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Determining the SCFs of tubular bridge joints with an alternative method

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ABSTRACT

Circular hollow sections are being used in various modern bridges. Although these bridges are highly appreciated because of their aesthetic value, they are considered to be costly, mainly due to the use of cast or welded joints. The fatigue strength of these structures is important since stress concentrations are reached near the weld toe of the joints. These are due to geometric discontinuity and to the welding process, thus making this type of bridge prone to fatigue damage caused by varying traffic loads.

There are various methods to determine the stress concentration factors (SCFs) of a welded tubular joint. The existing methods are not suitable for complex tubular joints or require vast computing time. An alternative method for determining the SCFs of complex tubular bridge joints is being proposed. This method is applicable to any tubular joint and accurately determines all SCFs of the joint. These SCFs allow fast computation of the hot spot stresses of the tubular joint loaded with any realistic load condition.

1. Introduction

Circular hollow sections are used in various types of modern bridges [1–4]. The use of tubes offers structural advantages since the bending stiffness, strength and buckling resistance are equal in all directions. High torsion stiffness and high strength-to-weight ratio are additional advantages of circular hollow sections. Although tubular bridges are highly appreciated because of their aesthetic value, they are considered to be costly, mainly due to the use of welded joints. The fatigue strength of these structures is important because high stress concentrations, so-called hot spot stresses, are reached near the weld toes of the joints [1]. Consequently these welded joints are the weakest parts and determine the global strength of the structure. The hot spot stresses must be kept sufficiently low to increase the fatigue resistance of the welded joints.

When designing tubular bridge joints, it is important to determine the fatigue life. Consequently the stress variations in the weld must be determined. The use of the hot spot stress method is recommended to determine these stresses and the corresponding fatigue life [5–7]. The hot spot stresses can be determined by making use of stress concentration factors (SCFs). Previous research describes how these SCFs can be determined. Romeijn's method [8–10] is applicable to various joints, but requires a lot of computing time. Schumacher's method [4] is applicable only on K-joints. Modern tubular bridges make use of more complex, multi-planar joints which need an adapted method to determine the stress concentration factors. Hence an alternative method, requiring less computing time, adapted to all types of tubular joints has been developed.

2. Finite element models

Numerical simulation is carried out using detailed three-dimensional FE models. Various tubular bridge joints have been modelled. The inner and outer surfaces of the chord need different meshes. The outer surface needs a mesh that coincides with the mesh of the braces. If the joint is reinforced with diaphragms, then the inner surface nodes must coincide with the mesh of the diaphragms. So the use of 20-node volume elements, as recommended by CIDECT [6] and Romeijn [8], is not feasible. Because of this, the joints are modelled with 10-node volume elements, tetrahedrae. An automatic tetrahedral mesh generator based on the Voronoi–Delauney method is used (Tetmesh-GHS3D) [11]. First the skin of the whole joint with weld must be modelled with triangular elements. The density of this surface mesh can be easily adjusted with the use of some parameters. In the vicinity of the weld toe, very small triangular elements are used. Once the complete boundary is meshed, the algorithm fills [11] the empty space with tetrahedrae. The triangular surface mesh is deleted automatically and the output is a tetrahedral mesh, which is further used in the FE code. The more elements are generated, the more detailed the model will be. However, more elements also means a longer calculation time. The convergence of the FE model has been researched. The number of elements close to the weld has been increased until no further significant change in stresses has been examined. The bridge joints generated during present research contain more than 250,000 elements.

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3. Hot spot stress method

The fatigue resistance of welded joints depends on a variety of parameters such as the ratio of the thickness of the tubes, the ratio of tube diameter to thickness, the gap between the secondary tubes on the main tube and the type of welding. Therefore the assessment of the fatigue strength of welded joints should be based on the structural hot spot stress method as mentioned in Annex B of EN 1993-1-9 [12]. The latter specifies the detail categories caused by the welding itself, without further influence of stress concentrations caused by geometric discontinuities. The hot spot stress method is widely used in the offshore industry [5]. For bridge structures it is more appropriate to use the guidelines from CIDECT [6] and IIW [7]. This method relates the fatigue life of a joint to the hot spot stress range at this location, rather than the nominal stress range. The procedure of the hot spot stress method has been researched by Romeijn [8,10]. First $L_{r,min}$ and $L_{r,max}$, which define the boundaries of the extrapolation area (Fig. 1), must be determined. The values recommended by Romeijn [8,10] are:

$$\text{Chord locations}: L_{r,\min} = 0.4 \cdot T \text{ and } L_{r,\max} = 1.4 \cdot T \tag{1}$$

$$\text{Brace locations}: L_{r,\min} = 0.4 \cdot t \text{ and } L_{r,\max} = 1.4 \cdot t \tag{2}$$

where T, t is the wall thickness of the chord, brace. A second order polynomial is then fitted through the computed or measured primary stresses in the extrapolation area. The primary stresses are the computed or measured stresses in a direction perpendicular to the weld toe for the chord member locations and parallel to the brace axis for the brace member locations. The intersection of the parabolic curve with the borders of the extrapolation area renders two stress values. These two stresses are then extrapolated linearly to the weld toe. This determined stress range at the weld toe is the hot spot stress range. The whole process is shown in Fig. 1. Schumacher [4] also used this method proposed by Romeijn [8,10], which was adopted in this research.

4. Determining the SCFs of a tubular joint

Dividing the hot spot stress ($\Delta\sigma_{hs}$) by the nominal stress ($\Delta\sigma_{nom}$) due to a basic member load which causes this hot spot stress, renders the stress concentration factor (SCF). These SCFs can be used for determining the hot spot stress of a joint with a realistic load scheme. Each joint has a set of SCFs. A SCF is characterized by its location on the joint and the basic member force which causes the hot spot stress. Multiplying all the SCFs of one location on the joint by the corresponding nominal stresses of the basic member forces results in the hot spot stress of that location for the relevant load combination. Consequently the SCFs of a joint can be used to determine all hot spot stresses of that joint caused by any load combination. The use of SCFs is described by [4,6–8]. CIDECT [6] and IIW [7] also give various equations and graphs which can be used to determine SCFs of various joints. To determine the SCFs of a joint, it must be isolated and loaded with basic member forces. For each SCF one tubular member must be loaded with one basic member force. This must be repeated for all tubular members and basic member forces in order to determine the whole set of SCFs of the joint. Various methods exist for determining all SCFs of a particular joint [4,8–10]. During present research an alternative method will be proposed.

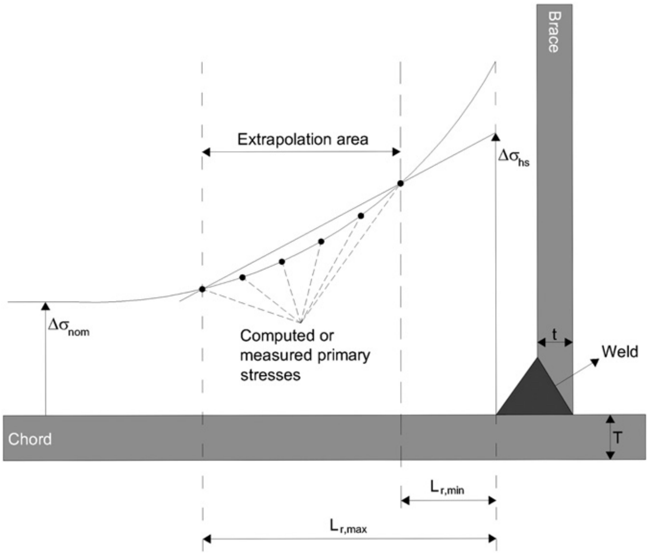

Fig. 1. Extrapolation of stresses to the weld toe.

4.1. Boundary conditions

First the boundary conditions of the isolated joint must be defined. These boundary conditions are very important while determining the SCFs, because the values must be independent of the boundary conditions. The hot spot stress must be derived directly from the basic member stress, without disturbance from other members. This requirement is easily fulfilled for chord forces. If one end of the chord is clamped and a basic member load is located at the free end of the chord, then the nominal stress is constant for the whole chord length. The forces in the braces are equal to zero; thus the determined SCFs are caused only by that single load. Should a basic load be applied on a free brace end then this load causes normal forces and bending moments in the chord. Hence hot spot stress values are not caused by brace loading alone, but also by chord loading, which disturbs the effect of the single brace member load. Schumacher [4] solved this problem by clamping one end of the chord and using the SCFs at the side of the free chord end. The normal forces and bending moments in this free end equal zero when the brace is loaded and the hot spot stresses are caused by the applied load only. The hot spot stresses on the other brace are not considered because it is loaded in compression. Romeijn [8] recommends applying compensating moments on the chord ends. This method requires large computing time, because the compensating moments are different for each location where the hot spot stress will be determined.

Inspired by these two methods of making the SCFs independent of the boundary conditions, an alternative method is being proposed. First the SCFs of all locations around the weld due to chord loading are determined by clamping one end of the chord and applying the loads at the free end. To determine the SCFs due to brace loading, both chord ends are clamped and then a basic member load is applied to a brace. The hot spot stresses around the weld due to this load are derived. Then a wireframe model of the considered joint with identical load and boundary conditions is constituted. The chord forces at the joint centre are determined. Using the latter allows deriving the chord nominal stresses. These stresses multiplied by the corresponding SCFs render hot spot stresses. The difference of the two types of computed hot spot stresses equals the hot spot stress caused by the single brace load. The model is independent of the boundary conditions because the hot spot stresses due to chord loading are subtracted from the total hot spot stresses. The remaining hot spot stresses are due to the applied brace loading. This method will be explained further (see Section 4.4).

4.2. Load cases

The next step is to determine the basic member forces which will be considered to determine the SCFs. There are 6 possible basic member forces for each tubular member: N_x, V_y, V_z, M_x, M_y and M_z. Romeijn [8]