EFFECTS OF REINFORCEMENT ON THE ULTIMATE STRENGTH OF TUBULAR JOINTS OF OFFSHORE JACKET PLATFORM

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CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS

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Dissertation submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
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Supervised by,

Mr. Mohamed Mubarak Abdul Wahab

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Syed Ariff Shah Bin Syed Amear

ABSTRACT

The current status of the Oil and Gas industry in terms of technological advances in oil recovery techniques, and market forces, has lead to a requirement for offshore platforms to remain operational for longer than original estimations. The economics of such an extension to the service life will be more favorable if enhancement of the fatigue life prior to deterioration of the integrity of the structural components that may be expected as the structure approaches the end of its original design life. A grout filled tubular member with an unreinforced cementitious grout material, forming a composite load carrying section. The increase in load carrying capacity of the member is predominately in compression and bending. Tensile strength is not increase as the grout is only confined by the tubular and not attached directly to the end supports. In addition as the grout is unreinforced its tensile strength is small relative to its compressive strength. Written in this report are the details of research to determine the influence of grout injection in life span enhancement of tubular joints of jacket platform. In this research, author specifies the type of joint which is the T-joint. Results of the lab testing shows that grout filled tubular T-joints has the highest ultimate load compared to unreinforced or hollow tubular T-joints. However due to the presence of the grout, reinforcement has caused the specimen to be brittle. Failures of such reinforced tubular T-joints are sudden and abrupt without any yielding behaviour.

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INTRODUCTION

1.1Background of Study

1.1.1 Offshore Platform

An offshore platform, often referred to as an oil platform or an oil rig, is a large structure used to house workers and machinery needed to drill wells in the ocean bed, extract oil and/or natural gas, process the produced fluids, and ship or pipe them to shore. Depending on the circumstances, the platform may be fixed to the ocean floor, may consist of an artificial island, or may float.

Most offshore platforms are located on the continental shelf, though with advances in technology and increasing crude oil prices, drilling and production in deeper waters has become both feasible and economically viable. A typical platform may have around thirty wellheads located on the platform and directional drilling allows reservoirs to be accessed at both different depths and at remote positions up to 5 miles (8 kilometers) from the platform.

Remote subsea wells may also be connected to a platform by flow lines and by umbilical connections; these subsea solutions may consist of single wells or of a manifold centre for multiple wells.

1.1.2 Fixed Platform

A fixed platform consists of a welded tubular steel jacket, deck, and surface facility. The jacket and deck make up the foundation for the surface facilities. Piles driven into the seafloor secure the jacket. The water depth at the intended location dictates the height of the platform. Once the jacket is secured and the deck is installed, additional modules are added for drilling, production, and crew operations. Large, barge-mounted cranes position and secure the jacket prior to the installation of the topsides modules. Economic considerations limit development of fixed (rigid) platforms to water depths no greater than 1,500 ft.

Surface facilities (also known as topsides) are the part of the platform that contains the drilling, production, and crew quarter modules. The size of each module is dictated by the volume of fluid to be handled, the number of personnel needed to operate the facility and operations, and the potential expansion needed to accommodate future production from other fields. Combined, the topsides dimensions could be 200 feet by 200 feet per deck level, with four decks, resulting in an overall height of 100 feet.

A jacket is a tubular supporting structure for an offshore platform consisting of four, six, or eight 7- to 14-ft diameter tubulars welded together with pipe braces to form a stoollike structure. The jacket is secured to the seafloor by weight and 7-ft diameter piles that penetrate several hundreds of feet beneath the mudline. Typical base dimensions are 400 feet by 500 feet. Skirts are also added to aid the jacket in fixing it to the seafloor. At the water line, dimensions can range up to 150 feet on a side. The water depth that the topsides will reside in normally dictates jacket height.

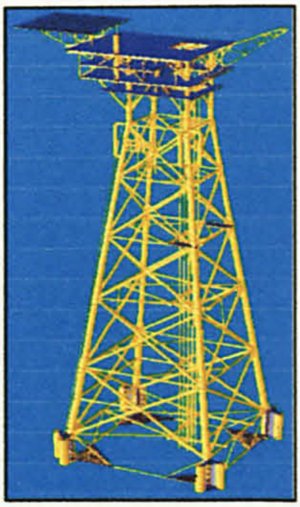

Figure 1: Steel Jacket Platform

1.2 Problem Statement

The current status of the Oil and Gas industry in terms of technological advances in oil recovery techniques, and market forces, has lead to a requirement for offshore platforms to remain operational for longer than original estimations. The economics of such an extension to the service life will be more favourable if enhancement of the fatigue life prior to deterioration of the integrity of the structural components that may be expected as the structure approaches the end of its original design life.

One such service life enhancement technique which may be of considerable benefit is the introduction of grout injection into tubular noes of the structure. The result would give a considerably stiffened bending of the chord walls such as occurs in conventional tubular nodes. Industrial practices experience suggests that these reduced Stress Concentration Factors (SCFs), and hence the hot spot stress range to which the critical areas will be subjected, may enhance the fatigue life of the node provided the mode of failure is not modified as a result.

However, the injection of the said grouting into tubular joints and members are done as part of the repair and maintenance schemes. The major advantage of using grouted connections is that the grouted annulus offers a large tolerance and therefore reduces fit-up problems. For this reason they are most suited to the repair damaged areas of structures where deformations from the as-built geometry have occurred; e.g. dents caused by impact.

Since grouting injection only being implemented as part of the repairing scheme, it can be consider that the structures are allowed to have a short life span. This life span is believed can be enhancing if grouting injection is included in the design requirement. From here, the issue of service life can be tackle at the beginning stage instead of doing a double job after damage has been done.

1.3 Project Objectives

The objective of the research is to determine the influence of grout injection in life span enhancement of tubular T-joint of jacket platform. The effects of considering grouting in the design stage are compared to the effects of grouting as part of the repair schemes. The effect of grouting as part of the repair scheme has been done before. So the testing for this research will only be on the scope of newly design tubular joint. This will be established by:

i. Determining the strength and ultimate load of unreinforced tubular T-joints
ii. Determining the strength and ultimate load of Grout filled tubular T-joints
iii. Determining the strength and ultimate load of Concrete filled tubular T-joints
iv. Comparing the strength of the three types of tubular T-joints

1.4 Theory

1.4.1 Definitions

Simple tubular joints, without the braces being overlapping with each other and also without gussets, diaphragms or stiffeners should use the guidelines given in the API RP2A. Terminology is defined in the figure below:

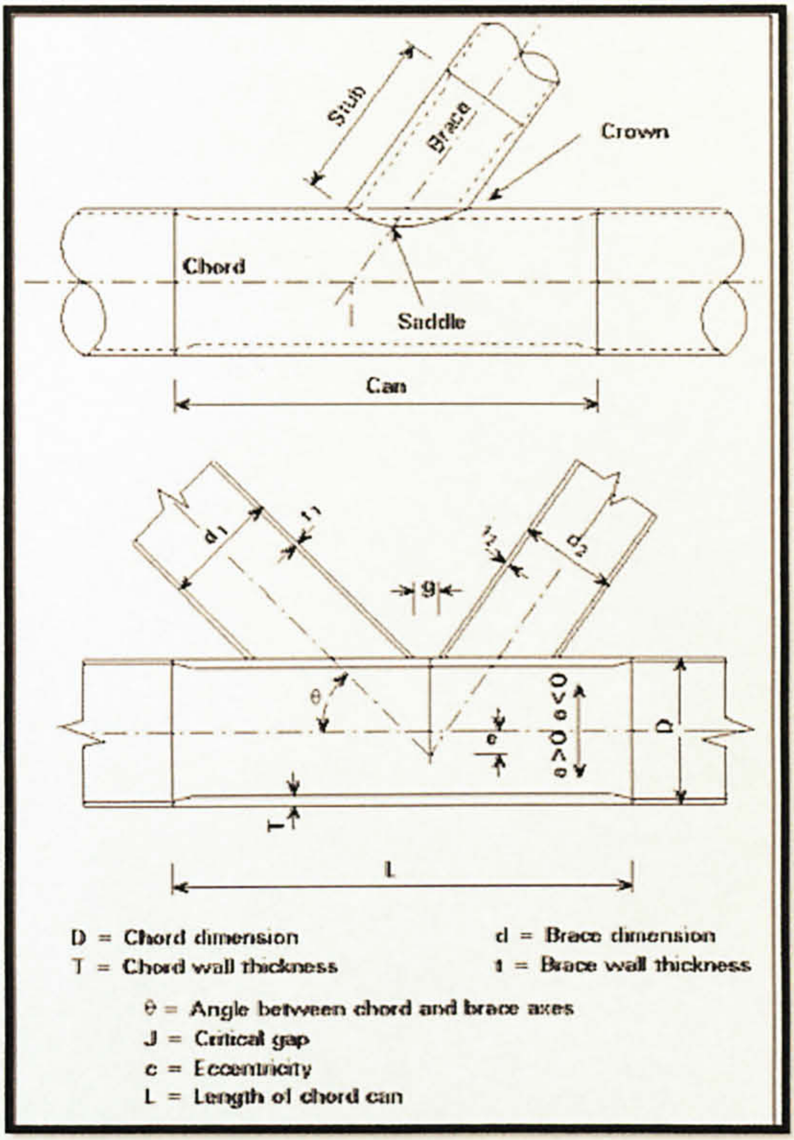

Figure 2: Definition

The CHORD is the main member, receiving the other components. It is necessarily a through member. The other tubulars are welded to it, without piercing through the chord at the intersection. Other tubulars belonging to the joint assembly may be as large as the chord, but they can never be larger. That is why it is sometimes called primary chord.

The CAN is the section where the thickness of the chord is higher compared to the other section as part of reinforcement.

The BRACES are the structural members which are welded to the chord. They physically terminate on the chord skin.

The STUB is the extreme section of the brace where the wall thickness is increased as the reinforcement.

Different positions have to be identified along the brace - chord intersection line:

- CROWN position is located where the brace to chord intersection crosses the plane containing the brace and chord.
- SADDLE position is located where the brace to chord intersection crosses the plane perpendicular to the plane containing the brace and chord, which also contains the brace axis.

Geometrical definitions ***(Refer to Figure 2)***

L is the length of the chord can

D is the chord outside diameter

T is the chord wall thickness

d is the brace outside diameter

t is the brace wall thickness (where there are several braces, a subscript identifies the brace)

g is the theoretical gap between weld toes e is the eccentricity, Positive when opposite to the brace side, Negative when on the brace side

θ is the angle between brace and chord axis.

1.4.2 Geometrical ratios

Can Slenderness Ratio

$$\alpha = \frac{2L}{D}$$

Brace to chord diameter ratio

$$\beta = \frac{d}{D} \text{ (always 1)}$$

Chord slenderness ratio

$$\gamma = \frac{D}{2T}$$

Brace to chord thickness ratio

$$\tau = \frac{t}{T}$$

Relative gap

$$\zeta = \frac{g}{D}$$

These are non-dimensional variables for use in parametrical equations.

1.4.3 Classifications

Tubular joints have different types and each type has its own geometry. This geometry is very important as it determine the load paths within the joint. This differ one type of joint to another. The following general classification is used, see Figure 3.

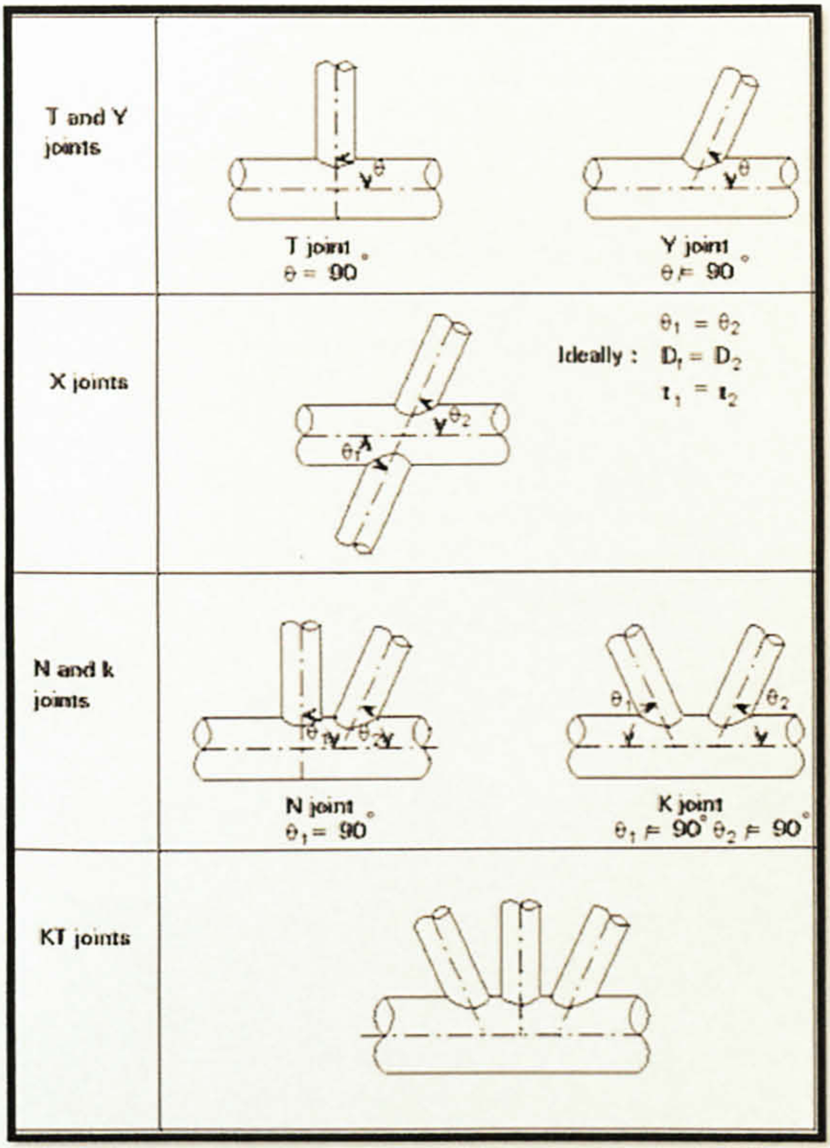

Figure 3: Joint Classification

T and Y Joints

These are joints made up of a single brace, perpendicular to the chord (T joint). When the brace is inclined to the chord, it becomes Y joints. In a T joint, the axial force acting in the brace is reacted by bending in the chord. In a Y joint, the axial force is reacted by bending and axial force in the chord.

X Joints

X joints include two coaxial braces on either side of the chord. Axial forces are balanced in the braces, which in an ideal X joint have the same diameter and thickness. In fact, other considerations such as brace length, which can be very different on each side of the chord, may lead to two slightly different braces. Angles may be slightly different as well. The most significant different of X joint is that the forces in the braces are balanced of each other. If the axial forces are not balance, it is not considered as X joint anymore.

N and K Joints

These joints have two braces. One of them may be perpendicular to the chord (N joint) or both inclined (K joint). The ideal load pattern of these joints is reached when axial forces are balanced in the braces, i.e. net force into chord member is low.

KT Joints

These joints include three braces. The load pattern for these joints is more complex. Ideally axial forces should be balanced within the braces, i.e. net force into chord member is low.

1.5 Scope of Study

1.5.1 Geometry Limitations

The geometrical ratios discussed above have limitations. These limitations determine the feasibility to be fabricated and to be effective. Table below shows the limitations and their range of values.

Table 1: Geometrical Limits and Typical Ranges

Parameter	Typical range	Limitations	
		Min	max
$\beta=\frac{d}{D}$	0.4 – 0.8	0.2	1
$\gamma=\frac{D}{2T}$	12 - 20	10	30
$\tau=\frac{t}{T}$	0.3 – 0.7	0.2	1
θ	40deg-90 deg	30 deg	90 deg

1.5.2 Static Strength

In the static strength of a tubular joint, there are three forces should be taken into considerations. They are the axial force, the in-plane bending moment and the out-of-plane bending moment for each brace.

The other components (transverse shear and brace torsion moment) are usually neglected since unlike the preceding loads, these loads do not induce bending in the chord wall. However, they are should not be totally neglected as sometimes it do occur in special cases. The axial load, in-plane and out-of-plane bending moments are normally the dimensioning criterion for tubular joints.

1.5.3 Punching shear

Shear stess developed by the brace load acting on the chord is called punching shear. The acting punching stress v_p can be written as below:

$v_p = \tau \, f \sin \theta$

where, f is the nominal axial, in-plane bending or out-of-plane bending stress in the brace (punching shear for each kept separate), see Figure 4.

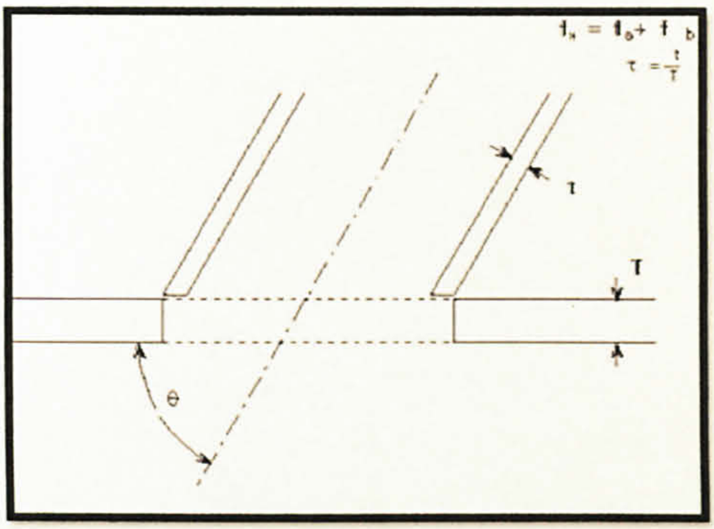

Figure 4 : Punching Shear

1.5.4 Stress Concentration

During fabrication, chord and brace are connected by welding. The weld connection causing discontinuities in the joints. This discontinuity of body causes the stresses acting on the connection of brace and chord are not uniform. Figure 5 shows an example of the stress distribution in a joint with local discontinuities at and in the vicinity of the brace chord intersection.

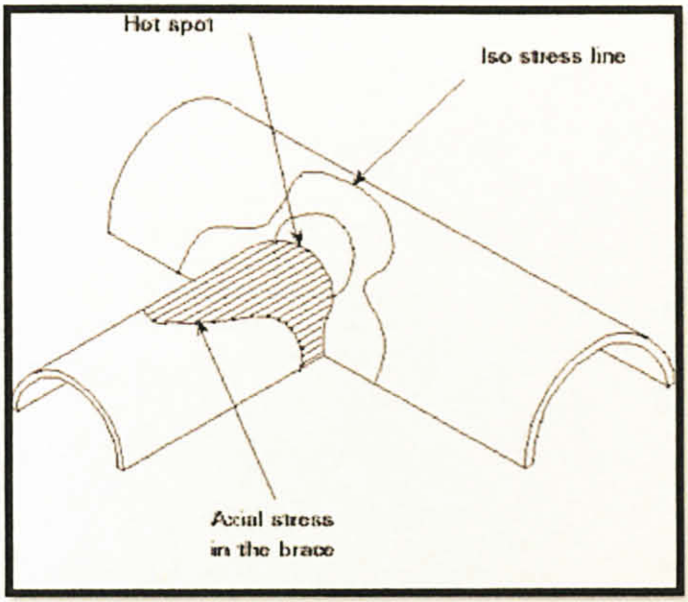

Figure 5: Stresses in a T-Node

1.5.5 Reinforced joints

Reinforcement or stiffening of the chord is to strengthen the chord by reducing the wall thickness. Ring stiffening inside the chord is the common reinforcement did on tubular joints. Reinforcement is the best option when a large diameter of chord requires larger wall thickness which in this case is not economical. There are very many different stiffening solutions for a large diameter chord. Therefore there are no parametric formulae available for these designs. Specific analyses must therefore be carried out for an accurate solution. This may involve finite element analysis. However due to time and resources constraint, this research will not involve any finite element analysis.

1.5.5.1 Ring Stiffening

Ring stiffening consists of ring plates welded in the chord can prior to welding the braces to it. The punching shear capacity of the chord still may be taken into account when calculating the forces acting on the stiffeners.

Ring stiffeners can be justified through parametric formulae available in various publications, the best known being published by Roark [7].

1.5.5.2 Filled Tubular Joints

1.5.5.2 (a) Definitions and Introduction

A grout filled tubular member filled with an unreinforced cementitious grout material, forming a composite load carrying section. The increase in load carrying capacity of the member is predominately in compression and bending. Tensile strength is not increase as the grout is only confined by the tubular and not attached directly to the end supports. In addition as the grout is unreinforced its tensile strength is small relative to its compressive strength. [2]

A method of calculating the load-deflection behavior and ultimate load for an eccentrically loaded concrete filled tubular member was developed previously and compared with the results of tests on columns of circular cross-section. Generally good agreement was obtained although the method is conservation in estimating the strength of stocky columns (L/D <15) [2]

1.5.5.2 (b) Applications [2]

Grout filled tubular can be used either as a repair method or as a strengthening method for new members. The major uses of grouted tubular are:

i. To increase the capacity compression and bending of existing members in a structures To increase the capacity of members in vulnerable areas (e.g. adjacent to boat landing) to resist local damage due to impact
ii. To increase the capacity of damaged members that are locally buckled, dented or bent.

1.5.5.2 (c) Factors affecting the strength of grouted tubular [2]

The following factors have been demonstrated to affect the strength of grouted tubular members and design guidance is offered on these:

i. Tubular geometry: length (L), diameter (D), wall thickness (T)
ii. Material properties of both steel tubular and grout
iii. Initial imperfections and other imperfections (damages before application of grout)

CHAPTER 2

LITERATURE REVIEW

2.0 Literature Review

Review for the study was taken abundantly from journals and the internet. Basically, spot to be highlighted for the study consists of tubular joints of offshore jacket platforms as well as the grouting effects on the performance of the tubular joints and the tubular member. Here are some notes taken for the study:

2.1 Grouted and Mechanical Strengthening and Repair of Tubular Steel Offshore Structures

By R G Harwood & E P Shuttleworth

The use of grouted and mechanical repair systems in underwater applications has increased dramatically due to the increased number of repairs being effected as designers and operators recognise the cost effectiveness of grouted and mechanical repairs and the availibility of test data describing their performance. There is no standard repair scheme however components within the various grounted and mechanical repair schemes that have already been employed are defined below:

i. Grounted Connection:

   A connection between two concentric tubulars formed by the injection of a cemetitious material into the annulur space between the tubulars. *(Unless specifically stated the outer tubular is taken to be continuous in the circumferential direction.)*

ii. Grouted Clamp:

   A clamp in which the outer sleeve is formed in two or more segments which are placed around an existing tubular joint. The splits are closed by pre-tightened bolts prior to the injection of a cementitious material into the annulur space between the clamp and the existing tubular joints.

iii. Mechanical Connection:

A connection formed between two concentric tubulars relying for load transfer on the friction capacity of the interface between the two tubulars. The outer tubular will be formed from two or more segments which are stressed together to generate a force normal to the friction surface.

iv. Mechanical Clamp:

A clamp in which the outer sleeve is formed in two or more segments which are placed around an existing tubular joint. The clamp body will be formed from two or more segments which are stressed together to provide the load path in the clamp.

v. Stressed Grouted Connection:

A connection formed between two concentric tubulars. The outer tubular is formed in two or more segments. Cementitious material is placed into the annular space between the tubular and allowed to reach a predefined strength prior to the application of an external stressing force normal to the steel-grout interface.

vi. Stressed Grouted Clamp:

A clamp in which the outer sleeve is formed in two or more segments which are placed around an existing tubular joint. Cementitious material is placed into the annular space between the clamp and the existing tubular joint and allowed to reach a predefined strength prior to the application of an external stressing force normal to the steel-grout interface.

vii. Grout Filled Tubular :

A tubular which has been filled with a cementitious material

2.2 The Punching Shear Strength of Tubular Joints Reinforced with Agrouted Pile

By I.E. Tebbett, Wimpey Laboratories Ltd.; C.D. Beckett, British Petroelum (Trading) Ltd.; and C.J. Billington, Wimpey Laboratories Ltd.

The majority of offshore steel jackets are connected to the seabed by tubular steel piles. The piles pass through the main legs, or skirt pile sleeves, and are driven into the seabed or placed and grouted into predrilled holes .The connection between pile and leg is usually made by welding the pile to the top of the leg however in many structures the annulus between each pile and leg or skirt pile sleeve is filled with cement grout. Grouting reduces corrosion of the pile and inside of the leg, improves the mechanism of load transfer by achieving continuous transfer along the leg and provides some reinforcement to the brace to leg joints. Presence of a pile and grout annulus results in an increased punching shear resistance of tubular joints in the main leg.

Basically, the ultimate strength of grouted joints of the geometry considered will significantly enhanced for axial tension, axial compression and in-plane bending load cases. For combined load cases in which brace stresses are all compressive, the possibility of punching shear failure is discounted and it can be shown that member stresses are the critical design criteria for static loading. Stress concentration factor of the joint is reduced due to the presence of a pile and grout annulus implying a corresponding increase in the fatigue life of the joint.

2.3 Joints of Offshore Platform

By Dr T S Thandavamoorthy, Non-member

Steel tubular framed structures or also known as offshore platforms are installed on the sea bed for the exploration and production of oil from the sea bottom. To support drilling and production facilities above the level of waves. The most popular structure for shallow water depth is the jacket or template platform that is fabricated mostly out of cylindrical steel tubular sections due to their merit over other structural shapes.

The typical structure consists of a deck, a substructure, and foundation piles. The substructure is a prefabricated tubular space frame, which extends from the sea floor to just above the sea surface, and is usually fabricated in one piece onshore, transported by barge, launched at sea, and upended on site by partial flooding. Tubular pilings are driven through the main legs to fix the structure to the sea bottom, provide support for the deck, and resist the lateral loads due to wind, waves and currents.

In the tubular frame, it consists tubular connection which are the intersection between two or more members, at least one of which is a tubular member. In the tubular connection, the intersection between various members is welded and thus forms a joint called welded tubular joint. Due to the welding process, massive heat is generated and hence the intersection becomes a heat-affected zone. Therefore, the joint in addition to the segments of various members, also consists of the weld deposit, heat-affected zone and the base metal at the intersection5.

The main member is denoted as chord and the secondary member as brace or branch. The outside diameter of the brace is less than or equal to that of the chord. A joint reinforced with welding of annular rings inside the chord at the welding intersection is called internally ring-stiffened joint. Internally ring-stiffened tubular joints are used widely in the construction of fixed steel as it will strengthen the joints, whereby internally ring stiffened joint is almost twice strong as the unstiffened joint of the same configuration and dimensions. Arrangement also imparted

enormous bending stiffness to the chord as a whole .Besides, by reducing the hot spot stresses around the chord/brace intersection due to the loads which the nodes are subject to in service.

2.4 Fatigue Life Enhancement of Tubular Joints by Group Injection

By Baker Jardine for The Health and Safety Executive

A requirement for offshore platforms to remain operational for longer than original estimations is needed due to the technologies advance. The economics of such an extension to the service life will be more favorable if action is taken to enhance the fatigue life prior to deterioration of the integrity of the structural components, that may be expected as the structure approaches the end of its original design life.

One such fatigue life enhancement technique which may be of considerable benefit is the introduction of grout into critical tubular nodes of the structure ,whereby grout considerably reduces the stresses generated under axial and out-of-plane bending conditions thereby reducing the stress and strain concentration factors around the brace/chord intersection weld. Besides, grout would appear to have the potential to increase the static capability

2.5 Fatigue and Ultimate Strengths of Concrete Filled Tubular K-Joints on Truss Girder

By Pison Udomworarat,Chitoshi Miki,Atsushi Ichikawa,Eiichi Sasaki,Takuya Sakamoto,Kaoru Mitsuki,Tetuya Hosaka

Steel tubular are used in many structural systems as it provides excellent buckling behavior, omni-directional strength. This particular structural system has a smaller surface area and in the absence of sharp corner, results a better performance for corrosion protection. When used in structures subjected to repetitive loads, however fatigue problems maybe occur in and around welded tubular joints.

A dominant factor affecting fatigue resistance of the tubular truss girder is high stress concentration at the intersection of chord and diagonal panel members where the local high stresses are the result of local bending and membrane stresses in the crown of the chord members between the diagonal members. Thus, concrete is used to fill the hollow tubes in the region of the joint to improve the structural performance of the panel joint of truss

2.6 Parametric Study of Hot Spot Stresses around Tubular Joints with Doubler Plates

A. Nazari1; Z. Guan2; W. J. T. Daniel3; and H. Gurgenci4

Structural designers use parametric equations to convert results of simple beam models to detailed hot spot stress distributions. Knowledge of hot spot stresses improves fatigue performance predictions. This paper extends the use of the parametric equation approach to joints with extra stiffening such as doubler plates. Doubler plates are commonly used on tubular structural joints against actual or anticipated punching shear failure.

Reinforced tubular T, Y, K, X, and DT joints with and without doubler plates are considered. Results without doubler plates are compared against past studies and also the recommended design formulas used in international codes. Finally, a sensitivity analysis is performed describing the effect of joint geometry variations on the stress concentration factor values.

CHAPTER 3

METHODOLGY

3.1 Specimen Design

The joints that will be used are the single T configurations as shown in Figure 6 where the dimension will be the constant variable. The diameter of chord is 89.5mm and nominal wall thickness of 4mm. The brace to chord diameter ration, beta, is 0.55 and the brace to chord wall thickness ratio, tau, is 0.8. Full geometric parameters are presented in Table 1.

Nine (9) specimens were fabricated with constant geometric parameters. Three (3) specimens are empty tubular T-joints; three (3) specimens are reinforced with SikaGrout 215 while the other three (3) are reinforced with concrete.

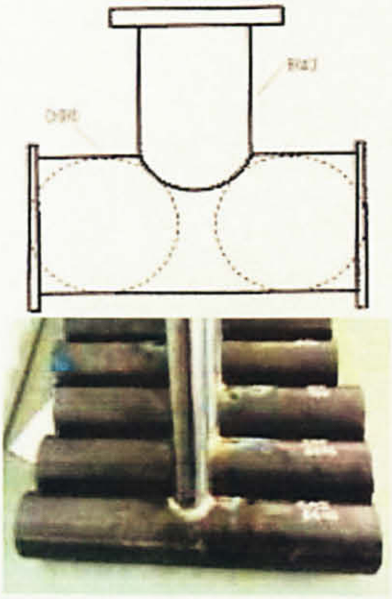

Figure 6: T-joint

Table 2: Specimen Geometric Parameters

Specimen	Member	D, d (mm)	T, t (mm)	Alpha, α	Beta, β	Gamma, γ	Tau, τ
E1	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
E2	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
E3	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
G1	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
G2	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
G3	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
C1	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
C2	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				
C3	Chord	89.5	4	10.5	0.55	11.19	0.8
	Brace	48.8	3.2				

Alpha = 2 x Chord Length / Chord diameter (2L/D)

Beta = Brace diameter / Chord diameter (d/D)

Gamma = Chord diameter / 2 x Chord wall thickness (D/2T)

Tau = Brace wall thickness / Chord wall thickness (t/T)

3.2 Grout Material

SikaGrout-215 is a pumpable dual-shrinkage compensated, self-levelling, prebagged cementitious grout with extended time to suit local ambient temperatures. The advantages of this particular type of grout compared to the other types of grout are as below:

- Good flow characteristics
- Rapid strength development
- High ultimate strength
- Non-corrosive
- Extended working time
- Good pumping properties

This grout is in grey premixed powder with wet density of approximately 2.20kg/L. There are three types of consistency recommended in the product data sheet and there are flowable, pourable and stiff. Pourable is chosen due to our specimen design and also to have an average condition of two extreme. The compressive strength for 28 days is 76N/mm^2

Table 3: Mix Ratio

Consistency	Water (Litres) per 25 kg of Grout
Flowable	4.0-4.4
Pourable	3.6-4.0
Stiff	3.0-3.4 (for special applications such as anchoring of starter bars)

3.2.1 Grout Mixing Procedures

1. The whole bag of SikaGrout-215 is added to a small concrete mixer.
2. About 70-80% of premeasured clean water (3.2L out of 4.0L) is then gradually added to the grout while mixing was starting.
3. After about 1 minute, the remaining water is then added.
4. Mixing continued for 2 to 3 more minutes until desired consistency is obtained.

3.3 Concrete Mix Design

Concrete with the characteristics strength of 40N/mm2 at 28 days is specified. The concrete mix was design in accordance to BS 1881: Part 125: 1986. The design mix form is attached in the Appendices. The premeasured quantities of the aggregates and water are shown in the table below.

Table 4: Premeasured quantities of the aggregates and water

Quantities	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregates (kg)
Per m^3(nearest 5kg)	466.66	233.33	502.503	1172.507
Per trial mix of 0.033	15.40	7.70	16.58	38.69

3.3.1 Concrete Mixing Procedures

1. Weight the quantities of cement, sand and course aggregates as calculated in the mix design to make 1:2:4 concrete mixes at water ration of 0.5.
2. Wet the concrete mixer.
3. Pour aggregate and mix 25 seconds.
4. Add half of water and mix for 1 minute and leave for 8 minutes.
5. Add cement and mix for 1 minute.
6. Add remaining water available and mix for 1 minute.
7. Stop the machine and do hand mixing homogeneity.
8. Pour out the concrete onto non porous surface.

NOTES: Make sure fine and course aggregates are prepared at least a day before casting in order to allow them to dry. This will influence the water content of the mix.

3.4 Test Rig

With regard to the orientation and the way of the load to be applied to the specimen, the suitable testing rig is the Self Straining Loading Frame with the capacity of 500kN. From the picture below, the actuator will applying load linearly in the downward direction.

Figure 7: Self Straining Loading Frame

3.5 Test Setup

In case of T-joint, the compressive load was applied to the brace from the actuator. Two supports are place at both near end of the chord in order to support the specimen while load is being applied on the braces. To make sure the T-joint did not move during testing, the joint is fastening in between two G-clamps which is locked to the support.

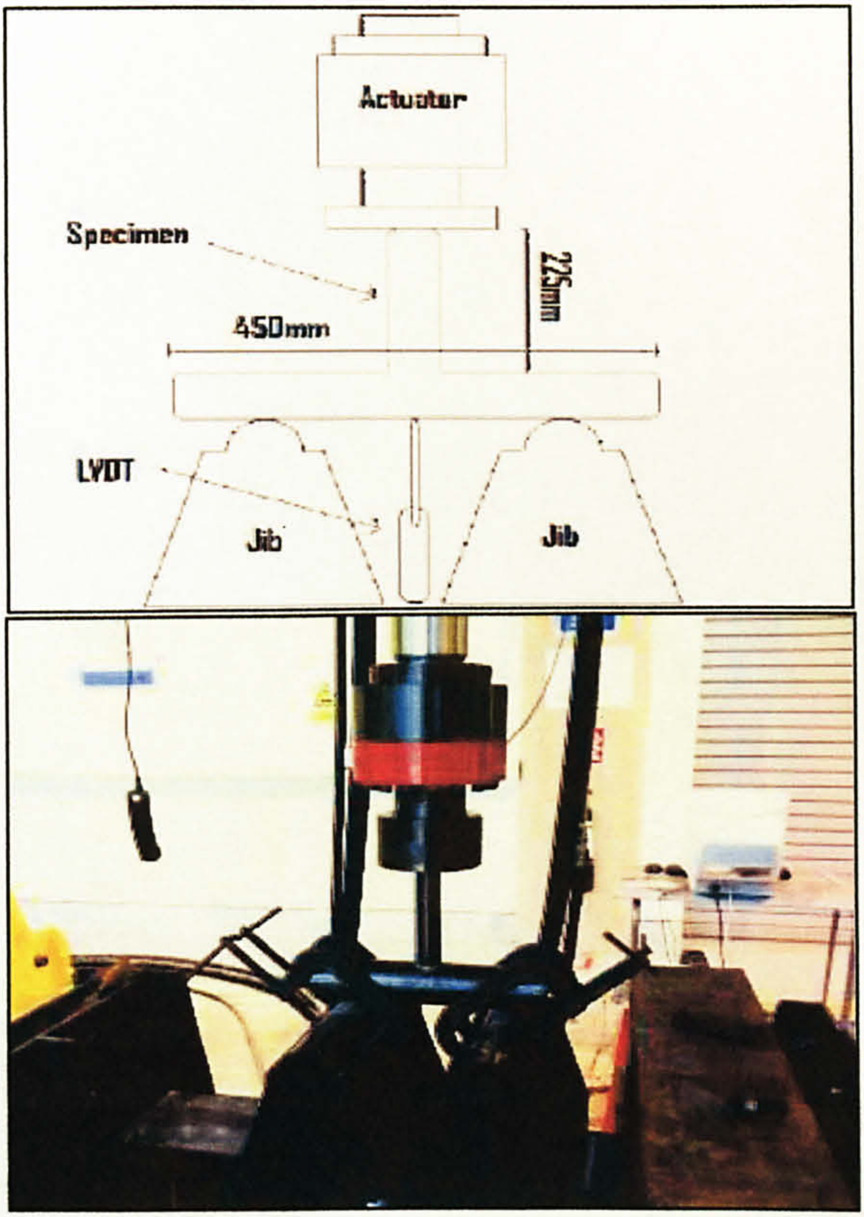

Figure 8: Testing Setup

The load is measured directly to the computer that is connected to the testing rig. Beside the load, strain gauges also are stick to the specimen to measure the strain at two different spot of the specimen. Other than strain gauges, one unit of Linear Variables Displacement Transducer (LVDT) is place at the bottom center of the specimen. This is to measure the displacement occurred. The displacement here is defined as the change of distance between initial position of the chord and position of chord after failure.

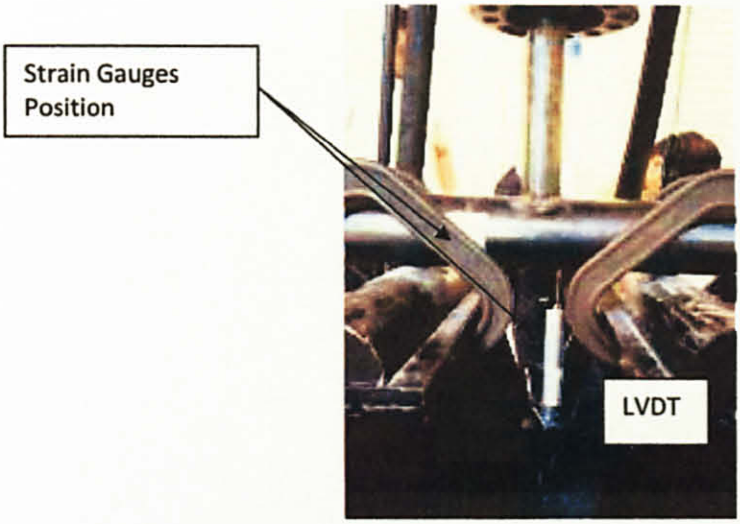

Figure 9: Position of strain gauges and LVDT

3.5.1 Testing Procedures

1. Specimen was setup as explained above.
2. The actuator is then lower down to touch the surface of the brace.
3. Prepare the software on the computer before running the test.
4. Connect the strain gauges and LVDT to the decoder that is connected to the computer.
5. Click "RUN" at the software to detect the strain gauges. Make sure there are three readings and this showed that everything is well connected. Press "STOP" to reset the reading.
6. Specified the rate of apply load as 0.1kN/s before starts the testing. As loading starts, click the "RUN" to start the reading on the strains gauges and LVDT.
7. Testing was done until specimen fails and results were analyzed.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Testing Results

The lab test results are shown in Table 5 and the load-deformation relationship are well plotted in graphs shown below. In this research studies, yield strength and the ultimate strength of the tubular T-joints are refer to the axial force applied to the brace. The yield strength is defined as the stress at which predetermined amount of permanent deformation occurs. At this point material is said to begin to deform plastically. Prior to the yield point, material deform elastically or in other words the deformation occurs allow the material to return to its initial condition when the stress applied is removed. Once the stress applied is bigger than the yield strength, deformation of material will be permanent and non-reversible.

Table 5: Test Results

Specimen	N_y (kN)	N_u (kN)	Deformation (mm)	N_u / Deformation (Kn/mm)
E1	37.5	57.77	9.158	6.308
E2	34.7	62.54	12.198	5.127
E3	24.7	53.55	9.793	5.468
G1	160	215.2	13.557	15.874
G2	102.5	108.82	3.572	30.465
G3	132.5	146.73	3.983	36.839
C1	151.25	157.85	5.556	28.416
C2	130	140.21	4.095	34.239
C3	110	120.75	3.605	33.504

4.2 Load-Deformation Relationship

Specimen E1

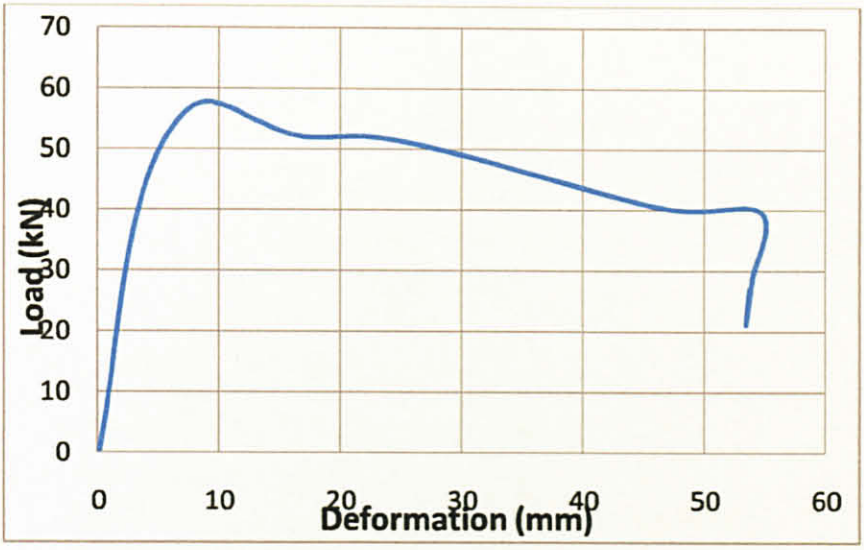

Figure 10 : Load-Deformation Relationship of E1 T-joint

From the results obtained, the ultimate load for E1 is 57.77kN at which it deformed as much as 9.158mm.

Specimen E2

Figure 11 : Load-Deformation Relationship of E2 T-joint

From the graph obtained, the ultimate load for E2 is 62.54kN at which it deformed as much as 12.20mm.

Specimen E3

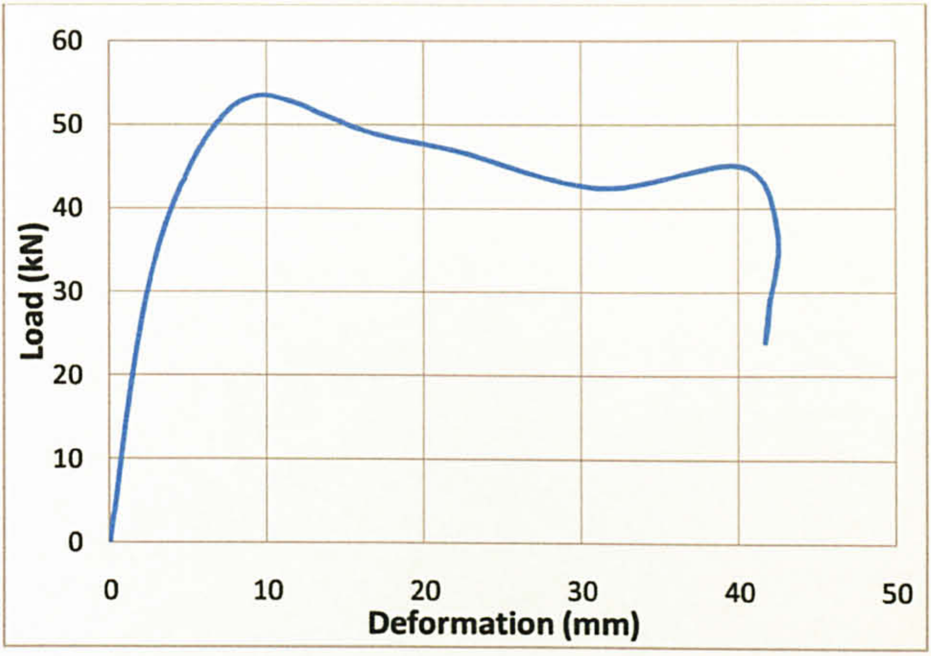

Figure 12: Load-Deformation Relationship of E3 T-joint

From the results obtained, the ultimate load for E3 is 53.55kN at which it deformed as much as 9.793mm.

Specimen G1

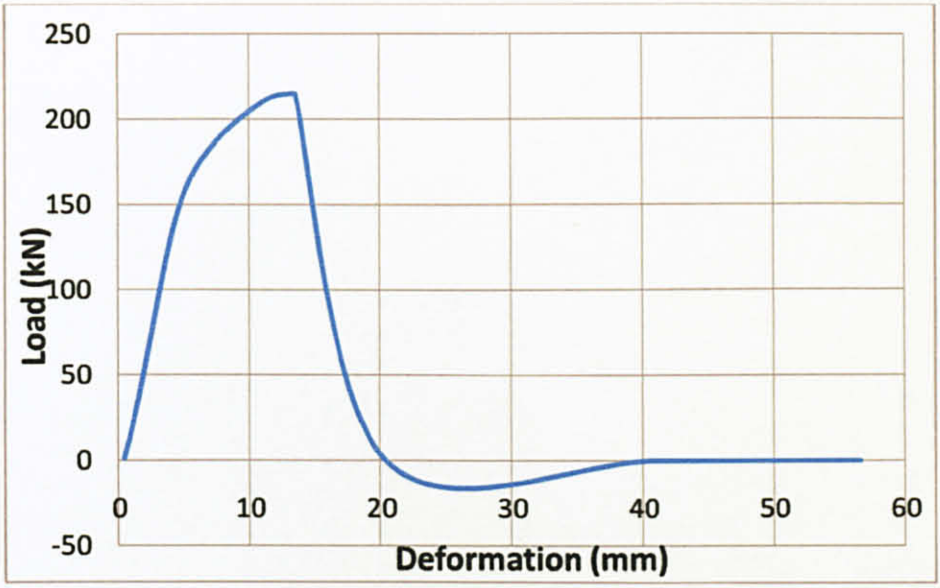

Figure 13: Load-Deformation Relationship of G1 T-joint

From the results obtained, the ultimate load for G1 is 215.2kN at which it deformed as much as 13.56mm.

Specimen G2

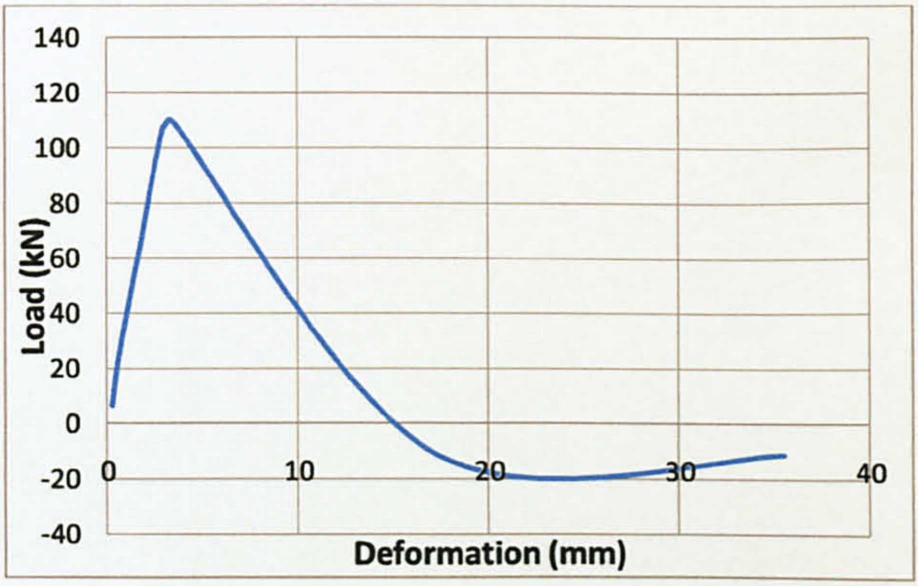

Figure 14: Load-Deformation Relationship of G2 T-joint

From the results obtained, the ultimate load for G2 is 108.82kN at which it deformed as much as 3.57mm.

Specimen G3

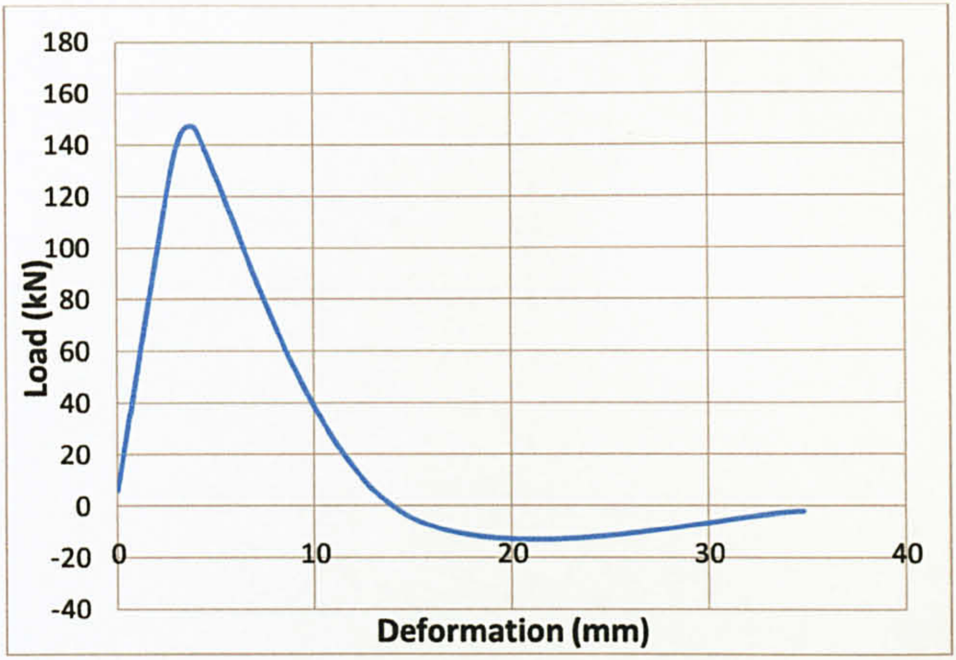

Figure 15 : Load-Deformation Relationship of G3 T-joint

From the results obtained, the ultimate load for G3 is 146.73kN at which it deformed as much as 3.98mm.

Specimen C1

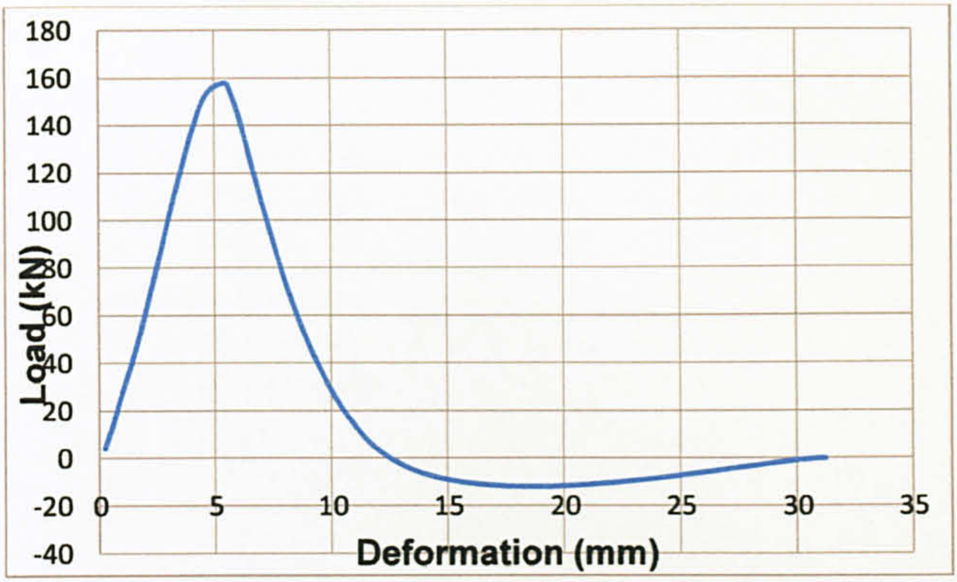

Figure 16: Load-Deformation Relationship of C1 T-joint

From the results obtained, the ultimate load for C1 is 157.85kN at which it deformed as much as 5.56mm.

Specimen C2

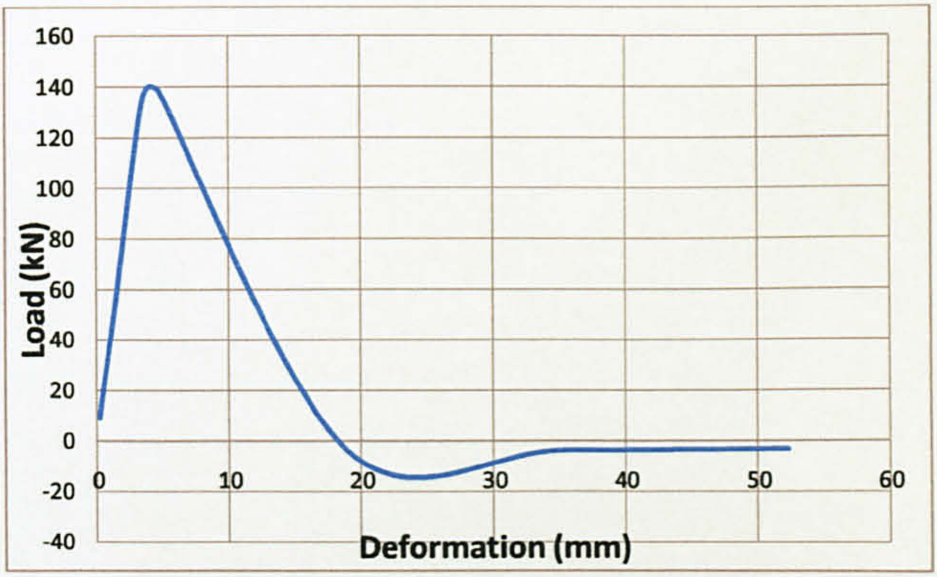

Figure 17: Load-Deformation Relationship of C2 T-joint

From the results obtained, the ultimate load for C2 is 140.21kN at which it deformed as much as 4.10mm.

Specimen C3

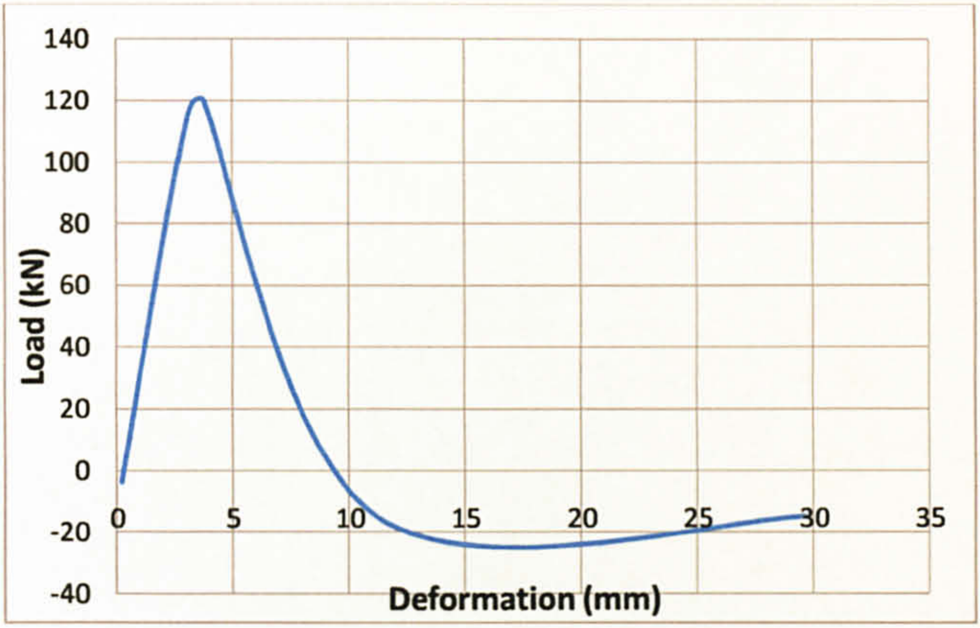

Figure 18: Load-Deformation Relationship of C3 T-joint

From the results obtained, the ultimate load for C3 is 120.75kN at which it deformed as much as 3.60mm.

Figure 20: Brace of slipped Specimen

Another way of analyzing the results obtained is to find the load to deformed 1mm of the specimen. This can be achieved by doing a simple calculation whereby the ultimate strength of a particular specimen is divided by the deformation caused by that amount of load. Calculations done are tabulated in the table below:

Table 6: Ultimate Load over Deformation

Specimen	N_u (kN)	Deformation (mm)	N_u / Deformation (Kn/mm)
E1	57.77	9.158	6.308
E2	62.54	12.198	5.127
E3	53.55	9.793	5.468
G1	215.2	13.557	15.874
G2	108.82	3.572	30.465
G3	146.73	3.983	36.839
C1	157.85	5.556	28.416
C2	140.21	4.095	34.239
C3	120.75	3.605	33.504

From the table above, grout filled tubular T-joint G3 required the highest amount of load to deform 1mm of the specimen. The amount of load required for both grout filled and concrete filled tubular T-joints to deform 1 mm of specimen are at the same range. The results are very high compared to unreinforced tubular T-joints which needed only 5 to 6 kN to deform 1mm. This has shown that, reinforcement of tubular T-joints has caused the capacity of the joint to increase to a great extent.

CHAPTER 5

CONCLUSION

5.0 Conclusion

Based on the results obtained from the laboratory testing and few published studies on the related topic, author achieved the objectives of this research work. The ultimate strength of unreinforced tubular T-joint can reach up to 60kN with deformation ranging from 9mm to 12mm. Grout filled tubular T-joint is more rigid and stiff thus allowing more load to be applied on the tubular T-joint. Grout filled T-joints has the ultimate strength as high as 215.2kN with deformation ranges from 15mm to 37mm. Regardless the failure mode of concrete filled tubular T-joint, the ultimate strength can still reach 151.25kN with deformation ranges from 28mm to 34mm. Both concrete and grout filled T-joints capacity has increased more than three (3) times the capacity of the unreinforced tubular T-joints.

CHAPTER 6

RECOMMENDATION

Reinforcement of tubular T-joints by grout and concrete injection will increase the ultimate strength to more than double of the strength of the un-reinforced tubular T-joints. For future studies on the related scope, the recommendations are as followed:

- To fabricate a special Jib that match the specimen design for a better and more accurate lab testing setup
- To fabricate the specimens using weld that comply with the API Standard
- To use Ultra High Performance Grout and different grade of concrete
- To study on the effects of diameter and length of both chord and braces to the ultimate strength

CHAPTER 7

ECONOMIC CONSIDERATIONS

The cost spent for this project will first be detailed before moving on to the business aspects and other elements that are relevant to the economic value of the project.

No.	Description	Quantity	Price (RM)
1	80mm diameter mild steel pipe	1	171
2	40mm diameter mild steel pipe	1	73
3	SikaGrout-215 (25kg per bag)	1	26
4	3" Pipe End Cap	10	50
5	Welding Job	12	300
TOTAL			620

Table 7: Project Cost Breakdown

From the breakdown shown in the table above, the cost of purchasing the pipe and the job of welding the pipes are the major contributors to the whole project cost. With the insufficient amount of steel pipes in the lab, author has decided to purchase the pipe that meets the desired specimen dimension. As for the welding of the steel pipes, author is not capable to weld with a consistent manner. This could affect the welding strength thus affecting the test results. By sending the pipes to welding expert, author can standardize the welding strength of all the specimens.

It is a well known fact that steel is more expensive than cement base products. From the results of the research, it is shown that with the same dimension of the tubular T-joints, introduction of grout or concrete will increase the load capacity tremendously. So in other words, a specified design load can be achieved with smaller diameter with the introduction of grout or concrete as reinforcement. This will definitely reduces the amount of steel used thus reducing the cost of the whole platform.

Specimen E3 and G1 are taken into comparison in terms of the cost. From the results obtained, specimen G1 has roughly double of the load capacity of E3. So to compare the difference of the cost, the design load is assumed to be 55kN. Thus by dividing the dimension of the specimen G1, it is assumed that the capacity of G1 will also be reduced twice. Below are the rates of the steel and grout developed on the basis of the prices offered to author by vendors.

Item	Description	Quantity	Price (RM)	Rate
1	SikaGrout-215 (25kg)	$0.0132m^3$ of mortar	26	RM1,969.70/m^3
2	80mm diameter pipe	6 m	171	RM28.50/m
3	40mm diameter pipe	6 m	73	RM12.20/m
4	20mm diameter pipe	6 m	36.5	RM6.10/m

Table 8: Price rates of material

Based on the dimension of E3 and the downscale dimension of G1, total volume and total length of steel pipe used are calculated. This consideration is purely base on the reduction of the diameter and NOT the length and thickness of the specimen.

	Item	Quantity	Rate	Cost	Total Cost
Un-reinforced	80mm diameter pipe	0.45m in length	RM28.5/m	RM12.8	RM 15.55
	40mm diameter pipe	0.225m in length	RM12.20/m	RM2.75	
Grouted	SikaGrout-215	0.0006696 m^3 of mortar	RM1969.70/m^3	RM1.30	RM 8.20
	40mm diameter pipe	0.45m in length	RM12.20/m	RM5.50	
	20mm diameter pipe	0.225m in length	RM6.10/m	RM1.40	

Table 9: Cost comparison

From the table above, grouted tubular T-joint cost half of the unreinforced tubular T-joints with regard to the same load capacity. This proves that by reducing the amount of steel, the total cost can be reduced significantly even with the addition of grout material into the tubular T-joints.

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