy, safe, long-term, and cost-effective manner.

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Johnny Poulsen, *CEO, Dolenco Tunnel Systems. With over 25 years of experience of building markets for waterproofing and concrete repair solutions, he has started and managed businesses in distribution and subcontracting of a wide range of specialized solutions. During this time, Poulsen has accumulated knowhow and expertise on tunnels and underground structures on the international market. With his experience, he has been leading the development of new, innovative business solutions, to accommodate the changing needs in underground construction. He continues to develop and adapt in the increasingly changing conditions for construction.*

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