

A PARAMETRIC STUDY ON EFFICIENCY OF TUBULAR JOINT CANS IN OFFSHORE STRUCTURES

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Abstract- In offshore platforms, the tubular joints are widely used due to the structural advantages it possess. It should be noted that the efficiency of a tubular joint can is one of the deciding factor in extending the life span of the offshore platform. So for a designer, the proper selection of geometry for a joint holds a key priority. But the designers usually encounter a challenge in selecting the proper geometry due to the restriction in the available standard sizes in the market. In this study, API-RP-2A-WSD (American Petroleum Institute Recommended Practice Working Stress Design) for simple joints are critically reviewed and a parametric study is undertaken to study the load carrying capacity of tubular joint by varying diameter ratio and wall thickness ratio. A fixed jacket offshore platform model is analysed to get the internal force distribution of a simple tubular joint and in conjunction with the parametric study, the allowable load variation vis-a-vis the variation in internal loads are considered to realize the efficiency of tubular joint. A visual basic program is developed to determine the allowable axial stress and allowable in-plane bending and out-of-plane bending stresses in the simple tubular joint by incorporating recommendations from API-RP-2A-WSD for different parameters. Graphs are generated and depicts the behaviour of tubular joints.

Keywords- Allowable stress, Brace, Offshore, Tubular joint can.

I. INTRODUCTION

Life without oil would be very different as it has transformed the lives of individuals and economics of nations. In offshore platform the tubular joints is widely used due to the structural advantages it possess. However the tubular members creates a complicated geometry at the intersection of members i.e. joint can portion, which made a general practice among designers to use some standard sections for offshore structures. So it is necessary for designers to use the most efficient sections for joint can, which depict the necessity of a parametric study on joint can.

In this paper a mathematical model of a fixed jacket offshore platform is developed and analysed. Also a parametric study on a simple tubular welded joint of the platform for varying parameters, such as diameter ratio (β) and wall thickness ratio (T), is carried out.

II. LITERATURE REVIEW

Marshall and Toprac [2] proposed a design criteria of the codes that govern construction of offshore drilling platforms. The criteria presented have been developed primarily on the basis of research and experience with fixed offshore platforms. All simple T, Y and K connections are tested on a common basis. Although K connections have lower elastic stresses than the corresponding T and Y connections, they also have less reserve strength, so that the ultimate capacities come out similar. Also the various joint efficiencies were compared with well-illustrated

behaviour of geometrical parameters. Yura et al. [3] carried out a total of 137 ultimate strength tests on simple T, Y, DT, and K tubular joints is used as a basis for development of new ultimate capacity formulas. The data are taken from a variety of sources and only relatively large geometries are considered. Axial tension, axial compression, in-plane bending, and out of- plane bending loads are represented. The failure condition is taken as the minimum of either maximum load, first crack load, or load at an excessive deformation limit. Also some predictions of past and present API RP 2A formulas are compared to the same data base. It is found that the new equations are more consistent in their level of prediction and result in less scatter. The new equations are also relatively simple in format. Marshall [4] carried out a comparison on four sets of tubular connection design criteria for axially loaded circular tubes. The four criteria are AWS D1.1, API RP2A [1], ISO/WD 15-1.2, and ANSI/AISC 360-05. When comparing existing AWS-AISC criteria for circular tubular connections to CIDECT, both in 1992 and 2004, neither criteria appear to have significantly different errors on the unsafe side. It is observed that all the criteria capture the effect of t/T in the same way, but without explicit expression in point load criteria for T, Y, and X connections.

III. BASIC THEORY

A. Offshore Structure

An off shore structure can be defined as the installation of structure in marine environment, usually done for the production and transmission of

oils, electricity, gases or other resources from beneath the sea floor. Depending on the water depth & environmental conditions the structural arrangements varies. Based on the function, offshore structures may be classified as shown in Fig. 1.

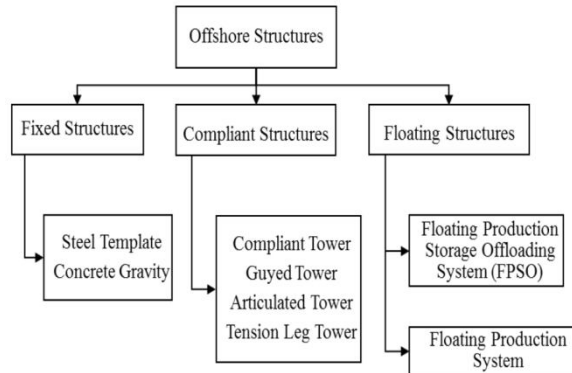


Fig. 1: Classification of offshore structures

B. Joint Can

The tubular members of an offshore structure are inter connected by welded joints. The welded joint consist of a chord (element of largest diameter) connected by one or more braces. These joints gives discontinuity to the structure which leads to stress concentration which in turn depends on joint configuration and loading type. Also it acts at a distance of almost half the diameter of the tubular member in both direction of the joints. Fig. 2 shows the region so formed around the joint having most of the stress concentration which is termed as Cans.

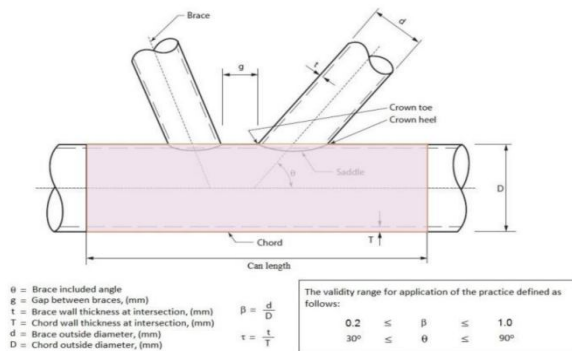


Fig. 2: Joint can details

C. Joint Can Parameters

Diameter ratio (β) – ratio of brace diameter to chord diameter (d/D). This parameter varies from 0 to 1.0 and gives an indication of the compactness of the joint. Wall thickness ratio (τ) – ratio of brace wall thickness to chord wall thickness (t/T). This parameter is used to determine the possibility of the brace fracturing before the chord wall fails.

IV. DESIGN OF TUBULAR JOINT

A. Basic Capacity of Simple Tubular Joint

Equation (1) and (2) is the basic capacity of simple tubular joints without overlap of principal braces and having no gussets, diaphragms, grout or stiffeners.

$$P_a = Q_u Q_f \frac{F_{yc} T^2}{FS \sin \theta} \quad (1)$$

$$M_a = Q_u Q_f \frac{F_{yc} T^2 d}{FS \sin \theta} \quad (2)$$

P_a refers to the allowable capacity for brace axial load, M_a refers to the allowable capacity for brace bending moment, Q_u refers to the strength factor, Q_f refers to the chord load factor, F_{yc} refers to the yield stress of the chord member at the joint (or 0.8 of the tensile strength, if less) in MPa, T denotes the chord wall thickness, FS refers to the factor of safety which is recommended as 1.60, d denotes the brace outside diameter and θ denotes the brace included angle. For simple, axially loaded Y and X joints where a thickened joint can is specified, the joint allowable axial capacity (P_a) shall not exceed the capacity limits referred in (3).

$$P_a = [r + (1 - r) (T_n / T_c)^2] (P_a)_c \quad (3)$$

$(P_a)_c$ refers to the allowable capacity for brace axial load as referred in (1), the value of parameter r is referred in (4) for $\beta \leq 0.9$ and as referred in (5) for $\beta > 0.9$, T_n refers to the nominal chord member thickness, T_c refers to the chord can thickness and in no case shall r be taken as greater than unity.

$$r = L_c / (2.5 D) \quad (4)$$

$$r = (4\beta - 3) L_c / (1.5 D) \quad (5)$$

L_c refers to the effective total length of chord and D denotes the chord outside diameter.

B. Basic Strength Factor, Q_u

Strength factor Q_u is defined as the theoretical ultimate strength of the simple joint. In order to include the effects of diameter ratio (β) into the punching shear criteria of X joints, the geometric factor Q_β as referred in (6) for $\beta > 0.6$ and as unity for $\beta \leq 0.6$. Also for the calculation of Q_u term for axial brace load in K joints a gap factor Q_g as referred in (7) for gap to outside chord diameter ratio (g/D) ≥ 0.05 and as referred in (8) for $g/D \leq -0.05$.

$$Q_\beta = \frac{0.3}{\beta (1 - 0.833 \beta)} \quad (6)$$

$$Q_g = 1 + 0.2 [1 - 2.8 g/D]^3 \quad (7)$$

$$Q_g = 0.13 + 0.65 \phi \gamma^{0.5} \quad (8)$$

Equation (9) gives the value of parameter ϕ and γ denotes chord thickness ratio. Linear interpolation between the limiting values referred in (7) and (8) may be used for $-0.05 < g/D < 0.05$ when this is otherwise permissible or unavoidable.

$$\phi = t F_{yb} / (T F_y) \quad (9)$$

t denotes the brace wall thickness at the intersection, F_{yb} refers to the yield stress of brace or brace stub if present (or 0.8 times the tensile strength if less) in MPa, T denotes the chord wall thickness at the intersection and F_y refers to the yield stress of chord in MPa. Q_u varies with the joint and load type as illustrated in table I.

Table I: Values of Strength factor, Q_u

Joint Type	Brace Load		
	Axial Tension	Axial Compression	In-Plane Bending
K	$(16 + 1.2\gamma) \beta^{1.2} Q_k$ but $\leq 40 \beta^{1.2} Q_k$		
T/Y	30β	$2.8 + (20 + 0.8\gamma)\beta^{1.6}$ but $\leq 2.8 + 36 \beta^{1.6}$	$(5 + 0.7\gamma)\beta^{1.2}$
X	23β for $\beta \leq 0.9$ $20.7 + (\beta - 0.9)(17\gamma - 220)$ for $\beta > 0.9$	$[2.8 + (12 + 0.1\gamma)\beta] Q_k$	$2.5 + (4.5 + 0.2\gamma)\beta^{2.6}$

C. Chord Load Factor, QF

Chord load factor, QF can be defined simply as the ratio of maximum brace load acting on a fully loaded chord to the maximum brace load acting on an unloaded chord. The chord load factor was calculated by using (10) to account for the presence of nominal loads in the chord.

Table II: Geometrical properties of brace for varying β

Set Number	1	2	3	4	5	6	7	8	9	10	11	12
Diameter, d_o (cm)	21.91	27.3	32.00	35.56	40.64	45.70	50.80	55.90	61.00	66.00	71.10	76.20
β value	0.205	0.255	0.299	0.332	0.380	0.427	0.475	0.522	0.570	0.617	0.664	0.712

$$Q_f = [1 + C_1 \left(\frac{FS P_c}{P_y} \right) - C_2 \left(\frac{FS M_{ipb}}{M_p} \right) - C_3 A^2] \quad (10)$$

$$A = \left[\left(\frac{FS P_c}{P_y} \right)^2 + \left(\frac{FS M_c}{M_p} \right)^2 \right]^{0.5} \quad (11)$$

Table III: Geometrical properties of brace for varying T

Set Number	1	2	3	4	5	6	7	8	9	10
Thickness, t_b (cm)	1.270	1.113	1.031	0.953	0.874	0.838	0.792	0.714	0.635	0.556
T value	0.363	0.318	0.294	0.272	0.250	0.239	0.226	0.204	0.181	0.159

C_1 , C_2 , and C_3 refers to the coefficients depending on joint and load type, Parameter A is referred in (11), P_c refers to the nominal axial load in chord, P_y refers to the yield axial capacity of the chord, M_p refers to the plastic moment capacity of the chord and M_c refers to the bending resultant.

D. Strength Check

The strength of joint is measured by joint interaction ratio (IR) for axial loads and/or bending moments in the brace. IR should be calculated using the expression referred in (12).

$$IR = \left| \frac{P}{P_a} \right| + \left(\frac{M}{M_a} \right)^2 ipb + \left| \frac{M}{M_a} \right| opb \leq 1.0 \quad (12)$$

P refers to the actual brace axial load acting on the joint, P_a refers to the allowable capacity for brace axial load, M refers to the actual brace bending moment for in-plane and out of plane bending and M_a refers to the allowable capacity for brace bending moment for in-plane and out of plane bending.

V. PARAMETRIC STUDY

A. Diameter Ratio (β)

The parametric study is carried out by varying the outside diameter of brace without varying thickness of the brace and geometry of the chord as shown in table II.

B. Wall thickness ratio (T)

In this case, the parametric study is carried out by varying the wall thickness of brace without varying

outside diameter of brace and geometry of the chord as shown in table III.

VI. RESULTS AND DISCUSSIONS

Fig. 3 gives the relationship between brace outside diameter plotted on the x-axis and allowable brace axial stress along the y-axis. It is observed that the allowable brace axial stress increases almost linearly with increase in brace outside diameter, but when it reach closer to the lower limit, a variation to the behaviour is seen.

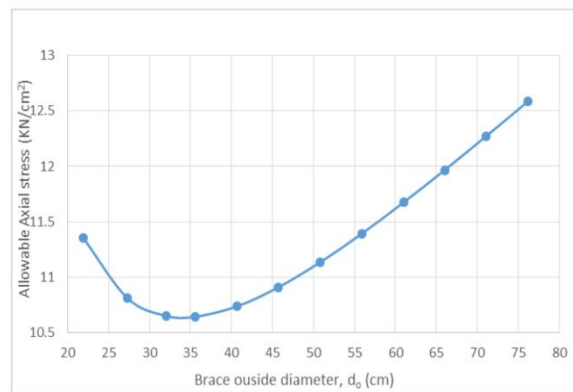


Fig. 3: Relationship between brace outside diameter and brace allowable axial stress

Fig. 4 shows the relationship between brace outside diameter plotted on the x-axis with allowable in-plane bending (IPB) stress along the y-axis. A gradual increase in allowable IPB stress takes place with increasing outside brace diameter.

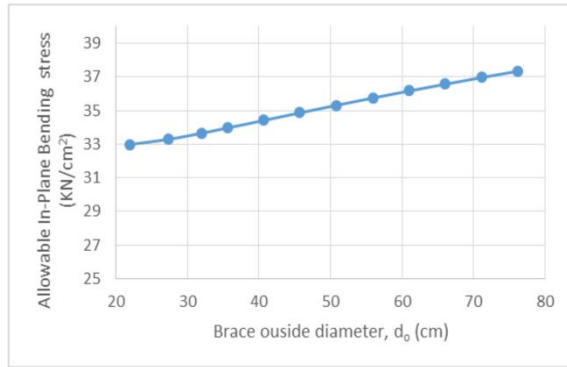


Fig. 4: Relationship between brace outside diameter and brace allowable in-plane bending stress

Fig. 5 gives the relationship between brace outside diameter plotted on the x-axis with allowable out-of-plane bending (OPB) stress along the y-axis. A remarkable decrease in allowable OPB stress takes place with increasing outside brace diameter.

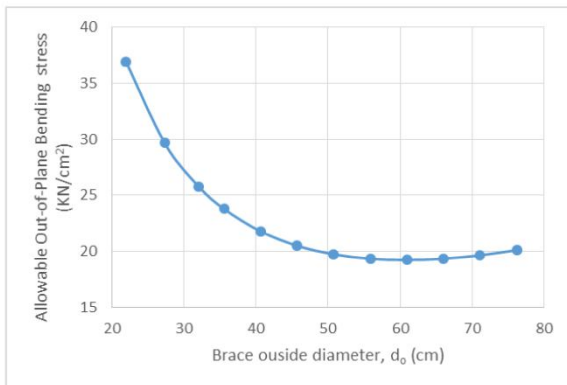


Fig. 5: Relationship between brace outside diameter and brace allowable out-of-plane bending stress

Fig. 6 shows the relationship between brace outside diameter plotted along x-axis and strength factor (Q_u) along y-axis. A linear increase in Q_u is observed with increase in brace outside diameter.

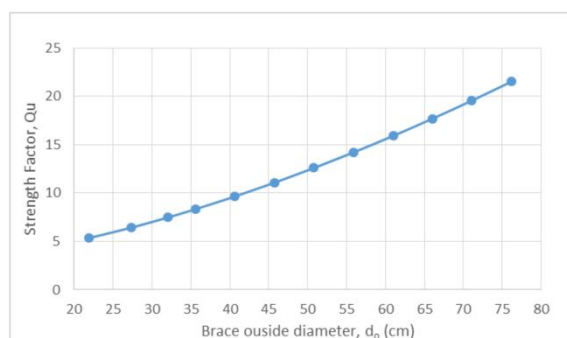


Fig. 6: Relationship between brace outside diameter and strength factor

Fig. 7 gives a relationship between brace thickness plotted in x-axis and brace allowable axial stress along y-axis. It is observed that with increase in brace thickness there is a remarkable decrease in brace allowable axial stress.

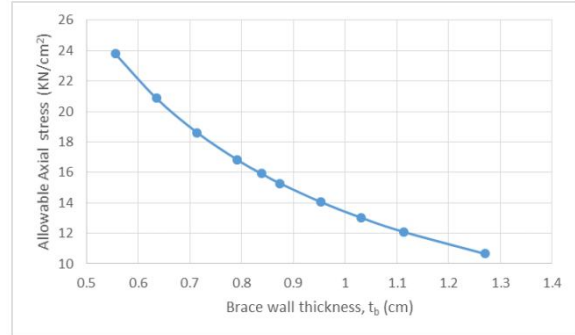


Fig. 7: Relationship between brace wall thickness and brace allowable axial stress

Fig. 8 gives the relationship between brace wall thickness plotted on the x-axis with allowable in-plane bending (IPB) stress along the y-axis. It is observed that with increase in brace wall thickness, allowable IPB stress in brace decreases considerably.

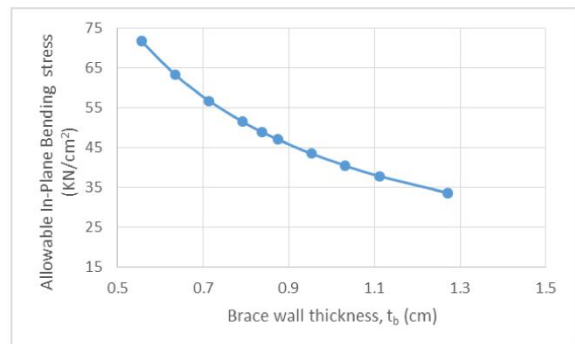


Fig. 8: Relationship between brace wall thickness and brace allowable in-plane bending stress

Fig. 9 gives the relationship between brace wall thickness plotted on the x-axis with allowable in-plane bending (IPB) stress along the y-axis. It is observed that with increase in brace wall thickness, allowable IPB stress in brace decreases considerably.

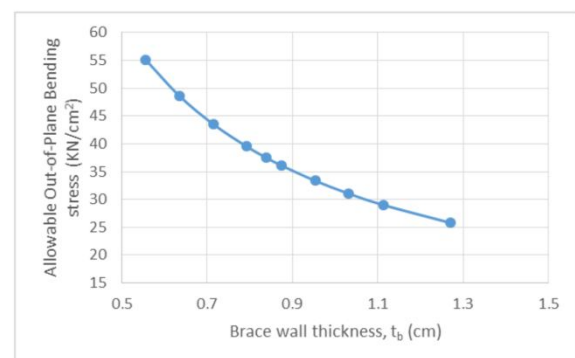


Fig. 9: Relationship between brace wall thickness and brace allowable out-of-plane bending stress

CONCLUSIONS

The parametric study is able to capture the behaviour of allowable load capacity of a simple tubular joint,

for varying diameter ratio (β) and wall thickness ratio (T). Hence from this study it can be concluded that within the validity range of the geometric parameter β , the allowable brace axial stress can be increased by increasing the brace outside diameter but outside the validity range this behaviour can't be relied on. Also if the designer need to increase the allowable brace axial stress of a joint where in-plane bending moment is predominant than out-of-plane bending moment, it is advisable to increase the brace outside diameter. From the parametric study of wall thickness ratio, it is inferred that in order to have an overall increase in axial and bending capacity of joint, it is recommended to decrease the brace wall thickness of the joint.

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