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Stress Concentration Factors of T Tubular Joints Reinforced with Doubler Plates[†]

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

Abstract

Tubular joints of offshore structures may be reinforced with doubler plates to enhance their punching shear strength. However, this may have negative effects when the joint is subjected to axial tension or bending. In this paper, a stress analysis of welded tubular T joints, strengthened with doubler plates and subjected to axial compression, axial tension, in-plane and out-of-plane bending is conducted by using the finite element method. The study shows that the reinforced tubular joints are effectively strengthened only when they are subjected to axial compression. The joints perform as well as the corresponding unreinforced joints in withstanding axial tension and bending provided certain criteria for selecting the doubler plates are employed. The effects of the size of the doubler plates used for reinforcement are also studied and the results indicate that the size of the plates does not have significant effects on the SCF of the reinforced joints.

KEY WORDS : (Stress Concentrations) (Reinforced Joint) (Doubler Plate) (Tubular Joint)

1. Introduction

For offshore structures, a commonly used method to reinforce the tubular joints due to last minute alternations and/or to accommodate additional loading is to weld internal ring stiffeners. Nevertheless, this encounters accessibility problems when the diameter of the chord, on which the internal ring stiffener is to be welded, is less than 800mm. The doubler plates are then adopted as an alternative measure to reinforce the joints. Though such reinforcement can effectively improve the performance of the joints, in terms of avoiding punching shear failure under axial compression, it may bring negative effects in withstanding axial tension and bending moments. Thus, the study of the behavior of welded tubular joints reinforced with doubler plates, subjected to various loading conditions, remains important.

The fatigue problem is one of the most important factors to be considered in the design of offshore structures. This problem can be solved only after the stress concentration factors (SCF) for different tubular joints with or without reinforcement are obtained since the fatigue analysis of tubular joints depends critically on the stresses

presented in the weld toe area, where cracks are found to initiate and grow. For round-to-round unreinforced tubular joints subjected to various loading conditions, the empirical SCF formulae have been well established by many researchers (Kuang et al.¹⁾, UEG²⁾, Efthymiou and Durkin³⁾, and Hellier et al.⁴⁾. Soh and Soh^{5), 6)} have studied the uniplanar square-to-square and square-to-round tubular joints, subjected to both basic and combined loadings. In the case of reinforced tubular joints, the stress analysis of ring stiffened round-to-round tubular joints has been performed by Agostoni et al.⁷⁾ and Callan et al.⁸⁾. However, literature on SCF for welded tubular joints reinforced with doubler plates is hardly available, at least to the extent of the authors' knowledge.

The purpose of this paper is to present a numerical study on the doubler plate reinforced tubular joints and observe the behavior of the joints subjected to various loading conditions. The well established finite element software package called MARC^{9), 10)} is used. In addition, doubler plates with different sizes and shapes were studied. Comparison was made between the T round-to-round tubular joints, with and without doubler plates.

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2. Finite Element Model

The geometrical complexity of the tubular joints renders analytical solutions for their stress distributions extremely difficult to obtain. In such cases it is necessary to resort to numerical techniques such as the finite element method, which is suitable for the analysis of boundary value problems with complex geometry of this sort. In Fig. 1, the T welded round-to-round tubular joint reinforced with doubler plate is shown. When using the finite element method, it is vital to select the appropriate element type to ensure accurate modeling of the actual response of the structure. In general, it is sufficient to model an offshore tubular joint using isoparametric brick elements for the intersection region and shell elements for the rest of the joint. However, it is extremely tedious to maintain the compatibility conditions of all the nodes lying on the interface between the brick and shell elements. In this study, therefore, the 20 noded three dimensional isoparametric brick elements (MARC element type 21) are employed to model the whole reinforced tubular joint structure. The element has three translatory degrees of freedom u , v and w at each of the nodes with a $3 \times 3 \times 3$ integration scheme. The quadratic interpolation polynomials are used for both the coordinate and displacement interpolations.

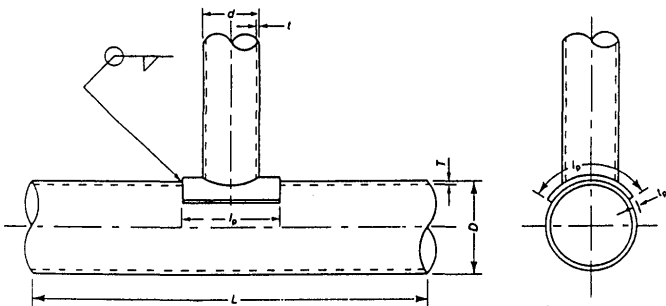


Fig. 1 Typical T welded tubular joint reinforced with doubler plate

Figure 2 shows a typical finite-element model devised for the investigation of T reinforced tubular joints. Only a quarter of the joint model is analyzed for axial loading due to the symmetry of the structure and loading condition. A half joint, which can be obtained from the quarter joint model by using mirror image technique provided by Mentat, must be used in case of bending as shown in Figs. 3 and 4. For all the cases, displacements normal to the plane of symmetry were restrained for all the nodes locating on the symmetry surfaces. Moreover, the ends of the chord are treated as simply supported so that all three displacement components of the nodes on the chord ends are restrained. As the chord

length is greater than 6 times the chord diameter, the stress at the brace/chord intersection is not affected by the chord end conditions. Gibstein¹¹⁾ has shown that for this chord length, the influence of chord length and end condition is marginal.

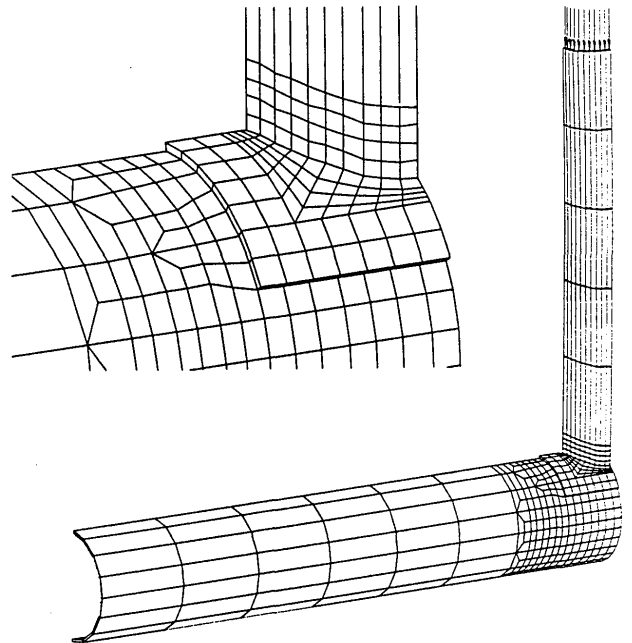


Fig. 2 Finite element model for T tubular joint reinforced with doubler plate subjected to axial load

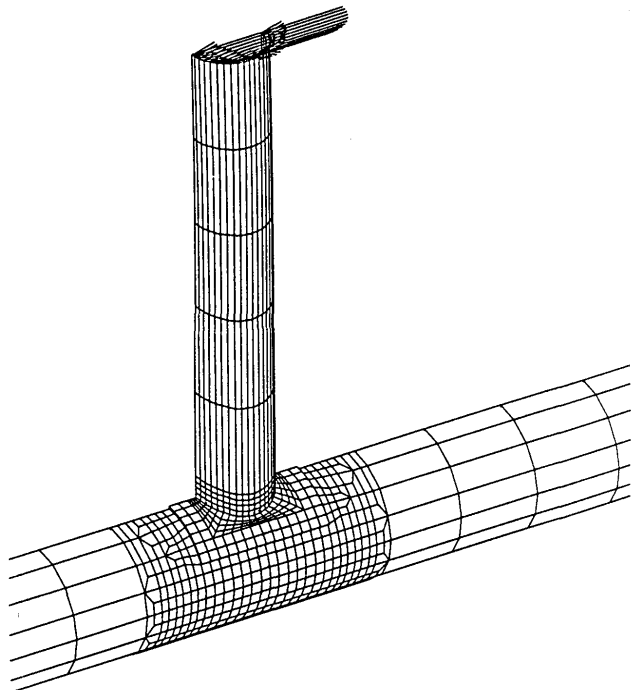


Fig. 3 Finite element model for T tubular joint reinforced with doubler plate subjected to in-plane bending

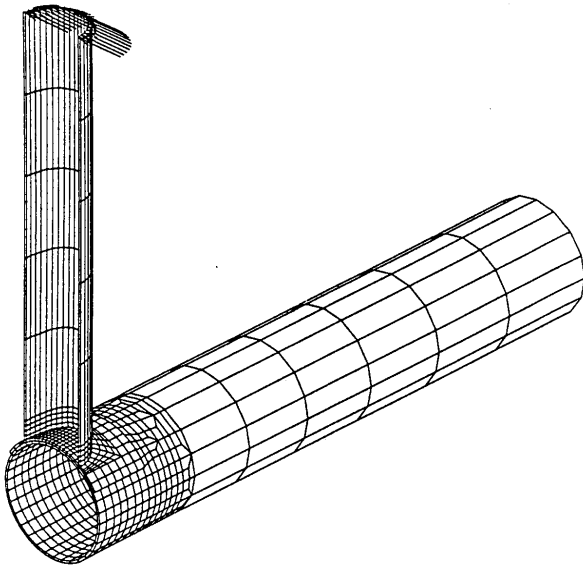


Fig. 4 Finite element model for T tubular joint reinforced with doubler plate subjected to out-of-plane bending

To study the rate of convergence of the finite element model employed, a comparison of computation time and accuracy has been conducted by varying the mesh size of the model. The number of elements required for the model in order to obtain converging stress results without using excessive computation time is identified. This process is commonly known as the convergence test.

A series of preliminary runs were performed on a one-quarter joint subjected to axial compression on the brace to determine the rate of convergence of the model. The optimum number of 20 noded brick elements for the one quarter reinforced T joint model is 540.

3. Stress Concentration Factors

In general, the SCF is defined as the ratio of the hot spot stress (i.e. the absolute maximum principal stress at the hot spot location) to the nominal stress. In the present study, SCFs were calculated for brace, chord, weld of the plate and chord separately. Unlike the unreinforced joints, a reinforced joint with doubler plate has different stress distribution when subjected to four types of basic loads through its brace: axial compression, axial tension, in-plane bending moment and out-of-plane bending moment. The SCFs were obtained by dividing the greatest principal stress at a given point around the intersection by the nominal stress in the brace for that mode of loading. The nominal stresses were calculated by dividing the total applied load by the cross section area of the brace in the case of axial loadings. For bending moments, the nominal stresses were derived from the simple beam theory using a moment arm measured from the brace end to crown position for in-plane bending, and to the saddle position for out-of-plane bending.

The steel material properties used in this investigation are assumed to have a modulus of elasticity (E) of 210 kN/mm² and a Poisson's ratio (ν) of 0.3. The SCF results, together with those corresponding to tubular joints without reinforcement obtained by other authors, are presented in Table 1.

Table 1 SCF comparison of the tubular joints with and without doubler plates ($d/D=0.60$, $t/T=1.0$, $t_p/t=1.0$, $D/T=45$, $L/D=10.22$, $d/l_p=0.57$)

Load type	Member	Reinforced Joints	Unreinforced Joint	
			UEG Guide	Efthymiou & Durkin
Axial Compression	Chord	6.57	24.44	24.54
	Brace	12.45	16.40	14.80
	Plate/Chord Weld	13.51	-	-
Axial Tension	Chord	6.56	24.44	24.54
	Brace	19.28	16.40	14.80
	Plate/Chord Weld	20.31	-	-
In-plane Bending	Chord	3.02	5.626	5.496
	Brace	6.72	4.544	3.756
	Plate/Chord Weld	5.94	-	-
Out-of-plane Bending	Chord	7.29	16.04	-
	Brace	15.28	11.11	-
	Plate/Chord Weld	14.55	-	-

From the above SCF analyses on reinforced tubular joints, we may conclude that the joints are as good as the corresponding unreinforced joints in withstanding axial tension and bending while their performance improves significantly under axial compression. Obviously, the size of the doubler plates used to strengthen the joints should play an important role on the performance of the reinforced joints. In this study, only the influence of the plate size (length and width) was investigated. The influence of the thickness on the overall performance of the reinforced joints will be studied in the future. The results show that the length and width of the doubler plate do not have significant effects on the hot spot stresses of the reinforced joints. However, the SCF in the chord/doubler plate intersection region can be reduced by simply smoothing the four corners of the square shaped doubler plate. This phenomenon would require further investigation to fully understand the effects of the configuration of doubler plate.

It should be pointed out that the doubler plate was not allowed to separate from the chord when the reinforced joints is analyzed under in-plane and out-of-plane bending, which may cause inaccuracies in the results listed in Table 1. Further investigation will be conducted by introducing the friction and gap link element provided by MARC to better simulate the mechanism between the chord and the doubler plate (refer to Fig. 5).

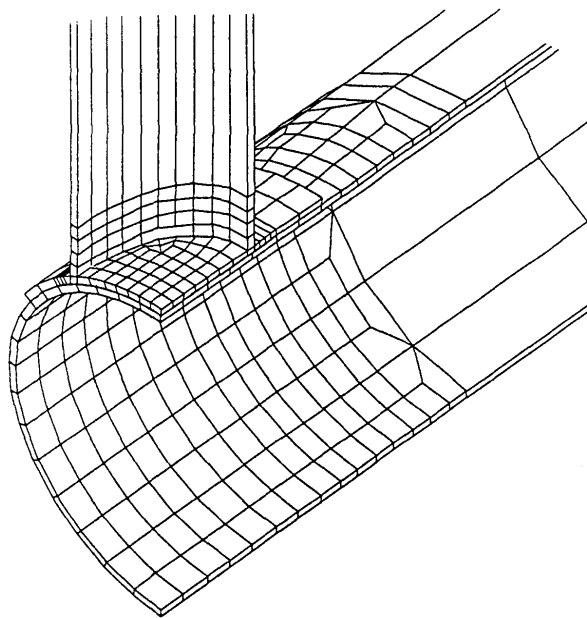


Fig. 5 Connection area of the chord and the doubler plate of reinforced T tubular joints

4. Conclusions

An SCF study has been carried out on T tubular joints reinforced with doubler plates and subjected to general loading. It shows that those reinforced joints would not cause more severe fatigue problems compared with the corresponding unstrengthened joints under axial tension and bending while significantly improving the performance under axial compression. The study also shows the length and width of the doubler plate do not have significant effects on the SCF of the strengthened joints. However, the configuration of the doubler plate may play an important role in terms of stress distribution around the intersection area. The corner smoothed doubler plates are recommended after both theoretical analysis and manufacturing practice are considered.

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