Remarkable Strengthening of an old Steel Highway Bridge

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Summary

The paper deals with the remarkable strengthening of a continuous steel plate girder bridge with three spans, built in 1939. Due to increased loads, unscheduled material properties (undersized yield stress) and detected cracks near the ends of cover plates, a lack of load carrying capacity for the main girders was decided. Based on fracture mechanics it was determined that an extensive unloading of the existing structure was necessary - excluding conventional strengthening. Therefore an exceptional solution was chosen. Additional main girders are situated on the upper side of the bridge deck, connected by prestressed tension rods for unloading the existing structure. First the three design variants for the new main girders (plate girder, truss, arch) are presented, analysed in a preliminary study. Finally the chosen solution of a tubular tied arch, selected also due to aesthetic reasons, is represented. The design concept, the structural design and erection are shown.

Keywords: steel bridge strengthening; prestressed tied arch.

1. Introduction

The existing structure called "Karolinen – bridge", situated within the picturesque Old Town of Salzburg / Austria, is a continuous plate girder bridge with three spans (L = 30 + 45 + 30 m) and was completed in 1939 at the beginning of the 2nd world war (Fig. 1). The two main girders, with a distance of 12 m, have a varying depth of 1.1 to 1.45 m (at midspan) and are fully welded.

During a regular inspection in summer 2003 some cracks on the lower flange of the main girder were detected near the ends of the cover plates. Tests on some samples show the following results:
- The steel quality is bad with limited weldability.
- The built-in steel has reduced yield strength, leading to an allowable stress of 165 N/mm^2 compared with actual stresses of about 218 N/mm^2.
- Based on fracture mechanics it could be shown that the cracks are stable if the normal stresses due to permanent and traffic loads are limited to a fictive allowable stress of 125 N/mm^2, which is about 50 % of the actual stresses.

2. Preliminary design study for strengthening the structure

Within a preliminary design study a concept for strengthening of the old structure was worked out, leading to three variants. All include additional continuous main girders, situated on the upper side of the bridge deck, directly above the old ones, with the same support locations. The connection in between with the old girders is done by a pair of tension rods, which support the old girder by

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means of a new crossbeam, situated underneath at the location of the cross girder. Prestressing of the individual pairs of tension rods provide the unloading of the old girders. - *Variant V1* is the simplest solution, using a new plate girder with a height of about 1.4 m. The distances between the hangers are about 6 m. - *Variant V2* is a continuous truss girder with diagonals only and with a height of about 3.5 m. The hangers are situated at the joints of the lower chord. - *Variant V3* is a continuous tied arch. The rise of the arch is 5.6 / 3.8 m in the main / side span. The arches have individual tie rods to prevent the old girder from additional axial forces.

Fig. 1: "Karolinen – bridge" in Salzburg / Austria before (left) and after (right) strengthening

3. Final strengthening solution

Based on the three variants the solution with the tied arches was chosen (Fig. 1), also due to aesthetic reasons. The desire for elimination of the bearings results in fixed connections between the arch bases and the old steel girders, shown in detail in the full paper. In order to reduce the axial forces in the old girders sliding plates were used during prestressing. Mentionable is also the design of prestressing (details in the full paper). Although the final prestressing forces in the hangers were nearly the same, the sequence of prestressing - only one pair of tension rods was prestressed by hydraulic jacks at the same time - had to be considered carefully. Only in the last prestressed hangers the actual prestressing force is equal to the final one. Sometimes the actual prestressing force is up to 25 % higher, sometimes up to 30 % less, than in the final condition.

4. Conclusions

Strengthening of old structures needs sometimes exceptional solutions. Unloading the structure from permanent loads, up to 50 %, and reduction of the final normal stresses of about 50 % was possible due to the erection of new main girders directly above the old ones and prestressing of the connectional hangers. Using cross beams under the old girders for the connection with the tension rods avoid welded joints to the old structure.

Different design of the new girders is possible - plate girder, truss girder or tied arch. The represented final solution, using tied arches with double tubular sections, has also aesthetic benefits.

The erection of the new girders is very simple, because no scaffolding is needed and can be done as far as possible under traffic.