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Fatigue analysis of a railway bridge based on fracture mechanics and local modelling of riveted connections

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ABSTRACT

In the context of fatigue evaluation of riveted railway bridges, cross-girder to main beam connections are frequently critical details. Secondary effects, such as out-of-plane bending and dynamic amplifications due to the proximity to loading paths which in the case of old bridges were not taken into account in the original design, may lead to severe increase of fatigue damage.

The fatigue assessment of old riveted railway bridges has been addressed in the last years by developing local models of critical riveted joints that are linked to global models. This local-global modelling approach aims at evaluating local secondary stresses. Former fatigue probabilistic analyses of riveted joints have been focused on resistance variability rather than on loading/stresses (actions) variability.

In this paper a probabilistic procedure to include the variability of loading in the fatigue analysis of complex riveted joints of railway bridges is proposed assuming loading as a random variable. Local finite element models were developed and later coupled with the global model in order to obtain the real stresses associated to real trains crossing the bridge. To reduce computational time, the results obtained from these local models were inputted in a Linear Fracture Mechanics model, supported by Paris fatigue crack propagation law. Monte Carlo simulation technique was applied to calculate the fatigue reliability of an old riveted railway bridge, considering traffic records from previous studies on the bridge.

1. Introduction

In the context of fatigue evaluation and for riveted railway bridges, cross-girder to main beam connections are, in general, the critical details [1, 2]. Secondary effects as is the case of out of plane bending and dynamic amplifications due to their proximity to the loading paths that were, in the case of old bridges, not taken into account in the design may lead to severe increase of the fatigue damage. Furthermore, the variability of the loading is not so often included in the analysis.

In the context of fatigue assessment of old riveted railway bridges, several authors have developed local models of critical riveted joints that were included in global models in order to evaluate local secondary stresses [3–6]. However, the complete stress history was not included in the analysis.

Refined fatigue assessment of old riveted bridges using complex finite element models is very difficult due to the large amount of stress cycles required to calculate fatigue damage, since it is a case of typical variable amplitude stress [7]. Former fatigue

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probabilistic analyses of riveted joints rarely accounts for the stress range variability.

Historically, the economic development has been always associated with the construction of railway lines, with subsequent increase of traffic, vehicle axle loads and speed. Therefore, old railway metallic bridges, in many cases with more than one hundred years, have been pushed over the years to carry out heavier vehicles and endure higher velocities than allowed by the original design. In addition, the cumulated degradation due to corrosion and fatigue, contributes to an increased concern about their safety.

This paper proposes a procedure to include the variability of loading into a probabilistic methodology aiming the fatigue analysis. The loading is assumed as a random variable. Since the shape function of Paris law depends on the loading, this aspect must be taken into account in the proposed procedure. Furthermore, local finite element models using volume elements and contact elements are developed and later coupled with the global model in order to obtain the real stresses associated with trains crossing the bridge. To reduce computational time, the results obtained from these local models are used in a Linear Fracture Mechanics model. In particular, several shape functions are obtained from these numerical studies and later included in the Paris law [8]. Monte Carlo simulation technique is used to calculate the fatigue reliability for an old riveted railway bridge. Results obtained from previous studies on the traffic evaluation of this bridge are included in the model [9]. The stress data obtained from a long term monitoring campaign is used to calculate the load function which allows the random generation of each train crossing on the bridge. The statistical characteristics of the random variables related to the material are obtained from an experimental study developed in other research work [9].

Advanced local Finite Element Models (FEM) models are developed in *APDL (ANSYS Parametric Design Language)* programming language available in *Ansys* software in order to allow the parameterization of the characteristics of the critical riveted connections. The contact between rivets and steel plates are included in these models using numerical algorithms that allow the simulation of friction contact between several structural elements. Since it is extremely complex to simulate in this local model all the stress histories related to each real train, the numerical model is used to calculate two shape functions corresponding to two characteristic trains with the highest and lowest axle loads. The real shape function (corresponding to all the real trains) has to be related to, or has to be a combination of the previous referred shape functions. Therefore, a genetic algorithm is implemented in order to find the shape function which minimizes the fatigue life.

2. Description of the bridge – case study

The study presented in this paper is supported by a case study which is the Portuguese riveted railway Trezói bridge. The Trezói Bridge (see Fig. 1) is located in the international "Beira Alta" railway line that links Portugal to Spain, at the km 62, north of Mortágua, in the village of Trezói. The bridge was constructed as part of a project to replace existing bridges in the "Beira Alta" railway line, carried out during the decade of 1950's, and was opened to traffic in August 1956. The project was funded by the Marshall Plan, and the conception, manufacture and mounting, together with 6 other bridges of larger span of the same line, was of the responsibility of the German House Fried Krupp.

This steel riveted bridge has three spans; their lengths are 48 m for the central span and 39 m for the other two spans. The total length of the bridge is 126 m. Two inverted Warren truss girders that forms the metallic deck of the bridge are 5.68 m height. The girder panels are 6.50 m wide in the central span and 6.00 m in the end spans. Two trapezoidal shape trusses acting as columns and two granite masonry abutments transmit the loads supported by the structure to the foundations. The bridge has a constant width of 4.40 m throughout its length. Fig. 2 illustrates the general geometry of the bridge.

The cross girders, as well as the stringers resting on them, were built using "I-shaped" sections. The cross girders are 71 cm height and are connected to the lateral vertical elements with riveted plates as shown in Fig. 2. The chords and diagonals of the truss girders are formed by double "U-shape" sections.

The bearing supports of the superstructure are metallic and allow free rotations in the structure plane. At the east support, the longitudinal displacements are constrained, while at the west support deformations caused by longitudinal horizontal forces (thermal actions, braking forces, etc.) are allowed.

The stringers are symmetrically placed with respect to the rails which is a fortunate conception option since non-symmetrical rails normally induce higher secondary stresses in the web of the stringers.

Fig. 1. The Trezói bridge.

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