Experimental and analytical investigations on the shear capacity of prestressed concrete bridges

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Abstract

A recalculation according to Eurocode 2 (EC2) of bridges, which have been built in Europe before the introduction of EC2, shows a deficit of the existing shear reinforcement. However, prestressed concrete bridges have additional load-bearing reserves. Even refined analytical approaches do not sufficiently capture the simultaneous effect of the concrete and reinforcement contribution on the shear capacity. Hence, it is important to verify the shear capacity of existing concrete bridges with a new improved design approach. In this work, sixteen large-scaled shear tests (16,5 m continuous post-tensioned girders with uniformly distributed loads) have been conducted. To examine the interaction of the concrete contribution and the strut-and-tie model, the specimens were built with low shear reinforcement and varying cross-sectional shapes. Finally, it will be shown that the service time of existing structures can be extended significantly by using the new analytical design approach.

Keywords: shear capacity, prestressed concrete girders, large scale, recalculation, bridge, Eurocode

1 Shear design of reinforced concrete girders with small amounts of shear reinforcement

The shear design according to EC2/NA(D) [1] as well as the derivation of the design approach are not suitable for determining the shear reserves of existing prestressed concrete bridges, because the application of the truss model requires a minimum shear reinforcement. At the time of construction of most bridges in Germany, the design was based on the main stress criterion, which differs from the design according to today's standards, resulting in a significantly lower amount of shear reinforcement. Therefore, there is an urgent need for more detailed design models with an accurate determination of the shear resistance. Extended design approaches have already been formulated in the German recalculation guideline, but they do not answer all remaining questions regarding the various influences on the shear resistance.

The current shear design according to EC2/NA(D) [1] of reinforced concrete structures distinguishes between three verifications: the verification for beams without shear reinforcement (Eq. (13)) as well as the verification of shear reinforcement (Eq. (4)) and verification of compression strut according to the truss model (c.f. Table 1). According to EC2, the shear design for beams with shear reinforcement is carried out solely by a truss model with variable compression strut inclination [2]. According to the plasticity theory, the compression strut angle can be chosen within fixed limits. In contrast, the National Annex for Germany uses a truss model with crack friction (Eq. (9)) [3], which considers a transmission crack friction force along the shear cracks with an minimum compression strut angle of 30° ($cot\ \theta \leq 7/4$) [4]. The effect of the inclined tendon may be considered.

With the introduction of the German recalculation guideline (German: Nachrechnungsrichtlinie, NRR) [5], a four-staged verification procedure was introduced for the evaluation of existing bridges, which allows extended design approaches in stage 2 and alternative scientifically based calculation methods in stage 4. Among other things, modifications in the shear design are permitted, which were stipulated in the old generation of standards (Eq. (7),(10)) ([6] before 2003). In a research project [7–9], short-term solutions for the modification of existing design approaches were developed due to the lack of uniform regulations. The results were the basis for the first amendment of the NRR [10] in 2015. The application to real structures and tests showed an improved determination of the shear resistance, but structures with low shear reinforcement ratios were still assessed conservatively. In order to enable an accurate assessment of the shear resistance of older bridges

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