Stress concentration factors for multiplanar joints in RHS

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Hollow sections are most suitable for welded connections between members. The welding procedure is fairly straightforward in RHS, because they do not require profiling which is necessary for circular hollow sections.
Although many multiplanar and uniplanar joints in structures are present, limited evidence is available for the fatigue behaviour of joints made of rectangular hollow sections. This is especially for the fatigue behaviour of multiplanar joints in square hollow sections which is the reason for setting up this research programme.
An extensive experimental and numerical investigation was carried out for the determination of Stress and Strain Concentration Factors in Square Hollow Sections.
This paper presents the numerical results for KK-multiplanar joints to demonstrate the influence of other braces.

Keywords: **Fatigue, Square Hollow Sections, Stress (Strain) Concentration Factors, Multiplanar joints, Influence Factors.**

1 Introduction

Since the production of the first rectangular hollow section by Stewards and Lloyds in 1952, rectangular hollow sections have developed to a point that they are a fully accepted type of structural steel section. Their popularity has increased world wide largely due to the increased knowledge and publicity about their structural behaviour and design. Rectangular hollow sections are used as columns or as members in truss structures, either simple frames or complex space frames for reasons of pleasing appearance, structural efficiency and economy.

Due to the lack of information on the fatigue behaviour of multiplanar joints in RHS, an ECSC (European Community of Steel and Coal) sponsored experimental research programme entitled "Fatigue behaviour of multiplanar welded hollow section joints and reinforcement measures for repair" (project No. 7210-SA/114) and an STW (The Netherlands Technical Foundation) sponsored numerical research programme entitled "Numerical Investigation on Stress Concentration Factors in Multiplanar Joints" (project No. DCT80-1457) has been carried out. Further, work has been carried out within the framework of CIDECT programme 5J.
These research programmes aim to provide evidence for the developement of fatigue design recommendations for structures consisting of multiplanar unstiffened welded joints between

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rectangular hollow sections. The design recommendations will be based upon the Hot Spot stress method which includes the effects of the overall joint geometry on the stress distribution. The geometrical Hot Spot stress / strain along a few established lines is determined by means of an extrapolation method that aims to exclude the local influence of the weld.

Results of the experimental investigation are discussed by Verheul et al (1992), Panjeh Shahi et al (1993a) and Panjeh Shahi (1994). Figure 1 gives a comparison between the experimental results and the results of the numerical investigation for calibration of the numerical FE models.

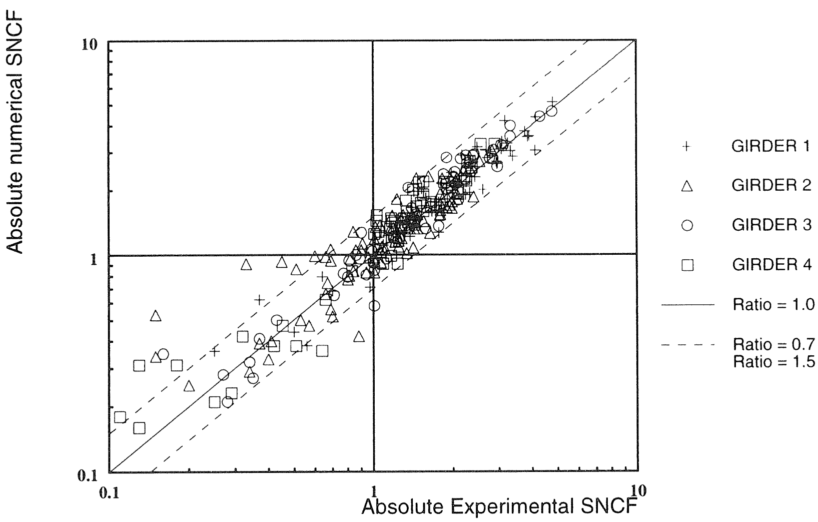


Fig. 1. SNCF for joints of four tested girders.

After calibration of the models, a parameter study for some uniplanar and multiplanar joint types is undertaken. Figure 2 shows the types of joints investigated numerically. In all the numerical models welds are modelled using 8 noded linear brick elements. Linear brick elements are also used for modelling the chord and the brace members. For detailed analysis of the results, see Panjeh Shahi (1994) and Panjeh Shahi et al (1993b).

In this paper the effects of the presence of braces or the loading on the stress concentration factors around the connection of a reference brace is demonstrated.
The Y-joint is taken as the basic connection, however the moments generated in the chord due to the axial loading of the brace are compensated by additional moments in the chord in such a way that the chord moments are zero at the brace-chord intersection (see Figure 3).
This is done for every axial load in a brace. Consequently the SCF's of a Y-joint only give the local effects at the connection due to the axial or bending moment in the brace. For the K- and KK-connections the sum of the compensation moments in the chord is zero.

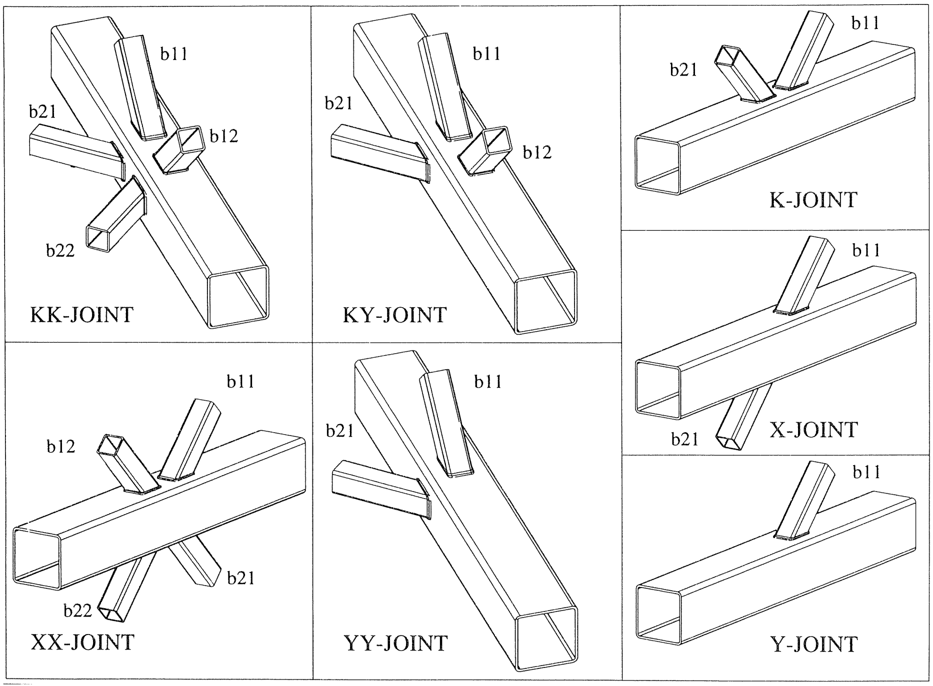


Fig. 2. Joins investigated during parameter study.

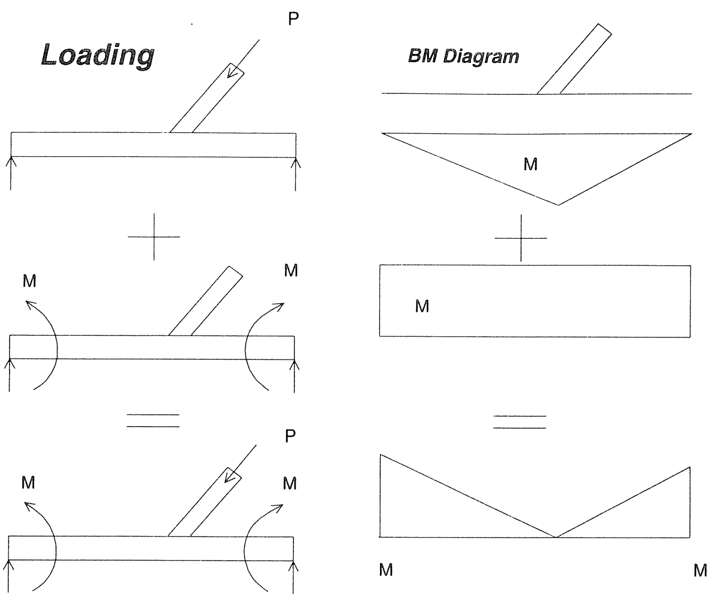


Fig. 3. Compensation for the chord bending.

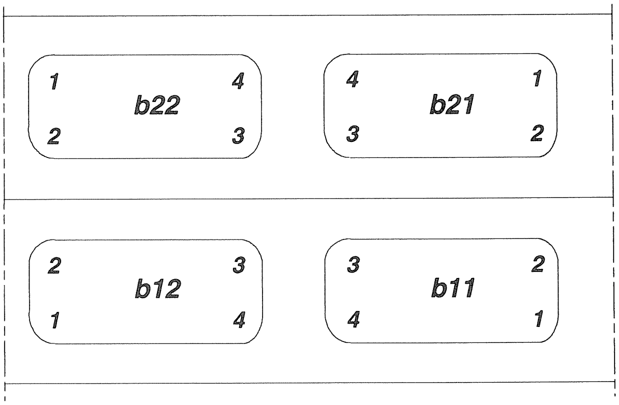


Fig. 4. Corner numbering system for KK-joints.

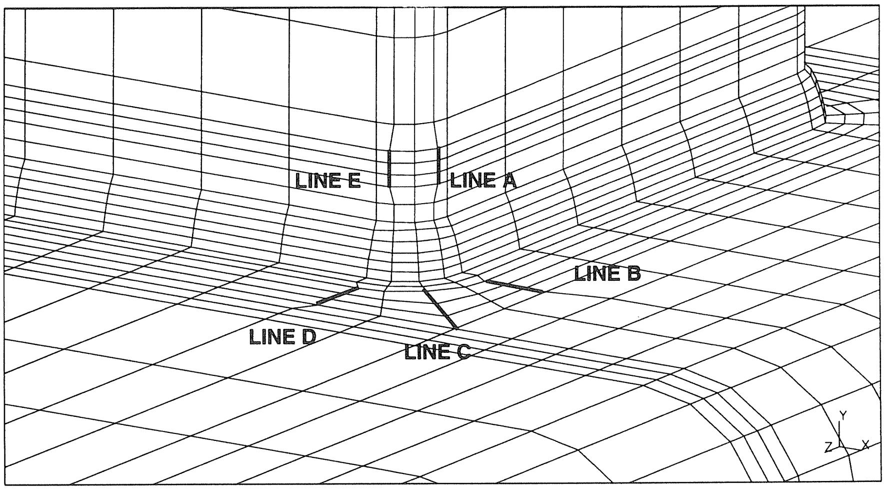


Fig. 5. FE mesh distribution for a T-joint.

In this way the stiffening effects of a brace and the loading effect can be easily presented. The effects are given for some important location and extrapolation lines around the connection of the reference brace to the chord (see Figure 4). The measurement lines A and E are on the brace and B, C and D are on the chord. See Figure 5 for a typical line location. Corners 1 and 2 are at the heel and corners 3 and 4 are at the toe. Corners 2 and 3 are located near the multiplanar braces. A quadratic curve is fitted through a minimum of four data points on the measurement lines. The stresses extrapolated to the weld toe are then normalised with respect to the nominal stress in the loaded brace for the SCF determination. For detailed information about the method of extrapolation see Panjeh Shahi (1994).

2 The effect of the presence of unloaded braces

The presence of braces in a connection can influence the stress distribution around the weld toe of the reference brace significantly, i.e. the stiffening effect.

To investigate the stiffening influence of an unloaded brace on the SCF's of a reference brace, comparisons are made between the SCF's in relation to β for three types of joints namely, Y-, K- and KK-joints.

Figures 6 and 7 show the influence of other braces on the SCF variations for the measurement lines A to E of corners 2 and 3 for the parameters $2\gamma = 25$, $\tau = 0.5$ and $\theta = 30°, 45°$ and $60°$ due to an axial load in the reference brace.

SCF's for the chord measurement lines B, C and D are shown in Figure 6 for corner 2 and corner 3 for the three joint types (Y-,K- and KK-).

Figure 7 presents the SCF plots for the brace measurement lines A and E.

Three line types are selected for the figures shown which are, a solid line for the Y-joint, a small dashed line for K-joints with braces in the uniplanar plane and large dashed lines for joints with braces also in the multiplanar plane, i.e. KK-joint.

The influence of an in-plane brace is shown by the changes in the SCF's by comparing Y- and K-joints.

The differences in the SCF's between K- and KK-joints due to the influence of the multiplanar braces are only marginal.

2.1 *Chord lines B, C and D*

In Figure 6 it is shown that for a β ratio 0.25 and different θ values the presence of other braces do not influence the SCF's for all the lines of corners 2 and 3. For these joint configurations the distance between the weld toes of the braces is large, therefore very little influence from one brace on the other brace is observed.

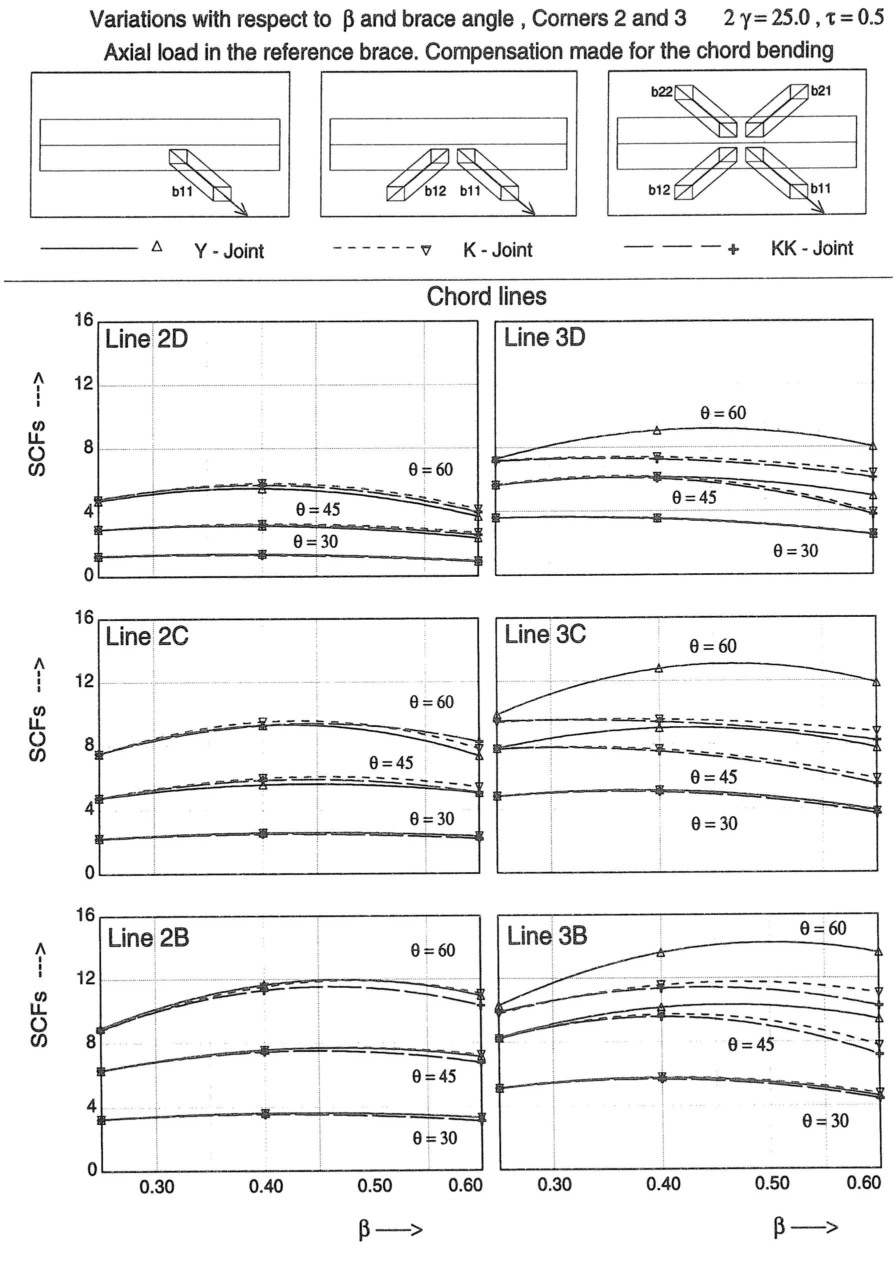
For corner 2 (heel) of the reference brace this is also valid for other β ratios.

For corner 3 (toe) especially for larger angle θ and larger β values the presence of other bracings, especially the in-plane brace, has an effect.

The largest influence is noted for lines 3B and 3C. The SCF's for Line 3B with parameters $2\gamma = 25$, $\tau = 0.5$, $\theta = 60°$ and $\beta = 0.6$ drop from 13.5 for a-Y-joint to 11.3 for a K-joint configuration. The SCF's for line 3C also drop from 12.0 for a-Y-joint to 8.8 for a K-joint configuration.

In general only a small reduction in the SCF's is noted when comparing a KK-joint to a K-joint configuration because, the multiplanar braces for β ratios smaller than 0.6 only marginally influence the stiffness of the chord corners.

The largest influence on the SCF's of the chord lines due to the presence of an unloaded brace is caused by an inplane brace, since this stiffens the gap area.



Note: SCFs for β = 0.6 and θ = 60 ° are with added gap in the joint

Fig. 6. The influence of the presence of other braces on the SCF*'s of the reference brace.*

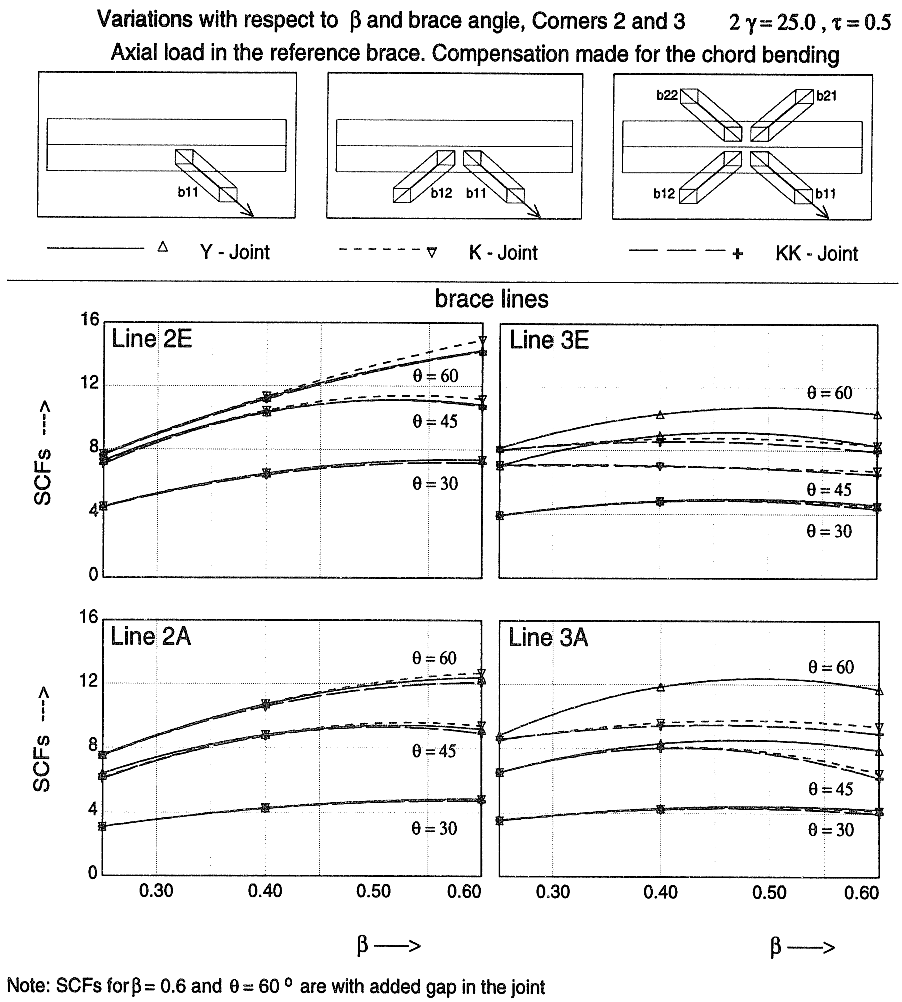


Fig. 7. The influence of the presence of other braces on the SCF*'s of the reference brace.*

2.2 *Brace lines A and E*

Considering Figure 7, it is noted that the SCF's of the brace lines of corner 2 (heel) are very little influenced by the presence of other brace(s).

The presence of an in-plane brace however, has a large influence on the SCF's of the brace lines of corner 3. The SCF's for Line 3A with parameters $2\gamma = 25$, $\tau = 0.5$, $\theta = 60^{\circ}$ and $\beta = 0.6$ drop from 11.7 for a Y-joint to 9.3 for a K-joint configuration. The SCF of the brace line 3E also shows a drop in the SCF from 10.5 for a Y-joint to 8.5 for a K-joint.

The influence of the presence of multiplanar brace(s) on the SCF's of the brace lines of corner 3 are not significant. Only a slight reduction in the SCF's of KK-joints compared to K-joints is noted.

3 The influence of the loads on various braces on the SCF's of the reference brace

The influence of a loaded brace on the SCF's of the reference brace be given by means of an influence factor (IF) defined as:

$$Influence\ Facor(\text{IF}) = \frac{\text{SCF}_{b(ij)}}{\text{SCF}_{b(11)}}$$

i.e. the ratio between the SCF for a given location of the reference brace due to an axial load on a particular brace in relation to the SCF for the same location due to an axial load on the reference brace.

As stated before in all the analysis, compensation is made for the chord bending due to the brace loading.

The (IF) ratios for one set of parameter $2\gamma = 25$, $\tau = 0.5$ and $\theta = 45°$ are presented in Figure 8 as a function of β. The left column of the plots present the (IF) ratio with respect to β for the axial load on the other uniplanar brace b12. The middle column shows the (IF) ratio for the axial load in the multiplanar brace b21 (nearest to the reference brace) while the right column of plots shows the (IF) ratio for the axial load in the other multiplanar brace b22.

In each plot, the two dashed lines show the (IF) ratio for the brace lines A and E, while the three continuous lines show the (IF) ratio for the chord lines B, C and D.

3.1 *The influence of the axial load on the uniplanar brace b12*

Studying the plots given in the Figure 8 carefully, it is clear that the largest influence on the (IF) is due to the load on the in-plane brace b12. (The first column of plots).

3.1.1 Corners 1 and 2 (heel position):

The (IF) ratios for corners 1 and 2 (the lower 2 plots) are small compared to those of corners 3 and 4 (the upper 2 plots). For $\beta = 0.25$ the (IF) ratio is less than 0.2. However, the (IF) ratio increases with increasing β to a maximum of 0.35 for line 2D with $\beta = 0.6$.

3.1.2 Corners 3 and 4 (toe position):

The IF ratios for corners 3 and 4 (the upper 2 plots on the left in Figure 8) show a larger influence of the load in the uniplanar brace b12 compared to that for corners 1 and 2. The (IF) ratio increases with increasing β to a value of 0.55 at line locations 3B and 4B.

It is noted that for a tensile load on the brace b12, a positive (IF) ratio is found for most measurement lines of the reference brace. This results in a considerable reduction in the SCF's for a K-joint or a KK-joint with balanced axial loading.

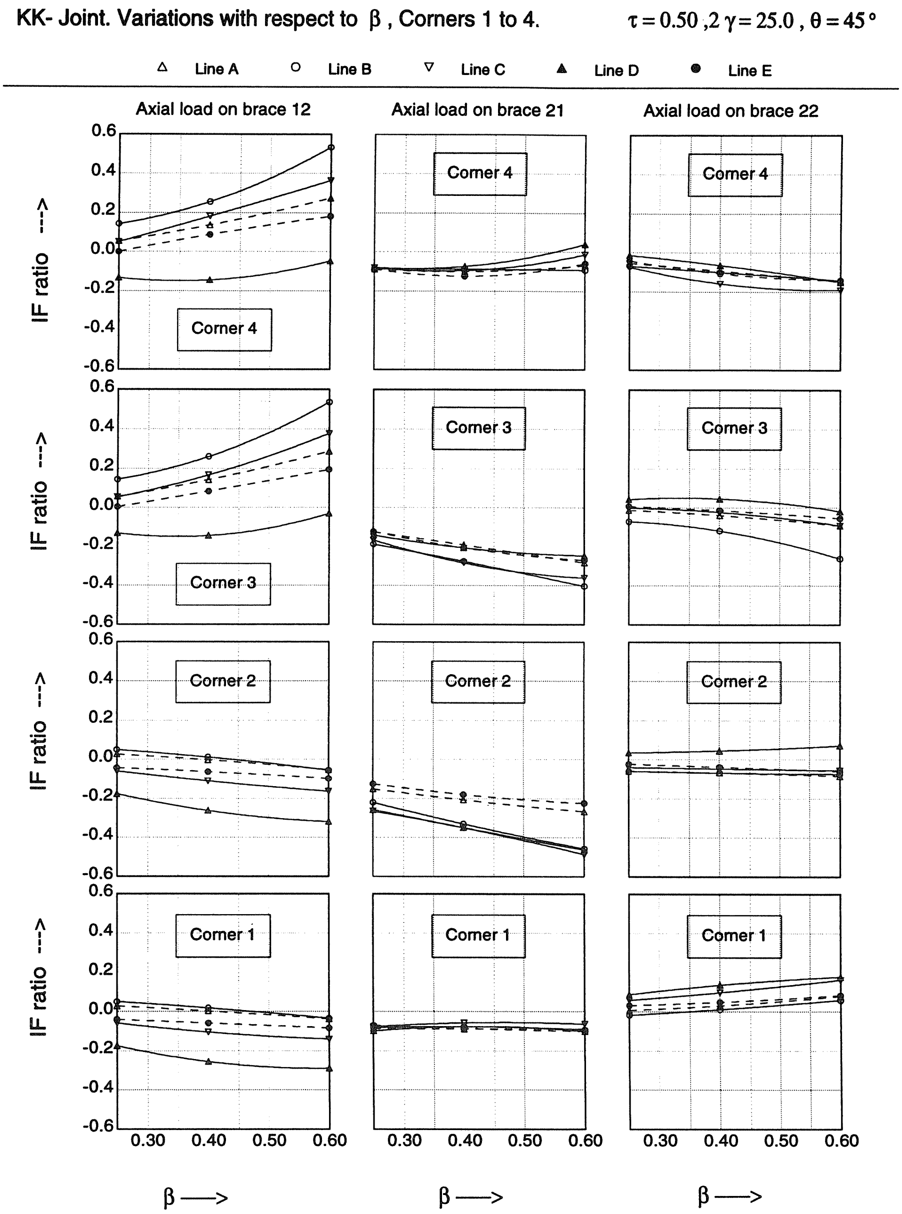


Fig. 8. The influence on the SCF*'s of the reference brace due to an axial load on other braces.*
IF = SCF b(ij)/SCF b(11).

3.2 *The influence of the axial load on the multiplanar brace b21*

Investigating the IF ratios for an axial load on the brace b21 (the multiplanar brace nearer to corners 2 and 3 of the reference brace), indicates that corners 1 and 4 are influenced very little. (2nd column

of Figure 8). As expected the IF ratio is larger for the corners 2 and 3 which are closer to the multiplanar loaded brace.
The IF ratio is small for low β values. As β increases, the IF ratio increases to a maximum value of 0.45 for the chord lines at corner 2 with $\beta = 0.6$. The IF ratio of the brace lines are influenced even less.
Since a tensile axial load on the multiplanar brace b21 results in a negative (IF) ratio on the reference brace, smaller (IF) are obtained for the balanced loaded KK-joints than for similar K-joints.

3.3 *The influence of the axial load on the multiplanar brace b22*

The influence of an axial load on the multiplanar brace b22 on the SCF's of the measurement lines of the reference brace is small. (3rd column of Figure 8).
Corners 1 , 2 and 4 are only slightly influenced. The largest IF ratio for these corners is 0.2.
Corner 3 being the nearest corner to the multiplanar brace b22 is slightly more influenced. For this corner the largest IF ratio is about 0.25 for line B with $\beta = 0.6$.

3.4 *Conclusion about the presence and loading influence of other braces*

The research has demonstrated the effect of the presence and loadings of the various braces on the SCF's in a multiplanar joint. It has been shown that a KK-joint has much smaller SCF's compared to a uniplanar joint such as a *y*-joint.
It shows that calculating SCF's for a multiplanar joint by excluding the effect of the unloaded brace, such as recommended by Efthymiou (1988) can be very conservative Further, the other joint parameters can significantly influence the stress pattern.
The influence of in-plane or out of plane bending moments in other braces on the SCF's of a reference brace are smaller when compared to that for axially loaded braces. This influence is however not insignificant and depending on the direction of the applied bending moments it can increase the SCF for one location while decreasing it for another location. In Panjeh Shahi (1995) the influence of bending moments in the braces is presented in detail.
In practice, a large number of load combinations can be applied to a multiplanar joint resulting in an unique stress distribution around the reference brace.
Therefore it is important that accurate results of member forces and moments are available when investigating uniplanar or multiplanar joints.

4 Development of parametric formulae

A parametric formula based on regression analysis of a parametric study is usually given for one line location and one load combination at a time.
For a square hollow section joint there are 20 possible locations where the largest hot spot stress could occur, on the basis of the geometry and loading parameters.
Parametric formula need to be given for every type of joint with a given load combination.
In practice, the ratios between the loads in the braces and the bending moments can be of any combination. Therefore for a multiplanar joint, it may not be practical to give parametric formulae because, the number of formulae would be so many that it would not be useful to designers.

Therefore a FORTRAN program "HOTSHS " has been developed which calculates the hot spot stresses for the 20 line locations around the reference brace for a given joint geometry and given load combinations, on the basis of the large data base of the present parameter study. For parameters chosen by a user which are not in the data base, a quadratic interpolation is carried out between the adjacent values. The program warns the user when the parameters are outside the range of the data bank.

5 Summary and conclusions

This research programme has produced new information about the SCF's and SNCF's of joints between square hollow sections.
Stress and strain concentration factors for the parameter ranges studied are now available for multiplanar KK-gap, XX, KY, YY and uniplanar K-gap, X- and Y-joints on the basis of this FE parametric study which includes the modelling of the weld geometry.
The parameter ranges covered in this programme are:

$0.25 \leq \beta \leq 0.6$
$12.5 \leq 2\gamma \leq 25.0$
$0.50 \leq \tau \leq 1.0$
$30^\circ \leq \theta \leq 60^\circ$

Based on this research following conclusions can be drawn:
- The influence of the loading on braces other than the reference brace on the SCF's and SNCF's near the weld toes of the reference brace are shown to be significant.
- The presence of an unloaded brace, may have a large reducing influence on the SCF's of the loaded reference brace.
- The influence of loadings on other braces is more pronounced for the chord lines than the brace lines.
- SCF's show a quadratic behaviour with respect to parameters β and θ.
- As the angle θ between the brace and the chord increases, the SCF's also increase in value.
- The location of the largest SCF in a joint is usually at corner 3 and 4 (toe-weld) on the chord. For the brace lines, the largest SCF's generally occur at corners 1 and 2 (heel weld). However when a combined axial load and bending moment as present in actual trusses is applied to the brace, the location of the largest SCF's may vary.
- A programme "HOTSHS " is developed which can calculate the hot spot stresses for a given load combination and joint geometry within the parameter ranges studied.

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Notation

IF	Influence factor
RB	Reference brace
SCF	Stress concentration factor
$SCF_{b(ij)}$	SCF at the reference brace due to load in brace b(ij)
SNCF	Strain concentration factor
a	Weld throat thickness
b_0	Width of the chord member
b_1, b_{bij}	Width of the brace member
F	Axial load in the brace
i,j	Integer used to denote multiplanar plane
ipb	In plane bending moment
opb	Out of plane bending moment
t_0	Chord thickness
t_1 ,t_{bij}	Brace thickness
β, β_{bij}	Brace to chord width ratio
2γ	Chord width to thickness ratio
θ, θ_{bij}	The brace angle with the chord
τ, τ_{bij}	Wall thickness ratio between the brace and the chord

References

EC3. Eurocode 3 (1992), Design of steel structures, Part 1 – General rules and rules for buildings. *European committee for standardization.*

EFTHYMIOU, M. (1988), Development of SCF formulae and generalised influence function for use in fatigue analysis, *Shell international petroleum maatschappij B.V., The Netherlands*.

PANJEH SHAHI E. (1994), Stress and Strain concentration factors of welded multiplanar joints between square hollow sections. *Delft University Press, Delft, The Netherlands.*

PANJEH SHAHI, E., WARDENIER, J., PUTHLI, R.S., DUTTA, D. (1993), Fatigue design recommendations and guidance for repair on KK multiplanar joints made of square hollow sections, *The proceedings of the third international offshore and polar engineering conference. Singapore.*

PANJEH SHAHI, E., PUTHLI, R.S., WARDENIER, J. (1993), Stress concentration factors in KK-multiplanar joints made of square hollow sections including welds., *Tubular Structures V, Proceedings of the fifth international symposium. E & FN Spon, Nottingham, United Kingdom, 25-27 August.*

PUTHLI, R.S., WARDENIER, J., MANG, F., DUTTA, D. (1992), Fatigue behaviour of multiplanar hollow section joints and reinforcement measures for repair Final report, Part V , Evaluation and design recommendations. *Stevin report 6.92.17/A1/12.06, TNO report BI-92-0079/21.4.6394*

VERHEUL, A., C.H.M., PUTHLI, R.S., WARDENIER, J., DUTTA, D. (1993), Fatigue behaviour of multiplanar hollow section joints and reinforcement measures for repair, Final report, Part II, Experimental investigation on K-type joints between RHS in complete girders.

Stevin report 6.92.06/12.06, TNO report BI-92-0036/21.4.6394

WINGERDE A.M. VAN (1992), The fatigue behaviour of T- and X-joints made of square hollow sections. *Delft University Press, Delft, The Netherlands.*