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Measurements for Evaluating the Remaining Service Life of a Riveted Bridge

Mesures in-situ pour l'évaluation de la durée de service restante d'un pont riveté

Messungen für die Beurteilung der Restnutzungsdauer einer genieteten Brücke

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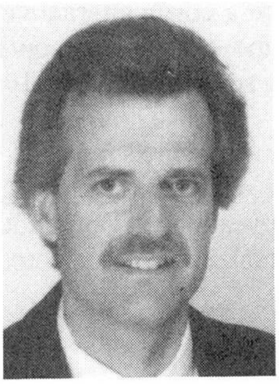

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SUMMARY

Accurate determination of stresses due to actual traffic loads is important when assessing the fatigue safety and the remaining service life of bridges. A 100-year-old riveted bridge carrying a busy railway line is investigated by in-situ measurements of the fatigue-determinant cross girders. This thorough assessment is cost-effective because no expensive measures had to be taken to keep the bridge in service.

RÉSUMÉ

Une détermination précise des contraintes dues aux charges de trafic actuelles est importante dans l'évaluation de la sécurité à la fatigue et de la durée de vie restante des ponts. Un pont-rail riveté, construit il y a 100 ans et faisant l'objet d'un trafic intense, est évalué à l'aide de mesures in-situ sur des entretoises. Cette évaluation détaillée s'est avérée avantageuse car on a pu renoncer à des interventions coûteuses pour maintenir le pont en service.

ZUSAMMENFASSUNG

Eine genaue Spannungsermittlung infolge wirklicher Verkehrslasten ist wichtig bei der Beurteilung der Ermüdungssicherheit und der Restnutzungsdauer von Brücken. Eine 100 Jahre alte genietete Brücke, welche einem starken Bahnverkehr ausgesetzt ist, wird mit Hilfe von Spannungsmessungen in den für die Ermüdung massgebenden Querträgern untersucht. Diese umfassende Beurteilung ist kostengünstig, weil keine teuren Massnahmen notwendig sind, um die Brücke weiterhin in Betrieb zu halten.

1. INTRODUCTION

The remaining service life of eight consecutive railway bridges of identical construction has been investigated. The bridges were built in 1894 and comprise riveted early mild steel members. The lattice-truss structure of a single 34m-span has a ballasted deck consisting of a reinforced concrete slab on corrugated steel resting on the cross girders (Figure 1). These girders are rigidly connected to the main girders; i.e. the cross section of the bridge is an U-frame. Since commencement of service 100 years ago, these single-track bridges have been subjected to a busy railway traffic totalling 3.6 million trains. Today the daily traffic is 150 passenger trains, and it is planned to maintain this traffic in the future.

In general, it is economical to keep well maintained bridges in service as long as possible. In the present case, bridge replacement would be a costly alternative because it is not feasible to interrupt railway service on this busy main line for more than some hours. Given the good structural condition, the owner decided to assess the remaining service life of the 100-year-old bridges.

A first structural analysis using simple statical models revealed sufficient load carrying capacity of the bridge. However, the fatigue safety check depicted the cross girders to be fatigue critical to such an extent that they should have failed many years ago. Consequently, a more refined assessement was necessary to investigate why no fatigue crack could be detected in the cross girders up to this day.

2. VERIFICATION OF THE FATIGUE SAFETY

As a result of the small spacing of the cross girders, every single axle or pair of closely spaced axles induces one single stress cycle in the cross girder. Given the high number of 3.6 million past train passages, the cross girders have been - up to date - subjected to an estimated number of 70 million stress cycles. A significant portion of them is in the domain of high stress ranges.

Because of this inherent fatigue loading, the fatigue safety of the cross girders is assessed with respect to the constant amplitude fatigue limit. It is postulated that the whole stress range spectra due to actual traffic is below the fatigue limit (Fig. 2a), i.e. no fatigue crack propagation has occurred in the riveted connection. This is expressed by the following equation:

$$\Delta\sigma(\Phi \cdot Q_{eff}) < \Delta\sigma_D / \gamma_{fat} \qquad (1)$$

The maximum stress range $\Delta\sigma(\Phi \cdot Q_{eff})$ due to actual loads Q_{eff} includes the dynamic coefficient Φ. The constant amplitude fatigue limit $\Delta\sigma_D$ for riveted connections is deduced from experimental results as obtained from riveted bridge elements (Fig.2b) [1,2]. Detail category ECCS 71 (AASHTO D) provides a reasonable estimate of fatigue strength of mildly corroded riveted bridge members. This detail category suggests a constant-amplitude fatigue limit $\Delta\sigma_D$ of 52 MPa which is the value considered in the present study. This value is rather conservative; the test results indicate a fatigue limit of 70 MPa (Fig. 2b). Finally, a fatigue resistance factor $\gamma_{fat} = 1.20$ is taken into account.

3. STRUCTURAL ANALYSIS OF THE CROSS GIRDERS

The structural behaviour, under actual load conditions, has to be modeled first to determine the maximum stress range $\Delta\sigma(\Phi \cdot Q_{eff})$ in the fatigue relevant tension flange of the cross girder. In the present case, there are a few rivets fixing the deck to the cross girders. This connection between deck and cross girder may lead to some kind of partial composite action under service loading.

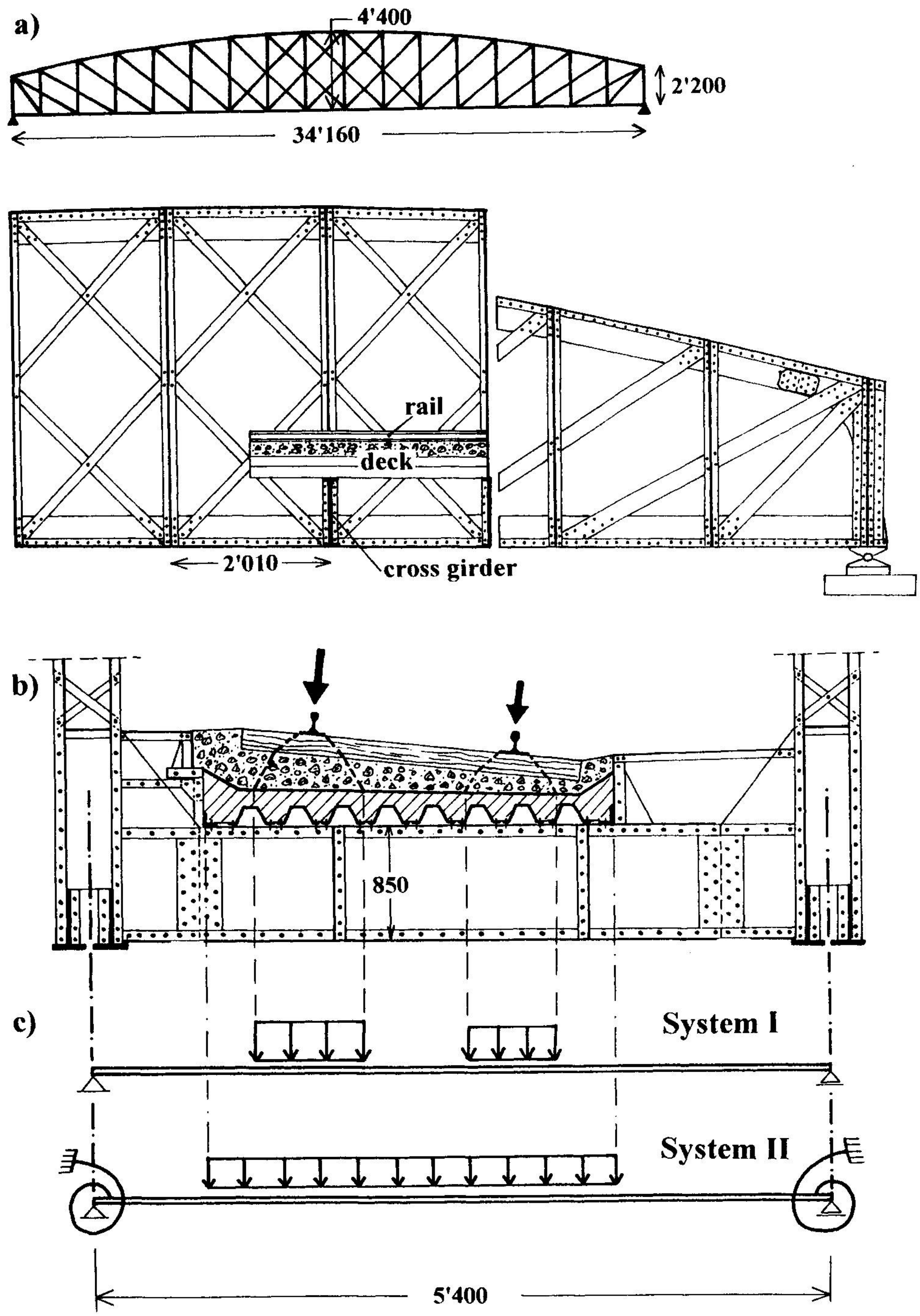

Fig. 1 Investigated bridge: a) view of the lattice girder, b) cross section, c) statical systems.

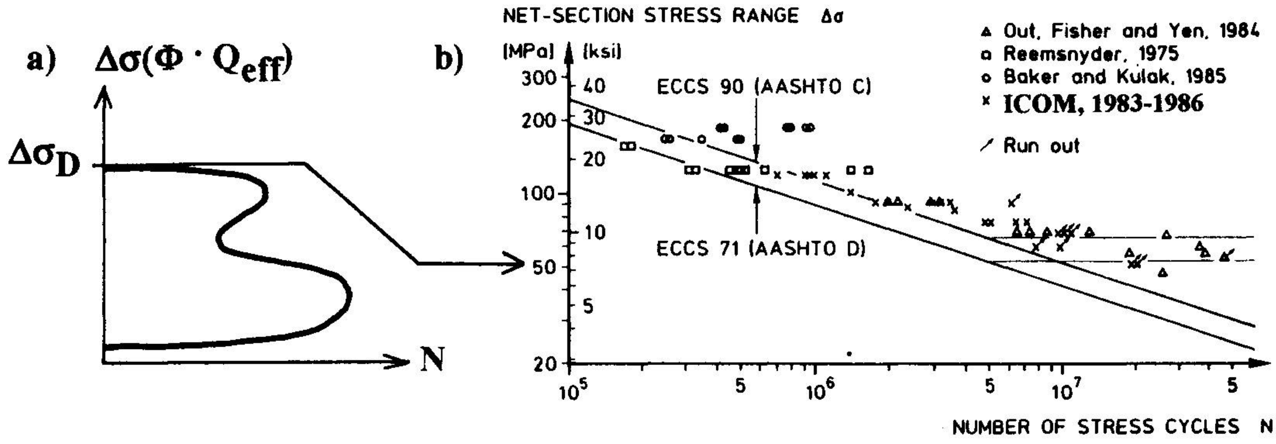

Fig. 2 a) Schematic representation of stress range spectra, b) Fatigue test results of full-scale riveted elements, from [1].

However, it is difficult to account for this partial composite action in a statical model. Also, the load distribution from the deck onto adjacent cross girders and the degree of fixity of the cross girders in the bottom flange of the two main girders are difficult to model. Finally, the actual dynamic coefficient is not known precisely. The two following structural systems have been adopted (Fig. 1c):

The **statical system I** representing a conservative approach, isolates the cross girder from the overall structural behaviour of the bridge. The statical model is a simple beam. The section modulus of the steel girder alone and a dynamic coefficient $\Phi = 1.40$ according to current codes have been considered. Loads have been distributed in the longitudinal direction assuming the cross girders to be a hard support for the deck slab.

In **statical system II**, the partial fixity of the cross girder in the bottom flange of the two main girders has been estimated according to [3]. The dynamic coefficient as given by code provisions appears to be too conservative for ballasted tracks, and a reduced $\Phi = 1.15$ has been assumed. Loads are distributed in the longitudinal direction accounting for the overall deformation of the bridge under load. No composite action between deck and girder has been considered, and the section modulus of the steel girder alone has been used to calculate the stress range.

Maximum stress range values $\Delta\sigma(\Phi \cdot Q_{eff})$ of 93 MPa and 71 MPa have been calculated assuming, respectively, the statical systems I and II. Both values are significantly above the fatigue limit $\Delta\sigma_D$, and the fatigue safety is not verified according to Eq. 1. There is still no explanation why no fatigue crack could be detected in the cross girders up to this day.

4. FIELD TESTING

Strain measurements have been performed in the next step to study the static and dynamic structural performance of the cross girders and to determine stresses under actual traffic loads. Three successive cross girders have been equipped with strain gauges (Fig. 3), and the stress-time histories due to passenger trains and a given engine load have been recorded (Fig. 4).

The location of the neutral axis along the cross girder is discussed first (Fig. 3). Two domains are distinguished; in the domain where the steel beam acts alone, the neutral axis is, as expected, located at mid-height of the beam. Under the deck slab, the neutral axis shows a significant shift upwards indicating a beneficial partial composite action between the deck and the cross girder.

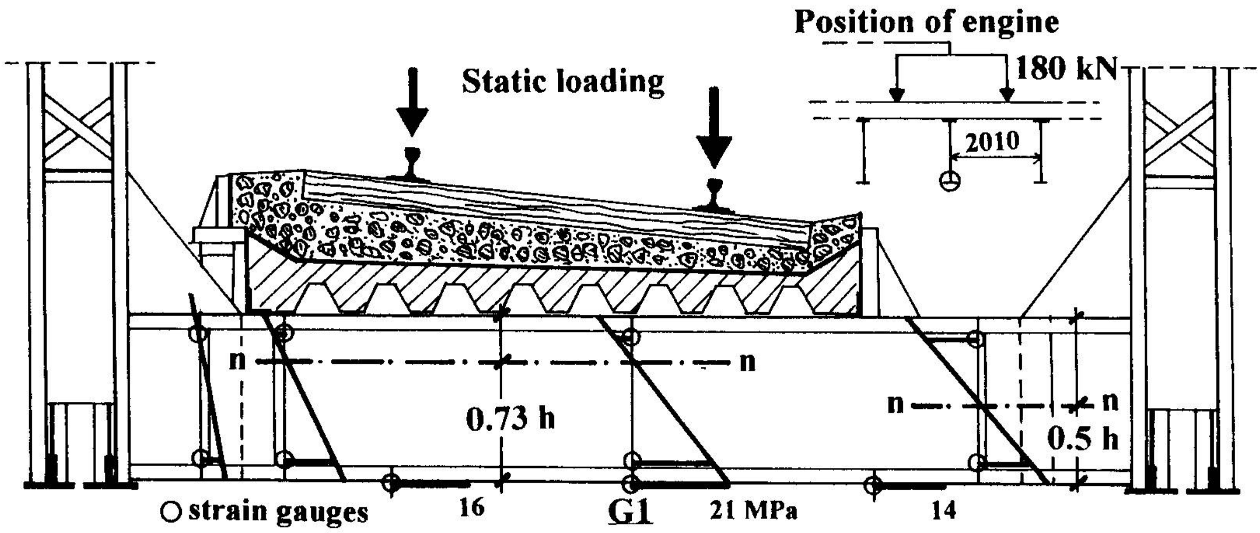

Fig. 3 Structural performance of the cross girder: in-situ measurement under static engine load.

The actual section modulus of the composite system is about 2.5 times larger than the section modulus of the steel girder alone. This explains why the measured stresses are significantly smaller than the calculated stresses.
The shear force at the interface between the upper flange of the cross girder and the deck is resisted by the few connecting rivets between deck and girder. The estimated shear stress of about 100 MPa in these rivets is high, but acceptable; it is equal to a conservative value of fatigue limit $\Delta\tau_D$ for rivets under shear stress [1].

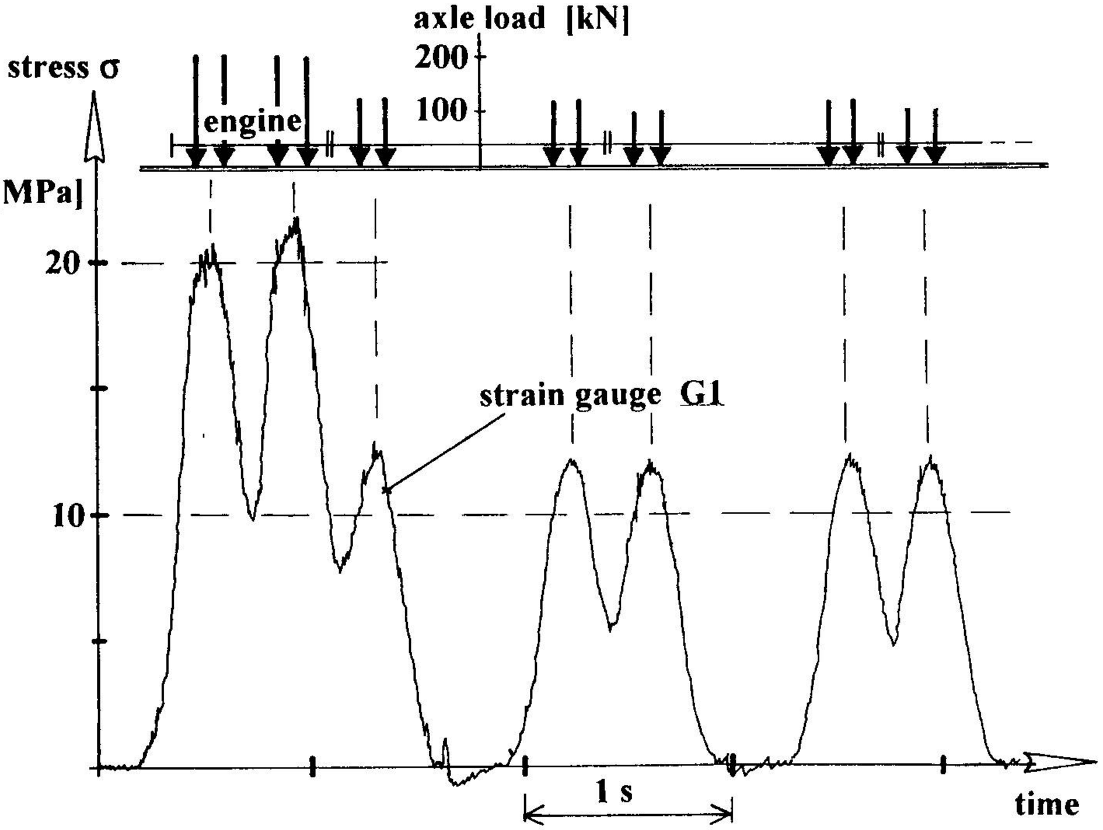

Fig. 4 Measured stress-time history in the bottom flange of the cross girder due to the passage of a passenger train. (The stress values have been deduced from the strain readings using a modulus of elasticity of 210 GPa.)

Figure 4 also indicates that the measured dynamic coefficient is small, i.e. Φ_{meas} = 1.05. This is explained by the good condition of the rails and the ballast bed acting like a damper. Finally, the partial fixity of the cross girder between the two main girders is confirmed by the measurements; the distance between zero-moment locations is 85 % of the span of the cross girder.

5. ASSESSMENT OF FATIGUE SAFETY

The measured maximum stress range $\Delta\sigma(\Phi \cdot Q_{eff})$ under actual traffic loads (including dynamic effects) is 25 MPa. Thus, all stress ranges due to past traffic have been significantly smaller than the constant amplitude fatigue limit of 52 MPa for riveted connections. No damage has occured due to fatigue which explains why no fatigue crack could be detected up to date. In the future, there will be no increase in axle loads, and consequently, the fatigue safety for future traffic is verified according to Eq. 1. The fatigue stress range in the cross girders (and also in all other elements of the structure) is below the fatigue limit. From the point of view of fatigue, a theoretically infinite number of future passenger trains could cross the 100-year-old bridge.

In a riveted structure, there might exist crack-like defects due to the riveting process or flaws in the material. Such defects and fatigue cracks due to out-of-plane displacements are not captured by the preceding investigation. Based on the information obtained, monitoring and maintenance strategies have been developed in view of a long remaining service life of 30 or even 80 years.

6. CONCLUSIONS

The assessment has shown that no extraordinary measures need to be taken to keep the bridge in service for many years to come providing that the inspection and maintenance guidelines are followed. Compared to the costs for bridge strengthening or replacement, the expenditures for this thorough investigation are minor.

Accurate stress determination under actual traffic loading plays a key role in the assessment of fatigue safety of bridges. In-situ measurements under well-defined loads, allow to study the structural performance of fatigue determinant members. Compared to calculated stresses using common (and often conservative) statical systems, lower stress range values are usually determined. These values may be also needed to clarify obvious contradictions between results of first analyses and the actual in-situ condition of the structure.

ACKNOWLEDGEMENTS

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