FIBER CONCRETE - CONSTRUCTION MATERIAL OF UNDERGROUND STRUCTURES

Matouš Hilar

Jan Pruška

Summary

Concrete is undoubtably dominating material used for the construction of underground structures. It can be used in three main forms related to its production:

- **Sprayed concrete** (shotcrete) used especially for the primary lining of the conventionally excavated structures, but it can be also used for the secondary linings or for single-shell (one-pass) linings.
- **Precast concrete** used especially either for the segmental lining of the structures excavated by tunnel boring machines (shields) or for overfilled structures.
- **Cast-in-place concrete** used especially either for the secondary lining of the conventionally excavated structures or for cut and cover structures.

The steel fibre reinforced concrete (SFRC) is more and more frequently used as material for the lining of underground structures. SFRC has been already used for many applications of sprayed concrete (mostly as primary linings) and also for many applications as precast concrete as segmental lining constructed behind circular tunnelling machines. Polypropylene (PP) fibres are often added to the cast-in-place secondary lining to improve their fire resistance; the secondary linings are either from reinforced concrete or from plain concrete (cast-in-place SFRC is not used for this type of lining).

There were two major applications of fibre reinforced concrete for underground structures in the Czech Republic. The SFRC was used for sprayed concrete plugs on the underground gas storage Pribram - Haje. The reinforced concrete with PP fibres was used for the secondary lining of the Klimkovice tunnel near Ostrava at the motorway D47. It is possible to expect further applications of fibre reinforced concrete in the Czech Republic. One option - use of SFRC for precast segmental lining - is currently evaluated.

Keywords: Steel fibre reinforced concrete, sprayed concrete lining, segmental lining, tunnel lining

1 SFRC for pressure-resisting seals of underground gas storage Háje

The Haje underground gas storage facility consists of a network of interconnected galleries (100 in total) 3.5 m in diameter, spaced 15 m on centres, driven in the east-west direction at a depth of 950 m below the surface. The aggregate length of the galleries reaches 45 km within area 1.5 km^2. The total pay storage amounts to 620 502 m^3. The storage facility is located completely outside the mining field of a former uranium-ore mine, although the hoisting shaft of the mine and the main cross tunnel of the mine were utilised during the construction. Four concrete plugs (Fig.1) separate the gas storage spaces from the old mining field (a pair of plugs in each gallery). Each concrete plug is 10 m long. The plugs were generated using steel fibre reinforced sprayed concrete. The plug construction and complex testing technique were verified on trial plugs in the underground laboratory. The plugs were built using wet-process sprayed SFRC (B40/3.8 V12) with high content of the fibres (90 kg/m^3).

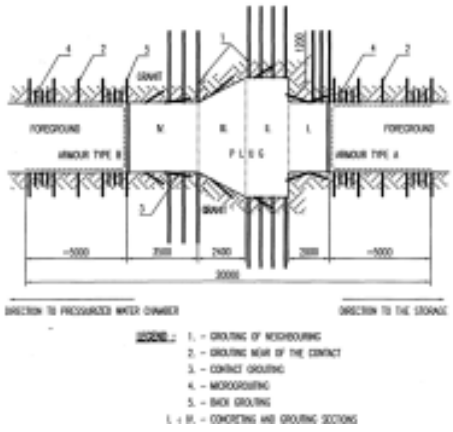

Fig. 1 Geometry of concrete plugs

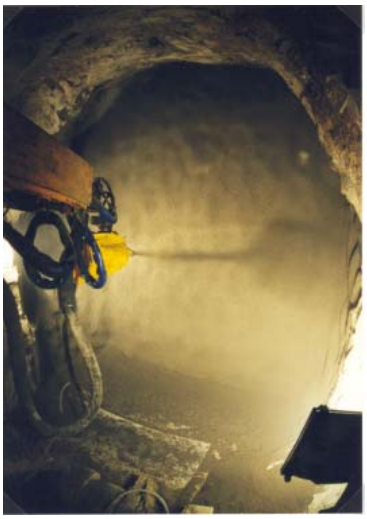

Fig. 2 Application of sprayed SFRC

2 The Klimkovice tunnel secondary lining reinforced with PP fibres

The Klimkovice tunnel is 1.1 km road tunnel situated on highway D47, the double-tube tunnel was constructed using New Austrian Tunnelling Method (NATM) from 2004 to 2008. The maximum thickness of the tunnel cover is approximately of 31m. The spatial parameters of both tubes are identical, i.e. the parameters of a C-category unidirectional double-lane tunnel. The average excavated cross-section (including overbreaks necessary due to the technology) amounts to 120 m^2. Emergency lay-bys 40m long are provided in the middle of each tube length. The tunnel cross-section is widened by 2.25 m in those locations, the excavated cross-section of lay-bys (including overbreaks necessary due to the technology) amounts to 156 m^2. The secondary lining (Fig. 2) is from C30/37

reinforced concrete. It is minimally 350 mm thick (in the crown of the arch), with a massive invert with a maximum thickness of 1.2 m. The secondary lining is divided according to the casting procedures into 12 m long expansion blocks. The vaults are supported with longitudinal foundation strips, with articulated joints at the expansion joints of the vaults. As a fire protection measure, fire resistance of the concrete lining was increased by adding polypropylene fibres to the mix. In addition, chloride resistance was enhanced in the most exposed sections by means of concrete aeration.

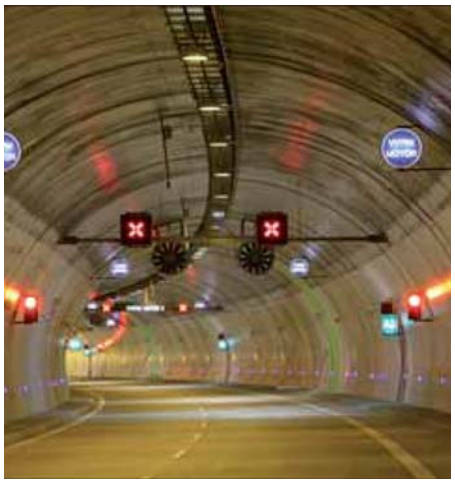

Fig. 3 The Klimkovice tunnel secondary lining

Fig. 4 The Klimkovice tunnel lay-by

3 Precast SFRC for segmental lining

The tunnels driven by tunnel boring machines have a circular cross section and are mostly lined with a single shell of precast concrete segments. The application and the use of steel fibre reinforced concrete (SFRC) in precast tunnel lining design is a growing trend in the foreign countries due to its advantages in performance, durability and ease of manufacture compare to traditionally reinforced concrete. Major benefits of SFRC segments in comparison with classic segments reinforced by rebars are:

- Higher resistance against aggressive environment (no danger of corrosion)
- Higher fire resistance (caused by utilization of polypropylene fibres)
- Higher durability
- Reduction of spalling risk of corners and edges during manipulation
- Lower requirements for repair during construction (limited damages)
- Lower requirements for maintenance during lifetime
- Easier and faster manufacturing (steel rebar cages are not required)
- Easier installation of tunnel equipment (no danger of drilling into steel rebars)
- Lower space requirements for manufacturing
- Easier material recycling after the end of construction lifetime
- Opportunity for the cost reduction of final structure
- Significant reduction of steel volume

- Energy reduction and CO_2 production reduction (smaller volume of steel)
- Lower requirements for human resources (preparation of armature is not required)

The construction of the Prague's metro line A extension is currently ongoing. Running tunnels for trains will be excavated by two Earth Pressure Balance (EPB) shields; precast segmental lining is traditional with steel cages. Research is currently ongoing to replace steel cages by steel fibres. The research includes testing of SFRC beams and segments. In case of satisfactory results it can be a base for a further application of SFRC for Czech tunnels.

4 Conclusions

The steel fibre reinforced concrete is more and more frequently used as material for the tunnel linings. This type of material is mainly used for tunnel linings in forms of sprayed concrete for primary lining of conventionally excavated tunnels or precast concrete for segmental lining of tunnels excavated by tunnel boring machines. SFRC is quite often combined with PP fibres to increase fire resistance of the structures.

So far there are only few applications of fibre reinforced concrete on underground structures in the Czech Republic. Two major applications (SFRC for plugs of gas storage facility Haje and secondary lining of the Klimkovice highway tunnel with PP fibres) were discussed in this paper. Further applications are expected to come in future; one of them can be a precast segmental lining. This option is currently evaluated.

Acknowledgement

Financial support by the research grant GACR P104/10/2023 is gratefully acknowledged.

References

[1] BARTÁK, J. ET. AL.: *Underground construction in the Czech Republic.* Satra, spol. s.r.o. 2007.
[2] BEŇO, J. – PRUŠKA, J. - HILAR, M.: *Betonová ostění podzemních staveb - nové trendy*. Stavební obzor 3/2011 (in print)

Doc. Ing. Matouš Hilar, Ph.D,
✉ Czech Technical University in Prague
Faculty of Civil Engineering
Department of Geotechnics
Thákurova 7
166 29 Prague, Czech Republic
☎ +420 224 354 547
🗐 +420 233 334 206
☺ matous.hilar@fsv.cvut.cz
URL http://departments.fsv.cvut.cz/k135

Doc. Dr. Ing. Jan Pruška
✉ Czech Technical University in Prague
Faculty of Civil Engineering
Department of Geotechnics
Thákurova 7
166 29 Prague, Czech Republic
☎ +420 224 354 547
🗐 +420 233 334 206
☺ Pruska@fsv.cvut.cz
URL http://departments.fsv.cvut.cz/k135