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Fatigue behaviour of a welded I-section under a concentrated compression (wheel) load

Jaap Wardenier [a,b,*], Peter de Vries [a], Gerrit Timmerman [c]

[a] Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600GA Delft, The Netherlands
[b] Centre for Offshore Research & Engineering and Department of Civil & Environmental Engineering, National University of Singapore, #E1A-07-03, 1 Engineering Drive 2, Kent Ridge 117576, Singapore
[c] PT Structural Design & Analysis B.V., Boelewerf 22, 2987 VD Ridderkerk, The Netherlands

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ABSTRACT

This paper deals with the evaluation of fatigue cracks under a concentrated compression (wheel) load in an I-section with full penetration welds between the web and flange. The objective is to investigate whether cracks stop or nearly stop when they have grown through the residual tensile stress field.

These experimental investigations are part of a review of a crane runway girder where after 20 years of service fatigue cracks were observed in the flange at the toe of the full penetration weld. The fatigue analysis of the actual crane runway girder is described in (Wardenier et al., 2017).

The fatigue tests under a concentrated wheel compression loading show that, for the specimens considered on a scale of about 1:2 with stiffeners at one side, the cracks only initiate and grow at the non-stiffened side to about 50 to 60% of the web thickness and then stop. Based only on the nominal stress range under the wheel, determined according to EN 1993-6 and neglecting the shear stress effect, an equivalent fatigue class of about 160 N/mm^2 was found for crack initiation in the web, whereas the minimum ratio in life between visually observed crack initiation and maximum crack length was about a factor 3.

Comparison of the codes for a wheel loading in compression shows large discrepancies in effective width and fatigue classes to be used.

1. Introduction

This paper deals with the evaluation of fatigue cracks under a concentrated compression (wheel) load in an I-section with full penetration welds between the web and flange. The objective is to investigate whether cracks stop or nearly stop when they have grown through the residual tensile stress field.

These experimental investigations are part of a review of a box type radial crane runway girder with full penetration welds between the web and flange where after 20 years of service fatigue cracks were observed in the flange at the toe of the full penetration weld. The observed cracks in the crane runway girder vary in length from a few mm to 330 mm with a summation of the lengths of all observed cracks being 750 mm, on a total length of 56,000 mm, thus being only 1.3%. The fatigue analysis of this actual crane runway girder is described in [1].

Although the external loading by the crane wheels is in compression, due to the residual tensile stresses in the outer layers of the welds the stress ranges at the critical locations at the weld toes are in tension, resulting in the observed fatigue cracks.

A test set-up with a rolling wheel with relatively high loading would result in a complicated test set-up with a low test frequency and consequently would be extremely expensive. That is why tests on a scale of about 1:2 have been carried out with a fixed wheel compression loading, dealt with in this paper, and with a line loading, described in [2].

Based on these results and those which became recently available from the German AIF/Fosta research program [3] by the University of Stuttgart conclusions are drawn regarding crack initiation, crack growth, end of crack growth and the classification.

To the authors knowledge no other scientific work with quantitative information on the fatigue behaviour of I sections with multi-layered welds subjected to external compression loading has been published.

1.1. Stresses under a concentrated wheel load compared to those under a rolling wheel

As extensively discussed by Kuhlmann et al. [3] and Euler and Kuhlmann in [4] a rolling wheel on a crane runway girder produces as shown in Fig. 1, for a particular location a normal stress range $\Delta\sigma$ and an additional local shear stress range $\Delta\tau_{local} = 2\tau_{local,max}$. This results for every wheel passing in a shift of the direction of the principal stress.

* Corresponding author at: Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600GA Delft, The Netherlands.
E-mail addresses: j.wardenier@tudelft.nl (J. Wardenier), P.A.deVries@tudelft.nl (P. de Vries).

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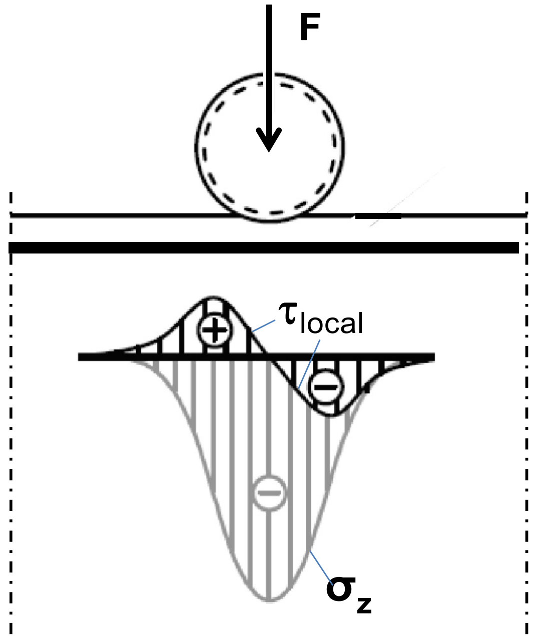

Fig. 1. Normal stress σ and local shear stress τ_{local} due to wheel load [3,4].

Therefore, Kuhlmann et al. [3] state that the summation of the individual damages for normal stresses and shear stresses as used in EN 1993-1-9 [5] and EN 1993-6 [6] is not appropriate for the non-proportional multi-axial loadings as occurring under a rolling wheel.

Under a concentrated wheel loading the local shear stresses τ_{local} at both sides of the concentrated load are proportional to the normal stress range σ_z but are not independent. For a constant wheel load the local shear stress range $\Delta\tau_{local}$ will be equal to $\tau_{local,max}$. Which is half of that under a rolling wheel. Since under a concentrated wheel loading the load is concentrated at one location and the crack(s), grow into a lower-stressed area, the crack growth in length direction will be slower than that under a rolling wheel, resulting in a better behaviour compared to that under a rolling wheel.

2. Test specimens

For the experimental investigations the actual crane runway girder in [1] with stiffeners at one side was simplified to an I-beam specimen. Due to the available plate thicknesses the average scale compared to the configuration in [1] is approximately 1:2. The specimens, shown with dimensions in Fig. 2, were made in such a way that both the top side and the bottom side of a specimen could be used.

The welds between the flanges and the web were intended to be made on scale and were made similar for the top and bottom flange with the web (also the same welding position). Thus, each specimen has 2 test locations A and B. To allow better NDT inspection of the welds, a removable rail was provided on the top flange and to the bottom flange of the specimen. Loading of a specimen at the top (at A in Fig. 2), gives in the weld at the bottom flange (at B) stresses below the cut off limit, which therefore do not affect the fatigue behaviour if the bottom part is tested thereafter. The only asymmetrical parts are the two stiffeners c.o.c. 470 mm that are located at one side only.

The welding procedure specification of the full penetration weld between the web and flange (SMAW process, electrodes, layers, preheating temperature) was carefully specified. Since in the actual crane runway girder prefabricated T sections are used, a horizontal down hand position was used for all welds. Welding distortions were limited during fabrication. Further, as in the actual crane runway girder, the flanges were machined flat from 40 mm to 35 mm. No afterwards heat treatments of the welds and surrounding areas have been used. All specimens were carefully MPA and ultrasonically checked by a qualified inspection company on defects but no positive signals of defects were identified. The procedure and acceptance criteria for the ultrasonic inspection were according to the ASME Boiler and Pressure Vessel Code (procedure N-UT-ASV-01 rev. A and acceptance criteria according to N-UT-AS VIII-A1 + rev.A).

However, after fabrication, it was observed that the foot print of the welds at the connection with the flange was larger than in the actual crane runway girder. This resulted, as discussed later on, in governing crack initiation at the weld toe with the web instead of crack initiation at the weld toe with the flange.

Since the crane vessel was built in the 80's, some steel types [1] were no longer available. However, the steel types for the test specimen were selected in close cooperation with the steel suppliers to obtain steel characteristics (yield and tensile stresses) close to the original types although the way of manufacturing could not be checked. The dimensions, steel grades and steel qualities of the test specimen of Fig. 2 are recorded in Table 1.

3. Test rig, testing procedure and measurements

3.1. Test rig

The test rig, shown in Fig. 3, consists of 2 welded box section columns provided with holes and supporting blocks to allow heavy welded transverse beam sections to be fixed at the required levels. The test

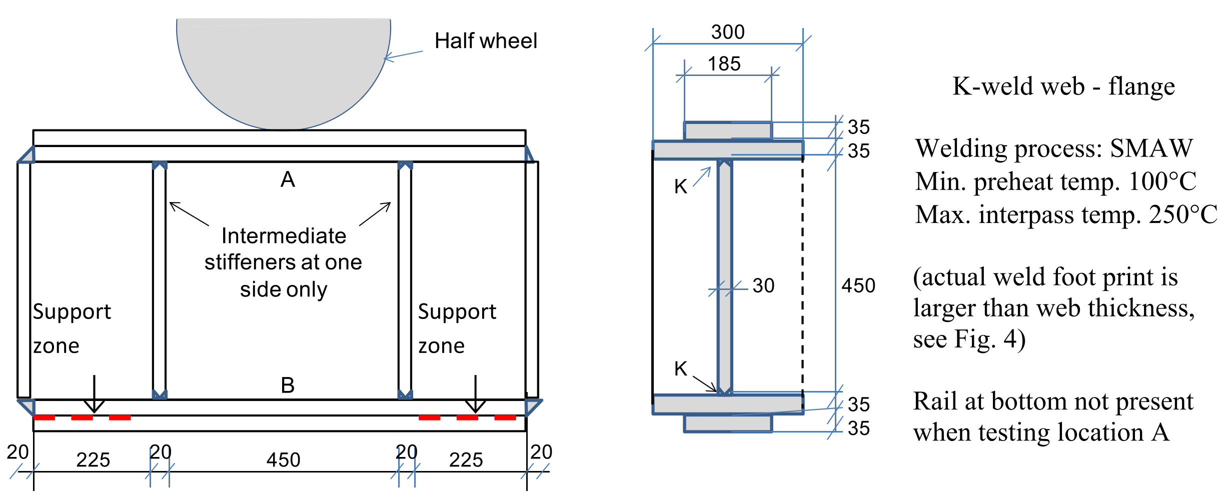

Fig. 2. I-beam test specimen for a concentrated wheel loading; average scale thicknesses 1:2.