



Faculty of Engineering  
Structural Engineering Department

# **THE ULTIMATE CAPACITY OF MULTI-PLANAR TUBULAR KK-JOINTS IN OFFSHORE STRUCTURES**

**By**

**Mahmoud Ahmed Mahmoud Khalaf**

B. Sc. (Honors) Civil Engineering - Structural Department  
Ain Shams University - June 2000

**A Thesis**

Submitted in Partial Fulfillement for the Requirements  
Of the Degree of Master of Science  
in Civil Engineering

**Supervised by**

Prof. Dr.

**Abdelrahim K. Dessouki**

Prof. of Steel Structures  
Structural Department  
Faculty of Engineering  
Ain Shams University

Dr.

**Sherif M. Ibrahim**

Assistant Prof. of Steel Structures  
Structural Department  
Faculty of Engineering  
Ain Shams University

**Cairo – 2008**

## **APPROVAL SHEET**

### **Examiners committee:**

Prof. Dr. Mokhtar Mahmoud Seddeik (.....)

Professor of Steel Structures

Faculty of Engineering

Cairo University

Prof. Dr. Hassan Ahmed Osman (.....)

Professor of Steel Structures

Faculty of Engineering

Ain Shams University

Prof. Dr. Abdelrahim Khalil Dessouki (.....)

Professor of Steel Structures

Faculty of Engineering

Ain Shams University

**Ain Shams University**  
**Faculty of Engineering**  
**Structural Engineering Department**

Abstract of M.Sc. Thesis submitted by:

Mahmoud Ahmed Mahmoud Khalaf

Title of the Thesis:

THE ULTIMATE CAPACITY OF MULTI-  
PLANAR TUBULAR KK-JOINTS IN  
OFFSHORE STRUCTURES

Supervisors: 1) Prof. Dr. Abdelrahim K. Dessouki

2) Dr. Sherif M. Ibrahim

Registration Date: 14/07/2003

Examination Date: 03/06/2008

## **ABSTRACT**

This research is concerned with the ultimate capacity of multi-planar tubular KK-joints in offshore structures under balanced axial loading. The effect of axially loaded chord under tension and compression is also covered in this research.

In this study a non-linear finite element model that takes into consideration both geometrical and material nonlinearities is presented to determine the ultimate capacity for three groups of unstiffened multi-planar tubular KK-joints.

Each group includes 48 specimens. The first group is investigated under no axial loading in chord, the second group is investigated under pre-loaded axial compression in chord and the third group is investigated under pre-loaded axial tension in the chord. The effect of varying the chord wall thickness, the brace diameter and the brace wall thickness on the ultimate capacity of joints is studied. One chord diameter for all the specimens was considered. In addition, different failure modes of joints are clearly detected. It was found that the increase of  $\beta$  (brace diameter to chord diameter) and  $\gamma$  (chord radius to chord wall thickness) increases the ultimate capacity while increasing  $\tau$  (brace wall thickness to chord wall thickness) has no effect on the joint strength. Also the joint strength decreases when the chord is axially loaded under compression while increases slightly when the chord is axially loaded under tension. Finally the general mode of failure was found to be chord bending (buckling) at the brace chord intersection zone.

All the results were compared with the design equations in API (Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, 2005). It was found that the design equations in the API are under predicting the ultimate capacity of multi-planar KK-Joints that failed under chord buckling even after eliminating all factors of safety except for the cases failed by brace local buckling.

A total of 108 joints with three different methods for reinforcing the chord member were investigated either using thick walled section (defined as CAN in offshore structures) at the brace/chord intersection, one internal annular ring stiffener inside of the chord member at the centre of the compression brace and two internal annular ring stiffeners, one at the centre of the compression brace and the other one at the centre of the tension brace. It was concluded that the ultimate capacity of joints stiffened with CAN achieved greater capacity than joints stiffened with annular ring stiffeners for  $\beta=0.4$  and  $0.6$  while for  $\beta=0.22$  joints with two internal ring stiffeners achieved higher capacities than CANNED joints.

**Keywords:** Offshore structures, tubular joints, ultimate capacity, multi-planar KK-joints, ring stiffened KK-joints.

## **ACKNOWLEDGMENT**

First and foremost, praise and thanks to Almighty Allah, the Most Gracious, the Most Merciful, and peace be upon His Prophet.

I would like to express my deepest gratitude and appreciation to my supervisor, Prof. Dr. Abdelrahim K. Dessouki for his invaluable guidance, support and encouragement.

I also greatly appreciate the help, guidance and support provided by Dr. Sherif M. Ibrahim throughout all stages of research.

Finally I would like to express my heartfelt appreciation to my father, my beloved mother, my dear wife and the whole family for lots of support and encouragement.

## **STATEMENT**

This dissertation is submitted to Ain Shams University – Faculty of Engineering for the degree of Master of Science in Structural Engineering.

The work included in this thesis has been carried out by the author in the Department of Structural Engineering, Ain Shams University, from August 2003 till May 2008.

This thesis was not submitted for a degree or a qualification at any other university or institution.

Date : 03/06/2008

Signature :

Name : Mahmoud Ahmed Mahmoud Khalaf

## **TABLE OF CONTENTS**

<b>APPROVAL SHEET .....</b>	<b>ii</b>
<b>ABSTRACT .....</b>	<b>iv</b>
<b>ACKNOWLEDGMENT .....</b>	<b>vi</b>
<b>STATEMENT .....</b>	<b>vii</b>
<b>TABLE OF CONTENTS .....</b>	<b>viii</b>
<b>LIST OF TABLES .....</b>	<b>xi</b>
<b>LIST OF FIGURES .....</b>	<b>xiii</b>
<b>NOTATIONS .....</b>	<b>xix</b>

### **CHAPTER1: INTRODUCTION**

1.1	General .....	1
1.1.1	Offshore structures .....	1
1.1.2	Tubular joints .....	4
1.2	Research Objective.....	11
1.3	Thesis Outlines .....	11
1.4	Literature Review .....	13
1.4.1	Unstiffened planar tubular joints.....	13
1.4.2	Stiffened planar tubular joints.....	32
1.4.3	Multi-planar tubular joints .....	39

### **CHAPETR 2 : FINITE ELEMENT OF MULTI-PLANAR**

#### **KK-JOINTS**

2.1	Introduction .....	49
2.2	Finite Element Method.....	49
2.3	Finite Element Computer Program used .....	50
2.4	Plate Element .....	51
2.5	Solution of Nonlinear Equations .....	52
2.5.1	Incremental control techniques .....	52
2.5.2	Iterative solution method .....	53
2.6	Geometrical Nonlinearity .....	54
2.6.1	Large strain analysis.....	54
2.6.2	Large deflection analysis .....	55



2.7	Material Nonlinearity .....	56
2.8	Verification of Finite Element Model .....	57
2.8.1	Tubular K-joints under balanced axial loading	58
2.8.2	Tubular multi-planar KK-joints under anti-symmetrical axial loading .....	70
2.8.3	Multi-planar KK-joints under symmetrical axial loading .....	75
<b>CHAPTER 3 : PARAMETRIC STUDY AND RESULTS</b>		
3.1	Introduction .....	80
3.2	Description of Joint .....	80
3.2.1	Geometry .....	82
3.2.2	Material .....	85
3.3	Loading and Boundary Conditions .....	87
3.4	Finite Element Meshing .....	89
3.5	Constant and Variable Parameters .....	91
3.6	Specimens Identification .....	92
3.7	Results .....	95
3.7.1	Effect of $\beta$ .....	95
3.7.2	Effect of $\gamma$ .....	100
3.7.3	Effect of $\tau$ .....	102
3.7.4	Effect of chord axial load .....	104
3.8	Failure Modes .....	110
<b>CHAPTER 4 : COMPARISON BETWEEN RESULTS AND DESIGN EQUATIONS IN API</b>		
4.1	Introduction .....	129
4.2	API Design Equations .....	129
4.3	Comparison of Results .....	132
4.4	Discussion .....	139
4.4.1	Compressed joints .....	139
4.4.2	Unloaded joints .....	140
4.4.3	Tensioned joints .....	140

## **CHAPTER 5 : STIFFENED JOINTS**

5.1	Introduction .....	142
5.2	Joints with CANS.....	144
5.3	Joints with Annular Stiffener .....	152
5.3.1	One annular stiffener.....	152
5.3.2	Two annular stiffeners .....	161
5.4	Efficiency of Stiffening Methods.....	170

## **CHAPTER 6 : SUMMARY AND CONCLUSIONS**

6.1	Summary .....	181
6.2	Conclusions .....	183
6.2.1	Effect of $\beta$ (brace to chord diameter ratio)..	183
6.2.2	Effect of $\gamma$ (chord radius to thickness ratio)..	183
6.2.3	Effect of $\tau$ (brace to chord thickness ratio) ...	183
6.2.4	Effect of chord axial load.....	184
6.2.5	API design equation evaluation .....	184
6.2.6	Chord Reinforcing.....	184
6.3	Recommendations for Future Work.....	185

## **REFERENCES**

## **APPENDIX**

## **LIST OF TABLES**

Table 1-1 – Tubular Joints Boundary Conditions Studied by Choo et al (2005) .....	32
Table 2-1 – Summary of the Geometric Parameters for FE Verification with Dexter and Lee (1999 A) .....	62
Table 2-2 – Comparison between Finite Element Results and Published FE Results of K-joints under Balanced Axial Loading .....	68
Table 2-3 – Summary of the Geometric Parameters for FE Verification of KK-joints under Anti-symmetrical Axial Loading .....	71
Table 2-4 – Comparison between FE Results and published Results (Lee and Wilmshurst 1997) of KK-joints under Anti-symmetrical Axial Loading .....	72
Table 2-5 – Summary of the Geometric Parameters for FE Verification of KK-Joints under Symmetrical Axial Loading .....	76
Table 2-6 – Comparison between Finite Element Results and Published Results (Lee and Wilmshurst 1996) of KK-Joints under Symmetrical Axial Loading .....	77
Table 3-1 – Scope of Parametric Study .....	81
Table 3-2 – Chord and Braces Outer Diameters and Wall Thicknesses .....	82
Table 3-3 – Specimens’ Identification .....	94
Table 3-4 – Specimens’ Modes of Failure for Compressed Joints .....	111
Table 3-5 – Specimens’ Modes of Failure for Unloaded Joints	114

Table 3-6 – Specimens’ Modes of Failure for Tensioned Joints	117
Table 4-1 – Values for $C_1$ , $C_2$ and $C_3$ .....	130
Table 4-2 – Values for $Q_u$ .....	131
Table 5-1 – Specimens’ Stiffened with CAN Modes of Failure for Compressed Chord Joint.....	145
Table 5-2 – Specimens’ Stiffened with CAN Modes of Failure for Unloaded Chord joint .....	146
Table 5-3 – Specimens’ Stiffened with CAN Modes of Failure for Tensioned Chord Joint.....	147
Table 5-4 – Specimens’ Stiffened with One Annular Ring Stiffener Modes of Failure for Compressed Chord Joint .....	153
Table 5-5 – Specimens’ Stiffened with One Annular Ring Stiffener Modes of Failure for Unloaded Chord Joint .....	154
Table 5-6 – Specimens’ Stiffened with One Annular Ring Stiffener Modes of Failure for Tensioned Chord Joint .....	155
Table 5-7 – Specimens’ Stiffened with Two Annular Ring Stiffeners Modes of Failure for Compressed Chord Joint .....	162
Table 5-8 – Specimens’ Stiffened with Two Annular Ring Stiffeners Modes of Failure for Unloaded Chord Joint .....	163
Table 5-9 – Specimens’ Stiffened with Two Annular Ring Stiffeners Modes of Failure for Tensioned Chord Joint .....	164

## **LIST OF FIGURES**

Figure 1-1 – Typical Four-legged Offshore Platform with Pile Inside Leg .....	2
Figure 1-2 – Offshore Jacket with Skirt Piles System.....	3
Figure 1-3 – Typical Planar Tubular Welded Joints.....	5
Figure 1-4 – Typical Multi-planar Tubular Welded Joints.....	6
Figure 1-5 – Typical Internally Ring-Stiffened Joint .....	7
Figure 1-6 – Typical Canned Joint (API 2005) .....	8
Figure 1-7 – Typical Overlapped K-Joint.....	8
Figure 1-8 – Typical Multi-planar KK-Joints.....	10
Figure 1-9 – Geometrical Dimensions of Completely Overlapped Tubular CHS Joint (Gho et al 2006) .	29
Figure 1-10 – Basic Dimensional Parameters of Reinforce T- Joint with Doubler Plate (Fung et al 1999).....	33
Figure 1-11 – A Six-hinge Failure Mechanism Model and the T-section Assumed at the Plastic Hinges (Lee and Llewelyn-Parry 2005) .....	37
Figure 1-12 – Chord Bending Failure Modes for KK-Joints ....	40
Figure 2-1 – Nonlinear 4-Node Quadrilateral Thin Shell (COSMOS/M, 2006) .....	52
Figure 2-2 – Force Control Technique (COSMOS/M, 2006) ...	53
Figure 2-3 – Modified Newton-Raphson Iterative Method (COSMOS/M, 2006) .....	54
Figure 2-4 – Large Strain Analysis (COSMOS/M, 2006).....	55
Figure 2-5 – Large Deflection Analysis (COSMOS/M, 2006) .	56

Figure 2-6 – Multi-linear Stress-Strain Curve (COSMOS/M, 2006) .....	57
Figure 2-7 – Loading and Boundary Conditions (Dexter and Lee 1999 A) .....	59
Figure 2-8 – Comparison between Load-Displacement of Thin and Thick Shell Elements for Specimen K_1_50_1.5 .....	64
Figure 2-9 – Comparison between Load-Displacement of Thin and Thick Shell Elements for Specimen K_1_50_0.4 .....	65
Figure 2-10 – Comparison between Load-Displacement for Specimen K_1_20_0.4.....	66
Figure 2-11 – Comparison between Load-Displacement for Specimen K_1_35_1 .....	67
Figure 2-12 – Finite Element Mesh (Specimen K_0.7_50_1.5) .....	69
Figure 2-13 – Deformed Shape (Specimen K_0.7_50_1.5) .....	70
Figure 2-14 – Finite Element Model (Specimen AS_KK_1) ....	73
Figure 2-15 – Deformed Shape for Anti-symmetrical Axially Loaded Specimen (Specimen AS_KK_1) .....	73
Figure 2-16 – Finite Element Model (Specimen AS_KK_6) ....	74
Figure 2-17 – Deformed Shape for Anti-symmetrical Axially Loaded Specimen (Specimen AS_KK_6) .....	74
Figure 2-18 – Chord Bending Failure Modes for KK-joints under Symmetrical Axial Loading (Lee at al. 1996) .....	78
Figure 2-19 – Finite Element Model (Specimen S_KK_6) .....	78

Figure 2-20 – Deformed Shape for Symmetrical Axially Loaded Specimen (Specimen S_KK_6) .....	79
Figure 3-1 – Typical Planer K-Joint (M.M.K. Lee and E.M. Dexter – 2005) .....	85
Figure 3-2 – Material Stress-Strain Curve (M.M.K. Lee and E.M. Dexter – 2005) .....	86
Figure 3-3 – Material Stress-Strain Curve Used in This Study .	87
Figure 3-4 – 3D View for KK Joint under Symmetrical Axial Loading .....	88
Figure 3-5 – Loading and Boundary Conditions Considered in the Study .....	89
Figure 3-6 – Typical FE Model for Brace Diameter = 219.075mm .....	90
Figure 3-7 – Typical FE Model for Brace Diameter = 406.4mm .....	90
Figure 3-8 – Typical FE Model for Brace Diameter = 609.6mm .....	91
Figure 3-9 – Effect of $\beta$ on Joint Strength ( $\gamma = 20$ - No axial Load in Chord).....	96
Figure 3-10 – Effect of $\beta$ on Joint Strength ( $\gamma = 40$ - No axial Load in Chord).....	97
Figure 3-11 – Effect of $\beta$ on Joint Strength ( $\gamma = 60$ - No axial Load in Chord).....	98
Figure 3-12 – Effect of $\beta$ on Joint Strength ( $\gamma = 80$ - No axial Load in Chord).....	99
Figure 3-13 – Effect of $\gamma$ on Joint Strength (No axial Load in Chord) .....	101