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Fatigue life assessment of large scale T-jointed steel truss bridge components

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ABSTRACT

Among current approaches for fatigue strength assessment, the effective notch stress method is widely employed by practising engineers designing welded joints. This is particularly important in the situation where the nominal stress and structural stress cannot be easily quantified. In this paper, the applicability of the so called effective notch stress approach on large-size T-joints in truss bridges is investigated through a comprehensive experimental programme supported by numerical analysis. A series of large-scale fatigue tests on prototype large-size T-joints with cope holes were conducted. These types of joints are normally used in fully welded truss bridges. Furthermore, a simple parametric study was conducted using finite element analysis to investigate the effect of plate thickness and cope-hole radius on effective notch stress. Comparison of the results with commonly used design guidance documents reveals that the effective notch stress approach provides a conservative estimate of the fatigue strength of the specimens tested in this experimental programme.

Notation list

The following symbols are used in this paper:

h	height of butt weld
K_f	fatigue notch factor
N	number of cycles
R	cope hold radius (also denoted as R_{ch})
r_{ef}	fictitious notch radius
t	plate thickness
t_f	flange thickness
t_w	web thickness
w	width of butt weld
$\Delta\sigma_k$	notch stress range
$\Delta\sigma_n$	nominal stress range
$\Delta\sigma_s$	structural stress range
ε_{hs}	hot spot strain
$\varepsilon_{0.4t}$	strain at 0.4t distance from weld toe
$\varepsilon_{1.0t}$	strain at 1.0t distance from weld toe
σ_n	nominal stress
σ_k	effective notch stress

1. Introduction

Steel bridges are a very common type of bridge structural system [1]. Estimation of the fatigue lives of these structures is an important task for bridge managers and owners [2]. The fatigue failure of the gusset plate connecting the web member to the chord member is a commonly observed fatigue failure mechanism in truss bridges [3–6].

More modern rapid construction techniques tend to employ fully welded truss bridge systems rather than more traditional methods, which often utilised combinations of both bolting and welding [2,7]. In fully welded connections either the gusset nodes or splices of the chord and bracing members are all welded together, mainly using transverse butt welds [8,9]. In butt weld connections, once fatigue cracks develop, further propagation will affect both the connection and the connected components.

Furthermore, the so called *nominal stress* approach (the global effect, see [10–12]) is a commonly employed method used in industry that provides a simple assessment procedure for practising engineers to assess the performance of welded joints [10–12]. However, this method excludes *stress-concentration effects* (local effect) which is counter to the current state of practice which calls for detailed analysis to develop better optimised construction methods [13,14]. On the other hand, the *structural stress* approach (the local effect), takes account of the influence of overall geometry and, according to recommendations from the International Institute of Welding (IIW) [12], *structural stress* can be derived by extrapolation of local strains measured at a specific distance

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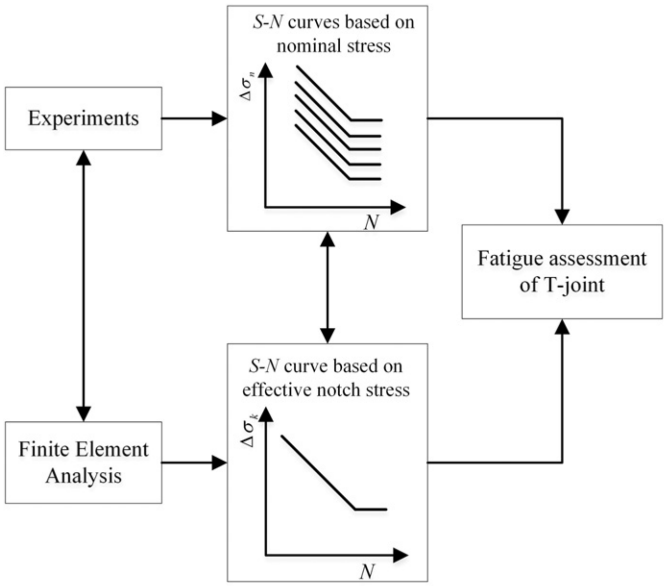

Fig. 1. Proposed fatigue life assessment procedure for T-jointed components accounting for effective notch stress.

from the weld toe. Dong et al. [15,16] used numerical analysis to develop a method that is used to propose a single master S-N curve for a variety of types of welded joints. This method modifies the *structural stress* distribution over the plate thickness.

1.1. Literature review

Xiao and Yamada [17] developed a method to compute the stress at 1 mm below the surface along the predicted crack path that accounts for the size and thickness effect. Various microstructural *notch hypotheses* [18–20] have been developed by considering the strength reduction that occurs due to notches. These methods give the average stress over a small length of material rather than the maximum elastic notch stress which governs the fatigue. According to Radaj et al. [21] a version of these models that incorporates a 1 mm radius notch (fictitious) into the weld toes or weld roots is the worst case condition when considering fatigue effects. This approach (*effective notch stress approach*) has been widely used in the design of welded joints e.g., [22]. These applications are mostly based on the design S-N curve (fatigue class 225, IIW recommendations, [12]) which were originally derived by numerical analyses, calibrated using the results of experimental testing which quantified effective notch stresses. In the aforementioned IIW method, a large amount of experimental data is required for model calibration purposes. However, there is a paucity of experimental data in the literature for large scale welded joints [23].

The fatigue of a welded joint is an extremely complex process and is highly influenced by local parameters, such as the weld profile, loading regime and weld defects. Weld defects (especially on-site manual welding) are difficult to predict and to some extent cannot easily be prevented [24]. Among all these influential factors, weld defects, especially in the case of field manual welding, is one of the most unpredictable and to some extent unavoidable [25]. The fatigue strength of welded joints often decreases when weld defects occur at a so called 'hot spot' (which is the location of maximum notch stress). It is advantageous to incorporate weld defects into the fatigue assessment procedures used in design.

Fricke and Paetzoldt [26] investigated the fatigue strength of the cope-hole details with varied geometry by the actual *notch strain* approach in the context of ship design. However, all the test specimens tested in [26] are of small scale. For steel bridges, Miki and Tateishi [27], developed regression formulae of stress concentration factors for specific welded joint details similar to [26], considering the *nominal* and *structural stress* approaches. In another study, Xiao and Yamada [28] conducted fatigue tests on intersecting attachments with cope-holes and concluded that the cope-holes have a limited impact on fatigue strength. However, they lead to transfer of the crack location from the transverse stiffener's edge to that of the cope-hole [28]. Aygül et al. [29] compiled a database of fatigue tests on specimens with cope holes and used finite element analyses to investigate the validity of the *effective notch stress approach*. They concluded that all the results plot above the generally used design S-N curve (category 225, according to IIW).

The previously cited studies focussed on tests on small-scale specimens. The size effect plays an important role in the fatigue life of steel structures. It should also be noted that the commonly used codes of practice for fatigue design and assessment are largely based on these smaller scale experimental tests [cf. Fricke [23] page 15]. As reviewed by Miki et al. [30] the Honshu-Shikoku bridges project in Japan led to many experimental studies on the fatigue performance of welded joints with high tensile strength steel members, with testing done on both full and large scale specimens (e.g., [31–34]). There is still a paucity of fatigue experimental data of large-scale butt welded joints with cope-holes reported in the literature. Therefore, there is a clear need for large scale benchmark experimental investigations studying this phenomenon.

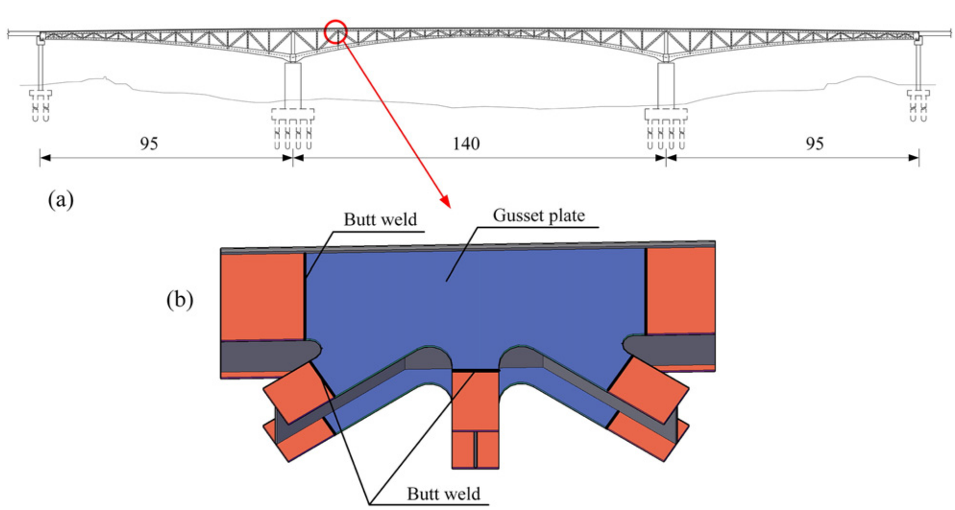

Fig. 2. (a) The general view of a fully welded truss bridge (span lengths shown in meters) and (b) location of butt welds and gusset plate.