Two Examples for the Design of Load Bearing Structures with Steel Fibre Reinforced Concrete

Thomas KASPER
Civil Engineer
COWI A/S
Kongens Lyngby, Denmark
tkas@cowi.dk

Thomas Kasper, born 1974, received his civil engineering degree from the Univ. of Weimar, Germany, and his PhD degree from the Univ. of Bochum, Germany.

Carola EDVARDSEN
Civil Engineer
COWI A/S
Kongens Lyngby, Denmark
cle@cowi.dk

Carola Edvardsen, born 1961, received her civil engineering degree and her PhD degree from the Univ. of Aachen, Germany.

Carsten S. SØRENSEN
Civil Engineer
COWI A/S
Kongens Lyngby, Denmark
css@cowi.dk

Carsten S. Sørensen, born 1954, received his civil engineering degree from the Engineering Academy of Aalborg, Denmark.

Summary

A major part of the foundation slab of a high bay warehouse at the Carlsberg brewery in Fredericia, Denmark, and the segmental tunnel lining of the district heating tunnel in Copenhagen, Denmark, have been designed with steel fibre reinforced concrete (SFRC) without traditional rebar reinforcement. This paper presents and discusses the design methods, advantages, special aspects, limitations and risks of steel fibre reinforced concrete for these load bearing structures.

Keywords: structural design; steel fibre reinforced concrete; durability; material testing; foundation slab; tunnel lining; numerical modelling.

1. Introduction

Steel fibre reinforced concrete is a beneficial and competitive solution for structures, which would require only a moderate amount of conventional reinforcement. Typical fields of application are tunnel linings, pavements and floors, foundations and pipes. Steel fibres introduce a ductile post-cracking and favourable crack distribution behaviour of the concrete. They increase its impact resistance and, as they do not require a concrete cover, they help to prevent local damage like wear, spalling at edges and chipping of corners. One important advantage of SFRC compared to conventionally reinforced concrete is its corrosion resistance and the resulting improved durability. Compared to conventional reinforcement, steel fibre reinforcement enables a simpler, time-saving and cost-efficient construction process. However, it has to be noted that the bearing capacity of SFRC is limited and that it cannot compete with conventionally reinforced concrete in terms of bending and tension capacity as well as bursting capacity under concentrated large loads. Furthermore, concrete mix design, material testing, casting technology and quality control require special care and effort. Steel fibre reinforced concrete has been a subject of intensive research and development for a long time. To allow for its use for load bearing structures, guidelines have been developed in various countries.

2. The projects

The 40 m high warehouse at the Carlsberg brewery (Fig. 1) is founded with an 83 x 116 m concrete slab on clay till and sand layers. The wind loads on the tall building are taken by wind bracings in the gable areas. Between 60 and 80 cm thick conventionally reinforced concrete has therefore been used for the slab in the gable areas. The 69 x 77 m inner part of the foundation is made of 40 cm thick steel fibre reinforced concrete. The combination of conventionally reinforced concrete in the gable areas and SFRC in the inner part has been chosen as an optimised solution for the project. According to two alternative bids from a contractor, the cost-savings for the inner part due to the use of SFRC were approximately 15 %.

https://doi.org/10.2749/222137908796294180

The 30 cm thick segments in the district heating tunnel are installed inside the advancing tunnel boring machine. They form a circular tunnel lining with an internal diameter of 4.2 m in limestone between 25 and 38 m below the city of Copenhagen (Fig. 2). Steel fibre reinforced concrete has been chosen due to estimated 10 - 15 % lower segment production costs compared to conventionally reinforced concrete with complicated reinforcement cages. Furthermore, minor segment damages during installation don't have to be repaired, because no concrete cover has to be restored to protect rebar reinforcement. Finally, steel fibre reinforcement ensures the 100 years service life of the tunnel. It eliminates the problem of corrosion due to saline groundwater and elevated temperatures of approximately 50 ºC resulting from the operation of the pipelines in the tunnel.

Fig. 1: High bay warehouse with a steel fibre reinforced concrete foundation slab

Fig. 2: Steel fibre reinforced concrete lining of the district heating tunnel (photograph by Henrik P. Sørensen)

3. Design and construction

The structural design of the foundation slab and the tunnel lining has been based on a German SFRC guideline. According to this guideline, the flexural tensile strength properties are determined from 4-point beam bending tests.

The foundation slab of the warehouse has been designed for closely spaced 250 kN characteristic long-term loads for complete filling of the racks. The bearing capacity and deformations of the slab have been verified by 3D elasto-plastic soil-structure interaction modelling.

Based on a combination of hand calculations and advanced numerical modelling, the segments of the tunnel lining have been designed for both temporary loading situations during installation and final loading from soil-structure interaction as well as thermally induced loading due to operation of the pipelines in the tunnel.

Design, production and construction were accompanied by material testing and quality assurance programmes. These programmes and the coordination between client, consultant and contractor have been found to be of vital importance for the success of projects with steel fibre reinforced concrete.

4. Conclusions

Based on available design guidelines and suitable modelling and design tools, steel fibre reinforcement is a technically and economically competitive solution for a certain range of load bearing structures. The benefits of this innovative material encourage further development and increased use in the future. Coordination between client, consultant and contractor and testing and quality assurance in the different project phases form the basis for success and risk management.