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Shear behaviour of prestressed precast SFRC girders

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ABSTRACT

The replacement of traditional shear reinforcement by the use of steel fibre reinforced concrete has been of special interest for precast concrete companies. In this way, they can increase production efficiency by eliminating the labour-intensive placing of traditional stirrups. Furthermore, the use of steel fibres will shorten the production process significantly. Although the feasibility of this technique has been proven in the past by both laboratory testing and real-life applications [3–8], its application cannot be considered as a daily practice. To get more insight into the shear behaviour of steel fibre reinforced concrete (SFRC) full-scale girders, an experimental programme has been performed on precast SFRC girders with a span of 20 m and a height of 1 m and with a fibre dosage ranging between 20 and 60 kg/m^3. Thereby the development of shear cracks is investigated in more detail by means of a digital image correlation technique (DIC). The obtained test results reveal that for the girders with higher fibre dosages the shear load can be increased with 78% before reaching a crack width of 2.5 mm. However, considering the ultimate shear failure load of prestressed SFRC girders, the beneficial effect of steel fibres has been found to be limited for higher dosages.

1. Introduction

The shear capacity of reinforced and prestressed concrete has been the subject of comprehensive research since the past century [9]. The complex nature of shear can be attributed to a number of different parameters influencing the shear behaviour such as concrete strength, longitudinal reinforcement ratio, shear span to depth-ratio, element height, cross-section type, aggregate size, shear reinforcement ratio and load conditions. As a consequence, high scatter of test results is observed in experiments and therefore, research efforts are still undertaken to improve existing shear strength models and to better understand the shear failure mechanisms.

Since, the tailoring and placement of traditional stirrups is considered to be labour intensive by precast concrete manufacturers, alternatives to avoid traditional stirrups will be of great economic benefit. Typically, prestressed large span concrete elements, are often designed to resist high bending moments and relatively limited shear forces. In these cases where minimum required traditional shear reinforcement should be placed, as obliged by current design provisions for RC structures [10,11], a viable solution can be found by using steel fibres [1,6,12–14].

Although the feasibility of steel fibres to replace traditional stirrups either completely or partially has been investigated and proven over the past two decades by several researchers [2,5–8,15,16], the number of practical applications is yet limited and engineers are not familiar with this new technique. The reasons for this are twofold. Firstly, shear test results for fibre reinforced prestressed or non-prestressed concrete elements are derived from experiments on relatively small specimens which do not match realistic dimensions of structural elements. Therefore it is necessary to extend the existing shear test database with results from full-scale tests on large span girders. A second reason is that only a few design standards [10,17] have shear provisions for elements reinforcement with fibres. Recently, this drawback was recognized by the International Federation for Structural Concrete (fib) and in the current Model Code 2010 (MC2010) [10] two calculation methods are presented for the shear capacity of FRC elements.

In order to investigate the shear capacity of full-scale girders, prestressed elements were made by a precast concrete company and tested under laboratory conditions. In total, 23 shear tests have been conducted on prestressed concrete girders comparing plain concrete reference girders with SFRC girders with a fibre dosage ranging between 20 and 60 kg/m^3. This paper provides a detailed overview and discussion of all obtained test results from the full

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span girders as well as the additional specimens used to determine the SFRC material properties. To allow a more thorough investigation of the crack propagation, the post-cracking shear behaviour of the girders is monitored by means of a digital image correlation (DIC) technique covering the complete shear critical area.

2. Materials and methods

2.1. Test specimens

To investigate the shear capacity of 20 m span prestressed precast SFRC girders, experimental shear tests are conducted on nine I-shaped girders manufactured by a precast concrete company. All girders have a constant height of 1 m. The cross-sectional dimensions and prestress strand configuration is shown in Fig. 1. The prestressing is achieved by means of high strength 12.5 mm strands pretensioned at an initial tensile stress equal to 1453 N/mm^2. The prestress force for each strand equals 135 kN. In the girders cross-section, mild reinforcement is placed at the upper side to resist tensile stresses when the girder is loaded by its self-weight and prestress only (Table 1).

For all of the SFRC girders, the fibre volume varied between 20 and 60 kg/m^3. In order to decrease the risk of fibre blocking due to limited free space between the prestress strands (i.e. 35 mm), it was decided to use short fibres. All used SFRC mixes contained high strength cold drawn wire hooked-end fibres (type DRAMIX RC-80/30-CP or RC-80/60-BP). The first type of fibre (CP) has a length of 30 mm, a diameter of 0.38 mm and a wire tensile strength of at least 3000 N/mm^2. The second type of fibre (BP) has a length of 60 mm, a diameter of 0.75 mm and a wire tensile strength of at least 2000 N/mm^2. These high performance types of steel fibre is combined with a concrete strength class of C50/60. Preliminary to the casting of the girders at the precast company, the SFRC mix composition has been optimized and trial batches were mixed first in the quality control laboratories of the admixture supplier. After obtaining evidence of good mixability, workability and strength development of the mixes, the mix composition as shown in Table 2 has been chosen for the production of the girders.

The production process of the girders consists of the following steps. The concrete without fibres is made in a ready mix plant

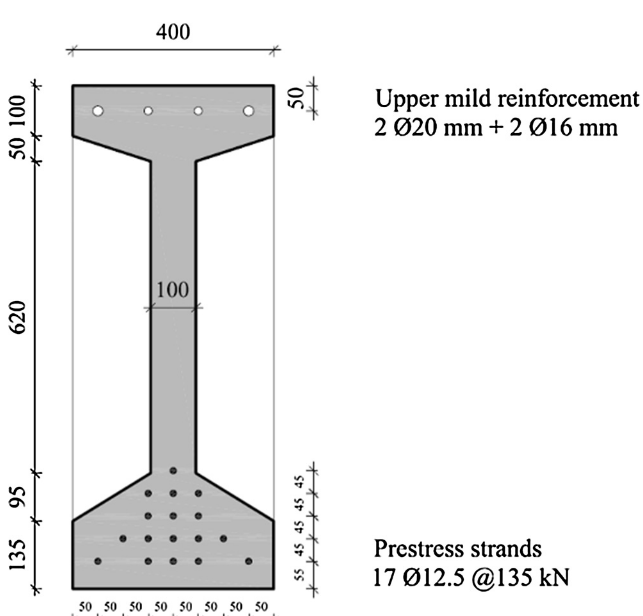

Fig. 1. I-shaped cross section (dimensions in mm).

Table 1
Shear reinforcement and designation for each girder.

Girder	Designation	Shear Reinforcement
1	REF	Plain concrete
2	REF/TR	Plain concrete/Traditional stirrups[1]
3	TR	Traditional stirrups
4	20A	20 kg/m^3 RC-80/30-CP
5	20B	20 kg/m^3 RC-80/30-CP
6	40A	40 kg/m^3 RC-80/30-CP
7	40B	40 kg/m^3 RC-80/30-CP
8	20+20	20 kg/m^3 RC-80/60-BP + 20 kg/m^3 RC-80/30-CP
9	60	60 kg/m^3 RC-80/30-CP

[1] At one side of the beam, traditional transverse reinforcement is placed and the other side of the beam is plain concrete.

adjacent to the precast plant and the concrete is mixed for about 2 min and charged in the truck-mixer. Then, the fibres are added to the concrete in the truck mixer and the concrete is mixed for an additional 5 min. The SFRC is then transported to the precast company and charged from the truck mixer into a concrete bucket (Fig. 2a) and poured into the formwork (Fig. 2b). Compaction of the concrete is done by means of vibrators attached to the formwork.

During casting of the girders, additional samples and specimens are cast from the same SFRC batch:

- 3 fresh concrete samples with a volume of eight litre, in order to determine the fibre content in the fresh state.
- 12 cubes with a side length 150 mm, for determination of the compressive strength on three cubes for the age of 2, 7, 14 and 28 days (EN 12390-3).
- 4 cylinders with a diameter equal to 150 mm and a height of 300 mm, for determination of the compressive strength at 28 days (EN 12390-3) and the modulus of elasticity (NBN B 15-203)
- 4 prisms (casted vertically) to perform tests to evaluate the shrinkage (2 tests according to NBN B 15-216) and creep (2 tests NBN B 15-228).
- 3–6 prisms with standard dimensions 150 mm × 150 mm × 600 mm, in order to characterise the post-cracking tensile capacity of the SFRC mix by means of three-point bending (EN 14651). The number of bending tests for each batch is given in Section 2.3 (Table 5).

After one day, the girders were demoulded (Fig. 2c) and when the cube compressive strength exceeded 50 N/mm^2 (at an age of about 2–3 days), the pretensioned prestressing strands are cut and the prestress is applied on the girder (Fig. 2d). The girders are stored in the production hall of the precast manufacturer and at the age of about 28 days, the girders are transported to the laboratory hall of Ghent University for testing.

2.2. Shear test programme & measurements

The test matrix of the 23 conducted shear tests is given in Table 3 in terms of applied test phase, shear span to depth ratio, shear reinforcement, concrete strength, age of testing and the application of the DIC-technique. The test programme involves multiple tests per girder as indicated in Fig. 3. In phase 1, the girder is first tested at one end (so called left shear span zone). In phase 2, the left support is moved and the girder is tested at the right shear span zone. For girders REF, 20A, 40A, 60 and TR a third phase test is conducted with a more central shear span zone. The shear span to depth ratio is kept constant for phases 1 and 3 at 2.5.

For shear tests done in phase 2, the a/d-ratio is either 2.5 or 3.0. A schematic of all different test setups adopted in this study is shown in Fig. 3. As a result of these test combinations, a total of