STEEL FIBRES IN TUNNEL LINING SEGMENTS – PAST AND PRESENT

VLASAK Oldrich[1], NELL Wilhelm[2], MATHIEU Stéphane[3]

Abstract

The article describes evolution of using precast elements in underground structures and mainly reinforcement of tunnel lining segments by steel fibres. It focuses also on key information about major latest TBM / TLS projects Crossrail London, Metro Doha and Ejpovice Railway Tunnels

Keywords: steel, fibres, tunnel, lining, segments, concrete

1. Introduction

Steel fibres are known as a concrete reinforcement for more than 40 years and they are used for wider and wider range of applications. During the first decades, the typical application of SFRC was an industrial floor, external pavement or a temporary sprayed concrete structure. Over time the existence of new guidance documents, design standards, CE markings etc. allowed to utilize benefits of steel fibres in structural applications as slabs on piles, foundation slabs, suspended slabs and also in the precast concrete industry. Probably the most dynamic development, from the point of view of steel fibres, has occurred in the last years in the tunnel lining segments field.

2. Milestones of tunnel lining segments usage

Prefabricated tunnel lining segments were used for the first time during a construction of a 396 m long the Thames Tunnel in 1825. A revolutionary tunnelling shield designed by English engineers Marc Isambard Brunel and Thomas Cochrane was used. The tunnel lining consisted of bricks.

The first cast iron segments in combination with an iron tunnelling shield patented by Peter William Barlow, were used in 1869 at the Tower Subway, a 410 m long circular tunnel built also beneath the River Thames in London. This tunnel was constructed within 14 weeks, so considering the technical conditions in 19th century, in surprisingly short time.

[1] VLASÁK Oldřich, ArcelorMittal Distribution, Biskupský dvůr 7, 11000, Praha 1, oldrich.vlasak@arcelormittal.com

[2] NELL Wilhelm, ArcelorMittal Bissen, Route de Finsterthal, 7769 Bissen, Luxembourg, wilhelm.nell@arcelormittal.com

[3] MATHIEU Stéphane, ArcelorMittal Bissen, Route de Finsterthal, 7769 Bissen, Luxembourg, s.mathieu@arcelormittal.com

Concrete tunnel lining segments similar to the ones used nowadays started to be used around 1940.

3. Steel fibres in tunnel lining segments

Tunnel lining segments are heavily reinforced concrete elements. Reinforcement is needed for three main stages. At first it is necessary to secure all handling and storing of segments, which is happening only few hours after casting. The second and very different loading occurs while the segments are installed by the tunnel boring machine. The third and usually the highest and the most important loading is active during the service state.

Weight of steel rebars usually varies from 80 to 150 kg/m3. Installation of rebars is difficult and time consuming. Small distances between rebars also make casting complicated. At first steel fibres were used only to decrease number of rebars and thickness of the precast elements, while some properties of the elements such as resistance to spalling, crack control, resistance to handling etc. improved. Deeper knowledge of SFRC as well as developed testing and design methods resulted in gradual decrease of number of rebars.

Continuous development of new high tensile strength steel fibres types in the end allowed to completely omit traditional reinforcement. This leaded to considerably higher production speed, time, material and resulting costs savings compare to the solution with traditional reinforcement.

4. Actual major projects

As the TBM technology in combination with steel fibres reinforced lining segments became now a state-of-the-art, it is being used at infrastructure projects all over the world. Here are some key projects that are currently running.

Fig. 2: Tunnel lining segments reinforced by ArcelorMittal steel fibres HE ++90/60 – Crossrail London

4.1 Crossrail London

This project, with 118 km of high speed rail link, 21 km of twin tube tunnels and investment of 18 billion EUR, represents the largest infrastructure project in Europe. For the Crossrail project two new fibre types with exceptional tensile strength of 2000 MPa were developed. Fibre type HE++ 90/60 was used for the tunnel lining segments, and HE++ 55/35 for sprayed concrete structures.

4.2 Doha Metro

The Doha Metro in Qatar with investments of 32 billion EUR is going to be one of the most advanced metro systems in the world. The total length of the tunnels will reach approximately 300 km. It will be divided in four lines, Red (North and South), Green, Gold and Blue, and include 98 stations. The network is being build in several phases. The Phase I is going to be completed in time for the 2022 Football World Cup.

SFRC for tunnel lining segments at the Doha Metro project was designed following the FIB Model Code 2010 standard. Two different high tensile strength (2000 MPa) fibres were used for this project.

Fig. 3: Tunnel lining segments – Doha Metro / Qatar

4.3 Ejpovice Railway Tunnels

In 2015 started construction of the longest railway tunnel in the Czech Republic. Originally the traditional method of drill & blast was planned. Mainly because of significant economical benefits, it was decided, that the TBM method with segments reinforced by steel fibres only will be used.

As at most of the tunnelling projects an automatic dosing unit is used. It is connected to the mixing computer, so the batching plant operator can easily set up desired quantity of fibres and they are automatically dispersed and transported for example with a conveyor belt to the mixer. Depending on a fibre type, speed of dosing can be up to 200 kg/min. In case of the Ejpovice tunnel, the dosing speed it is around 100 kg/min, so it takes roughly 25 sec to dose required 40 kg of steel fibres for one batch of 1 m^3. As described above, it is well known, that increasing of slenderness (length/diameter ratio) of the fibre is improving post cracking behaviour of the SFRC, while it increases risk of balling and in general it makes the workability of concrete more complicated. During the operational tests done at the batching plant, fibres with l/d ratio of 60 showed the best performance. Steel fibres with tensile strength of 1500 MPa were used.

Fig. 1: Steel fibres packed in big bags and an automatic dosing unit (left), formworks (right) – Ejpovice Railway Tunnels

5. Conclusions

Benefits of steel fibre reinforced concrete are very well known already for many years. With increasing knowledge about steel fibre reinforced concrete properties, new testing methods and new design standards, steel fibres are being accepted as valuable reinforcement for more and more applications. Steel fibres are substituting traditional mesh and rebars reinforcement also in tunnelling industry and this is valid not only for sprayed concrete applications, but as well as for tunnel lining segments. It is very interesting to follow the future development of the steel fibre reinforced concrete field and mainly take part in the development process.

References

[1] NATHAN Stuart, *The Tower Subway*, 2013

[2] THOMAS Alun, EBERLE Christoph, PSOMAS Sotiris, ITAtech design guidance for precast fibre reinforced concrete segments, 2015

[3] FIB Model Code 2010, Final draft, Volumes 1 and 2, FIB Bulletin No. 65 and 66, 2012

[4] Internal documents of company ArcelorMittal