Workshop on Observational Approach in Tunnelling: Evolvement, Issues and Challenges.
24th – 25th June 2022
Mumbai

Use of Steel Fiber for Segmental Lining

Steel Fiber Reinforced Concrete

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Amit Kaul
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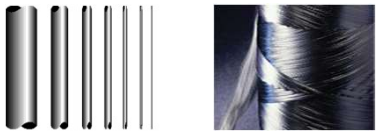
25th June 2022

Who Are We

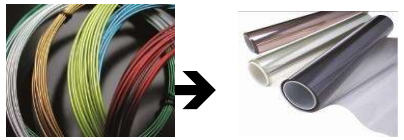
Bekaert In A Nutshell*

- ❑ Founded In 1880 By Leo Leander Bekaert
- ❑ Customers In 120 Countries And In The Most Diverse Industry Sectors
- ❑ Global Manufacturing Platform
- ❑ 28 000 Employees Worldwide
- ❑ Combined Sales Of 5 Billion Euro
- ❑ Consolidated Sales Of 3.3 Billion Euro
- ❑ Listed On Euronext® Brussels



6.5 mm → 1 µm

A human hair = 50 µm



From traditional coatings to advanced coatings

- ❑ **Bekaert Is A Worldwide Player Active In Selected Applications**
- ❑ **Based On Our Two Core Competences**
  - ❑ Advanced Metal Transformation
  - ❑ Advanced Materials And Coatings

History

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pioneering

1880
Leo Leander Bekaert starts a small business in barbed wire in Zwevegem, Belgium

1922
First investment abroad: Tréfileries de Bourbourg, France

1948
First investments in Latin America: Argentina and Chile

innovating

1952
Steel cord production start

1964
Establishment of R&D center in Deerlijk, Belgium

1965
Start-up of Engineering facility for machine design and manufacture

growing

Early 1970s
New steel cord plant openings and expansions in US, Brazil, Belgium, Japan

1972
Listing on the Brussels stock exchange to fund continued growth

1975-1977
Establishment of joint ventures in Ecuador and Brazil

diversifying

Early 1980s
Bekaert moves into composite materials, non-ferrous forged products, vacuum coatings and filtration

1988
New plant openings in the US in response to local demand

1990
Bekaert has become a truly international company with 15000 employees worldwide

BRIC

1993
Bekaert recognizes China's huge market potential and builds a first steel cord plant in Jiangyin, Jiangsu Province

Mid 90s
Investments and expansions in Brazil, India, Indonesia, China, Peru and Chile

2000-2010
Strong growth in China, Central Europe, and start-up production in Russia

transforming

2013
Bekaert lifts its ambition level and deploys global excellence programs across the business

2014-2016
Bekaert concludes its largest acquisition (Pirelli) and merger (Bridon) ever

2020
Bekaert delivers on all priorities set forth and counters the impact of the pandemic

Bekaert Journey in India

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1985

Bekaert entered India market with Dramix® steel fibres, with Tata Steel as an agency agreement in 1985.
First Project – Srisailam Hydro Power.

1995

Nathpa Jhakri hydropower project largest and longest headrace tunnel, and underground power complex.

1996

Marsyangdi hydropower project was one of the notable projects by Bekaert done in Nepal

1998

Tala Hydroelectricity is the biggest hydroelectric joint project between India and Bhutan

1999

1999 completed over 15 Hydro Projects and also Bekaert steel cord plant in Ranjangaon, Pune

2005-07

This partnership continued until 2005. Bekaert made a strong leadership position in the hydropower market.
2007 Bekaert started its own office for building products

2009

Worked with all major Government bodies in power sector since 1985 including, NHPC, NTPC, NEEPCO, SJVN, etc.

2010

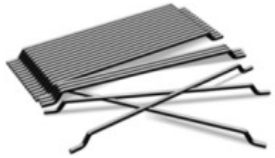
Bekaert continues to enjoy its leadership in the road tunnels sector with major projects like Jaipur tunnel , Rohtang road tunnel and Mumbai-Pune expressway (1998) reinforced with Dramix® SFRS

2012

Completed 400+ Projects (flooring + hydro) within a span of 4 years*. 31+ ongoing & completed tunneling projects. Worked with Indian railways, NHAI

2020

Introduced 2 New Applications
Cast In Situ Lining (USRBL)
& PSCL Application
(Mumbai Metro)

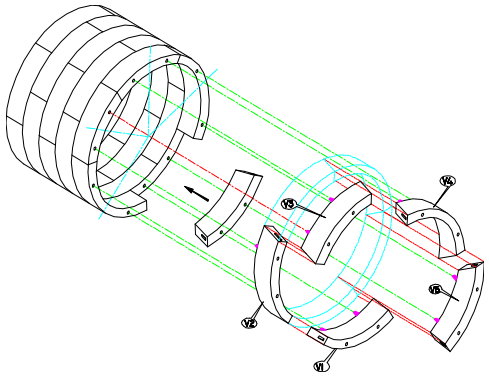


Modern Trends in Tunneling .....

- Conventionally Tunneling Was Always Considered In Mountains And Long Term (Time Consuming) Projects Due To Limited Resources And Technologies.
- With Increased Demands And Modern Techniques, The Tunneling Is Becoming Essential Part Of Infrastructure Development.
- With Increased Demands, Various New Methods Have Been Brought For Timely Completion With Minimum Possible Investments
- Tunnel Boring Machines (TBM's) Have Thus Become One Of The Ideal Resource As An Alternative Method To Conventional Drill & Blast (D&B) Tunneling In Variety Of Geological Conditions Varying From Very Hard Rock To Poor/ Squeezing Ground Conditions.
- TBM Has Advantage Of Limiting The Disturbance To Surrounding Ground And Produce Smooth Tunnel Wall Resulting In Significant Reduction In The Lining Costs And Makes Them Suitable To Use In Heavily Urbanized Areas And Significant Benefits In Long Mountainous Tunnels.

Advantages TBM Tunneling .....

- TBM Best Suited For Long Tunnels In Mountains- Continuous Boring & Lining Installation
- Most Suitable Options For Urban Tunnels
- **Reduced Cost Of Lining**- Uniform & Pre-cast
- **Faster Construction**- Project Completion Time
- Safe



Basic Requirements of Lining Segment

- **Hardened Properties**
  - Durability
  - Strength
  - Longevity
  - Finish
  - **Load Bearing & Load Transfer**
  - **Removal From Mold And Stacking For Curing**
  - Transportation From Yard To Site
  - **Repair & Maintenance**
- **Plastic Properties**
  - Ease Of Placing
  - Early Strength Development

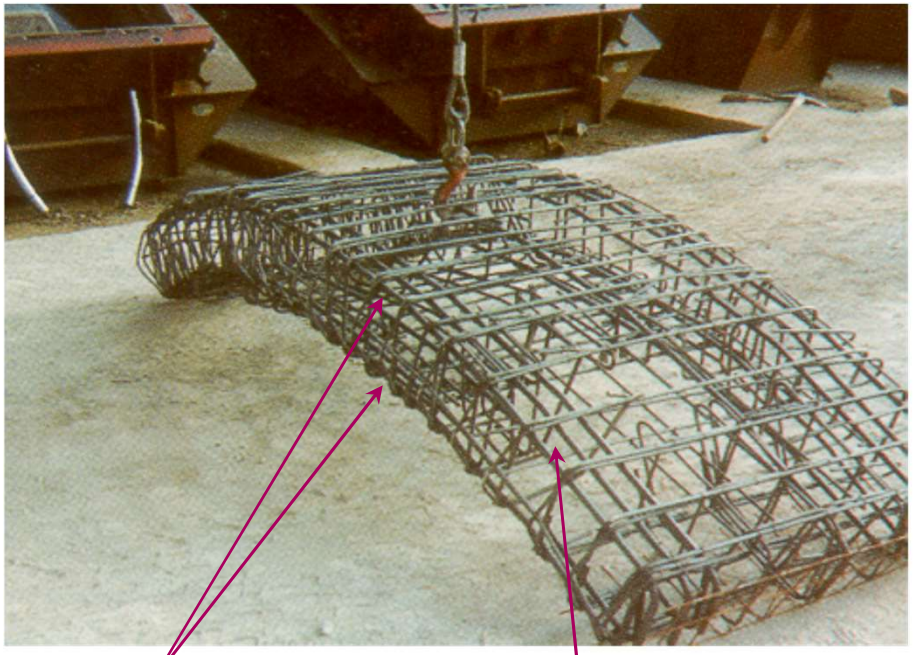
Current Practices….

- **Conventional Reinforcement**
  - Rebar Cages- Typical Reinforcement for Segments



Current Practices….

- **Conventional Reinforcement**
  - Rebar Cages- Typical Reinforcement for Segments



Heavy Reinforcement With Rebars: From 70 To 120 Kg/M³

The Reinforcement Cage Has To Resist:

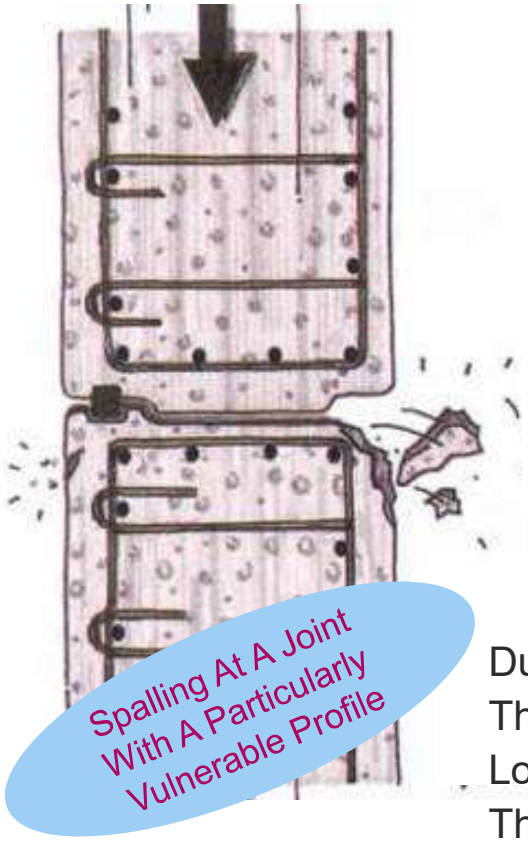
- Demolding Forces
- Stacking Forces
- Transportation Forces
- Spalling Forces
- Jacking Forces

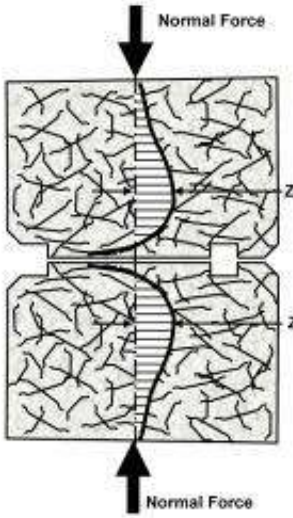
Possible Considerations…

- **Cycle Times:**
  - Cage Construction- Time & Labor Intensive
  - Installation of Reinforcement
- **Land Requirements:**
  - Sufficient Space- Reinforcement Yard
  - Casting Yard
- **Concrete Placement:**
  - Dense Reinforcement
  - Low Slump Concrete
- **Segment Quality:**
  - Cage Placement in Mold- Determine Quality

Possible Considerations…

- **Inadequate Reinforcement:**
  - Minimal Concrete Cover Requirement For Corrosion-Combined With-
  - "Particular" Edge Shape-Leads To-
  - Vulnerable Edges (Cover)
- **Bursting Forces**
  - Due To 2 Different Types of Loads

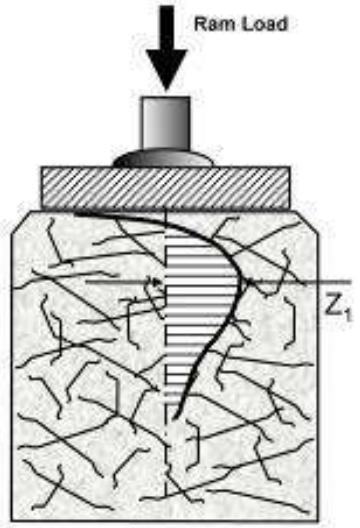




Ring bursting

In-place Forces Due To Compression In The Ring

During Installation By The Application Of Ram Loads To The Edge Of The Segments



Ram bursting

Possible Considerations…

- Inadequate Reinforcement & Bursting Forces

↓

- Leading To High Repairs
  - Durability?

?

- How Long Will You Guarantee This Repair?

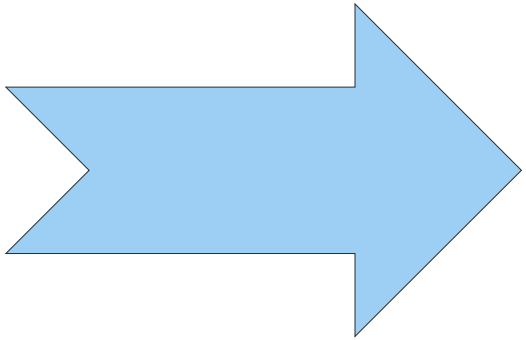
Summary Issues & Challenges

- **Current Systems With Re-bars Have Following Challenges:**
  - Need Big Space For Storing Reinforcement And Fabrications
  - **COVER- 40 or 50 mm- Most Vulnerable …**
  - Depending Upon Design Requirements Segments Can Have Congested Reinforcement Cages- **Quality Of Segments**?
  - Handling Reinforcement Cages- Need **Additional Resources** (Manpower, Machines, Etc.)
  - Low Workability Concrete (Mold Design, Surface Finishing, Etc.)- **Durability?**
  - High Degree Of Compaction Needed To Achieve Maximum Density & Especially In Thickly Reinforced Segments (Honeycombing, Etc. Segment Rejection)- **Durability?**
- **Consequences:**
  - Large Area Casting Yards Needed
  - Additional Contractors For Bar Bending & Reinforcement Cage Manufacturing
  - Additional Resources For Reinforcement Installation In Molds
  - **Increased Cycle Times- Project Timelines Over-run….**

How To Mitigate The Risks.....

By Replacing Steel Re-bars With Dramix® Steel Fiber For Segmental Lining

Wt. of Rebar's varies 70- 120 Kg /Cum

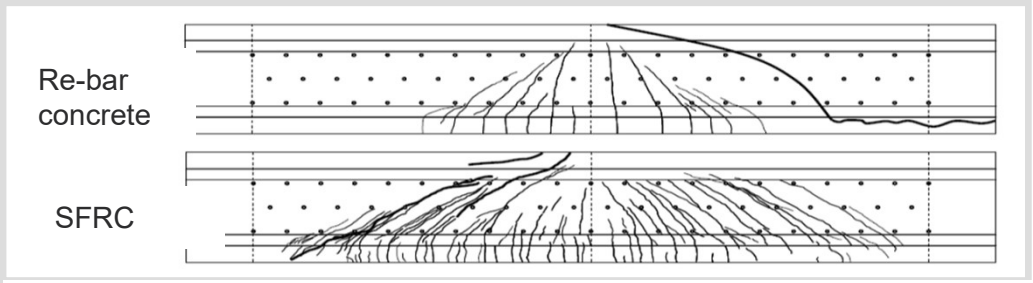


Dramix® 4D 80/60 BG
Fiber Dosages 25 – 40 Kg/Cum

Why Steel Fibre Reinforced Concrete?

- **Constructive**
  - Avoid Conventional Reinforcement (Mesh, Rebars)
  - Labor Reduction
  - Reduction Of Checking Time
  - Reinforcement Correctly Placed
- **Structural**
  - Smaller Crack Width Openings
  - Higher Durability
  - Higher Impact And Abrasion Resistance
  - Higher Fatigue Strength

- **Cracking Control**
  - The Fibers Sew The Cracks And Redistribute The Tensile Stresses In A Larger Concrete Area.
  - Reduce The Crack Width And Spread The Cracking Due To Loads Or Constraints.
  - Prevent Rebar Corrosion, Stop Water Paths, Better Aesthetic Presentation, Prevent Spalling Due To Load Or Impacts.
  - Increase Of Durability.



Results In A Shear Test Of A Full Scale Beam

We Replace….

We Will Just Add Fibers As Per Design Dosages At Batching Plant ……

Why To Reinforce Concrete……

Understanding Concrete Behavior…

The Principle Of Concrete Reinforcement

- Concrete Is Naturally BRITTLE And Has Low Tensile Strength And Ductility. When Subjected To Tensile Stresses, Unreinforced Concrete Will Crack And Fail.
- In Order To Change This Brittle Behaviour Into A More Ductile Behaviour, Mesh, Rebar Or **Steel Fibres** Are Added. The Role Of The REINFORCEMENT Is To Increase Load Bearing Capacity And Limit Crack Opening.

Why To Reinforce Concrete……

Understanding Concrete Behavior…

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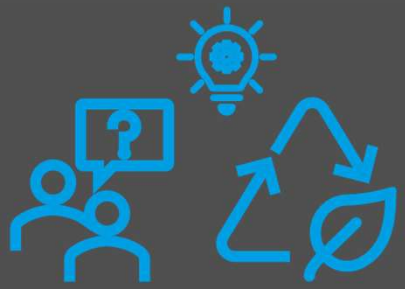
Nothing Is Less True!
Discover Why Steel Fibres Are The Perfect Alternative To Mesh Or Rebar Reinforcement In Many Applications.



Steel Fibre Reinforced Concrete V/s Conventional Rebar Concrete

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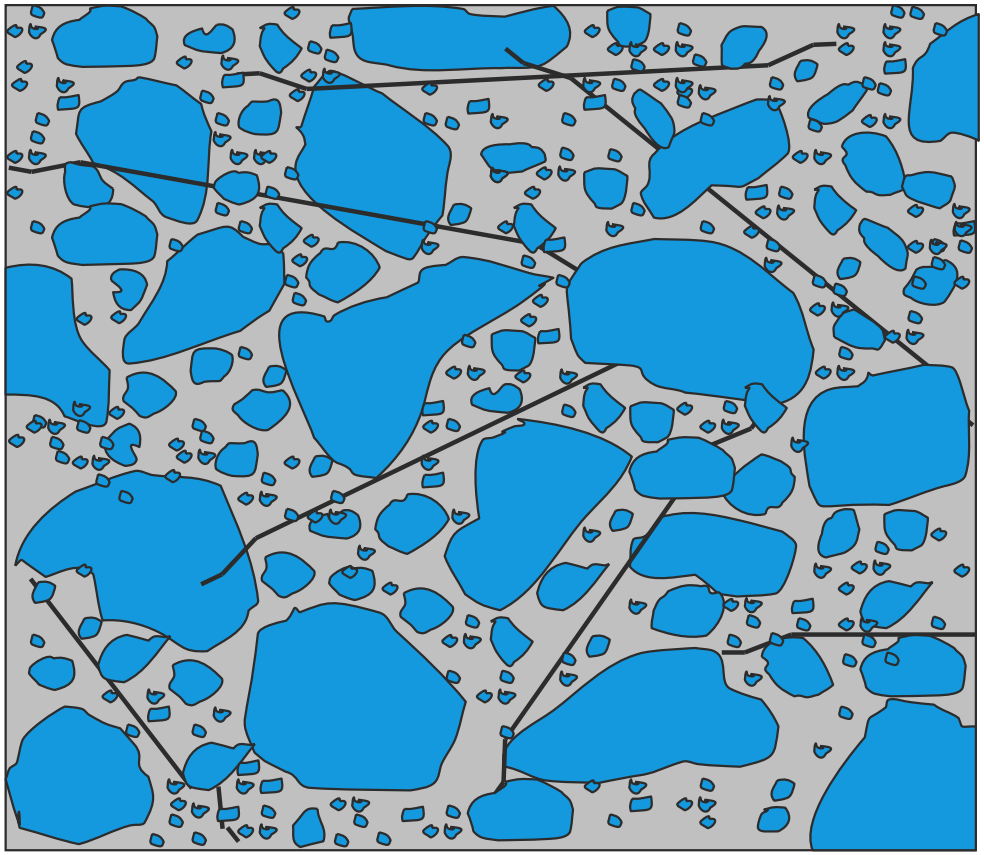
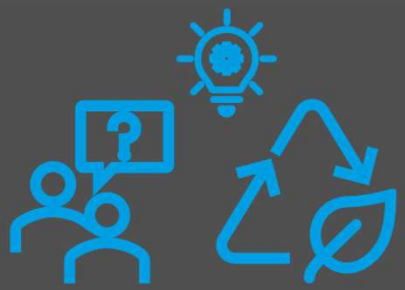
Introduction to Steel Fibre Reinforced Concrete

- The Fibre-reinforced Concrete (FRC) Is A Composite Material Made Of Basic Concrete In Which A Fibre Reinforcement Is Incorporated And Homogeneously Distributed.
- Steel Fibres Are Discrete, Discontinuous Pieces Of Reinforcement
- Steel Fibres Add Ductility To An Otherwise Brittle Concrete





How Do We Do It……

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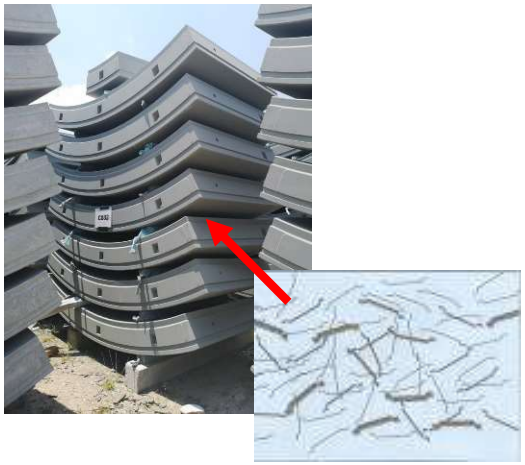
Solution We Always Choose…

- Faster
- Safer
- Easy to Use
- Economical
- Durable

How Will We Change …….

- **Possible Solutions:**



SFRC Only

Combined Solution: Low Amount Of Rebars For Critical Bending Moment + SF

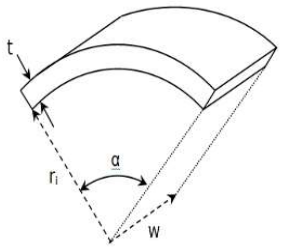
Combined Solution: Low Amount Of Rebars For Bursting + SF

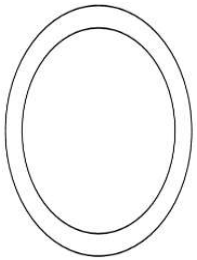
How Will We Change …….

- **Design Inputs…..**

1. SEGMENT INFORMATION

Thickness	t =	300	mm
Inner radius	r_i =	4600	mm
Width	w =	1600	mm
Angle	α =	56.842 (1to6) 18.948 (key)	degrees
Number per ring	n =	7	





2. CONCRETE INFORMATION

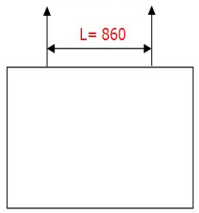
Compressive strength at 28 days	f'_c	50	Mpa
Flexural strength at 28 days	f_{r28}	5	Mpa

3. DEMOLDING

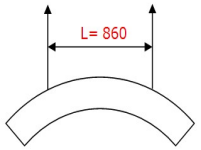
Compressive strength during demolding	$f'_{c,dem}$	12	Mpa
Flexural strength during demolding	$f_{r,dem}$	2.42	Mpa

Sketch demolding setup: (please dimension placement and spacing of lifting points)

Vertical casting



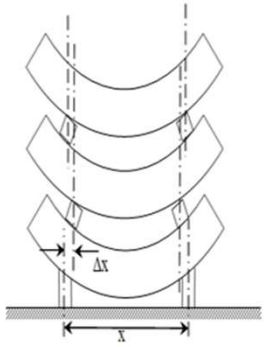
Horizontal casting



4. STACKING (only for horizontal stacking)

Compressive strength during stacking	$f'_{c,stack}$	25	Mpa
Flexural strength during stacking	$f_{r,stack}$	3.5	Mpa

Sketch of setup: (please dimension placement and spacing of stacking points)



Number of stacked segments	6	
x =	2650	Mm
Δx =	100	Mm

5. TBM DATA

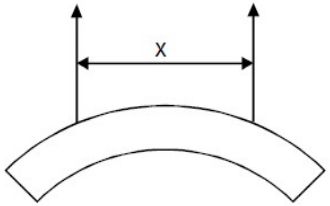
Hard Rock TBM		
Shoe length	L_r =	1000 mm
Number of jacks per ring	=	19
Operating thrust force/jack shoe	=	1250 kN
Total operating thrust force	=	23750 kN
Maximum thrust force/jack shoe	T_r =	1500 kN
Total maximum thrust force	=	28500 kN
NOTE: maximum ram thrust is the greater of the total maximum thrust force or 1.2 x total operating thrust force.		
∴ Design Ram Thrust	=	**28500 kN**

6. NORMAL AND BENDING FORCES IN THE SERVICE STATE

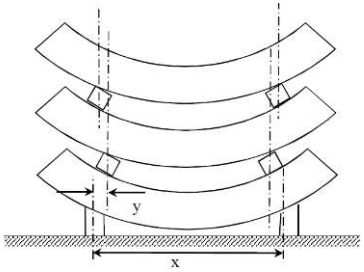
Unfactored		
Thrust at axis	T_a =	2378 kN/m
Thrust at crown	T_c =	2378 kN/m
Bending moment	M =	0 kNm/m
Factored		
Thrust at axis	T_{af} =	3174 kN/m
Thrust at crown	T_{cf} =	3174 kN/m
Bending moment	M_f =	0 kNm/m

How Will We Change …….

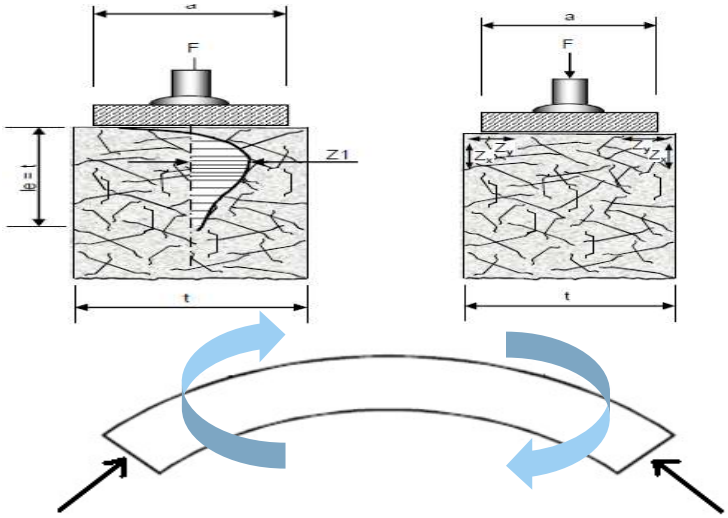
- **Demoulding Stresses**
  - Critical Moment Occurs For The Cantilever End Portion



- **Stacking Stresses**
  - Critical Moment Due To Batten Misalignment (Y)
  - Critical Shear Due To Large Stacking Height Above

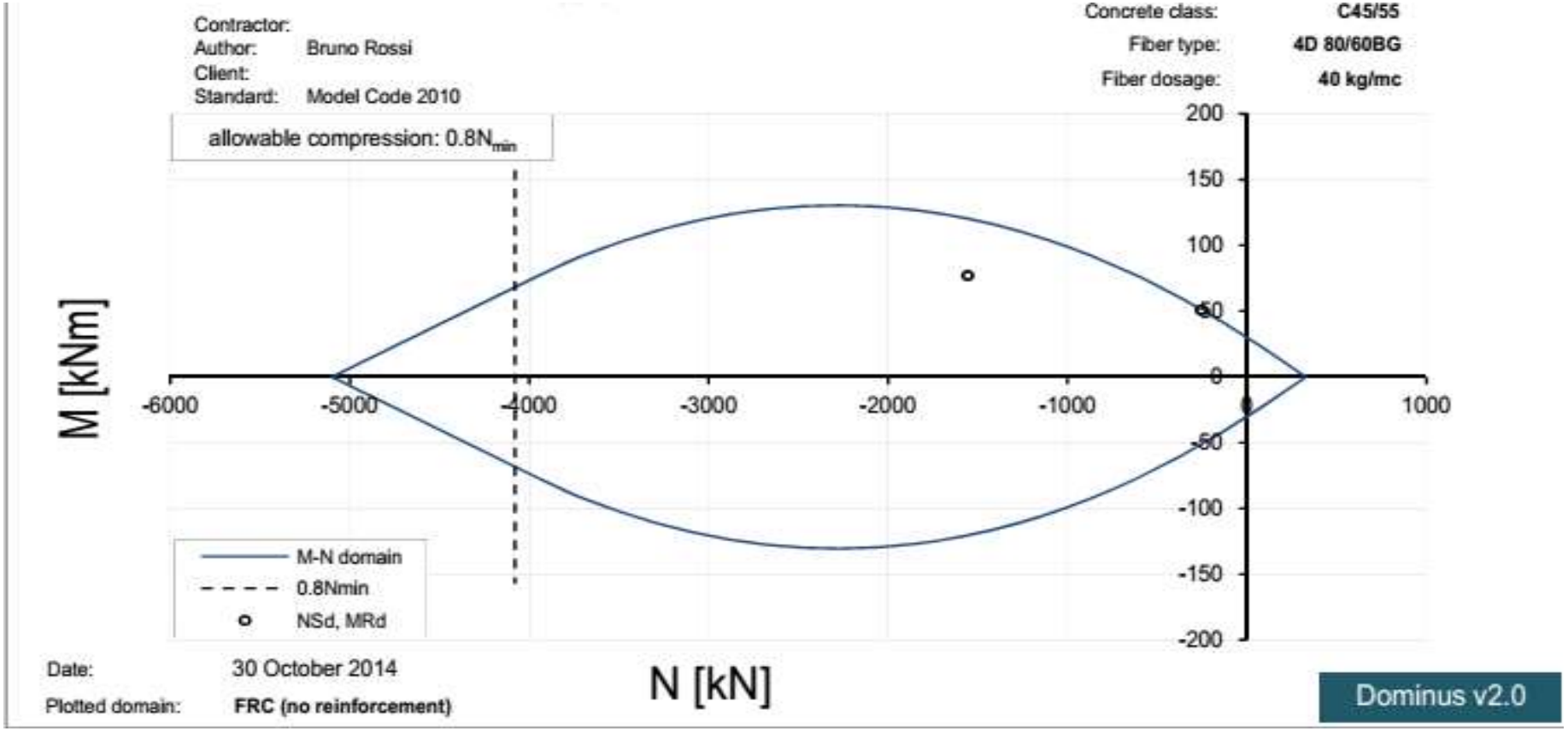


- **In- Service Stresses**
  - Section Forces Generated By The Ground, Gantry, Rail Load And Other Hoop Stresses
  - Sections Designed As Columns Under The Combined Action Of Axial Forces And Moments.



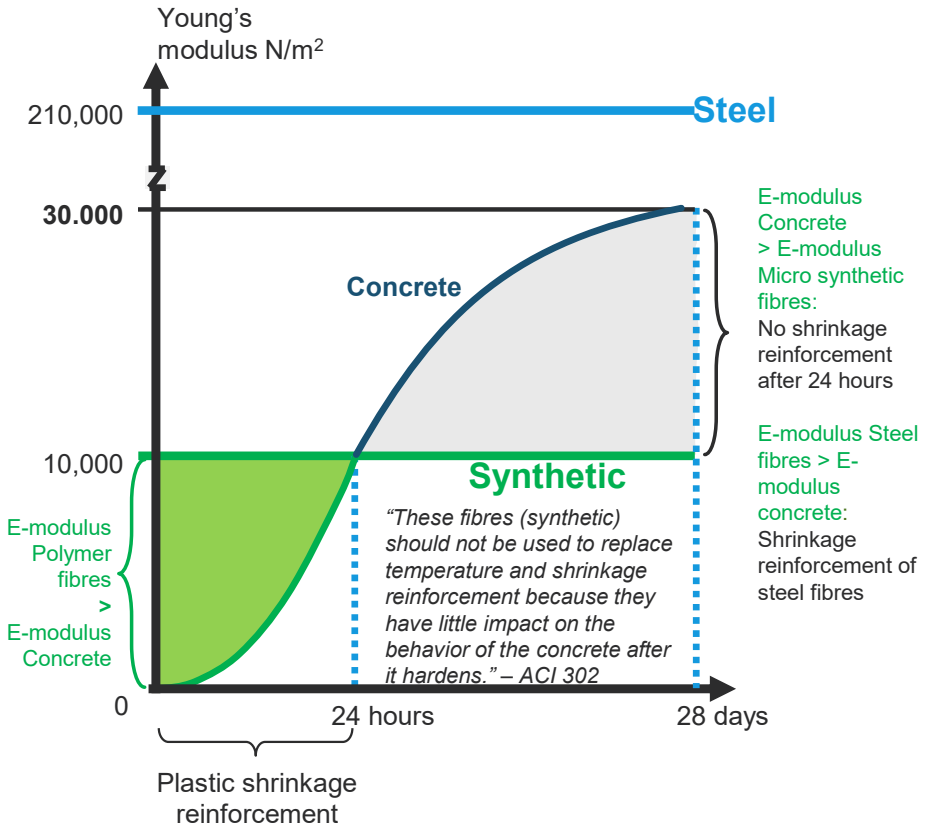
Our Proposal

- Design Using M-N Interaction



Fibre Reinforced Concrete?

- **PP Micro- Fibers For Plastic Shrinkage Control …**



Micro-synthetic Fibres Have Only A Plastic Reinforcement Effect In The First 24 Hours When Their Young's Modulus Exceeds The Fresh Concrete Young's Modulus.

Material	Young's Modulus
Concrete	+/- 30 GPa
Micro synthetic fibres	+/- 4 GPa
Macro synthetic fibres	3-10 GPa
Steel fibres	210 GPa

"In a composite material such as fibre concrete, a reinforcement effect can only be obtained when the reinforcing fibre has a higher Young's modulus than the base material."

Fibre Reinforced Concrete?

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… And For Passive Fire Protection

Fire Damage In Gotthard Tunnel, 2001

Fibre Reinforced Concrete (FRC)?

Plain Concrete
340 Mm Spalling Depth (RABT Fire Curve)

2 KG PP Fibre RC
15 Mm

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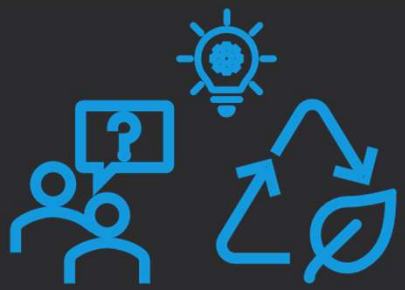

Case Study- CMRL

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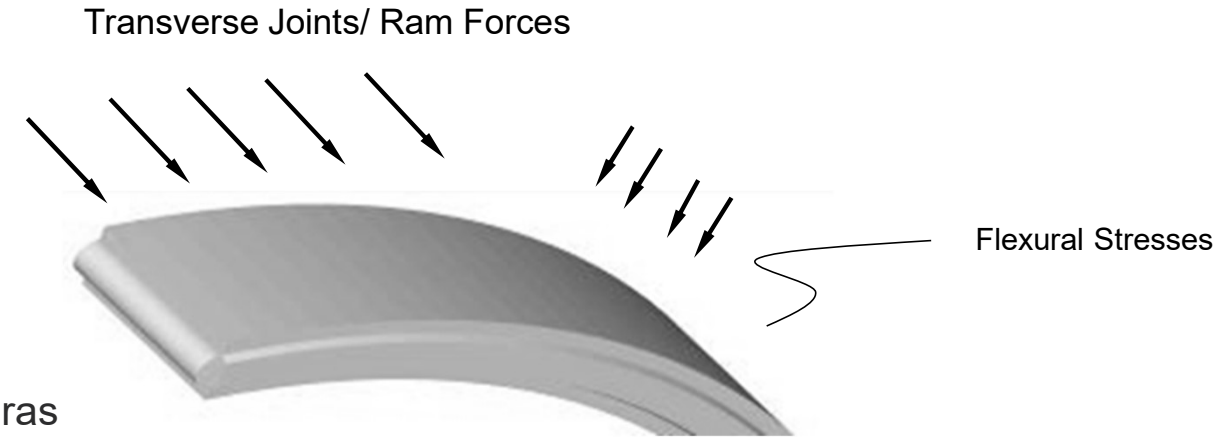
Case Study: Chennai Metro…….

Case Study: Chennai Metro…….

A Full-Scale Test Program On SFRC Segments To Ascertain The Validity Of Design

- 3 Field Scale Specimen Checked For Flexural Stresses
- 3 Field Scale Specimen Checked For Bursting/Ram Forces
- Fibre Distribution Check On Hardened Specimen
- Fibre Condition And Distribution Check On Hardened Specimen After 2 Years Of Installation



Tests Conducted At IIT Madras

Case Study: Chennai Metro…….

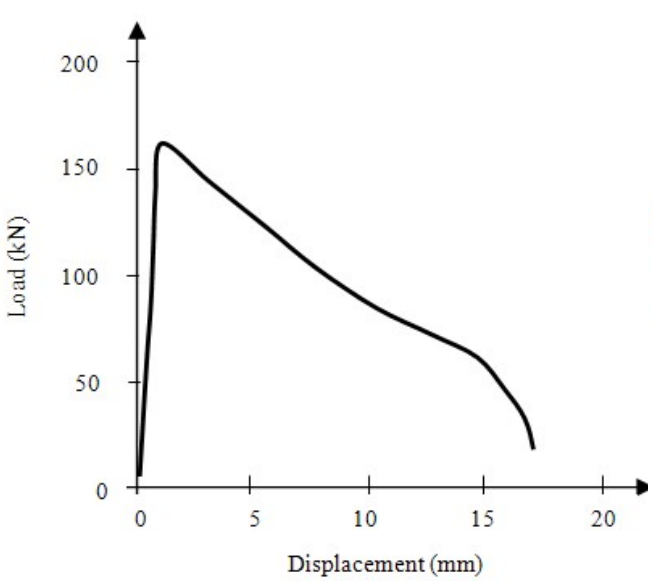
Flexural Testing Of SFRC Segments

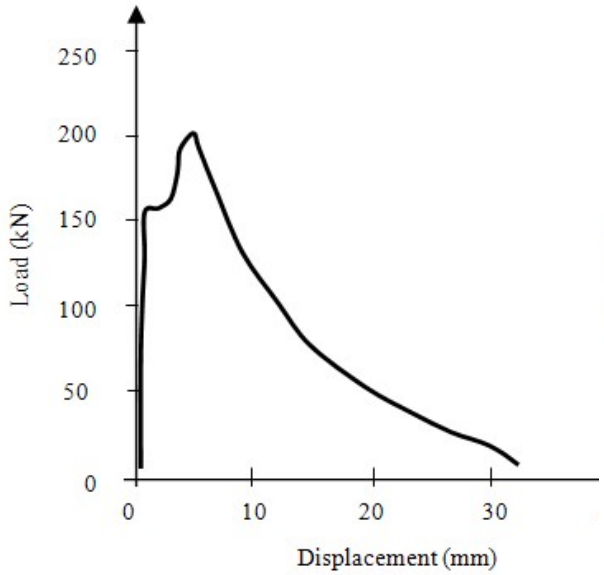
- Design Dosage = 35 Kg/m³
- Fibre Type = Dramix® 3D 80/60 CN
- Segment Arc Length = 1.79 M (Half Segment)
- Segment Supports = 1.2 M
- Maximum Loads And Moments Evaluated For 3 Specimen
- Actual Characteristic Flexural Stresses Of Segments Used For Plotting The M-N Diagram

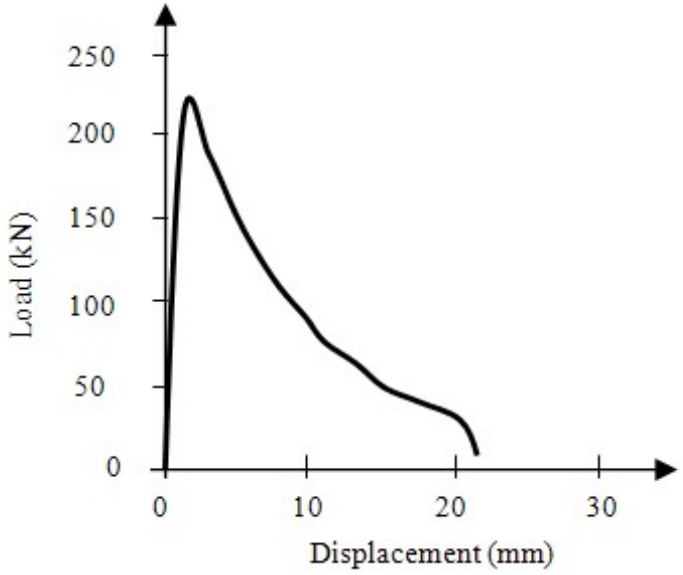
Tests Conducted At IIT Madras

Case Study: Chennai Metro…….

Flexural Testing Of SFRC Segments







Segment	Peak load (kN)	Peak moment (kN-m)
(a)	160	52.0
(b)	200	65.0
(c)	220	71.5

Meets The Design M-N Interaction Requirements, Ok

Case Study: Chennai Metro…….

Bursting Check Of SFRC Segments

- Design Dosage = 35 Kg/m³
- Fibre Type = Dramix® 3D 80/60 CN
- Segment Arc Length = 1.79 M (Half Segment)
- Ram Shoe Size= 1000 MM X 150 MM
- 3 Specimen Tested For Bursting Compression
- Maximum Operating Load Of TBM Ram Shoe Location = 300 Tons (Design)
- Maximum Test Load = 380 Tons (1.25 Times The Design Load)

Meets The Design Requirements, OK

Case Study: Chennai Metro…….

Fibre Content Checking

- Design Dosage = 35 Kg/m³
- Fibre Type = Dramix® 3D 80/60 CN
- 3 Cores Extracted From Each Specimen
- Average Fibre Content Reported
- All Values Lie Within The Prescribed Limits, Indicating Excellent Distribution Of Fibres In The Concrete Matrix

Segment	Average Fibre Content (kg/cu.m)
(a)	35
(b)	34.4
(c)	36.7

Meets The Design Requirements, OK

Case Study: Chennai Metro…….

Advantages

Technical Advantages

- High impact resistance
- Multidirectional reinforcement
- No damages at Edges and corner due to the spalling forces
- Post fire durability superior to rebar
- Fire protection in combination with micro- polypropylene fibre
- DURABILITY IMPROVEMENT

Economical Advantages

- Increase of productivity, time saving
- Reduction of repair cost of damage segments
- Elimination of storage and positioning of reinforcement cages
- Use of automatic dosing and dispensing equipment linked to the control panel of the batching

Cost Economics- Case Reference

BEKAERT
better together

STEEL FIBRE REINFORCED CONCRETE SEGMENTS			
	Unit cost		
	Unit Price Per		
Fibres			
Repair of damaged segments			**gments for repair**
% of segments requiring		281	
		Cost/Hour	
Labo		18.75	0.94
Co	0.25	1200.00	15.00
Adm	0.25	31.25	0.39
	Cost/Segment	**Total cost**	
C materials	25.00	7030	1.25
Total Cost/Cum Rs			**5617.58**

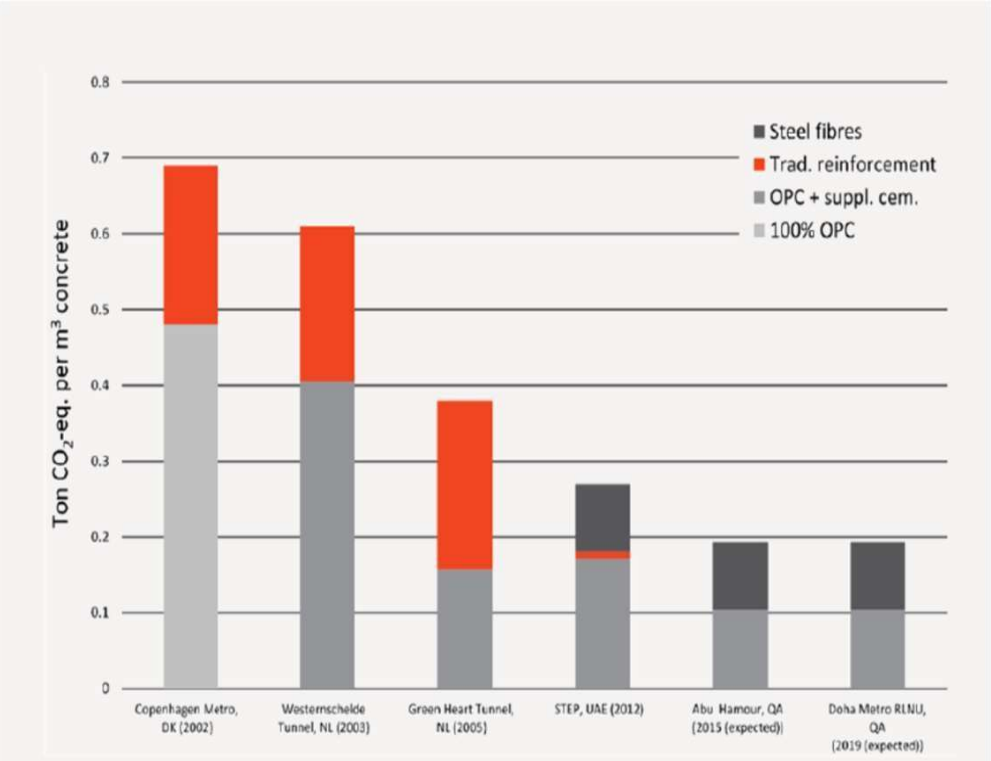
Saving Per Cu. M Of Concrete = Rs 1112 Or 16%

Cost Economics- Green Solutions…

BEKAERT
better together

Dramix® Minimizes The Impact On The Environment -Using Less Steel

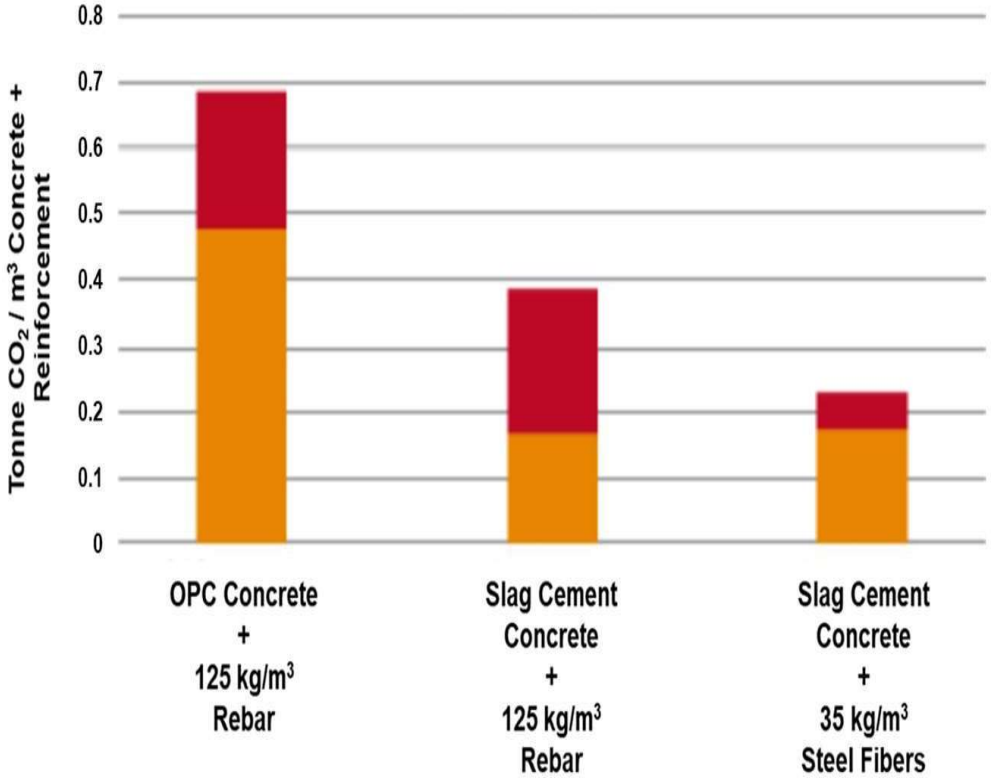
Comparison	Rebar / mesh	Dramix®
Concrete		
Energy consumption (GJ/m³)	2,89	2,89
Reinforcement		
Reinforcement (kg/m³)	100	40
Type	mesh	DRAMIX
Energy consumption (GJ/ton)	22,5	22,5
Energy consumption (GJ/m³)	5,14	3,79
Reduction of energy consumption	**26%**	



Use Of Fibres: >50% CO2 Reduction

Cost Economics- Green Solutions…

Dramix® Minimizes The Impact On The Environment -Using Less Steel



EPD CERTIFICATE

Basic information

This declaration is the Type III Environmental Product Declaration (EPD) based on EN 15804:2012+A1 and verified according to ISO 14025 by an external auditor. It contains the information on the impacts of the declared construction materials on the environment. Their aspects were verified by the independent body according to ISO 14025. Basically, a comparison or evaluation of EPD data is possible only if all the compared data were created according to EN 15804:2012+A1 (see point 5.3 of the standard).

Life cycle analysis (LCA): A1-A4, C1-C4 and D modules in accordance with EN 15804:2012+A1 (Cradle to Gate with options)

The year of preparing the EPD: 2021

Service Life: not declared by producer, specific calculation in accordance to EN 1990:2004

PCR: ITB-PCR A (PCR based on EN 15804+A1)

Declared unit: 1 kg of steel fibre

Product Standards: EN 14889-1 and ISO 13270–class A & conforms to ASTM A-820

Reasons for performing LCA: B2B

Representativeness: manufactured in Czech Republic, year 2019

References

LINE 14 North - 2 Paris Metro, Paris (France)

Entities Involved:

- Owner: RATP (Paris Transport Administration)
- Designer: Systra
- Contractor: JV Bouygues – Bessac – Soletanche Bachy
- Precast Plant: JV Capremib - Bonna Sabla

Tunnel Parameters:

- Year Of Construction: 2015 - 2016
- Designed Lifetime (Years): 100

Dimensions (M)

- Internal Diameter 7,75
- External Diameter 8,50
- Total Length (Excavated) 2,2 Km
- Quantity Dramix® 120 Ton

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 7 Per Ring
- Size Of Segments (L X W X T): 1,5 M X 1,8 M X 0,375 M
- Concrete Quality: C40/50
- Fiber Type: DRAMIX® 3D 80/60 BGP
- Fiber Dosage: 40 Kg/M3

Other Information

- First Steel Fibre Reference In Sacrificial Segments For Metro In French Market

LINE 16-1 Paris Metro, Paris (France)

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 (Years): 100

Dimensions (M)

- Internal Diameter: 8,70
- External Diameter: 9,50
- Total Length (Excavated): 16 Km
- Quantity Dramix®: 5,200 Ton

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 7 Per Ring
- Size Of Segments (L X W X T): 2 M X 4 M X 0,40 M
- Concrete Quality: C540/50
- Fibre Type: DRAMIX® 3D 80/60 BGP
- Fibre Dosage: 40 Kg/M^3

Other Information

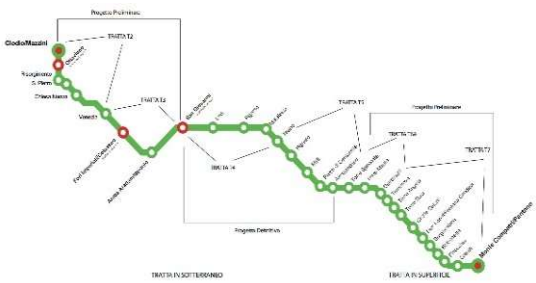
- First Important Reference In Definitive Segments In The French Market


Photo: Eiffage Genie Civil

Roma Metro Line C – T3 section, Rome (Italy)

Entities Involved

- Owner : Società Roma Metropolitane
- Designer: Rocksoil S.P.A
- Contractor(s): Metro C S.C.P.A.
- Precast Plant: Vianini Lavori S.P.A.



Tunnel Parameters

- Year Of Construction: 2008-2021

Dimensions (M)

- Internal Diameter: 6,10 M
- External Diameter: 6,70 M
- Total Length (Excavated): 2,8 Km

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 6+1 Per Ring
- Concrete Quality: C50
- Fiber Type: Dramix® 4D 80/60 BG
- Fiber Dosage: 40 Kg/M^3

Northern Line Extension, London (UK)

Entities Involved

- Owner : Transport For London (LUL)
- Designer: Mott Macdonald London
- Contractor(s): Ferrovial Laing O'rourke (FLO) JV
- Precast Plant: Morgan Sindall Ridham Dock

Tunnel Parameters

- Year Of Construction: 2016-2019
- Designed Lifetime (Years): 120 Years
- **Dimensions (M)**
  - Internal Diameter 5.2 M
  - External Diameter 5.7 M
  - Total Length (Excavated) 5.2 Km
  - Length Of DRAMIX® Reinforced Section 5.2 Km

- **Segmental Lining Parameters**
- Number Of Segments (Incl. Key): 6no
- Size Of Segments 3.63 Mx1.50 M X 0,25 M
- Concrete Quality: C50/60
- Fiber Type: DRAMIX® 4D 80/60BG
- Fiber Dosage: 30kg/M^3

Other Information

- Reading Sands And Gravels – Some Water Bearing And Some Clays

Heathrow Piccadilly Line Extension, London (UK)

Entities Involved

- Owner : Transport For London (LUL)
- Designer: Miller Tunnelling Ltd
- Contractor(s): Miller Tunnelling / Vinci Grand Projets JV
- Precast Plant: Miller Precast Ltd Ridham Dock

Tunnel Parameters

- Year Of Construction: 2004
- Designed Lifetime (Years): 120 Years
- **Dimensions (M)**
  - Internal Diameter 4.52 M.
  - External Diameter 4.82 M
  - Total Length (Excavated) 2.5 Km
  - Length Of DRAMIX® Reinforced Section 2.5 Km

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 7+1 = 8 Total
- Size Of Segments 2.0 M X 1.0 M X 0,15 M
- Concrete Quality : C50/60
- Fibre Type DRAMIX® 3D 80/60BG
- Fiber Dosage: 30 Kg/M^3

Other Information

- London Clay

JLE – Jubilee Line Extension (C103), London (UK)

Entities Involved

- Owner : Transport For London (LUL)
- Designer: Babtie Consulting London
- Contractor(s): Aoki/Soletanche JV & Costain Taylor Woodrow JV
- Precast Plant: Charcon Tunnels

Tunnel Parameters

- Year Of Construction: 1996
- Designed Lifetime (Years): 120 Years
- Dimensions (M)
  - Internal Diameter 4.45 M
  - External Diameter 4.85 M
  - Total Length (Excavated) 1.2 Km
  - Length Of Dramix® Reinforced Section 1.2 Km

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 8+2 = 10
- Size Of Segments (L X W X T): 1.373 M & 1.424m X 1.0 M X 0.200 M
- Concrete Quality: C50
- Fiber Type: Dramix® 3D 80/60 BG
- Fiber Dosage: 30kg/M^3

Other Information

- London Clay

Metrosud, Napoly (Italy)

Entities Involved

- Owner : Metro Napoly
- Designer: ROCKSOIL
- Contractor(s):

Tunnel Parameters

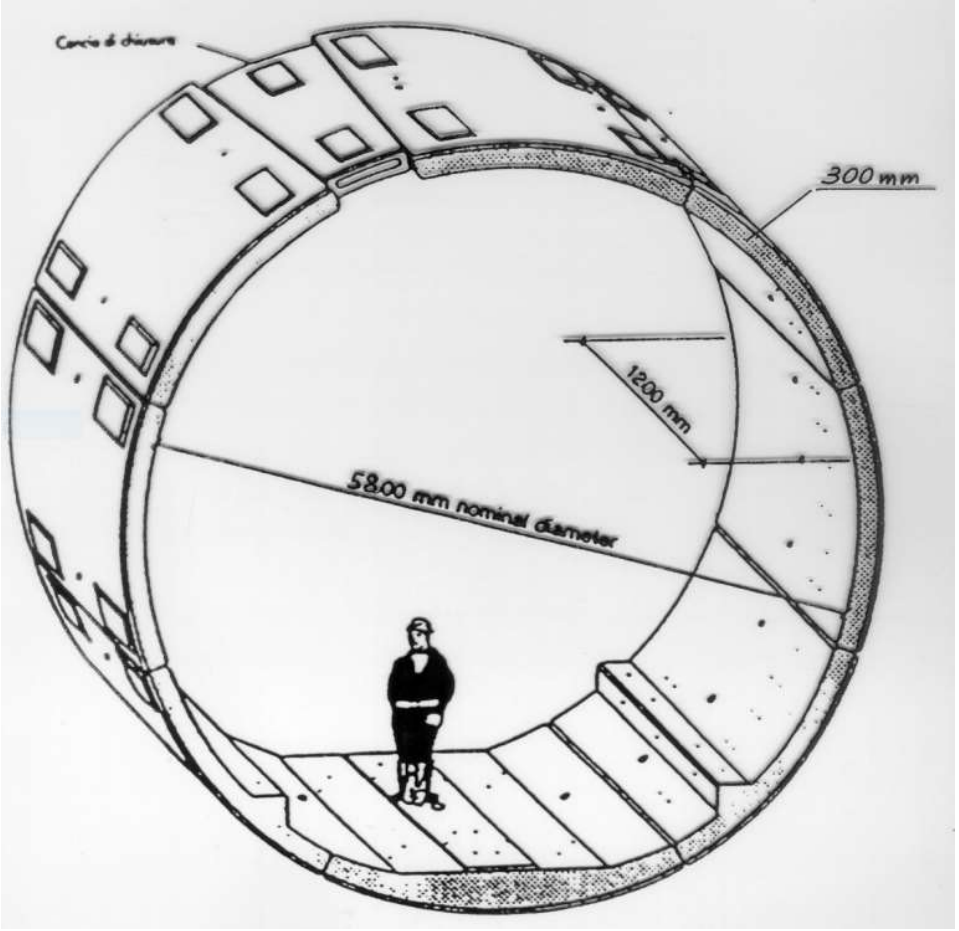
- Year Of Construction: 1992
- Designed Lifetime (Years):
- **Dimensions (M)**
  - Internal Diameter 5.80 Lm
  - External Diameter 6.10 Lm
  - Total Length (Excavated) 15295 Lm
  - Length Of DRAMIX® Reinforced Section 3000 Lm

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 10 (Total Or Per Ring)
- Size Of Segments (L X W X T): 1,85 M X 1,2 M X 0,3 M
- Concrete Quality: C50
- Fiber Type: DRAMIX® 3D 65/50 BG
- Fiber Dosage: 40kg/M^3

Other Information

- Volcanogenic Soils, With Tuff And Pozzolan



Nice Tramway, Nice (France)

Entities Involved

- Owner : NICE MUNICPALITY
- Designer: SETEC
- Contractor(s): BOUYGUES
- Pre-caster STRADAL

Tunnel Parameters

- Year Of Construction: 2016
- Designed Lifetime (Years): 100
- Dimensions (M)
  - Internal Diameter 8.5 M
  - External Diameter 8.9 M
  - Total Length (Excavated) 2930 M
  - Length Of DRAMIX® Reinforced Section 400 M

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 8
- Size Of Segments (W X T): 1,6 M X 0,40 M
- Concrete Quality: C40/50/
- BG Fiber Type: DRAMIX® 4D 80/60 BG
- Fiber Dosage: 40kg/M^3

Other Information :

In Accordance With The *Fib* Ceb-fip Model Code 2010, The Structural Design Of Sfrc Elements Is Based On The Post-cracking Residual Tensile Strength Provided By The Steel Fibers . The Performance Class 4c Is Required

Expolink Dubai Route 2020, Dubai (UAE)

Entities Involved

- Owner : Dubai Municipality
- Designer: Parsons Systra
- Contractor(s): JV Acciona - Gulermak
- Precast Plant: Dubai Precast

Tunnel Parameters

- Year Of Construction: 2017
- Designed Lifetime (Years): 120
- Dimensions (M)
  - Internal Diameter 8,50 M
  - External Diameter 9.30 M
  - Total Length (Excavated) 2,8 Km
  - Quantity DRAMIX® 1.200 Ton

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 7 Per Ring
- Size Of Segments (L X W X T): 3 M X 1,6 M X 0,40 M
- Concrete Quality: C45/50
- Fiber Type: DRAMIX® 4D 80/60 BG
- Fiber Dosage: 40 *Kg/M³*

Other Information

- Epoxy Coating On Top Of Each Segment

Doha Metro Green Line, Doha (Qatar)

Entities Involved

- Owner : Qatar Rail
- Designer: D&B By JV Contractors
- Contractor: JV Porr – Saudi Binladin – HBK (Local)
- Precast Plant: JV Plant At Site

Tunnel Parameters

- Year Of Construction: 2013 -2014
- Designed Lifetime (Years): 120
- Dimensions (M)
  - Internal Diameter 7,10 M
  - External Diameter 7,80 M
  - Total Length (Excavated) 34 Km
  - Quantity DRAMIX® 7.000 Ton

Segmental Lining Parameters

- Number Of Segments (Incl. Key): 7 Per Ring
- Size Of Segments (L X W X T): 2 M X 4 M X 0,35 M
- Concrete Quality: C40/50
- Fiber Type: DRAMIX® 4D 80/50 BG
- Fiber Dosage: 40 Kg/M^3

Other Information

- First Time Design Following Model Code.
- Very Hot Temperature And Geological Chemical Aggressive Environment

Circle Line 6 C882, Singapore (Singapore)

Entities involved

- Owner : Land Transport Authority
- Designer: AECOM
- Contractor(s): CSCEC-Nishimatsu JV
- Precast plant: SPC Precast

Tunnel parameters

- Year of construction: 2018
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 1200 m
  - Length of DRAMIX® reinforced section 1200 m

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D-80/60-BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 & 1 kg/m^3

Circle Line 6 C885, Singapore (Singapore)

Entities involved

- Owner : Land Transport Authority
- Designer: AECOM
- Contractor(s): China Railway Tunnel Group
- Precast plant: SPC Precast

Tunnel parameters

- Year of construction: 2018
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 1200 m
  - Length of DRAMIX® reinforced section 1200 m

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 80/60 BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 & 1 kg/m^3

North East Line extension C715, Singapore

Entities involved

- Owner : Land Transport Authority
- Designer: CSCEC
- Contractor(s): CSCEC
- Precast plant: SPC Precast

Tunnel parameters

- Year of construction: 2018
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5,8 m
  - External diameter 6.35 m
  - Total length (excavated) 0.71 km
  - Length of DRAMIX® reinforced section 0.71 km

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 80/60 BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 & 1 kg/m^3

Thomson Line T206, Singapore

Entities involved

- Owner : Land Transport Authority
- Designer: ARUP Singapore
- Contractor(s): Shanghai Tunnel Engineering Co. (Singapore) Pte Ltd
- Precast plant: SPC Precast

Tunnel parameters

- Year of construction: 2016
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5,8 m
  - External diameter 6.35 m
  - Total length (excavated) 2800 m
  - Length of DRAMIX® reinforced section 2800 m

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 80/60 BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 & 1 kg/m^3

Thomson Line T207, Singapore

Entities involved

- Owner : Land Transport Authority
- Designer: TY Lin Singapore
- Contractor(s): Shimizu Corporation
- Precast plant: SPC Precast

Tunnel parameters

- Year of construction: 2016
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 6300 m
  - Length of DRAMIX® reinforced section 6300 m

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 80/60 BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 & 1 kg/m^3

Circle Line 5 C856, Singapore

Entities involved

- Owner : Land Transport Authority
- Designer: WSP
- Contractor(s): Sembcorp Engineers Constructors
- Precast plant: Contech Precast

Tunnel parameters

- Year of construction: 2006
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 500 m
  - Length of DRAMIX® reinforced section 500 m

Segmental lining parameters

- Number of segments (incl. key): 5+1
- Size of segments (L x W x T): 3.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 65/60 BG
- Fiber dosage: 30 kg/m^3

Circle Line 1 C825, Singapore

Entities involved

- Owner : Land Transport Authority
- Designer: AECOM
- Contractor(s): STECS-Woh Hup-NCC JV
- Precast plant: SPC Precast

Tunnel parameters

- Year of construction: 2005
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 500 m
  - Length of DRAMIX® reinforced section 500 m

Segmental lining parameters

- Number of segments (incl. key): 5+1
- Size of segments (L x W x T): 3.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 65/60 BG
- Fiber dosage: 30 kg/m^3

Klang Valley MRT SBK Line, Malaysia

Entities involved

- Owner : MRT Corp
- Designer: ARUP
- Contractor(s): MMC Gamuda Malaysia
- Precast plant: SPC Precast/EP Precast/MDC Precast

Tunnel parameters

- Year of construction: 2016
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 9500 m
  - Length of DRAMIX® reinforced section 9500 m

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 80/60 BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 & 2 kg/m^3

Klang Valley MRT SSP Line, Malaysia

Entities involved

- Owner : MRT Corp
- Designer: ARUP
- Contractor(s): MMC Gamuda Malaysia
- Precast plant: SPC Precast/EP Precast/MDC Precast/KOMT Precast

Tunnel parameters

- Year of construction: 2018
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 5.8 m
  - External diameter 6.35 m
  - Total length (excavated) 13500 m
  - Length of DRAMIX® reinforced section 13500 m

Segmental lining parameters

- Number of segments (incl. key): 7+1
- Size of segments (L x W x T): 2.6 m x 1.4 m x 0.275 m
- Concrete quality: C50/60
- Fiber type: DRAMIX® 3D 80/60 BGP & DUOMIX M6 Fire
- Fiber dosage: 40 kg/m^3 down to 35 kg/m^3 & 2 kg/m^3 down to 1.5 kg/m^3

Sydney Metro Chatswood to Sydenham, Australia

Entities involved

- Owner : Transport NSW
- Designer: Aurecon
- Contractor(s): John Holland CPB Ghella
- Precast plant: Boral

Tunnel parameters

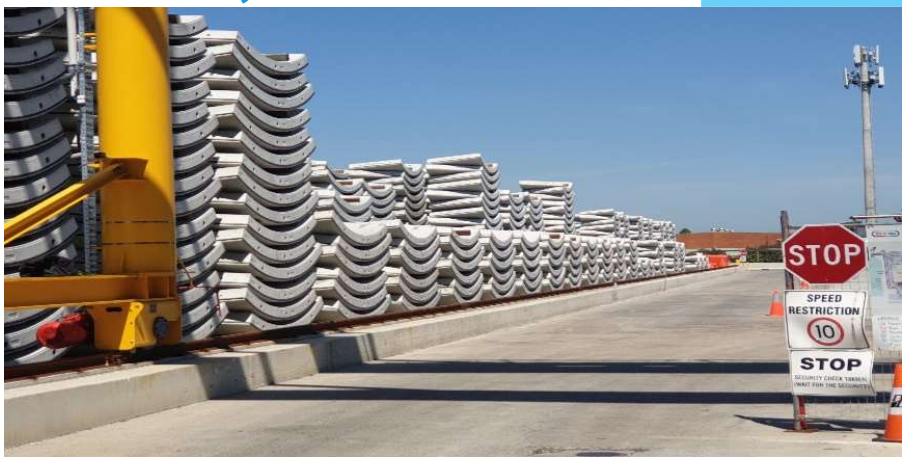
- Year of construction: 2019-2020
- Designed lifetime (years): 100
- Dimensions (m)
  - Internal diameter
  - External diameter 6.69 m
  - Total length (excavated) 15.5 km
  - Length of DRAMIX® reinforced section 15.5 km

Segmental lining parameters

- Number of segments (incl. key): 99746
- Size of segments (L x W x T): 3.5 m x 1.7 m x 0.26 m
- Concrete quality: 80MPa
- Fiber type: DRAMIX® 4D 80/60 BG
- Fiber dosage: 36 kg/m^3

Other information

- Drilling through highly abrasive sandstone either side of the harbour. Under the harbour were heterogeneous geologies including sand silt and clay with high water pressures. Depth with35m overburden and 34m depth of water



Forrestfield Airport Link, Perth Western (Australia)

Entities involved

- Owner : Public Transport Authority of Western Australia
- Designer: Webuild Design and Construct
- Contractor(s): Salini Impreglio (Webuild) &NRW Pty Ltd
- Precast plant: Boral

Tunnel parameters

- Year of construction: 2019-2020
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter
  - External diameter 7 m
  - Total length (excavated) 7 km
  - Length of DRAMIX® reinforced section 7 km Hybrid

Segmental lining parameters

- Number of segments (incl. key): 54000
- Size of segments (L x W x T): Thickness 0.275 m
- Concrete quality: 80MPa
- Fiber type: DRAMIX® 4D 80/60 BG
- Fiber dosage: 36 kg/m^3

Other information

- Tunnel drilled through heterogeneous geology.

Evergreen LRT Line (Vancouver, B.C., Canada)

Entities involved

- Owner : TransLink (British Columbia)
- Designer: McMillen Jacobs
- Contractor(s): SNC - Lavalin
- Precast plant: APS Precast Structures, Langley, B.C.

Tunnel parameters

- Year of construction: 2014
- Designed lifetime (years): 100 years
- Dimensions (m)
  - Internal diameter 9.14 m
  - External diameter 9.84 m
  - Total length (excavated) 2 km
  - Length of DRAMIX® reinforced section 2 km

Segmental lining parameters

- Number of segments (incl. key): 7 + 1 (8 total or per ring)
- Size of segments (L x W x T) thickness 0,350 m
- Concrete quality: C40
- Fiber type: DRAMIX® 3D 80/60 BGP
- Fiber dosage: 40 kg/m^3

Other information

- Type of ground / ground conditions: Variable soils, sticking and clogging clays, abrasive minerals, boulders, and groundwater.

Channel Tunnel Rail Link (CTRL), London (UK)

Entities involved

- Owner : Euro Star
- Designer: Rail Link Engineering Ltd
- Contract 220: Nishimatsu/Cementation/Skanska JV
- Contract 240: Costain/Skanska/Bachy/Soletanche JV
- Contract 103: Kier / Nuttall JV
- Precast plant: Malling Holzman JV part of Laing O'Rourke Group

Tunnel parameters

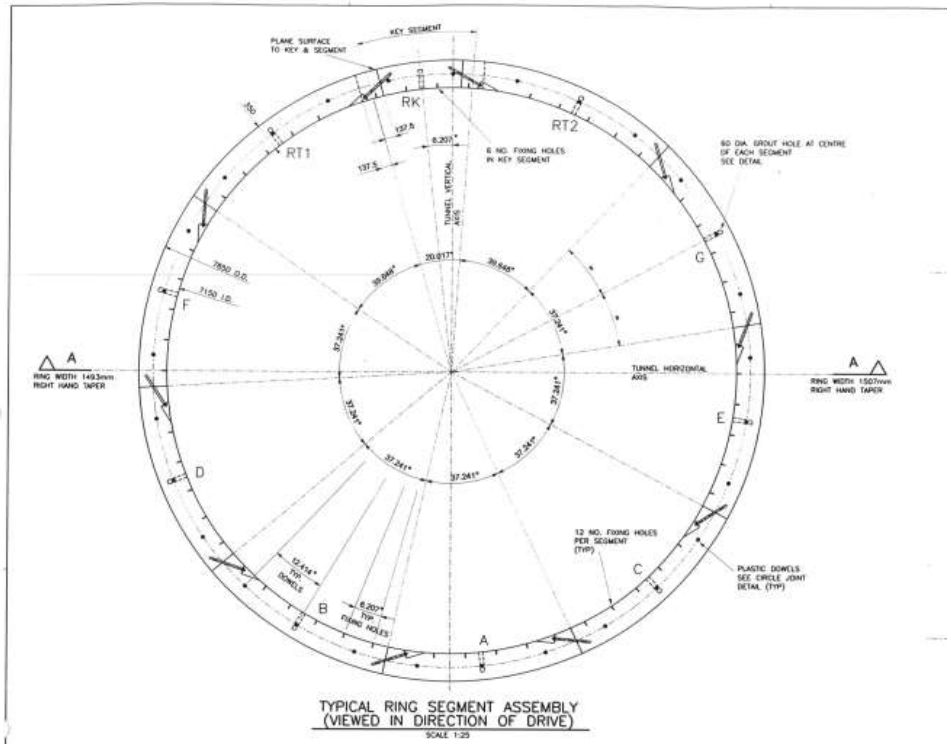
- Year of construction: 2003/4
- Designed lifetime (years): 120
- Dimensions (m)
  - Internal diameter 7.15 m
  - External diameter 7.85 m
  - Total length (excavated)
  - C220: 7.5 km x 2
  - C240: 4.7 km x 2
  - C103: 650 m x 2
  - Length of DRAMIX® All of the above in fibre only

Segmental lining parameters – 220 / 240 only

- Number of segments (incl. key): 9 + key = 10 in total.
- Size of segments (L x W x T): Ext 2.551 m x 1.5 m x 0,350 m
- Concrete quality: C60
- Fiber type: DRAMIX® 3D 80/60 BG
- Fiber dosage: 30 kg/m^3

Other information

- London clay and water bearing sands and gravels.



Channel Tunnel Rail Link (CTRL), London (UK)

CTRL - Segment Performance

Overall damage rate to segments

Manufacturing process			Construction process		
No. of segments made	Rejected	Repaired	Minor damage no repair needed	Minor damage controlled repair	Major repair
(No.)	(%)	(%)	(%)	(%)	(No.)
260,000	0.8	2.8	2.2	0.3	1

References FRC….

Bhanupalli Bilaspur Rail Project (Ongoing)

- Client- Indian Railway/ RVNL
- General Consultant- AECOM
- Application : Cast In Place Lining
- Contractor : Max Infra
- Product- Dramix 3D®65/60 BG
- Dosages Used- 45 Kg /Cum
- Grade Of Concrete- M 35
- Thickness- 300 mm

References FRC….

USBRL T48- Gammon, (Ongoing)

- Client- Indian Railway /IRCON
- General Consultant- Lombardi India
- Application : Cast In Place Lining
- Contractor : Gammon India
- Product- Dramix 3D®65/60 BG
- Dosages Used- 45 Kg /Cum
- Grade Of Concrete- M 35
- Thickness- 300 mm to 400 mm

References FRC….

USBRL T49 A- HCC, (Ongoing)

- Client- Indian Railway /IRCON
- General Consultant- Lombardi India
- Application : Cast In Place Lining
- Contractor : HCC
- Product- Dramix 3D®65/60 BG
- Dosages Used- 45 Kg /Cum
- Grade Of Concrete- M 35
- Thickness- 300 Mm

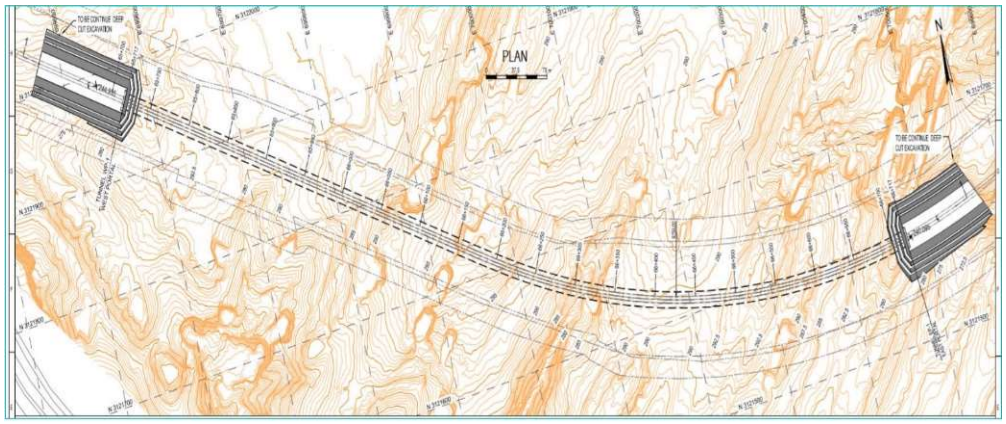
References FRC….

USBRL T1- ABCI, (Ongoing)

- Client- Indian Railway /KRCL
- General Consultant- Geo Consultant
- Application : Cast In Place Lining
- Contractor : ABCI
- Product- Dramix 5D®65/60 BG
- Dosages Used- 25 Kg /Cum
- Grade Of Concrete- M 35
- Thickness- 500 mm

References FRC….

DFCC Project- WDFC Phase-II, Package CTP-14



- Client- Indian Railway
- General Consultant- Nippon Koei / SMEC
- Application : PSCL
- Contractor : Sojitz- L&T Consortium
- Product - Dramix 4D®65/35 BG
- Dosages Used- 25 Kg /Cum & 35 Kg/ Cum
- Grade Of Concrete- C32/40
- Thickness- 225 to 430 mm

References FRC….

UGC 06- Sahar Cross- Over- Mumbai Metro

- Client- Mumbai Metro Rail Co Operation
- General Consultant- MAPLE
- Application : PSCL
- Contractor : J Kumar- CRTG (JV)
- Consultant- Bedi Consulting Ltd
- Product- Dramix 4D®65/35 BG
- Dosages Used- 30 Kg /Cum
- Grade Of Concrete- C32/40
- Thickness- 300 Mm

Worldwide Pre-Cast Segment Reference

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Worldwide Reference Cast-In-Situ Tunnel Lining

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Year	Title	Tunnel type	Country	Thickness (mm)	Fibre type	Fibre name
2020- 2022	Metro Fortaleza-Linea Este	Metro	Brazil	350	Steel Fibres+ PP	Dramix® 3D8060BG + Micro Synthetic
2019- 2021	Paris Metro Line 16-1 definitive segments	Metro	France	40	Steel	3D 80/60 BGP
2015- 2016	Metro linea 6-Sao Paulo	Metro	Brazil	400	Steel + PP	Dramix®3D8060BG + Micro Synthetic
2012- 2014	Metro linea 5 Lote 7-Sao Paulo	Metro	Brazil	400	Steel + PP	Dramix® 3D8060BG+ Micro Synthetic
2012- 2013	Metro linea 5 Lote 3-Sao Paulo	Metro	Brazil	400	Steel + PP	Dramix® 3D8060BG + Micro Synthetic
2020	Snowy Hydro 2.0	Utility	Australia	380	Steel	Dramix 3D 80/60 BG
2020	Cross River Rail	Rail	Australia	270	Steel	Dramix 4D 80/60 BG
2020	Second Narrows Tunnel - Vancouver, BC	Hydro	Canada	228.6	Steel	Dramix® 4D 8060BG
2020	Ashbridges Bay Outfall Tunnel - Toronto, ON	Sewage	Canada		Steel	Dramix® 4D 8060BG
2020	Coxwell Bypass Tunnel - Toronto, ON	Sewage	Canada		Steel	Dramix® 4D 8060BG
2020	Réseau Express Métropolitain (REM) - Montreal, QC	Metro	Canada		Steel	Dramix® 4D 8060BG
2020	Annacis Island Outfall Tunnel	Hydro	Canada	460	Steel	Dramix 4D 80/60 BG
2020	Paris Metro Line 15 South T2-1/T3-1 sacrificial segments	Metro	France	35	Steel	4D 80/60 BGP
2020	Paris Metro Line 15 South T3c sacrificail segments	Metro	France	35	Steel	4D 80/60 BGP
2020	Safety Tunnel Kerenzerberg	Road	Switzerland		Steel	Dramix® 3D 8060BGP
2020	Hatta Dam Tunnels	Road	UAE	100	Steel	Dramix 3D 65/35
2020	Hatta Dam Tunnels	Hydro	UAE	120	Steel	Dramix 3D 65/35
2020	Ettihad Rail	Rail	UAE		Steel	Dramix 3D 45/35
2020	Interstate 75 Tunnel - Detroit, MI	Sewage	USA		Steel	Dramix® 4D 8060BG
2020	Westerly NEORSD Storage Tunnel	Sewage	USA		Steel	Dramix® 4D 8060BG
2020	Bergen Point Outfall Tunnel	Sewage	USA		Steel	Dramix® 4D 8060BG

Reference Project

With This Technology we have completed more than 150 Projects

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World Wide References- Segmental Lining With Steel Fibres

132	2019	CBBT Parallel Thimble Shoals Tunnel - Chesapeake, VA	Road	USA	12.8	457.2		Steel	Dramix® 4D 8060BG	Yes	No
133	2017	South Hartford CSO - Hartford, CT	Sewage	USA	6.1	305		Steel	Dramix® 4D 8060BG	Yes	No
134	2016	Ohio Canal Interceptor CSO - Akron, OH	Sewage	USA	9.14	355.6		Steel	Dramix® 3D 8060BG	Yes	No
135	2016	Blacklick Creek Sanitary Interceptor Sewer	Sewage	USA	3.05	229		Steel	Dramix® 5D 6560BG	No	Yes
136	2015	Dugway Storage Tunnel - Cleveland, OH	Sewage	USA	7.93	305		Steel	Dramix® 3D 6560BG	Yes	No
137	2015	First Street CSO - Washington, DC	Sewage	USA	6.1	250		Steel	Dramix® 3D 6560BG	Yes	No
138	2015	LA Water River Supply Conduit - 5&6 - North Hollywood, CA	Hydro	USA	3.05	250		Steel	Dramix® 3D 6560BG	Yes	No
139	2013	Central Subway Line - San Francisco, CA	Metro	USA	5.4	275		Steel	Dramix® 3D 80/60 BG	No	Yes
140	2012	Euclid Creek Sewer - Cleveland, OH	Sewage	USA	7.93	305		Steel	Dramix® 3D 80/60 BG	Yes	No
141	2009	Bright Water Sewer System, Phase 1	Sewage	USA	5.3	330.2		Steel	Dramix	No	Yes
142	2006	Brightwater Sewer Tunnel - Central	Sewage	USA	5.12	177		Steel	Dramix®	Yes	No
143	2006	Brightwater Sewer Tunnel - East	Sewage	USA	5.87	254		Steel	Dramix®	Yes	No
144	2006	Brightwater Sewer Tunnel - West	Sewage	USA	4	177		Steel	Dramix®	Yes	No
145	2006	San Vicente Water Tunnel	Hydro	USA	4	177		Steel	Dramix® 3D 8060BG	Yes	No
146	2005	Big Walnut Sewer	Sewage	USA	3.65	250		Steel	Dramix® RC80/60BN	No	Yes
147	2020	Interstate 75 Tunnel - Detroit, MI	Sewage	USA	4.3			Steel	Dramix® 4D 8060BG	Yes	No
148	2020	Westerly NEORSD Storage Tunnel	Sewage	USA	7.6			Steel	Dramix® 4D 8060BG	Yes	No
149	2020	Bergen Point Outfall Tunnel	Sewage	USA	3.7			Steel	Dramix® 4D 8060BG	Yes	No
150	2020	LA Metro Westside Extension - Special Segments at Fault Zone	Metro	USA	6.6	304.8		Steel	Dramix® 5D 65/60BG	No	Yes
151	2019	Silicon Valley Clean Water Tunnel	Hydro	USA	4.8	254		Steel	Dramix® 4D 80/60BG	Yes	No
152	2016	River Supply Conduit 5 & 6 - North Hollywood, CA	Hydro	USA	2.743	203.2		Steel	Dramix 3D 65/60 BG	Yes	No

- Conclusion….

Available Resources….

- 400+ Projects References
- Established Design Codes/Guidelines
- Accepted Testing Methodologies
- Environmentally Friendly

Conclusion…

- **Steel Fiber Reinforced Concrete Is A Global Solution:**
- **Cost Saving**
  - Fabrication Yard for Reinforcement Cage Not Required
  - Reduction In Resources
  - Reduction in Repair Costs
- **Durability- Improved**
  - Better & Even Distribution Of Fibres- 3-Dimensional Reinforcement
  - Cracking Control
  - Better Performance Against Bursting Forces
- **Time Saving**
  - Reduction in Time- No Cage Required
  - Faster Production of Segments
- **Easy To Use**
  - Easy Addition Of Fibres At Batching Plant
  - Reduction in Energy For Compaction
- **Green Solution**
  - Reduction in CO_2 Emissions

Conclusion….

- **The Principle Of Steel Fibre Concrete Reinforcement In A Nutshell:**
  - **Elimination Of Traditional Reinforcement (Mesh Or Rebar)**
    → Faster & Safer Construction
  - **Homogeneous Distribution**
    → Uniform Reinforcement Of Your Concrete Structures
  - **Redistribution Of Stresses**
    → High Ductility & Increased Load Bearing Capacity
  - **Excellent Crack Control**
    → A Significant Reduction Of Concrete Cracking And Spalling Of Segments
  - **Optimal Resistance** Against Impact And Dynamic Loads

Right Fibre For The Right Application….

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	Dramix® Steel fibers	Synmix® macro synthetic fibers	Duomix® micro synthetic fibers
Plastic shrinkage reinforcement			✓
Anti-spalling aid at fire			✓
Temporary linings (such as in mines) Allowing large deformations	✓	✓	
Durability and sustainability (steel)	✓		
Crack controlling reinforcement	✓		
Structural reinforcements	✓		
Heavy impact	✓		
Fatigue	✓		

Material	Steel Mesh / Steel fibre 	Micro / Macro Polymer Fibre Extruded polypropylene / polyethylene 
Typical length of fibres	30-60 mm	micro: 6 - 20 mm macro: 30 - 65 mm
Typical diameter of fibres	0.5 - 1.0 mm	micro: 0015 - 0.030 mm macro: 0.5 - 10 mm
Young's Modulus	210000 MPa	3000 - 10000 MPa
Tensile strength	500 - 2000 MPa	200 - 600 MPa
Density	7850 kg/m³	910 kg/m³
Melting Point (°C)	1500°C	165°C does not reinforce
Creep behaviour in tension (Tg glastransition temperature)	+370°C	-20°C

Right Fibre For The Right Application….

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…& All Fibres Are Not Same…

Material	Steel Mesh / Steel fibre 	Micro / Macro Polymer Fibre Extruded polypropylene / polyethylene 
Typical length of fibres	30-60 mm	**micro**: 6 - 20 mm **macro**: 30 - 65 mm
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Thank You So Much

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FIRST LINING/TEMPORARY SUPPORT

Spray Concrete

3D Dramix®

3D Dramix® 65/35BG

Synmix®

FINAL LINING

Spray Concrete Lining
PS anti spalling

4D Dramix®

4D Dramix® 65/35BG

Precast Segments

4D Dramix® +

4D Dramix® 80/60BG

Duomix® M6 Fire

FINAL LINING

Cast in place
Inner Lining

5D Dramix® +

5D Dramix® 65/60BG

Duomix® M6 Fire


Thank You So Much
For Your Attention
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