UNIVERSITI PUTRA MALAYSIA

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# STATIC STRENGTH OF ELLIPTICAL CHORDS T-TUBULAR JOINTS SUBJECTED TO MECHANICAL LOADING

**By**

**ABDALLA F. HAMED**

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## NOMENCLATURE

| | |
|---|---|
| +A | Axial tension load applied to a (whole) brace. |
| -A | Axial compression load applied to a (whole) brace. |
| $A^*$ | $A/\sigma_y T^2$ (Non dimensional form for –A and +A loads). |
| $B_\alpha$ | Pure bending couple applied to a (whole) brace at $\alpha$ angle. |
| B | Bending moment (in general). |
| IPB ($B_0$) | In-plane bending moment. |
| OPB ($B_{90}$) | Out-of-plane bending moment. |
| $B^*$ | $B/dT^2\sigma_y$ (Non dimensional form for IPB and OPB loads). |
| c | Suffix for combined loading. |
| C | Axial force in chord. |
| D, L, T | Chord diameter, length and wall thickness respectively. |
| d, l, t | Brace diameter, length and wall thickness respectively. |
| CYT | Type of joint with 4 braces in two orthogonal planes. |
| $K_a$ | Footprint length factor, ½ + ½ cosec$\theta$. |
| T | Type of joint with one brace $\theta = 90°$. |
| Y | Type of joint with one brace $\theta \neq 90°$. |
| s | Suffix for simple loading. |
| $\alpha$ | Inclination of plane of bending. |
| $\beta, \gamma, \iota$ | Shape ratios ( $\beta = d/D$, $\gamma = D/2T$, $\tau = t/T$). |
| $\psi$ | Total crack angle |

| | |
|---|---|
| $\sigma_u$ | Ultimate tensile strength(UTS) of model material. |
| $\sigma_y$ | Yield strength. |
| $P_u$ | Ultimate load. |
| $M_u$ | Ultimate moment at the chord surface. |
| $Q_\beta$ | Factor for effect of geometry. |
| $Q_g$ | K-joint gap modifying factor. |
| N, M | Ultimate capacities for joints under combined loads (axial and out of plane bending) |
| $N_u$, $M_u$ | Ultimate capacities for joints under pure axial and out of plane bending loads respectively. |
| $g_t$ | Transverse gap between braces. |
| $P_{u,K}$ | Predicted strength of planer K-joint. |
| $(P_u)_{nd}$ | Non-dimensional strength under anti-symmetrical loading ($P_u \sin\theta_c^{`} / \sigma_y T^2$). |
| $\beta^{`}$ | $= d^{`}/D = \{\sin[\Phi/2 + \sin^{-1}(\beta + 2e_t/D)]\}$. |
| $e_t$ | Out of plane eccentricity. |
| $\zeta_t$ | $= g_t/D$. |
| $\theta_c$ | Angle between chord axis and plane in which compression braces lie. |
| $\Phi$ | Out of plane angle between the planes in which the braces lie. |
| FE | Finite element. |
| FEA | Finite element analysis. |

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**Chairman: Associate Professor Ir. Dr. Barkawi Bin Sahari, Ph.D.**

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T –Tubular joints of elliptical and circular cross-section tubes for the main tube (chord) with circular cross-section tubes for the braces have been studied.

Experimental tests for the joint strength of these welded T-joints under tension, compression, in plane bending and out of plane bending have been carried out. A rig has been designed and built for that purpose. Three cases of T-joint connections were selected. For Case 1, the brace was perpendicular to the circular chord outer diameter. For Case 2, the brace was perpendicular to elliptical chord minor diameter and for Case 3, the brace was perpendicular to elliptical chord major diameter. The chord was held as fixed-fixed for all cases. The material used for all tubes was mild steel. The ultimate loads and ultimate moments obtained from the tests are converted to non-dimensional strengths throughout this investigation. This was done to make efficient comparisons.

Finite element models for similar T-joints have been developed and used to analyze the effect of axial loading and bending moment. Tension, compression, in-plane bending and out-of-plane bending load modes were studied.

A comparison between experimental results and finite element analysis was also carried out. Another comparison between experimental results and existing empirical equation results for similar circular chords tubular joints was also carried out.

The results extracted from this study for tension, compression, in-plane bending and out-of-plane bending modes for the ultimate loads and moments of Case 1, are 53.85 kN, 25.43 kN, 0.76 kN.m and 0.40 kN.m respectively. On the other hand, the results for Case 2 of the ultimate loads and moments are 42.48 kN, 18.39 kN, 0.63 kN.m and 0.37 kN.m respectively. While for Case 3 the ultimate loads and moments are 64.86 kN, 28.95 kN, 1.00 kN.m and 0.55 kN.m respectively.

The results obtained show that for axial tension and compression loading modes, Case 3 increases by 17.0% and 12.2% respectively when compared to Case 1 while 24.0% and 27.3% increase were found for in-plane and out-of-plane bending load modes respectively. This shows a significant improvement in the static strength for elliptical chords tubular joints (Case 3) under different loading modes when compared to circular chords tubular joints (Case 1).

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebalasion dari skeperluan untuk ijazah Master Sains.

**Kekuatan Statik Penyambungan Tiub T Dengan Tiub Utama Elip Dikenakan beban Mekanikal**

Oleh

**ABDALLA F. HAMED**

**November 1999**

**Pengerusi: Profesor Madya Ir. Dr. Barkawi bin Sahari, Ph.D.**

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Kajian sambungan tiub-T bagi keratan rentas bujur dan bulat untuk tiub utama dengan pengikat yang mempunyai keratan rentas berbentuk bulat telah dibuat.

Ujikaji untuk kekuatan sambungan-T yang dikimpal telah dijalankan dalam keadaan tegangan, mampatan dan lenturan planar. Satu radas ujikaji direkabentuk dan dibina untuk tujuan ini. Tiga kes sambungan T telah dipilih untuk kajian ini. Kes 1, pengikat adalah bersudut tepat kepada tiub utama yang berbentuk bulat pada garispusat major. Kes 2, pengikat adalah bersudut tepat dengan tiub utama membujur pada garispusat minor. Bagi Kes 3, pengikat adalah bersudut tepat dengan tiub utama pada garispusat major. Untuk semua kes, tiub utama berada pada kedudukan yang tertentu. Bahan yang digunakan untuk semua tiub adalah keluli lembut. Beban dan momen muktamad yang diperolehi daripada ujikaji ini telah ditukarkan kepada kekuatan tidak berdimensi. Ini dibuat untuk mendapat perbandingan yang rapi.

Model unsur terhuigga untuk sambungan-T yang serupa telah dihasilkan dan digunakan untuk menganalisis kesan beban paksi dan momen lenturan. Mod tegangan, mampatan, lenturan planar dan beban lenturan tak planar telah dikaji.

Suatu perbandingan di antara keputusan ujikaji dan analisis unsur terhuigga terhad telah dibuat. Tambahan pula, satu lagi perbandingan dengan tiub utama bulat juga telah dijalankan.

Keputusan kajian tentang daya mampatan pembengkokan di dalam satah dan pembengkokan di luar satah bagi beban maksima dan daya momen masing- masing adalah 53.85 kN, 25.43 kN, 0.76 kN.m dan 0.40 kN.m. Sebaliknya keputusan untuk Kes 2 bagi beban maksima dan daya momen masing-masing adalah 42.48 kN, 18.39 kN, 0.63 kN.m dan 0.37 kN.m. Manakala untuk Kes 3 pula beban maksima dan daya momen masing-masing adalah 64.86 kN, 28.95 kN, 1.00 kN.m dan 0.55 kN.m.

Keputusan yang diperolehi menunjukkan bahawa mod tegangan paksi dan beban mampatan untuk Kes 3 bertambah kepada 17.2% dan 12.2% jika dibandingkan dengan Kes 1 manakala pertambahan 24.0% dan 27.3% didapati untuk mod beban lenturan planar dan diluar planar. Ini menunjukkan pertambahan yang ketara dalam kekuatan statik sambungan tiub untuk tiub utama membujur (Kes 3) di bawah mod beban yang berlainan jika dibandingkan dengan sambungan tiub dengan tiub utama berbentuk bulat (Kes 1).

# CHAPTER I

# INTRODUCTION

It is well known that the tubular sections provide an outstanding strength in proportion to its weight compared to other shapes when all directions (x, y, z) are considered.

In the past the use of tubes was hampered because of connection details. But with the advent of welding, it is no more difficult to joined tubular shapes than it is to join rolled shapes. However, some problems have been encountered in actual construction in making welded joints that are both strong enough and yet economical. Although there is a wealth of information both experimental and analytical regarding the structural behavior of elements made of rolled I-shapes, the same is not true for the tubular sections. This is especially true for connections.

Designers have used a varied number of methods in trying to connect a tubular member either to another tube or a different shape. Some of these seem to be very expensive in detail while others appear weak and not safe. Some spectacular failures of important structures have been attributed to faulty connection design.

## Application of Tubular Joints

The tubular shapes, being very efficient, are used extensively in equipment, hardware construction, pipelines and industrial installation. The tubular shape components has been used both in buildings for columns and trusses. Tubular members are also used in many truss type construction which require long slender compression members, since the tubular cross-section exhibits a high strength to weight ratio.

Generally, steel hollow tubes welded together are used to form the offshore structure. Tubes of different sections have been used, and it is recognised that they are efficient in resisting axial, bending and torsional loads.

The circular cross-section tubes are preferable to other types of sections and used extensively in offshore structure because their drag characteristics minimize wave forces on the structure, and their closed cross-section provides for buoyancy needed during installation in the ocean environment.

## Types of Tubular Joints

Tubular structures are usually made of a few main large diameter tubes called chord welded with a number of smaller diameter tubes called braces. These chords and braces are joined to each other by welding. Stress-relief process such as annealing is essential for the joint region. In many cases non-destructive tests of the welded joints are also necessary.

## Loading Modes

In general, there are six different loading modes acting on any brace of a tubular joint. The most common single loading modes on a joint is axial tension (+A), axial compression (-A), out of plane bending ($B_{90}$), and in-plane bending ($B_0$). In many cases the chord in addition, is under axial compression or tension loads, and there are a few cases where the brace is under torsion moment also. For actual structures a combination of these loading modes may act on the same tubular joint at the same time. Bending at any angle $\alpha$ ($B_\alpha$) between the in-plane ($0^0$ bending) and out-of-plane bending ($90^0$ bending) cases exist often as a combination of in-plane-bending and out of plane-bending and this may combined also with axial loading.

## Material of Tubular Joints

Steel is the basic material for these tubular joints. Different types of steel are in use while mild steel is more common. Many investigations were carried out on circular steel tubular joints of different types for their ultimate failure strength. Other types of material such as aluminum, copper and lead-tin alloy were also used as tube material.

# Analysis of Tubular Joints

## Experimental Analysis

Experimental tests are generally the way to find the strength of any tubular joints because tubular joints are of intricate geometrical configuration; it is difficult to determine their stress distributions and ultimate static strength by means of closed form analytical method. Therefore, laboratory tests have been used as the primary means of obtaining these data. Most tests of joints for offshore structures are of model tests because the original structure joints are large in size for laboratory tests.

One of the main reliable collections of most of these tests are tabulated and supported by empirical equations at the Underwater Engineering Group (UEG) Handbook and the Department of Energy (U.K.) report. Experimental and empirical equations were developed for most types of circular tubular joints, while there is still gap for other shapes or cross-sections.

## Analytical Analysis

Finite element analysis of these tubular joints is the other approach for the subject. It is one of the most powerful methods, but still, in many cases expensive to run especially for elastic-plastic and creep problems.

Generally experimental tests are required as a guide or comparison tool for finite element investigation. It is an effective way to give extra confidence in the results obtained.

## Objectives

The main objectives of this work are:

1- To design and fabricate an experimental rig.

2- To fabricate T-joint models of circular and elliptical chords with circular braces.

3- To study the effect of elliptical chords on the static strength of T-tubular joints under different loading modes experimentally.

4- To predict the behavior of elliptical chords T-joints under different loading modes using finite element method.

5- To compare the experimental results with existing empirical equations.

6- To compare the experimental results with finite element results.

The thesis is divided into several chapters. A review of literature is presented in chapter 2. Chapter 3 describes the experimental work as well as the analytical work using the LUSAS software. Chapter 4 is concerned with the results obtained for the experimental work, finite element analysis, discussion of the results obtained and comparison between them. Chapter 5 presented the discussion of the work carried out. The conclusion of this work and recommendations for further work are presented in chapter 6.