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Dubai Storm Water Tunnel Lining Segments

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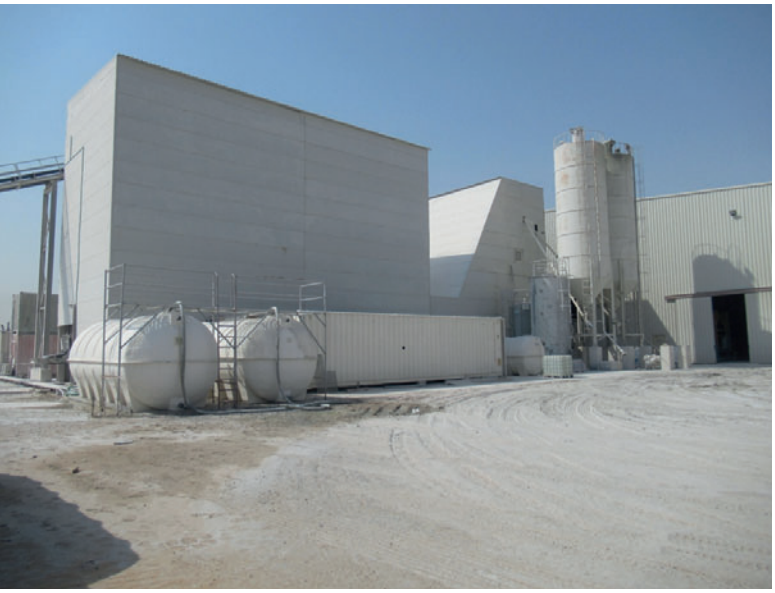
The objective of the Deep Tunnel Storm Water System project by Dubai Municipality's Drainage Projects Department, is to collect, store and convey groundwater and rainwater runoff from almost 490 km² (about 40%) of Dubai's urban area. This includes Dubai South, Al Maktoum International Airport, EXPO 2020 Dubai, and other adjacent localities. The Deep Tunnel Storm Water System forms part of Dubai's vision for a smart and sustainable city. It will provide the infrastructure needed to serve Dubai's growing residential and business communities, to be able to cope with increasing urbanisation that causes rising ground water levels and the rare rain events. The economic impact of rain events, though rare, is significant for Dubai and hence a robust infrastructure by way of the deep tunnel system is being implemented. To support the tunnel construction, PORR-Six Construct Joint Venture has set up a precast segment factory to produce the approximately 43,000 tunnel segments.

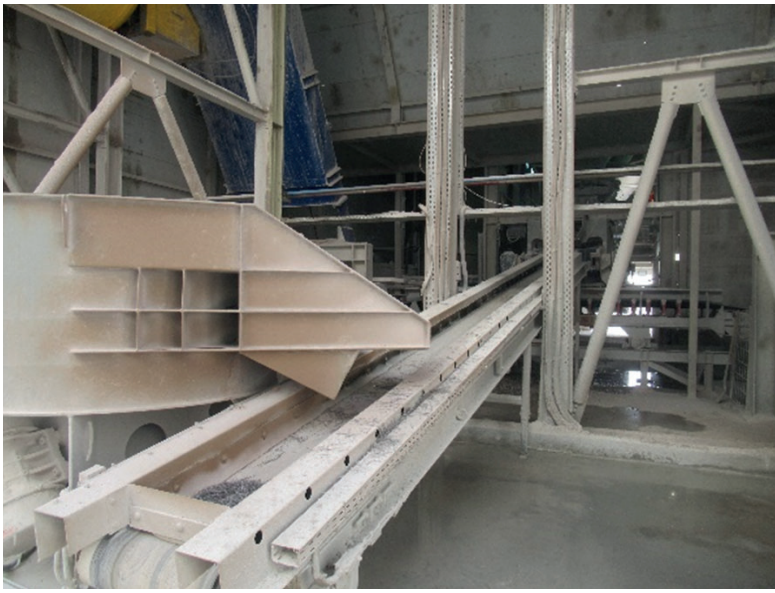
Segment Design

The tunnel segments have lining thickness of 350mm and a segment width of 1.6m or 2.0m, depending on the radius of tunnel curvature. Each segment ring consists of eight equally long segments. Gaskets are cast directly into the segments for a more secure fit, unlike the approaches of using adhesives. Shear dowels are used to allow for a quicker and more accurate installation of the segments inside the tunnel.

The segments are designed with steel fibre reinforcement instead of traditional rebar, in order to meet the extremely high durability requirements and the design life of 100 years for the project. The ideal volume and aspect ratio of reinforcement, together with the high durable concrete mix C 55/67, was determined to yield the optimal structural strength of the segments.



Batching Plant, right side



Fibre Dosing Unit with buffer conveyor belt

Precast Segment Factory

During development and finalisation of the technical specification for the factory layout and needed equipment different aspects had to be considered. Harsh weather and environmental conditions in the Middle East beside fast track project schedules, low operating and maintenance costs, reliability of equipment and sustainability and safety aspects as key points influenced the final decisions.

Based on the project experience of the PORR precast team and the different factors it was decided to use a static production system with a mirrored factory shed 60m by 132m, a batching plant with two mixers and a Keckis cold water agrregate cooling system instead of the usually used iced cool system in the Middle East. This combination of batching plant and cooling system makes this factory set up unique amongst the precast factories in the Middle East and probably worldwide.

Batching plant

The batching plant as heart of the factory consists out of two main buildings with three horizontal levels, the two chiller systems and a separate operator control room.

The batching plant, the flying bucket concrete transport system and the aggregate cooling system are controlled by a combined Simma control system. Both main buildings are cladded with insulated wall panels.

The ground level of the Main Building 1 houses the steel fibre dosing unit including buffer conveyor and the aggregate cross conveyor feeding the two elevator buckets for left and the right side of the factory. The steel fibres are fed via the buffer belt into the stream of raw materials coming from the other side. This set up avoids any kind of balling of fibres.

On the second level two BHS Sonthofen 2.25m^3 double shaft mixers are installed including all control systems of the plant and on level three one will find all required scales for water, admixtures and liquefied Microsilica.

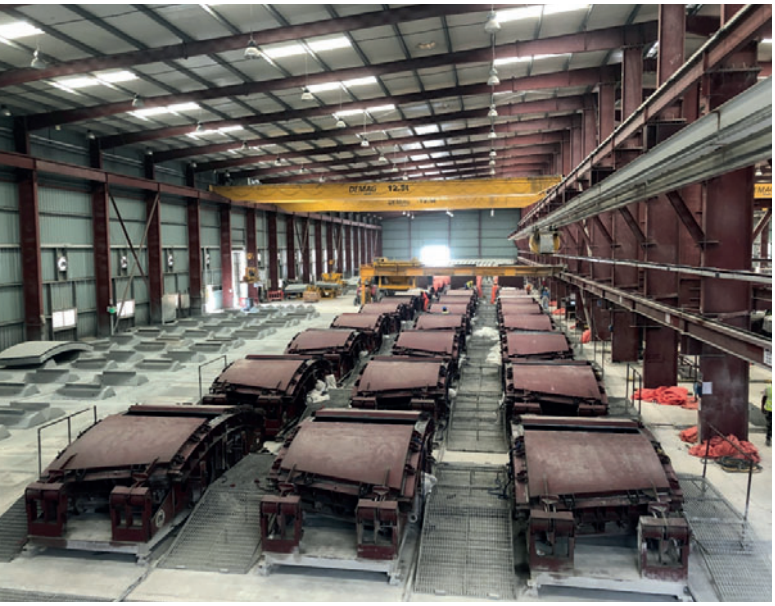
On ground floor of Main Building 2 the main weighing conveyor is installed and on level two 4 aggregate silos with capacity of 84m^3 material including cooling water 1 double silo for 5mm and dune sand without cooling and in level three the distribution conveyor system to fill the silos.

Based on the mix design four different fractions of crushed limestone are in use in 20mm, 10mm, 5mm and dune sand. Two water chillers are part of the batching plant to produce the mixing ice water down to 2 degree centigrade and the required cold water for aggregate cooling down to 6 degree centigrade.

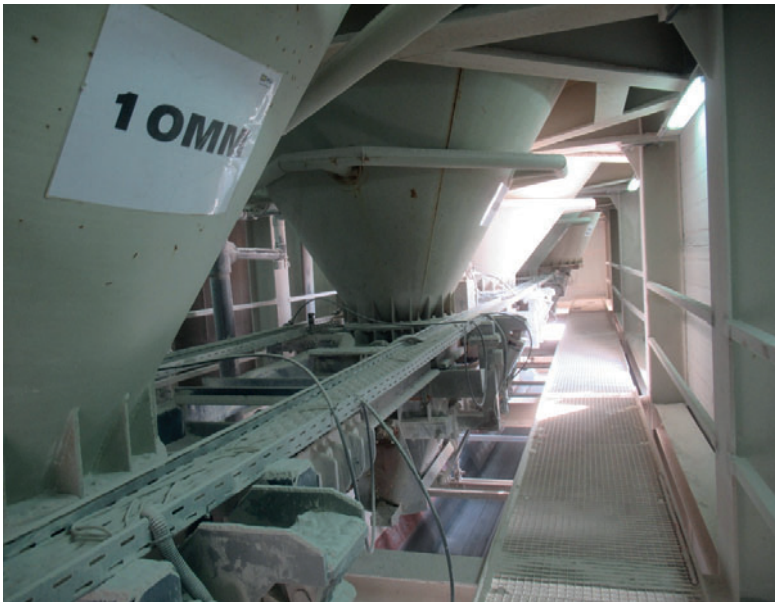
The Keckeis aggregate cooling system allows cooling of the 20mm and 10mm fraction using two silos for each fraction. One silo per fraction is available for concrete production and the second silo is in cooling process. For cooling the material in the silo will be flooded entirely with the cool water produced by the chillers. To cool down one silo from material temperature of approximately 50-60 degree centigrade to 10 degree centigrade it takes about 1 hour.

The water circulates between silo and chiller without washing out fines. Special valves on the bottom of the silos allow draining completely the silo before switching to concrete production mode. The result is a saturated cooled raw material without residual water in the first batches.

The saturated condition of the main materials also guarantees a unique stable consistency and workability of the produced



Precast Segment Factory, left side



Level 2 in Building 2, showing the material silos

One of the Chiller Units

concrete. Furthermore, this system consumes over 40% less energy compared to an equivalent ice cooling system. This is in line with the high demand of the client, Dubai Municipality Drainage Projects Department, for high standards in regard to saving of energy and resources and high-level sustainability in the projects.

Additives for the precast concrete

For the lining segments, Sharjah based Ha-Be Middle East FZE, subsidiary of the German parent company Ha-Be Betonchemie GmbH, provided a technical solution focussing on the following Dubai Municipality project specification requirements:

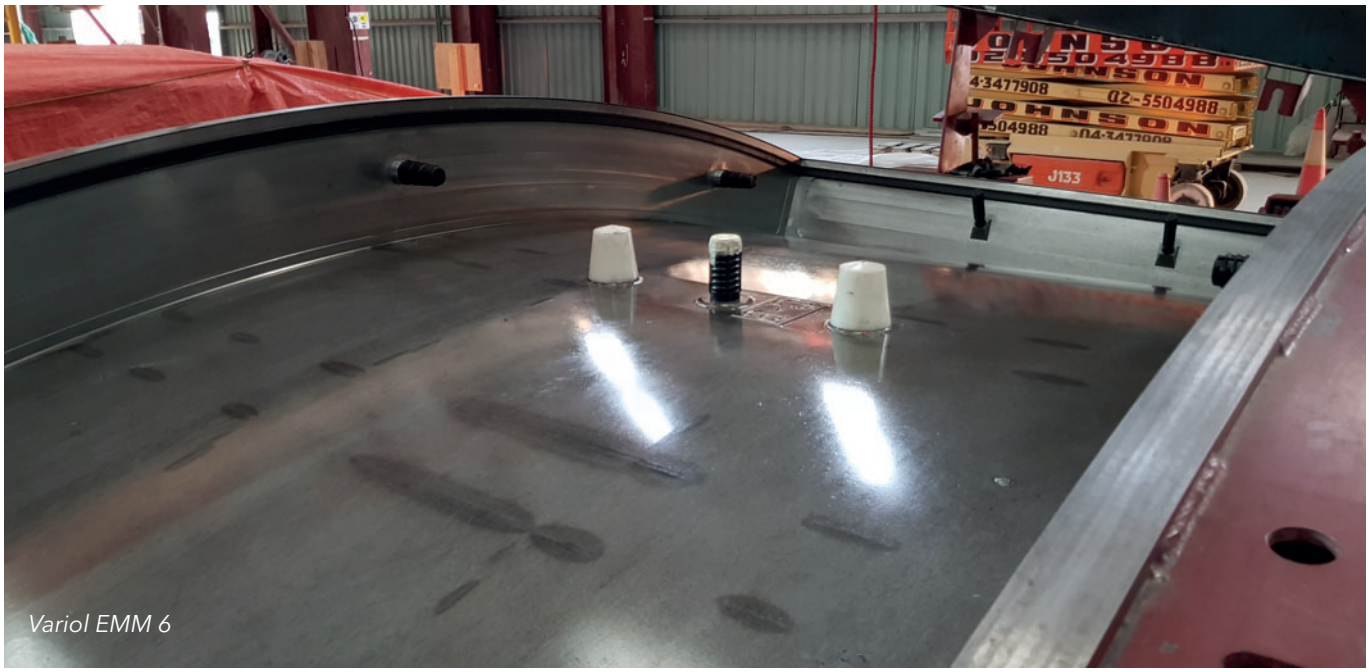
- Concrete class C55/67
- Maximum water/cement ratio 0.34
- Maximum Rapid Chloride Penetration Test (RCPT) 1200 coulombs
- Maximum Chloride Migration (CM) 2.50 x10-12
- Maximum Water Permeability (WP) 10 mm
- Maximum Water Absorption (WA) 1.50 %
- Early strength after 6 hrs. minimum 12 N/mm²
- Workability slump 160 +/- 40 mm

Accordingly, Ha-Be Middle East proposed the following materials:

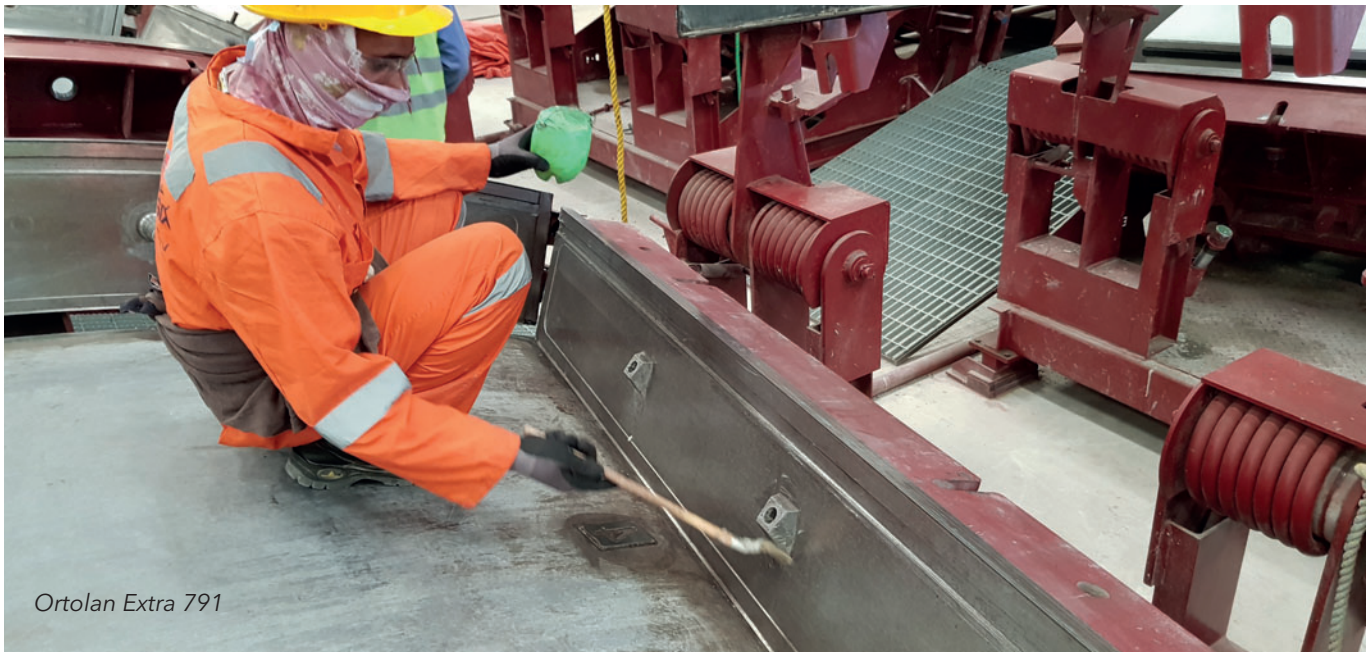
- Pantarhit® PRC 444 - High Performance Superplasticizer for Precast Concrete
- Ha-Be Silica Fluid – Silica Fume Suspension for durable concrete
- Variol EMM 6 – Concrete release agent for formwork

Pantarhit® PRC 444 is used to control the workability, viscosity and early strength development. The polycarboxylate based high performance superplasticizer produces a thixotropic effect. It provides excellent flow of the concrete during the vibrating / compacting process, allowing for easy distribution inside the formwork, while achieving the maximum density to guarantee the required durability. After filling the concrete has to attain a consistency stiff enough to finish the top surface as soon as possible. Additionally, the product has to perform with very low water/cement ratio as well as with multiple binder combinations.
Ha-Be Silica Fluid was proposed as an alternative to conventional silica fume. The liquid state of the product grants valuable benefits:

- **Handling**
  The material allows for supply in bulk tanker and storage in vertical storage silos with optimised supply times.



Variol EMM 6



Ortolan Extra 791

- **Health, safety & environment**
  The material is ready to use and does not need to be handled directly by the client. No hazardous fumes are emitted, reducing exposure of personnel and environment to zero.

- **Fresh and hardened concrete performance**
  The dispersion effect of the silica slurry is considerably superior to that of powdered silica fume, allowing for shorter mixing times and lower viscosity of the fresh concrete, improving flow and workability.

Durability results are improved, as the silica particle distribution inside the concrete is uniform and the tendency of fine powder to form accumulations when in contact with the mixing water is eliminated.
Ha-Be Silica Fluid has a proven track record across the Middle East and North Africa Region and has performed well in numerous projects in UAE, Oman and Egypt that required high durability concrete.
Variol EMM 6 is an emulsified mineral oil and was proposed as the releasing / oil layer can be reduced to the lowest point while still being effective enough to allow easy, damage-free removal of the segments from the formwork.
Ortolan Extra 791 is a solvent free pasty formwork wax especially suitable for complex and detailed moldings, the product is for smooth, non-absorbent formwork in precast production. In the formwork for the tunnel segments, this product was proposed for the areas where a usual release agent was too low in viscosity to stick to the surface. For this the proper detailing formwork was given and ensured.

Steel Fibres for the precast lining segments

For this remarkable project the Porr-Six Construct JV was required to offer steel fibres complying with the following specifications:

Performance class 4c regarding fib model code 2010

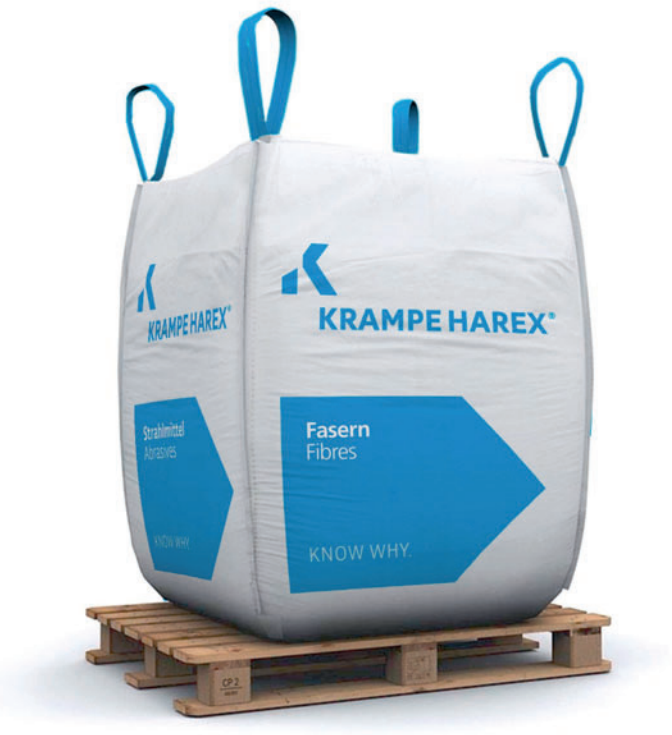
1. Material: low carbon, cold drawn wire (EN 14889-1: Group 1)
2. Shape: circular cross section with hooked ends
3. Minimum tensile strength of the wire: 1800 MPa
4. Nominal length of steel fibres: 40 mm to 60 mm
5. The aspect ratio (L/D) of the steel fibres shall be in the range 50 to 100

Total quantity approximately 4,750 tons. Delivery period starting August 2018 until December 2019. Delivery was in big bags with suitable measures to avoid corrosion during transport and storage.

Steel fibres are already well known for their huge benefits and there are already many projects worldwide with very good results especially on durability and economical savings. KrampeHarex proposed their DE 60/0.9 H fibre. A cold drawn wire fibre from their high-performance portfolio with 60mm length, 0.9mm diameter, aspect ratio of 67 and a tensile strength of 1,900MPa. Due to experience from other projects and from research in KrampeHarex concrete lab, this was the most appropriate fibre for a planned concrete C55/67 with expected real compressive strength after 28 days of >80MPa. The high performance, the quality and tensile strength, combined with a very good ratio of length and diameter is a great match for very good performance results on steel fibre reinforced concrete with continuous good test results during the whole production time. Another important aspect is the very good workability. The fibres do not ball and there is no need for a glue which could have negative effects from reactions with components from the concrete mix design.

Compared to traditional reinforcement, the use of steel fibres in tunnel lining segments have a lot of advantages: The durability is higher, the production process is faster and simpler,

KrampeHarex internal quality control, beam test for SFRC performance



Big Bag with 500kg steel fibres for easy refill of dosing unit

there are less cracks and damages on segments, the service live is longer due to less need for maintenance, an overall saving on time and costs.

KrampeHarex was involved from the very beginning, sharing expertise and experience, supporting in planning and optimising the concrete mix design together with the responsible precast plant manager and the technical manager from the additive supplier. After first trials and fine tuning we were able to produce continuous good results with reliable performances fulfilling the requirements from the technical specification.

A dosage rate of 40kg/m³ of KrampeHarex DE 60/0.9 H was enough to reach the required performance class 4c regarding fib model code. The performance of the SFRC is classified with the Post-cracking residual strength and the two parameters f_{R1k} "4" (the strength interval) and a letter "c" (the ratio f_{R3k} / f_{R1k}), with $0.9 \leq f_{R3k} / f_{R1k} \leq 1.1$

So here a minimum characteristic residual strength of $f_{R1k} \geq 4.0$ and a ratio f_{R3k} / fR_{1k} of 90-110% of f_{R1k} must be achieved. It is important to have regular consistent minimum performance results, not only on initial trials. Due to the right choice of the most appropriate fibre type with enough length of 60mm, a good ratio to have best workability and easy dosing and mixing with homogenous fibre distribution, the ongoing tests showing all very good results, proving the performance and achievement of required specifications.

The delivery of the planned total demand of 4,750t fibres is ongoing. It started in August 2018 and is planned with last volumes arriving in the plant in January 2020. During this period of time KrampeHarex will ship 216 containers with 40ft and 22t of steel fibres in big bags per container. ■

FURTHER INFORMATION

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