Contents

Introduction, context and aim

The life span of any civil engineering structure is estimated as 80 to 100 years. During this period, the structure might be used for varying purposes or the live load (e.g. traffic load) may increase, hence, the planning engineer has to rely on accurate forecasting of load models.

In the field of bridge engineering, the predicted accurate increase in the freight traffic from 1998 to 2015 was around 76 %, while in 2008 it was observed that the further growth predictions until 2025 obsolete.

The poor condition in bridge engineering is not solely due to increased traffic loads. Also, the former analysis and design rules may not correspond to state of the art today. According to today’s requirements, the strength of numerous structures is no longer sufficient. The pre-stressed concrete bridges which were built before 1968 are appropriate examples for this (HEGGER ET AL. [6]). Ever since the beginning of reinforced and pre-stressed concrete construction, the proof for shear force was performed solely with respect to the allowable shear stresses. It was not until 1966 under BMW-directives (BMV-RICHTLINIE [2]) that the concept of ‘minimum reinforcement’ was adopted.

The suitability of textile reinforcement for shear strengthening of structural components was showed during the research within the Collaborative research center 528: Textile reinforcement for structural strengthening and rehabilitation [1]. Textile reinforcement has the potential to succeed in the open market as a very efficient alternative reinforcement as demonstrated in first applications (e.g. CURBACH ET AL. [4], SCHLADITZ ET AL. [9]). It is prerequisite, though, that the use of TRC remains not restricted to components with predominantly static loading. Shear strengthening’s also are needed for fatigue stressed components, where bridge buildings among other things are included in.

Experimental investigations

General

The DAfStb research project on the shear resistance of textile reinforced strengthenings for concrete members is based on the investigations under static loading conducted in the DFG collaborative research center 528. T-beams (with identical dimensions and reinforcements to the SFB specimen) have been tested and examined with respect to the influence of cyclic loading (Fig. 1).

For the purpose of a feasibility study, seven T-beams were subjected to a threshold load of two million load cycles. Thereafter, tests were conducted to find the residual load bearing capacity of the specimen. All possible effects of the cyclic loading on the bearing capacity of the T-beams have been documented in the form of crack opening widths and the deformations relevant to the bearing capacity.

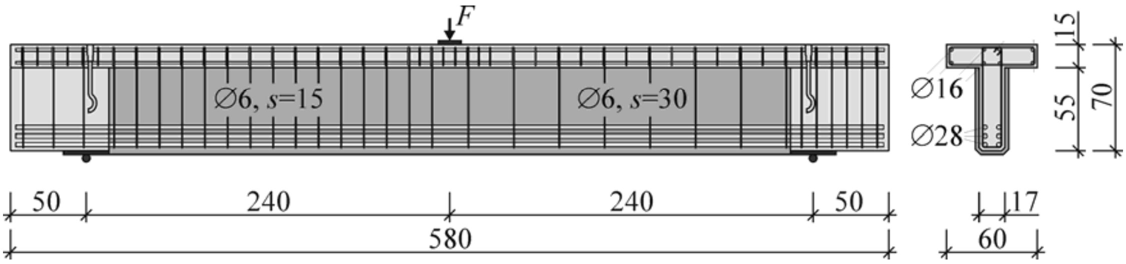

Fig. 1: Cross- section of the test specimen with the reinforcement design

The viability of the adhesive bond between the slab and the layer of reinforcement in the strengthened specimen were tested without additional design solutions for anchorage. The strengthening layers end outside the compressive bending zone. The possible failure of the bond between the textile reinforcement layer and the T-beam is monitored at several locations, by measuring the relative displacements between the reinforced concrete component and reinforcing layer. It is crucial to detect the onset of the bonding failure and its location as this indicates the boundary condition of the bearing capacity.

The bearing capacity of the T-beams was verified by calculations after the tests. With the existing engineering based computational models, the resistance of the steel bar reinforcement and textile reinforcement are determined and verified against the sum of all breaking loads. The aim of this recalculation is to examine the applicability of the CRC 528 developed truss model for textile reinforced concrete shear reinforcement for components subjected to non predominantly static loading.

Results of Experiments on Behaviour of T-beams

The shear strength of the T-beam after the application of the strengthening layer is generally higher than that of the originally reinforced beam, even though the strengthening layer is bonded only to the web of the T-beam through anchoring. Load reducing effects of non predominantly static loading could not be determined using the obtained fracture loads. Due to the subsequent hardening of the concrete, the ultimate loads of the cyclic loaded specimen were higher than in the reference experiment, where the beams were loaded only statically. Hence, the influence of the cyclic loading was maybe compensated.

Deformations were measured locally by strain gauges and inductive displacement transducer and 2-dimensional with a photogrammetric system. With the help of the photogrammetry we could confirm the former results of MALEK & SAADATMANESH [8] and BRÜCKNER [3] who observed higher axial stiffness of the web as a result of strengthening. The change in stiffness ratio in the web was determined by measuring the crack width or by measuring the inclination of the main compression. The crack width was considerably reduced by the textile reinforcement, especially at low degree of stirrups. But the lower crack widths are not only beneficial for the serviceability. At risk of failure the bending pressure zone due to constricting shear cracks, a limitation of crack widths may even lead to higher load bearing capacities as the investigations of BRÜCKNER [3] have shown on rectangular beams.

The inclination angle of the main compression is increased in the strengthened specimen - at an equal loading rate and at failure. Transferred to the truss model of the steel stirrup reinforcement means a steeper compression strut that the steel stirrup reinforcement transfer less load if the component is strengthened. The carrying capacity of the additional strengthening layer is consequently greater than the load difference between reinforced and unreinforced components.

The effects of non predominantly static loading stresses were perceived neither in the crack width nor in the inclination of the main compression. We didn’t observe any plastic increase of the crack width between the initial and the end load. Due to that it is assumed that there hasn’t been any damage of the reinforcement or the bond.

The tested load capacities of the T-beams were compared with the predictions of existing calculation models. Based on a jointly load distribution of the two web reinforcements - the stirrup and the textile - the bearing ratios of both reinforcements were superposed according to the truss model in DIN 1045-1 [5] or respectively to the model recommended in BRÜCKNER [3].

There is a systematic deviation between the calculated resistance and the verified resistance (shown in Fig. 2). The load bearing capacity of the T-beams with and without reinforcement are underestimated. Since every beam has shown the same deviation, it is assumed, that there is a load bearing capacity, which is not considered in the truss model with parallel tension and compression chords. It is conceivable that an additional load component is produced by a curved upper chord, which is usually neglected in favor of a simpler verification.

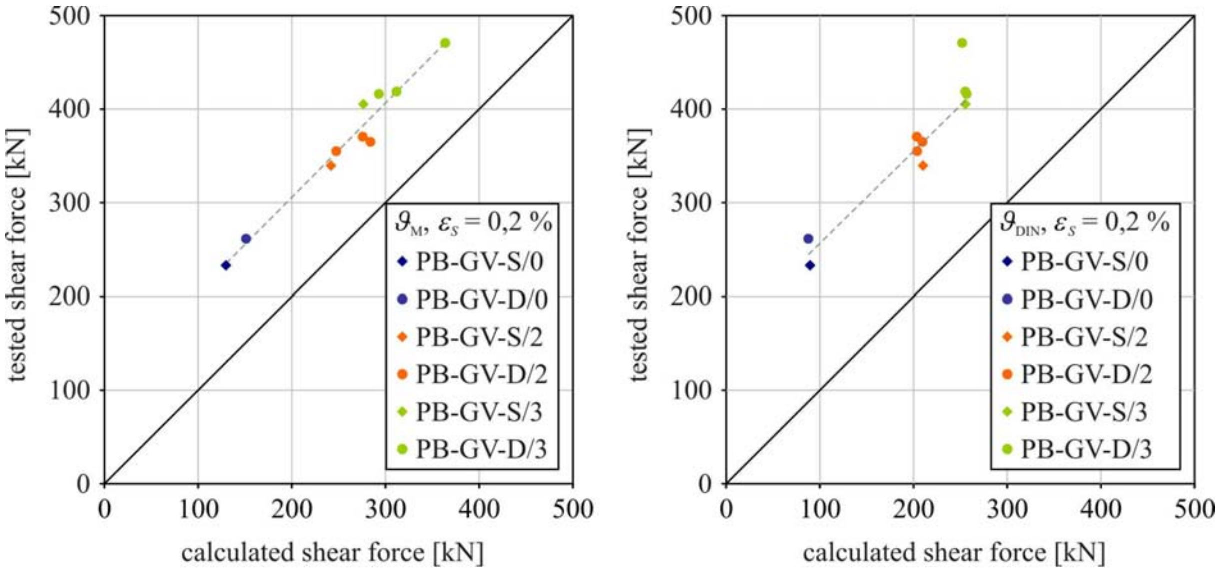

Fig. 2: Comparison of calculated and tested bearing capacity by use of measured inclination of the main compression (left) or inclination of the main compression according to DIN 1045-1 [5] (right)

Outlook

The behaviour of a component under shear loading is very complex and even for common reinforced concrete still not clearly described. The influences of a strengthened component lead to further analysis and verifying.

So far the experiments were restricted to components with shear reinforcements with minimal reinforcement ratio. The analysis of the two halfs of every beam with different reinforcements have shown that a higher reinforcement ratio effects as well the crack width as the angle of the main compression. According to the truss model a variable inclination of the main compression would lead to a non-linear dependency of the shear resistance and the stirrup reinforcement ratio of the components, which would need further research.

Along the reinforcement ratio the concrete strength has significant influence of the shear resistance of a component, as you can see in earlier researches (LEONHARDT & WALTHER [7]). A with the concrete strength increasing shear resistance could be used to compensate the influence of non predominantly static loading. This would be a good topic for further research.

The kind of shear failure is influenced by the cross-sectional shape of beam. A T-beam with high resistance of inclined compression chords collapses in form of tension failure of the web reinforcement. A rectangular beam on the other hand collapses due to failure of the compressive area in form of constricting shear cracks. This kind of failure has not yet been analysed. The crack patterns are influenced i.e. by the shear slenderness, the reinforcement ration or the kind of web reinforcement.

In the experiments, a cyclic stress with a permanent load of 80 % and a stress range of 30 % of the service load has not lead to a detectable damage of the T-beams. The threshold load should be increased in the further experiments in order to show the limits of the bearable cyclic stress, since the bonding analysis has shown a significant influence. An increase of the number of load cycles in the beam tests shouldn’t be necessary considered the results of this research, but the influence of the bonding properties should be verified.

For practical application of TRC-shear strengthening in bridge buildings it has to be considered the influence of changing temperature. There hasn’t been any research so far about textile reinforced components, which are exposed directly to environmental influences with typical surface temperatures between -30°C to 80°C. There are many other fields that need more research, such as textile concrete for shear reinforcements under permanent load, the influence with respect to the bond and the influence of a pre-stressing. Further research is needed in order to be able to make verified statements

References

[1] http://tu-dresden.de/forschung/forschungskompetenz/sonderforschungsbereiche/sfb528/

[2] BMV-RICHTLINIE: *Zusätzliche Bestimmungen zu DIN 4227 für Brücken aus Spannbeton.* BUNDESMINISTERIUM FÜR VERKEHR/HAUPTVERWALTUNG DER DEUTSCHEN BAHN (HRSG.), Bonn, 1966 (in German)

[3] BRÜCKNER, A.: *Querkraftverstärkung von Bauteilen mit textilbewehrtem Beton.* Institut für Massivbau, Technische Universität Dresden, Dissertation, 2011 (in German)

[4] CURBACH, M.; BRÜCKNER, A.; ORTLEPP, R.; WEILAND, S.: *Textilbewehrter Beton – Anwendung für Verstärkung.* In: DAFSTB (HRSG.): Neue Entwicklungen im Betonbau: Tagungsband der Fachtagung 2007 des Deutschen Ausschusses für Stahlbeton in Zu-

sammenarbeit mit der Bundesanstalt für Materialforschung und –prüfung, Berlin, 2007 (in German)

[5] DIN 1045-1: *Tragwerke aus Beton, Stahlbeton und Spannbeton – Teil 1: Bemessung und Konstruktion*. Ausgabe August 2008, zurückgezogen (in German)

[6] HEGGER, J.; KARAKAS, A.; PELKE, E.; SCHÖLCH, U.: Zur Querkraftgefährdung bestehender Spannbetonbrücken – Teil I: Grundlagen. *Beton- und Stahlbetonbau* 104 (2009), H. 11, S. 737-746 (in German)

[7] LEONHARDT, F.; WALTHER, R.: Schubversuche an einfeldrigen Stahlbetonbalken mit und ohne Schubbewehrung. In: *Deutscher Ausschuss für Stahlbeton*. Heft 151. Berlin : Ernst & Sohn, 1962 (in German)

[8] MALEK, A.; SAADATMANESH, H.: Ultimate Shear Capacity of Reinforced Concrete Beams Strengthened with Web-Bonded Fiber-Reinforced Plastic. *ACI Structural Journal* 95 (1998), No. 4, pp. 391-399

[9] SCHLADITZ, F.; LORENZ, E.; JESSE, F.; CURBACH, M.: Strengthening of a Barrel-Shaped Roof using Textile Reinforced Concrete. In: *33rd Symposium of the International Association for Bridge and Structural Engineering* (*IABSE*), Bangkok, 2009, S. 416-417 – Book of Abstracts and CD-ROM – ISBN 978-3-85748-121-5