ANALYSIS OF REINFORCED T-JOINTS CONSTRUCTED FROM RECTANGULAR HOLLOW SECTIONS UNDER COMBINED ACTIONS

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ABSTRACT

In this paper, a finite element model is developed and applied to RHS T-joints to evaluate the axial rigidity of the joints. The joints are subjected to an axial force, P, acting through the branch member only or an axial force, P, acting through the branch member combined with a normal force, N, and a bending moment, M, acting on the chord member (combined actions). Four types of reinforced T-joints are analyzed in order to determine the axial rigidity, C, produced by each type and to evaluate the efficiency of the reinforced joints towards combined actions developed in the joint. The rigidity of reinforced T-joints is determined analytically for various geometrical parameters of the joint. Comparisons between different types of reinforcements of the T-joints are carried out in order to evaluate the joint strength, performance, and economic aspect.

Keywords: Rectangular hollow sections, T-joint, Reinforcements, Axial rigidity, Combined actions.

INTRODUCTION

T-joint consists of a vertical branch member and a horizontal chord member. T-joints can be classified to some basic shapes as considered by British Steel Corporation [1]. As seen in Figure 1, the types of joints are:

Unreinforced T-joints

This is the simplest and least expensive type of T-joint. It is sufficient in many great cases, especially when both the chord and the branch members have the same width.

T-joints reinforced by transverse plate (type 1)

The reinforcement is made from plates welded with the two transverse walls of the branch member in order to increase the rigidity of the joint. British Steel Corporation [1] mentions that this type of reinforcement is not recommended. Tests have shown that these reinforcements add nothing, or very little, to the strength of the joint [1]. This type of reinforcement is used for the joints of width ratio, $\beta=b/B<1.0$.

T-joints reinforced by haunches (type 2)

The haunches are made from parts of square or rectangular hollow section material, used for the chord, and are obtained by making suitable cuts at 45° to the axis of the hollow section. In this type, a considerable improvement in the joint stiffness was obtained experimentally by Korol *et al.* [5] and theoretically by El-Hifnawey [3]. In their researches, haunches have proved to be an efficient and economical way of strengthening T-joints. El-Hifnawey [3] modeled the RHS T-joint in her research work reinforced by haunches under axial force, P, by simulating the chord flange as a thin plate resting on simple supports in the short direction and elastic supports in its longitudinal direction. The load is modeled as a uniformly distributed load acting on the perimeter of the inclusion between the branch member with haunches and the chord member. She concluded that by using a haunch size, λ_{*} =1.5 the axial rigidity increased to 1.32 the case with no haunches.

T-joints reinforced by stiffening plates (type 3)

An aesthetically attractive method is to use a simple stiffening plate welded to the connecting flange of the chord to which the vertical branch member is attached. Then, the structural efficiency of the unequal width T-joints can be significantly increased by appropriately sizing the connections. The Stelco [12] hollow structural section (HSS) manual recommends sizing of stiffener plates to commensurate with the experimental results obtained. However, restrictions had been made because of the limited number of tests carried out. In 1982, Korol and Mitri, [6] presented the finding of using a simple yield line analysis of the T-joint reinforced by stiffening plate. They examined a large number of combinations of member sizes to identify the optimum plate length and thickness.

T-joints reinforced by truncated pyramid (type 4)

This type of reinforcement is used for the joints of width ratio, $\beta<1.0$. The reinforcement is made from truncated pyramid welded with the walls of the branch member and the top flange of the chord member. The standards provided by the British steel corporation [1] mention that the use of truncated pyramid is by far the most effective form of reinforcement and also the most costly.

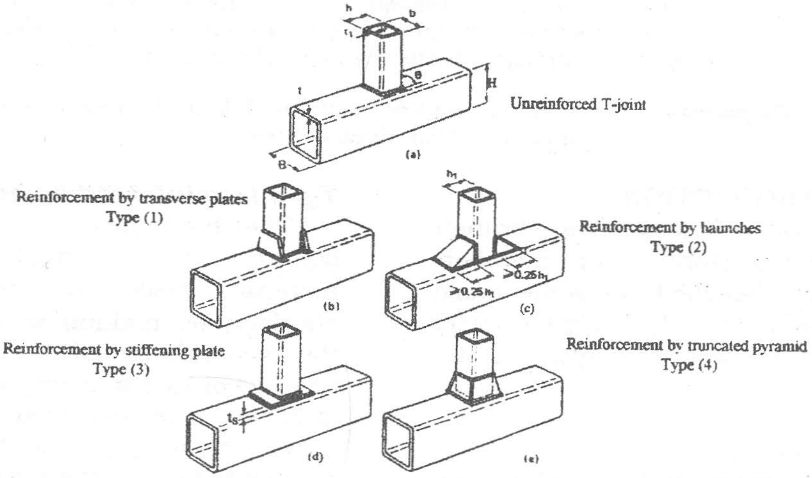
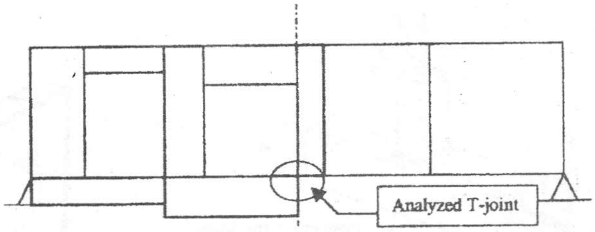


Figure 1 Types of T-joints

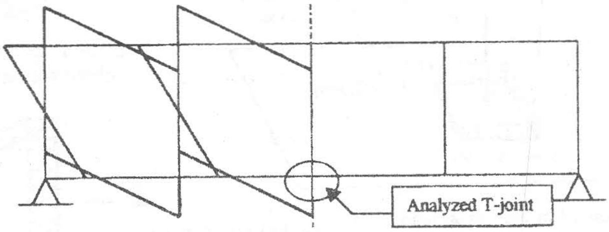
APPLIED FORCES

The T-joint is subjected practically to many forces resulting from the analysis of the structural system used in. Square and rectangle T-joints loaded by an axial force, P, through the branch member have been studied experimentally by Kato *et al.* [4], Korol *et al.* [5], Zhao *et al.* [19], Yu *et al.* [16], Zhao, [17], Partanen *et al.* [10], Packer [8], Zhao *et al.* [20] and Zhao [18]. Also, the T-joints have been studied theoretically by El-Hifnawey, [3], Zhao, and Hancock [21], Yu *et al.* [14,15], Lu *et al.* [7], Soh *et al.* [11], Korol *et al.* [6] and El-Heweity, [2]. In all of these researches, the T-joint is analyzed under a normal force coming from the branch member (axial force) only, although, the axial force is not the only force acting on the joint. Figure 2 shows the expected internal forces developed in a Vierendeel girder under vertical forces. As seen from the figure, the mid-span joint may be subjected to bending moment, M, and a tensile normal force, N.

In this study, the combined actions of the normal force and bending moment acting on the chord member together with the axial force through the branch member are examined. The effect of these actions on the axial rigidity of the joint is studied.



(a) N.F.D of representative Vierendeel girder under vertical forces.



(b) B.M.D of representative Vierendeel girder under vertical forces.

Figure 2 Expected internal forces developed in a Vierendeel girder under vertical forces

The ratio between the branch axial force, P, and the chord normal force, N, or the chord positive bending moment, M, is taken equal to unity, i.e. both N/P=1 and M/P =1(in meter units). These ratios are not the real ratios between the actual combined actions. Nevertheless, these ratios are considered only in order to investigate the effect of these forces on the rigidity of the joint and not to obtain the real value of rigidity.

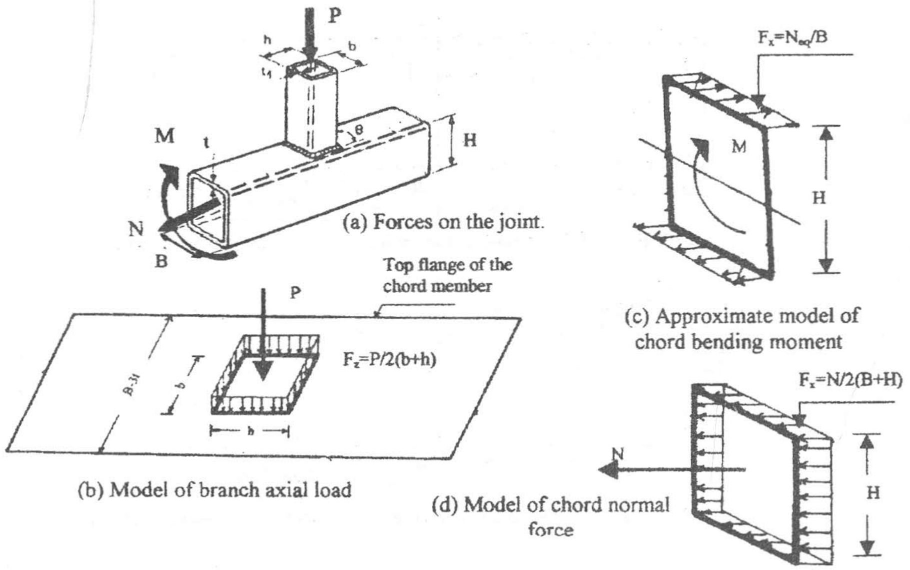
MODELLING OF T-JOINT

In order to carry out this research, the finite element program SAP90 [13] is employed. The features of modeling the joint by this program are summarized as follows:

- The behavior of the T-joint is simulated by three-dimensional model.
- A simple four nodes quadrilateral thin shell element is used.
- In order to separate the influence of bending moment acting on the chord member from the vertical force applied to the branch member, two supports are placed at both ends of the chord member to force zero moments at the ends of the chord member, as seen in Figure 3.
- The in-plane bending moment, M, placed at the ends of the chord member is simulated by a couple through two equivalent normal forces, $N_{eq.}$, acting at the ends of the chord member.

$$N_{eq.} = \frac{M}{H} \tag{1}$$

- The in-plane chord normal force, N, or N_{eq} is distributed as a line load along the perimeter of the ends of the chord cross-section (Figure 3). In order to achieve this distribution, the elements at the ends of the chord member are assumed to be very stiff compared to the other elements.
- Furthermore, the top flange plate of the chord member within the inclusion is presumed to undergo only rigid body deformations. This is so because of the stiffening effect provided by the periphery of the branch member. Accordingly, the force along the edges of the branch member is assumed to be distributed as a line load [16].
- In the analysis of the T-joint, it is assumed that the branch member behaves as a beam column.
- The branch member is assumed to move vertically only and prevented from rotational or horizontal displacement.
- Only one quarter of the joint needs to be analyzed due to symmetry.



(a) Forces on the joint.

(b) Model of branch axial load

(c) Approximate model of chord bending moment

(d) Model of chord normal force

Figure 3 Simulation of loads acting on the T-joint

AXIAL RIGIDITY (C)

It is defined as the slope of the P-δ curve in the elastic region when the joint is subjected to axial branch force, P, while δ is the corresponding joint deflection as seen in Figure 4 i.e.,

$$C = \frac{P}{\delta} \qquad (2)$$

To calculate the axial rigidity of the joint, C, the joint is forced to undergo a constant deflection, δ, at all the nodal points on the perimeter of the inclusion. The corresponding values of the shear forces and the moment are calculated in order to obtain the force, P, as :

$$P = 4\left[\int_0^{b/2} Q_x\,dy + \int_0^{a/2} Q_y\,dx + R\right] \qquad (3)$$

where, $R = -2\,M_{xy}$, Q_x and Q_y are shear forces per unit length in x and y direction respectively and R is the corner force.

A sketch plan for the inclusion showing the internal forces used to determine the applied axial force, P, around the inclusion is given in Figure 5.

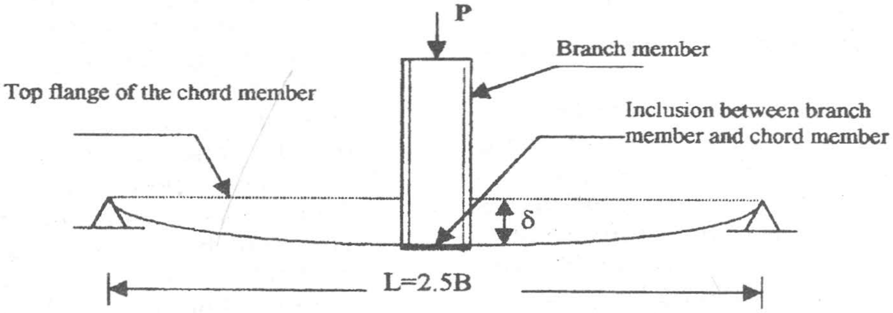


Figure 4 T-joint undergoing rigid body mode deflection at the inclusion

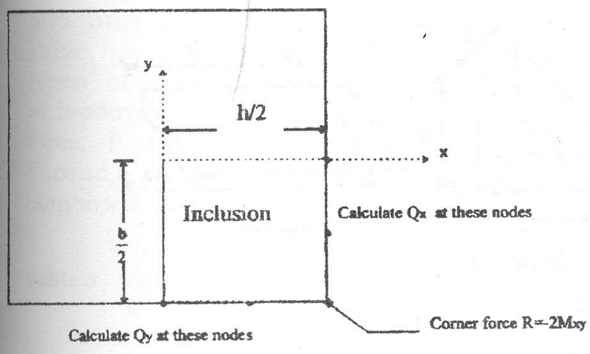


Figure 5 Sketch plan for the position of internal forces used to determine the applied axial force, P.

PARAMETRIC STUDY

In this study, nine joints have been analyzed. In the research program, each joint is analyzed three times. First, the nodal points of the inclusion are forced to undergo a unit vertical deflection and no external forces are applied to the joint. Second, a tensile normal force, N, is applied to the chord member. Finally, a positive bending moment, M, is applied to the chord member.

The geometrical parameters of the joints such as the width ratio, β, and width to thickness ratio of the chord, 2γ, are varied to evaluate their effect on the behavior of the T-joints. These parameters are β= 0.5, 0.8, and 1, and 2γ= 15, 25, and 35.

Unreinforced and reinforced T-joints are considered in the study. The Four types of reinforced joints are tested in the program, (types 1, 2, 3, and 4). For each type of the reinforced joints, dimensions and sizes of reinforcement are either constant or varied depending on the researches done before in this field. In all cases, program SAP90 is used to calculate the internal forces at the nodes around the inclusion in order to obtain the axial force, P, and consequently the axial rigidity, C.

CHARACTERISTICS OF T-JOINTS USED

The nominal dimensions of T-joints analyzed in this study are tabulated in Table 1 with an assumed corner radius $r = 1.5t$. The length of the chord member is taken 2.5 the width of chord member and the height of the branch member is taken equal to the maximum of either 3h or 3b (three times the depth or the width of the branch member respectively)[4]. The material properties of the chord, the branch, and the reinforcement are the same and they are of steel of grade 37 with yield stress 240 kN/cm^2.

Table 1 Nominal dimensions of T-joints used.

Joints	Chord Member (mm)			Branch Member (mm)			Length of Chord
	H	B	T	h	b	t_1	
J01	150	150	10.0	75	75	3.2	375
J02	150	150	6.0	75	75	3.2	375
J03	150	150	4.3	75	75	3.2	375
J04	150	150	10.0	120	120	3.2	375
J05	150	150	6.0	120	120	3.2	375
J06	150	150	4.3	120	120	3.2	375
J07	150	150	10.0	150	150	10.0	375
J08	150	150	6.0	150	150	6.0	375
J09	150	150	4.3	150	150	4.3	375

DETAILS OF REINFORCEMENT USED

The details of reinforcement for the reinforced T-joints are shown in Figure 6.

Type (1) reinforcement

The joint Reinforced by transverse plates is used for $\beta<1.0$, so the dimensions of the transverse plate may be determined according to the width ratio,β, of the analyzed joint. The transverse plate is of a trapezoidal shape, its narrow base equals the width of the branch member and its wide base equals the width of the chord member. The slope of the transverse edge is taken 1:2. For the own knowledge of the author, there are not any recommendations for the thickness of the transverse plate used in this type of joints. So, the thickness of the plate is varied in order to determine the optimum thickness to be used in the reinforcement. The thickness of the transverse plate, t_T, is taken equal to 3, 6, and 9 times the thickness of the branch member respectively.

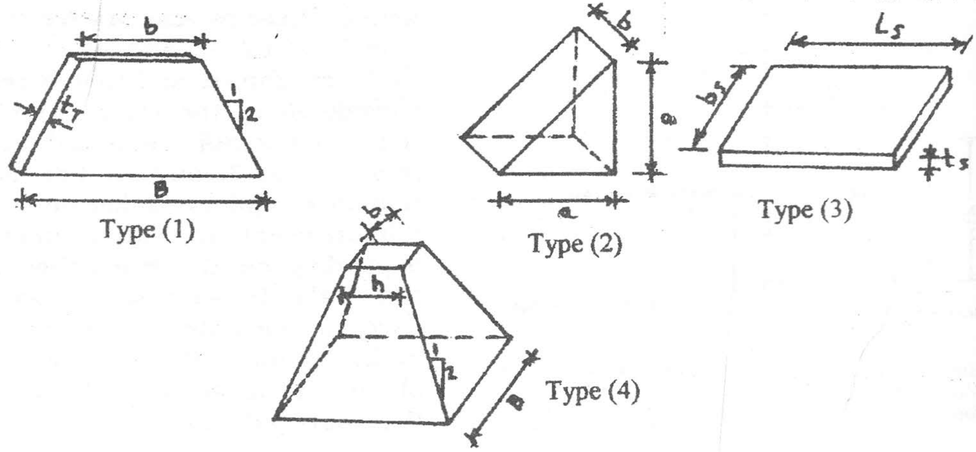


Figure 6 Details of reinforcement for reinforced T-joints

Type (2) Reinforcement

The joint reinforced by haunches is used for $\beta \leq 1.0$. The dimensions of the haunch may be determined according to the geometry of the joint used. The haunch size ratio, λ, is taken equal to 1.5, and 2.0 respectively. The slope of the haunch is 1:1 and the thickness of the haunch is the same as the thickness of the chord member. The length of the haunch can be calculated from the following relation

$$\lambda = \frac{2a+b}{b} \tag{4}$$

where, a is the length of the haunch, and b is the width of the branch member.

Type (3) Reinforcement

The joint reinforced by stiffening plate is used for $\beta < 1.0$. Many recommendations are given in order to determine the optimum dimensions of the stiffening plate. Many standards [1, 6, and 9] recommended that the optimum plate width, b_S, should be equal to the width of the flat portion of the chord flange, i.e., B-3t, while the plate length to width ratio should be equal to or bigger than 2.0, i.e $L_S/b_S \geq 2.0$. The thickness of the plate, t_S, is different in these standards. Table 2 shows the recommendations for the thickness of the stiffening plate.

Table 2 Thickness of the stiffening plate as recommended in three different standards.

Korol *et al.* [6]	Packer *et al.* [9]	British Steel Corporation [1]
$\frac{t_1}{t+t_S} \leq 0.25$	$t_S \geq 4t_1 - t$	$t_S=2t$.

The thickness of the stiffening plate, t_S, used in this analysis is taken equal to double the chord member thickness, t.

Type (4) Reinforcement

The joint reinforced by truncated pyramid is used for $\beta < 1.0$. The dimensions of the truncated pyramid can be determined depending on the value of the width ratio, β, of the joint. The truncated pyramid has four faces each face is of a trapezoidal shape. For each face, the short base equals the width of the branch member and the long base equals the width of the chord member. The slope of the transverse edge of each face is taken 1:2. To the author's knowledge, there are no available recommendations for the thickness of the truncated pyramid used in this type of reinforcement. So, the thickness of the truncated pyramid is taken equals to the thickness of the branch member.

RESULTS

The axial rigidities, C, of both reinforced and unreinforced T-joints are tabulated in Table 3. Comparisons between different types of reinforcements are given. Two cases of loading are considered. First, only an axial force, P, is developed in the branch member. Second, in addition to the axial force, P, combined actions of a normal force, N, and a bending moment, M, acting on the chord member are examined.

The effects of width ratio, β, and the width to thickness ratio, 2γ, on the value of the axial rigidity, C, in the two cases of loading are also studied and summarized in Table 3 and Figures 7 to 13.

Table 3 Values of axial rigidity for reinforced and unreinforced T-joints of different geometrical parameters.

i) Case of axial force only

2γ	β	Axial Rigidity (C) in KN/mm							
		Unreinforced T-joints	Reinforced T-joints						
			Type (1)			Type (2)		Type (3)	Type(4)
			$t_T=3t_1$	$t_T=6t_1$	$t_T=9t_1$	$\lambda=1.5$	$\lambda=2.0$		
15	0.5	135.37	509.17	633.71	702.74	260.83	343.36	897.67	1116.45
	0.8	278.16	523.83	583.77	622.28	697.36	987.86	1151.15	944.29
	1.0	463.61	-	-	-	1378.55	1867.41	-	-
25	0.5	29.12	346.62	360.10	366.84	70.07	90.19	330.14	663.57
	0.8	62.00	274.57	296.82	307.88	266.32	370.23	535.62	438.21
	1.0	120.66	-	-	-	771.01	1053.63	-	-
35	0.5	10.56	279.72	330.25	354.23	30.24	37.55	162.21	473.26
	0.8	22.55	228.26	272.18	295.68	140.15	186.28	325.84	299.22
	1.0	38.58	-	-	-	531.35	736.92	-	-

ii) Case of combined actions

2γ	β	Axial Rigidity (C) in KN/mm							
		Unreinforced T-joints	Reinforced T-joints						
			Type (1)			Type (2)		Type (3)	Type(4)
			$t_T=3t_1$	$t_T=6t_1$	$t_T=9t_1$	$\lambda=1.5$	$\lambda=2.0$		
15	0.5	85.48	157.68	168.01	172.25	141.02	170.80	244.04	225.10
	0.8	130.79	152.41	156.75	159.13	215.52	287.98	237.55	227.60
	1.0	154.36	-	-	-	303.92	438.66	-	-
25	0.5	24.43	105.04	106.29	106.91	52.17	64.59	129.73	146.94
	0.8	43.98	100.90	103.44	104.30	121.62	171.27	139.46	121.85
	1.0	59.92	-	-	-	189.51	263.34	-	-
35	0.5	9.66	80.54	84.09	85.41	25.19	30.53	80.04	108.49
	0.8	18.78	72.00	76.37	78.03	78.20	107.18	97.62	89.35
	1.0	23.16	-	-	-	141.52	189.51	-	-

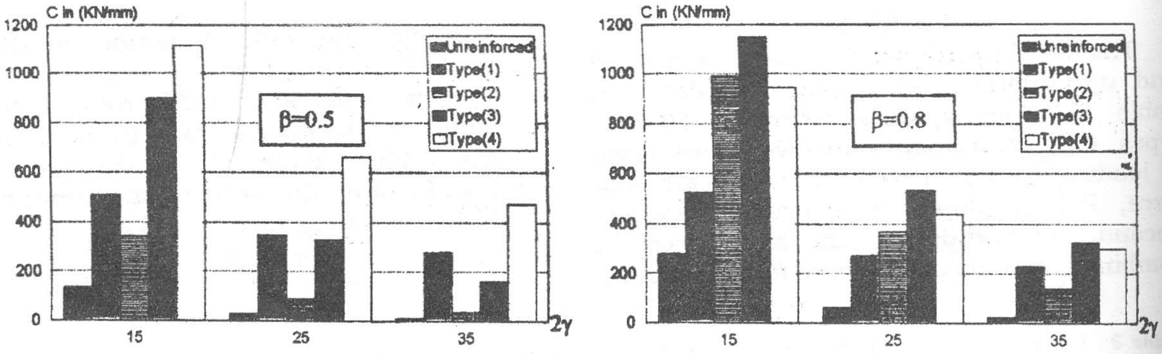


Figure 7 Effect of the type of reinforcement on value of the axial rigidity, C, for different geometrical parameters in case of axial force only.

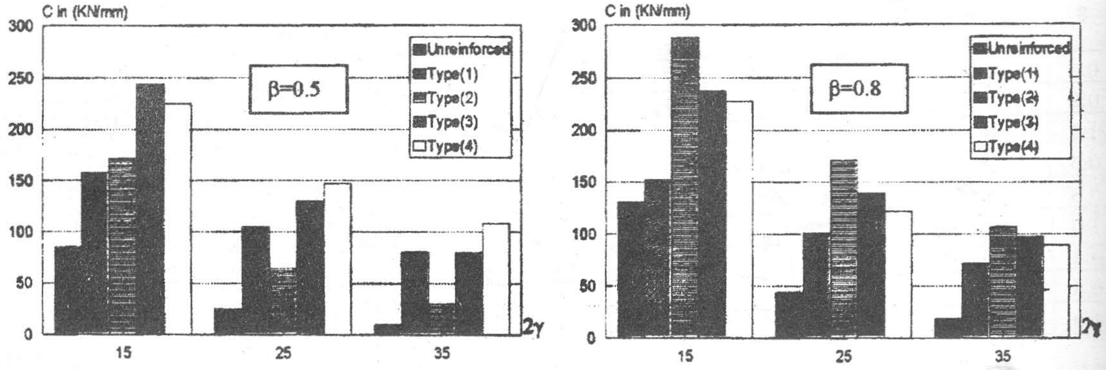


Figure 8 Effect of the type of reinforcement on the value of the axial rigidity, C, for different geometrical parameters in case of combined actions

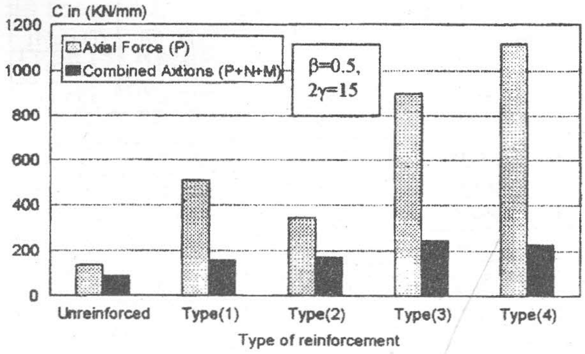


Figure 9 Effect of combined actions on the value of the axial rigidity, C for different types of reinforcements.

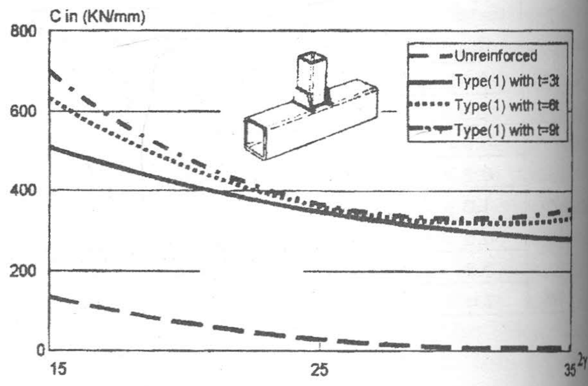


Figure 10 Effect of plate thickness, T_t(reinforcement type 1) on the value of the axial rigidity, C.

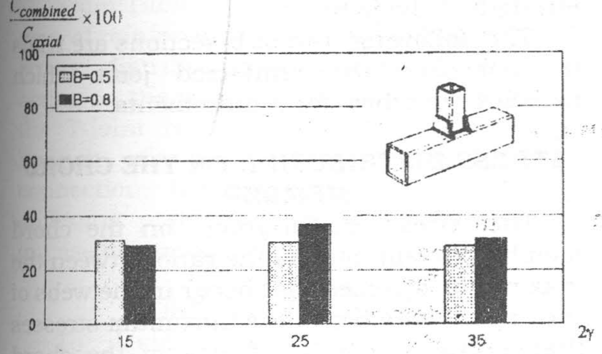


Figure 11 Effect of combined actions on joint rigidity

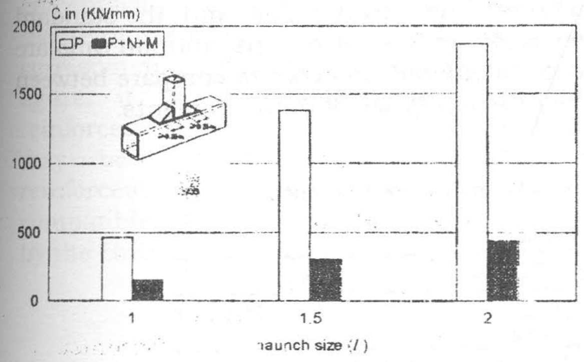


Figure 12 Effect of haunch size, λ, on the value of axial rigidity, C, in the two cases of loading.

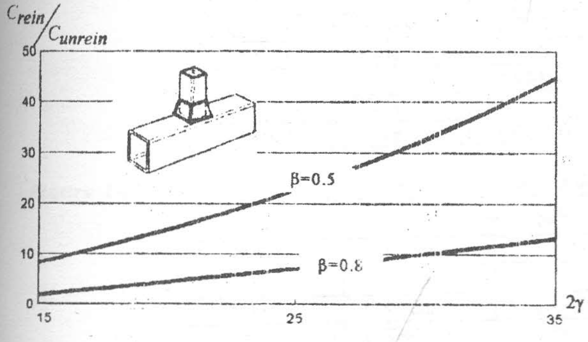


Figure 13 Effect of Width ratio, β, on the ratio C_{rein}/C_{unrein} in case of reinforcement by truncated pyramid (type 4)

From table 3 and the Figures 7 to 13, the following observations can be found:

- Figures 7 and 8 show that for all types of T-joints under axial force only or under combined actions, the axial rigidity, C, increases by increasing the width ratio, β. This increase reaches its maximum value for β=1.0 which indicates that equal width joints are more rigid than unequal width ones. Also, the axial rigidity decreases by increasing the width to thickness ratio, 2γ. This is so because increasing this ratio makes the joint more flexible.
- Figure 9 shows the effect of the combined actions on decreasing the axial rigidity of the joints, this effect is changed by changing the type of reinforcement. The reduction of the axial rigidity ranges from 60-90% for the unreinforced joints and 20-80% for the reinforced joints.
- Figure 10 shows that for T-joints reinforced by transverse plate, the axial rigidity, C, increases minimally by increasing the thickness of the transverse plate, t_T. This increase does not exceed 10% in case of combined actions and 25% in case of axial force only. Consequently, the thickness of the transverse plate used in reinforcing the joint may be taken equals to three times the thickness of the branch member (i.e. $t_T=3t_1$).
- Figure 11 shows that the combined actions decrease the axial rigidity of type 1 reinforcement by approximately 70%. Also, in this case the joint stiffness is approximately constant for different ranges of width ratio, β, and width to thickness ratio of the chord, 2γ.
- Figure 12 shows that for T-joints reinforced by haunches, the axial rigidity of joints increases tremendously by increasing the haunch size. For example, by reinforcing the T-joint with a haunch of size 1.5, the axial rigidity reaches 2.0-6.0 times (depending on the other parameters) the axial rigidity for the joint with no haunches. Using a haunch size of 2.0, the axial rigidity reaches 1.5-3.0 times the axial rigidity for the joint with 1.5 haunch size.
- Figure 13 shows that the truncated pyramid, as a type of reinforcement, is more effective for a joint with narrow branch member.

DETERMINATION OF THE OPTIMUM TYPE OF REINFORCEMENT

To determine the best reinforcement to use in stiffening the T-joint, the following requirements may be satisfied:

- Highest value of axial rigidity.
- Best stress distribution on the chord member.
- Most economic connection.

The results obtained in Table 3 show that reinforcing the joint by a stiffening plate (type 3) or by a truncated pyramid (type 4) may provide the target maximum axial rigidity.

Reinforcement by truncated pyramid (type 4) may increase the rigidity of the joint by approximately 44 times the rigidity of the unreinforced joint for the same geometrical parameters. Also, T-joint reinforced by transverse plate (type 1) is a good type of reinforcement, although recommendations carried out by the British steel corporation mentioned that this type add nothing to the strength of the joint.

The following two sub-sections are trials to determine the reinforced joint which satisfies the other two requirements.

STRESS DISTRIBUTION ON THE CHORD MEMBER

The stress distribution on the chord member herein means the ratio between the maximum stresses that occur in the webs of the chord member to the maximum stresses that occur in the top flange of the chord member. This ratio is calculated for different types of reinforcements. Table 4 provides the stress distribution ratios for different joints under both of axial force only and combined actions. The mean value and the standard deviation of the stress distribution ratio are also calculated in order to compare between the different types of reinforcements.

Table 4 Stress distribution of reinforced T-joints of different ranges of 2γ and β.

i) Case of axial force only

2γ	β	σ_{web} $\sigma_{topflange}$				
		Type (1) $t_T=3t_1$	Type (2)		Type (3)	Type (4)
			$\lambda=1.5$	$\lambda=2.0$		
15	0.5	0.3840	0.6217	0.5545	0.4818	0.4477
	0.8	0.1602	1.4383	0.5134	0.5910	0.4653
	1.0	-	0.8825	0.3315	-	-
25	0.5	0.7501	0.6219	0.5613	0.2778	0.5643
	0.8	0.3490	0.5114	0.4854	0.6056	0.8416
	1.0	-	0.9973	0.4117	-	-
35	0.5	1.0642	0.6311	0.5756	0.2759	0.7442
	0.8	0.2133	0.4356	0.4340	1.1936	0.9530
	1.0	-	1.0021	0.4471	-	-
Mean		0.4868	0.7935	0.4794	0.5710	0.6694
Cov.		0.3504	0.3166	0.0809	0.3377	0.2086

ii) Case of combined actions

2γ	β	σ_{web} $\sigma_{topflange}$				
		Type (1) $t_T=3t_1$	Type (2)		Type (3)	Type (4)
			$\lambda=1.5$	$\lambda=2.0$		
15	0.5	1.5208	0.6699	0.7875	1.2579	0.3363
	0.8	1.1074	0.6422	1.1261	1.0987	0.3139
	1.0	-	0.4158	0.2322	-	-
25	0.5	1.5799	0.2478	0.3510	1.0595	0.3285
	0.8	0.8567	0.8111	1.0136	1.0173	0.4154
	1.0	-	0.4266	0.2302	-	-
35	0.5	1.6066	0.0396	0.1249	1.0495	0.3300
	0.8	1.1080	0.6529	0.8165	1.0595	0.4248
	1.0	-	0.4120	0.2284	-	-
Mean		1.2966	0.4798	0.5456	1.0904	0.3582
Cov.		1.3285	0.2402	0.3875	0.0861	0.0486

From Table 4 and Figures 14 and 15, The type of reinforcement which satisfies the best stress distribution depends on the force acting on the joint. In case of axial force only, the T-joint reinforced by haunches with a haunch size of 1.5 may be the best connection while the T-joint reinforced by stiffening plate may be the best connection in case of combined actions.

MOST ECONOMIC JOINT

To decide the most economic type of reinforcement, one may compromise between the gain in joint rigidity provided by the chosen reinforcement and its expected cost.

Figure 16 shows the ratio between the percentage of additional rigidity gained by the reinforcement and the percentage of the corresponding increase of the cost. From the figure, it can be seen that the T-joint reinforced by the truncated pyramid (type 4) may be the most economic type of reinforcement. This observation is compatible with the recommendations given by the British steel corporation [1].

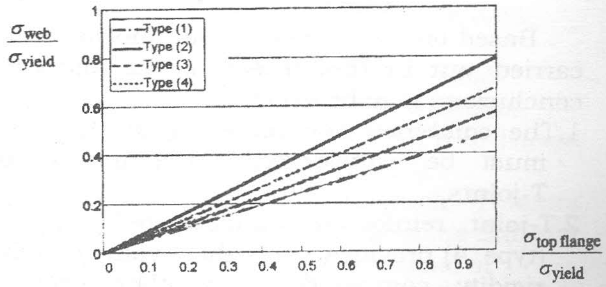


Figure 14 Comparison between the maximum stresses at the web and the top flange of the chord member in case of axial force only.

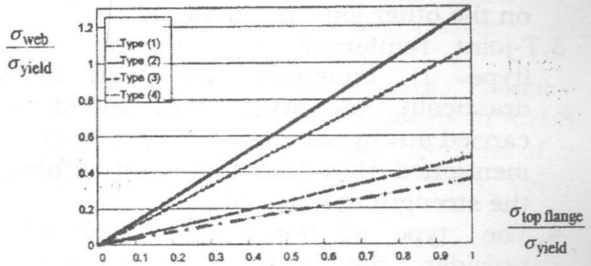


Figure 15 Comparison between the maximum stresses at the web and the top flange of the chord member in case of combined actions.

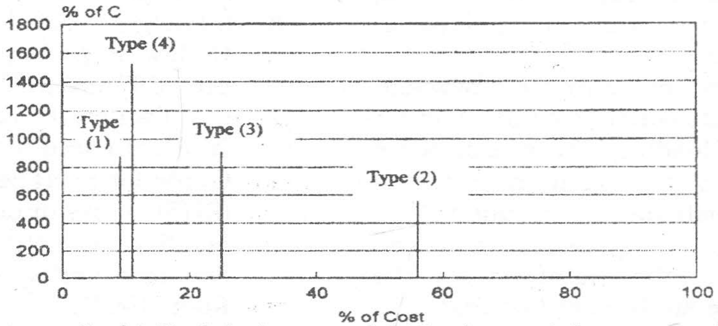


Figure 16 Comparison between % of C (% of the increase of rigidity due to reinforcement to that of unreinforced) and % of cost (% of increase of the material used to that of the unreiforced joint) (axial forial force only).

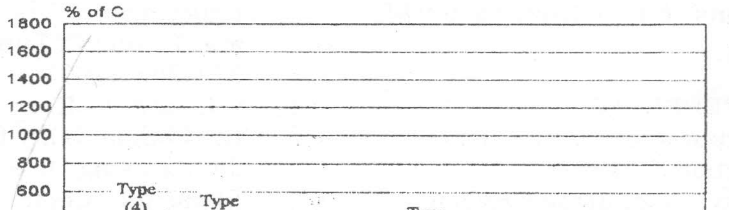


Figure 17 Comparison between % of C (% of the increase of rigidity due to reinforcement to that of unforced) and % of cost (% of increase of the material used to that of the unreinforced joint (combined actions).

CONCLUSIONS

Based on the numerical parametric study carried out in this research, the following conclusions may be drawn:

1. The combined actions acting on the joint must be considered in the analysis of T-joints.
2. T-joint reinforced by a truncated pyramid (type 4) provides the highest value of axial rigidity compared to the other types of reinforced joints. In some cases, it may yield up to approximately 44 times the rigidity of the unreinforced joint for the same geometrical parameters depending on the other joint parameters.
3. T-joint reinforced by transverse plates (type 1) increases the joint rigidity drastically although recommendations carried out by the British steel corporation mentioned that this type add nothing to the strength of the joint.
4. The type of reinforced T-joint which provides the best stress distribution depends on the force acting on the joint. In case of axial force only, the T-joint reinforced by haunches with a haunch size of 1.5 may be the best connection while the T-joint reinforced by stiffening plate may be the best one in case of combined actions.
5. T-joint reinforced by truncated pyramid may be the most economic connection for the two cases of loading. These results are compatible with the recommendations given by the British steel corporation [1].
6. The influence of the geometrical parameters of the joint must be considered in the analysis of T-joints.
7. More representative load ratios must be considered in order to study the effect of combined actions on the axial rigidity of T-joints.

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تحليل وصلات T المقواه والمكونة من قطاعات مستطيلة مفرغة تحت تأثير الأحمال المتزاملة

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ملخص البحث

فى هذا البحث تم عمل نموذج نظرى باستخدام طريقة العناصر المحددة لحساب جساءة وصلات T المكونة من قطاعات مستطيلة مفرغة تحت تأثير حالتى تحميل. الحالة الأولى، تم فيها حساب جساءة الوصلات تحت تأثير حمل محورى يؤثر على الضلع الرأسى للوصلة فقط. أما الحالة الثانية فقد تم حساب الجساءة للوصلات تحت تأثير الحمل المحورى المؤثر على الضلع الرأسى بالاضافة الى وجود قوة محورية وعزم انحناء يؤثران على الضلع الأفقى للوصلة (الأحمال المتزاملة).

تم تحليل أربعة أنواع من الوصلات المقواه لحساب الجساءة المناظرة لكل نوع من أنواع التقويات وذلك لتقييم مدى كفاءة هذه التقويات فى تحمل الأحمال المؤثرة على الوصلة. كذلك تم الأخذ فى الاعتبار دراسة تأثير المتغيرات الهندسية للوصلات على قيم الجساءة لحالتى التحميل التى تم دراستها.

تم أيضا" عقد مقارنات بين أنواع التقويات المختلفة وذلك لتحديد أفضل الوصلات المقواه من حيث الجساءة، توزيع الاجهادات على الوصلة و اقتصادية التقوية المستخدمة.