A COMPARATIVE STUDY OF “PROFILE-CUT” AND “CLAMPED-END” FOR MATERIAL HANDLING EQUIPMENT

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ABSTRACT

This research will primarily look at metal joints for boom braces in heavy lifting equipment. Currently, there are many offshore and onshore materials handling manufacturer in the world which apply several method for the design of the boom. “Profile-cut” joints are commonly used for boom braces joint but another alternative joint known as “clamped-end” braces are now used in material handling equipment industry. In “clamped-end” method, the ends of the boom braces are mechanically squashed from the original diameter to fit at the tubular surface with minimal possible distance without the need to create a “profile-cut”. The “clamped-end” braces are then fillet welded. This research will describe the computer simulation work on the design of both types of joints. The joints will be model using Solidwork 2011 and analyze using FEA software, COMSOS. Besides that, the result of the analysis will be verified by using secondary FEA software, ANSYS. The simulation result and mechanical performances of the two types of joints will be discussed.

CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOLS AND ABBREVIATIONS

FEA	Finite Element Analysis
API	American Petroleum Institute
DNV	Det Norske Veritas
BV	Bureau Veritas
CNC	Computer Numerical Control
FPSO	Floating Production Storage and Offloading
AWS	American Welding Society
$fac/fb_{yy}/fb_{zz}$	Maximum Allowable Stress
M	Moment
z	Coordinate of the point measured from z axes
I	Moment of inertia
$F_x/F_y/F_y$	Force

CHAPTER 1

INTRODUCTION

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1.0 Introduction

Basically, what we're talking about heavy load material handling equipment, most people will think of crane. Crane is a type of machine used for lifting, generally equipped with a hoist device or winder (also called a wire rope drum), wire ropes and sheaves, that can be used both to lift and lower materials and to move them horizontally. It uses one or more simple machines like a hoist to create mechanical advantage and thus move loads beyond the normal capability of a human. Cranes are commonly employed in the transport industry for the loading and unloading of goods, in the construction industry for the movement of materials and in the manufacturing industry for the assembling of heavy equipment. There are a few type of crane which can be seen in market such as boom box crane, tower crane, telescopic box crane, lattice boom crane and many more.

The most recognizable part of any crane is the boom. This is the steel arm of the crane that holds the load. Rising up from just behind the operator's cab, the boom is the essential piece of a crane, allowing the machine to raise loads to heights of several meters. For lattice boom design, the boom is made of lightweight, thin wall and high strength carbon steel. It is divided into 2 part, chord and brace. The chord is the horizontal member in a boom structure that defines the framework of the structure and the brace is used to stiffen the framework. Both part are been design to take compression and bending load.

The common method used in most offshore or onshore material handling manufacturer these days when dealing with braces welded onto the chord is the “profile-cut” at the contacting end so that the bracing’s end and the chord’s rounded shaft will be in full contact before the joint is being fillet welded. Although this method is more commonly used by most crane manufacturers, there are still companies out there (for example Titan Crane Ltd.) that are using an alternative method called the “clamped-end” braces. Clamped-end braces is a method where the contacting end of the braces are squashed to give it a smaller diameter in order to give the chord and the brace a closer distance without the need to profile-cut it which in turn saves material, labour and time. Furthermore, CNC machines that might provide a faster “profile-cut” to the manufacturer can be rather costly and the traditional milling machines can be quite a troublesome and time consuming to get a perfect fit between the brace and the chord. Similarly, the clamped-end brace is fillet welded to the chord.

From this two method mention above, there are questions about whether a clamped-end brace is comparable to a regular “profile-cut” brace in terms of performance in a joint. Therefore, a comparative study of these two kinds of brace joints will be done with the aid of computer simulation using Solidwork Simulation and ANSYS.

1.1 Research Background

A profile-cut brace is commonly used in T-, Y-, K- tubular connection to provide a perfect fit between the main member and branch member before they are being fillet welded together. Although not specifically stated, the diagram below showing the K-tubular joints in API, DNV, BV for the tubular joints branch member with a “profile-cut”. A profile-cut brace is created by milling the contacting end of the brace to fit the curvature of the chord that it is welded onto, usually, they are created with milling machines or more advanced CNC machines. Both of this method in creating profile-cut braces can be either time consuming or very costly, nevertheless, when the author look at most tubular joints in heavy machinery, profile-cut is still widely used.

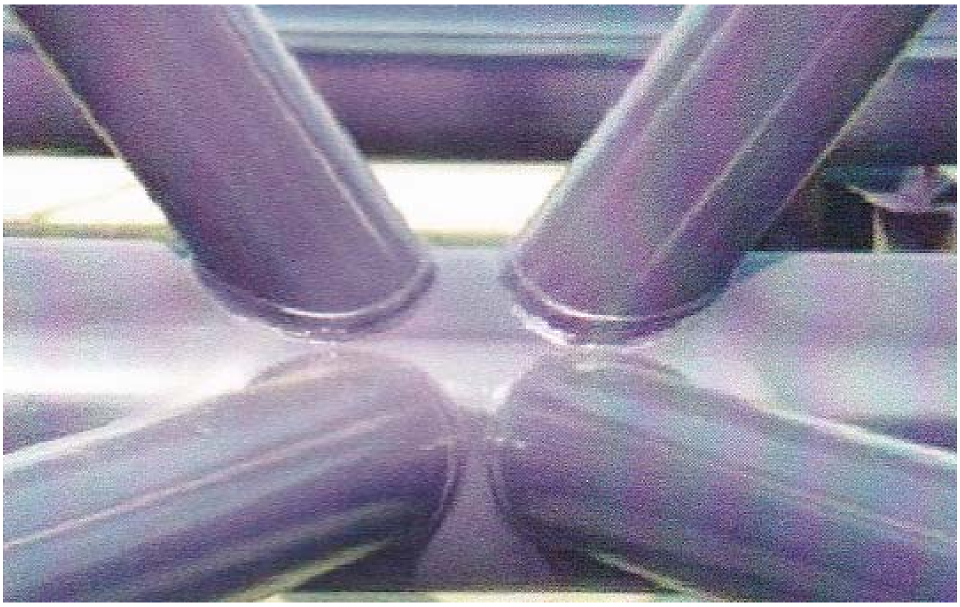


Figure 1.1: Profile-cut

A clamped-end brace is an alternative method used by material handling manufacturer example Titan Crane Ltd. in the construction of offshore and onshore crane. A clamped-end brace is a brace that is squashed, therefore this joints is also known as “squashed-end” brace. The brace being used by cranes have a seam; therefore, the squash is done at 45° to the seam. The clamped-end squashing process is done under cold working. The brace’s end is being squashed using hydraulic powered clamped and a piece of metal is inserted into the orifice of the brace to prevent it from being flattened. The clamped-end brace’s contact with the chord will still be at a tangent but the gap between the edges of the brace end and the chord shaft is minimized and the gap is fillet welded together to form the joint.

Basically this project will compare the two joints type by computer simulation and the result that the author obtain will be discuss to see is “clamped-end” has an equivalent capability to take the same load as “profile-cut”.

Figure 1.2: Clamped-end

1.2 Problem Statement

Currently "clamped-end" is a new method used by material handling manufacturer when dealing with braces welded onto the chord to replace with a common method, "profile-cut" which in turn saves material, labour and time. Even though this method is been used by some crane manufacturers, but still there is no guide line on which method is acceptable when dealing with braces welded onto the chord. Therefore, there are questions about whether a "clamped-end" brace is comparable to a regular "profile-cut" brace in terms of performance in a joint and this project will help to clear any speculation about the performance of this method. This research will also give a guideline for the material handling manufacturer, on the method to be applied when dealing with boom section.

1.3 Research Objectives

The objectives of this research are:

i. To model a joining section of boom cord and boom brace and analyse the comparison between “profile-cut” and “clamped-end” with the same working load.
ii. To compare the performance of the two joint type; “profile-cut” and “clamped-end”.

1.4 Scope

The scopes of this research are:

i. Favelle Favoc Ltd. Rope luffing crane model 7.5/10K with the maximum lifting capacity of 30 tonne.
ii. Maximum allowable design stress is based on existing crane product use by Shell Sarawak (RSF)
iii. Three sections of boom, both with different joint connection ("profile-cut" and "clamped-end") are modelled and analyse by using Solidwork Simulation, using the same boundary condition and loading.
iv. All the welding specification is based on AWS D1/ D1.1M:2006.
v. All material used in this project is based on common material used by crane manufacturer such as steel with the grade 80QA and A106.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

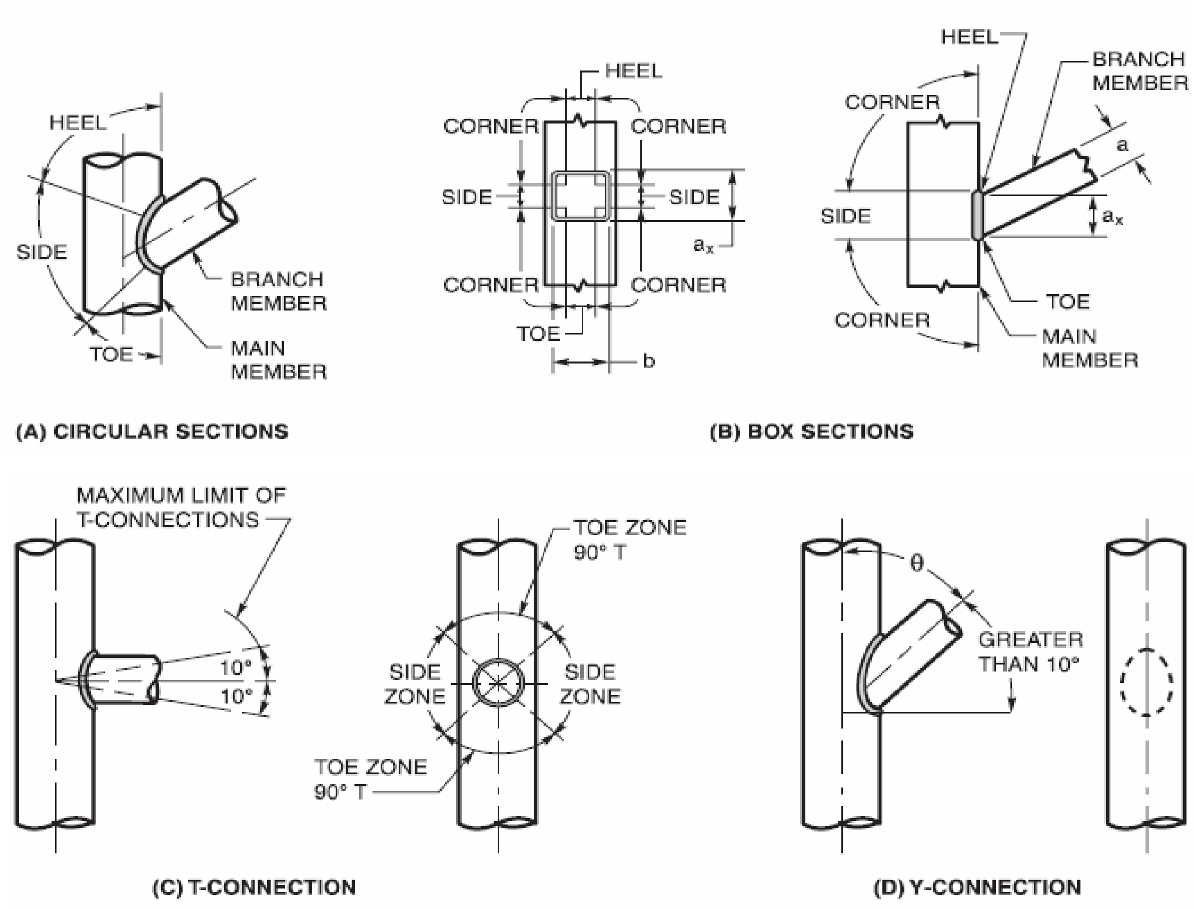
LITERATURE REVIEW

2.0 Profile-Cut Design

Currently, most of the crane manufacturer will apply "profile-cut" method when dealing with braces welded onto the chord. This method is used in T-, Y- and K- tubular connection to provide a perfect fit between the main member and branch member before they are being fillet welded together in the material handling equipment construction. This method is being used widely not just in crane manufacturing but almost all tubular joint connections. But currently, there are no specific requirement stated in the API 2C and other crane design specification such as DNV, BV and Lloys code that they will require this kind of joint for the boom design. Even though, there are no specific method for the boom brace and chord welding, the profile-cut is the most well accepted method.

2.0.1 Profile-Cut Design Base On AWS D1.1

Figure 2.1 shows some example of tubular connection that has been establish by AWS D1.1 that has been used by all crane manufacturers. Basically the most importance criteria that needs to be aware by the manufacturer is the weld size which need to be carefully extablish to meet the requirement of the design. To prevent progressive failure of the weld and ensure ductile behavior of the joint, the minimum welds provided in simple T-, Y-, or K-connections shall be capable of developing, at their ultimate breaking strength, the lesser of the brace member yield strength or local strength (punching shear) of the main member. The ultimate breaking strength of fillet welds shall be computed at 2.92 times the basic allowable yield stress develop by finite element studies and tested. The criteria is based upon combined consideration of ultimate strength for fillet welds with leg size less than 1/4 in.



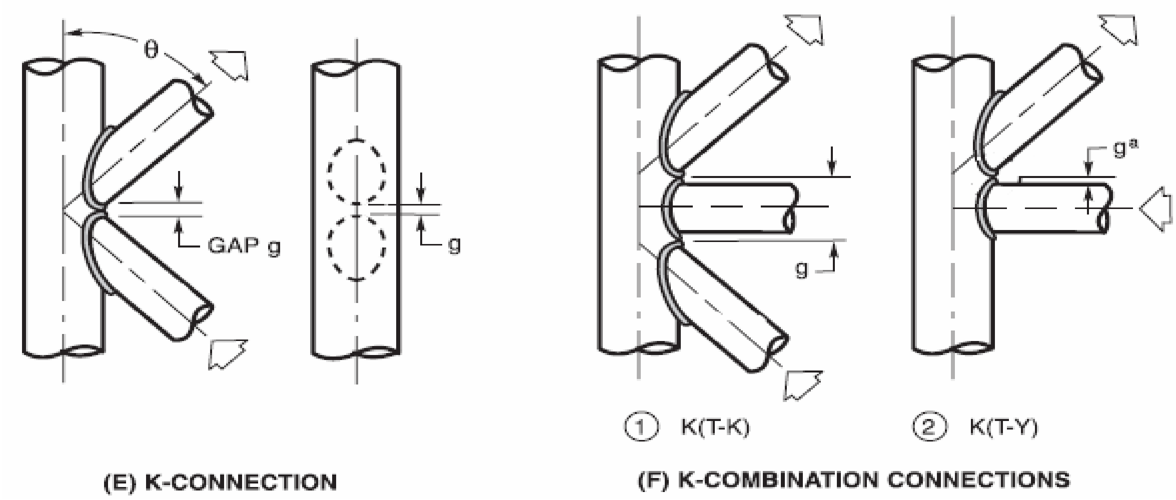


Figure 2.1: Parts of a tubular connection

2.1 Clamped-End

A clamped-end brace is an alternative method used by some crane manufacturer to replace profile-cut. Currently, this method is very new for this industry, however there are some crane manufacturers which uses it. Basically, the original brace diameter will be squashed to 3/5(raff estimation since there are no specific standard/journal/code to prove the diameter require) its original diameter.

The clamped-end squashing process is done under cold working. The brace's end is being squashed using hydraulic powered clamped and a piece of metal is inserted into the orifice of the brace to prevent it from being flattened. The clamped-end brace's contact with the chord will still be at a tangent but the gap between the edges of the brace end and the chord shaft is minimized and the gap is fillet welded together to form the joint.

Figure 2.2: Hydraulic squash machine 60 tonne

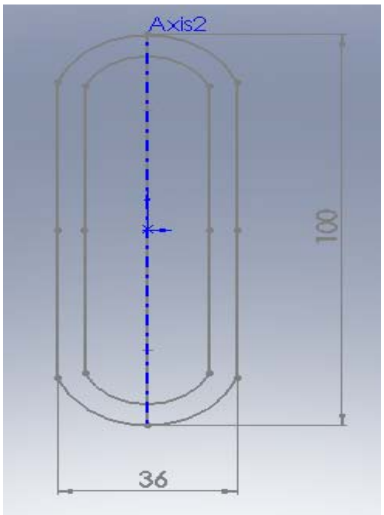


Figure 2.3: Estimate dimension of "clamped-end" for 60.3mm brace

2.2 Calculation Methods (General Calculation from API 2C)

The failure-mode calculations shall consider failure based on the following:

a) The failure load for all structural steel components shall be calculated using the lesser of the minimum yield stress or the critical buckling stress where applicable, with respect to the appropriate axial cross-sectional area and/or —plastic bending section properties.

Stresses in critical parts of the crane structure shall be measured and evaluated to the following criteria:

a) Uniform stress regions are areas of near-uniform stress where yield occurs when the largest principal stress exceeds the uniaxial tensile yield strength and produce permanent deformation of the member as a whole. In uniform stress regions, a minimum strength margin of 1.5 is required, where a strength margin is computed as the minimum specified member yield strength divided by the measured gage stress. ($\sigma_1 \leq \sigma_y$).

Peak stress regions are small areas of high stress surrounded by larger areas of considerably lower stress where exceeding the yield strength will not produce permanent deformation of the member as a whole. Strain gages in the peak stress location should have a minimum strength margin (minimum specified yield strength divided by measured gage stress) of 1.1. (American Petroleum Institute, API 2C 7th Edition, p.71-72).

2.3 Boom Parts and Materials

The booms are made up of 3 main parts, the thick chords, which made up the frame of the entire boom, the braces and they are being welded onto each other.

The three parts are made up of 3 different kinds of materials as shown in *Table 2.1*:

Parts	Materials	Standards	Measurements
Chord	Steel	Sumistrong 80QA	114.3 OD × 7.9 WT
Brace	Steel	A106 Grade B	60.3 OD × 5.5 WT
Weld	Weld filler	E 7018	-

Table 2.1: Parts and their materials details

The two different kind of steel for chord and brace have some similarities and difference in their material properties. The three different materials come from different kind of standards and each of them comes with their given specification although they all do not match one another. In this section, the author will look at each of the three materials one by one.

2.3.1 Sumistrong 80 QA

Sumistrong 80 QA is a kind of strong steel tubes specially made by Sumimoto Steels under their Sumimoto Special Series. Its specification covers seamless, high strength, low alloy, quenched and tempered materials to be used under for boom main chord and boom bracing pipe and tubing. (Simitomo Metals, 2010, Tubular Product for Automotive and Construction).

The material exhibits the following mechanical properties:

Ultimate Tensile Strength	475 MPa
Yield Strength	385 MPa
Elongation	15%
Maximum Yield to Tensile Ratio	93%
Young's Modulus	2.0×10^{11} Pa
Density	7850 kg/m^3
Poisson's Ratio	0.3

Table 2.2: Chord 80QA material properties

The material exhibits the following mechanical properties:

Carbon	0.22%

Manganese	1.20%
Silicon	0.50%
Chrome	0.30%
Molybdenum	0.10%
Nickel	0.40%
Vanadium	0.12%

Table 2.3: Chord 80QA chemical composite

2.3.2 A106 Grade B

The A106 Grade B steels are carbon steel nominal wall pipe for high-temperature service suitable for bending, flanging and similar forming operations. The A106 Grade B's used in this crane is seamed tube and possess the characteristics of carbon steels with specific yield and tensile strength. (Metals International Limited, 2007, Seamless Pipes for General Purpose).

The material exhibits the following mechanical properties:

Ultimate Tensile Strength	415 MPa
Yield Strength	260 MPa
Elongation	22%
Maximum Yield to Tensile Ratio	93%
Young's Modulus	2.0×10^{11} Pa
Density	7850 kg/m^3
Poisson's Ratio	0.3

Table 2.4: Brace A106 material properties

The material exhibits the following chemical composite:

Carbon	0.25%

Manganese	0.27%
Phosphorus	0.035%
Sulphur	0.035%
Silicon	0.10%
Chrome	0.40%
Copper	0.40%
Molybdenum	0.15%
Nickel	0.40%
Vanadium	0.80%

Table 2.5: Brace A106 chemical composite

2.3.3 AWS E7018

According to AWS D1/ D1.1M:2006, Prequalified Base Metal – Filler Metal Combinations for Matching Strength table for steel specification ASTM A106 Grade B, the matching filler metal will be electrode E7018. (American Welding Society, 2006, AWS D1.1.1M, p. 383).

The material exhibits the following mechanical properties:

Yield Strength	490 MPa
Tensile Strength	540 MPa
Elongation	27%

Table 2.6: Weld filler AWS E7018 material properties

The material exhibits the following chemical composite:

Carbon	0.12%
Manganese	1.60%
Phosphorus	0.04%
Sulphur	0.035%
Silicon	0.75%

Table 2.7: Weld filler AWS E7018 chemical composite

2.4 Type of Booms

A crane is a tower or derrick that is equipped with cables and pulleys that are used to lift and lower material. They are commonly used in the construction industry and in the manufacturing of heavy equipment. Cranes for construction are normally temporary structures, either fixed to the ground or mounted on a purpose built vehicle.

They can either be controlled from an operator in a cab that travels along with the crane, by a push button pendant control station, or by radio type controls. The crane operator is ultimately responsible for the safety of the crews and the crane.

2.4.1 Lattice Boom Crane

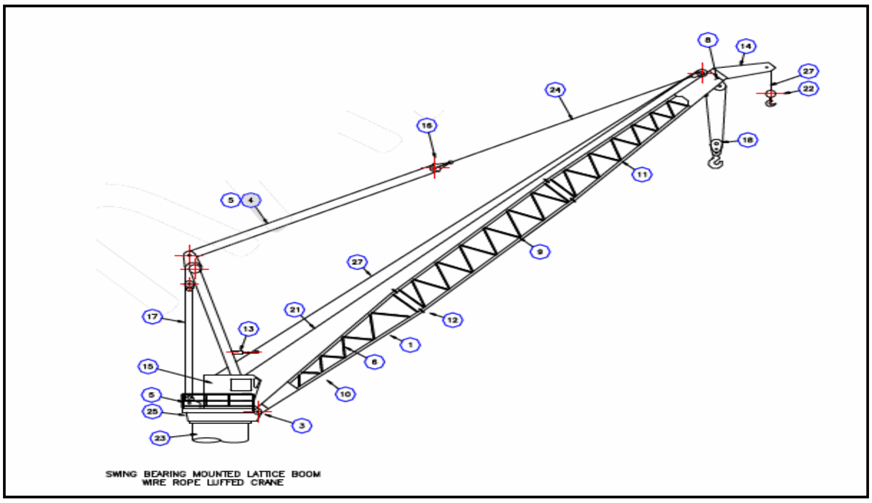


Figure 2.4: Lattice boom crane (rope luffing crane)

The lattice boom supports the working load and is the most common boom used in offshore and onshore. It is used on all types and makes of cranes and is mounted at the boom butt on the revolving superstructure. The basic boom consists of the boom butt and boom tip, and the length is increased by adding boom extensions.

Lattice boom sections are made of lightweight, thin wall, high strength alloy tubular or angle steel and are designed to take compression loads. The most common boom is tubular. Basically, for heavy weight lifting, this type of boom has the most advantages in the lifting capacity but if considering the maximum angle and radius in the crane, it has the disadvantages since it only has the very limited radius. (American Petroleum Institute, API 2C 7th Edition, p.2-3).

2.4.2 Box Boom Crane

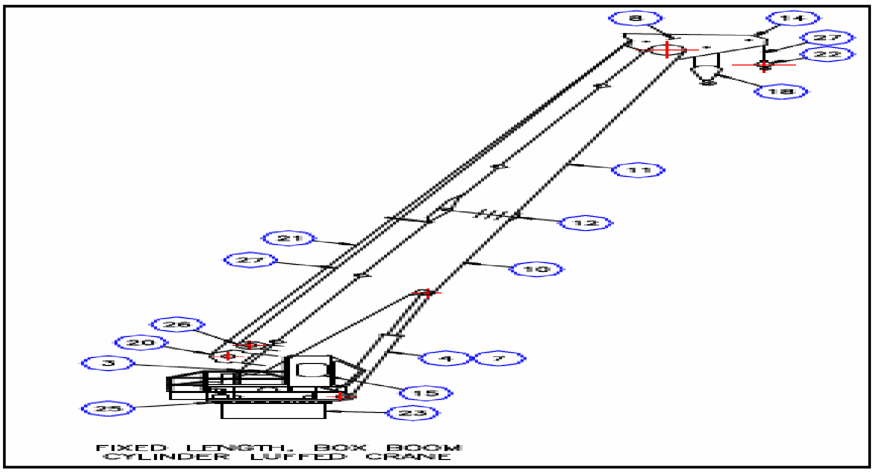


Figure 2.5: Box boom crane (ram luffing crane)

Box-type boom with solid structure crane which is been used to avoid uncontrolled boom motion under harsh operating condition. It has the minimum occupying space, low center of gravity for maintaining better stability of vessel and extreme short working radius.

This type of crane has the lowest maintenance costs over life time period if compare with lattice boom crane. This type of boom doesn't require any luffing rope and therefor spare parts costs can be reduced. But the disadvantage of this crane is it has the lowest loading capacity compare with lattice boom crane. (American Petroleum Institute, API 2C 7th Edition, p.2-3).

2.4.3 Tower Crane

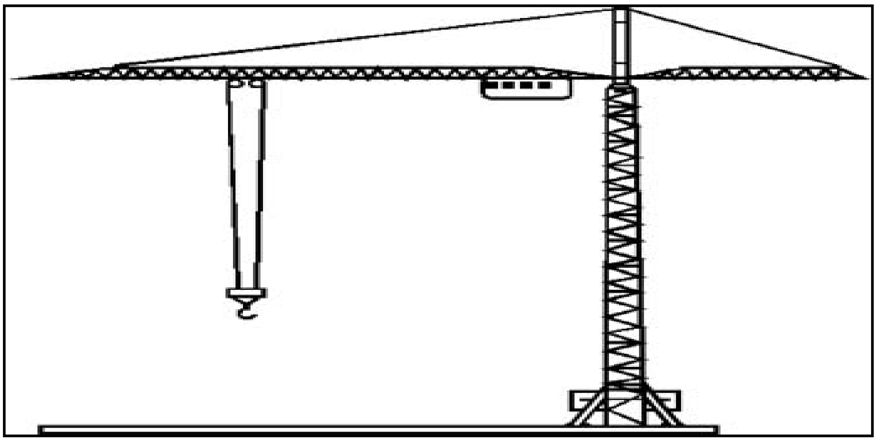


Figure 2.6: Tower crane

A hammer head crane is basically been used for onshore material handling equipment. This kind of design has a hook block that attach to the trolley which able to travel horizontally to the boom. With a tower crane, its height allows for lifting up to or from extremely high places. A tower crane is one that is fixed to the foundation, although it can also be attached to the side of a structure. The counter-jib carries a counterweight, usually of concrete blocks, while the jib suspends the load to and from the centre of the crane. (American Petroleum Institute, API 2C 7^{th} Edition, p.2-3).

2.4.4 Telescopic Box Boom Crane

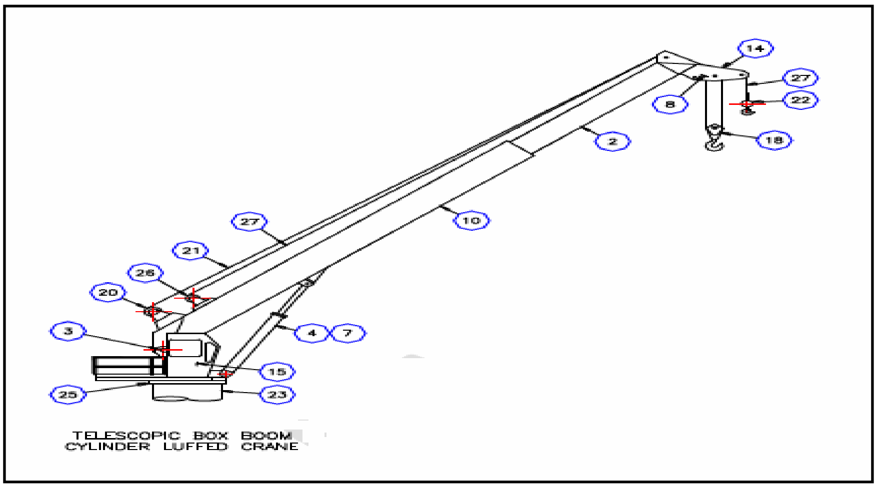


Figure 2.7: Telescopic box boom crane

A telescopic crane boom including a plurality of telescopically assembled tubular box sections including a base box section and an innermost box section having an open cross-section, and a boom head with a frame fixed to the outside circumference of the innermost box section. The head has a plurality of deflecting pulleys mounted on the frame, but no part extending inside the open cross section on the innermost base box section, whereby at least one additional box section can be inserted into the innermost box section in order to extend the boom.

This type of crane mostly can be seen for the mobile type crane and it has the advantages of maximum reach compare to normal boom box crane. (American Petroleum Institute, API 2C 7^{th} Edition, p.2-3).

2.4.5 Mounted Folding Boom Crane

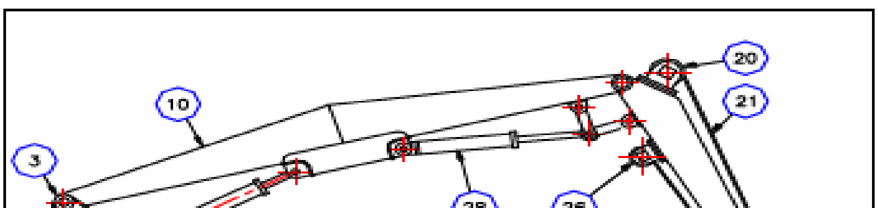


Figure 2.8: Mounted folding boom crane (knuckle boom crane)

The Knuckle Box Boom Crane is a pedestal-mounted, slew-bearing crane with a ram cylinder luffing knuckle boom of box construction. The crane is designed for offshore applications on all types of vessels operating under offshore conditions. It performs external lifts over the side of the vessel and internal lifts on the deck of the vessel.

The ability of the Knuckle Box Boom Crane to stabilize suspended loads during adverse weather conditions widens the weather window for operation of the crane. As a result, the driver is able to operate the Knuckle Box Boom Crane long after more traditional cranes have stopped operating.

The Knuckle Box Boom Crane has increased maneuverability, allowing it to reach inaccessible places on board the vessel. It is ideally suited for installation on Floating Production Storage and Offloading (FPSO) and ships where vessel motions can create severe load handling problems during bad weather conditions. The crane can be equipped with a specialized yoke for handling drill pipes, casing and risers and with a turning device for load handling. (American Petroleum Institute, API 2C 7th Edition, p.2-3).

2.5 7.5/10K Lattice Boom Offshore Crane Introduction

The crane boom models analyzed in this entire study will be based on 7.5/10K Lattice Boom Offshore Crane since this is the most common model for platform and vessel application. The 7.5/10K offshore cranes have full lattice boom and comes in multiple lengths with the longest being 36 meters long. The boom is made up of three different sections: the boom bottom, which connects to pivot, the boom extension section, or boom middle section which determines the total length of the boom by the number of this particular section and finally, the boom top which holds the hoist of the crane. The boom top and boom bottom are both tapered sections whereas the boom extension sections are rectangular sections. Further details of the 7.5/10K can be seen from detailed drawing in **APPENDIX A**.

2.6 Inspection Procedure

Inspection procedures for cranes in service are divided into three general categories based upon their usage or duty cycle, which in turn determines different, appropriate intervals at which inspections are to be performed. The usage categories should be assigned by the users on a consistent crane-by crane basis. The intent is to measure their duty cycle as the duration of time for which the crane is in actual use. (American Petroleum Institute, API 2D 5th Edition, p.19-24).

2.6.1 Infrequent Usage

Infrequent Usage applies to those cranes that are used for 10 hours or less per month, based on the averaged use over a quarter. These cranes are subject to a pre-use inspection and an annual inspection. Crane usage should be reviewed on a periodic basis by the owner to ensure proper inspection intervals.

2.6.2 Moderate Usage

Moderate usage applies to those cranes that are used for more than 10 hours but for less than 50 hours per month, based on the averaged use over a quarter. These cranes are subject to pre-use, quarterly, and annual inspections.

2.6.3 Heavy Usage

Heavy usage applies to those cranes that are used for 50 hours or more per month. These cranes are subject to pre-use, monthly, quarterly, and annual inspections. Cranes assigned to this category need not be reviewed to determine the number of hours used each month unless otherwise specified by the owner.

For the details of the crane inspections procedure, please refer to **APPENDIX B** for details. All this inspection procedure is based on the API Recommended Practice 2D, 5th Edition "Operation and Maintenance of offshore Cranes. (American Petroleum Institute, API 2D 5th Edition, p.19-24).

2.7 Welding Inspection Procedure

All inspection procedure are based on API Specification 2C for Offshore Pedestal-Mounted Cranes. Refer to *Table 2.8* for welding inspection method that may be considered critical in some crane design for welding section.

Inspection Method And Standard	Acceptance Criteria	Applies to	Detectable Discontinuities	Applications
(VT) Visual AWS D1.1 2008 Section 6.9	AWS D1.1 2008 Table 6.1	Surface	P, SI, UC, CR, LAM and marginally for: IF, IJP, OL	All surfaces
(PT) Liquid Penetrant ASTM E165	AWS D1.1 2008 Table 6.1 (Visual)	Surface	P, SI, UC, OL, CR, LAM	Nonferrous metals
(MT) Magnetic Particle ASTM E 709	AWS D1.1 2008 Table 6.1 (Visual)	Surface and near surface	OL, CR, LAM and marginally for: P,SI, IF, IJP,UC	Fillet welds, welds less than 3/8"
(RT) Radiographic: AWS D1.1 2008 Inspection Part E	AWS D1.1 2008 Section 6.12.1	Tubular connection	P, SI, IJP, UC, and marginally for: IF, CR	Full penetration connections where accessible and where a permanent record is desired
	AWS D1.1 2008 Section 6.12.2	Non-tubular connections		
(UT) Ultrasonic AWS D1.1 2008 Inspection Part F	AWS D1.1 2008 Section 6.13.2	Non-tubular connections	IF, IJP, CR, LAM and marginally for: P, SI, UC, OL	Full and partial penetration connections 3/8" and greater
	AWS D1.1 2008 Section 6.13.3	Tubular connections		
(UT) Ultrasonic ASTM A578	ASTM A578 level B	Lamellar discontinuities	LAM and marginally for: P, SI,	Rolled plates loaded in tension in the through thickness direction.
Legend P = porosity, SI =slag inclusion, IF = incomplete fusion, IJP = incomplete joint penetration, UC = undercut, OL = overlap, CR = cracks, LAM = laminations				

Table 2.8: Weld inspection method and standard (API Specification 2C)

Base on *Table 2.8*, the inspection method for boom brace joint will be radiographic method since the connection between brace and chord is been categorize under tubular connection.

Figure 2.9: Welding inspection

2.8 Finite Element Analysis

Finite element analysis is a method for performing engineering analysis on structures in which complex geometries are broken down or divided into smaller, simpler and more manageable elements. In this manner, simple mathematical calculations then replace complex solutions which are then commonly performed in a computer.

In accomplishing a successful finite element analysis, a design may be enhanced with better understanding of its behavior and reaction under varying conditions. Among its improvements are reductions of material usage, minimizing failures and even reduce testing time or increase the efficiency of testing procedures that ultimately lead to lower costs.

All newly designed cranes require a certain industrial certification as evidence of its integrity as fully functional and ready for deployment. Prior to certification, some design verification approaches are used on prototypes or on a physical model. Often a strain gauge test is used to measure stress levels at high stress concentration levels. The boom section on a lattice boom crane is one of the most interested sections among the other crane body parts.

2.8.1 Boom Point Assignment

The initial plan of analyzing the entire crane boom with just one load point at the end with a 300kN load was not being used due to the computational limitation in modeling and finite element analysis. An alternative plan of analysis just a few points along the boom was used. 2 points were taken from the boom top and boom bottom while 3 points were taken from the boom middle section. Each of the points was renamed. Refer **APPENDIX C** for clear view.

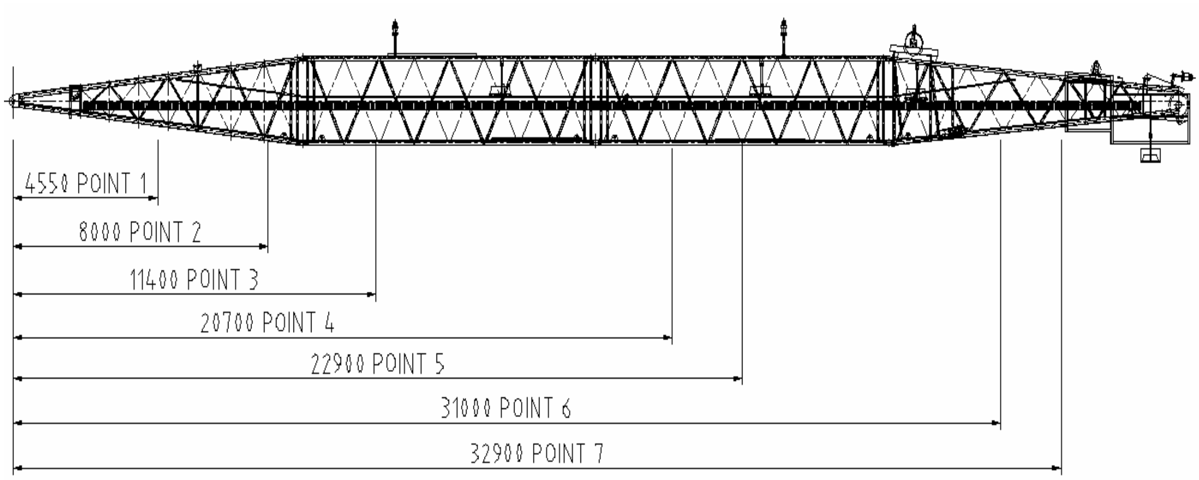


Figure 2.10: Boom point assignment

Boom Points	Point Name
Boom Top	
32900	Boom Top 2
31000	Boom Top 1
Boom Middle	
22900	Boom Middle 3
20700	Boom Middle 2
11400	Boom Middle 1
Boom Bottom	
8000	Boom Bottom 2
4550	Boom Bottom 1

Table 2.9: Boom point assignment

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