Shear fatigue assessment of prestressed concrete bridges

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Summary

Many existing bridge structures were designed in the 1960s and 1970s according to former codes which do not represent the expected traffic loads. These structures typically feature comparable low shear reinforcement ratios and a high degree of prestressing. Their shear bearing capacity was originally determined based on the principal tensile strength criterion and can often not approved by the strut and tie models of the current code provisions. Within a research programme, fatigue tests on prestressed concrete beams have been performed. This paper gives a short summary of the experimental investigations and the observed shear fatigue failures. Based on the resisted load cycles until failure, modified approaches for shear fatigue in terms of Goodman-Diagrams based on the principal tensile strength criterion have been developed. The application to bridge structures in order to assess the shear strength under cyclic loading is presented.

Keywords: concrete; fatigue; shear; bridge; prestressed; assessment.

1. Introduction

The demands on the load-carrying capacity of bridges increased over the last decades due to higher traffic volume, especially concerning heavy good vehicles. Many existing bridge structures in Germany were designed in the 1960s and 1970s according to former codes which do not represent the expected traffic loads. These structures typically feature comparable low shear reinforcement ratios and a high degree of prestressing. The shear bearing capacity was originally determined based on the principal tensile strength criterion and can often not be approved by the strut and tie models of the current code provisions [1]. To account for the increased loads and the service life, a shear fatigue evaluation has to be performed.

The number of load cycles until failure and the failure announcement of prestressed concrete beams under cyclic shear load have been investigated at the Institute of Structural Concrete at RWTH Aachen University. The first series of the test programme consisted of beams without shear reinforcement (6×I-beams, 7×T-beams) [2], while the beams of the second series featured low shear reinforcement ratios (14×I-beams) [3]. The test beams were designed referring to the conditions of existing bridges, especially concerning the cross-section geometry, the prestressing and the longitudinal and transversal reinforcement ratios. For typical structures of the German highway network, static calculations with different load models were performed in order to obtain reasonable load regimes.

2. Shear fatigue evaluation and conclusions

The crack development and fatigue failure of the I-shaped and the T-shaped beams without shear reinforcement differed. The cyclic shear failure by diagonal cracking of the I-beams occurred in a brittle manner without prior visible announcement. Despite the distinct bending and shear crack development of the T-beams, a failure under the applied loads was not observed in five tests. In one test, the T-beam failed due to the sudden development of a diagonal crack under cyclic loading. The beams were able to resist significantly more cycles than predicted by the approaches for shear

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fatigue of the current design rules [1]. This is mainly due to an underestimation of the static shear strength for the investigated I-beams and T-beams without shear reinforcement. Therefore, it is not appropriate as reference strength to limit the shear load amplitude as prescribed by the design rules. The performed cyclic tests on beams with low shear reinforcement ratios (ρ_w = 0,15 % and 0,22 %) reveal, that already a small amount of stirrups provides a distinct period of failure announcement.

Based on the resisted load cycles until failure, modified approaches for shear fatigue of beams without shear reinforcement in terms of Goodman-Diagrams based on the principal tensile strength criterion have been developed (Fig. 1). If a load combination lies within the enclosed grey shaded area, no failure due to shear fatigue has to be expected. When a point lies outside the shaded area, a shear fatigue failure is predicted. The first approach limits the permitted shear loads determined on the principal tensile strength criterion (Fig. 1, left). In the second approach, a limitation of the permitted principal tensile stresses under cyclic shear is given (Fig. 1, right). They may only be applied to uncracked regions, and hence permitted maximum flexural stresses are defined.

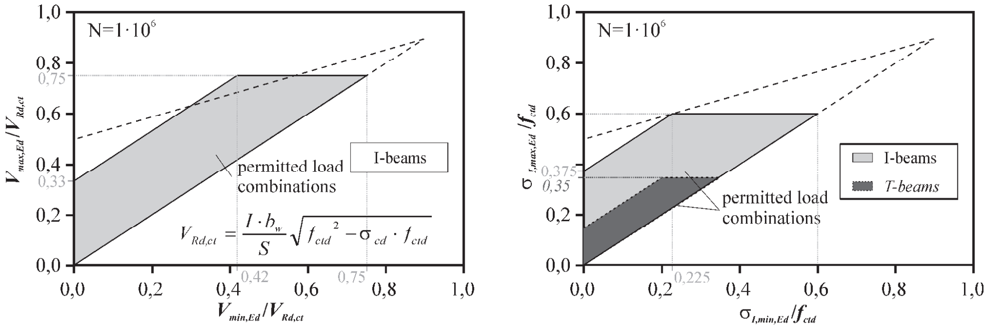

Fig. 1: Limitation of shear load amplitude of prestressed I-beams (left) and limitation of principal tensile stress of prestressed I-beams and T-beams (right)

In order to assess the shear strength of prestressed concrete bridges under cyclic load, an approach for the shear fatigue evaluation is proposed. It is primarily based on the verification of the bridge structure as prestressed member without shear reinforcement applying the developed Goodman-Diagrams. The evaluation of prestressed box girder bridges can be performed by limitation of the maximum and minimum shear loads or alternatively by limitation of the principal tensile stresses. For T-beams, only the approach based on the principal tensile stresses is applicable. If the resistance cannot be verified by this means, a limited verification is possible for structures with shear reinforcement ratios greater than the required minimum value according to [1]. For these structures a pronounced failure indication can be assumed as described in [3]. To check the respective structures for the existence and the development of cracks, a detailed bridge inspection has to be performed in regular intervals.

In order to extend and verify the approaches for other types of cross-sections, shear reinforcement ratios and load combinations, further investigations are necessary. In addition, investigations on the effective shear fatigue loads seem to be reasonable. For the evaluation of existing structures, the already experienced loads and the planned service life should be considered. Independently of the presented fatigue evaluation, the shear capacity in the ultimate limit state under static loading has to be verified.

[1] DIN EN 1992-2, German Design Code: „Eurocode 2: Design of concrete structures - Part 2: Concrete bridges - Design and detailing rules“, Berlin/Germany, 2010.

[2] TEWORTE, F., HEGGER, J., “Fatigue of prestressed beams without web reinforcement under cyclic shear”, *Beton- und Stahlbetonbau*, Volume 108, No. 1, pp. 34-46, 2013.

[3] TEWORTE F., HEGGER J., “Fatigue of Prestressed Concrete Beams with low Shear Reinforcement Ratios – Experimental Investigations”, 18th Congress of IABSE, Seoul, 2012.