2008
Prague

Shear force strengthening of large reinforced-concrete components using textile-reinforced concrete (TRC)

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Abstract

Test results will demonstrate that textile-reinforced concrete (TRC) can be used to strengthen the shear resistance of large reinforced-concrete (RC) elements. Practical aspects, such as subsoil treatment of the RC surface and the application process of the reinforcement, are given particular consideration. In addition it will be shown that the increase in shear resistance can also improve serviceability,

1. Introduction

The importance of improving the structural behaviour of existing reinforced-concrete (RC) components continues to dominate due to building conversions, increased loads or the corrective maintenance of constructions. Until now, these improvements have often been provided by strengthening with RC (Wörner[1]), in which the minimal strengthening layer thickness of concrete cover for steel reinforcement is 6 cm.

Whether or not, as well as how, TRC can be used to strengthen components has been examined in numerous studies (see for example Brameshuber[2] and Hegger *et al.*[3]). TRC is a composite material consisting of layers of high-tensile fine-grained concrete and textile reinforcing. The small maximum aggregate size of the fine-grained concrete matrix (e.g. 1 mm) allows for the use of a strengthening layer size of less then 2 mm. Alkali-resistant glass (AR-glass) or carbon are used for fibre material in the textile fabric; reinforcement in up to four directions may be produced depending on the load to be incurred. Therefore, the strengthening layer can specifically be reinforced and the bearing capacity optimised.

Several tests concerning the retrofit of flexural components (Brückner *et al.*[4] and Weiland *et al.*[5]), as well as related practical uses and applications (Weiland *et al.*[10]), have been proven, qualifying the use of TRC. Furthermore, the reinforcing effect relative to shear resistance has been demonstrated on small beams and T-beams (Brückner *et al.*[6]). Triantafillou and Papanicolaou[7] provide further comparison of carbon fibre textile shear force strengthening of small beams in both organic (resin-based) matrix materials and inorganic (cement-based) mortars. Current investigations concern proof of the practicality of TRC strengthening applications to larger components.

Anchorage of the strengthening of T-beams presents particular difficulties in strengthening against shear forces. According to the accepted strut-and-tie model, the balance of the internal forces can only be reached by anchoring the ties of the strengthening within the flexural compression zone. The compression zone in T-beams is inaccessible to the strengthening layer as a result of the adjacent slab. The strengthening can only be brought around the web to the bottom edge of the slab and, therefore, can only be anchored beyond the compression zone. Nevertheless, a ultimate load gain is possible as shown in the following sections. Test examinations, in terms of clinging bonds between existing concrete and the strengthening, as well as possible mechanical anchorages, are discussed in detail in Brückner *et al.*[6].

2. Test specimen and material

2.1. Reinforced concrete beam

Shear force strengthening by TRC was examined on two different cross-sections. A shear slenderness of 3–4 (Kani[11]) was selected. This refers to the relationship that exists between the distance of a single load and the effective depth of the unit, given the specimen geometry. Each specimen is specifically arranged so that two different tests can be conducted. The first unit is a beam with a length of 5.00 m and a span of 2.50 m. The second unit is a slim T-beam with a total length of 8.30 m and a span of 5.00 m. The geometry of these specimens, as well as the configuration of the reinforcement, are presented in Figures 1 and 2.

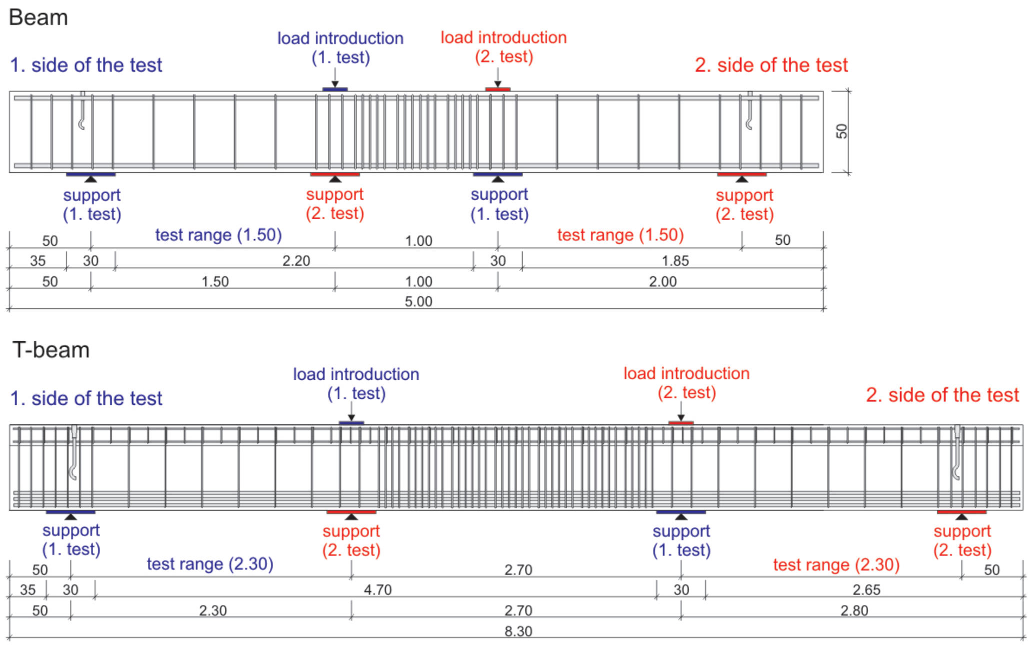

Figure 1: Longitudinal section of beams and T-beams

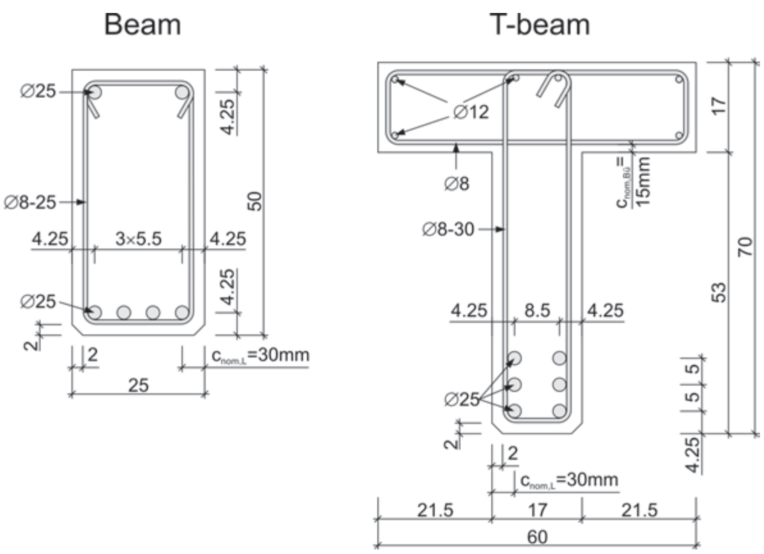

Figure 2: Cross-section of beams and T-beams in the test range

The steel stirrups reinforcement in the test range was planned as minimal reinforcement in order to provide continuous support of the concrete strut in the cracked state. The longitudinal reinforcement, as well as the bearing capacity of the concrete strut, were considerably oversized so as to provoke a shear strength failure.

Tables 1 and 2 depict the characteristics of the concrete and steel. Compressive strengths were determined by cubes (150 × 150 × 150 mm) while the modulus of elasticity was determined by cylinders (Ø150 × 300 mm).

Speciment	Ultimate load [kN]	Ø Ultimate load [kN]	Load increment [%]	Failure mechanism
beam 1.1	617	634	reference	shear
beam 1.1	651			
beam 2.1	679	707	12	shear
beam 2.1	735			
beam 3.1	833	839	32	shear
beam 3.2	846			
T-beam 1.1	615	638	reference	shear
T-beam 1.2	661			
T-beam 2.1	763	763	20	shear
T-beam 2.2	763			
T-beam 3.1	808	809	27	flexure
T-beam 3.2	809			

Table 1: Material properties of concrete (mean from 12 tests)

Bar	Tensile strength [N/mm²]	Modulus of elasticity [N/mm²]
Ø 8	584	204000
Ø 12	667	201000

Table 2: Material properties of steel bar (mean from 6 tests)

2.2. TRC strengthening

The strengthening layer consisted of fine-grained concrete with textile reinforcement, a mixture of Type II cement, aggregate with a maximum aggregate size of 1 mm, fly ash, micro-silica and superplasticiser (Jesse[9]). The concrete compressive and flexural tensile strengths were 70 N/mm^2 and 5 N/mm^2, respectively, as determined by tests on prisms (160 × 40 × 40 mm) in accordance with the regulations of DIN EN 196[12].

A multi-axial fabric of AR-glass with a mass per unit area of 263 g/m^2 was used as the textile reinforcement (Figure 3). The rovings used had a fineness of 1200 tex and were arranged at ± 45° every 10.8 mm. A brace thread was provided lengthwise in order to stabilise the form. The tensile strength of the textile fabric in uniaxial tension tests was 900 N/mm^2 according to Jesse[9].

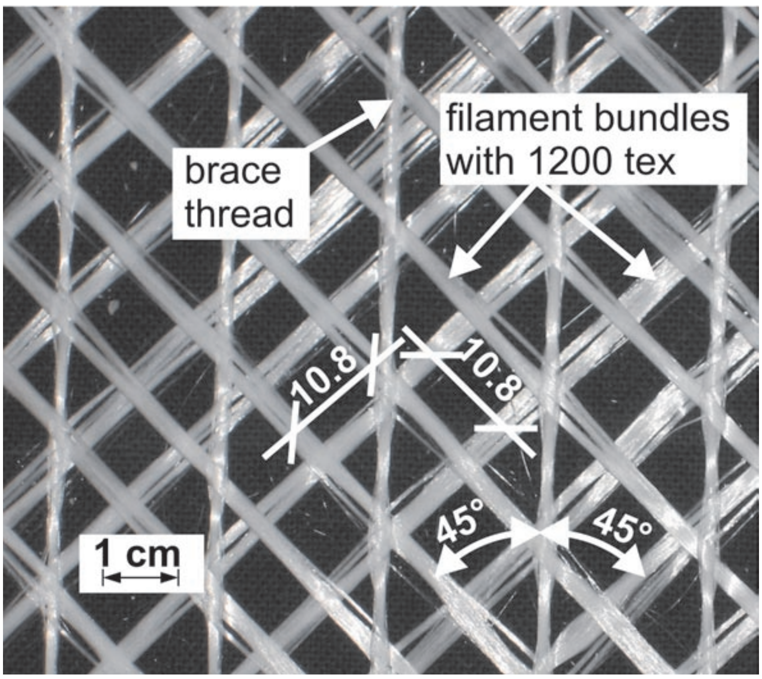

Figure 3: Textile fabric of the reinforcement

Only the clearance span of the specimen was strengthened while the support area was allowed to remain free so as to produce a practical-oriented arrangement of reinforcement. The continuation of the reinforcement into the compression zone is not possible in the case of T-beams; therefore, the strengthening is only taken to the bottom edges of the slab (T-beam) and neutral-axis (beam), respectively in order to accurately model this situation (Figure 4).

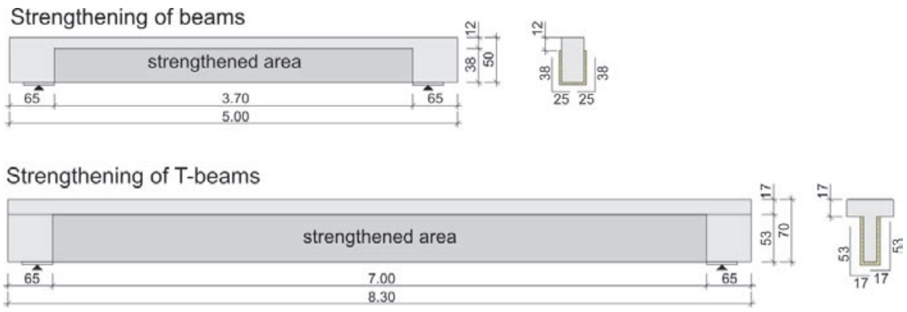

Figure 4: Arrangement of the strengthening

3. Application of TRC strengthening

The surface of the existing concrete must be roughened by sandblasting before applying any strengthening. The maximum particle size was based on attaining a roughness depth of 1 mm (Ortlepp[8]). The application of the textile reinforcement was achieved by the application of individual, separate layers.

The first layer of fine-grained concrete was laminated or sprayed onto the wetted, sandblasted surface of the RC body. The textile fabric was then 'pushe' into the layer until it was fully soaked and surrounded by the concrete (Figure 5). All additional layers (thickness per concrete layer about 2 mm) were applied manually until the required level of reinforcement was reached. The strengthening was completed by the application of a final layer of fine-grained concrete cover. A strengthening cover of four layers of textile reinforcement can be attained with a thickness as small as 1 cm.

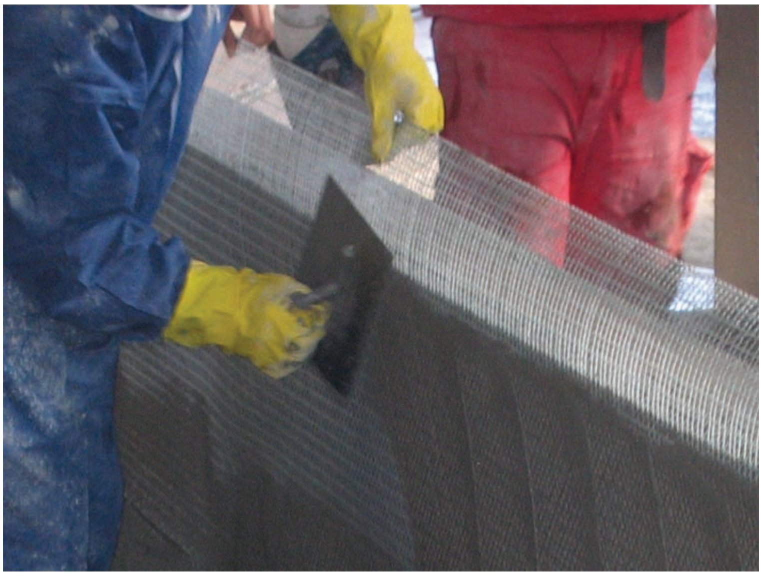

Figure 5: Application of the textile reinforcement

4. Experimental investigations

Experimental examinations included unreinforced reference specimens, as well as components strengthened by varying amounts of cover (Table 3). Two different three-point shear tests were conducted on each specimen.

Speciment	Strengthening	Area per side [mm²/m]
beam 1	-	-
beam 2	2 layer AR-glass	86.1
beam 3	3 layer AR-glass	129.1
T-beam 1	-	-
T-beam 2	3 layer AR-glass	129.1
T-beam 3	4 layer AR-glass	172.2

Table 3: Strengthening reinforcement of beams and T-beams

To initiate the load a testing cylinder was used to apply a single load of up to 1 MN. The load deformation was operationally controlled and discharged in four load steps (Figures 7 and 8). Gauge marks were determined by the photogrammetric survey, as well as linear variable differential transformer (LVDT) and strain gauges. The deflection, the deformation throughout the cross-sectional depth, and displacements within the shear zone were calculated given the measuring point arrangement (Figure 6).

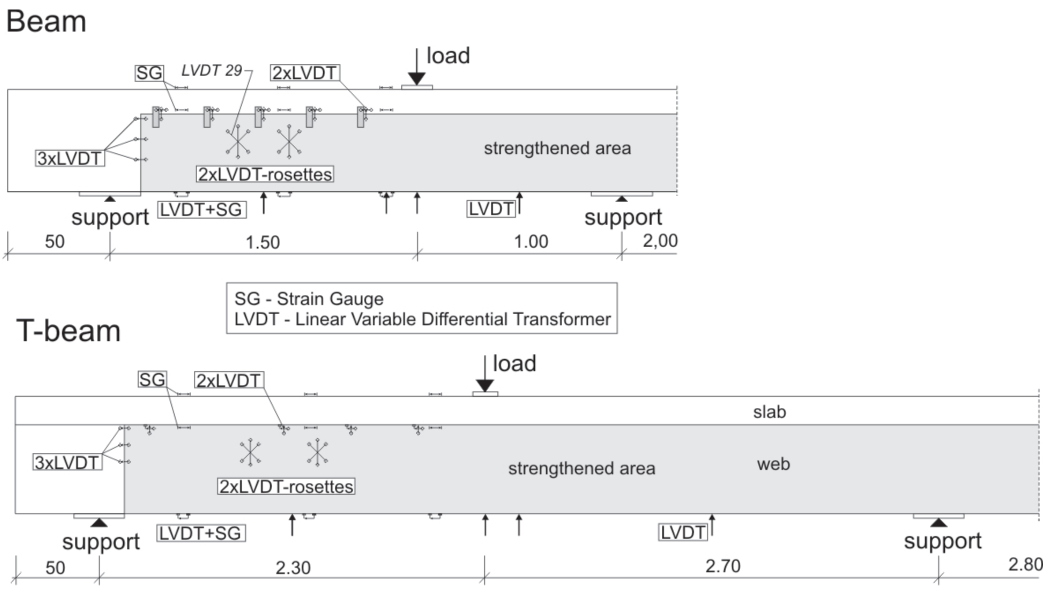

Figure 6: Arrangement of the measuring equipment

5. Results

Experiments showed a higher shear resistance of strengthened components than unstrengthened specimens. This shear resistance increased with increasing numbers of layers (Table 4).

Speciment	Compressive strength [N/mm²]	Splitting tensile strength [N/mm²]	Modulus of elasticity [N/mm²]
beam 1	40.5	2.78	31200
beam 2	38.5	2.68	28600
beam 3	38.0	2.50	28300
T-beam 1	40.5	2.78	31200
T-beam 2	37.0	2.72	27650
T-beam 3	35.6	2.30	28300

Table 4: Load-carrying capacity of the tested beams and T-beams

Strengthened components exhibited considerably lower deflection compared to that of unstrengthened specimens at the same load level (Figures 7 and 8).

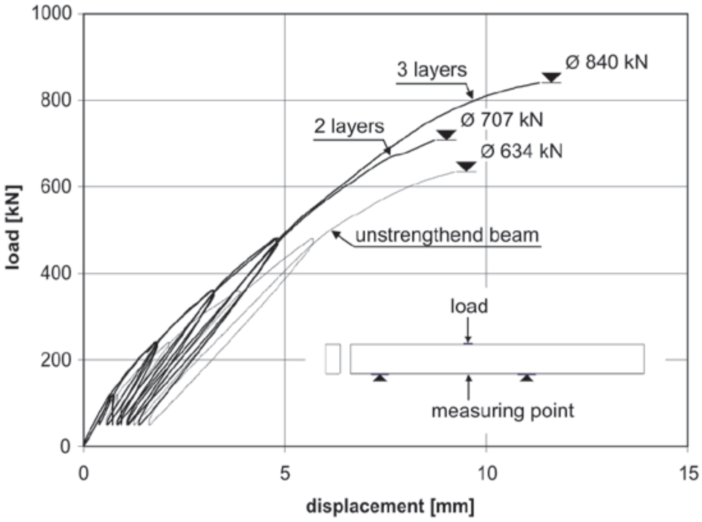

Figure 7: Load–displacement diagram of beams

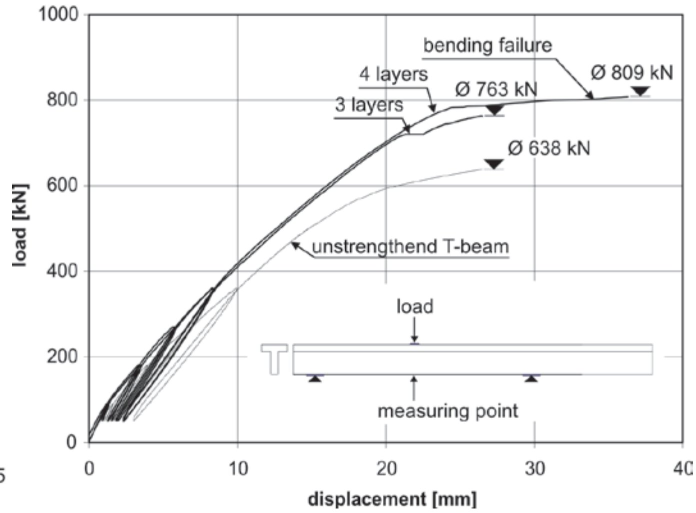

Figure 8: Load–displacement diagram of T-beams

In addition, measurements in the shear crack area (IWA 29 in Figure 6) indicate the existence of smaller deformations of the strengthened components in these areas. Figure 9 shows that the deformation through the beam cross-section decreased with the application of increasing amounts of textile reinforcement.

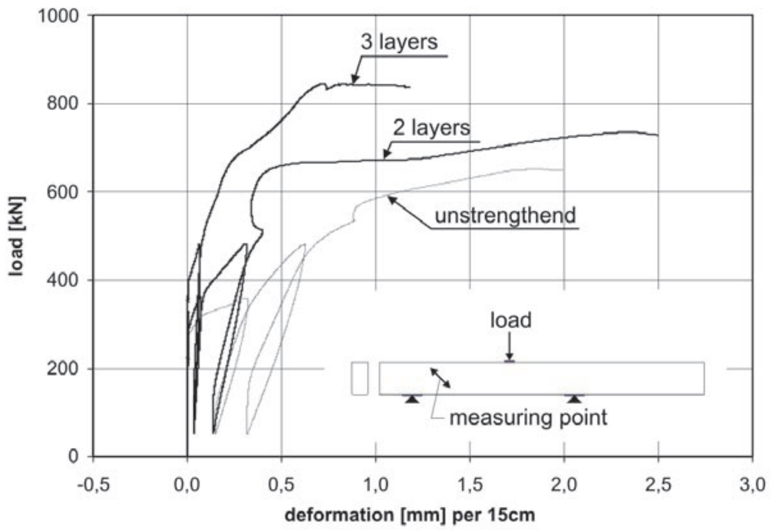

Figure 9: Diagonal deformation in the shear crack area of beams

A finer, distinct cracking was observed in all areas of the strengthened elements compared to unstrengthened components. Delaminating of the strengthening was observed in some sub-areas, which requires further analysis.

6. Summary

Initial tests on the practical applications of the strengthening of RC components by TRC were conducted so as to evaluate the structural behaviour of resulting shear force strengthening. Test results can be summarised as follows:

1. Configuration of TRC strengthening can significantly increase the resistance of concrete elements. The augmentation of the shear resistance is decidedly determined by the number of textile strengthening layers applied.
2. Improved serviceability, including significantly reduced deflection under the same load with visibly finer cracking, also resulted.
3. The crack widths of large, shear cracks were reduced, clearly as a result of strengthening as the textile reinforcement actively carried and transferred the loads incurred.
4. The size of the textile reinforcing layer is considerably smaller than that of traditional strengthening by shotcrete with steel reinforcement. The lighter strengthening material which only requires thin concrete layers greatly facilitates the ease of application.
5. Noticeable delaminating in sub-areas requires separate examination and investigation in future analyses.

7. Acknowledgements

The authors gratefully acknowledge the support of the German Research Foundation for this research. Furthermore, the authors would like to thank the 'Torkret AG' and their partners within the Collaborative Research Centre 528, 'Textile Reinforcement for Structural Strengthening and Retrofitting', for their support.

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