DETERMINATION OF DAMAGE EQUIVALENT FACTORS FOR THE FATIGUE DESIGN OF TIMBER CONCRETE-COMPOSITE ROAD BRIDGES WITH NOTCHED CONNECTIONS

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ABSTRACT: The fatigue verification of all structural members including the shear connectors is one important part of the design of timber-concrete composite (TCC) road bridges, because traffic represents a variable cyclic load. Based on S-N lines for the resistance and fatigue load models as actions, a simplified fatigue verification concept is developed for single span TCC bridges with notched shear connections.

KEYWORDS: Timber-concrete composite, road bridge, notch, fatigue

1 INTRODUCTION

In the past, a lot of knowledge has been gained about the ultimate static load carrying capacity, the stiffness, different types of connectors between timber and concrete and the long-term behaviour of TCC beams, which is sufficient for the design of slabs or foot bridges. Nowadays, there is also an increasing interest in building TCC road bridges. Different types of vehicles represent a variable cyclic load that can lead to fatigue failure of the system. Therefore the designer has to verify the fatigue strength of the structural members (timber beams and concrete deck) and of the shear connectors in particular. Whereas the design of steel-concrete composite beams is state-of-the-art and part of the standards, the knowledge on the fatigue behaviour of TCC beams is limited.

Due to high stiffness, high strength values and the simplicity of construction, notched connections between timber and concrete are especially appropriate for bridges. In an earlier research work the fatigue behaviour of this type of connector has been investigated and a first S-N line is now available. Experimental investigations on the fatigue behaviour of notches showed a brittle shear failure mechanism in the timber beam in front of the notch [1].

The next step is to analyse the simplified fatigue verification based on EN 1995-2 and its modification regarding TCC road bridges.

2 METHODS AND RESULTS

2.1 DAMAGE EQUIVALENT FACTOR

In the design process, two different Fatigue Load Models (FLM 3 and FLM 4 according to EN 1991-2) may be used. The model FLM 3 consists of a single vehicle load, whereas FLM 4 represents five different types of lorries. FLM 3 is a simplified model for which only the total number of constant amplitude load cycles ΔFmax per year can be taken into account. The consequence is a conservative estimation of the damage due to traffic loads. With the more detailed FLM 4 stress ranges may be calculated for each of the different types of lorries and may be summed up corresponding to the individual number of cycles according to the linear damage accumulation hypothesis (Palmgren-Miner rule). Since this method is time-consuming, simplified verifications have been developed for steel, concrete and steel-concrete composite bridges, but not for timber bridges, where the stress range due to FLM 3 is modified by damage equivalent factors λ.

The factors depend on the bridge geometry, the lifetime of the bridge, the traffic composition and a certain traffic flow. Such damage equivalent factors are now under development for TCC single span bridges based on traffic simulations and derived by the comparison between the effects of FLM 3 and FLM 4 [1, 2]. Equation (1) shows the simplified fatigue verification for constant amplitude load cycles that involves the modified maximum stress according to FLM 3 and the fatigue strength fat,d.

\[
\sigma_{d,max} \leq \frac{f_{fat,d}}{\gamma_{M, fat}} = k_{fat} \cdot \frac{f_s}{\gamma_{M, fat}} \quad (1)
\]
where \( \sigma_{d,max} = \sigma_{d,min} + \lambda \cdot \Delta \sigma_d \) = maximum stress, \( k_{fat} \) = factor representing the reduction of strength with number of load cycles, \( f_k \) = characteristic strength and \( \gamma_{M,fat} = 1.0 \) = material safety factor for fatigue. The minimum load is caused by dead loads only. To investigate the fatigue behaviour of the notches between timber and concrete, symmetrical push-out tests and tests on composite beams have been performed [1]. Based on 11 push-out specimens under cyclic loading, a first S-N line has been developed for a notched connection. The experimental investigations show a good concordance between the evaluated \( k_{fat} \)-value derived from the test results and the \( k_{fat} \)-value given in EN 1995-2 for the determination of the fatigue strength for longitudinal shear stresses corresponding to the dominating failure mechanism of a shear timber failure at the notch. Figure 1 shows the S-N line of a notch based on EN 1995-2 for a life time of 100 years and a ratio of maximum to minimum applied forces of \( R = 0.4 \). In Figure 1, the y-axis represents the fatigue strength based on the characteristic strength value modified with \( k_{fat} \) and the x-axis shows the number of cycles to failure in a logarithmic scale. The damage equivalent load for the fatigue verification according to the constant amplitude load cycles due to FLM 3 modified with factors \( \lambda \) has to be smaller than the equivalent fatigue strength at 500,000 load cycles. This forms the basis in order to scale the factors \( \lambda \).

### 2.2 DETERMINATION OF THE DAMAGE EQUIVALENT FACTOR

To derive modification factors for the fatigue verification of the timber elements within TCC road bridges, different typical bridge geometries and materials are analysed for load models FLM 3 and FLM 4. Single span bridges with span lengths of 10, 15, 20, 25 and 30 m and three different cross-sections (see Figure 2) are chosen for the simulation. Furthermore, glulam strength class GL 28c according to EN 14080 and concrete strength class C 30/37 according to EN 1992-1-1 are used. As shear connection between concrete and timber elements, notches with a depth of 5 cm and a length of 20 cm are selected for each bridge type. Prior to the traffic simulation with FLM 3 and FLM 4, all the bridges are preliminarily designed for the Ultimate Limit State considering dead loads, long-term behaviour, temperature effects and Load Model 1 according to EN 1991-2. For the preliminary design, as well as the calculation of influence lines for the traffic simulation, a lattice truss model, see e.g. Grosse et al. [3], is used. Thereby, the internal shear force at the most loaded outer notch, that has to be transferred by the connector, can be read out directly and influence lines for a moving single load of 1 kN can be derived. By these influence lines, load collectives can be developed for the single vehicle load of FLM 3 as well as for the five types of lorries of FLM 4, representing the range of the longitudinal shear force at the notch (\( \Delta F_{No} \) in Figure 1).

### 3 CONCLUSIONS

S-N lines for notches between timber and concrete and structural members, as well as a simplified fatigue verification concept are required for the economical application of TCC road bridges. Within the paper, for the fatigue verification first investigations on an improved concept including damage equivalent factors \( \lambda \) dependent on bridge geometry, lifetime and traffic situation, will be presented in order to simplify the design of TCC structures for cycling loads.

### REFERENCES

