ArcelorMittal Fibres

Reinforced concrete solutions

ArcelorMittal

The world’s leading steel and mining company – We are part of it.

ArcelorMittal Fibres, an ArcelorMittal WireSolutions business, is part of ArcelorMittal Group.

Guided by a philosophy to produce safe, sustainable steel, ArcelorMittal is the leading manufacturer and supplier of quality steel products in all major markets and is present in 60 countries and has an industrial footprint in 18 countries.

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ArcelorMittal Fibres
Reinforced concrete solutions

our mission

To transform reinforced concrete in pursuit of a better-built world.

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our

vision

To make steel fibre reinforcement the first choice for those designing and building the world's every day ambitious concrete structures.

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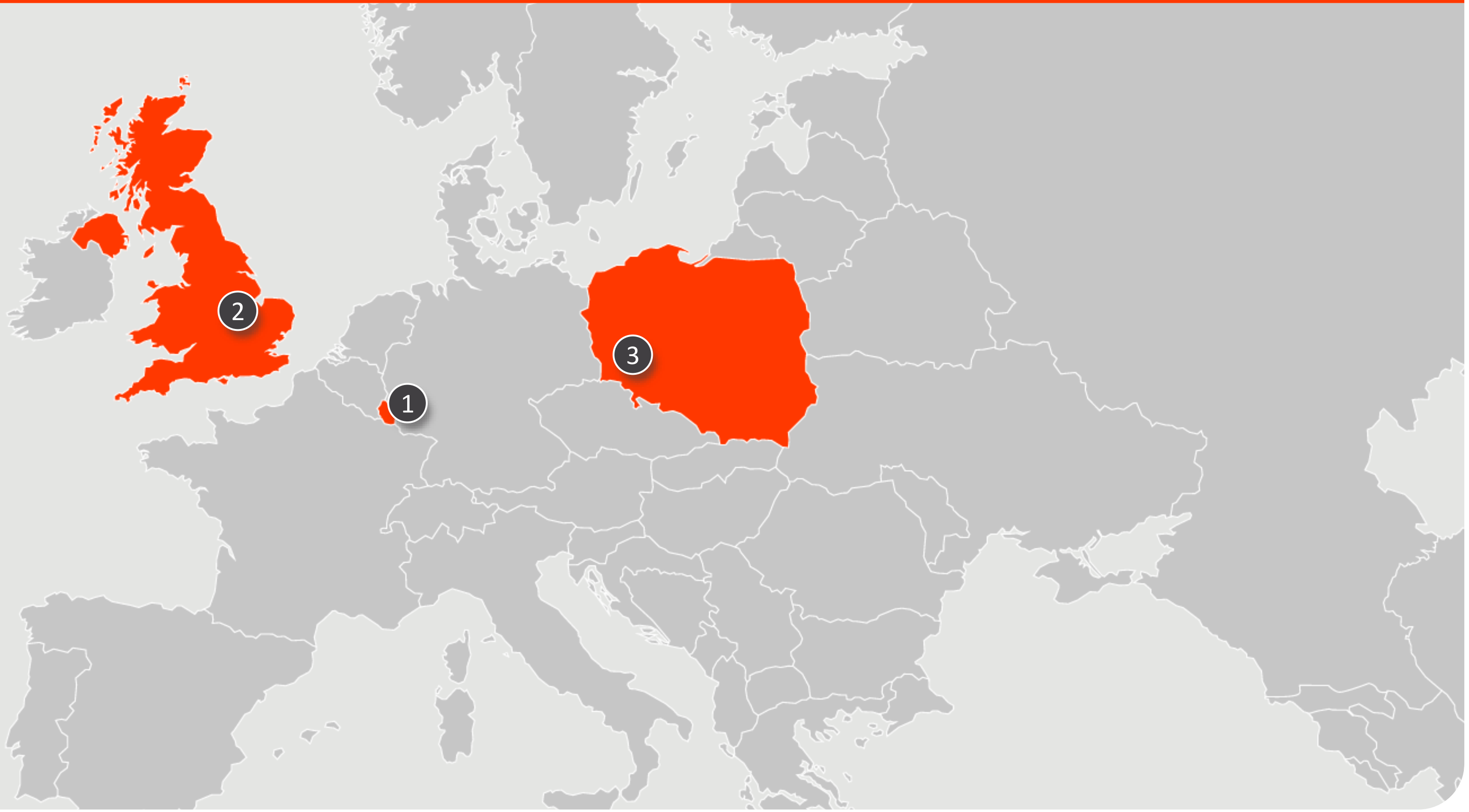
Our fibre manufacturing plants

1. Bissen, Luxembourg

   Head Office, Engineering
   Department and R&D Centre

2. Sheffield, UK

3. Syców, Poland



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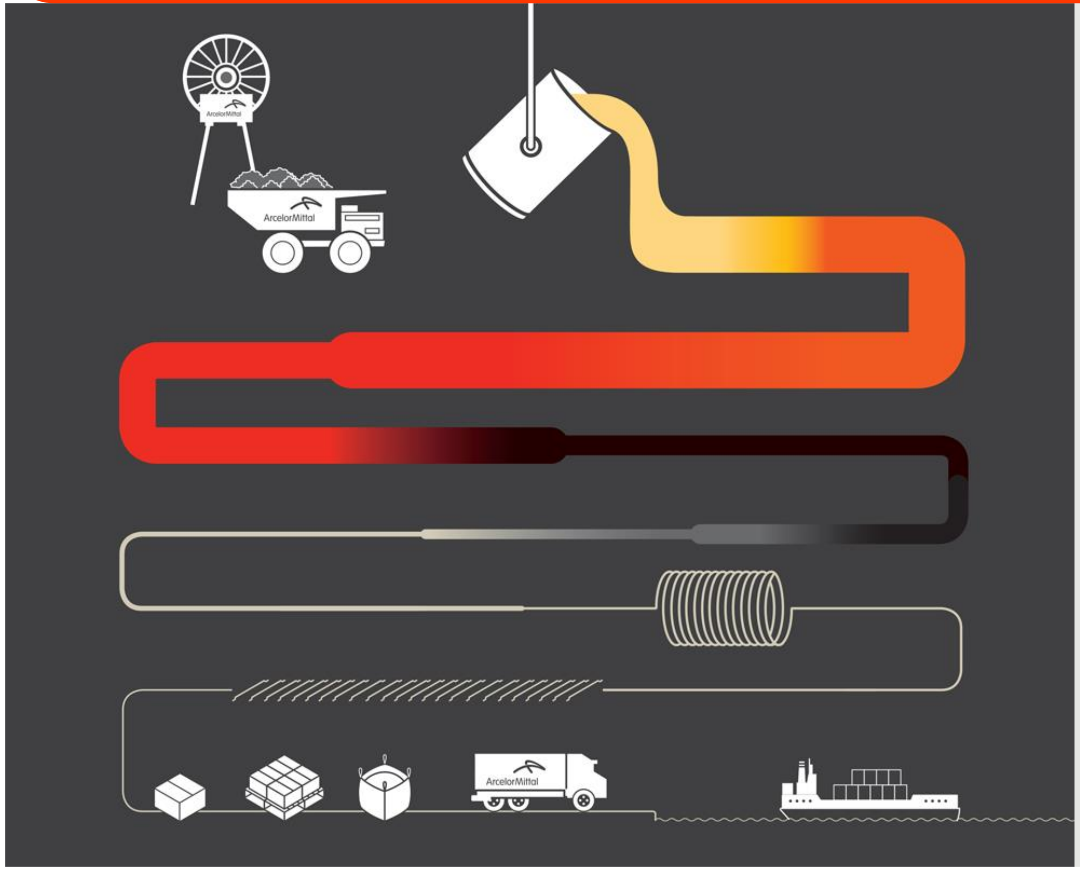
Vertical integration. Unparalled value.



ArcelorMittal's vertically integrated business model provides us with complete control over the quality of our raw materials and in our production methods ensuring the highest standards of steel fibre production.

In conjunction with our world class technical expertise, we are able to deliver unparalleled quality and value.

CE EN 14889-1 type 1

Conforms to:
ASTM A820 / A820M-04 TYPE 1

QUALITY ASSURANCE MANAGEMENT ISO 9001

ENVIRONMENTAL MANAGEMENT ISO 14001

OCCUPATIONAL HEALTH & SAFETY OHSAS 18001

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Sustainable Research and Development

Operating for all ArcelorMittal group units, ArcelorMittal Fibres benefits from the group's worldwide research and development resources.

This is the cornerstone of sustainable development and innovation and it ensures the continuous renewal of ArcelorMittal's product offer.

The sectors we serve

TUNNELS

PRECAST

INFRASTRUCTURE

BUILDINGS

FLOORS

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ArcelorMittal Fibres

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Solutions

Supporting you from start to finish.

The right advice. The right fibres.

The right solutions.

ArcelorMittal Fibres do much more than manufacture and supply a comprehensive range of premium quality steel fibres. We support you to ensure the success of your project from start to finish.

Solutions

ArcelorMittal will advise and provide support to your construction project.

We provide expertise on:

- setting up your **project specification**
- the most appropriate **fibre type** to comply with the specification
- **optimum dosage rates** to guarantee performance
- **concrete mix** design optimization
- the supervision of **performance tests**
- on-site support and advice on **dosing and mixing**
- the installation of **dosing equipment**.

We provide all the support your project requires, from the early planning stages through to project completion.

We are here to support and assist you at every stage.

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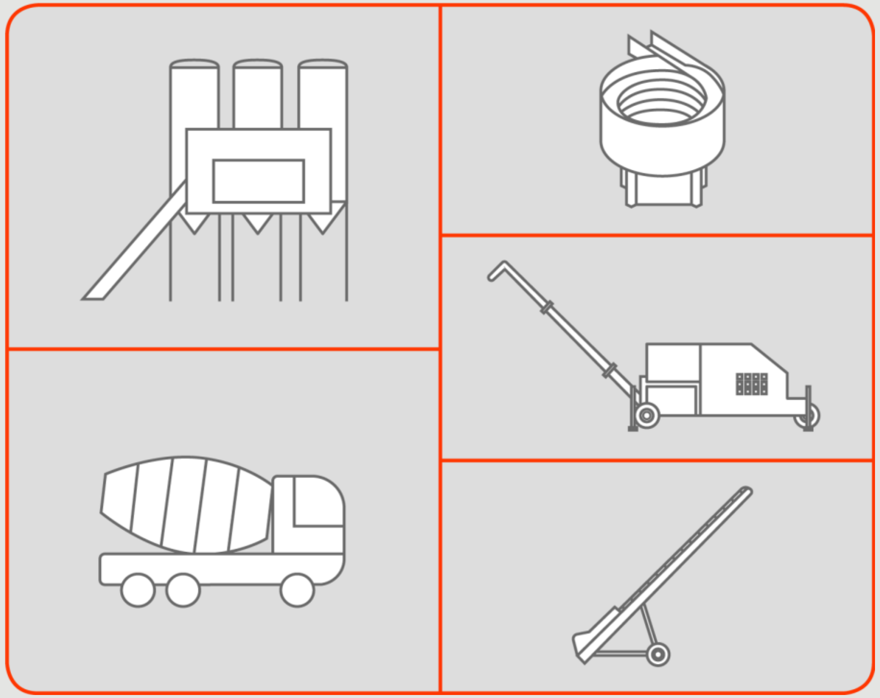
Dosing and Mixing



✓ Introduce fibres with sand and aggregates

✓ Add fibres to fresh concrete

✓ Onsite support and technical advice on mixing and dosing equipment

✓ Wide range of solutions with automatic dosing equipment, blast-machines and conveyor belts available


the
tunnelling and
mining sector
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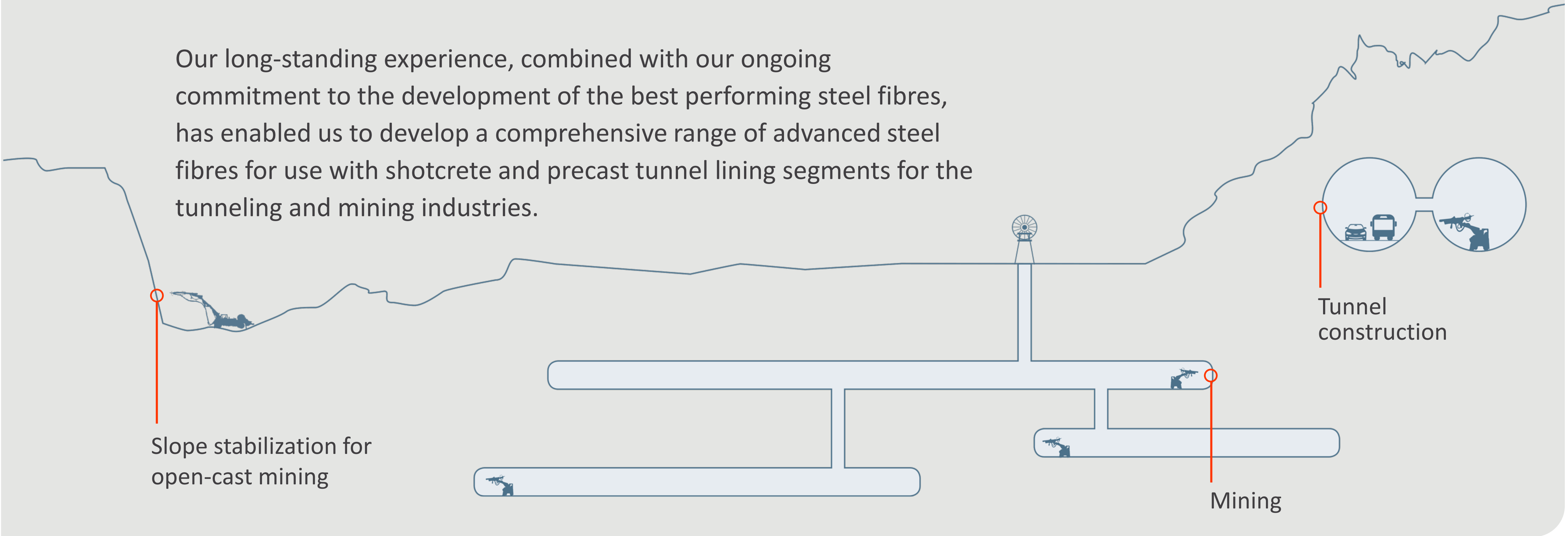
ArcelorMittal Fibres for tunnels and mines

Our long-standing experience, combined with our ongoing commitment to the development of the best performing steel fibres, has enabled us to develop a comprehensive range of advanced steel fibres for use with shotcrete and precast tunnel lining segments for the tunneling and mining industries.



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Fibres for tunnel lining segments applications

Hook end steel fibre

HE++ 90/60

HE++ 75/50

HE+ 1/60

Our fibres are manufactured using the highest quality, fully traceable, drawn steel wire. Their unique shape and precision dimensions, together with their very high tensile strength, deliver increased reinforcement performance with lower dosages.

ArcelorMittal Fibres manufacture steel fibres in 3 wire qualities with different tensile strength:

Standard	1150 to 1200 N/mm^2
+	1500 to 1800 N/mm^2
++	>1900 N/mm^2

CE EN 14889-1 type 1

Conforms to: ASTM A820 / A820M-04 type 1

ISO 9001 · ISO 14001 · OHSAS 18001

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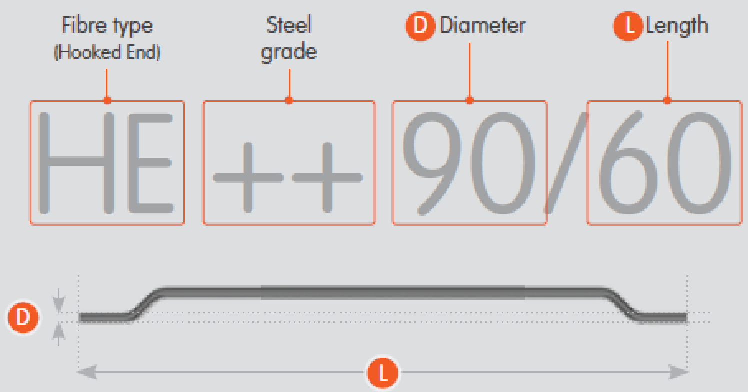
ArcelorMittal HE++ 90/60 engineered for tunnel lining segments

Fibre specification ›

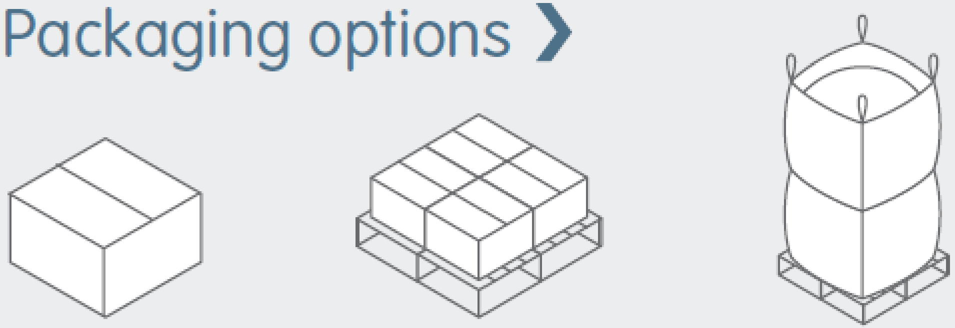


- D Diameter: 0.90mm
- L Length: 60mm
- Aspect Ratio (L/d): 67

Material characteristics ›

- Tensile strength of drawn wire: 1900 N/mm²
- Number of fibres per kg: 3200

Packaging options ›



25kg boxes	48 x 25kg boxes/pallet	2 x 500kg big bags/pallet
Nett weight 25kg	Nett weight 1200kg	Nett weight 1000kg

Certification ›

CE EN 14889-1 type 1

Conforms to:
ASTM A820 / A820M-04 type 1

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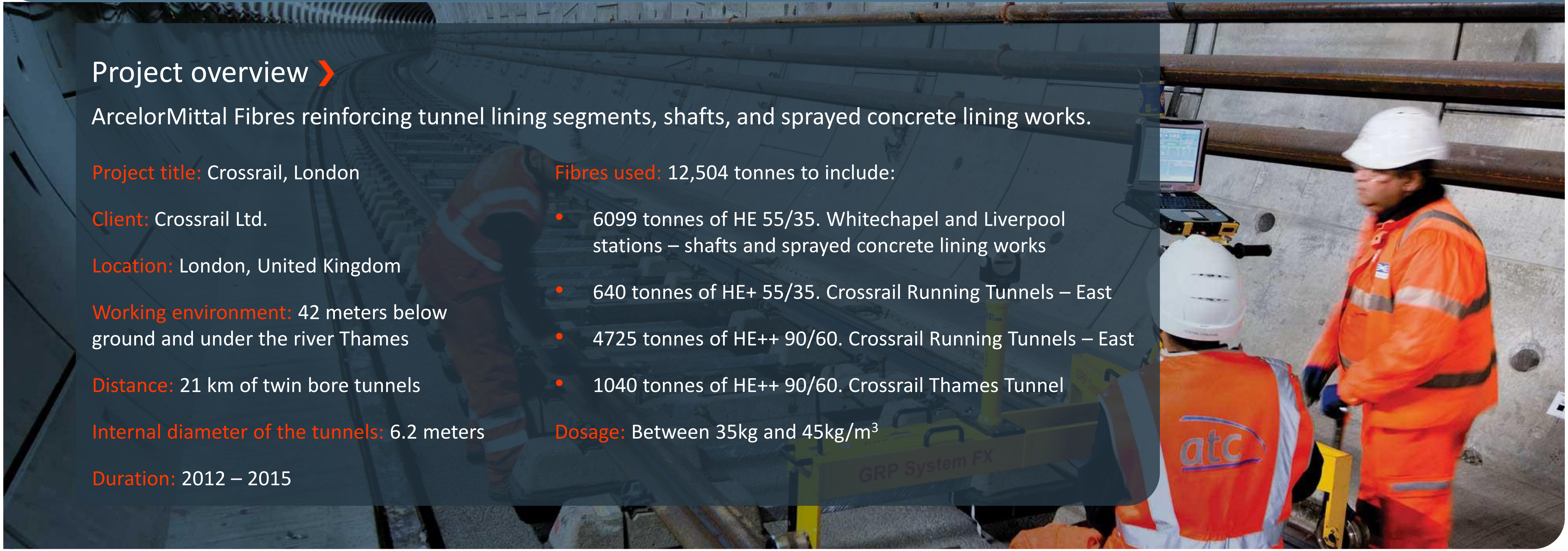
CASE STUDY

Crossrail, London



Project overview ❯

ArcelorMittal Fibres reinforcing tunnel lining segments, shafts, and sprayed concrete lining works.

Project title: Crossrail, London

Client: Crossrail Ltd.

Location: London, United Kingdom

Working environment: 42 meters below ground and under the river Thames

Distance: 21 km of twin bore tunnels

Internal diameter of the tunnels: 6.2 meters

Duration: 2012 – 2015

Fibres used: 12,504 tonnes to include:

- 6099 tonnes of HE 55/35. Whitechapel and Liverpool stations – shafts and sprayed concrete lining works
- 640 tonnes of HE+ 55/35. Crossrail Running Tunnels – East
- 4725 tonnes of HE++ 90/60. Crossrail Running Tunnels – East
- 1040 tonnes of HE++ 90/60. Crossrail Thames Tunnel

Dosage: Between 35kg and 45kg/m^3

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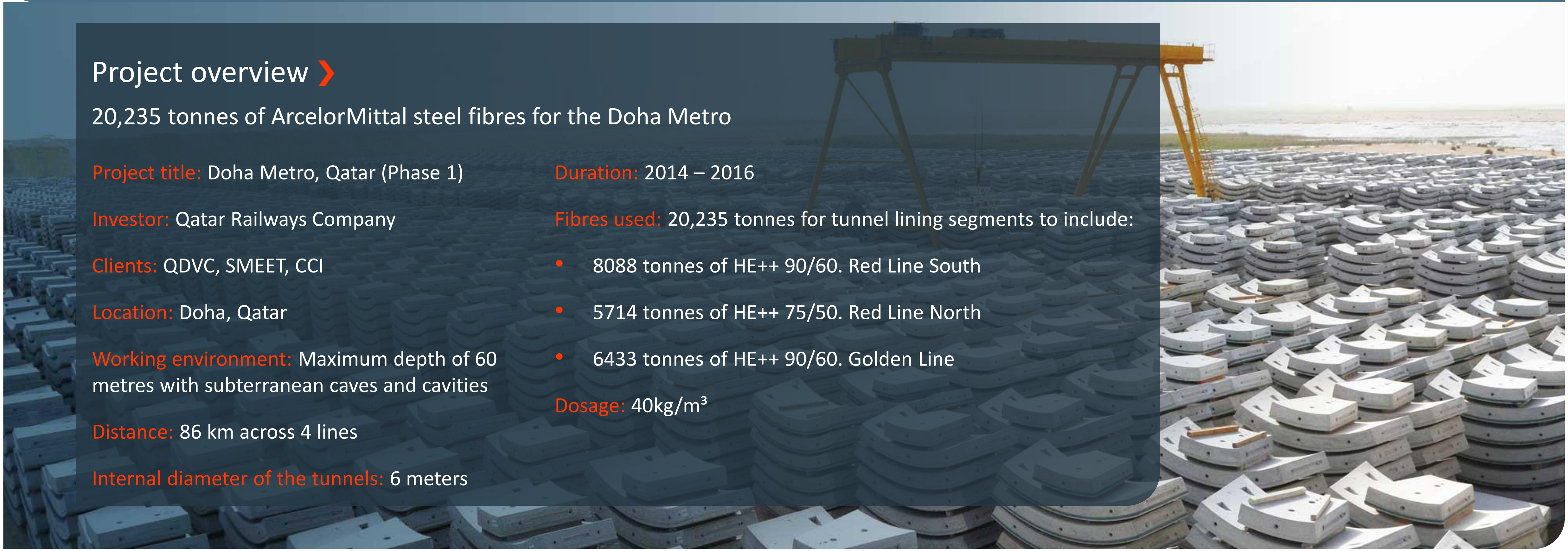
CASE STUDY

Doha Metro, Qatar



Project overview ❯

20,235 tonnes of ArcelorMittal steel fibres for the Doha Metro

Project title: Doha Metro, Qatar (Phase 1)

Investor: Qatar Railways Company

Clients: QDVC, SMEET, CCI

Location: Doha, Qatar

Working environment: Maximum depth of 60 metres with subterranean caves and cavities

Distance: 86 km across 4 lines

Internal diameter of the tunnels: 6 meters

Duration: 2014 – 2016

Fibres used: 20,235 tonnes for tunnel lining segments to include:

- 8088 tonnes of HE++ 90/60. Red Line South
- 5714 tonnes of HE++ 75/50. Red Line North
- 6433 tonnes of HE++ 90/60. Golden Line

Dosage: 40kg/m^3

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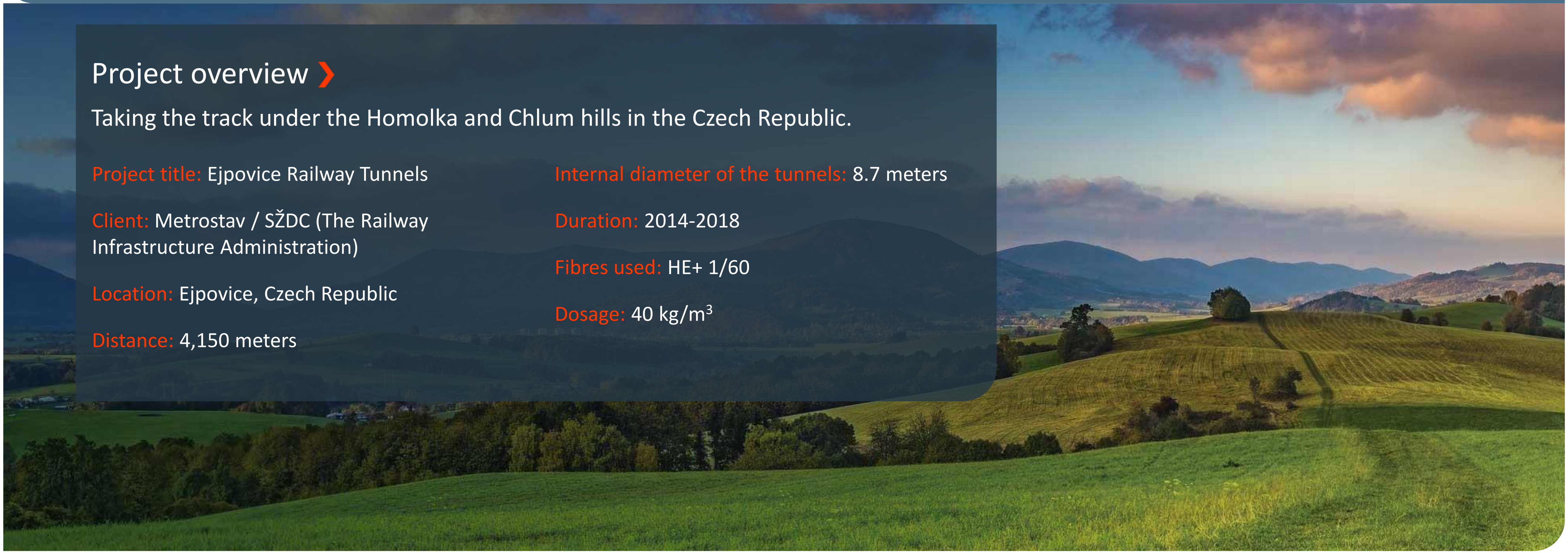
CASE STUDY

Ejpovice Railway Tunnels, Czech Republic



Project overview ❯

Taking the track under the Homolka and Chlum hills in the Czech Republic.

Project title: Ejpovice Railway Tunnels

Client: Metrostav / SŽDC (The Railway Infrastructure Administration)

Location: Ejpovice, Czech Republic

Distance: 4,150 meters

Internal diameter of the tunnels: 8.7 meters

Duration: 2014-2018

Fibres used: HE+ 1/60

Dosage: 40 kg/m^3

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CASE STUDY

HS2 C1 – Chiltern Tunnels, United Kingdom

Project overview ›

15281 tonnes of ArcelorMittal HE++90/60 high quality fibres are planned for the Chiltern tunnel section of HS2

Project title: HS2 – C1: Chiltern Tunnel

Investor: HS2 Ltd.

Contractor: Align JV (Bouygues Travaux Publics, VolkerFitzpatrick, Sir Robert McAlpine)

Concrete producer: TARMAC

TLS producer: Align JV

Location: United Kingdom

Working environment: Railway

Distance: 16.0 km (twin tube)

Internal diameter of the tunnels: 9.10 metres

Duration: 2021 – 2024

Fibres proposed: 15281 tonnes of HE++90/60 for tunnel lining segments

CASE STUDY

Grand Paris Express, France

Project overview ›

11600 tonnes of ArcelorMittal HE++90/60 high quality fibres are planned for use in over 22km of tunnel lining segments underneath the city of Paris

Project title: Grand Paris Express

Client: Société du Grand Paris

Contractor: Line 16 Lot 2: WE BUILD-NGE.
Line 18 Lot 1: Razel Bec Fayat Sefi-Intrafor

TLS producer: Line 16 Lot 2: Alliance JV.
Line 18 Lot 1: Stradal

Location: Paris, France

Working environment: Subway

Distance: Line 16 Lot 2 – 11.1 km. Line 18 Lot 1 - 11.8 km

Internal diameter of the tunnels: 8.70 metres

Duration: 2021 – 2023

Fibres proposed: 11600 tonnes of HE++90/60 for tunnel lining segments to include:

- 5600 tonnes of HE++90/60. Line 16 Lot 2
- 6000 tonnes of HE++90/60. Line 18 Lot 1

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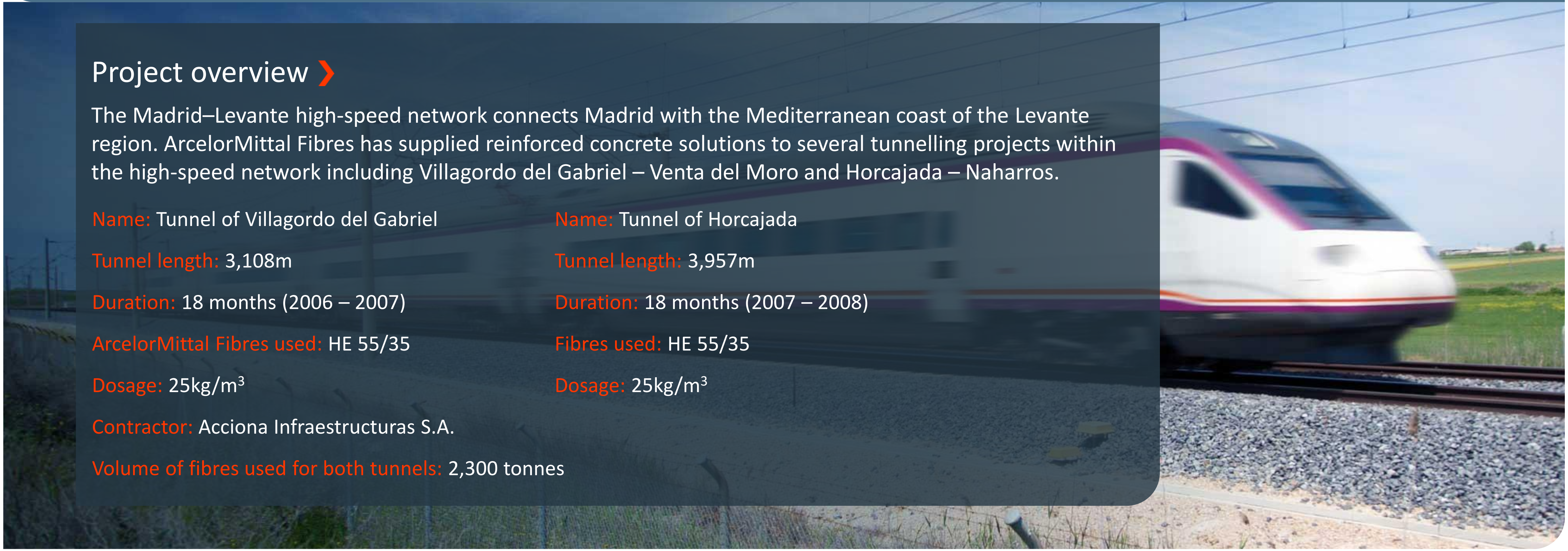
CASE STUDY

High-speed Railway Line – Madrid, Levante



Project overview ❯

The Madrid–Levante high-speed network connects Madrid with the Mediterranean coast of the Levante region. ArcelorMittal Fibres has supplied reinforced concrete solutions to several tunnelling projects within the high-speed network including Villagordo del Gabriel – Venta del Moro and Horcajada – Naharros.

Name: Tunnel of Villagordo del Gabriel

Tunnel length: 3,108m

Duration: 18 months (2006 – 2007)

ArcelorMittal Fibres used: HE 55/35

Dosage: 25kg/m^3

Name: Tunnel of Horcajada

Tunnel length: 3,957m

Duration: 18 months (2007 – 2008)

Fibres used: HE 55/35

Dosage: 25kg/m^3

Contractor: Acciona Infraestructuras S.A.

Volume of fibres used for both tunnels: 2,300 tonnes

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CASE STUDY

Drill and Blast tunnel, Norway

Project overview ❯

Relocation of the E134 through a tunnel between Gvammen to Århus will successfully shorten the E134 route by approximately 11km. In addition, the new road, with very little gradient, reduces driving time for heavy vehicles by about 18 minutes, making the journey both safer and faster.

Project title: Drill and Blast tunnel, E134 Gvammen-Århus

Client: Ferdigbetong A/S

Contractor: NCC Norway A/S

Location: Telemark Fylke, Norway

Developer: Statens Vegvesen. Norwegian Road Administration

Length: Approximately 11.7km. Approximately 9.4km of which is tunnel

Speed limit: 80km/h

Road width: 10 metres

Tunnel category: C (tunnel cross section T10.5)

Total cost: Approximately NOK 2.0 billion

Financing: State funds (100%)

Duration: 2014 – 2018

Fibres used: 1,250 tonnes to include:

- 650 tonnes of standard HE 55/35, 1200 N/mm^2
- 600 tonnes of new premium HE+ 55/35GL, 1800 N/mm^2

Dosage: Between 23kg/m3 and 28kg/m^3

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Design of SFRC TLS

Bruno ROSSI - Senior Engineer Tunneling

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Design of SFRC Tunnel Lining Segments

- Steel Fibre Reinforced Concrete (SFRC) - Technical and economic benefits
- Fibre standards, testing procedures and design guidelines for FRC
- EN 14651 bending test and Model Code 2010 classification
- From mechanical properties to design values
- Design guidelines for FRC Tunnel Lining Segments, loading cases and input data
- How to specify the FRC for the Tunnel Lining Segments
- Our support

Steel Fiber-Reinforced Concrete_1

- The Fibre-Reinforced Concrete (FRC) is a composite material made of basic concrete in which a fibre reinforcement is incorporated and homogeneously distributed
- Fibres can be made of steel, polymers, glass or natural materials
- Fibres addition in concrete controls plastic and hydraulic shrinkage cracking, reducing crack spacing and crack width, thereby improving durability (even in aggressive chlorinated environment as Doha Metro)
- Fibres with an High Young's Modulus considerably improves the concrete post-cracking behaviour, depending on fibre characteristics, concrete matrix strength and dosage rate.
- Fibre materials with a Young's-Modulus which is significantly affected by time and/or thermo-hygrometrical phenomenon, are not covered by the Model Code 2010 and, in general, should not be considered as structural materials
- Structural design of FRC elements is based on the post-cracking residual strength provided by fibre reinforcement (Model Code 2010)

Steel Fiber-Reinforced Concrete_2

- For structural use, a minimum mechanical performance of FRC must be guaranteed (Model Code 2010) The application and the use of this material in precast tunnel lining design is a growing trend due to its advantages in performance, durability and ease of manufacture compared to traditionally reinforced concrete.

Tunnel name	Year	Country	Function	Inner Diameter (ID) (m)	Thickness (mm)	Dosage (kg/m^3)	Fiber only
Metrosud	1982	Italy	Subway	5.80	300	N.A.	•
Heathrow Baggage Handling	1993	UK	Service	4.50	150	30	•
Essen	2001	Germany	Subway	6.30	350	N.A.	•
Trasvases Manabi (La Esperanza)	2001	Ecuador	Water supply	3.50	200	30	•
Lotschberg	2007	Switzerland	Temporary pilot	4.50	220	N.A.	•
Hobson Bay	2009	New Zealand	Wastewater	3.70	230	35	•
Copenhagen District Heating tunnel	2009	Denmark	Water supply	4.20	300	35	•
FGC Terrassa	2010	Spain	Railway	6.00	300	25	•
Brighwater	2011	USA	Wastewater	5.10	260	35	•
Pando	2012	Panama	Water supply	3.00	250	40	•
STEP Abu Dhabi Lot T-02	2014	UAE	Wastewater	6.30	280	30	•
London Crossrail	2015	UK	Railway	6.20	300	35 - 45	•
Legacy Way	2015	Australia	Road	11.30	350	40	•
Ejpovice	2016	Czech Republic	Railway	8.70	400	40	•
Doha Metro (Red and Gold lines)	2016	Qatar	Subway	6.00	300	40	•
Thames Tideway Central Section Tunnels	2020	UK	Sewerage	7.80	350	32	•
HS2 N1 - Long Itchington Wood	2021	UK	Railway	9.10	400	40	•
Świnoujście tunnel	2021	Poland	Road	12.00	500	43	•
Grand Paris Express (Lines 16.2, 16.3 & 18.3)	u.c.	France	Subway	8.70	400	45	•
HS2 C1 - Chiltern Tunnels	u.c.	UK	Railway	9.10	400	40	•
City Rail Link - Auckland	u.c.	New Zealand	Subway	6.00	300	30	•
Central Interceptor - Auckland	u.c.	New Zealand	Sewerage	4.50	250	30	•
Mularroya Water Tunnel	u.c.	Spain	Water supply	2.90	225	40	•

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Technical and economic benefits

Constructive:

- Reinforcement correctly placed, no cover limitations
- Improved precast production efficiency by partial or total elimination of ordinary steel reinforcement, avoiding mesh and rebar's cage handling and placing
- Higher robustness of the segments
- Reduced damaged segments

Cost savings:

- Around 39% according to the ITATECH Design Guidance for Precast Fiber Reinforced Concrete Segment – Draft Report

Structural:

- From brittle to ductile material
- Smaller crack width openings and crack lengths
- Higher resistance against impacts during handling and placing of the segments
- Higher durability: the resistance against chloride and carbonatation induced corrosion of SFRC is higher than in traditional reinforced concrete

Fibre standards and testing procedures

EN 14889-2006:
Fibres for concrete – Part 1: Steel fibres – Definitions, specifications and conformity

ILNAS-EN 14889-1:2006

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 14889-1

August 2006

ICS 91.100.30

English Version

Fibres for concrete - Part 1: Steel fibres - Definitions, specifications and conformity

Fibres pour béton - Partie 1 : Fibres d'acier - Définitions, spécifications et conformité

Fasern für Beton - Teil 1: Stahlfasern - Begriffe, Festlegungen und Konformität

This European Standard was approved by CEN on 26 June 2006.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 14889-1:2006: E

EN 206-2013:
Concrete – Specification, performance, production and conformity

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 206

December 2013

ICS 91.100.30

Supersedes EN 206-1:2000, EN 206-9:2010

English Version

Concrete - Specification, performance, production and conformity

Béton - Spécification, performances, production et conformité

Beton - Festlegung, Eigenschaften, Herstellung und Konformität

This European Standard was approved by CEN on 28 September 2013.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 206:2013 E

EN 14651-2005:
Test method for metallic fibre concrete. Measuring the flexural tensile strength (limit of prop. (LOP), residual);

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 14651:2005+A1

September 2007

ICS 91.100.30

Supersedes EN 14651:2005

English Version

Test method for metallic fibre concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)

Méthode d'essai du béton de fibres métalliques - Mesurage de la résistance à la traction par flexion (limite de proportionnalité (LOP), résistance résiduelle)

Prüfverfahren für Beton mit metallischen Fasern - Bestimmung der Biegezugfestigkeit (Proportionalitätsgrenze, residuelle Biegezugfestigkeit)

This European Standard was approved by CEN on 3 April 2005 and includes Amendment 1 approved by CEN on 16 August 2007.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 14651:2005+A1:2007: E

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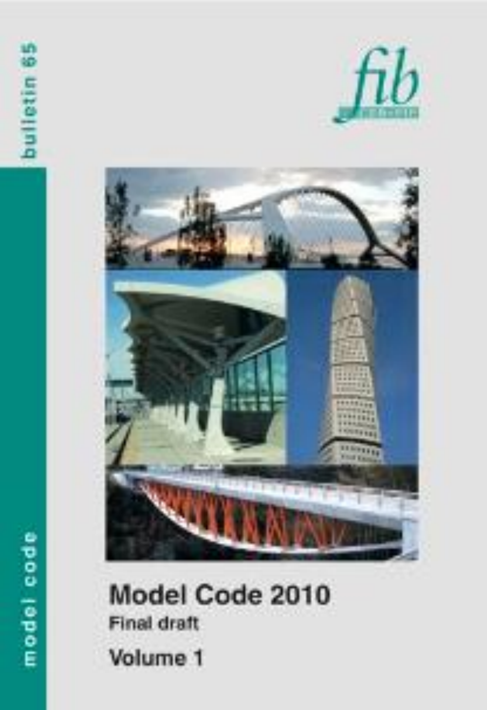
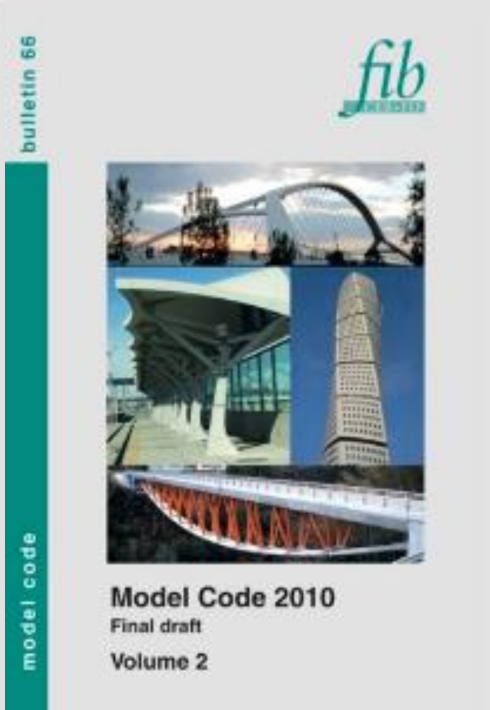
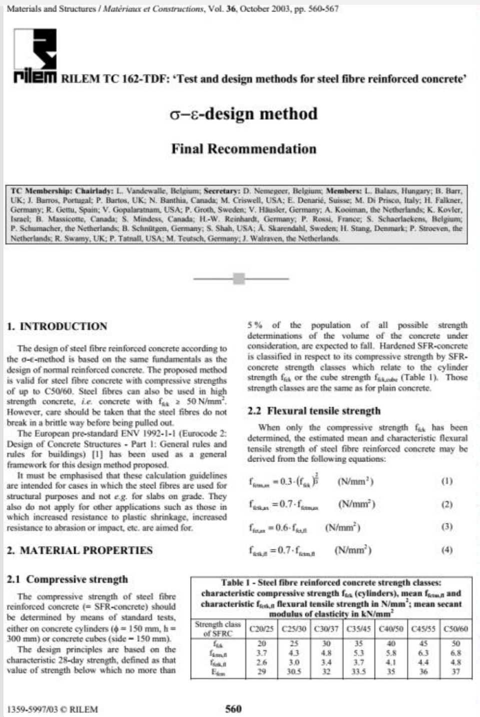
Design guidelines for Fibre-Reinforced Concrete (FRC) structures

- Eurocode 2
- Fib Model Code 2010: Chap. 5.6 Fibres/Fibre Reinforced Concrete & Chap. 7.7 Verification of safety and serviceability of FRC structures
- RILEM TC 162-TDF
- DAfStb
- SS 812310:2014







Materials and Structures / *Matériaux et Constructions*, Vol. **36**, October 2003, pp. 560-567

RILEM TC 162-TDF: 'Test and design methods for steel fibre reinforced concrete'

σ–ε-design method

Final Recommendation

TC Membership: Chairlady: L. Vandewalle, Belgium; **Secretary:** D. Nemegeer, Belgium; **Members:** L. Balazs, Hungary; B. Barr, UK; J. Barros, Portugal; P. Bartos, UK; N. Banthia, Canada; M. Criswell, USA; E. Denarié, Suisse; M. Di Prisco, Italy; H. Falkner, Germany; R. Gettu, Spain; V. Gopalaratnam, USA; P. Groth, Sweden; V. Häusler, Germany; A. Kooiman, the Netherlands; K. Kovler, Israel; B. Massicotte, Canada; S. Mindess, Canada; H.-W. Reinhardt, Germany; P. Rossi, France; S. Schaerlaekens, Belgium; P. Schumacher, the Netherlands; B. Schnütgen, Germany; S. Shah, USA; Å. Skarendahl, Sweden; H. Stang, Denmark; P. Stroeven, the Netherlands; R. Swamy, UK; P. Tatnall, USA; M. Teutsch, Germany; J. Walraven, the Netherlands.

1. INTRODUCTION

The design of steel fibre reinforced concrete according to the σ-ε-method is based on the same fundamentals as the design of normal reinforced concrete. The proposed method is valid for steel fibre concrete with compressive strengths of up to C50/60. Steel fibres can also be used in high strength concrete, *i.e.* concrete with $f_{fck} \geq 50$ N/mm². However, care should be taken that the steel fibres do not break in a brittle way before being pulled out.

The European pre-standard ENV 1992-1-1 (Eurocode 2: Design of Concrete Structures - Part 1: General rules and rules for buildings) [1] has been used as a general framework for this design method proposed.

It must be emphasised that these calculation guidelines are intended for cases in which the steel fibres are used for structural purposes and not *e.g.* for slabs on grade. They also do not apply for other applications such as those in which increased resistance to plastic shrinkage, increased resistance to abrasion or impact, etc. are aimed for.

2. MATERIAL PROPERTIES

2.1 Compressive strength

The compressive strength of steel fibre reinforced concrete (= SFR-concrete) should be determined by means of standard tests, either on concrete cylinders (ϕ = 150 mm, h = 300 mm) or concrete cubes (side = 150 mm).

The design principles are based on the characteristic 28-day strength, defined as that value of strength below which no more than 5 % of the population of all possible strength determinations of the volume of the concrete under consideration, are expected to fall. Hardened SFR-concrete is classified in respect to its compressive strength by SFR-concrete strength classes which relate to the cylinder strength f_{fck} or the cube strength $f_{fck,cube}$ (Table 1). Those strength classes are the same as for plain concrete.

2.2 Flexural tensile strength

When only the compressive strength f_{fck} has been determined, the estimated mean and characteristic flexural tensile strength of steel fibre reinforced concrete may be derived from the following equations:

$$f_{fctm,ax} = 0.3 \cdot (f_{fck})^{\frac{2}{3}} \quad (N/mm^2) \qquad (1)$$

$$f_{fctk,ax} = 0.7 \cdot f_{fctm,ax} \quad (N/mm^2) \qquad (2)$$

$$f_{fct,ax} = 0.6 \cdot f_{fct,fl} \quad (N/mm^2) \qquad (3)$$

$$f_{fctk,fl} = 0.7 \cdot f_{fctm,fl} \quad (N/mm^2) \qquad (4)$$

Table 1 - Steel fibre reinforced concrete strength classes: characteristic compressive strength f_{fck} (cylinders), mean $f_{fctm,fl}$ and characteristic $f_{fctk,fl}$ flexural tensile strength in N/mm²; mean secant modulus of elasticity in kN/mm²

Strength class of SFRC	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{fck}	20	25	30	35	40	45	50
$f_{fctm,fl}$	3.7	4.3	4.8	5.3	5.8	6.3	6.8
$f_{fctk,fl}$	2.6	3.0	3.4	3.7	4.1	4.4	4.8
E_{fcm}	29	30.5	32	33.5	35	36	37

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SVENSK STANDARD
SS 812310:2014

SWEDISH STANDARDS INSTITUTE

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Fiberbetong – Dimensionering av fiberbetongkonstruktioner

Fibre Concrete – Design of Fibre Concrete Structures

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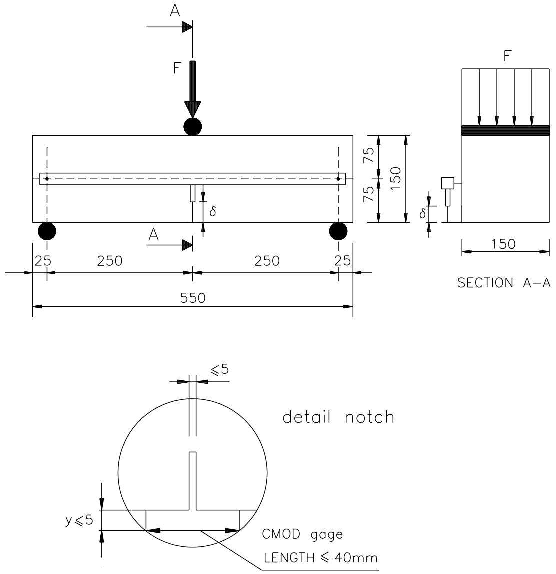
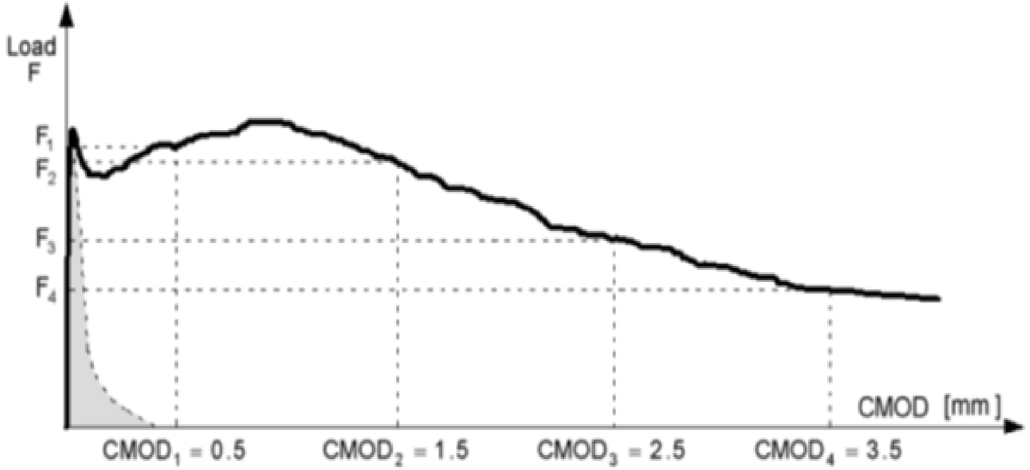
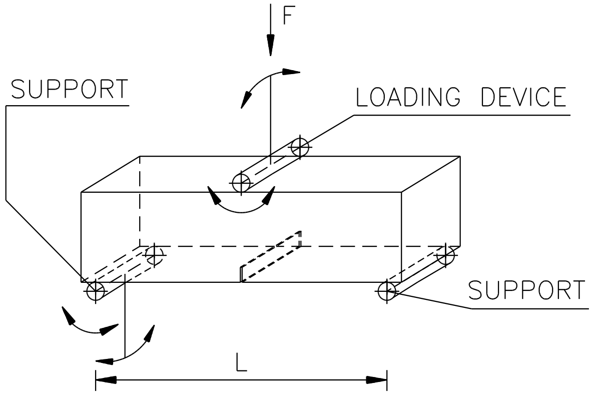
EN 14651 bending test and Model Code 2010 classification

EN 14651-2005: Test method for metallic fibre concrete.

Measuring the flexural tensile strength (limit of prop. (LOP), residual)







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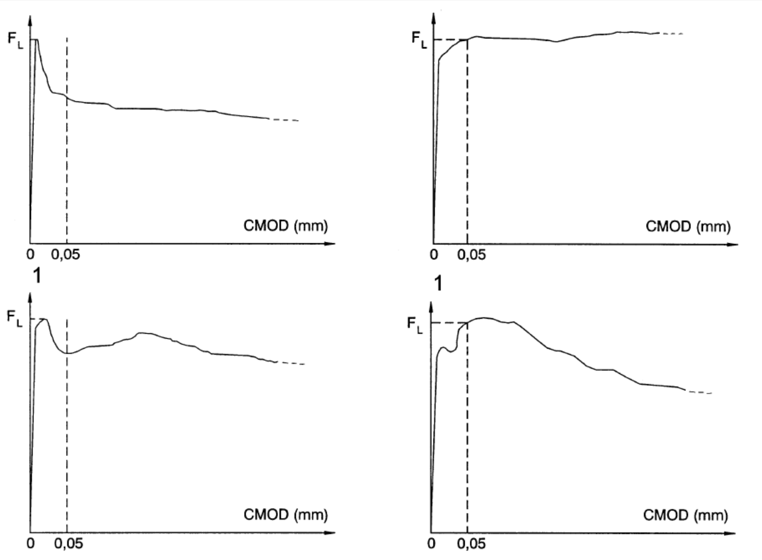
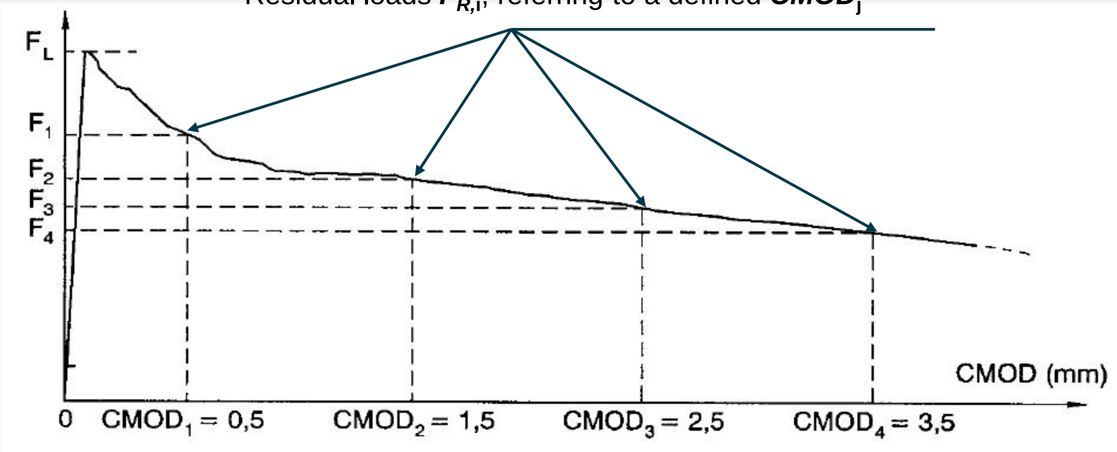
EN 14651 bending test and Model Code 2010 classification

Load corresponding to the limit of proportionality F_{LOP}



Post-cracking residual loads F_{Rj}

Residual loads $F_{R,i}$, referring to a defined $CMOD_j$



CMOD = Crack Mouth Opening Displacement (crack width)

EN 14651 bending test and Model Code 2010 classification

Characteristic test results: $f_{Rjk} = f_{Rim} - k_x \cdot \sigma_p$

f_{Rjk} = characteristic value of the residual flex strengths (N/mm^2)

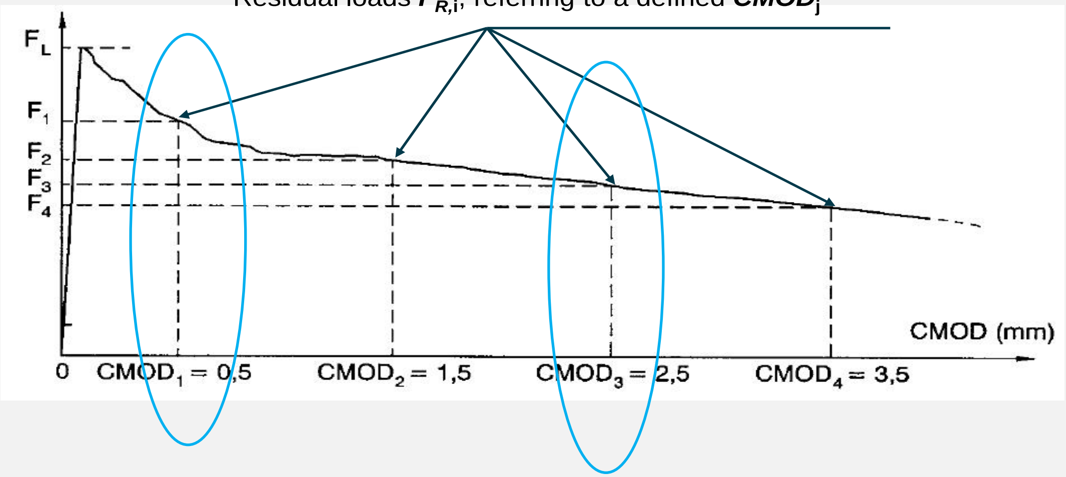
f_{Rjm} = mean value of the residual flex strengths (N/mm^2)

k_x = factor dependent on the number of the specimens

σ_p = standard deviation (N/mm^2)

f_{R1k} = residual flex strengths (CMOD$_1$ = 0,5 mm) (**Serviceability Limit State**)

f_{R3k} = residual flex strength (CMOD$_3$ = 2,5 mm) (**Ultimate Limit State**)



CMOD = Crack Mouth Opening Displacement (crack width)

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EN 14651 bending test and Model Code 2010 classification

$f_{R,1k}$ is the strength interval (1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, … [MPa]) and a letter *a*, *b*, *c*, *d* or *e* is the ratio $f_{R,3k} / f_{R,1k}$:

a if $0{,}5 \leq f_{R,3k} / f_{R,1k} < 0{,}7$
b if $0{,}7 \leq f_{R,3k} / f_{R,1k} < 0{,}9$
c if $0{,}9 \leq f_{R,3k} / f_{R,1k} < 1{,}1$
d if $1{,}1 \leq f_{R,3k} / f_{R,1k} < 1{,}3$
e if $1{,}3 \leq f_{R,3k} / f_{R,1k}$

Fibre reinforcement can substitute (also partially) conventional reinforcement at ultimate limit state if the following relationships are fulfilled:

$$f_{R,1k} / f_{Lk} > 0.4$$
$$f_{R,3k} / f_{R,1k} > 0.5$$

Beam test results from real projects

Country	Project name	Application	Fiber type	Dosage rate kg/m3	Concrete grade specified (Mpa) (*)	f_{LOPm} (Mpa)	f_{R1m} (Mpa)	f_{R2m} (Mpa)	f_{R3m} (Mpa)	f_{R4m} (Mpa)
UK	CrossRail C305	TLS	HE++ 90/60	35	C50/60	7.09	6.53	8.29	8.15	7.77
UAE	Doha Metro - Golden Line	TLS	HE++ 90/60	35	C45/55	6.28	6.22	7.37	7.68	7.67
Peru	Majes Siguas II	TLS	HE++ 90/60	30 35	C45/55	7.38 7.28	6.99 8.12	8.61 8.71	9.13 9.14	8.57 7.99

(*) By experience, due to durability and production requirements, the compressive strength is always higher than the specified one

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From mechanical properties to design values

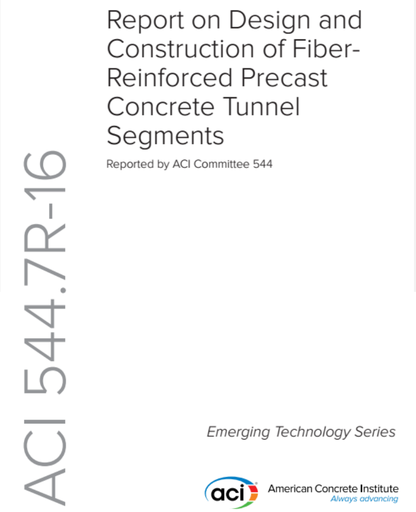
Here below the steps to derivate the design values from a bending test:

- Applied Loads $\mathbf{F_j}$ vs Crack openings $\mathbf{CMOD_j}$ (**EN 14651 bending test**)
- Flexural tensile strengths: limit of proportionality $\mathbf{f_L}$, residual $\mathbf{f_{R,j}}$ (**EN 14651 / Model Code 2010**)
- Characteristic values: $\mathbf{f_{Rjk} = f_{R,jm} - k_x\ s_p}$ (**RILEM TC162-TDF**)
- Classification: strength intervals $\mathbf{f_{R,1k}}$ and residual strength ratios $\mathbf{f_{R,3k} / f_{R,1k}}$ (**MC 10**)
- Minimum requirements to be fulfilled: $\mathbf{f_{R,1k} / f_{Lk} > 0{,}4}$ and $\mathbf{f_{R,3k} / f_{R,1k} > 0{,}5}$ (**MC 10**)
- Constitutive laws (**MC 10, RILEM TC162-TDF**)
- Material and loading safety factors: At ULS, a reduced safety factor γ_F **≥ 1.3** may be adopted for **improved control procedures** (**MC 10, EC 2**)
- Design values for the different loading conditions
- Moment capacity and interaction diagram M-N: (**MC 10, EC 2**)

Design guidelines for FRC TLS

For the FRC Tunnel Lining Segments, some guidelines have been published all over the world (fib, ITA-AITES, France, Germany, USA, UK):

- AFTES Recommendations GT38R1F1 - La conception, le dimensionnement et la realisation de voussoirs prefabriques en beton de fibres metalliques;
- DAUB (German Tunnelling Committee) - Recommendations for the design, production and installation of segmental rings;
- **ACI 544.7R-16 - Report on Design and Construction of Fibre-Reinforced Precast Concrete Tunnel Segments**;
- ITA-TECH (WTC 2016) - Design Guidance for Precast Fibre Reinforced Concrete Precast Segments - Draft Report;
- ITA-WG02 (WTC 2016) - Twenty years of tunnel segments practice: lessons learnt and proposed design procedure;
- PAS 8810 - 2016, Design of concrete segmental tunnel linings - Code of practice
- **fib Bulletin 83 - 2018 - Precast tunnel segments in fibre-reinforced concrete**



hs2 engine for growth
British Tunnelling Society
bsi.

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Loading cases (ACI 544.7R-16)

Production and transient stages (Chapter 4):

- Demolding (Load case 1)
- Stacking (Load case 2)
- Transportation (Load case 3)
- Handling (Load case 4)

Service stages (Chapter 6):

- Earth pressure, groundwater and surcharge loads (Load case 8)
- Longitudinal joint bursting load (Load case 9)
- Loads induced due to additional distortion (Load case 10)
- Other loads (earthquake, fire, explosion) (Load case 11)

Construction stages (Chapter 5):

- Tunnel-boring machine (TBM) thrust jack forces (Load case 5)
- Tail skin back-grouting pressure (Load case 6)
- Localized back-grouting (secondary grouting) pressure (Load case 7)

Input Data for Tunnel Lining Segments design

For a preliminary segmental lining design, the following information are required:

- **Geometry of the Tunnel Segments**: thickness, radius, width, segment angle, number of the segments per ring, RAM shoes dimensions;
- **Material properties**: compressive and residual flexural strengths, at early and long-term age;
- **Material safety factors**: concrete, FRC and steel rebars depending on the loading conditions (EC2);
- **Load safety factors**: for demoulding, the dynamic factor is γ_D = 3,00; for stacking γ_F = 1,35 (static load factor) and γ_D = 1,50 (dynamic load factor) for TBM thrust loads, γ_j = 1,05 (for maximum load);
- **Demoulding and handling**: type of lifting device (mechanical or vacuum), lifting points spacing or vacuum width;
- **Segments storage**: n° of segments stacked, stacking spacing, misalignment of the supports;
- **TBM thrust loads**: max. TBM load, n° of rams, ram shoe dimensions, eccentricity;
- **Axial forces N, bending moments M, shear forces V** (ground loading)

Load and material safety factors_1

The material & load safety factors are taken in accordance with the EC2 and MC10:

Load cases	Load safety factors				Material safety factors		
	Static		Dynamic				
Demoulding	1,35		3,00	(1)	1,30		(4)
Stacking	1,35		1,50	(2)	1,30		(4)
Spalling - TBM thrust jack forces	1,50 (nom. load)	1,05 (max. load)	---	(3)	1,30 (nom. load)	1,20 (max. load)	(5)
Bursting - TBM thrust jack forces	1,50 (nom. load)	1,05 (max. load)	---	(3)	1,30 (nom. load)	1,20 (max. load)	(5)
Earth pressure, groundwater and surcharge loads	1,50		---		1,30		(4)
Longitudinal joint bursting loads	1,50		---		1,30		(4)

1) Demoulding and stacking depend on the segment selfweight, so a safety factor 1,35 could be adopted
2) The dynamic load safety factor (≥ 1,50) is applied to the last segment only
3) TBM thrust jack forces load safety factor could be reduced up to 1,05 if the maximum TBM load value is considered
4) The material safety factor could be reduced up to 1,30 for improved control procedures (Model Code 2010)
5) The material safety factor for TBM thrust jack forces could be reduced up to 1,20 (Note 2, 9.3 Design actions and loads, PAS 8810: 2016 and ACI 544.7R-16)

Load and material safety factors_2

LOAD CASE	LOAD FACTORS
Load case 1: stripping (demolding)	$1.4w$
Load case 2 : storage	$1.4\ (w + F)$
Load case 3 : transportation	$1.4\ (w + F)$
Load case 4 : handling	$1.4w$
Load case 5 : thrust jack forces	*1.2J (1.0 if max machine thrust available)*
Load case 6 : tail skin grouting	$1.25\ (w + G)$
Load case 7 : secondary grouting	$1.25\ (w + G)$
Load case 8 : earth pressure and groundwater load	$1.25\ (w + WA_p) + 1.35\ (EH + EV) + 1.5\ ES$
Load case 9 : longitudinal joint bursting	$1.25(w + WA_p) + 1.35\ (EH + EV) + 1.5\ ES$
Load case 10 : additional distortion	$1.4M_{distortion}$
Note: w = self-weight; F = self-weight of segments positioned above; J = TBM jacking force; G = grout pressure; WA_p = groundwater pressure; EV = vertical ground pressure; EH = horizontal ground pressure; ES = surcharge load; and $M_{distortion}$ = Additional distortion effect	

Table 2 : Example of load factors for various governing load cases (ACI 544.7R, 2016)

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How to specify the SFRC for the Tunnel Lining Segments

- Compressive strength f_{ck} **(EN 206, EN 12390-3)**:
  - Early age
  - Long-term age (@28 days)
- Flexural strengths **(EN 14651)**:
  - Limit of proportionality f_{LOPk}
  - Residual flexural strengths $f_{R,jk}$
- Initial qualification of the material (trial testing) **(fib bulletin 83)**:
  - n º of specimens to be tested
  - Student factor k_{xknown} depends on the number of the specimens (**Eurocode 0**, **RILEM TC 162-TDF**)
- Tests during the segments production **(fib bulletin 83)**:
  - Min 3 specimens for every control set, per production day or per a given concrete volume
  - Fixed student factor k = 1.48, if more than 15 data sets are considered
- Fibre content **(EN 14721)**:
  - Fresh and hardened state: the measured content cannot differ more than 20% from the nominal value

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Tunnel Lining Segments (TLS)_1

- ❑ When can we use steel fibres?
  - For segments mainly compressed with low bending moments N >> M
  - When low ratio between developed segment length vs thickness L_d / th < 10
  - When only minimum reinforcement defined in RILEM TC 162-TDF is needed
  - Where the excavation type is mechanized : TBM with in general max diameter SFRC is < 13 m
- ❑ Advantages in precast tunnel segments
  - Reduction of crack widths and lengths: improved durability
  - Higher resistance against impacts during handling and installation: reduced number of repairs and rejected segments
  - Improved precast production efficiency: no reinforcement cages handling and placing: **Cost savings as per the following slide** (**Excel file based on**)
  - No limitations in the drawing of cross-section and prevention of complex reinforcement
- ❑ Standardization: Current Eurocode 2, fib Model Code 2010, RILEM TC 162-TDF, DAfStb, available design guidelines for TLS in France (AFTES), Germany (DAUB), USA (ACI544,7R-16), UK (PAS)
- ❑ Testing and material properties: EN 12390-3, EN 14651, EN 206, Etc …
- ❑ Performances: RFS should always be in characteristic values,

  Example : with min C40/50, C45/55, C50/60 concrete : f_{R1k} > 4.00 MPa, f_{R3k} > 4.00 MPa

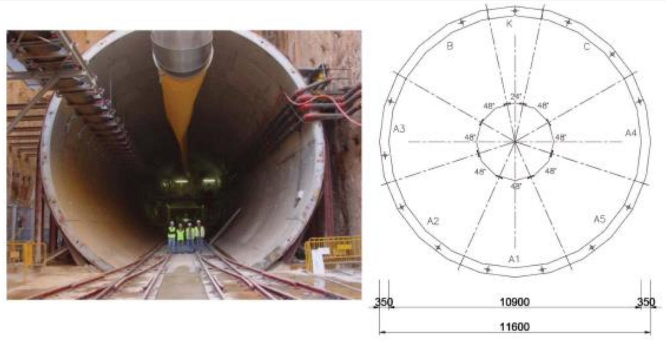
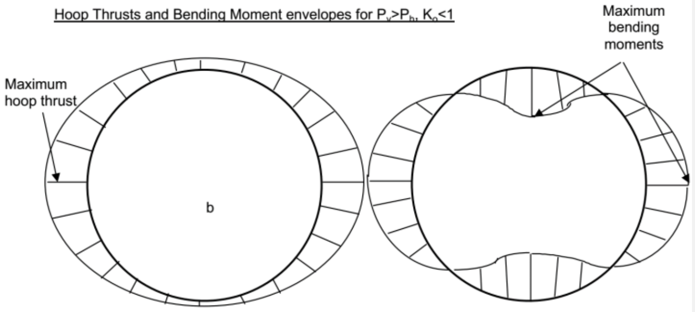


Fig. 10.2—Segmental lining configuration for Barcelona Metro Line 9 (Gettu et al. 2004).



$$\lambda = \frac{\text{mean developed segment length}}{\text{segment thickness}}$$

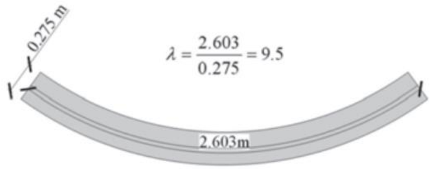


Figure 2 : An example of a segment aspect ratio λ

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Tunnel Lining Segments - Design tool

AM Segmental Lining Design_v1.0: This tool is based on **Groeneweg, 2007**, **ACI 544.7R-16**, **Leonhardt**, **Morsch**, **Guyon**, **DAUB** and **DAfStb**

WireSolutions
SFRC Design
ArcelorMittal Design of Segmental Lining
with ArcelorMittal Steel Fibers

ArcelorMittal

v1.0

Project number:
Date : 9/16/2018
Project name : Pune & Bengaluru Metro
Project area :

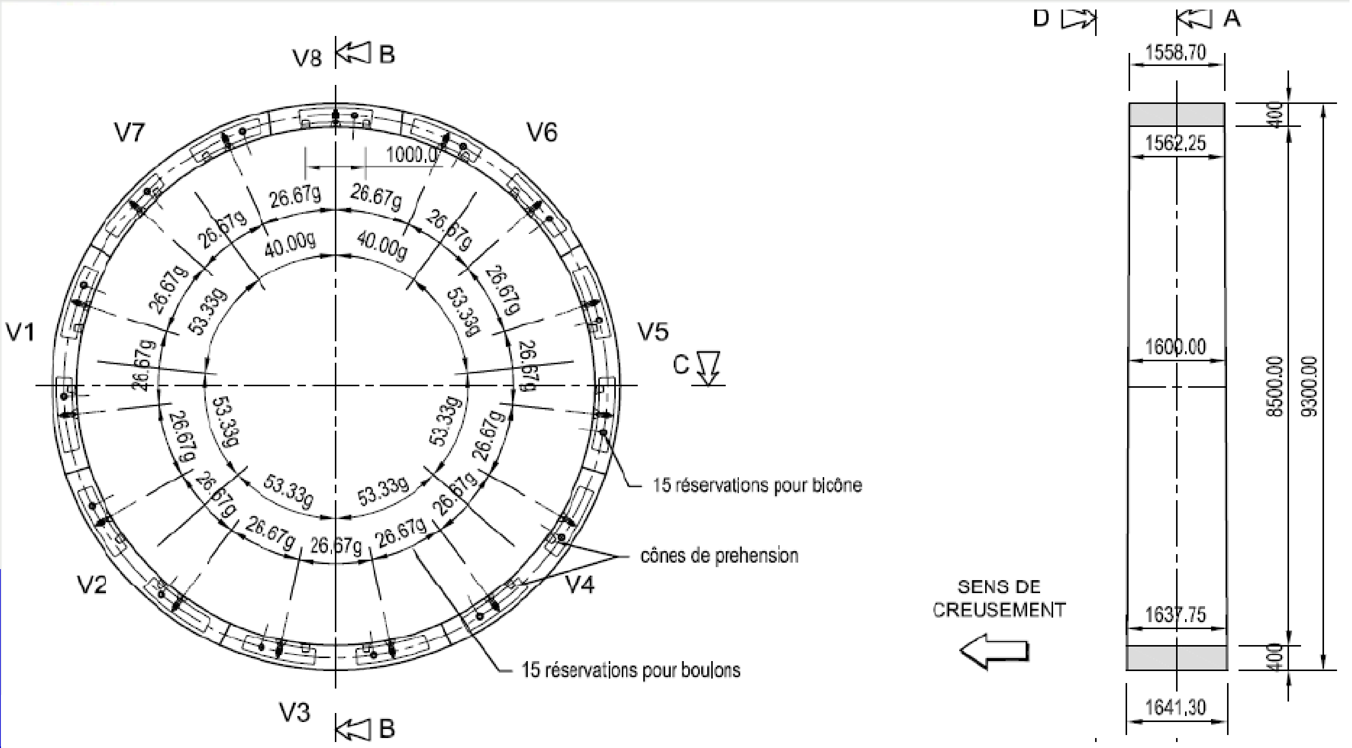
Customer: TATA Projects
E-mail :
Phone :
Fax :
Mobile :

Designer: Bruno ROSSI
ArcelorMittal Bissen & Bettembourg
Technical customer support
BP 16 - L-7703 Bissen
Tel.: +352 / 83 57 72-0
Fax.: +352 / 83 57 72-209
email: fibresupport@arcelormittal.com

Remarks:

1. Segment information

Length	$L =$	0	m'
Thickness	$t =$	275	mm
Inner radius	$r_i =$	2900	mm
Width	$W =$	1400	mm
Segment developed length	$l_d =$	3578.5	mm
Number per ring	$n =$	5	
Key		1/3	
Segment slenderness	$l_d/t =$	13.01	
Characteristic compressive strength (cylinder) at 28 days	$f_{ck} =$	45	N/mm^2
Fibre type		HE++ 90/60	
Fiber's dosage		35	kg/m^3
Residual flexural strength at 28 days	$f_{R3k} =$	5.000	N/mm^2



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Tunnel Lining Segments – Demoulding & stacking

1. Segment information			
Length	$L =$	0	m'
Thickness	$t =$	300	mm
Inner radius	$r_i =$	3050	mm
Width	$W =$	1700	mm
Segment developed length	$l_d =$	3351.0	mm
Number per ring	$n =$	6	
Key		0	
Segment slenderness	$l_d/t =$	11.17	
Characteristic compressive strength (cylinder) at 28 days	$f_{ck} =$	45	N/mm^2
Fibre type		HE++ 90/60	
Fiber's dosage		40	kg/m^3
Residual flexural strength at 28 days	$f_{R3k} =$	5.50	N/mm^2
2. Demoulding			
Lifting points spacing (*60% developed length l_d*)	$X_d =$	2011	mm
Segment unit linear weight	$q_w =$	7500	N/m^2
Dynamic load factor	$\gamma_{dyn} =$	2.00	
Design bending moment	$\mathbf{M_{Sd} =}$	**4.22**	**kNm/m**
Characteristic compressive strength (cylinder) at demoulding	$f_{ck,dem} =$	12.3	N/mm^2
Material safety factor for demoulding	$\gamma_{ct,dem} =$	1.50	
Conversion factor of 28 days strength into strength @ demoulding (Eurocode2)	$\beta_{cc,dem}$	0.27	
Resisting flexural strength at demoulding	$f_{Rd,dem} = \beta_{cc,dem} \cdot f_{R3k} / \gamma_{ct,dem} =$	1.00	N/mm^2
Moment resistance at demoulding	$\mathbf{M_{Rd,dem} = f_{Rd,dem}\ w\ t^2 / 6 =}$	**15.04**	**kNm/m**
		The design is verified!	
3. Stacking			
Number of stacked segments	$N =$	6.0	
Misalignment of stacking points	$y =$	100	mm
Stacking supports spacing (*60% developed length l_d*)	$x =$	2011	mm
Segment unit linear weight	$q_w =$	7500	N/m^2
Permanent static loads factor	γ_d	1.50	
Dynamic load factor (applied to the *last segment to be stored*)	γ_{dyn}	2.00	
Design bending moment	$\mathbf{M_{Sd} =}$	**13.21**	**kNm/m**
Characteristic compressive strength (cylinder) at stacking	$f_{ck,stk} =$	19.1	N/mm^2
Material safety factor for stacking	$\gamma_{ct,stk} =$	1.50	
Conversion factor of 28 days strength into strength @ stacking (Eurocode 2)	$\beta_{cc,stk}$	0.42	
Resisting flexural strength at stacking	$f_{Rd,stk} = \beta_{cc,stk} \cdot f_{R3k} / \gamma_{ct,stk} =$	1.55	N/mm^2
Moment resistance at stacking	$\mathbf{M_{Rd,stk} = f_{Rd,stk}\ w\ t^2 / 6 =}$	**23.31**	**kNm/m**
		The design is verified!	

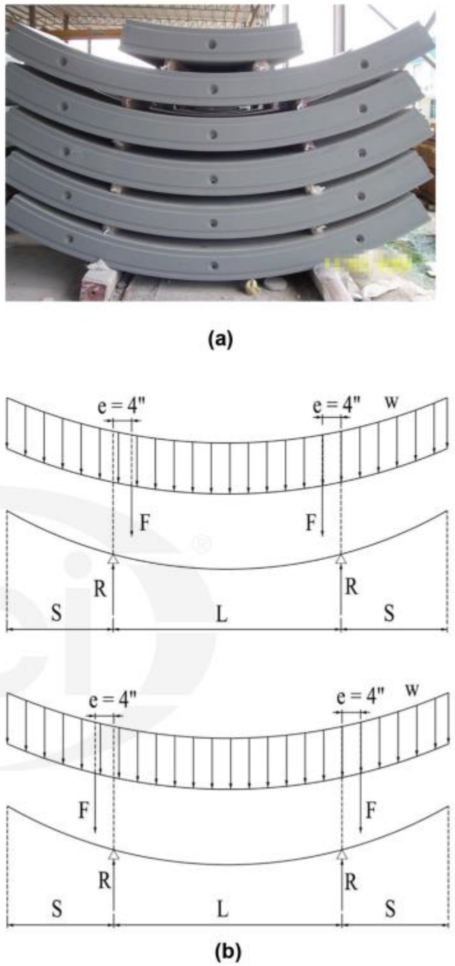

Fig. 4.2—(a) Segments piled up within one stack for storage; and (b) forces acting on bottom segment for Load Case 2.

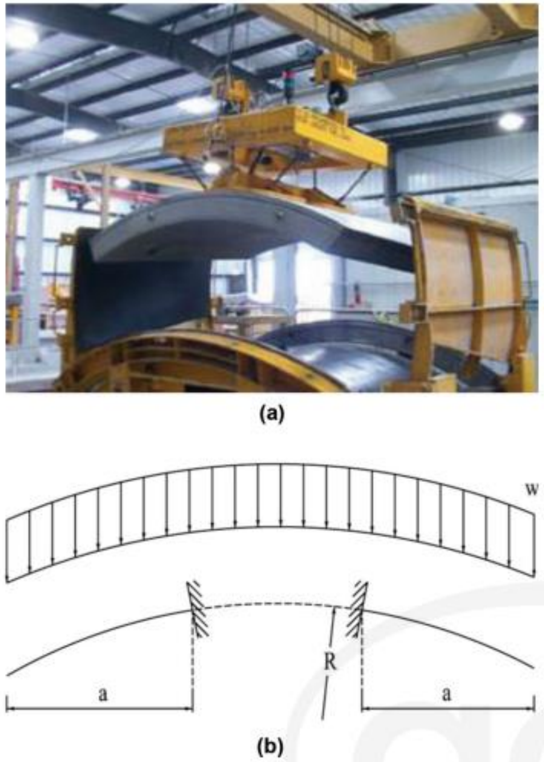

Fig. 4.1—(a) Stripping in the segment manufacturing plant; and (b) forces acting on segments for Load Case 1.

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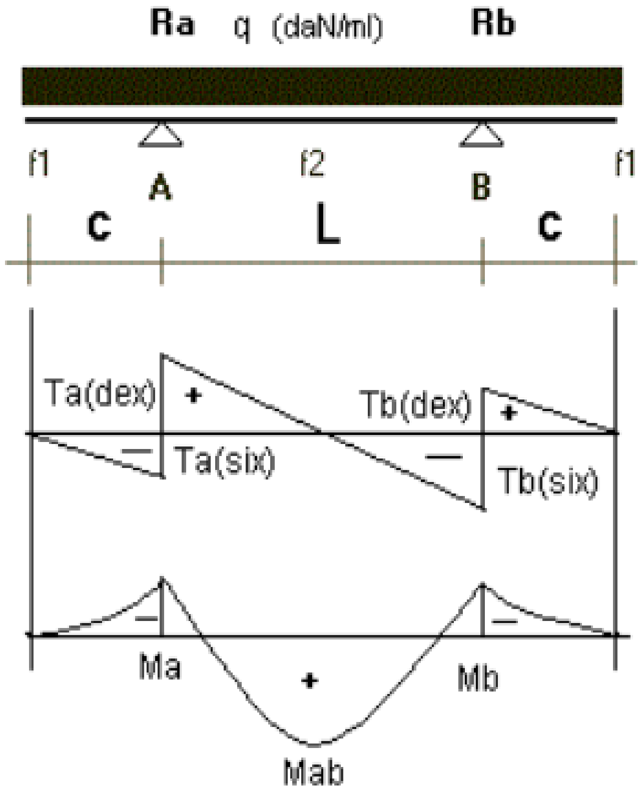
Tunnel Lining Segments – Demoulding

Developed length = c + L + c					Acting bending moments			Design bending moment
					M_A	M_{A-B}	M_B	$M_{Sd} = \max(M_A, M_{A-B}, M_B)$
c / (c+L+c)	c	L	c	c + L + c	$qc^2/2$	$qL^2/8 - qc^2/2$	$qc^2/2$	
	m	m	m	m	kNm/m	kNm/m	kNm/m	kNm/m
20%	0.67	2.01	0.67	3.35	3.37	4.22	3.37	4.22



$$Q = q(2c + L)$$

$$Ra = Rb = 0{,}5\, q(L + 2c)$$

$$Ma = Mb = -\,0{,}5\, q\, c^2$$

$$Mmax = q\left(\frac{L^2}{8} - \frac{c^2}{2}\right)$$

$$f1 = q\, c\, \frac{c^2(6L + 3c) - L^3}{24\, E\, J}$$

$$f2 = \frac{q\, L^2}{384\, E\, J}\,(5L^2 - 24c^2)$$

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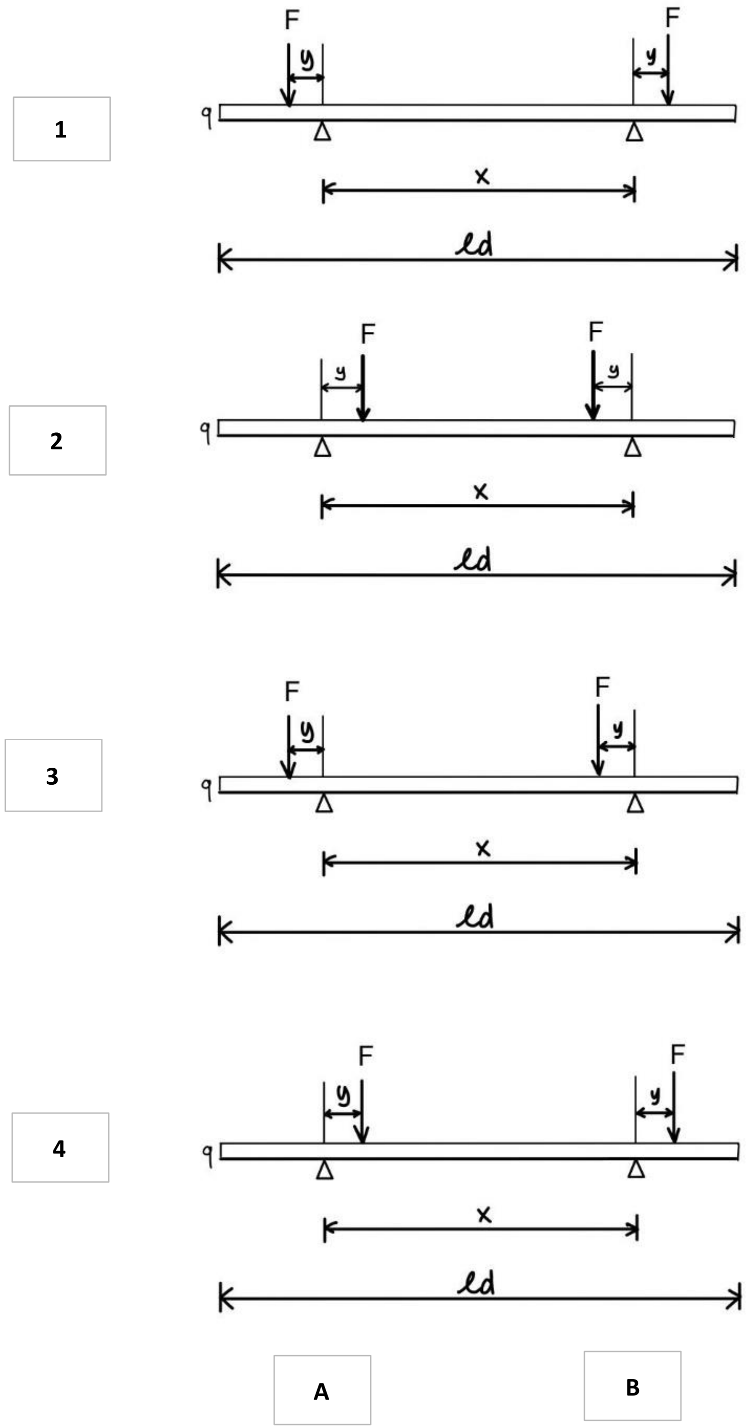
Tunnel Lining Segments Stacking

			1	2	3	4	
thickness	th	mm	300	300	300	300	
misalignment	y	mm	100	100	100	100	
supports spacing	x	mm	2011	2011	2011	2011	
segment developed length	l_d	mm	3351	3351	3351	3351	
segment weigth per linear meter	q	kN/m/m	7.5	7.5	7.5	7.5	
number of stacked segments	n		6	6	6	6	
N-1 stacked weight	F	kN/m	62.8	62.8	62.8	62.8	
Permanent static loads factor	γ_{static}		1.50	1.50	1.50	1.50	
Dynamic load factor (applied to the last stored segment)	γ_{dyn}		2.00	2.00	2.00	2.00	
N-1 stacked applied force	F_D	kN/m	100.5	100.5	100.5	100.5	
First segment stacked	S_D	kN/m	37.7	37.7	37.7	37.7	
Support reaction	R_A	kN/m	119.4	119.4	129.4	109.4	
	R_B	kN/m	119.4	119.4	109.4	129.4	
Bending moments	M_A	kNm/m	-12.58	-1.68	-12.58	-1.68	
	M_{middle}	kNm/m	-6.89	13.21	3.16	3.16	**13.21**
	M_B	kNm/m	-12.58	-1.68	-1.68	-12.58	
	$M_{A1} = M_{B1} = M_{A3} = M_{B4}$						
	$M_{A2} = M_{B2} = M_{A4} = M_{B3}$						



ACI 544.7R-16, Chapter 4: How to design SFRC TLS under TBM loads

in Chapter 4. If the required residual tensile strength σ_p of FRC segments is higher than allowed for conventional fiber dosage rates, reinforcing bars are designed for additional reinforcement against the significant bursting stresses developed by jacking forces. In such a case, the residual tensile strength of FRC segments is specified using the maximum value allowed for conventional fiber dosage rates. Equations (5.1.1e) and (5.1.1f) have been adopted to determine the required area A_s of reinforcing bars with a yield stress of F_y for a combined reinforcement system of fibers and bars.

$$T_{burst} = \phi\sigma_p a_l d_{burst} + \phi F_y A_s \text{ for radial direction} \quad (5.1.1e)$$

$$T_{burst} = \phi\sigma_p h_{anc} d_{burst} + \phi F_y A_s \text{ for tangential direction} \quad (5.1.1f)$$

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Reinforced concrete solutions

Tunnel Lining Segments – TBM thrust jack loads

AM Segmental Lining Design_v1.0

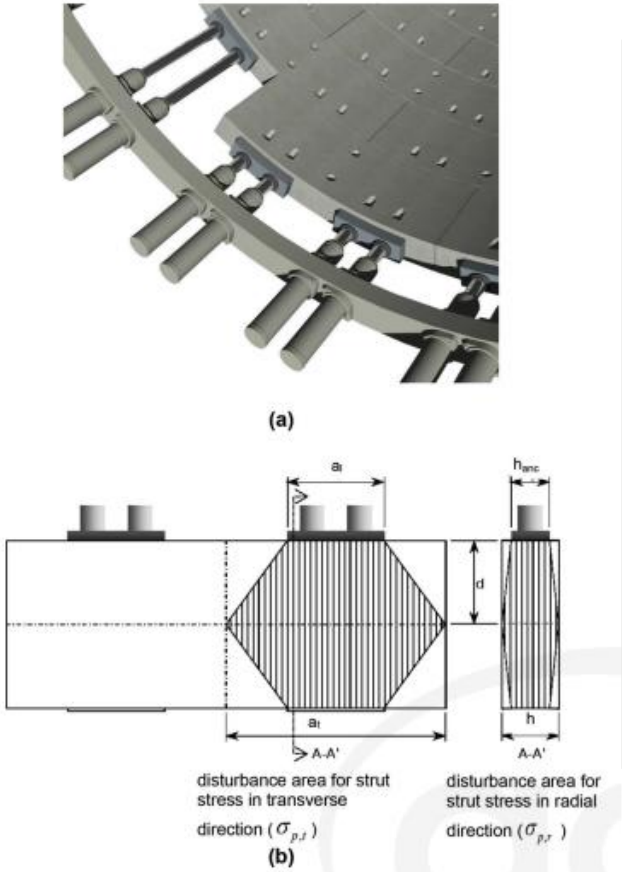


Fig. 5.1—(a) Thrust jacks pushing on circumferential joints; and (b) schematics of a simplified disturbance area of bottle-shaped strut under TBM jack shoes (Groeneweg 2007).

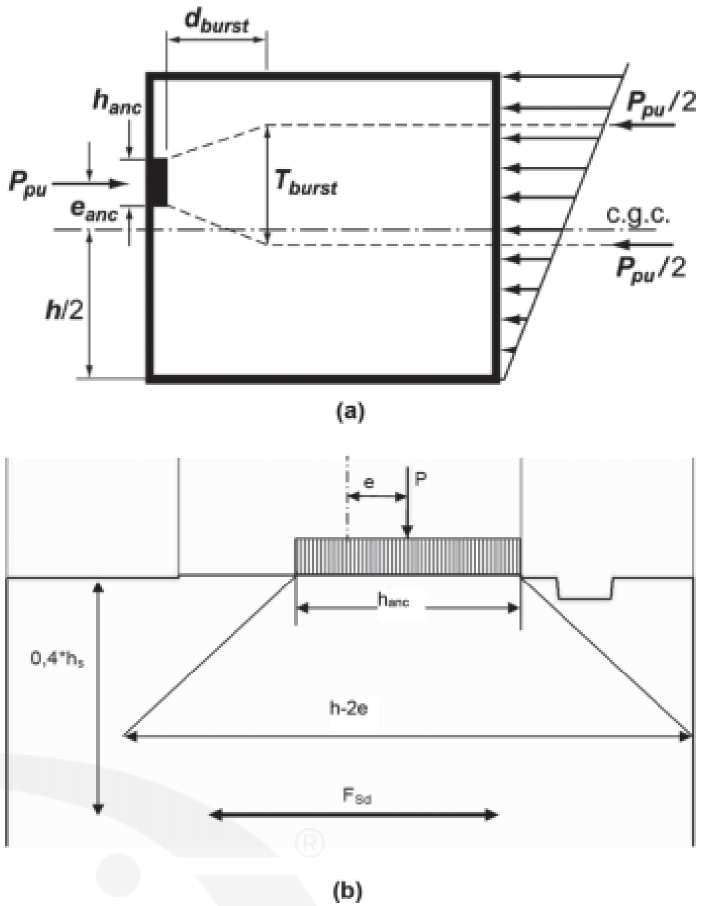


Fig. 5.1.1—Bursting tensile forces and corresponding parameters recommended by: (a) ACI 318; and (b) German Tunneling Committee (2013).

Tunnel Lining Segments – TBM thrust jack loads

AM Segmental Lining Design_v1.0

4. TBM applied load data		
Thickness	275	mm
Total load RAM jacks	42575	kN
Number of RAM shoes (each shoe has two jacks)	16	
Longitudinal joint e_{l1}	25	
Longitudinal joint e_{l2}	63	
Ring joint e_{r1}	25	
Ring joint e_{r2}	63	
Width of the RAM shoe	200	mm
Length of RAM shoes	1029	mm
RAM load eccentricity	15	mm

5. Radial - Spalling force at circumferential joints (TBM)		
Jacking force exerted by the TBM	2586	kN/m
RAM load safety factor	1.20	
Spalling force Z_R (Leonhardt)	51.62	kN/m
Depth of the spalling stress distribution at ULS (Leonhardt)	73.50	mm
Area on which the spalling force is distributed at ULS	73500	mm^2/m
Spalling stress (radial direction)	**0.702**	**N/mm^2**
Characteristic compressive strength (cylinder) at 28 days	45	N/mm^2
Fibre type	HE++ 90/60	
Fiber's dosage	40	kg/m^3
Material safety factor for spalling (MC10)	1.30	
Resisting tensile strength at spalling	**1.282**	**N/mm^2**
	The design is verified!	

6. Radial - Bursting force at circumferential joints (TBM)		
Jacking force exerted by the TBM	2586	kN/m
RAM load safety factor	1.20	
Effective width of the TBM RAM: a_{eff} = min (a ; t - e_{w1} - e_{w2} ; 0,75 t)	187.00	mm
Bursting force Z_S (Leonhardt & ACI 544.7R-16))	183.65	kN/m
Depth of the bursting stress distribution at ULS (DAUB / DafStb)	220.50	mm
Area on which the bursting force is distributed	220500	mm^2/m
Bursting stress (radial direction)	**0.833**	**N/mm^2**
Characteristic compressive strength (cylinder) at 28 days	45	N/mm^2
Fibre type	HE++ 90/60	
Fiber's dosage	40	kg/m^3
Material safety factor for bursting (MC10)	1.30	
Resisting tensile strength at bursting	**1.282**	**N/mm^2**
	The design is verified!	

6.5 Design with strut-and-tie models

6.5.1 General

DIN EN 1992-1-1, a new paragraph (R.2)P is added

(R.2)P The tension forces of the strut-and-tie models shall only be absorbed by the steel fibre reinforced concrete if one of the following conditions has been satisfied:

– the tensile stresses in the uncracked state are less than $f^f_{ctd,u}$ or
– it can be demonstrated that the crack width can be limited to $w_k = 0.5$ mm at the ultimate limit state.

Otherwise, reinforcement shall be inserted, where the contribution of the steel fibres to the tensile load-bearing capacity must not exceed 30% (with $f^f_{ctd,u}$).

6.7 Partial area loading

DIN EN 1992-1-1, Paragraph (4) is supplemented

The tension bar of the strut-and-tie in Figure R.5 may be made of steel fibre reinforced concrete alone or executed with reinforcement as specified in 10.6. The analysis shall be performed using $f^f_{ctd,u}$ or $f^f_{ctR,s}$.

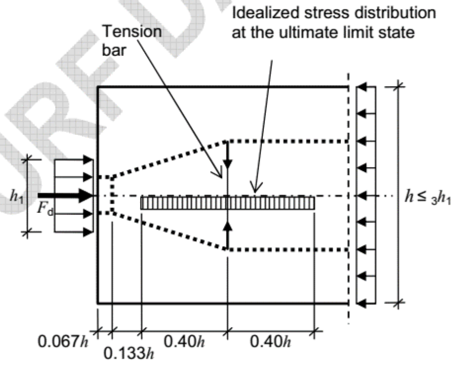
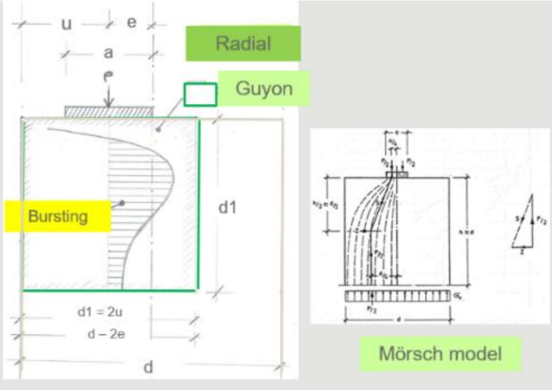
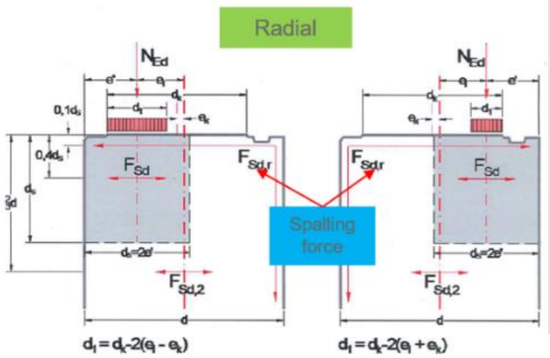


Figure R.5 – Strut-and-tie for partial area load design





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Reinforced concrete solutions

Tunnel Lining Segments – TBM thrust jack loads

B. Schnütgen & E. Erdem, Annex 1 to Final Report Sub-task 4.4,
Splitting of SFRC induced by local forces, BRITE-EURAM BRPR-CT98-0813

Institute for Reinforced and Prestressed Concrete Structures

Ruhr-University Bochum

Brite EuRam BRPR-CT98-0813

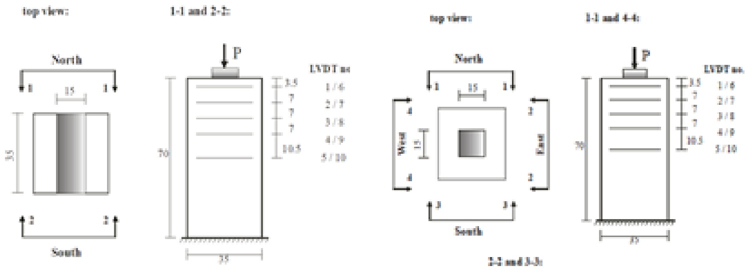
Sub-task 4.4

Splitting of SFRC induced by local forces

Table 1: Summary of tested specimens

specimen no.	fibre type		content [kg/m³]	load configuration *	nominal dimensions [mm]		
	RC 65/40	RC 65/60			width	depth	height
1	x			L	350	350	700
2	x		35	L	350	350	700
3	x			L	350	350	700
4	x			L	350	350	700
5	x			L	350	350	700
6	x			L	350	350	700
7		x		L	350	350	700
8		x	60	L	350	350	700
9		x		L	350	350	700
10	x			P	350	350	700
11	x			P	350	350	700
12	x			P	350	350	700

* In the column indicating the load configuration for the tests, an „L" means line load configuration, whereas a „P" means point load configuration. These configurations will be described later in this report.



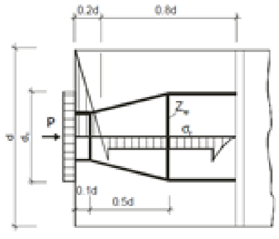
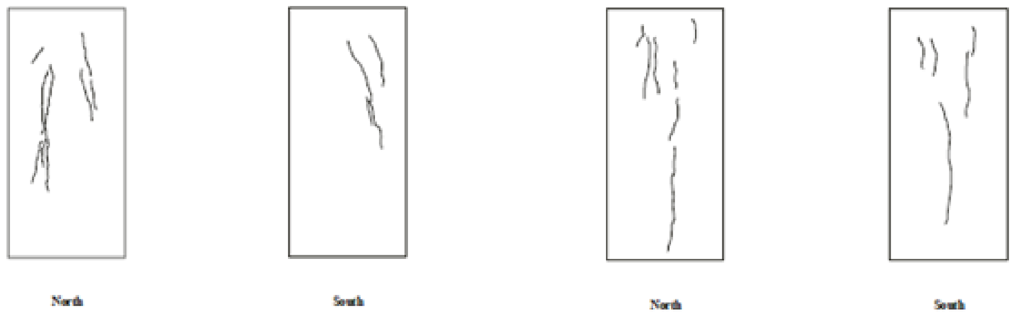


Figure 35: Assumed stress distribution and truss model (bold lines) for line load c



Model for the behaviour after cracking: the position of the trusses are significantly larger than the above image

program the utilised length was chosen so that the theoretically calculated stresses in the specimens were equal to $0.45 \cdot f_{eq,2}$. The main result is, that if this length is chosen appropriate, satisfactory results for the maximum loads can be achieved using the same truss model as for conventionally reinforced members. As a general rule, a value for the depth of the zone undergoing splitting stresses of 450 mm ($\approx 1.3 \cdot d$) gives satisfactory results for the specimens subjected to a line load whereas for the point loaded specimens a value of 350 mm ($= 1.0 \cdot d$) yields very good results.

$d_{burst} \geq$ 1,00 thickness (smearing depth)

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Reinforced concrete solutions

Tunnel Lining Segments – TBM thrust jack loads

DAfStb Guideline for steel fibre reinforced concrete – Part 1

6.5 Design with strut-and-tie models

6.5.1 General

DIN EN 1992-1-1, a new paragraph (R.2)P is added

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Otherwise, reinforcement shall be inserted, where the contribution of the steel fibres to the tensile load-bearing capacity must not exceed 30% (with $f^f_{ctd,u}$).

6.7 Partial area loading

DIN EN 1992-1-1, Paragraph (4) is supplemented

The tension bar of the strut-and-tie in Figure R.5 may be made of steel fibre reinforced concrete alone or executed with reinforcement as specified in 10.6. The analysis shall be performed using $f^f_{ctd,u}$ or $f^f_{ctR,s}$.

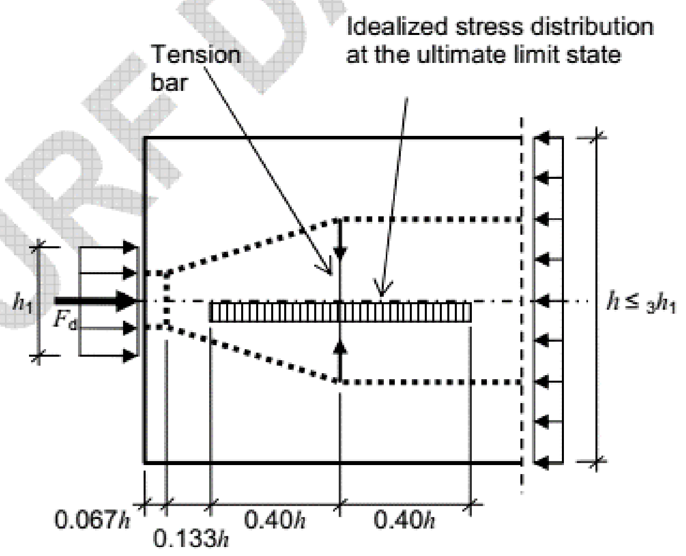

Figure R.5 – Strut-and-tie for partial area load design

Tunnel Lining Segments
Project Information Sheet
(for design purpose)

WireSolutions

SFRC Design

ArcelorMittal Design of Segmental Lining
with ArcelorMittal Steel Fibers

ArcelorMittal

v1.1

Project number:
Date :
Project name :
Project area :

Customer:
E-mail :
Phone :
Fax :
Mobile :

Designer: BR
ArcelorMittal Bissen & Bettembourg
Engineering and technical department
Route de Finsterthal L-7769 Bissen
Tel. : +352 / 83 57 72 224
Mobile : +39 / 34 70 69 42 34
Fax. : +352 / 83 57 72 209
email : bruno.rossi@arcelormittal.com

Remarks:

Legend: *Mandatory cells* / *Optional cells*

1. Segment information

Thickness	$t =$		mm
Inner radius	$r_i =$		mm
Width	$W =$		mm
Number of segments per ring	$n =$		
Key			
Characteristic compressive strength (cylinder) at 28 days	$f_{ck} =$		N/mm^2
Fiber's dosage			kg/m^3

2. Demoulding

Lifting points spacing (X_d = 3/5 * segment developed length is recommended)	$X_d =$		mm
Dynamic load factor	$\gamma_D =$		
Characteristic compressive strength (cylinder) at demoulding	$f_{ck,dem} =$		N/mm^2
Material safety factor for demoulding	$\gamma_{ct,dem} =$		

3. Stacking

Number of stacked segments	$N =$		
Misalignment of stacking points	$y =$		mm
Stacking supports spacing (Xd = 3/5 * segment developed length is recommended)	$x =$		mm
Permanent load factor	$\gamma_{sta} =$		
Dynamic load factor	$\gamma_{dyn} =$		
Characteristic compressive strength (cylinder) at stacking	$f_{ck,stk} =$		N/mm^2
Material safety factor for stacking	$\gamma_{ct,stk} =$		

4. TBM applied load data

Total load RAM jacks	$\Sigma F =$		kN
Number of RAM shoes (each shoe has two jacks)	n° =		
Longitudinal joint e_{l1}	$e_{l1} =$		mm
Longitudinal joint e_{l2}	$e_{l2} =$		
Ring joint e_{r1}	$e_{r1} =$		mm
Ring joint e_{r2}	$e_{r2} =$		
Width of the RAM shoe	$a =$		mm
Length of RAM shoes	$l_{RAM} =$		mm
RAM load eccentricity	$e =$		mm

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Tunnel Lining Segments Project Info template (for sale purpose)

ArcelorMittal WireSolutions
Steel fibres for concrete reinforcement

ArcelorMittal

Project Info Template

Date	10/11/2018		
Status	Information		
Country	Germany		
Sales Person	South America		
Application	TLS		
Tunnel use	Sewerage		
Project name	Berlin Supersewer		
Lot Name	Lot 02		
Project Owner	Municipality of Berlin		
Main Contractor	Strabag		
Sub -Contractor	MobilBaustoffe		
m3 of concrete	13000		
Fibres Quantity (tonne)	520		
Concrete Grade	C45/55		
Test type	Beam EN 14651		
	characteristic		Unit
	fLOP		MPa
	fR1		MPa
	fR2		MPa
	fR3		MPa
	fR4		MPa
Fibre type	HE++ 90/60		
Dosage rate			
Project Starts			
Project Ends			
Estimated Monthly consumption			
Incoterm	EXW		
Price			
Currency	EUR		

Production details

Concrete volume per Segment	
Segments per Ring	
Concrete Volume per Ring	
Rings per days in average planned	
Rings per days in average real	
Rings per day maximum planned	
Rings per day maximum real	
Total number of Segments planned	
Total number of Segments built in	
Total number of Segments produced	
Total number of Rings planned	
Total number of Rings built in	
Total number of Rings produced	
Total demand of concrete planned	
Total demand of concrete real	

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Tunnel Lining Segments
Quantities Estimation

Tunnel Lining Segments quantities			
TLS thickness	th	mm	500
TLS Internal Diameter	Φ_{int}	m	12.00
Ring width	w	m	2.00
Number of segments per ring	n		7
Key			0.00
Segment developed length	l_d	mm	5610.0
Segment slenderness	l_d / th		11.2
Tunnel length		m	1500.00
Twin tube		m	1.00
TLS total length	L_{Tot}	m	1500
Total number of rings	L/w		750.00
Number of segments and keys per ring			5250.00
Concrete volume per linear meter	V/ml	m^3 / m	19.63
Concrete volume per ring	V/ring	m^3 / ring	39.27
Segment volume	V	m^3 / m	0.01
Total weight of ring	W/ring	tons / ring	98.17
Total concrete volume	Vtot	m^3	29452
Fiber Type			HE ++ 90/60
Fibre's dosage per concrete cubic meter		kg / m^3	40
Total Fibres tonnage		**tons**	**1178.10**

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Contact us

The world is building on our expertise.

ArcelorMittal Fibres operates internationally. We are providing steel fibre reinforced concrete solutions for the tunnelling industry and participating in some of the world's major infrastructure projects.

Let's talk TUNNELS

Contact: ***bruno.rossi@arcelormittal.com***

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