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Autor: Ogle, R.B. / Kulak, G.L.

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Fatigue Tests on Rectangular Hollow Sections: Truss Joints

Essais de fatigue sur des sections creuses rectangulaires: assemblages dans les treillis

Ermüdungsversuche an Rechteckrohren: Fachwerkknoten

R.B. OGLE
MHBH Consulting Engineers, Ltd.
Edmonton, AB, Canada

G.L. KULAK
Professor
University of Alberta
Edmonton, AB, Canada

SUMMARY
Fatigue tests were carried out on nine full-size trusses made from rectangular hollow sections. Two K-joint configurations were examined, gap and overlap. Three trusses were of cold-formed steel and six were of hot-formed steel. Both the tests and finite element analyses showed that testing joints in isolation may give fatigue strengths which are greater than testing the same joints in trusses. For these K-type joints, overlap joints performed better than gap joints. The use of hot-formed steel did not affect the results.

RESUME
Des essais de fatigue ont été effectués sur neuf treillis en vraie grandeur composés de barres à sections creuses et rectangulaires. Deux assemblages de type K ont été examinés. Trois treillis étaient en acier écroui à froid et six étaient en acier formé à chaud. Les essais aussi bien que les analyses par éléments finis ont montré que l'essai des assemblages peut donner des résistances à la fatigue supérieures à celles des mêmes assemblages essayés dans les treillis. Les assemblages dont les barres se recouvrent, se comportent mieux que ceux ayant un espace entre les barres. L'utilisation d'aciers différents n'a pas influencé les résultats.

ZUSAMMENFASSUNG
An neun Fachwerkträgern aus Rohren mit rechteckigem Hohlquerschnitt wurden Ermüdungsversuche durchgeführt. Zwei Typen von K-Verbindungen wurden geprüft. Drei Träger bestanden aus kaltverformten und sechs aus warmgewalzten Profilen. Die Versuche wie auch eine Finite-Element-Berechnung zeigten, dass isolierte Knotenverbindungen grössere Ermüdungsfestigkeiten ergeben können als Versuche an gleichen Knoten in einem Fachwerk. Knoten mit sich übergreifenden Streben verhielten sich besser als solche mit einem Zwischenraum zwischen den Streben. Die Stahlsorten haben die Versuchsresultate nicht beeinflusst.

1. INTRODUCTION

Because of their excellent structural properties, hollow structural sections (HSS) of either hot-formed or cold-formed structural steel are finding increased use in civil engineering structures. These sections can be either circular (CHS) or rectangular, including square, (RHS). Although combinations of these types can be found in trusses, only those cases with rectangular sections as both chord and web members will be discussed herein. The objective of the study was to investigate the fatigue behavior of trusses made from RHS, especially those involving K-type joints. The detail examined included both overlap and gap joints.

A review of some current North American [1,2], British [3], and European [4] specifications indicates that none specifically include design rules for the fatigue strength of HSS joints. The ECCS draft document on fatigue [5] likewise does not yet include this detail. Design procedures are set forth for circular-to-circular tube connections as found in offshore structures [6]. This involves prediction of hot-spot stresses by a finite element analysis, calculation of the stress concentration factor (SCF), and then comparison with the fatigue life of the appropriate weld type.

Previous investigations of the fatigue strength of hollow structural sections have been conducted in Europe [7], Great Britain [8], and Japan [9]. Mainly because of the expense involved, most of these investigations have been carried out on isolated joints. In addition, the "chord" portion of the joint was in compression in many of the tests, apparently as a convenience in arranging the test set-up. The tests reported in this study were all carried out on joints contained within full-size trusses so that the effect of secondary bending moments might be examined. As well as obtaining the test results, a finite element analysis was used to predict hot-spot stresses.

2. FACTORS AFFECTING FATIGUE STRENGTH

Stress range, number of load applications, and the type of detail are usually sufficient to predict the fatigue strength of welded steel structures [10]. The flaw size, weld profile, and geometrical properties of the critical region are not explicitly considered since they are contained within the type of detail being tested. HSS joints contain even more geometrical factors than usual for welded details. These include the ratios of web member width to chord width, web member wall thickness to chord member wall thickness, chord wall thickness to width, and the amount of gap or overlap at the intersection of the web members and chord. Because of the large number of geometrical variables possible, only gap and overlap joints were examined in this study. Fig. 1 defines gap and overlap.

3. EXPERIMENTAL PROGRAM

Nine full-size trusses were tested. The general configuration and geometry are shown in Fig. 2. The critical joint was expected to be L1 where the K-joint was either gap or overlap. In all cases, the lower chord was an HSS 152.4 x 101.6 x 6.35 and the web diagonals framing into Joint L1 were each HSS 88.9 x 88.9 x 4.78. Test Series 1 (TS1) comprised three identical trusses made from hot-formed steel (nominal yield 350 MPa). The K-joint L1 was overlapped 40%, with resulting zero joint eccentricity. Test Series 2 (TS2) was identical to TS1 except that cold-formed steel was used. Test Series 3 (TS3) had similar overall geometry to the first two series, used hot-formed sections, but had gapped joints. The amount of the gap was 30 mm, and the resulting eccentricity was 43 mm. In the case of the gap joints, fillet welds were used to attach the web members to the chord face. In the overlap joints, fillet welds were used at the web-to-chord intersections and a full penetration groove weld, including backing bar, used where the web members met one another.

The stress range for the joint was defined as that present in the tension diagonal (L_1U_2). It was established under actual loading conditions using strain gages on the member. Strain gages were used to measure local stresses in the region of the joint. They were also placed on the member in such a way as to measure bending stresses throughout the truss.

Failure in a joint was considered to have occurred when approximately one-quarter of the cross-section L1-U2 had cracked through.

4. TEST RESULTS

4.1 Secondary Stresses

Practically all previous fatigue testing of HSS joints has been conducted on isolated specimens acting under axial forces only. This corresponds to the member forces that would be obtained from an analysis of the structure assuming pinned connections. Obviously, such an analysis disregards the presence of bending moments and shears which exist in the real structure as a result of joint fixity. Part of the purpose of this study was to see whether these effects have an important influence on fatigue life. In addition, analytical methods which attempt to predict these secondary effects were examined.

A direct stiffness program was used to analyze the trusses. The accuracy of the method in predicting the measured bending stresses in a typical member which frames into joint L1 can be seen in Fig. 3. This is considered typical. The measured maximum bending stress was 19%, 48% (chords), 21%, and 33% (web members) of the nominal axial stress for the four members which frame into joint L1 of TS3 (gap joint). It is likely, therefore, that secondary stresses were important in the fatigue life of these trusses. Secondary stresses were not measured in series TS1 and TS2 but they would not have been as significant since joint L1 had zero eccentricity in those trusses.

4.2 Crack Initiation and Growth

In all three test series, cracking was observed in the lower K-type joint L1, and in six of the nine trusses failure occurred at this joint. In the other cases, failure occurred at the upper K-joint, U2. The fatigue lives of all specimens are shown in Fig. 4.

In both Test Series 1 and 2 (overlap joints), cracking initiated in the vicinity of the groove weld. The cracks grew downward into the fillet welds, and at a later stage, separate cracks started at the fillet welds on the acute angle side of the web members. In Test Series 3 (gap joints), cracking started at the toe of the fillet weld where the front of the tension web member joined the top of the chord. Eventually, the cracks were always aligned transverse to the longitudinal axis of the tension member.

4.3 Measurement of Local Stresses

The test program allowed measured stresses in the joint region to be compared with those calculated using a finite element analysis. The loading for the finite element analysis included the case of axial load only, and this allowed examination of past testing in which the "chord" of an isolated joint was in compression. The general load case used permitted input of either measured or theoretically calculated member axial forces, moments, and shears.

The theoretical analysis showed that chord precompression has a significant effect on the stresses in the gap region of gap joints. Changing the chord force from compression to tension increased the maximum principal tension stress in the gap by a factor of about 1.4. There are test results that support this conclusion [11]. The same increase was not present in overlap joints, however. In the overlap joints tested, force transfer was mainly through the sidewalls of the diagonals.

The effects of moment and shear in the truss members on the stresses in the joint region were different for gap and overlap joints. In the former, the principal tension stress increased by a factor of about 1.45 in the most highly stressed element. In the overlap joint, at least for this geometry, the finite element model showed that stresses in the crotch of the joint, where the fatigue cracks did initiate, did not increase appreciably when moments and shears were included. The experimental strains obtained in these tests were not consistently useful for comparison with measured strains. However, very short gages placed very close to the fillet weld toes in the gap joints did show strains consistent with calculated values.

4.4 Fatigue Strength Results

The results of all three series in this program are shown in Fig. 4. Also shown are data provided by Mang [12] from tests on isolated K-type joints. Although the latter do not have the same dimensions as the specimens in this study, the important non-dimensional parameters are very similar. It can be seen that the isolated joint data generally plots above the data obtained from complete trusses, and this indicates that isolated joints may have a higher apparent fatigue strength. This could be due either to the effect of secondary bending in the truss specimens or, perhaps, to the fact that the isolated joints had precompressed chords.

Although there are not many data points, the test results reported in this study indicate that (1) fatigue life is not significantly influenced by differences between hot-forming or cold-forming of the members, and (2) gap-type K joints have a lower fatigue resistance than overlap-type K joints. Shown in Fig. 4 for purposes of comparison is the most restrictive fatigue resistance curve now prescribed in North America for welded details [2].

Another way of examining the results is to apply a stress concentration factor (SCF) to the nominal axial stress range. This SCF should account for the secondary stresses due to moment and shear, and, perhaps, the effect of the weld profile. For the gap joints tested in this study, this approach gave reasonable, but unconservative, agreement with the fatigue strength of welds alone. For the overlap joints, the use of a SCF showed good correlation (slightly conservative) when compared to the weld strength.

5. SUMMARY AND CONCLUSIONS

Tests were conducted on nine full-size trusses made of rectangular HSS steel members in order to assess the fatigue strength of the K-joints. Both overlap and gap joints were examined, and both cold-formed and hot-formed tubes were used. The effect of secondary stresses due to moments and shears in the truss members was evaluated both analytically and experimentally. The results are compared to tests on similar joints which were tested in isolation. Based on these tests, the following conclusions can be stated:

- there are no significant differences in fatigue strength with respect to the use of hot-formed or cold-formed sections.
- for K-type joints, overlap joints perform better in fatigue than do gap joints.
- testing HSS joints in isolation may give fatigue strengths which are greater than testing the same joints in trusses.
- the effects of the secondary moments and shears which are present in actual trusses result in significantly higher stresses than nominal for gap-type K-joints. There does not seem to be a significant increase for overlap joints when the joint eccentricity is zero, however.

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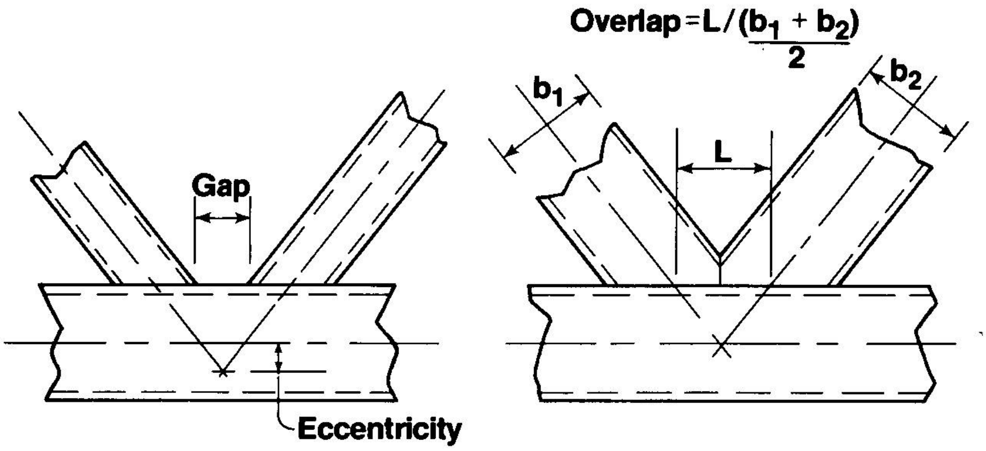

Fig. 1 Gap and Overlap Type Joints

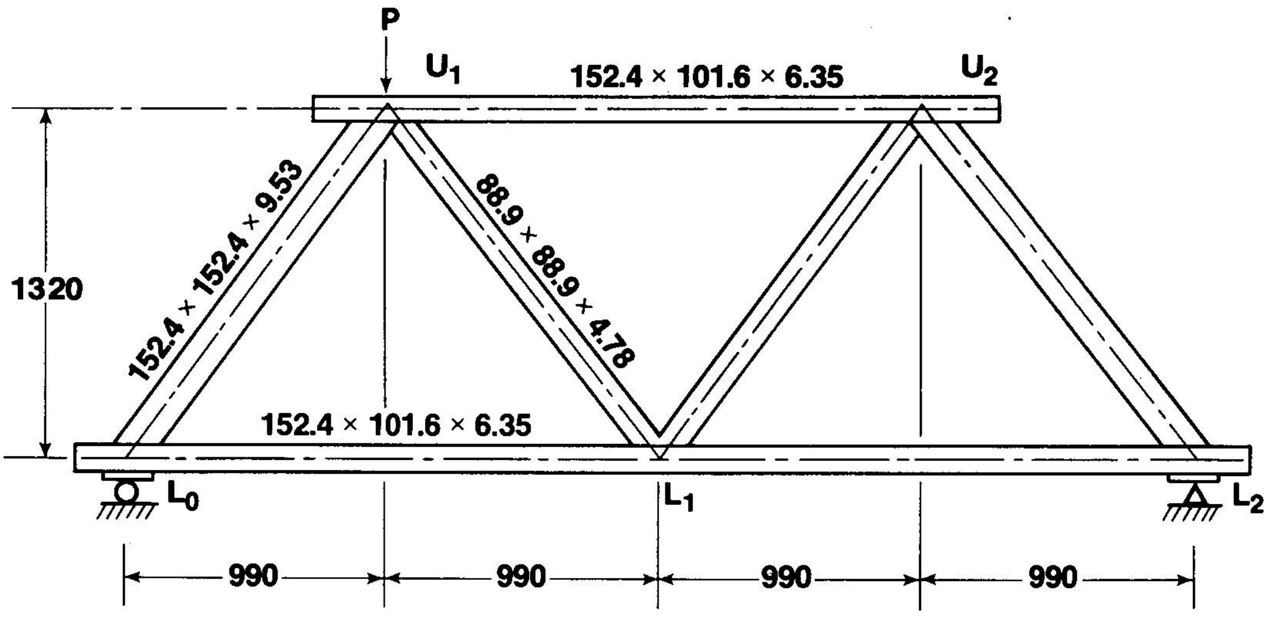

Fig. 2 Truss Configuration

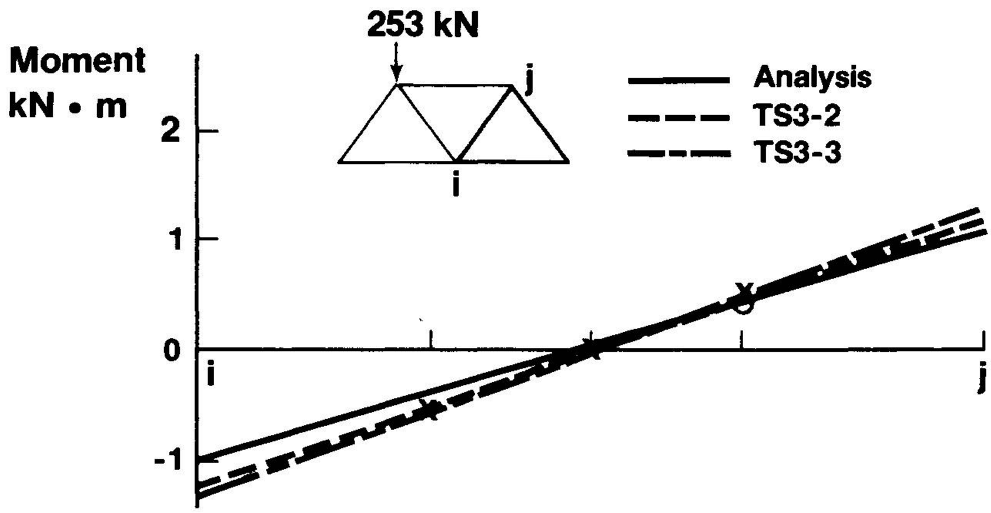

Fig. 3 Measured and Predicted Bending Stresses

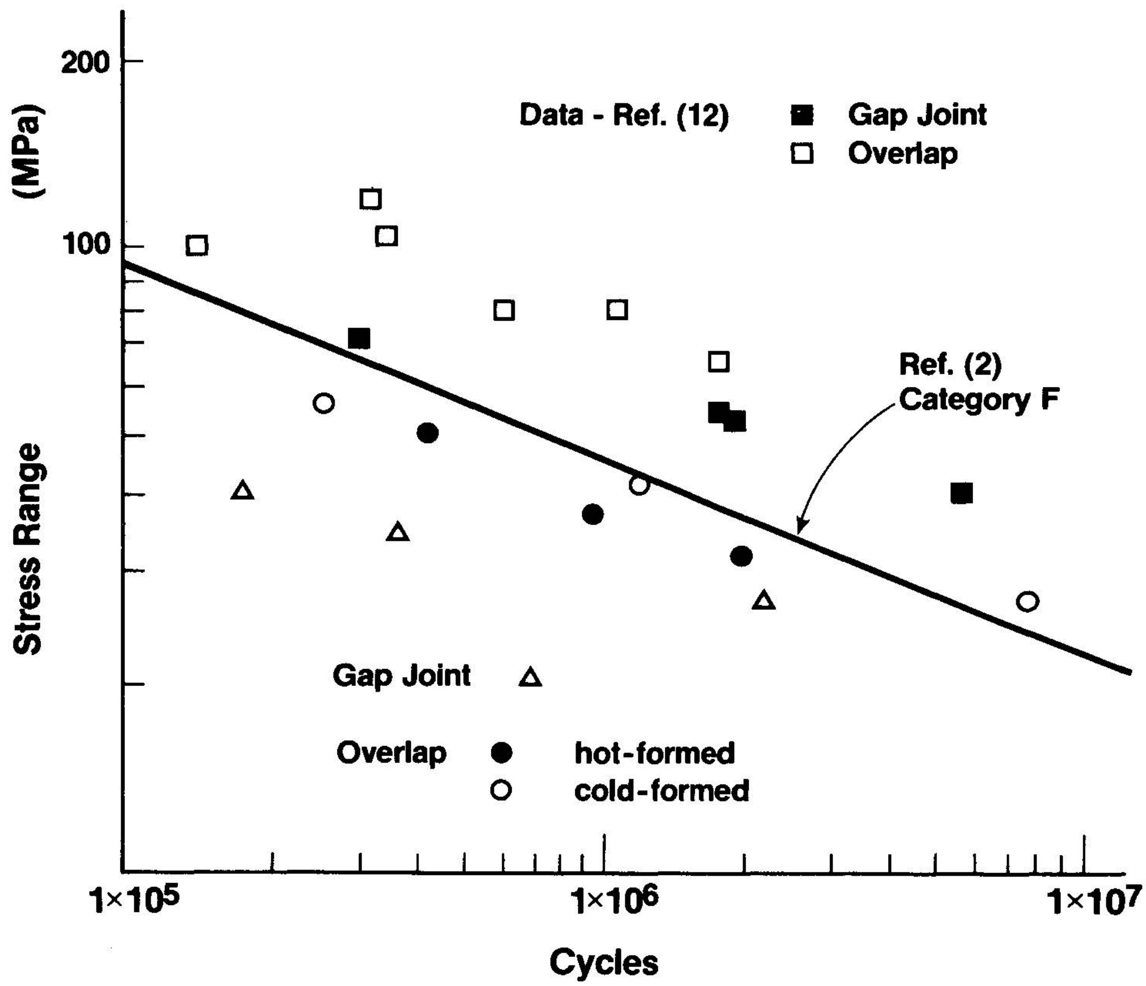

Fig. 4 Fatigue Strengths

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