STEEL-FIBRE-REINFORCED PRESTRESSED PRECAST GIRDERS

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Abstract

The author has developed a prestressed steel-fibre-reinforced girder made of self-compacting concrete (SCC) without conventional steel reinforcement. The fibre salary, dimension and strength as well as the composition of the concrete and the pretensioning were varied so long, until wide range girders could be produced in a precast plant. The loadbearing capacity of this innovative and cost-efficient construction method has been verified by calculations, in large-scale tests and practical applications.

Keywords: prestressed steel-fibre-reinforced girders , without conventional steel reinforcement, self-compacting concrete, four experimental beams, large scale tests, continuous load test, successful practical use

1. Introduction

SCC is characterized by its special fresh concrete properties, its high flowability and the ability to deaerate itself. Mechanical compaction equipment as, for example, vibrators, is not necessary. SCC surrounds the reinforcement and self-levels under the influence of gravit [9]. In the meantime, it is gaining increasing significance also in Germany. The old DIN standard 1045 [1], with its restrictions on the slump and the maximum amounts of additions, as well as the stipulated compaction, made no provisions for SCC. With the publication of the new DIN 1045 [2], these restrictions have somewhat shifted in the direction of the SCC. The standard, however, still does not regulate SCC. For this reason, the DAfStb published in June 2001, as a supplement to the old DIN 1045, a code of practice to that effect [3]. Due to the low experience with SCC in practice of structural engineering, however, this code has not yet been everywhere implemented by the construction supervisory board in Germany. Accordingly, the use of SCC is still subject to technical approval, or approval granted on a case-to-case basis. The practical experience that has in the meantime been gained with the use of SCC with appropriate approvals show that the properties of the hardened concrete, the modulus of elasticity, the creep and shrinkage behaviour and the bond properties of reinforcing steel and prestressing steel show that, in comparison to the above-stated concretes, there exist no differences to concrete designed to DIN 1045 [2]. SCC, in addition to the classic components of cement, aggregates and water; contains highly effective superplasticizers and super-fine particles. The high fines content imparts the mix with the ability to retain water so that the coarser

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aggregates do not obstruct the fluidity, nor do they lead to segregation. SCC is particularly well suited for use in precast plants [4]. SCC, among other things, has the following advantages: 1. The high fines content gives the SCC a particularly high dimensional stability. It is therefore especially well suited for use in slender structures. 2. SCC required as a rule no post-production processing; the occurrence of gravel pockets or air voids is negligible. The colouring of the concrete is noticeably more uniform. SCC is recommended for obtaining architectural concrete surfaces of superior quality. 3. Reduction of noise and vibration during casting. Vibration is not necessary when processing SCC. The noise level and the vibration during compaction are virtually reduced to zero.

2. Steelfibre concrete

The DAtStb has worked out a „steelfibre concrete" code [5] with which the user, following its implementation by the construction supervisory authorities, will be given a regulatory framework for design having the character of a national standard.

In the past, the German Concrete Association has issued a number of codes. With the publication of these codes, users are now able to design structural concrete members with steelfibre concrete. These codes, however; do not have the character of a national standard. For this reason, the design of steelfibre concrete is subject to technical approval or approval on a case-to-case basis. By the assessment of the technical approvals for structural components made of steelfibre concrete called in this report the DBV code „steelfibre concrete" [6] forms the basis. Experiences gained with steelfibre concrete show that the performance characteristics of structural concrete members can be greatly enhanced. An increase in loadbearing capacity can in most cases be achieved only for specific areas of application, as for example for plane loadbearing structures. While the flexural strength of linear members can be hardly increased with steelfibres, the increase in shear resistance that can be achieved is remarkable. Rosenbusch, in his doctoral thesis [7], shows that for structural members not exposed to high shear, the necessary shear or

Tab.1: Compilation of the steelfibres used, together with their dimensions and strengths

Member	Slenderness/Length [-]/[mm]	Strength [N/mm²]
Beam 1	48/50	1500
Beam 2	80/60	1200
Beam 3	80/60	2400
Beam 4	48/50	1500
	73/55	2200

minimum reinforcement can be substituted by steelfibres. These findings prompted the author to develop precast prestressed beams of SCC with steelfibre addition, but without conventional shear reinforcement. Tests performed in Delft have shown that SCC is able to transport a fibre content of up to 140 kg/m3, without losing its self-compacting properties. However, optimum workability and effectiveness of the steelfibres can be achieved only with the addition of approx. 40 kg/m3.

3. Material and preliminary testing

In 2002, there was obtained from the DIBt an approval (NO. 73.51-1770) for an SSC without steelfibres. To this approved SCC, then there was added a specific amount of steelfibres per m3 to create a self-compacting steelfibre concrete. In order to substitute the shear reinforcement for precast concrete beams with steelfibers, four experimental girders were manufactured with various types of steelfibres. The composition of the steelfibres used and their properties are listed in. For experimental girder No. 4, a fibremix of two types of fibres was used. While casting the experimental beams for large-scale testing, flexural beams were manufactured for determining the tensile strength after cracking. The flexural girders were tested as specified in the DBV code ,,steelfibre concrete" [6]. Fig. 1 shows the results of this test.

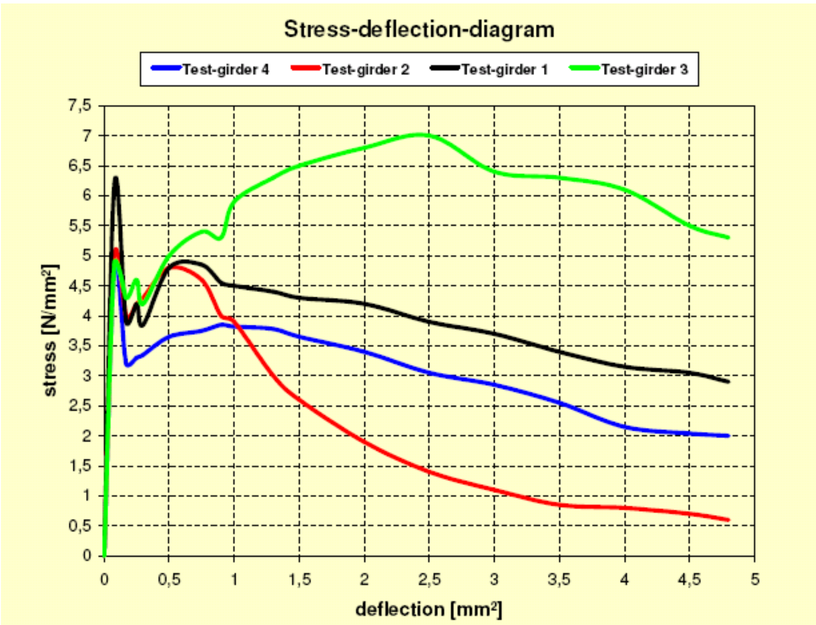

Fig. 1: Stress-deflection diagram of the concretes used for the experimental beams

4. Experimental beams

A conventionally reinforced beam that ones had already used in a previous construction project was used for the experiment. In the experimental beams the fibres were used to substitute both the shear stirrups and the stirrups in the area where the prestressing forces are introduced. The elimination of the complex reinforcing works results in a noticeable cost advantage for this construction system. A total of four beams were manufactured to study their behaviour in service as well as their structural behaviour. The single-span prestressed concrete beams investigated had an I-shaped cross-section (see Fig. 2 and 3). In the area of support, the cross-section changes into a T-shaped cross-section. In the area of the supports and at the quarter points of the beams, circular blockouts for service ducts were provided. The beams were prestressed with horizontal strands guided by upper and lower chords. The arrangement of the tendons in the lower chord was varied during preliminary testing until the steelfibres no longer separated and no segregation during casting occurred.

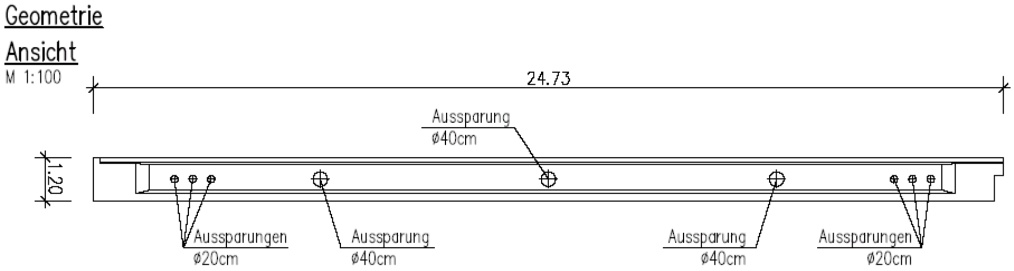

Fig. 2: Elevation of the experimental beam

In addition to the preliminary tests, analytical observations based on the DBV code „steelfiber concrete" [6] were conducted together with laboratory tests. It was found that no shear reinforcement was required. Another advantage of the described construction method is that the blockouts can be drilled into the beams also after casting.

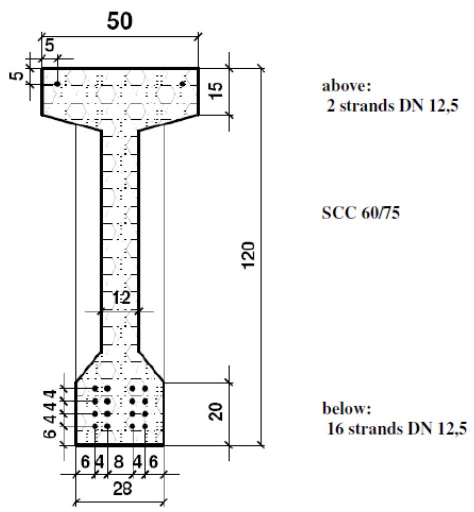

*Fig. 3:*View and cross-section of an experimental beam

5. Manufacture

The four experimental beams were cast at the precast plant without any problem. The SCC in all beams had good flow properties. An influence of the prestressing reinforcement on aggregates or steel fibres was not observed. Fig. 4 shows how the concrete flows in the form, from the print of discharge to mid-span and from there to the end of the girders, aerating in the process. Fig. 5 shows this experimental girder after demolding. The quality of the architectural concrete surface is excellent.

Fig. 4: The concrete shown flowing from the discharge point in mid span to end of the beam

Fig. 5: The demolded girder, the blockouts at the quarter points have not yet been drilled.

6. Behaviour in service

To investigate the beams' behaviour in service, two of the tour experimental beams were subjected to a continuous load test. The load was applied utilizing sleepers(Fig. 6). The load imposed by the sleepers equals 1.4 times the service load. In this state, no cracks induced by bending or shear were observed. The experimental beams were stored in such a way that always ore halt of the beams were exposed to weathering, the other halt being protected by a roof (see Fig. 6). The aim of this test was to establish to what extent the non-galvanized steel fibres in the two experimental beams showed signs of corrosion due to weathering. So far, no such signs of corrosion are visible or the beams; neither on the sides exposed to weathering nor on the protected sides.

Fig. 6: Experimental beams loaded with sleeper in a continuous load test

However; the possibility that discolorations due to corrosion will develop in the course of time cannot be precluded.

7. Load tests

Two of the tour experimental beams were subjected to load tests in order to establish that the binders constructed in this way still possess the required loadbearing capacity. For this.

Fig. 7: Experimental set-up for the test still before the load is prepared

reason, the author recommended an experimental arrangement that would lead to shear failure. The experimental set-up for the load test performed out of doors is shown in Fig.

7First cracks due to bending occurred in mid-span upon reaching 1.3 times the service load. At 1.55 times the service load, first shear-induced cracks occurred near the blockouts on the beam ends. As the service load was increased, the cracks began to considerably open up (see Fig. 8). However, the crack surfaces were still connected to each other by the steelfibres.

Fig. 8: Wide shear induced cracks near the blockouts, which in the state of failure, extend through the entire web

The fibres were effective until attainment of the failure load and enabled in this way ductile failure of the member. The results of the loading tests of the two experimental beams did not much differ from another. Only the failure load of the two experimental

Fig. 9: Fracture surface of the experimental girder

beams was different, due to the different tensile strength of the concrete after cracking (see Fig. 1). The fracture surface showed a uniform distribution of steel fibres, as shown in Fig. 9.

Fig. 10 shows the force-deformation curve of an experimental beam in mid-span, illustrating the beam's linear-elastic load-bearing behaviour in the service load range. First cracks due to bending occurred only clearly above the service load range. Shear-induced cracks were observed to occur only after attaining a somewhat higher load level.

When increasing the load it can be seen that the stiffness of the binder markedly decreases beginning at 2.2 times the service load and with progressing crack formation. At this loading stage, the cracks have extended in length from the web into the compression chord. An increase of the loading of the beams resulted in considerable deformations and crack widths.

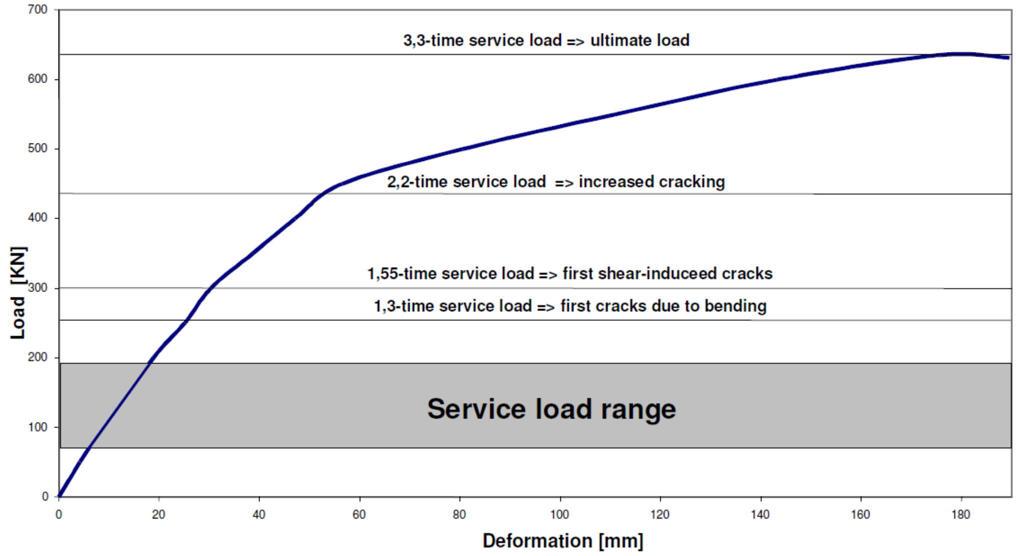

Fig. 10: Load-deformation diagram in mid span

Failure load was attained after a shear-induced crack had penetrated the compression zone. Advance warning that failure load was imminent was evidenced by attainment of a plateau level upon approaching failure load in that a further load increase resulted in only a minimum increase in deformation. This shows that the beams posses a highly ductile load-bearing behaviour.

8. Conclusions

Based on the preliminary tests and the calculations performed by the author in advance it could be shown that the described prestressed steel-fibre-reinforced beams made of SCC could be manufactured without the benefit of conventional reinforcement, both for shear resistance and for resisting transverse tensile stresses in the area where the prestressing forces are introduced. The load tests performed on two experimental beams showed that the experimental SCC beams reinforced with steel-fibres up to attainment of 2.2 times the service load exhibited a nearly linearly elastic load-bearing behaviour. After that, the load-deformation diagram showed that a marked plateau level had been reached so that the specimens under constant stress and increasing strain exhibited a ductile behaviour until failure occurred at 3.3 times the service load.

Fig. 11: PM Leuna under construction

By this time, no crack formation has occurred on the experimental beams subjected to the continuous load test, which is still underway to establish the behaviour in service. These beams show moreover no corrosion of the fibres although, despite the fact that always one half the beams is exposed to weathering.

Fig.12: roof trusses and purlins; the sparking between the trusses is 10 meters

After handle the development stage successful the roof structure of the construction scheme of a paper-mill in Leuna/Germany had been realized with steel-fibre reinforced beams for the first time in Germany [10]. The new special building method consisted 100 roof trusses and 850 purlins, all without conventional steel reinforcement (see Fig. 11 +12).

Acknowledgements

The support of Czech Technical University in Prague, Faculty of Civil Engineering, Department of Concrete and Masonry Structures is gratefully acknowledged, just as the LGA Nuremberg, Structural Analysis Division, Germany this performance to make possible.

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