Title	Ultimate Capacity of Doubler Plate Reinforced Square Hollow Section T-Joints(Mechanics, Strength & Structure Design)
Author(s)	Soh, Chee-Kiong; Chan, Toong-Khuan; Fung, Tat-Ching et al.
Citation	Transactions of JWRI. 2000, 29(2), p. 85-90
Version Type	VoR
URL	https://doi.org/10.18910/6227
rights	
Note	

Ultimate Capacity of Doubler Plate Reinforced Square Hollow Section T-Joints †

Chee-Kiong SOH*, Toong-Khuan CHAN, Tat-Ching FUNG*** and Keiji NAKACHO******

Abstract

This paper reports on an investigation into the ultimate strength of a reinforced Square Hollow Section T–joint under brace axial compression. The project consists of both experimental and numerical studies. A full-scale reinforced T-joint specimen was tested to failure and the results were compared to those obtained from a finite element model. The FE model was able to predict the ultimate failure load and displacements accurately with an error of less than 2% for the failure load and less than 1% for the brace end displacement at the failure load. A parametric study was then conducted to understand the influence of the geometric parameters on the ultimate strength of the reinforced joint. The results of the parametric study show that decreasing α (chord length to chord diameter ratio), and increasing γ (chord diameter to thickness ratio) will increase the ultimate strength of the joint. The parameter β (brace diameter to chord diameter ratio) does not have a significant affect on the strength of the joint. It is also observed that there is an optimum plate and chord thickness that provides significant increases in the ultimate strength of the joint. The results have shown that the plate reinforcement greatly increases the ultimate load of the joint as compared to the capacity of a similar unreinforced joint for small β values. An equation to predict the ultimate load of doubler plate reinforced T–joint is proposed.

KEY WORDS : (Reinforced T-Joint) (Ultimate Capacity) (Doubler Plate) (Square Hollow Section)

1. Introduction

Tubular members are well known for their efficient distribution of material, particularly with regard to beam bending or column buckling about multiple axes. However, welding circular members together along curved lines is both difficult and costly; not to mention the complexity in behaviour of such joint when subjected to different load combinations. On the other hand, rectangular hollow sections (RHS) are generally more economical than circular hollow sections (CHS) as the joints are formed with straight cuts. In structures where a deck or panelling is laid directly on the structural members, RHS offer easy connection on to its flat surfaces.

A reinforcing doubler plate may be welded to the chord to strengthen a joint instead of increasing the thickness of the entire member. The study of the precise influence of a doubler plate is still in the preliminary stage, even though it has been generally agreed that it can greatly enhance the axial load bearing capacity of CHS joint [1), 2)].

2. Joint Parameters and Objectives

The geometrical parameters of a uniplanar SHS joint are shown in **Fig. 1**. The parameters α, β, γ and τ are commonly used as non-dimensional parameters for the analysis and design of CHS or RHS joints. The chord length parameter alpha (α) indicates the beam bending characteristic of the chord, the diameter ratio beta (β) is used as a measurement for the compactness of a joint, the chord diameter to thickness ratio gamma (γ) describes the thinness or radial stiffness of the chord, and tau (τ) describes the ratio of brace and chord thicknesses [3)].

The aim of this project is to understand the behaviour of a doubler plate reinforced square hollow section (SHS)

† Received on January 31, 2001
* Professor and Head of Div. of Structures and Mechanics, Nanyang Technological University (Singapore)
** Associate Professor, Nanyang Technological University
*** Associate Professor, Nanyang Technological University
**** Associate Professor

Transactions of JWRI is published by Joining and Welding Research Institute of Osaka University, Ibaraki, Osaka 567-0047, Japan.

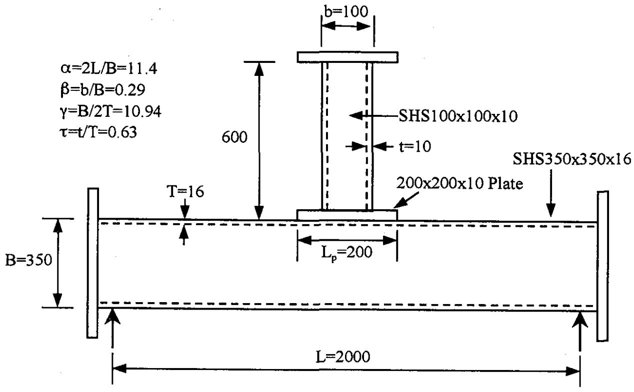


Fig. 1 Geometric parameters and dimensions of test specimen

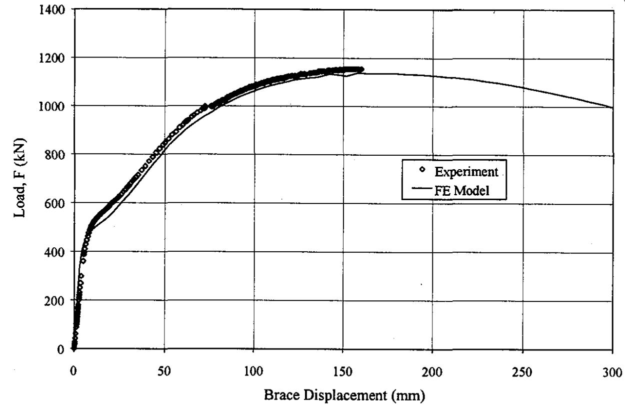


Fig. 2 Brace load versus displacement plot for the test specimen and FE model

T-joint with emphasis on the influence of joint parameters (α, β and γ) on the static ultimate strength. The ultimate strength and failure mode under the basic axial load condition will be investigated through a parametric study with the use of finite element models of the T-joint. A comparison with a non-reinforced T-joint will be carried out to quantify the influence of the doubler plate.

In this parametric study, a square doubler plate of width equal to 0.8 times the chord dimension (L_p x L_p = 0.8B x 0.8B) and thickness equal to the brace thickness (t_p = t) was employed. It was found that increasing the width of the doubler plate beyond this size did not have a significant influence on the ultimate capacity of CHS members [2].

3. Uniplanar T-Joints

The hollow section T-joint is considered one of the most common joints found in steel structures. Numerous experimental studies have been conducted on uniplanar joints involving the static and fatigue strength during the last 30 years. Design equations to predict the ultimate capacity were obtained through regression analyses or curve fitting of the experimental data. For T-joints under axial load, several failure modes were observed: local joint failure, overall chord bending or shear failure.

Wardenier [3] has reported on the behaviour of SHS T-joints based on a series of experiments and proposed the following equation to predict the ultimate axial compressive load:

$$\frac{F_u}{f_y T^2} = \frac{1}{1-\beta}\left[\frac{2\beta}{\sin\theta} + 4\sqrt{1-\beta}\right]\frac{1}{\sin\theta} \qquad (1)$$

where

F_u = ultimate load
f_y = yield stress
θ = brace angle
T = chord thickness
β = brace diameter to chord diameter ratio
= b(brace) / B(chord)

4. Experimental Work

The mechanical properties of the material were obtained from tensile tests. Average yield stresses of 255 MPa and 269 MPa, and ultimate stresses of 405 MPa and 435 MPa were obtained for the chord and plate, respectively. In the experimental study, a square doubler plate of 200x200x10mm was used.

The specimen details and test layout were as shown in Fig.1. The load was applied vertically on the brace by a 2000kN hydraulic jack and the displacement was recorded at the top of the brace. The ultimate load of the SHS T-joint was 1154.3 kN at a vertical brace displacement of 157.07 mm. The T-joint has tremendous capacity beyond the point of first yield, and deforms substantially until reaching a peak as shown in **Fig.2**.

5. Finite Element Model

The analysis for the non-linear elastic-plastic large deformation response of the doubler plate reinforced T-joint in this project was carried out using a commercial finite element software. The finite element mesh for the T-joint for axial compressive load is shown in **Fig. 3**. Only a quarter of the joint was modelled due to symmetry. End plates were included in the FE model and the lower edges of the plates were vertically restrained to simulate simple supports. Loading for compression was by displacement control, as opposed to the alternative load control method. In the displacement control method, the displacement steps of the loading nodes were prescribed. The external applied force was determined as the sum of all the nodal reaction

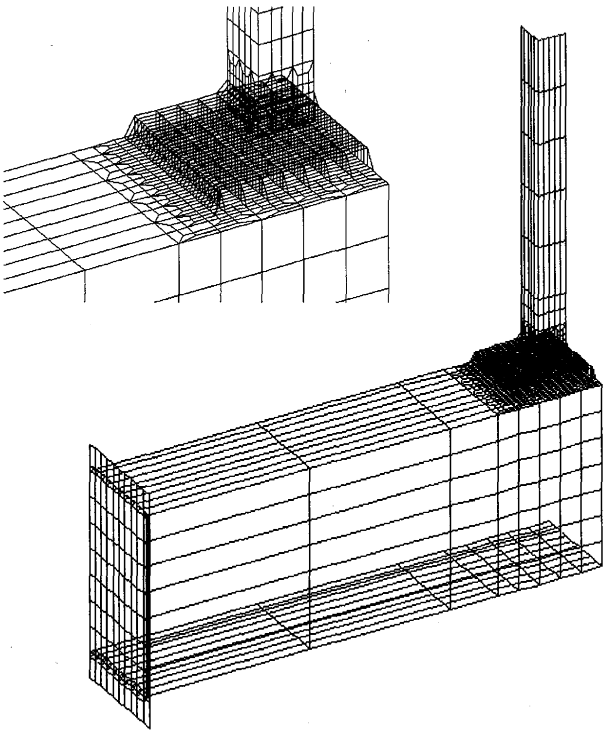


Fig. 3 Finite element model of the reinforced SHS T-joint (a quarter-model)

forces. The four-noded thick shell element was chosen as this element updates the thickness of the element as soon as the element deforms. In order to model accurately the stiffening effects of the reinforced joint, two-noded gap-friction elements were used to simulate the actual interaction between the chord and the doubler plate.

The load-displacement curve for the finite element model was compared against the experimental results in Fig.2. The predicted ultimate load from the FE model was 1138.5kN; only 1.4% lower than the experimental result. The peak load was predicted to occur at a displacement of 158.2mm; a difference of less than 1% from the experimental value. This excellent correlation of the predicted behaviour and the experimental results indicate that the FE model is adequate and accurate.

6. Parametric Study

The objective of this study is to characterize the behaviour of a SHS T-joint reinforced with a doubler plate under axial compressive loads in the brace. Three main non-dimensional parameters, α, β, and γ, thought to be the governing factors for the ultimate strength of unreinforced T-joint, were analysed. The parameter τ was constant for all analysis.

A total of 36 models were constructed and were loaded with brace axial compression. Three β values (β = 0.3, 0.5 and 0.7) and three γ values (γ = 10, 18 and 26) were considered. Four α values (α = 10, 15, 20, 25) were analyzed to include the effect of overall chord bending as α is expected to significantly affect the ultimate strength. The parameter τ was not varied in this study but was kept constant at 0.625. The ultimate brace axial load, F_u, was converted to a non-dimensionalised parameter, F_u/f_yT^2 for ease of comparison in the parametric study.

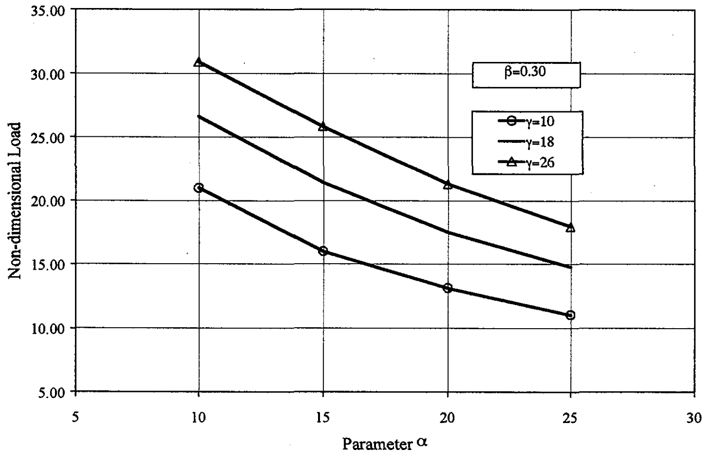
The non-dimensional ultimate load, F_u/f_yT^2, is plotted against α for various β and γ values in **Figs.4 (a)-(c)** to compare the influence of the various geometric parameters. It was observed that increasing values of α and decreasing values of γ resulted in a decrease of the non-dimensional ultimate load. The reduction in strength with increasing values of α can be substantial with long chord lengths due to the effect of chord bending. It was further observed that the non-dimensional ultimate load tended to increase slightly when β was increased from 0.5 to 0.7.

In summary, it can be concluded that decreasing α values and increasing β and γ values will result in increasing non-dimensional ultimate loads. This observation was similar to the findings made by Choo et al. [1] for unreinforced uniplanar T-joint loaded by axial compression.

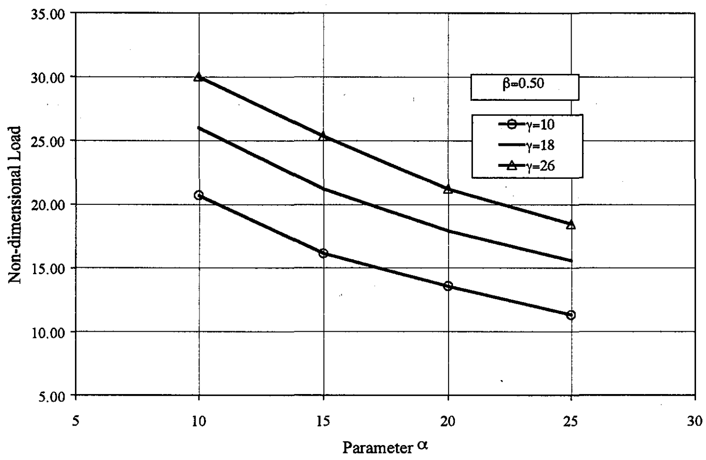
7. Strengthening Effect of Doubler Plate

The ultimate strength of the reinforced SHS T-joint was compared with the ultimate strength of a similar unreinforced T-joint to determine the strengthening effect of the doubler plate. The strength of the unreinforced T-joint under axial compression was obtained from empirical equations proposed by Wardenier [3]. **Fig.5** shows the ratio of the finite element prediction for a reinforced joint compared with the predicted strengths for an unreinforced T-joint. The strengthening effect of the doubler plate was significant for joints with small α values but was less significant with increasing chord length. Increasing the γ parameter had the effect of marginally increasing the non-dimensional load although the proposed equation by Wardenier did not include this parameter. However, the non-dimensional ultimate load was observed to be almost identical to that of an un-reinforced joint with α = 25, β = 0.7 and γ = 10. This joint failed by buckling of the chord wall due to the secondary bending moments and the doubler plate was seen to have no strengthening effect.

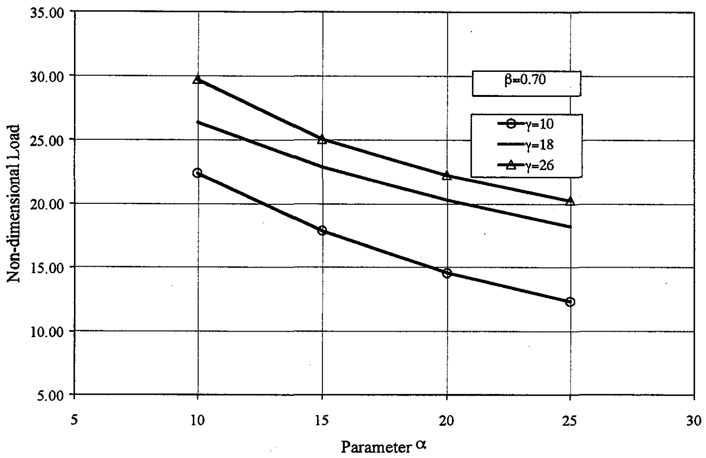
A regression analysis of the numerical data was carried out by adapting the form of the Kurobane [4] equation for a CHS and a revised empirical equation as shown Eq. (2) was proposed for the ultimate capacity of the reinforced SHS T-joint.



(a) $\beta = 0.30$



(b) $\beta = 0.50$



(c) $\beta = 0.70$

Fig. 4 Plots of non-dimensional load versus α

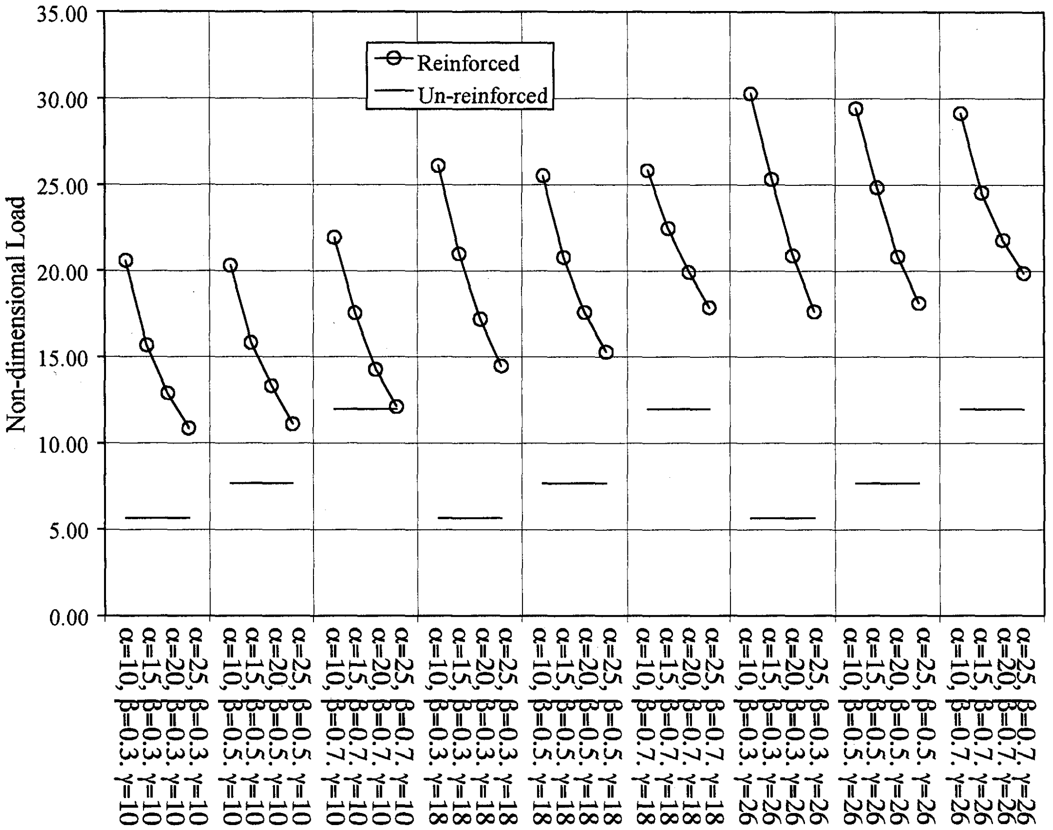


Fig. 5 Comparison of the non-dimensional load predictions for reinforced and unreinforced joints

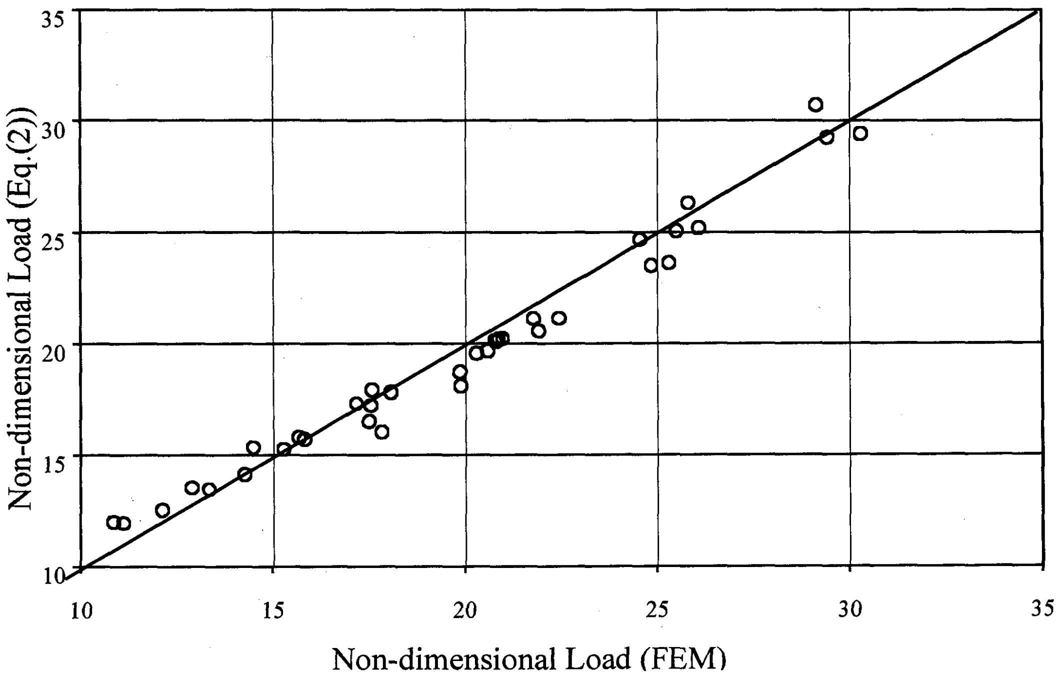


Fig. 6 Comparison of the non-dimensional load predictions from Eq. (2) and FEM

$$\frac{F_u}{f_y T^2} = 14.82\left(1 - 0.52\beta + 0.62\beta^2\right)(2\gamma)^{0.42}(0.5\alpha)^{-0.54} \tag{2}$$

The coefficient of multiple determination, defined as the ratio of regression sum of squares over the total sum of squares, was 0.972, indicating that the correlation between the numerical and predicted values was excellent. A plot of the non-dimensional ultimate load predicted from the proposed equation compared with the predictions of the finite element model is presented in **Fig. 6**. The residual error, which is defined as the difference between the non-dimensional ultimate loads obtained from the revised empirical equation and the results of the finite element model, was less than 1.82.

8. Conclusions

The influence of chord length parameter (α), brace to chord diameter ratio (β) and chord diameter to thickness ratio (γ) on the ultimate static strength of doubler plate reinforced T-joint was investigated and characterised through this parametric study. The basic axial compressive load case was considered.

Compared to the unreinforced T-joint, the trends of the influence of all three geometric parameters on the reinforced joint were observed to be generally similar. An increase in the parameter α produced a reduction in the non-dimensional ultimate axial loads while increasing β and γ parameters, increased the non-dimensional ultimate axial loads in the brace.

An equation for the prediction of ultimate axial capacity of the doubler plate reinforced T-joint was proposed.

References

1) Y.S. Choo, G.J. Vegte, N. Zettlemoyer and J.Y.R. Liew : Static strength of T-joints reinforced with doubler or collar plates, Proc. 8th Intl. Symp. on Tubular Structs. (Singapore, 1998), pp139-145.
2) T.C. Fung, T.K. Chan and C.K. Soh : Ultimate capacity of doubler plate reinforced tubular joints, J. Struct. Engrg (ASCE), Vol.125(1999), No.8, pp891-899.
3) J. Wardenier : Hollow section joints, Delft University Press (Delft, The Netherlands, 1982).
4) Y. Kurobane, Y. Makino and K. Ochi : Ultimate resistance of unstiffened tubular joints, J. Struct. Engrg (ASCE), Vol.110(1984), No.2, pp385-400.