Bekaert

Dramix®

The future of reinforced low-carbon lining

West Connex M4-M5 Link Tunnels

Achieving safe, durable and low-carbon lining

Anyone involved in underground construction knows how many factors come into play when designing structures below ground; not to mention the many risks during its construction. Having many decades of experience in the most challenging lining projects in tunnels and mines, we not only have the in-depth expertise and know-how to ensure the safety of these projects, we also offer fiber concrete reinforcement solutions which guarantee a more durable and sustainable underground structure.

We have a wide portfolio of fiber concrete reinforcement solutions, and offer a high quality fiber for each kind of application, whether your project needs primary/final sprayed concrete linings, cast-in-place or precast segmental linings or temporary/permanently sprayed concrete. Used in numerous tunnels and mines around the world, Dramix® steel fibers have proven themselves as a key component in achieving safe, durable and low-carbon lining.

Grand Paris Metro Line 16-1

France

The Grand Paris Metro Line 16-1. 19.3 km (12 mi) of tunnels lined with precast segments reinforced with Dramix®. A significant amount of steel was saved because Dramix® steel fibers were used as the solution rather than steel bars. Comparing the two, 40 kg/m³ of steel fibers has been used whereas a traditional reinforcement solution would result in 85 km/m³. That's more than 50% of steel saved.

West Connex

Australia

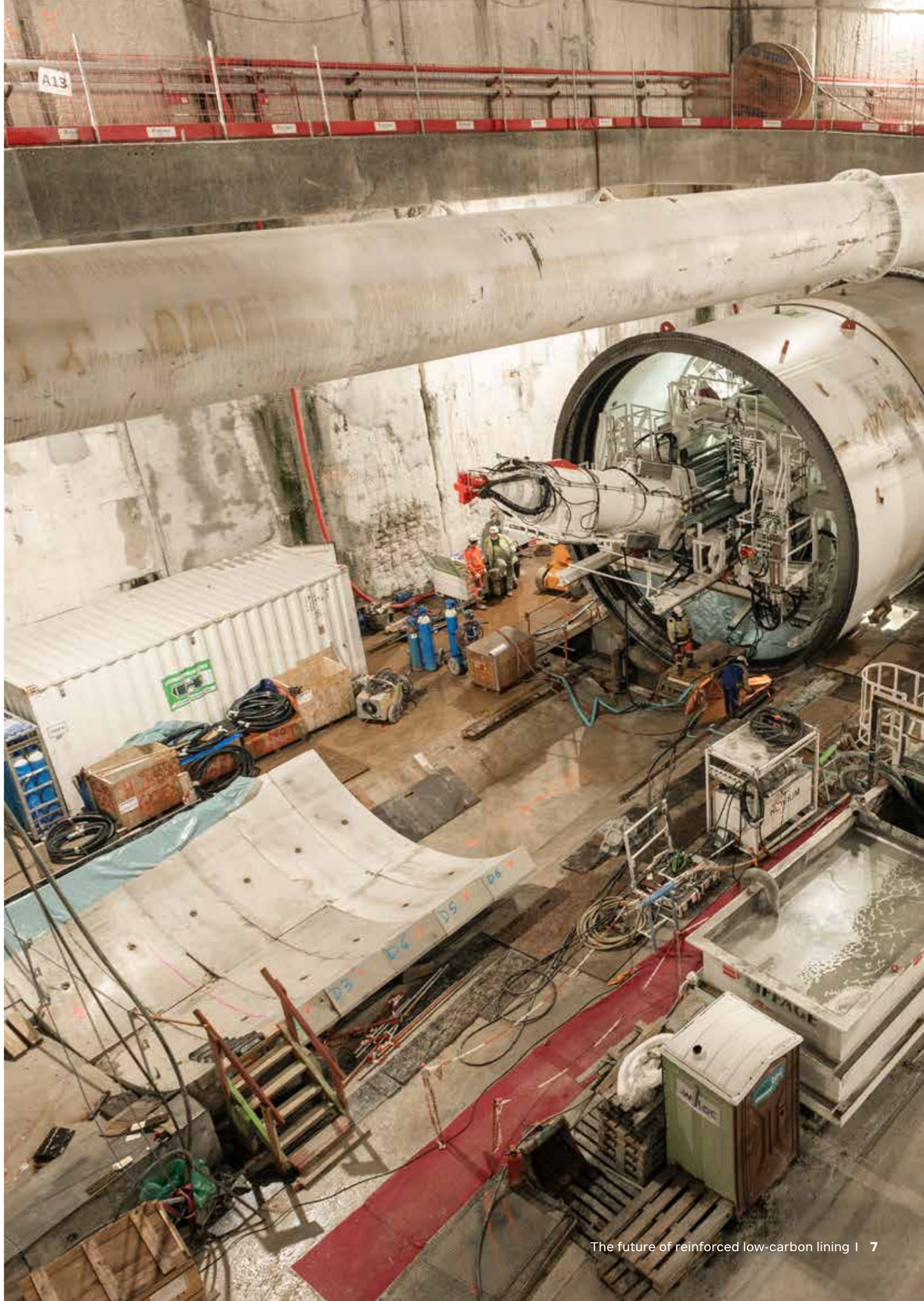
WestConnex, owned and operated by Transurban, is a 33 kilometer predominately underground motorway tunnel network in Sydney, New South Wales, Australia. The use of Dramix® 4D 65/35BG high performance steel fiber in the shotcrete mix allowed the excavation and support of very wide tunnels with complex shapes in a cost-effective manner. Using the 4D65/35BG also allowed for a reduced dosage rate compared to other options, reduced lining thickness while maintaining extremely high performance, with significant economic and sustainability benefits to the projects.

About steel fiber concrete reinforcement

Steel fiber reinforced concrete (SFRC), as its name suggests, is concrete that has been reinforced with steel fibers. Steel fibers bridge the crack at very small crack openings, transfer stresses and develop post crack strength in the concrete. Unlike conventional reinforcement, which consists of steel bars or mesh, steel fibers are relatively short, discontinuous elements that are randomly distributed throughout the concrete member.

Further, traditional reinforcement is provided at distinct locations, whereas steel fibers form a homogeneous reinforcing network across the entire concrete cross-section, thus providing increased strength, ductility and post-crack properties throughout the entire structure.

Several key reference projects throughout this brochure involving our steel fiber concrete reinforcement solutions showcase not only their successes over the last several decades, but also how globally accepted this type of reinforcement has become for underground applications.



The preferred choice to reinforce concrete underground

	Concrete with traditional reinforcement	Steel fiber reinforced concrete
Sustainability	●●○	●●●
Total cost of ownership	●○○	●●●
Performance and Durability	●●○	●●●
Faster and safer	●○○	●●●

Sustainable & lowers footprint

Steel fiber reinforced concrete provides long-term, structural stability in underground projects; the reinforcement support is designed with the future in mind. For example, Dramix® steel fibers enable a service lifespan of concrete tunnels of 120 years, thanks to optimal crack control and structural stability. SFRC lowers your footprint significantly in comparison to traditional reinforcement in two ways: significant steel and concrete savings.

Save steel

Dramix® SFRC achieves the same technical performance as traditional reinforcement but cuts the amount of steel used up to 60%, cutting the carbon footprint of any underground project by default. Cutting the amount of steel has other hidden benefits: the fuel consumption for transport per unit weight is substantially lower. Dramix® SF can be densely packed, maximizing the reduction of greenhouse gases.

Save concrete

To properly provide the required rock support, traditional reinforcement (steel bars & mesh) needs a concrete cover (up to 7 cm) on top for two reasons. First, traditional reinforcement rusts, consequently increasing the volume, creating forces that can spall the concrete. In contrast, SFRC is resistant to corrosion and rust. Second, it needs the cover to keep the rebar in place to guarantee a structural, safe construction, whereas steel fibers are small and reinforce every part of the concrete.

No microplastics in the ocean

Steel still is the most recycled material, and the Bekaert R&D team, together with universities, continue to investigate recyclability. Remelted or reused steel could be directly reused as steel fibers to reinforce tunnels and mines. SFRC delivers a microplastic and pollution-free solution, as is increasingly required by government in shotcrete applications for subsea tunnels.

Lower total cost of ownership

The operating cost structures of tunneling and mining operations globally have increased significantly in recent years.

More efficient work cycle: the fibers are added at concrete plant and as the concrete arrives on site, it is ready to be projected

Boosted construction speed: installing mesh is labor intensive and complex

The reduction of equipment downtime and change-over time

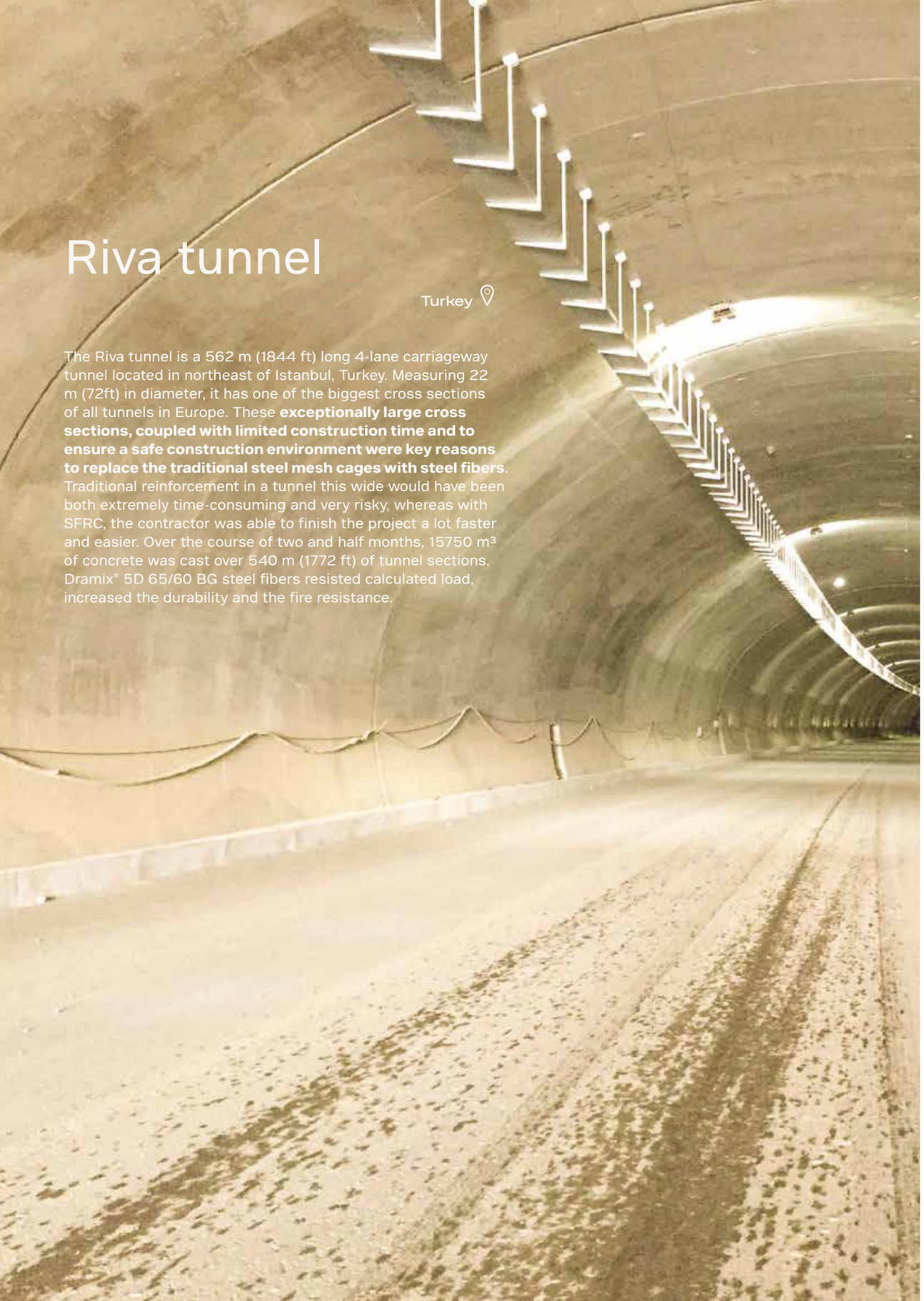
More durable segments, increased service life

Consistent, reliable performance

As we have full control of supply from wire rod to fiber, we can guarantee a stable quality. Quality at Bekaert goes beyond mere product specifications. We implement a Total Quality Management system in production. Thanks to this intensive quality approach we can offer controlled quality of our Dramix® steel fibers, whatever the environments you are working in, and comply to your specifications.

Safety

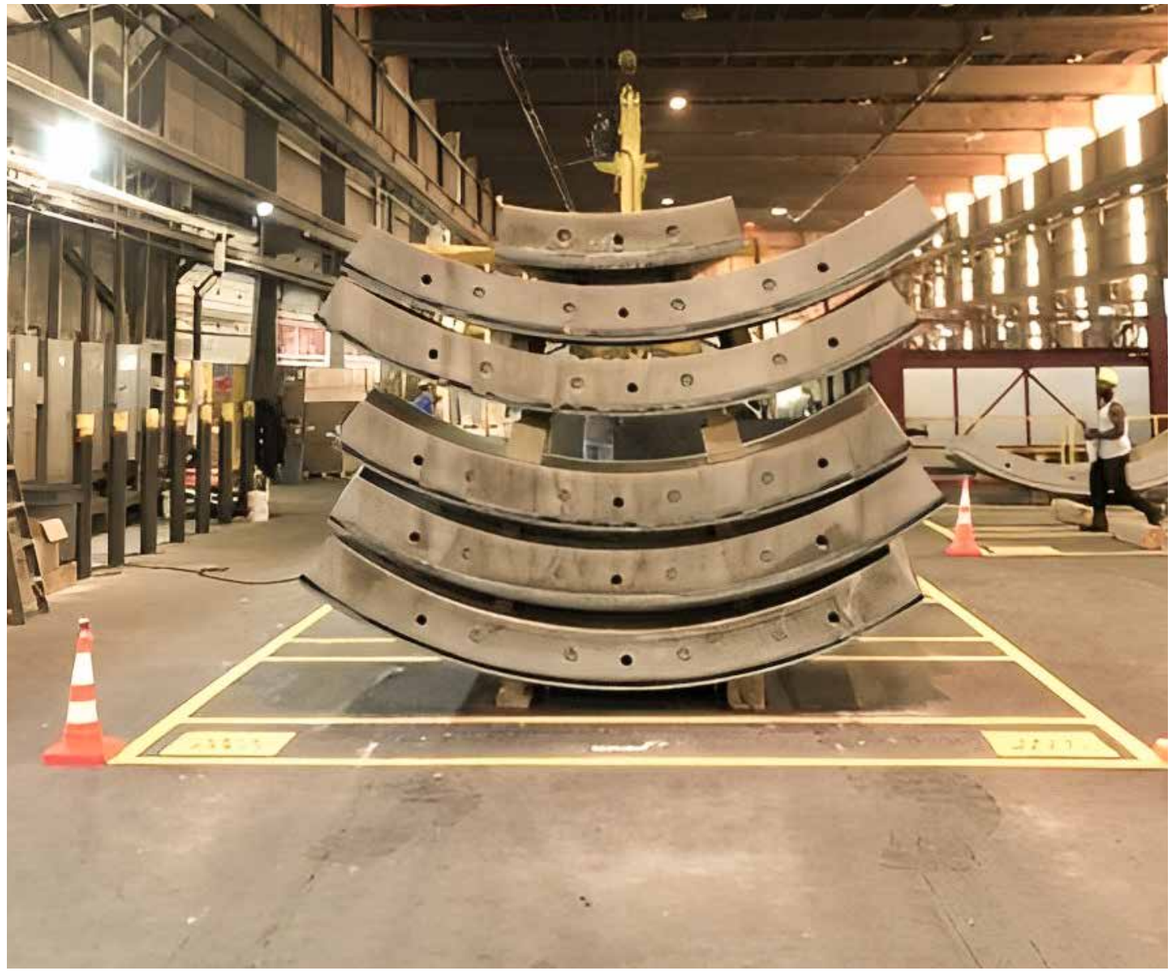
Safety is obviously of critical importance in tunnels and mines. They can be hazardous environments, with an ever-present risk of fire, flood, explosion and collapse. A continuous effort to optimize the process safety without compromising speed, ease of construction, or installation performance is our focus. Our high-quality Dramix® steel fibers for tunneling and mining applications can be mixed with concrete without clumping and have an outstanding reputation when it comes to safety. SFRC is easy to implement even in areas with difficult accessibility, and it spares workers from harmful activities like the stacking and handling of different sizes or shapes of rebar and mesh, mesh cutting or welding or tripping.



Riva tunnel

Turkey

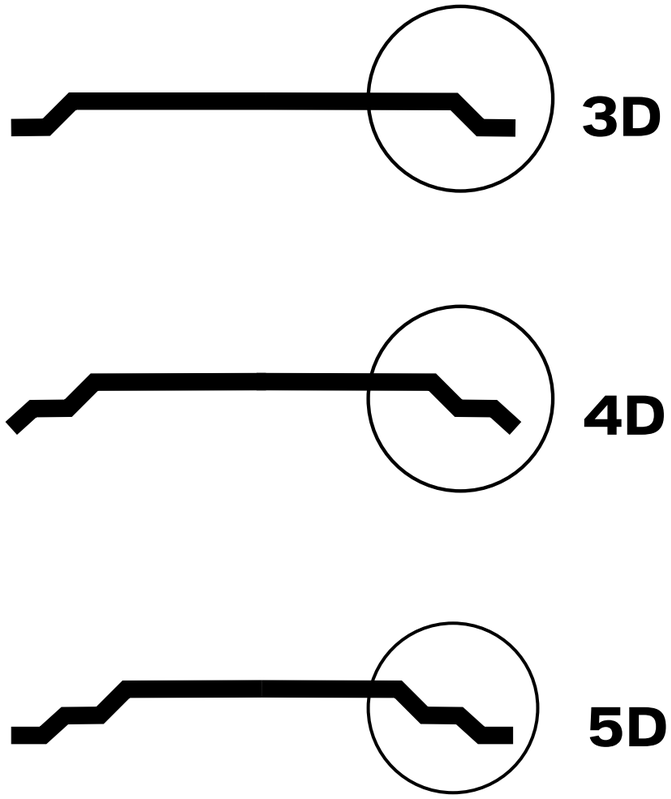
The Riva tunnel is a 562 m (1844 ft) long 4-lane carriageway tunnel located in northeast of Istanbul, Turkey. Measuring 22 m (72ft) in diameter, it has one of the biggest cross sections of all tunnels in Europe. These **exceptionally large cross sections, coupled with limited construction time and to ensure a safe construction environment were key reasons to replace the traditional steel mesh cages with steel fibers**. Traditional reinforcement in a tunnel this wide would have been both extremely time-consuming and very risky, whereas with SFRC, the contractor was able to finish the project a lot faster and easier. Over the course of two and half months, 15750 m³ of concrete was cast over 540 m (1772 ft) of tunnel sections. Dramix® 5D 65/60 BG steel fibers resisted calculated load, increased the durability and the fire resistance.



South Hartford Tunnel

USA

The South Hartford Conveyance and Storage Tunnel (SHCST) is a 20 ft- diameter, 21,800 ft-long bored tunnel that was excavated in shale, siltstone and basalt through several fault zones with high groundwater pressures up to 9.6 bars. For the first time in North America, Dramix® 4D fibers were used for the optimal reinforcement design of precast segments. The 4D fiber satisfies the serviceability requirements by limiting time-dependent effects of creep on crack opening and more significantly guarantees ductility requirements in conventional fiber dosage rates by providing an ultimate bending moment higher than the cracking bending moment.



Dramix®, unique, high quality fiber reinforcement

Our Dramix steel fibers are adapted to specific commercial and technical requirements, at every step in the value chain, whether it is for segmental, in-situ or sprayed concrete lining. Depending on the application, we offer a unique fiber.

Successfully applied in thousands of projects and millions of square feet around the world, Dramix® steel fibers have proven themselves to be an extremely durable reinforcement solution for underground projects.

But what makes Dramix® steel fibers so unique?

Unparalleled strength

Dramix® steel fibers are designed to provide superior crack control in sprayed concrete or for segmental linings/in-situ linings. Bekaert is the only company in the world offering steel fibers with the following features:

- Deformable end-hooks for optimized anchorage
- Extra-high tensile strength (3200 MPa)
- High fatigue resistance
- High length/diameter ratio.

Glued fibers are a cut above the rest

Dramix® steel fibers are bundled with water-soluble glue. The glue helps prevent fiber balling during mixing and ensures a homogenous distribution of fibers throughout the concrete mix. This results in:

- A more efficient mixing process
- Three-dimensional reinforcement
- No exposed fibers at the concrete surface
- Better crack control
- A homogenous steel fiber mix

Three fiber types

The Dramix® steel fiber concrete reinforcement series consists of three fiber types featuring different hooked ends and elongation:

Dramix® 3D is the cost-efficient fiber for non-structural support, such as temporary linings. They serve their purpose and provide the support needed to ensure the safety of your underground operations, but other fibers are preferred when the mine or tunnel is to be used for over 100 years.

Dramix® 4D provides optimal crack control to concrete structures with high serviceability requirements, ideal for segmental lining and permanent sprayed concrete linings.

Dramix® 5D remains firmly anchored inside the concrete as the wire slowly elongates to compensate stress. It is the perfect solution for cast in-place, structural precast elements.

Synthetic fibers

Specific technical strengths and weaknesses of different kinds of fibres are often less well-known, and lead to confusion. Our experts will always advise the most optimal solution for your underground application. Steel fibers excel in structural applications, SLS and ULS, whereas macro-synthetic fibers are good both temporary structures as well as temporary lining in mining (when low performance and large deformation is allowed). Micro synethtic fibers, on the other hand, have anti spalling properties in fire.

That is why, in addition to our Dramix® steel fibers, our portfolio covers macro-synthetic fibers (Synmix®) and micro-synthetic fibers (Duomix®).

Lee Tunnel

UK

The 6.9 km (4.3 mi) long Lee Tunnel in East London connects the Beckton Sewage Treatment Works and the Abbey Mills Pumping Station. Dramix® steel fiber reinforcement was used for all three elements of this tunnel, involving precast segmental lining, permanent lining to the shafts and the secondary lining to the main tunnel. Various Dramix® types were used to suit the various applications, Dramix® 5D 6560 BG in particular because of its excellent bending hardening properties in the main tunnel works. In total, Dramix® steel fibers replaced over 17,000 tons of traditional reinforcement steel in the secondary lining alone to the main tunnel. In certain segments of the final linings of the five shafts, Dramix® saved steel by replacing part of the reinforcement, in other segments, it replaced mesh completely. Thus, a significant number of emissions was saved in the Lee Tunnel Project.

Dramix®, the future of low-carbon lining

Intelligent design and construction is the key to sustainable tunnelling and mining. Our flagship projects have taught us that steel fiber reinforcement has a direct, significant impact on the carbon footprint of any project because of the material savings (steel and concrete), lower transportation costs, limited wastage and end of life recycling.

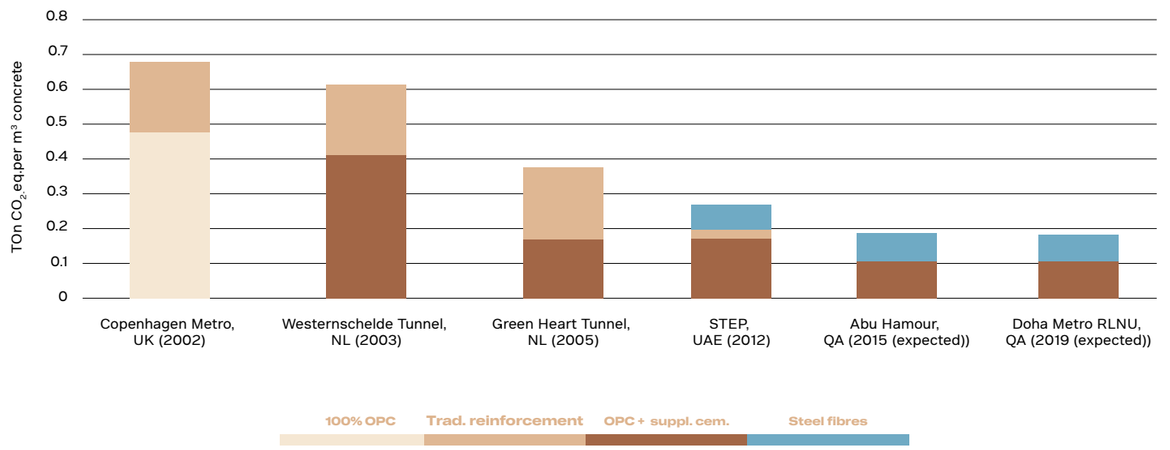
Save concrete, save steel
As discussed on p. 5-6, using Dramix® steel fiber reinforcement instead of traditional reinforcement will save both concrete and steel in your underground structures, therefore significantly reducing your footprint (up to 60%). The synergetic relationship between steel fiber reinforcement and cement mixed with FA (Fly Ash) and GGBS (Ground Granulated Blast Slag) further increases the emissions savings (up to 75%) as compared to reinforcement solutions involving only Ordinary Portland Cement (OPC). The graph below illustrates this significant CO_2 gap. If the Doha Metro (right) had been built like the one in Copenhagen, that would have resulted in 400,000 tons of extra CO_2.

Efficient transportation
Dramix® steel fibers enable densely packed reinforcement material. This means that we do not transport air, as opposed to transporting steel mesh. Therefore, the fuel consumption for transport per unit weight is substantially lower. Less mechanical handling with lifting material, adds to the reduction of greenhouse gasses.

Waste and end of life recycling
Dramix® wastage is limited as it is directly mixed with concrete, whereas rebar is cut and yields more scrap on job site. At the end of its lifecycle, 95% of Dramix can be recuperated and 90% of recuperated amount can be recycled in a steel mill to remelt to make wire rod. 10% can be reused. We continue to research new ways to recuperate and recycle the maximum amount of concrete.

EPD certified
Bekaert has obtained multiple Environmental Product Declarations for its Dramix® portfolio, manufactured in different production plants. This allows anyone to compare concrete reinforcement products and see the impact they have on the environment. This objective tool demonstrates how much CO□ can be saved using Dramix® steel fibers compared to other concrete reinforcement solutions.

More credits
Finally, low carbon tunneling and mining allows you achieve more credits in building certifications such as LEED, increasing the value of your underground project.



A long line of successes built on sheer experience

When you partner with Bekaert, you can rely on a diversified product portfolio, combined with innovation and operational excellence.

For decades, Bekaert has successfully completed more than 500 tunnelling projects worldwide totaling over 3000km, offering solutions to the world's most challenging projects in Metro, highway, rail, water, and mining sectors, resulting in more than 280,000 tons of steel cage saved, and a significant reduction in CO2 emissions by 30-40%
You can count on us for support for each step of your project, from concept design to on-site quality support. Our services include recommendations on design, construction detailing, concrete optimization and automatic total quality control procedures.
We are also happy to share our knowledge with you and your team. Feel free to ask us for a workshop or training on the topic of steel fiber reinforcement in your offices.

Our concrete reinforcement solutions are engineered to your needs. We control the quality of products made for you from the wire rod to the steel fiber reinforced concrete (elements) underground.

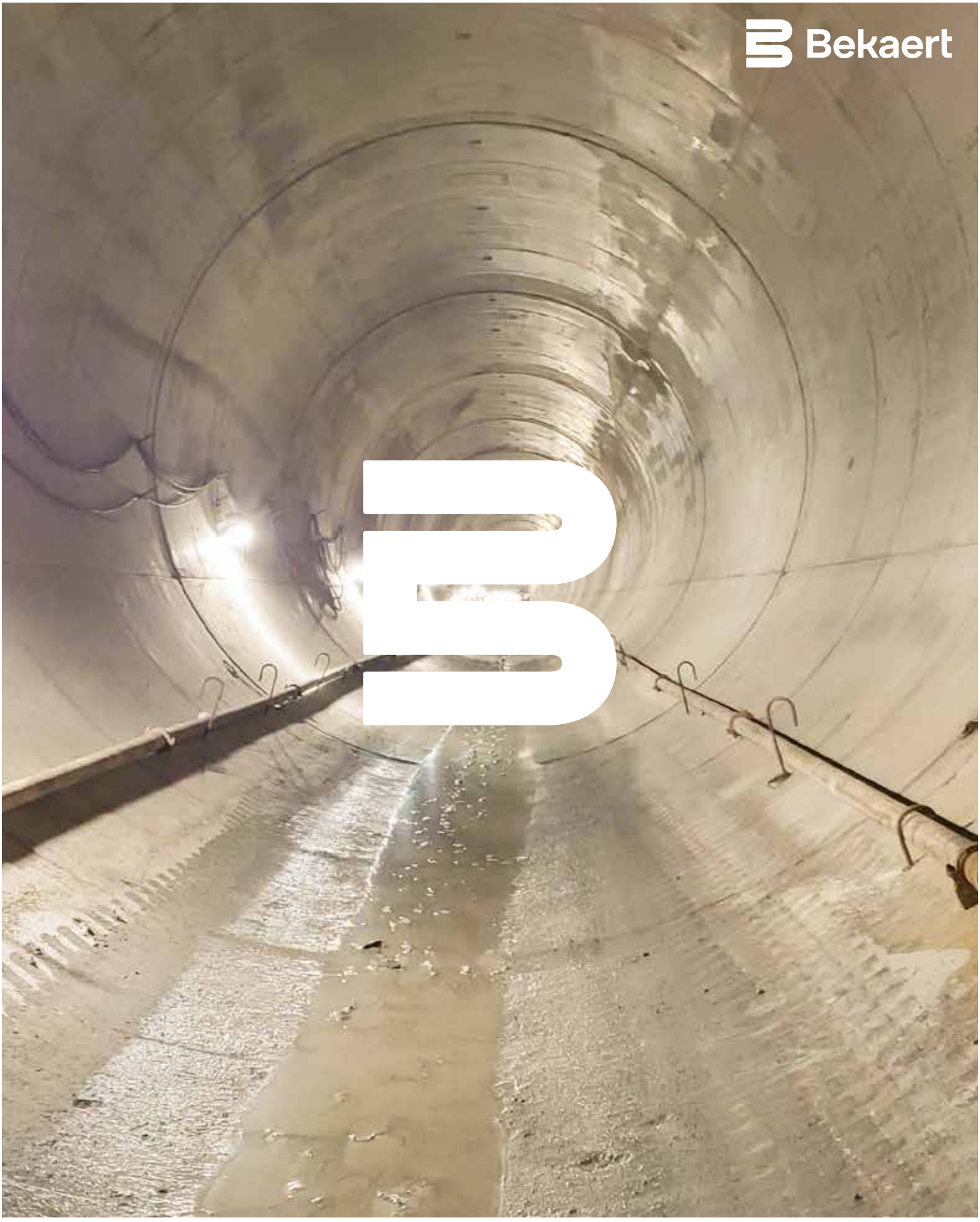
Norms
Nowadays, all materials used in the tunnels and mines must comply with all the required norms.
All of Bekaert's concrete reinforcement solutions for tunnelling and mining comply with the most relevant global construction, fire and safety standards.

Total Quality Management
Maintaining a high level of quality is a continuous process. That is why our quality procedures are regularly evaluated and why we use the feedback of our customers to do so. Our extensive quality control and defect filtering offers a consistency warranty while eliminating excessive waste and safeguarding the quality of your product.
Choosing Bekaert is choosing for a high-performance product supported by Total Quality Management.

Gotthard base tunnel

Switzerland

The Gotthard Base Tunnel is a railway tunnel through the Alps in Switzerland. With a route length of 57.09 km (35.5 mi), it is the world's longest railway and deepest traffic tunnel and the first flat, lowlevel route through the Alps. It lies at the heart of the Gotthard axis and constitutes the third tunnel connecting the cantons of Uri and Ticino, after the Gotthard Tunnel and the Gotthard Road Tunnel. It took 14 years to build the 57-km-long Gotthard train tunnel. **At the time, shotcreting using steel fibers was very unconventional, but it was a key project that showcased its advantages** back then: the process is a lot more safe (workers used to have to mount the reinforcement in a just-excavated tunnel, whereas now a robot-arm sprays the reinforced concrete at a safe distance) and it's more sustainable (both concrete and steel is saved).



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