MOVING TO LOW CARBON PRECAST SEGMENT WITH FIBRE REINFORCED CONCRETE

by

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BEKAERT

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FIBRE REINFORCED CONCRETE …

- **…provide a**
  - discontinuous
  - evenly distributed
  - 3-dimensional
- reinforcement network to concrete.

- **…are engineered to**
  - replace
  - reduce
  - improve
- traditional concrete reinforcement.

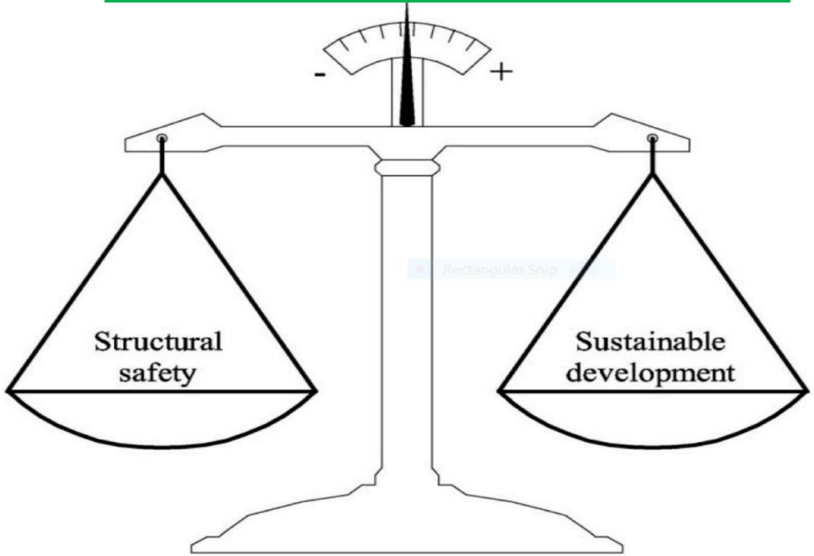
- **It’s a proven technology for more than 40 years.**

Why Steel fibres are the most suitable structural reinforcement material, specially considering low deformation and cracking control

1. THE YOUNG'S MODULUS IS SUFFICIENT TO REINFORCE AT LEAST FIVE TIME TO THAT OF CONCRETE AND BECAUSE A THERMAL EXPANSION EQUAL TO THAT OF CONCRETE
2. STEEL FIBRE ALLOW CRAKING CONTROL
3. STEEL FIBRES CREEP CAN ONLY OCCUR ABOVE 370°C
4. STEEL FIBRES MELT ONLY ABOVE 1500 ^{o} C

The assessment of concrete linings requires the definition of both the **Sustainability Index and Mechanical Index**

HIGH PERFORMANCE STEEL FIBRE



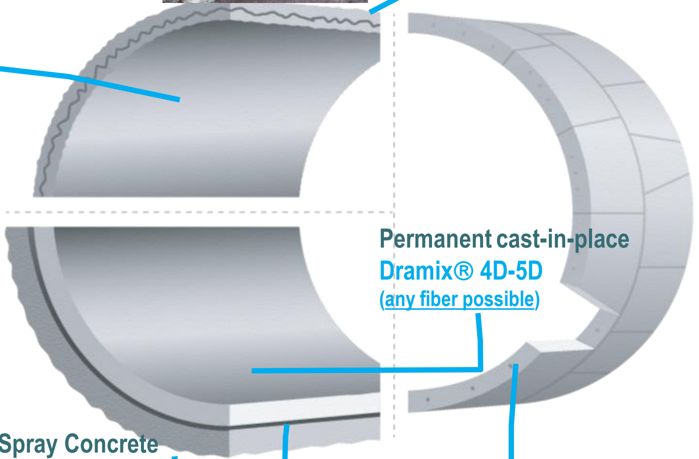
Contemporarily, a low environmental impact guarantees a sustainable development, which is in accordance with the Brundtland Commission of the United Nations (March 20, 1987), the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Current Use of FRC in underground

Products per tunneling applications

Permanent Spray Concrete Lining
Dramix® 4D 65/35BG
(any steel fiber possible)

Optional spray membrane
(part of Supercon project)
Dramix® D 80/30BGP



Permanent cast-in-place
Dramix® 4D-5D
(any fiber possible)

Temporary Spray Concrete
Dramix® 3D 65/35BG if nothing required, any steel fiber possible
Synmix®

Geotextile & sheet membrane

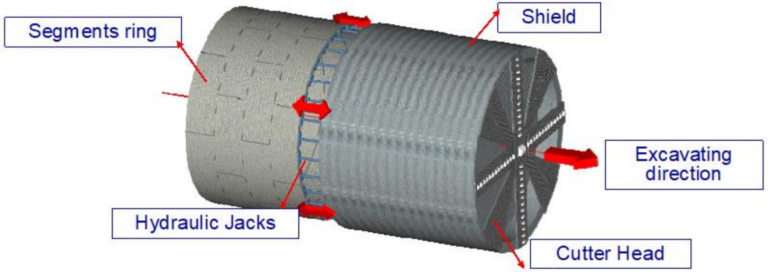
Segmental lining with TBM
Dramix® 4D 80/60BGP 3D 80/60BGP if only 4C required
(any steel fiber possible)

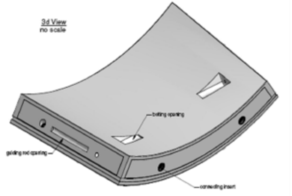
Industry we serve

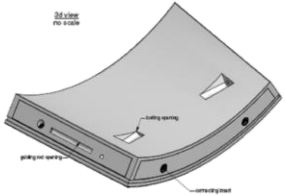
- MINING
- ROAD
- HYDRO
- METRO
- RAIL
- CSO
- UTILITY

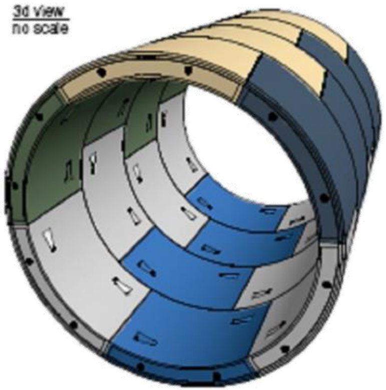
Fire resistance & anti-explosive spalling
Duomix® M6 Fire

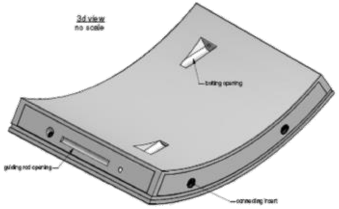
MORE AND MORE MECHANIZED EXCAVATION USING TBM

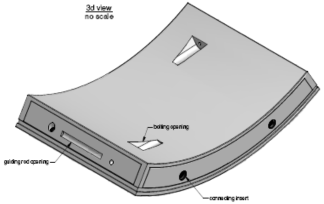






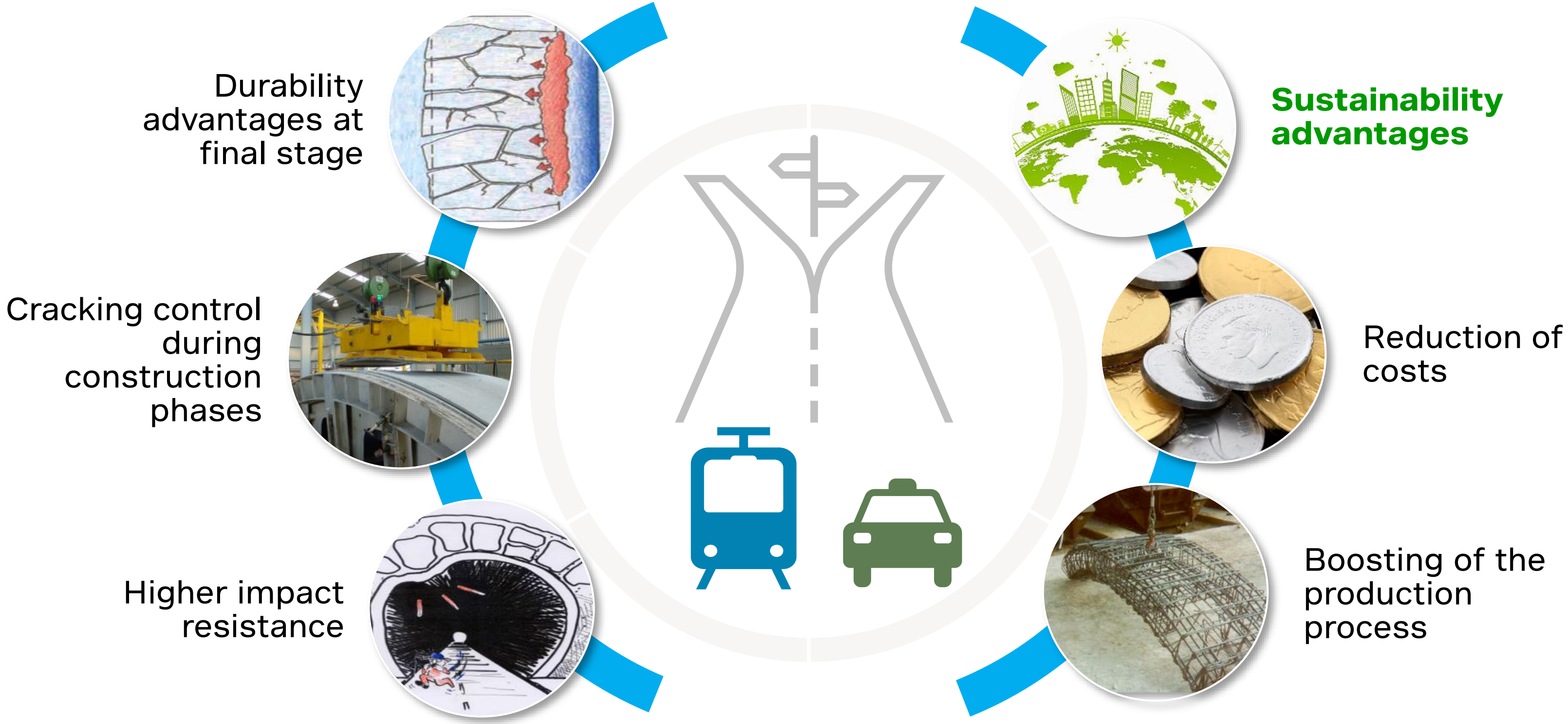






MORE AND MORE FIBRE REINFORCED CONCRETE PRECAST SEGMENT

State of the art summarized by fib bulletin 83



Key Underground projects from more 300

pioneering | innovating | expanding | recognition | new design codes | transforming

1990

Munich Water Tunnel, Germany

- Contractor: Bilfinger und Berger
- Designer: C.V. Buchan
- Owner: Munich City Works
- Fiber type: Dramix® RC80/60BN
- Length: 11.8 km
- Diameter: 2.2 m
- Thickness: 180 mm
- Concrete class: C45

- **All start from Heathrow baggage**

2003

CTRL (Channel Tunnel Rail Link), UK

- Client: RLE (Rail Link Engineering Ltd. Designer: Ove ARUP & partners
- Fiber type: Dramix® RC80/60BN
- Length: 40 km
- Diameter: 7,15 m
- Thickness: 35 cm

2006

Singapore Metro Line

- Contractor: Woh Hup – STEC –
- NCC JV – Tasei Corporation
- Fiber type: Dramix® RC65/60BN
- Length: 750 m & 650 m
- Diameter: 5.8 m
- Thickness: 275 mm
- Concrete strength: 60MPa
- Dosage rate: 30 kg/m

2010

Brisbane Airport link, AU

- Client: BrisConnections
- Contractor: TJH JV
- Designer: PBA JV & Hallcrow
- Fiber type: Dramix® RC80/60BN Duomix® M6 Fire
- Length: 15 km
- Diameter: 11,24m

2014

Lee Tunnel, UK Concrete Society Awards

- Contractor: Morgan Sindall/Vinci
- Grand Projets/Bachy Soletanche
- (MVB JV)
- Designer: Aecom/UnPS
- Owner: Thames Water
- Fiber type: Dramix® 3D 8060BG
- Length: 6.9 km
- Diameter: 7.2 m
- Thickness: 350mm
- Concrete class: C50/60

2016

Doha Metro, Qatar

- Contractor: JV Porr – Saudi BinLadin – HBK
- Designer: D&B by JV contractors
- Fiber type: DRAMIX® 4D 80/50 BG
- Diameter: 7.8 m
- Thickness: 350mm
- Length: 34 km

2020

Grand Paris, France

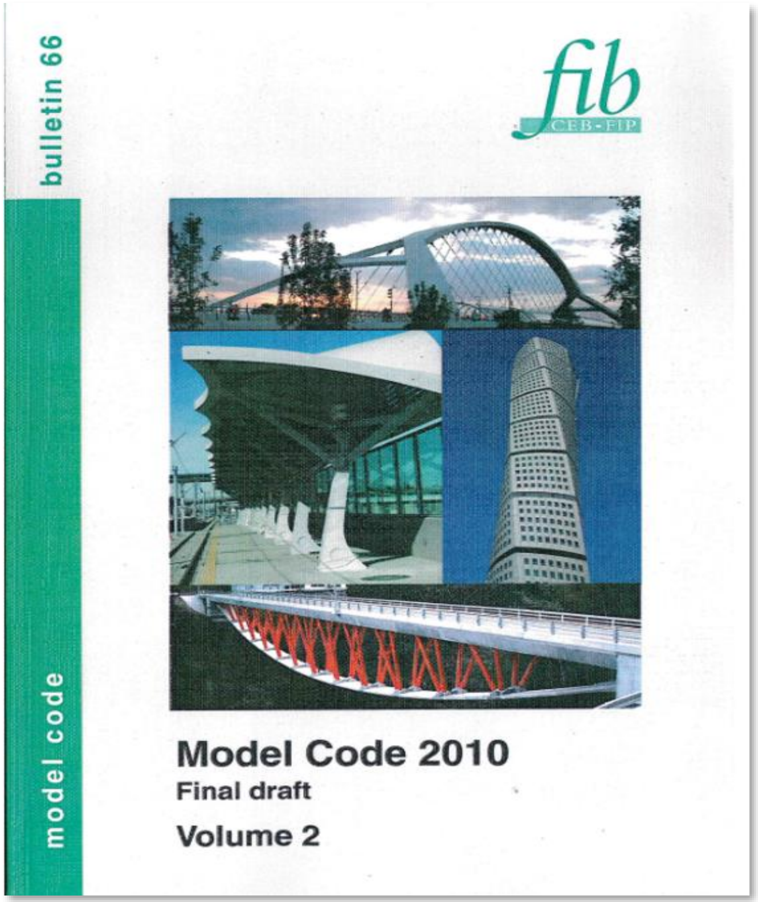
Owner : Société du Grand Paris (SGP)
Designer: Egis
Contractor: Eiffage Génie Civil
Diameter: 9,50m
Length: 16 km
Thickness: 400mm
Concrete quality: C540/50
Fiber type: DRAMIX® 3D 80/60 BGP
First important reference in definitive segments in the French Market

2022

Toronto Project, Canada

FRC PRECAST SEGMENT INTERNATIONAL GUIDELINE JOURNEY

2012	Model Code 2010
2013	AFTES
2016	ITA TECH Volume 1 ITA WG2 Lesson learn
2017	ACI 544 Fib Bulletin 83
2018	ITA TECH Volume 2
2019	ITA WG2 Design
2021	TAI Guideline for Design
2022	Singapore **Standard** 4c mini
2023	DMRC Fib 83 inside



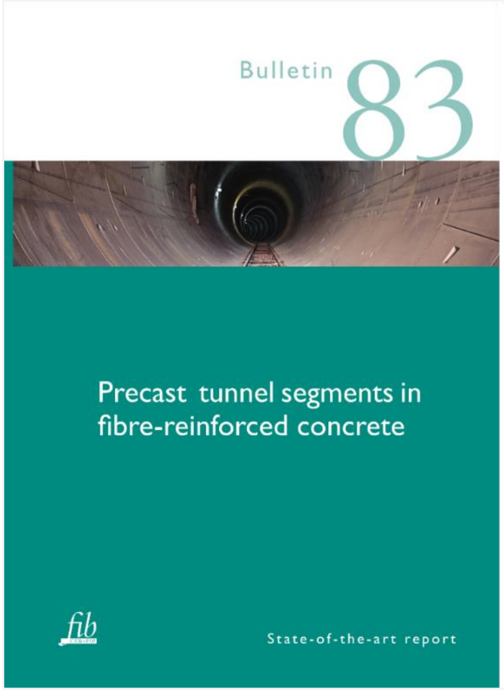
International (2010/2012)

- Published 2012
- Pre-normative (e.g. future Eurocode)
- Proposed by fib as operational document
- Fibres are included in MC2010 which is the base for the future EuroCode (2024?)

FIB Bulletin 83

- Clear guidelines on how to characterize FRC material performance
- Clear state of the art
- Clear design guidelines

NEW PUBLICATION 2018



Precast tunnel segments in fibre-reinforced concrete

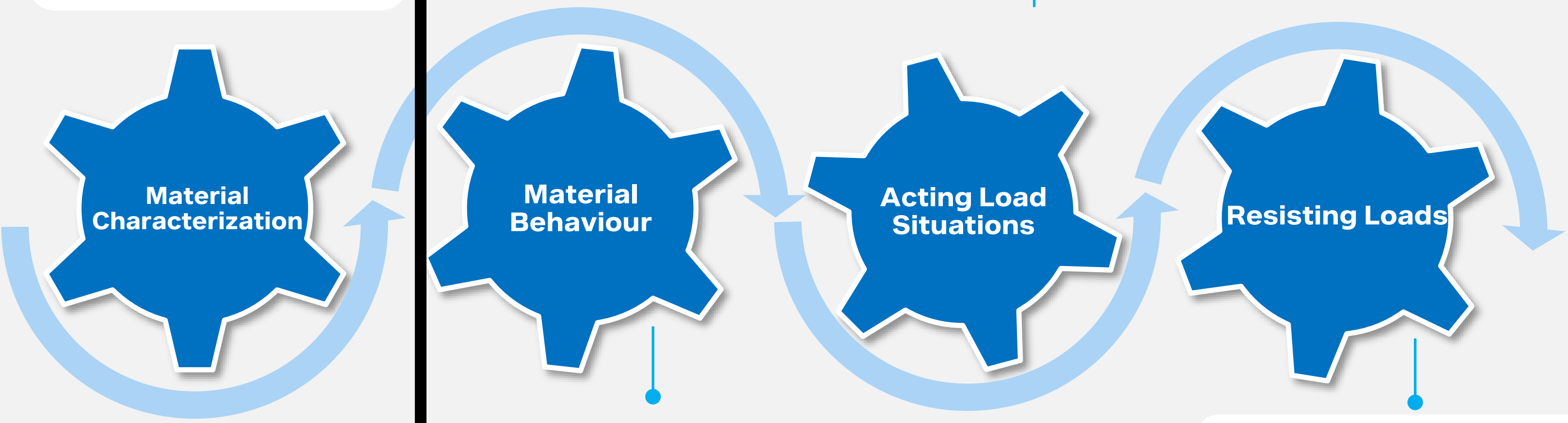
Contents

Design Flow

FIRST STEP IS KEY

- Beam tests according to EN14651
- Performance classes
- Material requirements
- 4c mini to 6d

- Demolding
- Stacking
- Transport & Placing
- Service

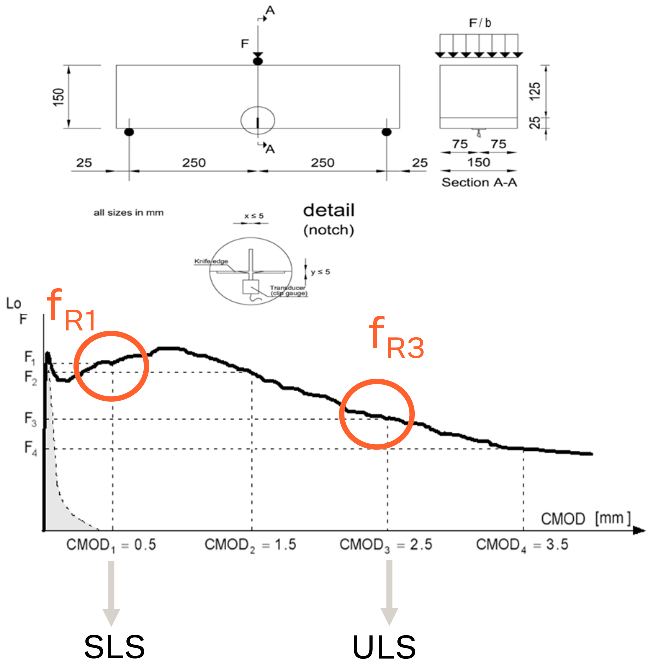


- Constitutive laws
- Material safety factors and other impact factors

- Bending moment capacity
- Shear capacity
- Resistance against spalling/bursting
- Resistance against impact

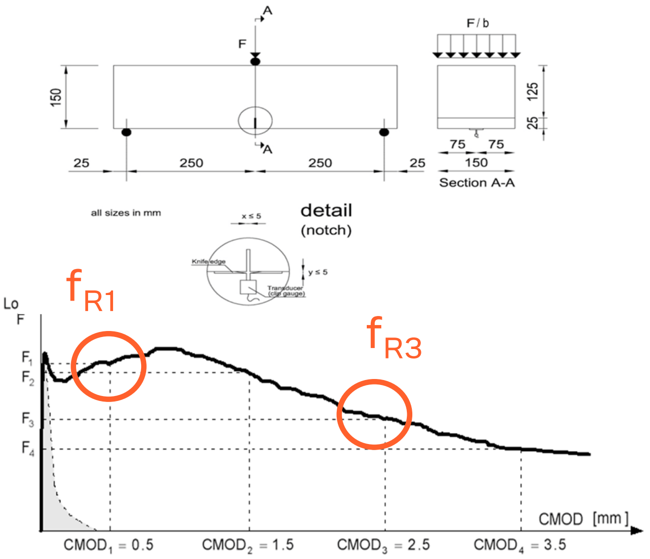
Standardized beam test for SFRC

EN 14651



Standardized beam test for SFRC

EN 14651



Classification according to ModelCode 2010:

5d

f_{r1k}

1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0

f_{r3k}/f_{r1k}

a: $0.5 \leq f_{r3k}/f_{r1k} < 0.7$

b: $0.7 \leq f_{r3k}/f_{r1k} < 0.9$

c: $0.9 \leq f_{r3k}/f_{r1k} < 1.1$

d: $1.1 \leq f_{r3k}/f_{r1k}$

Requirement according to ModelCode 2010:

$f_{r3k}/f_{Lk} > 0.4$

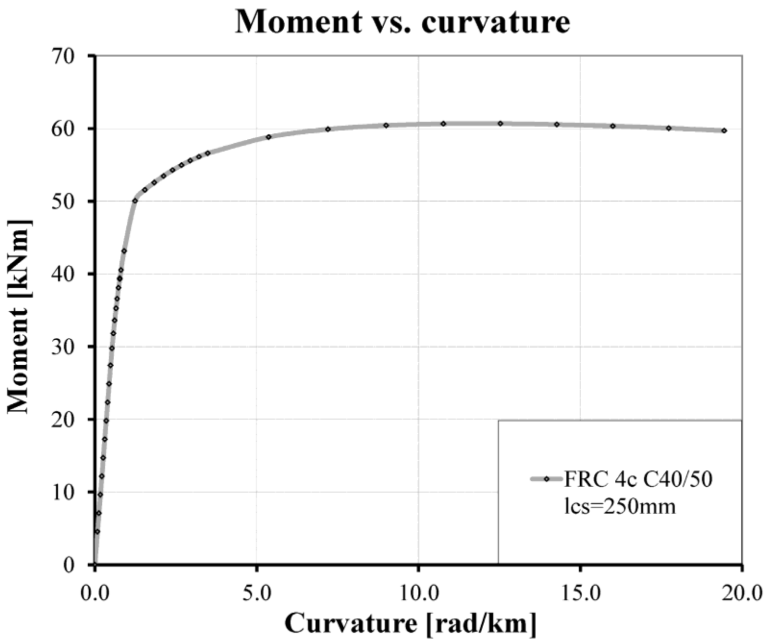
$f_{r3k}/f_{r1k} > 0.5$

→ Fibers can substitute conventional reinforcement in ULS

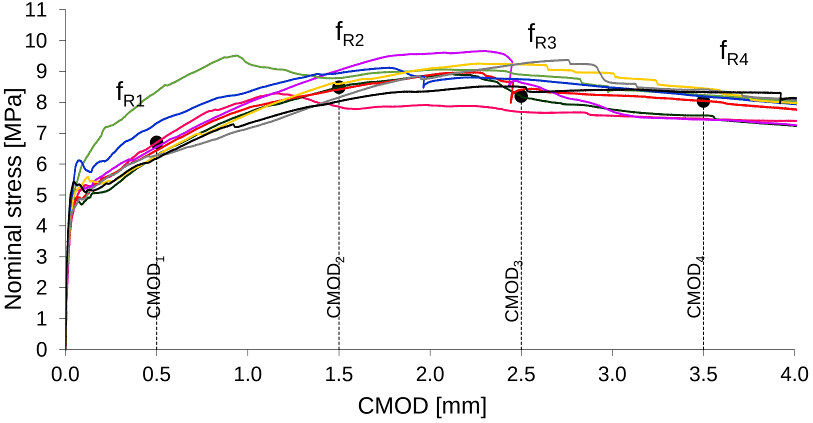
FRC only solution

Hardening behaviour in bending (at sectional level) allows immediately:

- Structural ductility (ULS)
- Cracking control (SLS)



Material Example 40kg/m3 Dramix 4D 80/60BGP



	f_L [Mpa]	f_{R1} [MPa]	f_{R2} [MPa]	f_{R3} [MPa]	f_{R4} [MPa]
Beam_01	4.68	6.70	7.86	7.69	7.47
Beam_02	4.90	6.28	8.49	8.20	7.58
Beam_03	4.78	6.45	8.41	8.42	8.04
Beam_04	5.15	6.56	9.04	8.64	7.44
Beam_05	5.72	7.33	8.95	8.75	8.19
Beam_06	5.03	6.27	8.60	9.23	8.45
Beam_07	5.63	7.75	10.2	8.99	8.54
Beam_08	4.60	6.28	8.16	9.25	8.40
Beam_09	5.43	6.18	8.03	8.50	8.33
Average	5.10	6.64	8.64	8.63	8.05
Characteristic	4.30	5.58	7.26	7.65	7.19

Hardening post crack behaviour

Performance class type
5e according to MC2010

Load conditions

Transient load stage

demoulding

stacking

handling, transportation

Lead to bending moments and shear forces

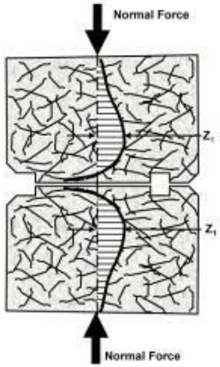
Usually designed as uncracked in transient load stage, but with increased ductility

1. A material condition: $f_{R1k} / f_{LOPk} \geq 0.4$ and $f_{R1k} / f_{R3k} \geq 0.5$
2. A structural condition: $M_u \geq M_d$ which results in a required f_{R3k}

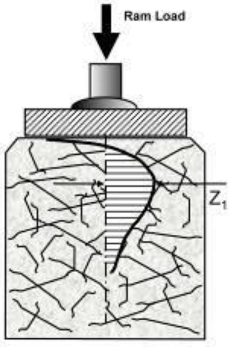
Load conditions

Bursting forces – main challenge when designing precast segments

Bursting in segments occurs from two different types of loads



Ring bursting



Ram bursting

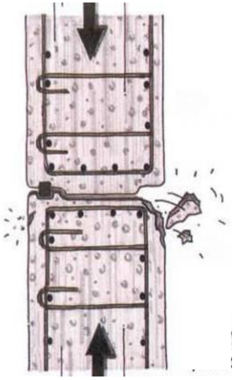
In-place forces due to compression in the ring

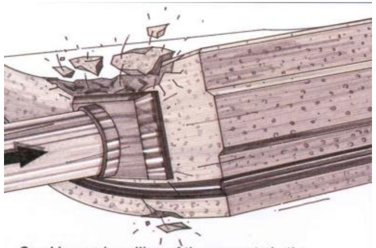
During the installation by the application of ram loads to the edge of the segments

Traditional reinforcement

- Minimal concrete cover requirements for corrosion
- Particular shape edges

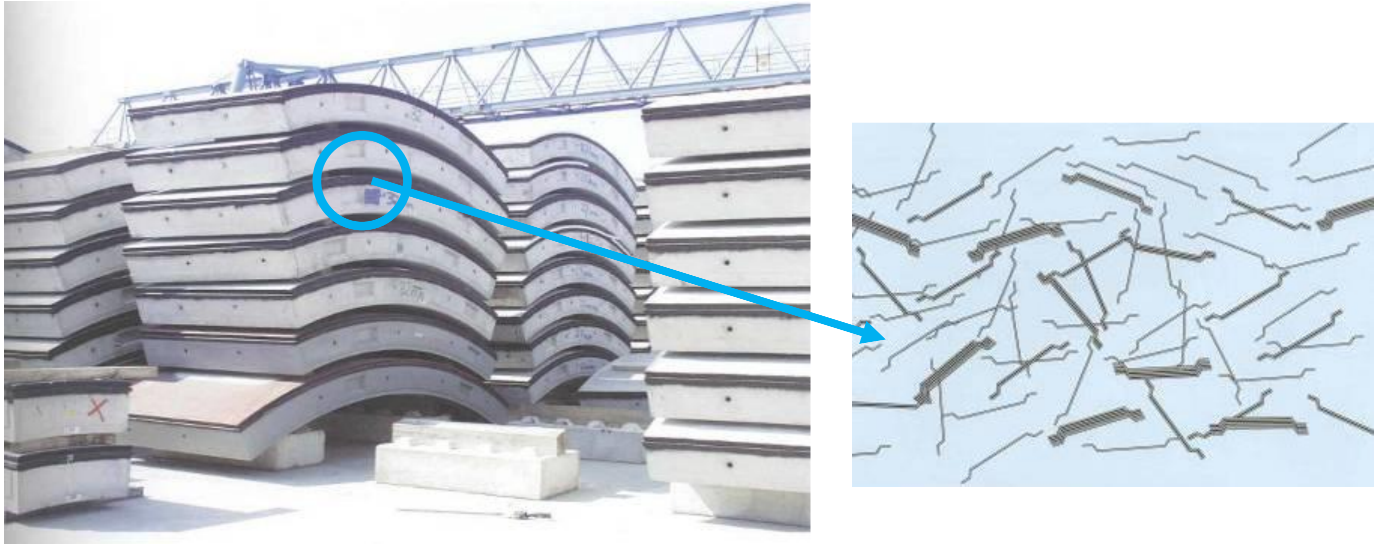
→ Vulnerable edges





Cracking and spalling of the concrete in the cover zone at the joint of a segment.

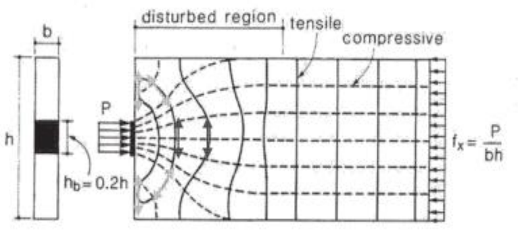
Steel fibre reinforced concrete (SFRC)



Load conditions

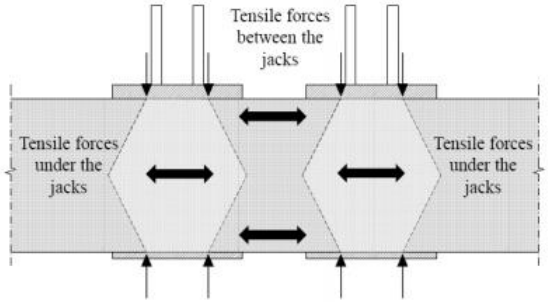
Bursting forces – main challenge when designing precast segments

Bursting forces during TBM thrust phase



(a) Principal stress trajectories

local segment behaviour



global segment behaviour

Tensile strength SFRC:

$$f_{Rd,split} = \alpha_3 \cdot \frac{f_{R3,k}}{\gamma_{ct,split}}$$

Conversion factor
bending tension -> axial tension

Load conditions

Final stage

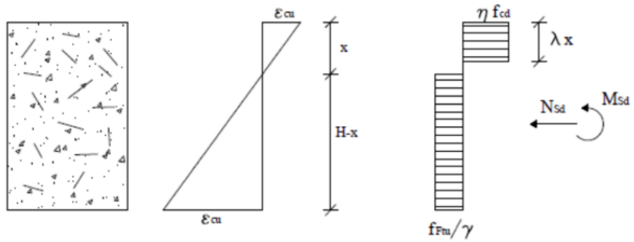
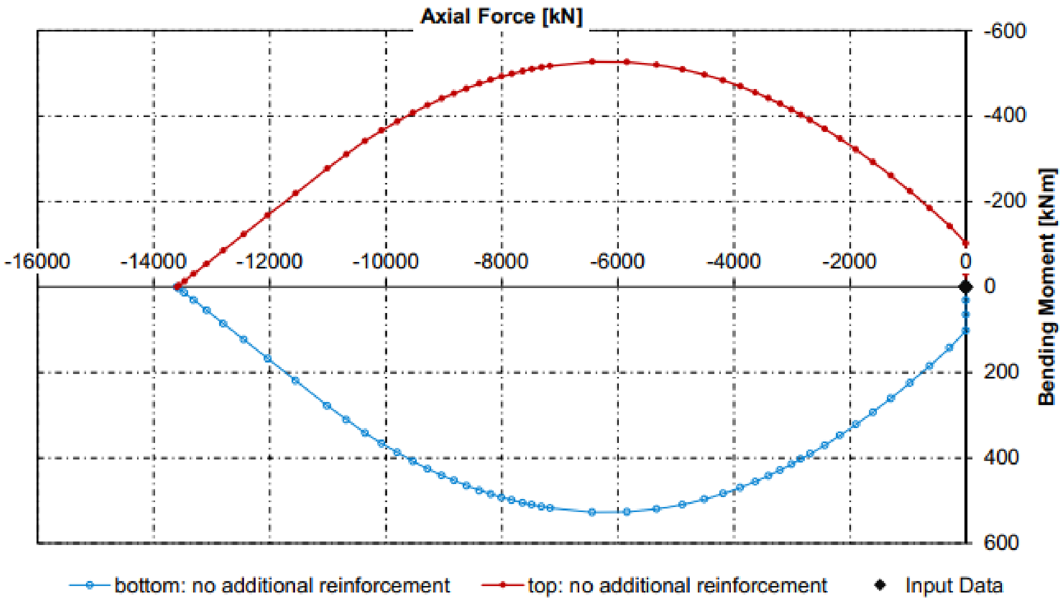


Fig. A1-1: Simplified constitutive relationships of FRC, for the evaluation at ULS.

At geotechnical level, no difference between SFRC and RC

Combination of M and N



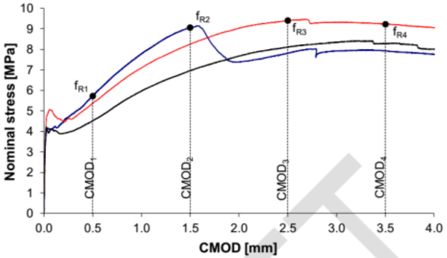
Example for 300mm – C40/50 – 5d

Alternatively: design by testing

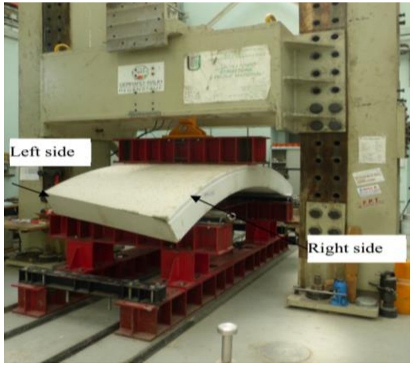
Dramix® 4D 80/60BGP - Tests led by Prof. Meda

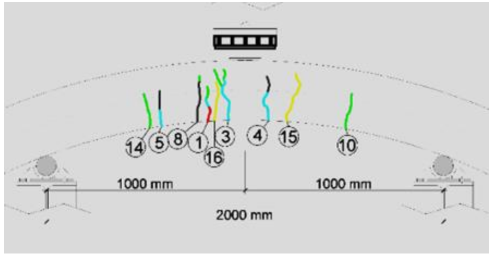
Università degli Studi di Roma "Tor Vergata"
CIVIL ENGINEERING AND COMPUTER SCIENCE DEPARTMENT
TERC – TUNNELLING ENGINEERING RESEARCH CENTRE

Material Characterization

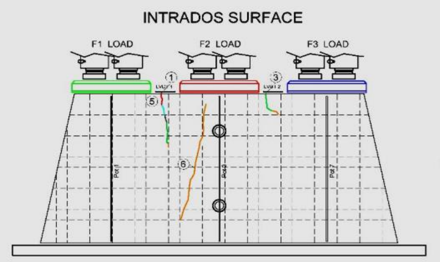


Bending Test





Point Load Test

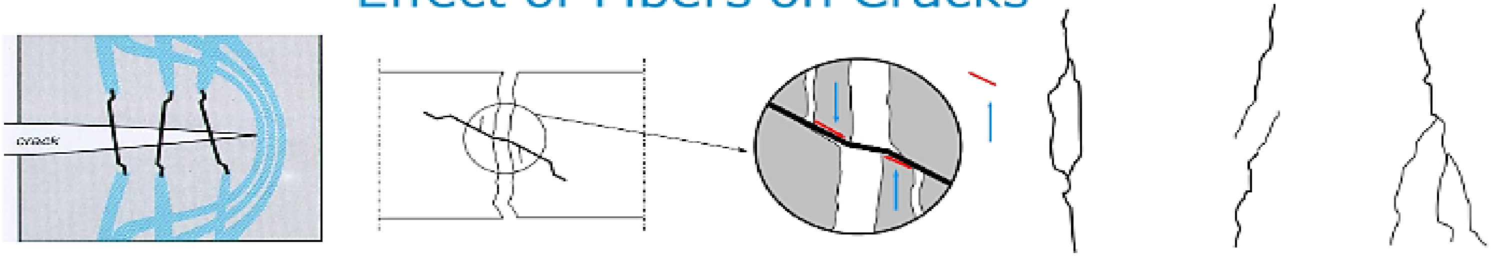


Durability a key issue : 120 years design life

SFRC BEST SOLUTION

Solution: Segments reinforced with steel fibers, *having a bending hardening behavior*, contain cracks much thinner Effect of Fibers on Cracks segment reinforced with steel rebar.

Effect of Fibers on Cracks



- "Comparing crack width in RC segments with FRC segments indicate a better performance in favor of fibers by as much as an average value of 43%"

In order to assess the durability of SFRC a number of parameters such as the exposure conditions and concrete quality, have to be considered, in particular with regards to chlorides.

BEKAERT better together

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fib bulletin 83

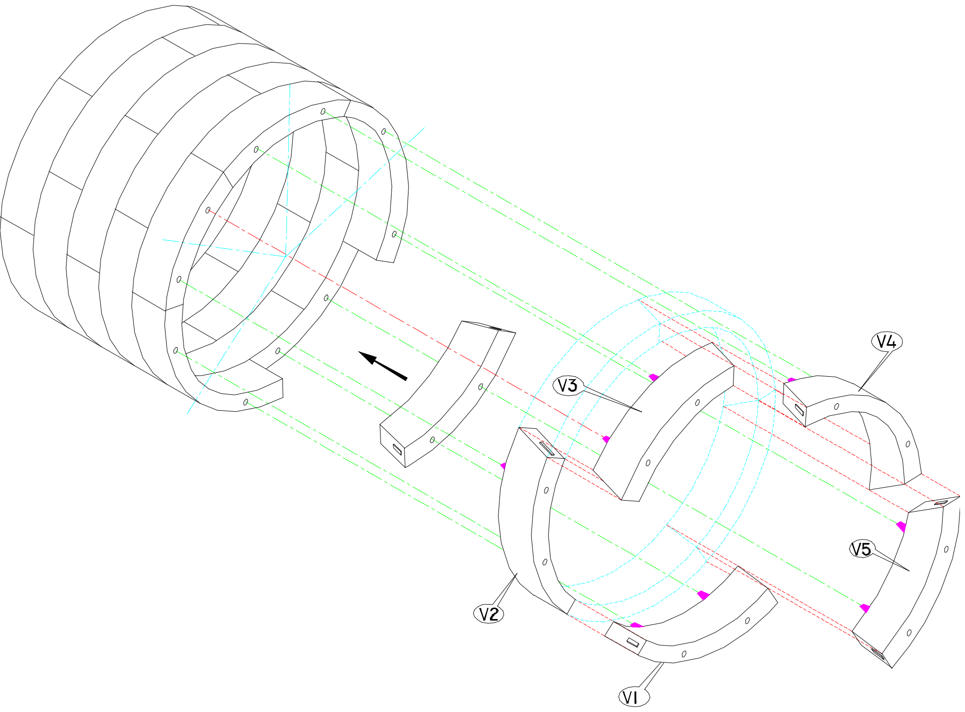
Focus on durability

Conclusions chapter 8

- **Uncracked concrete**
  - If chloride/carbon dioxide threshold is reached, fibers can corrode
  - Only in vicinity of surface (outer 1-5mm)
  - Does not result in cracking/spalling: volume increase corrosion very limited!
- **Cracked concrete**
  - Main recommendation today: wk = 0,20 mm
- **Stray-current fiber corrosion**
  - E.g. from metro systems
  - Experiments show risk is significantly reduced compared to traditional concrete

→ Overall improved durability to corrosion compared to conventional reinforcement

New development in the segmental lining design



Ever increasing concrete compressive strength for fast demoulding

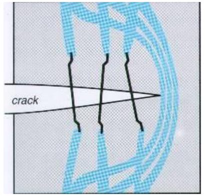
Higher concrete compressive strength

=

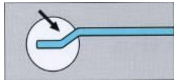
More steel to meet “non brittle failure” requirements

The quality of Dramix® is due to a combination of factors...

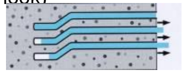
- Wire strength
- Wire elongation
- Shape
- Length
- Diameter
- L/D ratio



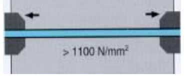
- A **high length-diameter ratio** (L/D ratio)
- **Hooked ends**



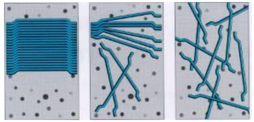
- **Controlled pull-out** (due to deformation of the hook)



- **High tensile strength steel**



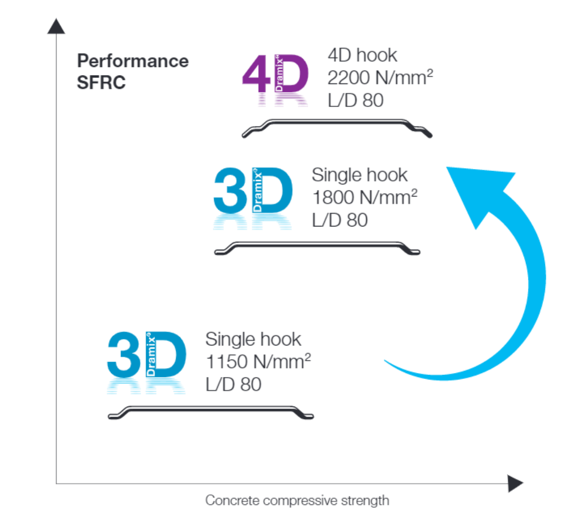
- A system of glued fibre bundles enables fibres with a high L/D ratio to be mixed easily and uniformly throughout the concrete



The tensile strength of a steel fibre has to increase in parallel with the strength of its anchorage. Only in this way can the fibre resist the forces acting upon it.

4D 80/60/BGP = 4 644 fibre/kg

40kg/m3 4D 80/60BGP > 11 000 lm/m3



l/D	80/60	65/60	45/50
Length (mm)	60	60	50
Diameter (mm)	0.75	0.90	1.05
Aspect Ratio	80	65	45
Network (m/kg)	276	200	147

Tunneling Tomorrow

Bye, bye concrete ?

“Concrete is recognized as the second most widely consumed commodity on the planet after water. It also contributes approximately 8% of global carbon emissions; the main source of these emissions is the manufacture of Ordinary Portland Cement (CEM I)

In a tunnelling project, **it is generally considered that 60% to 70% of embodied carbon is contained in the concrete linings of the shafts and tunnels**. It is paramount, therefore that the tunnelling industry does its utmost to significantly reduce or eliminate its use of cement in all applications – segmental linings, in-situ linings, sprayed concrete and annulus grouts.” C.A

“When it comes to crimes against the environment, one of the tunneling’s most often –used materials is one of the biggest offenders: cement. Expert says that the cement industry produces 5 percent of the global warming gases. “ I believe that in 10 years we will see concrete replaced by others materials, such as geopolymer”

Tom Melbey
ITA Workshop

Carbon Footprint Reduction in Construction Projects

- **Carbon Emission Throughout the Entire Life Cycle of Infrastructure**
  - Product Stage & Construction Stage (Stage A), Usage Stage (Stage B), End of Life Stage (Stage C)
- **Embodied Carbon**
  - Includes Stage A1 through A5 & Contribute ~80% of Total Carbon Emission of Infrastructure Projects
- **Measures to Reduce Embodied Carbon**
  - Design Optimization
  - Reducing Portland Cement & Steel
  - Enhancing Equipment Efficiency
- **Design Optimization Measures**
  - Innovative Designs
  - Efficient & Economical Design
- **Measures to Reduce Cement & Steel**
  - Use of Supplementary Cementitious Materials (SCMs) Such as Slag, Fly Ash, Silica Fume
  - Use of Fiber Reinforcement In Place of Rebar
  - Paste Volume Reduction Through Aggregate Optimization

BUILDING LIFE CYCLE INFORMATION																ADDITIONAL INFORMATION
PRODUCT STAGE			CONTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFIT AND LOAD
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw materials supply	Transport	Manifacturing	Transport	Construction	Use	Maintenance	Repair	Replacement	refurbishment	operational energy use	operational water use	de-construction / demolition	Transport	Waste processing	Disposal	reuse, recovery or recycling

Breakthrough in the Middle East - Timeline

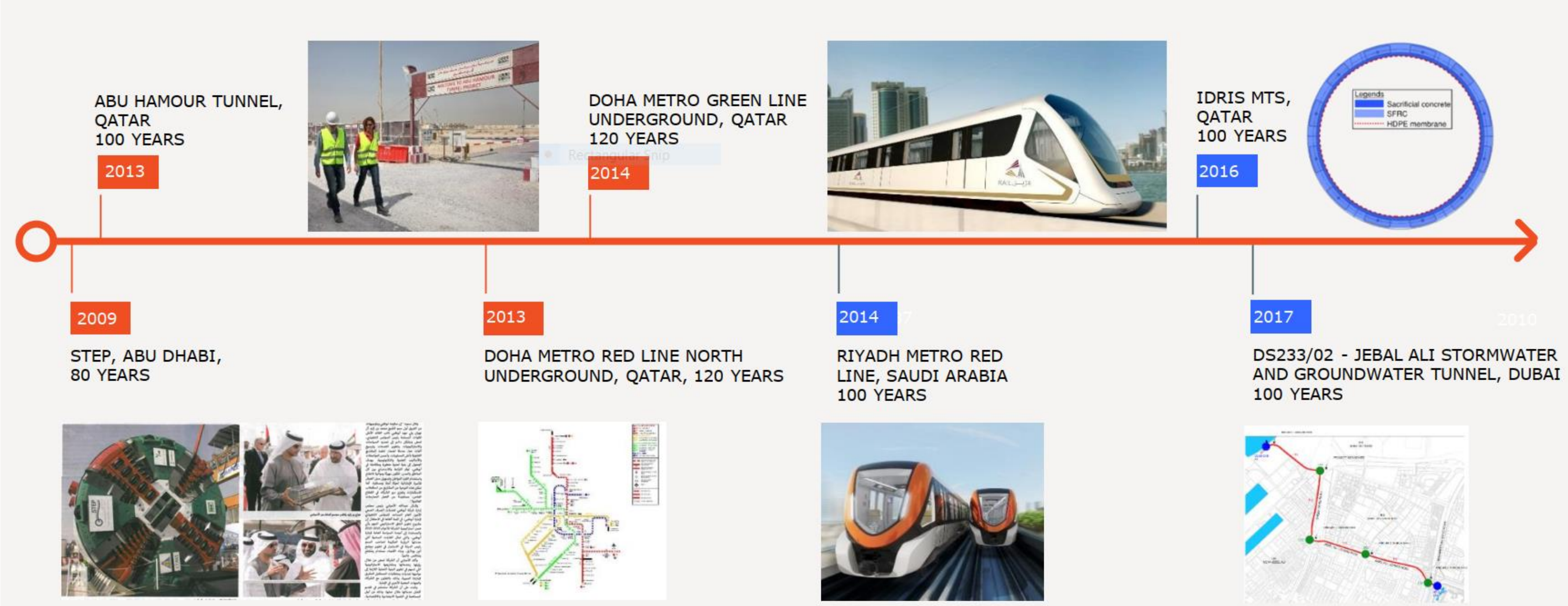
Achievements made without sacrificing durability, through:

Very high chloride content : 160 – 90,000 mg/l (5x higher thanNorth sea)
- High levels of sulphates : 130 – 6,000 mg/l

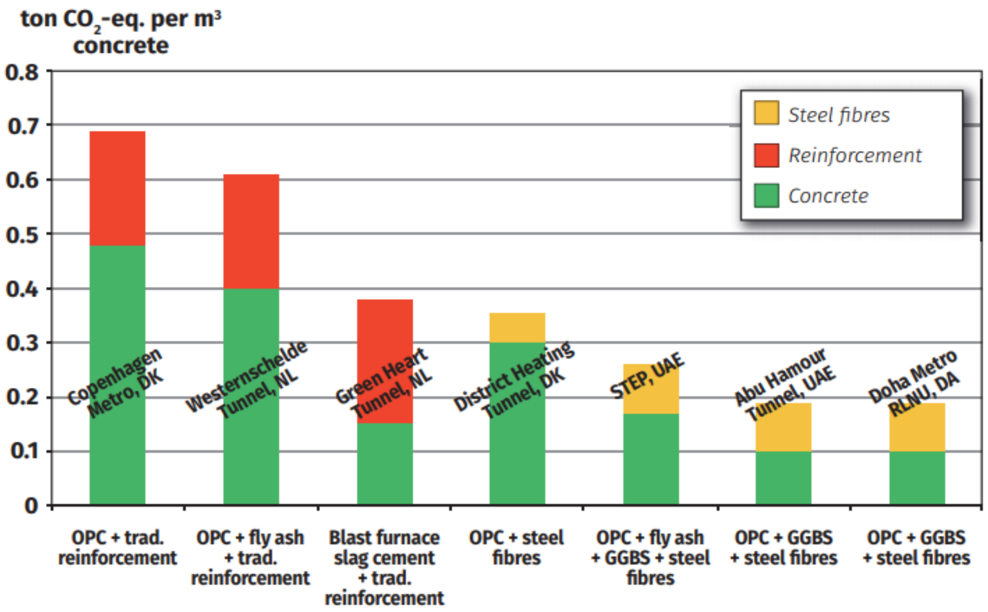
- **Steel fibre: Reduced CO2 emmission**
- Concrete mix design: High content of sup. Cementitious materials **(GGBS & FA) → Reduced CO2 emission**

Lesson learn : Durability and Sustainability goes hand in hand

A paper by consultant COWI Denmark entitled **'The consultant's view on service life design" C. Edvarsen**



Low Carbon Concrete Lining for tunnels - voice of the customers



Comparison of embodied CO2 for different types of binder and steel reinforcement used for various major infrastructure projects

A paper by consultant COWI Denmark entitled **'The consultant's view on service life design"** provides this example how much CO2 emission saving was reached by replacing traditional concrete and steel-reinforced with steelfiber reinforcement and adding GBBS/FA to the concrete mix.

- **Use of GGBS & FA: > 75% CO_2 reduction**
- **Use of steel fibres: > 50% CO_2 reduction**

- **Doha Metro have just 0,2to vs 0,7to of CO2 emission which Copenhagen Metro had.**

- **If Doha Metro would be built "traditional"… = 400.000 tons more CO2 emission**

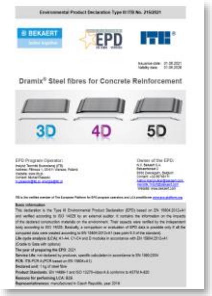
Note:
GGBS (Ground Granulated Blast-furnace Slag) is a cementitious material whose main use is in concrete and is a by-product from the blast-furnaces used to make iron.

FA (Fly ash) is a particulate material produced from the combustion of coal in thermal power plants. It´s also a by product The fine powder does resemble Portland Cement but it is chemically different. Fly ash chemically reacts with the byproduct calcium hydroxide released by the chemical reaction between cement and water to form additional cementitious products that improve many required properties of concrete.

Measuring the Carbon Emissions

------- EPD's are created for reporting, not for comparison but they can be compared on fair and equitable basis -------

Environmental Product Declaration (EPD)



What is an EPD?

- 3rd party certified certification that allows to transparently communicate the key environmental performance indicators of Dramix® over its lifetime

How Dramix performs?

Dramix® EPD Score
0.88kgCO2e

Dramix® recycled content*
25%

How we continuosly improve?

Sustainable wire rod sourcing

Energy purchasing from renewable sources

Green building solutions

Quantifying Dramix® Sustainability Impact

What is a life cycle assessment (LCA):

- Science-based methodology for quantifying lifetime environmental impacts of building

How we calculate:

BEKAERT better together + One Click LCA

- LCA software for construction
- Compare the CO_2 savings
- Creates awareness with transparency

What's in it for customer

- Informed decision making on sustainability at design phase
- Building Certification impact
- Control the environmental impact of design and comply with standards

**average, based on 2022 data, all plants*

Dramix®

Grand Paris Express in a nutshell:

Line 16

Entities involved

• Owner	Société du Grand Paris (SGP)
• Designer	Egis
• Contractor	Eiffage Génie Civil
• Precast plant	Bonna Sabla

Tunnel parameters

• Year of construction	2020 - 2021
• Designed lifetime	100 years
• Total length (excavated)	19 km
• Diameter	8,70
• Quantity	5.200T

Segmental lining parameters

• # of segments	7 per ring (incl. key)
• Size of segments	L 2m x W 4m x T 0,40m
• Concrete quality	C50/40
• Fiber type	Dramix® 3D 80/60 BGP
• Fiber dosage	40 kg/m³

Voice of the Owner: Less Steel to Save Steel

- *“Our innovation policy is above all a lever for making the Grand Paris Express a project in the service of ecological transition and developing practices in the world of public works.*
- *This is why we are orienting many of our projects towards sustainable design and construction, such as reducing concrete, choosing materials or even operating solutions for the metro that consume less energy.*
- *Innovations have already given significant results….*
- ***The use of fiber-reinforced concrete for the construction of the segments of part of line 16.** This is a first in France in underground work. Compared to reinforced concrete, fiber-reinforced concrete notably represents **savings of around 5,000 tonnes of steel for 10 kilometers of tunnels”***
- *AFTES CONGRESS/SPG Website*

Jean François MONTEILS

Chair of the Board of Sociéte du Grand Paris

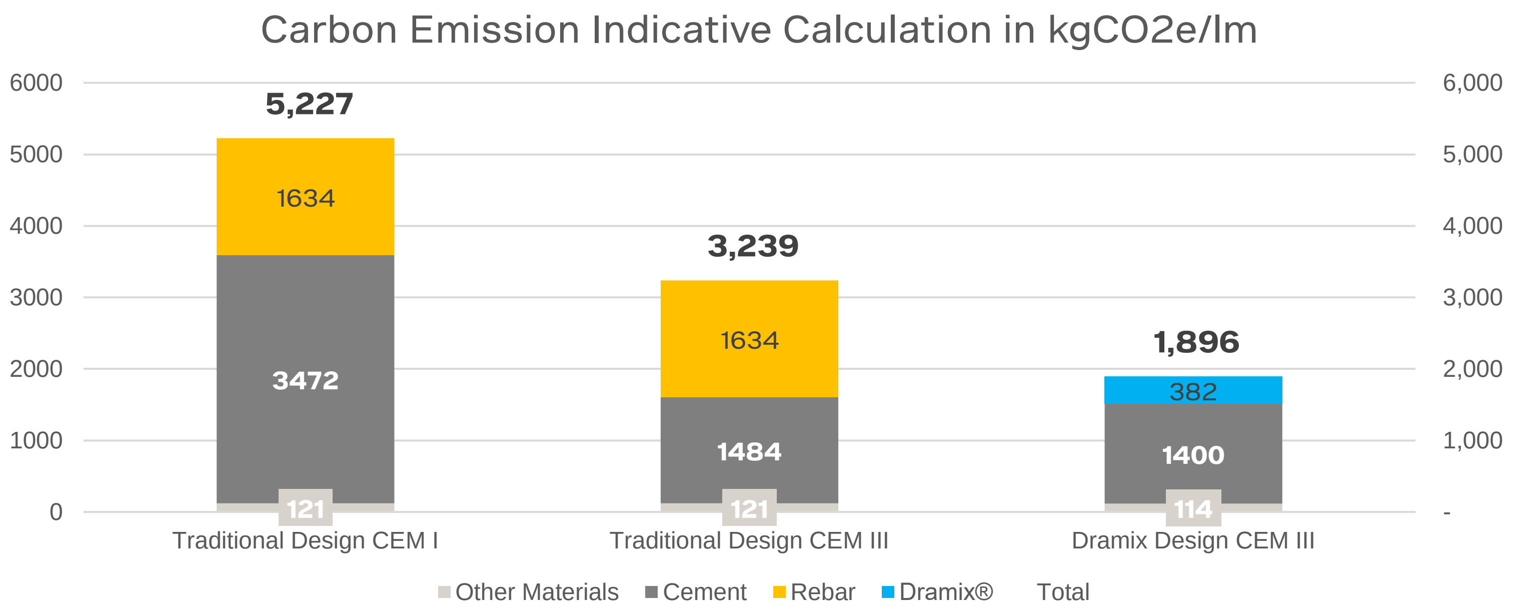
BEKAERT better together

Fibre-reinforced concrete takes over in Greater Paris

- Futhermore in terms of resources, FRC can reduce the quantities of concrete by 2 to 3 cm segment thickness.

- In addition to the quantities of steel and concrete saved, fiber-reinforced concrete also reduces CO2 expenditure, both in cement factories and in steelworks: **10,000 tonnes of CO2 are saved on average for 10 km of tunnels compared to Rebars**
.

Example of Once click LCA calculation for Metro precast segment



This calculation is based on the generic EPD values during the early design phase, indicative calculation to demonstrate potential CO2 savings, as project evolves the exact materials used during construction may change the results.”

WEBUILD Case study – Concrete segmental lining FAL project

- The Forrestfield-Airport Link (FAL) delivers an 8.5
  km extension of the existing PTA urban rail network in Perth, Western Australia.
- The twin-bored tunnels travel underneath the Swan River, Tonkin Highway and Perth
  Airport. The project includes three new
  stations.

WEBUILD Case study – Concrete.segmental lining FAL project

- Case study :
  - steel fibre-reinforced concrete;
  - light steel reinforcement rebar cage;
  - polypropylene fibres to comply with the fire resistance requirements;

Concrete requirements: 120 year service life

Carbon footprint for 1 m^3 of reinforced concrete

In terms of the specific concrete mix design for the precast segmental linings, several trials were performed with cast concrete beams according to standard BS EN 14651 (single trial was made with nine concrete beams) **with 35kg/m^3 of Dramix® 4D 80/60BGP steel fibres. The characteristic values of these results were more than the serviceability state 5.08MPa at CMOD1 and 5.28MPa at CMOD3.** The results have confirmed the assumptions for the quantity reduction and the mix with 35kg/m^3 of steel fibres content was adopted in project works.

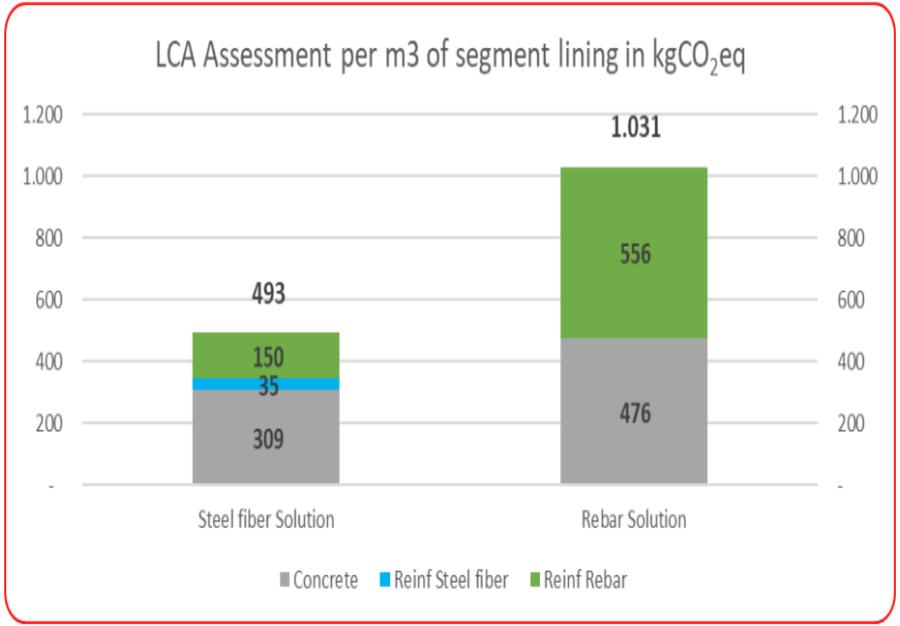
Carbon Footprint

Steel fiber Solution

Dramix	35 kg/m^3
Dramix amount per ring	1.707 kg
Rebar	35 kg/m^3
Rebar amount per ring	1.707 kg
Concrete	Triple blend 425 kg/m^3 (GP+GGBS+SF)

Rebar Solution

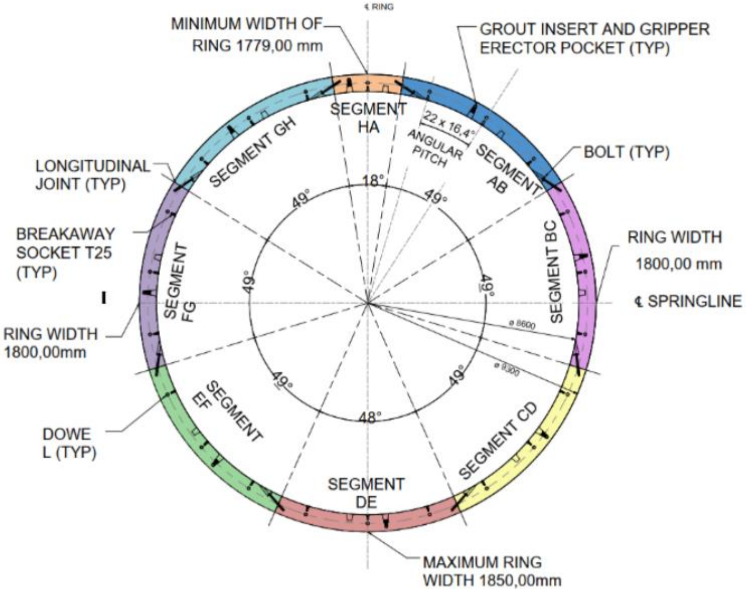
Rebar	130 kg/m^3
Rebar amount per ring	6.342 kg
Concrete	CEM I 400 kg/m^3

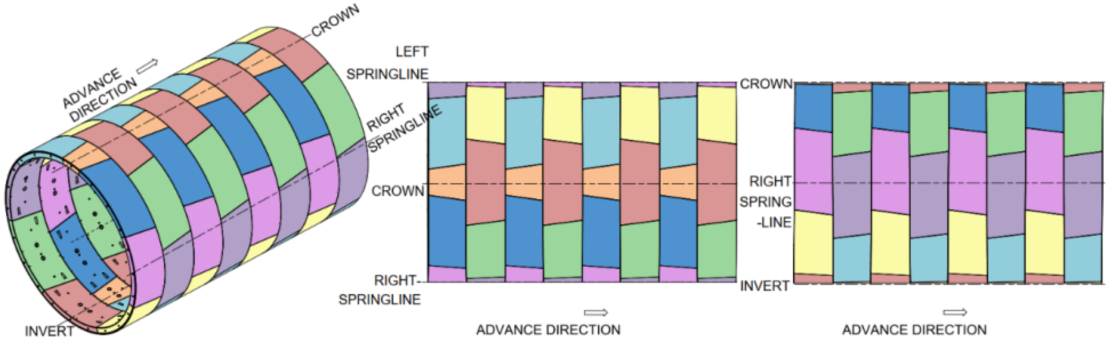


Montreal Blue Line Extension

Design by AECOM

- 6 km two-track tunnel
- 5 new stations
- Internal diameter 8,6m
- 7+1 segments
- Thickness 350mm
- 40 kg/m³ Dramix 4D 80/60BG





Applying ACI 544.7R for Design and Construction of FRC Tunnel Segments in North America with Fiber-Enabled Carbon Footprint Reduction – M. Bakhshi & V. Nasri

Project Example: CO_2 Reduction in Montreal Blue Line Ext. TBM Tunnel

- **Design Optimization**
  - Segment Thickness Reduction from 40cm in Design with Rebar to 35cm in Final Design with Steel Fiber
- **Optimization of Concrete Mix Design**
  - Partial Replacement OPC with SCMs (Slag by 22% & Silica Fume by 5%)

Mix Design Component	CO_{2eq} Factor	Baseline Concrete Mixture (OPC) with Rebar: Mass (kg/m^3)	Baseline Concrete Mixture (OPC) with Rebar: CO_{2eq} (kg/m^3)	Baseline Concrete Mixture (OPC) with Rebar: % Replacement by Mass	Optimized SCM Concrete Mixture with Rebar: Mass (kg/m^3)	Optimized SCM Concrete Mixture with Rebar: CO_{2eq} (kg/m^3)	Optimized SCM Concrete Mixture with Rebar: % Replacement by Mass	Optimized SCM Concrete Mixture with Steel Fiber: Mass (kg/m^3)	Optimized SCM Concrete Mixture with Steel Fiber: CO_{2eq} (kg/m^3)	Optimized SCM Concrete Mixture with Steel Fiber: % Replacement by Mass
Portland Cement	0.92	475	437		346.8	319.1		346.8	319.056	
Slag	0.1466	0	-	0%	104.5	15.3	22%	104.5	15.3	22%
Fly Ash	0.093	0	-	0%	0	0	0%	0	0	0%
Silica Fume	0.014	0	-	0%	23.8	0.3	5%	23.8	0.3	5%
Admixtures	1.67	4.5	7.5	1%	4.5	7.5	1%	4.5	7.5	1%
Aggregate	0.006	1430	8.6		1430	8.6		1430	8.6	
Steel bar	1.85	80	148		80	148		-	-	
Steel Fiber	0.9	-	-		-	-		40	36.8	
		Total	601.1		Total	498.8		Total	387.6	

Just By Eliminating Intrados and Extrados Cover:

Unit Carbon Saving:

- SCM: 17%
- Fiber: 19%
- Total (SCM+Fiber):36%

Project Example: CO_2 Reduction in Montreal Blue Line Ext. TBM Tunnel (2)

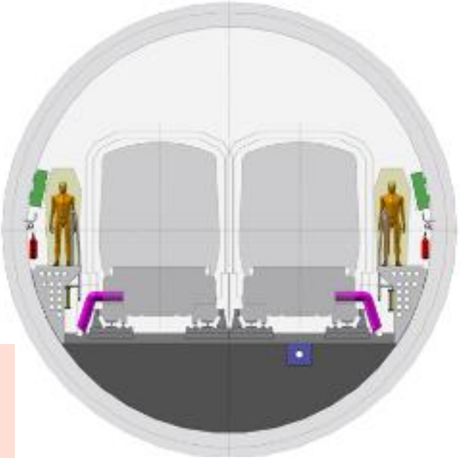
- **Total Carbon Saving with <u>Optimized Design</u> & Using SCM & Fiber**

	Ring width (m)	Tunnel length (m)	D_{ex} (m)	D_{in} (m)	Ring Volume (m^3)	Total concrete volume (m^3)	CO_{2eq}/m^3 (kg)	CO_{2eq}/1 m tunnel (ton)	Total CO_{2eq} (ton)
40 cm Thick Segments OPC w/ Rebar	1.8	6000	9.4	8.6	20.4	67858	601.1	6.8	40,790
35 cm Thick Segments SCM w/ Fiber	1.8	6000	9.3	8.6	17.7	59046	387.6	3.8	22,886

Total Carbon Saving with Optimized Design Enabled Using Fiber:

- Use of SCM: 8,578 ton (21%)
- Use of Fiber: 9,325 ton (23%)
- Total: 17,903 ton (44%)

Reduction in thickness primarily by concrete cover requirement 60-75mm on both intrados and extrados to ensure durability against corrosion according to Canadian code CSA A23.1:19 (2019)



Conclusion

- The main source of carbon emission in tunnel construction is concrete.
- Reduce the thickness of the precast segment ,combined with less steel and new generation of binder will decrease C02 emission by more than 50 %
- **High performance Dramix® steel fibre will play a key role in this Hollictic process**
- Model Code 2010 , fib bulletin 83 provide design principle
- Fib bulletin 83 state of the art report detail guidance for precast segment
- Fibre Reinforced concrete could be used safely considering the right testing method and performance criteria based on EN 14 651
- Certain low carbon binders are not available everywhere, but steel fibers are, so implementing those would be a great start

Thanks for your attention

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