University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Master of Offshore Technology/Subsea Technology	Spring semester, 2012 Open / ~~Restricted access~~
Writer: Pavan Kumar Illendala	……………………………………… (Writer's signature)
Faculty supervisor: Arnfinn Nergaard External supervisor(s): Harald Strand	
Title of thesis: Structural Analysis to determine the stress induced loading on Wellhead Housing system supported by CAN and Sea bed BOP Supporter	
Credits (ECTS):	
Key words: Wellhead, Conductor Anchor Node (CAN), Sea bed BOP Supporter , Soil Stiffness,	Pages: 92 (Including this front page, abstract , acknowledgement, Appendices) Stavanger, June 15th 2012. Date/year

ABSTRACT

The present work investigates the effect of the bending loads on the wellhead systems and predicts the response of the conductor with the introduction of CAN™ (Conductor Anchor Node) and Seabed BOP Supporter.

Performance of the wellhead and conductor system is dependent on field design parameters. These parameters can include local environmental loading, drilling rig motions, marine riser stack-ups and BOP (Blow-out Preventer) configuration and soil conditions. These loads may cause severe damage to the wellhead system. In order to reduce the effect of these loads, the possibility of incorporating other components such as the CAN™ and Seabed BOP Supporter can be considered.

The present work aims at introducing the mentioned CAN™ and Seabed BOP Supporter in the wellhead system and assessing their influence on the bending moment response of the conductor. This has been analyzed considering different load cases outlined below.

Load Case 1: The analysis was carried out considering a conventional drilling mode with a 30" wellhead system, drilling riser and a BOP system.

Load Case 2: The analysis was performed considering Wellhead system with BOP and drilling riser supported in a CAN™ foundation developed by NeoDrill AS.

Load Case 3: The analysis also considers Seabed BOP Support in addition to the CAN™. The Seabed BOP Supporter is located in between CAN™ and BOP. The purpose of a Sea bed BOP supporter is to transfer pre-set part of BOP weight directly to CAN™ and to counteract riser induced BOP moments on Wellhead.

3-D FE (Finite Element) model based on PIPE element was established for the mentioned three load cases. The analyses have been performed by considering various factors that include internal axial casing load, external load from BOP, drilling riser tension, foundation soil support stiffness, and the cement level within the annulus of the conductor and surface casing. The shear loads that occur when the well is configured for drilling operations are applied at the lower flex joint over a range from -490kN to +490kN.

The results from the analysis are discussed against the two criteria established to assess the structural integrity of the wellhead conductor. These criteria are: allowable bending capacity of the conductor and limiting flex joint rotation angles.

The results show that the introduction of CAN™ and Seabed BOP Supporter influences the response for bending moment of Wellhead conductor considerably. The results further conclude that the reduction in the bending moment of the conductor is in the order of 25% and 80% due to introduction of CAN™ and Seabed BOP Supporter in the wellhead system, respectively.

ACKNOWLEDGEMENTS

I am indeed very grateful for my supervisor, Professor Arnfinn Nergaard, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject. I also owe my deepest gratitude to Mr. Harald Strand, Technical Manager at NeoDrill AS for allowing me to investigate and work on his innovative patented design Conductor Anchor Node and patented idea CAN Seabed BOP Supporter.

I am particularly indebted to Dr. Dasharatha Achani, Principal Engineer in Subsea 7, for his support in FE modeling and for training me in the ANSYS software. I wish to thank him for his patience and steadfast encouragement during my thesis.

My Sincere thanks also go to Mr. Robert Olsen, Senior Engineer in GE Oil and Gas, for his technical support and guidance throughout my thesis.

I specially wish to thank my wife and daughter for providing a lovely environment and giving me moral support.

Lastly, and most importantly, I wish to thank my beloved parents, Satyanarayana Illendala and Bhanumathi Illendala. They raised me, supported me, taught me, and loved me. I wish to dedicate my thesis to my parents.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

WH	Wellhead
LP	Low Pressure
HP	High Pressure
CAN	Conductor Anchor Node
WHH	Wellhead Housing
BOP	Blow out Preventer
LMRP	Lower Marine Riser Package
PGB	Permanent Guide Base
FEA	Finite Element Analysis
API	American Petroleum Institute
ISO	International Standard Organization

1. Introduction

World's energy demand is growing day by day and newer innovative methods are being developed for various sources of energy, but oil and gas still remain one of the main sources of energy to keep up the world energy need.

As the world's current oil and gas reservoirs are depleting newer fields are being explored. Finding oil is becoming more and more challenging day by day. Exploring for oil in deeper seas is becoming more common. As the depth increases hydrostatic pressure increases and pressure in the reservoirs can even be very high. The only solution to withstand these pressures is to have a BOP (Blow out Preventer) and Riser with suitable capacities which come in greater sizes and are heavier in weight.

During offshore subsea drilling using a floating rig, a common problem which is faced is that if vessel offsets and tensions are not carefully controlled, excessive bending loads can be transferred to the wellhead and associated connectors. These overloading can cause damage of the wellhead. Naturally, damage to such a critical component must be avoided. On the other hand, damage can also be a result of fatigue caused by oscillating bending moments of smaller magnitude [7],[8],[11].

Subsea well conductors and wellhead systems often follow a common design. However, the loading on these wells may vary considerably between applications. Design parameters such as water depth, rig type, BOP size, and environmental loading and seabed conditions can greatly influence the wellhead loading and conductor response. So it is essential that these parameters are fully evaluated to ensure appropriate selection of a conductor and wellhead system.

Oil and rig companies are constantly searching for solutions to reduce these excessive loading on wellhead systems which are economically viable to implement. NeoDrill AS has come up with an innovative concept and field proven well foundation technique such as patented Conductor Anchor Node (CAN) [14]. In addition, a patented idea which is under development called a CAN Seabed BOP Supporter which is used to transfer the bending loads from BOP directly into CAN.

1.1. Objective

The objective of the thesis work is to investigate the effect of the bending loads on the wellhead systems and predict the response of the conductor at the seabed due to the vessel movement. The effect of CAN and Seabed BOP Supporter on the wellhead system will also be investigated.

1.2. Limitations and assumptions

In FE (Finite Element) modelling the wellhead system along with CAN and Seabed BOP supporter and conductor soil interactions, the assumptions on the following features were made to simplify the model.

a. Soil type

The soil type and properties are assumed to be soft clay at the top with stiff clay as the depth increases. Sand is also taken into consideration at a particular depth.

b. Cement shortfall

Cement level within the annulus between 30” conductor and 21” casing is taken to be at the mudline.

c. Scour at seabed

The seabed of most of the North Sea consists of sandy soil. This sand is constantly moving due to waves and current. When a structure is placed offshore, it causes local increase of the current and wave motions. This fast flowing water stirs sand particles, picks them up and transports them away from the structure, creating a hole around the structure. This phenomenon is called scour. But, in the present thesis no scour is assumed at the sea bed [16].

d. Data

Data on soil, wellhead system, casing program, and riser tension does not pertain to any specific field but are realistic representation of typical drilling activity.

1.3. Structure of the Thesis

The main contents of the present thesis include theory, FE modeling and analysis, results and discussion, and finally conclusions. The content of the report is organized in seven chapters outlined below.

Chapter 1: Presents an introduction, the objective of the thesis work and the limitations of the problem considered.

Chapter 2: Outlines basic concept of state-of-art well foundation techniques. Further, this chapter gives an introduction to the subsea wellhead systems and mentions sequential steps followed during drilling an offshore subsea well. Innovative foundation techniques developed by NeoDrill AS is also mentioned with a brief explanation of installation of the CAN [14].

Chapter 3: Describes an overview of different loading on the wellhead system and the mechanism of the load transfer through the wellhead are described. The chapter also describes the Load-deflection (p-y) curve generations for different soil types based on the API RP 2 WSD [2],[6],[10].

Chapter 4: Summarizes the study parameters for the conductor system, including configuration and loading.

Chapter 5: Presents the details about the analysis approach and a general description of finite element model. Also presents the plots for p-y curves for different soil types at various depths used in the analysis.

Chapter 6: Presents the results from analysis and discusses the predictions for different load cases.

Chapter 7: Summarizes the conclusions.

2. State of the art well foundation techniques

2.1. Introduction to Subsea Wellhead Systems

Subsea wellhead systems are normally designed according to the standards and codes below:

- API 6A, *Specification for Wellhead and Christmas Trees Equipment.*
- API 17D, *Specification for Subsea Wellhead and Christmas tree Equipment.*
- ISO10423, *Petroleum and natural gas industries — Drilling and production equipment — Wellhead and Christmas tree equipment.*
- ISO13628-4, *Subsea wellhead and tree equipment.*

The subsea wellhead is the main structural component which supports the loads generated during drilling and production operations. Whilst drilling or work-over is taking place the wellhead is the main support item in the completed well.

The three main functions of a wellhead can be considered as follows,

1. To provide a location for suspension of casing strings:
   Each of the casing strings which run up through the well is physically suspended within the wellhead housing. Should the well be used for production, the production tubing is additionally supported and locked in position in the wellhead via the tubing hanger;

2. To provide sealing and pressure containment:
   This sealing and pressure containment takes place in two distinct areas, between the well and the environment and to provide isolation between the casing and downhole structures.
   During drilling operations a blowout preventor (BOP) is installed on the wellhead at the base of the marine drilling riser. The BOP is mandatory and is used to protect the rig and the environment at the seabed level. It avoids a blowout in case of gas kick from the well.

3. Allows the installation of flow control equipment:
   Should the well be converted from an appraisal well into a future production (normal case) or water injection well, the subsea Xmas tree can be installed to provide flow control from the well or from the injection line or manifold.

2.2. Foundation technique by conventional Subsea drilling

The drilling process involves drilling a number of hole sizes, starting with the largest hole of 36”. Following the drilling, the casing is set in the hole and cemented in. Further, smaller sizes of holes are drilled and casings are set as well as cemented. The drilling continues till the reservoir location.

This is illustrated by a typical well system shown in Figure 2-1. Ultimately, the 5½” production tubing will be set in the well and provide the flow path of the reservoir hydrocarbons to the surface.

2.2.1. Spudding-in

A 36” diameter bit (called a “hole opener”) along with a guide frame is lowered to the seabed. A relatively short section of hole is drilled to a depth of around 100m. Sea water is often used as the circulating fluid and cuttings are brought to the seabed. It is important that this portion of the hole is vertical and monitored as the drilling proceeds. While the hole is open it may be temporarily filled with a gel-water based fluid or bentonite to stop it sloughing (when the sides of the hole fall in).

2.2.2. Outer Conductor

30” conductor casing is run into the hole. Centralizers are used to keep the casing string in the middle of the hole. These are fitted round the joints as conductors run. The permanent guide base (PGB) is attached to the top of last joint of 30” conductor before the joint is run. The conductor protrudes about 1.5m into the PGB. This provides anchorage to the next string of casing (20”).

2.2.3. Cementing the Conductor Casing

The casing is anchored to the wall surface of hole by cementing. A drill string is run into the conductor casing, through which cement is pumped. The cement further extends into the shoe at the bottom of the casing. The cement displaces the sea water and rises up into the space between the outer diameter of the steel casing and the hole wall. This continues until cement is seen to be emerging at the seabed level. The cement is allowed to harden over a few hours.

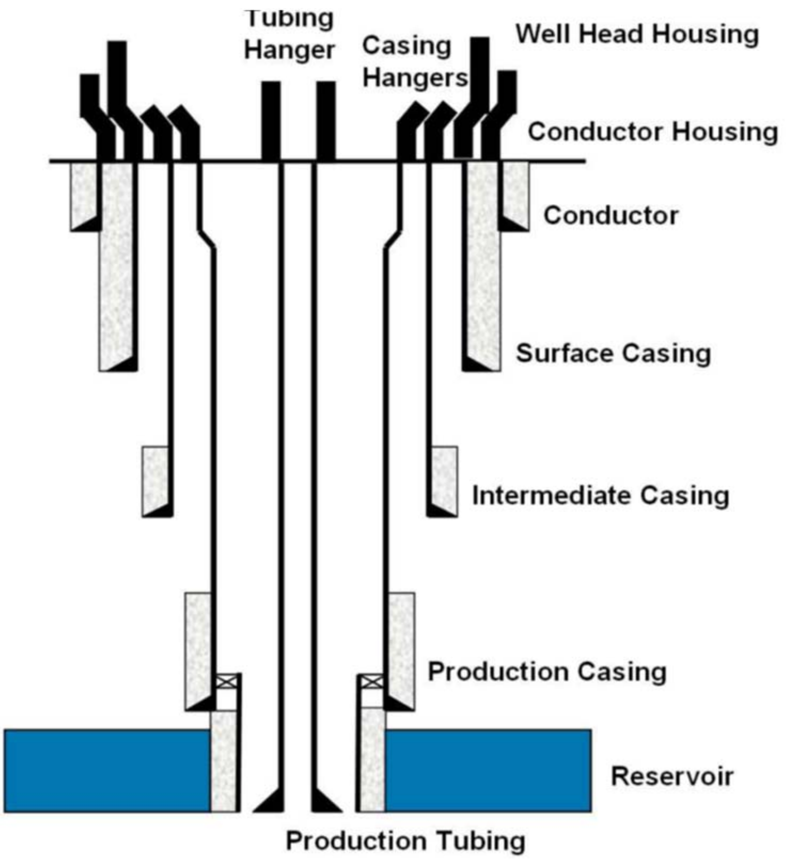


Figure 2-1 Illustration of a typical casing diagram [7]

2.2.4. Drilling 26” Hole

A 26” hole is now drilled to a depth of about 500m. Sea water is again used as the drilling fluid and the drill cuttings are discharged to the seabed. Measures to prevent sloughing may be required.

2.2.5. Running and cementing 20” casing and 18¾” Wellhead

The shoe at the bottom of the 20” casing is guided into the aperture in the PGB and the casing is run to the bottom of the hole. A wellhead is attached to the top of this casing. The wellhead is a device with internal fittings called casing hangers. It suspends the various sizes of casing and tubing strings which will be run during the remainder of the well program. The upper end of the wellhead has an internal hole of 18¾” diameter. It is designed to closely latch onto the 18¾” BOP stack when the stack is run. The wellhead is run with the last inner 20” casing, after which the casing is cemented.

2.2.6. Running the BOP Stack and the marine riser

The BOP Stack is attached to the lower end of the 21” bore marine riser and the stack is run. The riser acts as a conduit for tools, drilling fluid and drill cuttings returning from the well. By means of this all further operations are organized from the drill deck.

2.2.7. Drilling 17½” Hole

The cement filled shoe of the 20” casing is next drilled with a 17½” bit to a depth of about 2,000 m. Drilling mud is circulated from the drilling facilities. It is circulated through the drill string with the circulation continuing up the hole (now containing cuttings) and through the marine riser and further continues onto the mud deck. Furthermore, it passes over a shale shaker which removes the cuttings and allows the mud to be re-circulated. When the hole has been completed it is logged with electric and sonic wire-line logging devices to determine the conditions in the hole before running the casing.

2.2.8. Running and cementing $13^{3/8}$” Casing

The $13^{3/8}$” casing is run to the bottom of the hole. Cementing requires a very large quantity of material for this length of hole. The cement will be prepared in the mixing and pumping equipment on the drill facilities. The amount of cement is carefully calculated from the knowledge of the hole diameter along its length. The amount required is to fill the annulus and to leave a certain amount of cement inside the bottom of the casing above the shoe. The shoe is drilled out at the start of the next hole section. The cement is forced down the casing and back up the outer portion of the hole. It is important to displace all the mud which previously occupied this space. Separation of the mud and the cement interface is assisted by a plug which travels ahead of the cement. Once the calculated amount of the cement interface is pumped into the well another plug is used to provide the driving force to force the cement all the way to the top of the casing annulus.

2.2.9. Drilling 12¼” Hole

In order to drill 12¼” hole, the cement shoe of the $13^{3/8}$” casing is drilled out with a 12¼” bit and the hole is drilled to about 3.5 km.

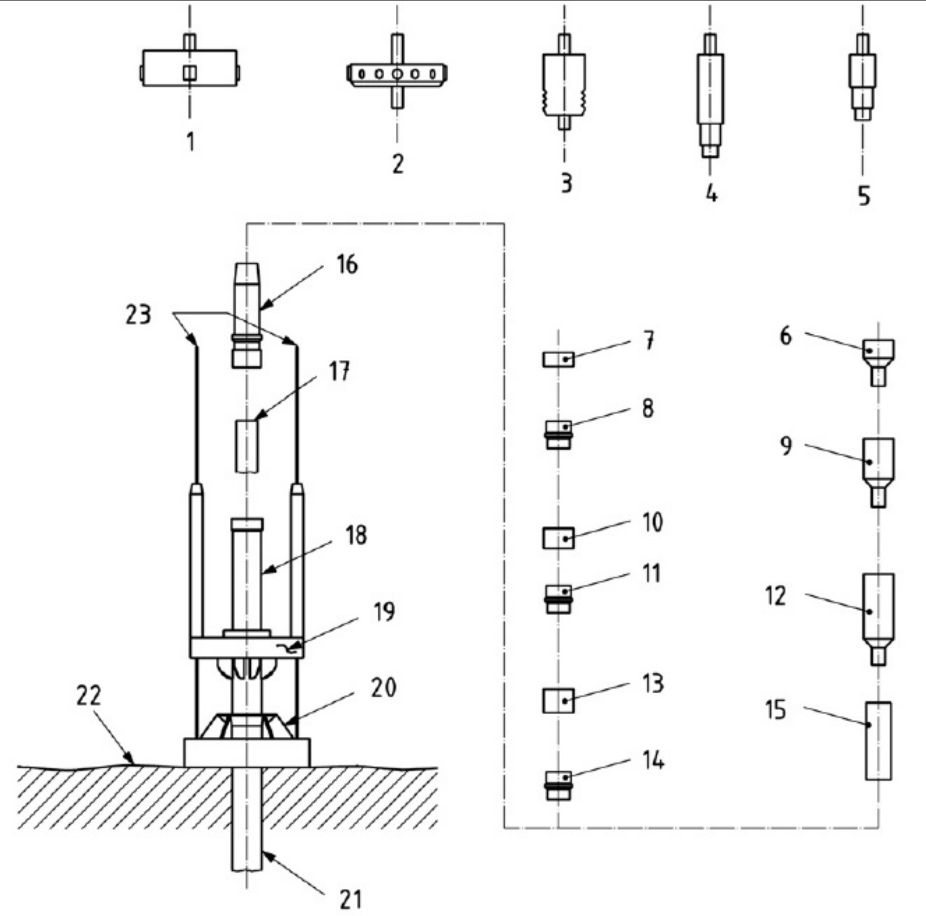
2.2.10. Logging, Running and Cementing $9^{5/8}$” Casing

The 12¼” hole is first cleaned by mud circulation. Logs are run. The casing is run and cemented similar to the $13^{3/8}$” casing as explained above.

2.2.11. Drilling 8½” Hole to total depth

The 8½” hole drilled to the final depth may require a different mud system. If it so, the new mud system has to be prepared and used to displace the other mud system from the hole. The hole is drilled to its final target depth.

The Figure 2-2 illustrates the sequence of installation of the various wellhead equipment and tools discussed above



Key

1	TGB running tool
2	762 mm (30 in) housing running tool
3	high-pressure housing running tool
4	casing hanger running tool (drillpipe or fullbore)
5	test tool
6	177,8 mm (7 in) wear bushing
7	244,5 mm × 177,8 mm (9 5/8 in × 7 in) annulus seal assembly
8	177,8 mm (7 in) casing hanger
9	244,5 mm (9 5/8 in) wear bushing
10	339,7 mm × 244,5 mm (13 3/8 in × 9 5/8 in) annulus seal assembly
11	244,5 mm (9 5/8 in) casing hanger
12	339,7 mm (13 3/8 in) wear bushing
13	508,0 mm × 339,7 mm (20 in × 13 3/8 in) annulus seal assembly
14	339,7 mm (13 3/8 in) casing hanger
15	housing bore protector
16	high-pressure wellhead housing
17	casing [normally 508,0 mm (20 in)]
18	low-pressure conductor housing [normally 762,0 mm (30 in)]
19	PGB
20	TGB
21	762,0 mm (30 in) conductor casing
22	sea floor
23	guidelines

Figure 2-2 Subsea Wellhead System Building Blocks [1]

2.3. Foundation technique by CAN Installation

“The following sub-sections are largely retrieved from [14]”.

2.3.1. Installation of CAN

The innovative concept CAN well foundation has been developed by NeoDrill AS. The CAN is a specially designed suction anchor type of structure. It consists basically of an open ended (down) cylindrical outer shell with a strong lid section and a concentric center pipe/ conductor guide which extends as deep as CAN skirt.

The CAN is lowered down near to seabed by a vessel crane (see Figure 2-3) where the vessel heave compensation is changed to set down mode to attain a controlled CAN self-penetration. Thereafter, the ROV equipped with a suitable pump is docked to the CAN to pump out the captured water. This process causes the CAN internal pressure to reduce. The pressure differential attained in this way will in turn generate a net downwards directed force which will push the CAN further into the sediment. Through the large lid area, substantial push-in force can be mobilized by applying moderate differential pressure.

Figure 2-3 CAN being run through the splash zone [14]

2.3.2. Installation of Conductor

Once the CAN is in place, the same installation vessel may be used to undertake the conductor installation. The CAN structure will guide the conductor during its installation, as well as giving it mechanical support after installation. CAN is installed by means of toe driving or top driven [12]. In toe driving, a hydraulic hammer is run to drive the conductor into the soil until landing WHH in the CAN. In this way the conductor is “installed by wire”, which is a much more cost efficient method than drilling and cementing. Figure 2-4 shows a typical CAN / Conductor stack-up.

If it is preferred for various reasons, the conductor may also be installed through the CAN by the drilling unit using jetting.

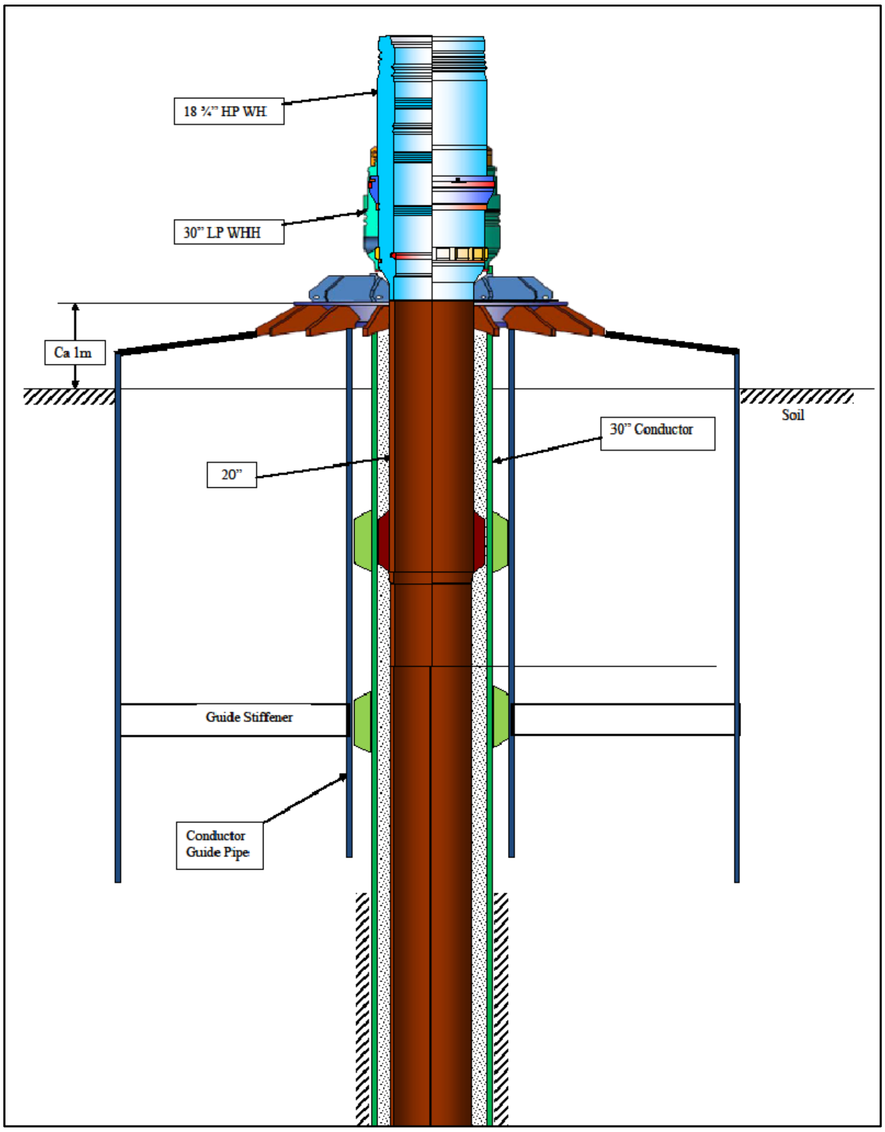


Figure 2-4 CAN/Conductor Typical Stackup [11]

2.4. Use of CAN Seabed BOP Support

After installation of CAN and 30" Conductor, the 26" section is drilled as explained above. HP Wellhead housing and 20" surface casing are installed in conductor housing and the casing is cemented in place. The next sequence is the installation of a BOP which is latched to the bottom of the marine drilling riser and is locked to the HP housing with a connector. In general, environmental loading caused by rig movements are transferred from riser to BOP into wellhead and conductor. In order to reduce these loads on WH, NeoDrill AS has come up with an innovative concept of transferring the loads to the CAN by installation of a Seabed BOP Supporter. The Seabed BOP supporter is installed to the bottom of the BOP frame. When the Supporter is run down along with BOP, the lower end of the supporter lands on the CAN and is locked to a special reinforcement provided on the CAN. A schematic illustration of the Seabed BOP Supporter is shown in the Figure 2-5 below. The Main functions of the BOP Seabed Supporter are to counteract the riser induced

BOP moments on well head and to transfer pre-set part of the weights of BOP and riser directly to CAN.

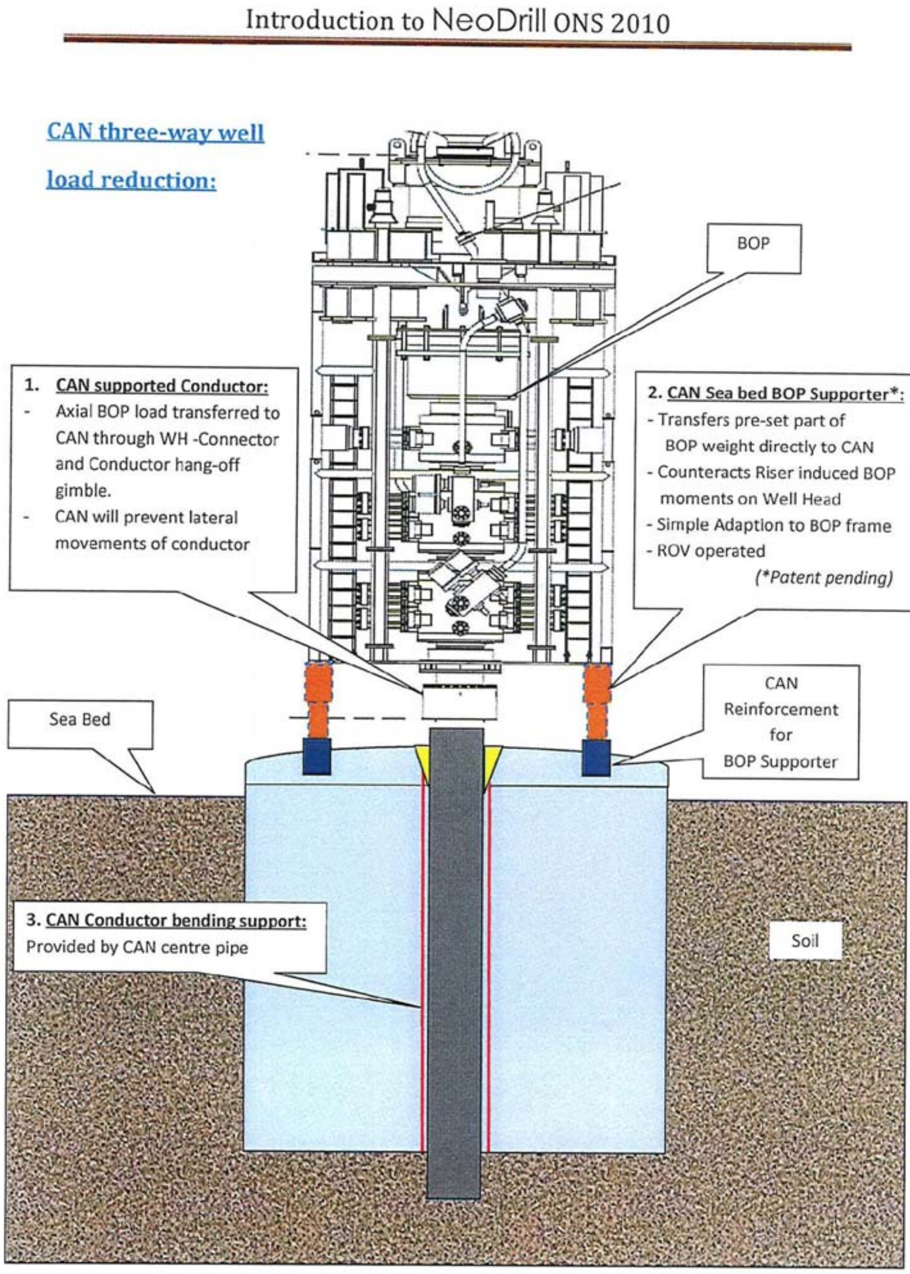


Figure 2-5 CAN/Seabed BOP Supporter/BOP typical Stackup [Ref. NeoDrill Brochure]

3. Loading on Wellhead Systems

The primary environment loading on the wellhead occurs during the drilling phase. The loading is mainly caused by sea current, wave loads and drilling vessel movements. A high varying bending moment induced by these loads is transmitted through the riser onto the wellhead housing and then to the 30” housing/casing/formation. It is now common policy to run the top joint of 1½” casing wall thickness joints of 30” diameter to provide the resistance against the anticipated loads whereas, previously, only 1” casing wall thickness was considered.

In addition to the drilling loads the wellhead may be subjected to impact and snagging loads associated with construction activities and accidental incidents such as fishing trawl board impacts and pullover forces. These loads are transmitted through the production tree into the wellhead connector and into the 30” conductor.

Figure 3-1 below shows the force diagram for a wellhead during the drilling operation. Where, F_x and F_y shown in figure indicate the sum of the external forces on the riser in the x and y directions, respectively. W is the weight of the BOP and wellhead, and F_d is the direct wave force on the BOP and wellhead upper seabed [5],[17].

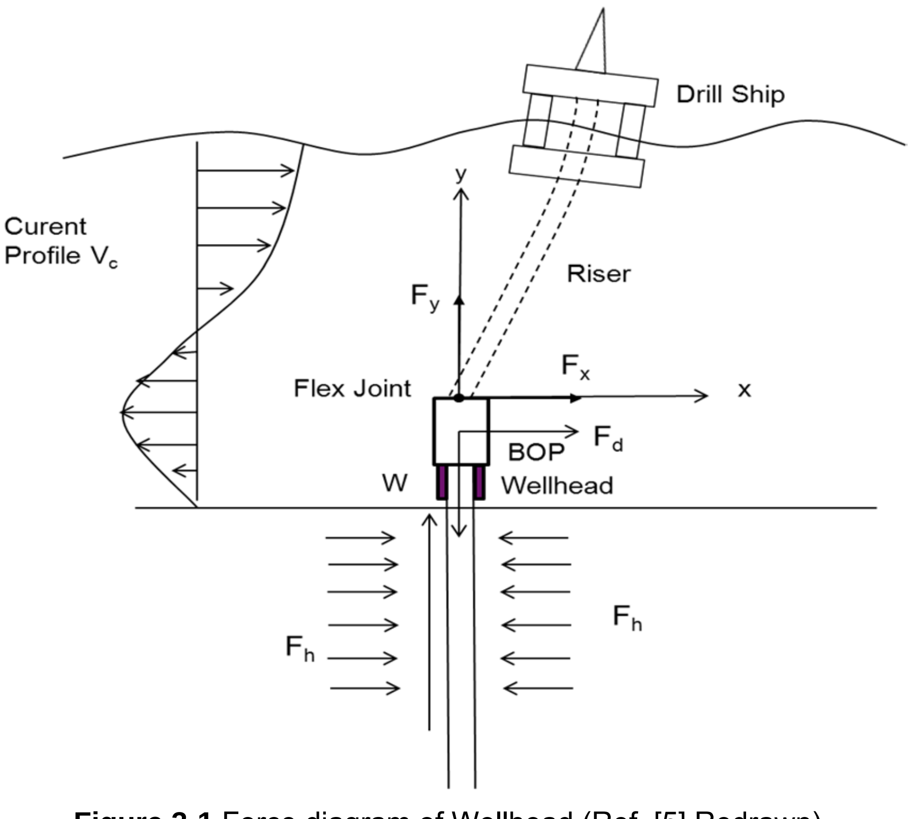


Figure 3-1 Force diagram of Wellhead (Ref. [5] Redrawn)

The casing string's displacement equation can be explained as follows [5]:

$$\frac{d^2}{d^2x}\left[EI(x)\frac{d^2y}{d^2x}\right]+\frac{d}{dx}\left[N(x)\frac{dy}{dx}\right]+Dc(x)p(x,y)=q(x) \qquad \text{Eq-3.1}$$

Where,

$EI(x)$: bending stiffness of combination of casing string. Cement ring kNm^2;

$q(x)$: unit external force, kN/m;

$Dc(x)$: depth of the casing string, m;

$N(x)$: axial force, kN;

$p(x, y)$: unit (area) horizontal soil force.

Depending on the type of soil, the horizontal soil force, p(x, y), is determined by following equations.

a. Lateral bearing capacity for soft clay (as per API RP 2A WSD Section 6.8.2) [2]

For static lateral loads the ultimate unit lateral bearing capacity of soft clay p_u has been found to vary between 8*c* and 12*c* except at shallow depths where failure occurs in a different mode due to minimum overburden pressure. Cyclic loads cause deterioration of lateral bearing capacity below that for static loads. In the absence of more definitive criteria, the following is recommended:

p_u increases from 3*c* to 9*c* as *X* increases from 0 to X_R according to:

$$p_u = 3c + \gamma X + J\frac{cX}{D} \qquad \text{Eq-3.2}$$

And

$$p_u = 9c\ for\ X \geq X_R \qquad \text{Eq-3.3}$$

Where

p_u = ultimate resistance, psi (kPa),

c = undrained shear strength for undisturbed clay soil samples, psi (kPa),

D = pile diameter, inch (mm),

g = effective unit weight of soil, lb/in^2 (MN/m^3),

J = dimensionless empirical constant with values ranging from 0.25 to 0.5 having been determined by field testing,

X = depth below soil surface, inch (mm),

X_R = depth below soil surface to bottom of reduced resistance zone, inch. (mm).

For a condition of constant strength with depth, above equations are solved simultaneously to give:

$$X_R = \frac{6D}{\frac{\gamma D}{c}+J} \qquad \text{Eq-3.4}$$

b. Load-deflection (p-y) curves for soft clay (as per API RP 2A WSD Section 6.8.3) [2]

The p-y curves for piles in the soft clay are generally non-linear. For the short term static load case they may be generated from Table 3-1 below.

Table 3-1 Relationship of lateral resistance and deflection [2]

$X>X_R$		$X<X_R$	
p/p_u	y/y_c	p/p_u	y/y_c
0	0	0	0
0.5	1.0	0.5	1.0
0.72	3.0	0.72	3.0
1.00	8.0	$0.72X/X_R$	15.0
1.00	∞	$0.72X/X_R$	∞

In the above table the following applies:

p = actual lateral resistance (kN/m),

y = actual deflection (mm),

$y_c = 2.5\ \varepsilon_c\ D$ (mm),

ε_c = strain which occurs at one-half the maximum stress in laboratory undrained compression tests of undisturbed soil samples.

The form of the pre-plastic portion of the static resistance curve can be approximated with the parabolic equation [6]:

$$\frac{p}{p_u} = 0.5\left(\frac{y}{y_c}\right)^{\frac{1}{3}} \qquad \text{Eq-3.5}$$

c. Lateral bearing capacity for sand at a depth X below the mudline (in accordance with API RP 2A-WSD section 6.8.6) [2]

The ultimate lateral bearing capacity for sand has been found to vary from a value at shallow depths determined by following equation:

$$p_{us} = (C_1 * X + C_2 * D) * \gamma * H \qquad \text{Eq-3.6}$$

And to a value at deep depths determined by following equation:

$$p_{ud} = C_3 * D * \gamma * H \qquad \text{Eq-3.7}$$

p_u = ultimate resistance (force/unit length), lb/in (kN/m) (s = shallow, d = deep),

g = effective soil weight, lb/in^3 (KN/m^3),

H = depth, inch (m),

Φ´ = angle of internal friction of sand, degree,

C1, C2, C3 = Coefficients determined from Figure 3-2 as function of Φ´,

D = average pile diameter from surface to depth, inch (m).

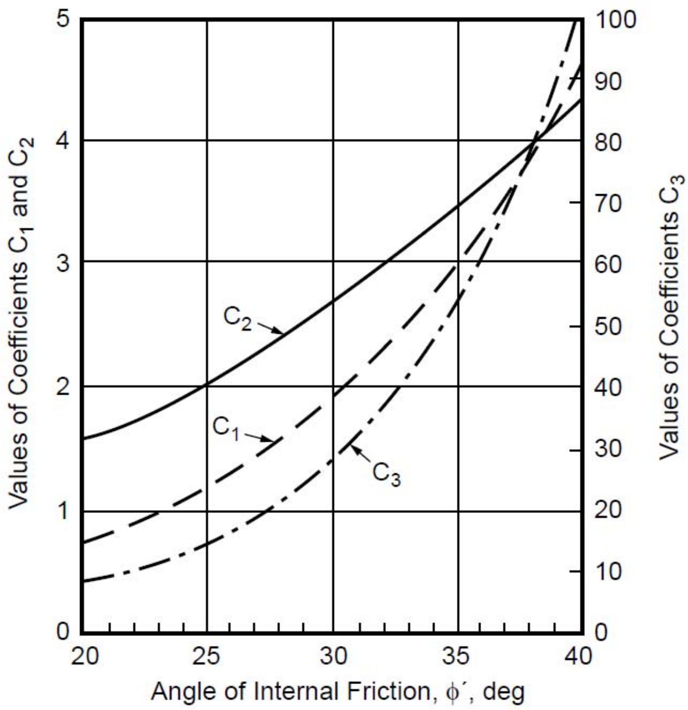


Figure 3-2 Coefficients as a function of Φ' [2]

d. **Load-Deflection (p-y) curves for Sand (in accordance with API RP 2A-WSD section 6.8.7) [2]**

The lateral soil resistance-deflection (p-y) relationship for sand are also non-linear and in the absence of more definitive information may be approximated at any specific depth H, by the following expression:

$$P = A * p_u * tanh\left[\frac{k*H}{A*p_u} * y\right] \qquad \text{Eq-3.8}$$

Where,

A = factor to account for cyclic or static loading condition and evaluated by

A = 0.9 for cyclic loading,

A = (3.0-0.8H/D) ≥ 0.9 for static loading,

p_u = ultimate bearing capacity at depth H, lb/in (kN/m),

k = initial modulus of subgrade reaction, lb/in^3 (kN/m^3),

y = lateral deflection, inches (m),

H = depth, inches (m).

After obtaining the displacement of the casing string, the bending moment can also be obtained and used to judge the stability of the wellhead.

4. Design Basis

This section summarises the study parameters for the conductor system including configuration and loading. The objective of the analysis is to investigate and compare different bending moments induced due to the riser tension from the selected three load cases.

For all the load cases, a typical wellhead stack-up is assumed as one of a case consisting of 30" Conductor housing welded to a 30" x 1.5" wall thickness pipe along with 3 intermediate joints of 12.5 m in length and a 14m shoe joint at the bottom. The high pressure Wellhead Housing consists of 21"/20"/13-3/8" extension joints. For the purpose of this report the input data used in the analysis is assumed and an effort has been made to keep the data to be realistic. The Input data is presented in Figure 4-1 and Table 4-1 below.

Table 4-1 Component Basic Characteristics

Component	
LMRP Weight in air	Weight = Assumed 100 tonne Height = 0.9 m OD = 4.5m ID = 476mm
BOP Weight in air	Weight = Assumed 170 tonne Height = 8.3 m OD = 5.5 ID = 476mm
Lower Flex Joint Weight	Weight = Assumed 15 tonne Height = 3.8 m
Conductor Housing	Height = 1.17m OD= 0.908 m (35.75") , ID = 0.782 m (30.8")
Conductor	30" x 1.5" LP Housing Extension and Conductor
HP Wellhead Housing	Height = 1.62 m (63.75") OD = 0.68 m (26.8"), ID = 0.47 m (18.5")
HP Housing and 20" Casing	21" x 1.25" HP Housing Extension and Surface Casing, 20" x 1" crossover, and 13-3/8 casing string Assumed suspended weight 100kips (45 Tonnes)
Internal casing / tubing load	2275kN
Riser Bottom Tension	490kN / 50 tonne

Maximum Wellhead Angle	1.5°
Flex Joint	Rotational Stiffness = 92kNm/deg of Rotation Angle limit = -10° to +10°

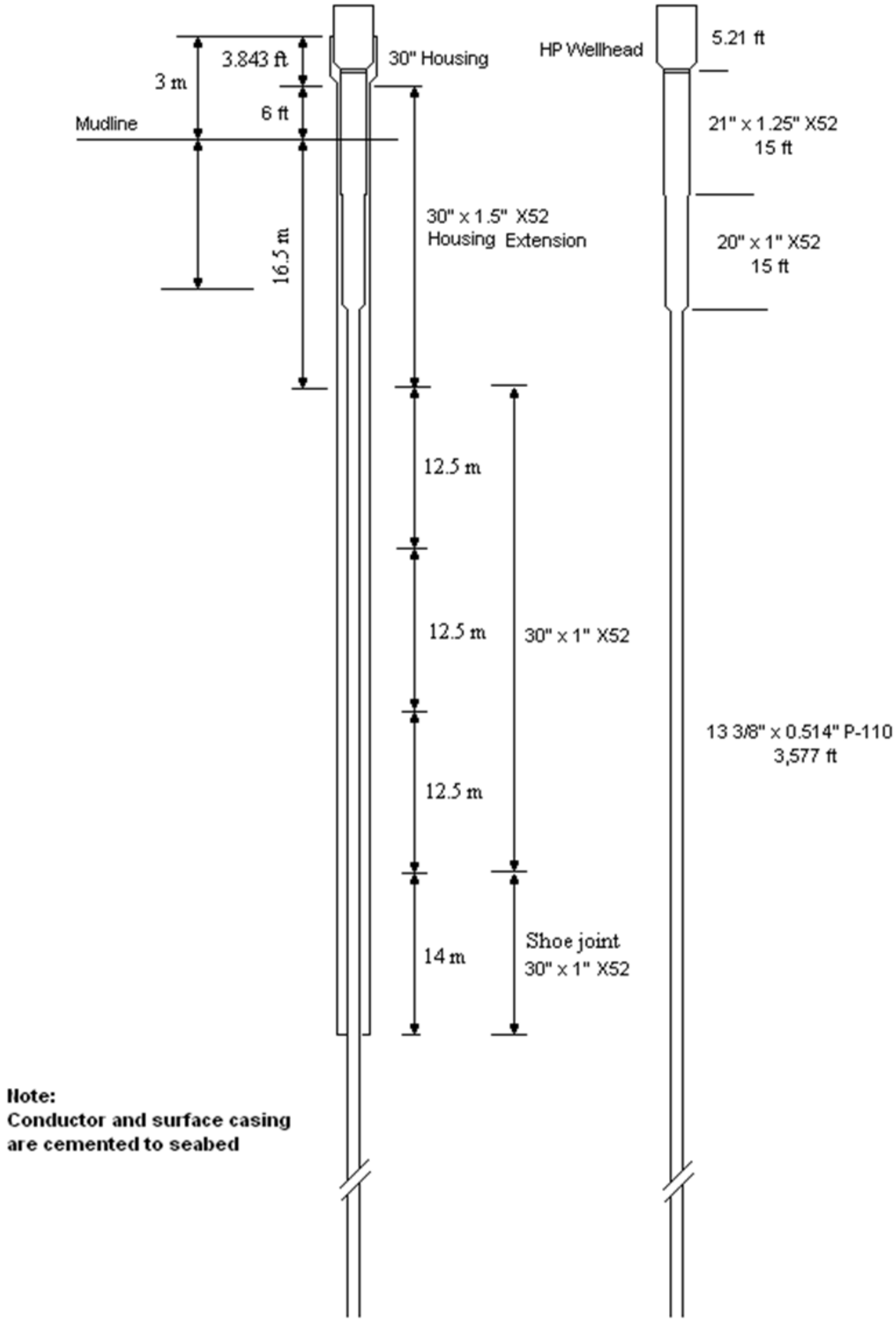


Figure 4-1 Wellhead Stackup

4.1. Design Parameters

This section deals with the design parameters established for the interaction of the systems described in the following sections.

4.1.1. Wellhead / Conductor System:

The wellhead / 30” conductor stack-up system is given in Figure 4-1. The analysis addresses the scenario where the marine drilling riser system is landed on top of the 18¾” wellhead. The lower flex joint, LMRP and BOP are all included in the model of the system. The mass of the subsea components and their effect on bending of the conductor due to both wellhead inclination angle and flex joint angle is addressed in the analysis. Loads from the remainder marine drilling riser system are accounted for by the use of riser tension. The riser tension is assumed to act at the top of flex joint over a selected range of flex joint angles (-10° to +10°). The rotational stiffness of the flex joint is also accounted for in the analysis. The cement level within the annulus is taken to be at the mudline.

4.1.2. Conductor / Soil Interaction

To perform an accurate analysis on the sub-surface conductor, detailed soil information is required. The conductor assessment has been made based on assumed soil parameters for the purpose of this report. The parameters listed in Table 4-2 below are assumed for soft clay to stiff clay. Based on the soil properties, non-linear force per unit length (p) versus deflection (y) curves have been generated for the present work and used in the analysis.

Table 4-2 Assumed Soil Parameters

Label	Description	Depth of base (m)	Undrained Shear Strength (kPa)	Submerged Unit Weight (kN/m^3)
Layer 1	Very Soft Clay	0 – 7	24	9.69
Layer 2	Sand	7-8	Φ=30°	10.13
Layer 3	Soft Clay	8-31	24-184 kPa	10.6
Layer 4	Firm to Stiff Clay	31-68	184-450 kPa	10.88

Figure 4-2 Illustrate the Wellhead, Conductor and subsea equipment stack-up

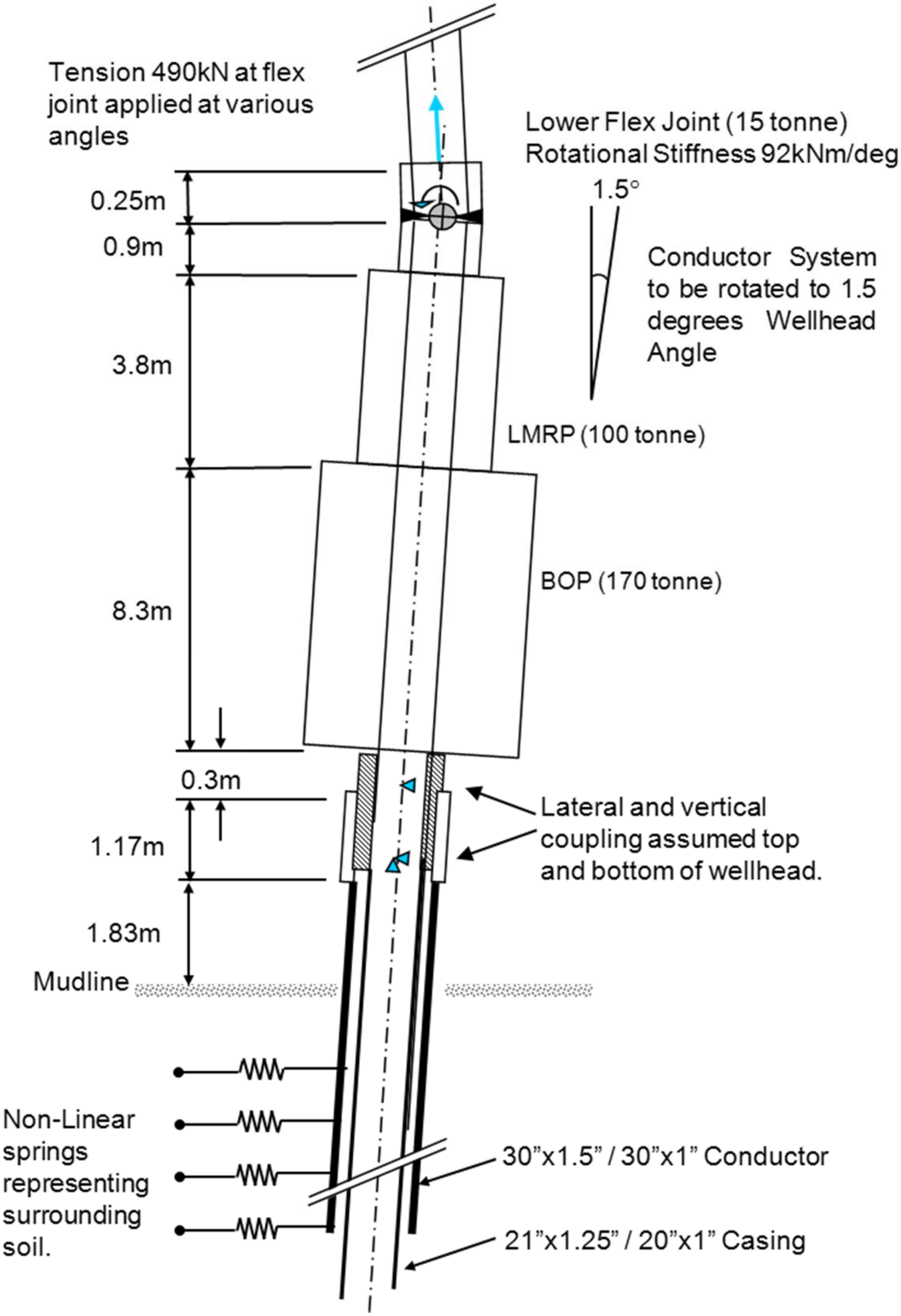


Figure 4-2 Load Case 1: Illustration of Wellhead, Conductor and Sub-Sea Equipment Stack-Up

4.1.3. Conductor / CAN Interaction

As mentioned before, a concept of CAN system has been developed and field proven to improve the well foundation [14]. Figure 4-3 shows an illustration of the wellhead and CAN stackup. The main purpose of the CAN is to reduce the induced bending moments in the conductor. To perform the analysis by introducing the CAN, CAN stiffness properties are required. The stiffness properties of the CAN are adopted from the previous thesis [9], which is based on the similar soil conditions assumed in this work. The Force-Displacement properties of the CAN are presented in the following Table 4-3.

Table 4-3 CAN Stiffness [13]

Displacement (m)	Force (kN)
0.000	0
0.030	140
0.060	230
0.100	310
0.130	355
0.170	374
0.200	379
0.240	385
0.270	390
0.300	393
0.340	398
0.370	400
0.400	402
0.430	405
0.470	412
0.500	418

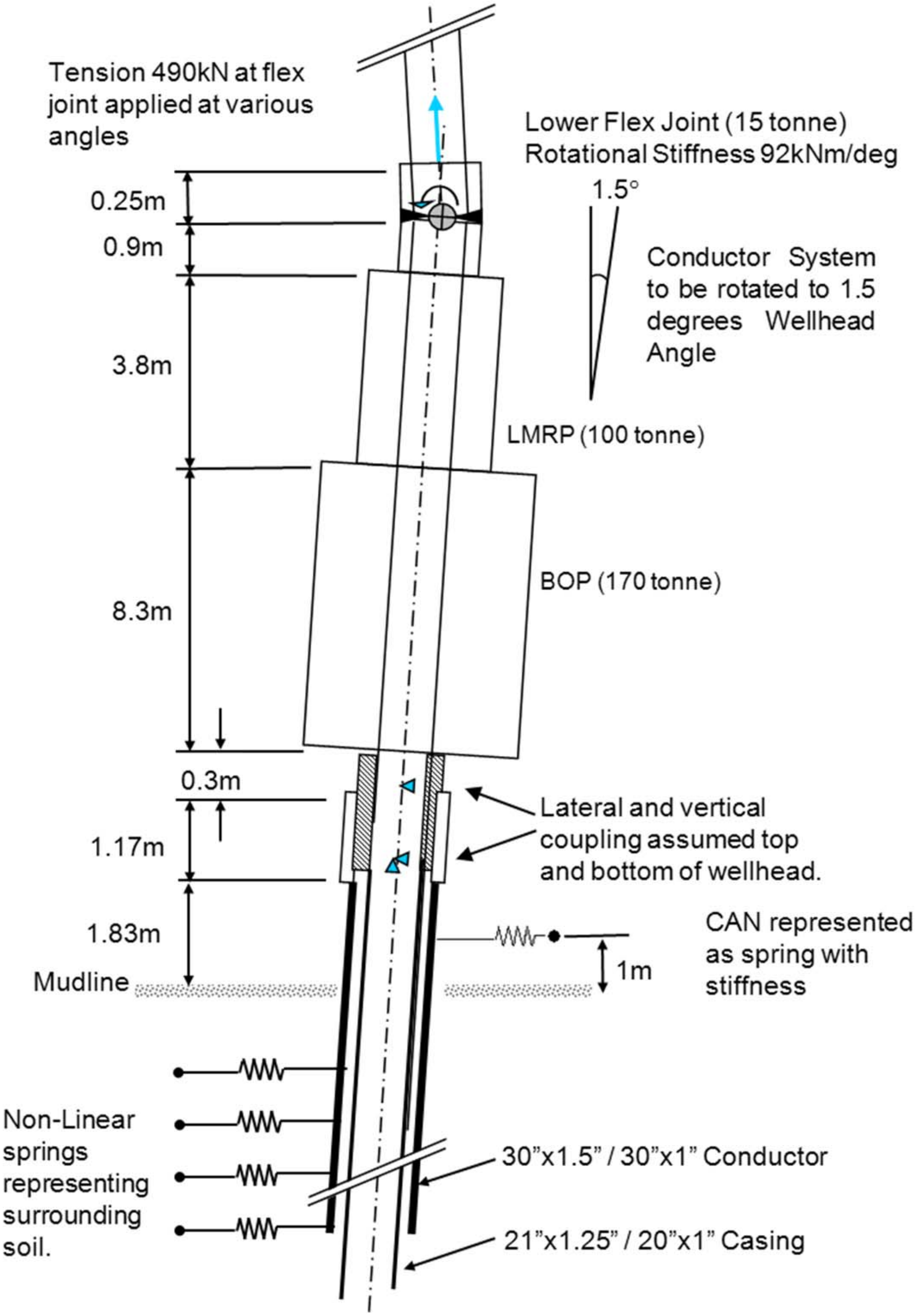


Figure 4-3 Load Case 2: Illustration of Wellhead, Conductor and Sub-Sea Equipment Stack-Up supported in a CAN Foundation

4.1.4. CAN / Seabed BOP Support Interaction

In order to achieve the reduced bending moment on whole wellhead system it is intended to further introduce a Seabed BOP Support structure into the system in addition to the CAN. The top of the Seabed BOP supporter is attached to the bottom of the BOP frame and the bottom of the structure is constrained to the CAN. An Illustration of the Wellhead stackup with the Seabed BOP supporter is given in the Figure 4-4.

In the present work the cross-section properties of the Seabed BOP Support structure are assumed to reflect the cross-section of a pipe. The characteristics assumed for the selected pipe are listed in Table 4-4.

Table 4-4 Characteristics of Seabed BOP Supporter

Height	2.2 m
Outer Diameter	0.2 m (7.8”)
Thickness	0.015 m (0.6”)

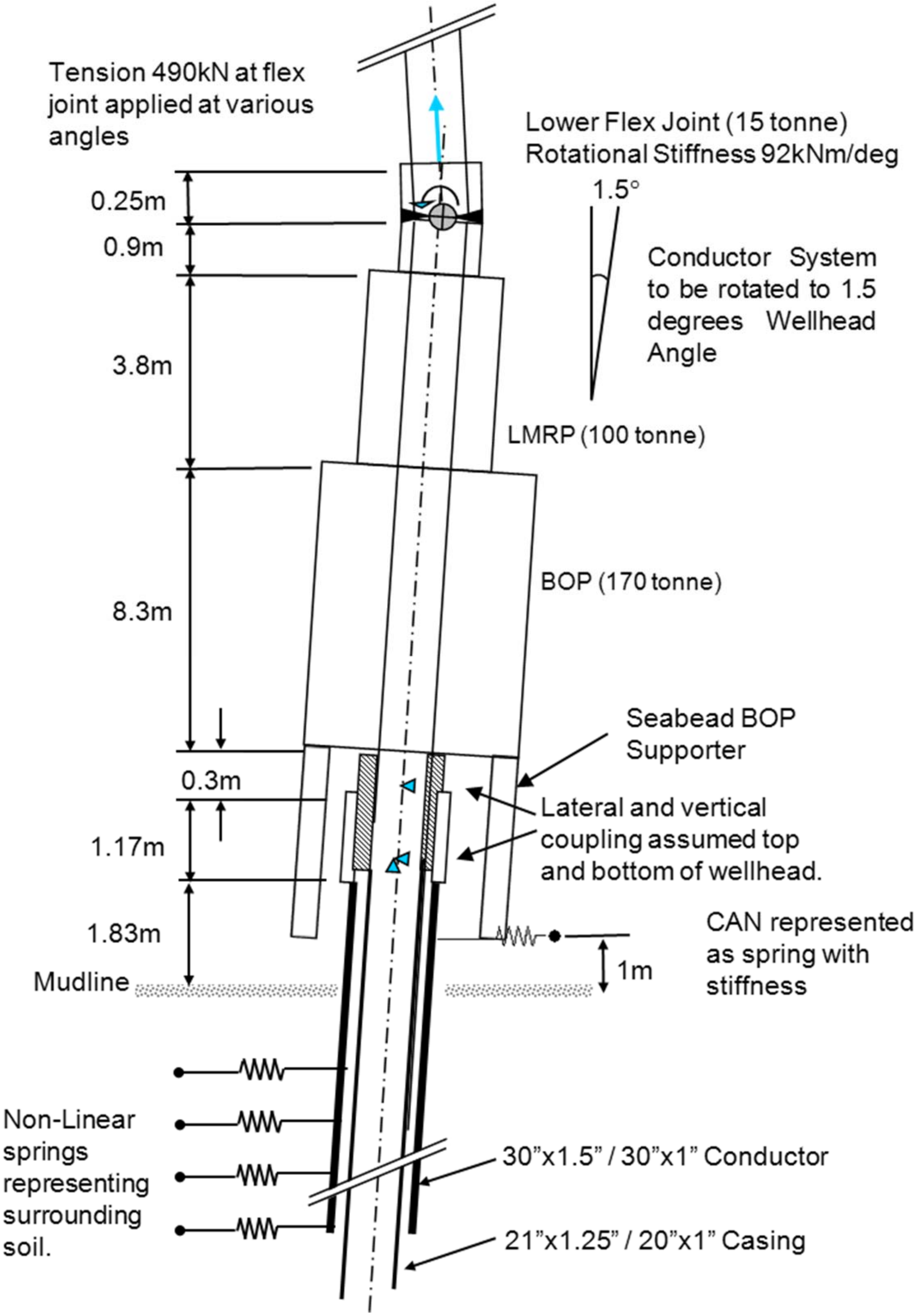


Figure 4-4 Load Case 3: Wellhead, Conductor and Sub-Sea Equipment Stack-Up supported in a CAN Foundation along with a Seabed BOP Supporter.

4.2. Loading and Load case definition

The top of the wellhead high pressure housing is set at 3m above the mudline. The combined weight (dry) of the BOP, LMRP and Flex Joint is 2847kN and countering this force, a riser tension of 490kN is applied. The internal casing loads are included in the calculation of the allowable bending moment for the conductor. The conductor capacity is calculated based on the methodology given in API RP 2A WSD [2] and it accounts for compressive loading on the conductor. The conductor capacity calculations are presented in Appendix B. In addition, an assessment of the wellhead is carried out for the loading due to riser angle. The rotational stiffness of the flex joint is achieved through the application of bending moment at the appropriate location on the system.

4.2.1. Load Case 1

The loads induced from the flex joint at the top transfers through the path: from LMRP to BOP, to HPWH, to LPWH, to conductor and finally into the soil. This load path is defined as Load Case 1 in this thesis work.

4.2.2. Load Case 2

The loads induced from the flex joint at the top transfers through the path: from LMRP to BOP, to HPWH, to LPWH, and further shared by conductor and CAN, and finally into the soil. This load path is defined as Load Case 2.

4.2.3. Load Case 3

The loads induced from the flex joint at the top transfers through the path: from LMRP to BOP, and from BOP to CAN and soil through the Seabed BOP Supporter. This load path is defined as Load Case 3.

5. Method of Analysis

The analysis of the 30” conductor system was carried out using the Finite Element (FE) Method. The methodology of the analysis for load case 1 is based on the work performed in [15] and it further developed for the other two load cases 2 and 3. The FE model of the wellhead system was established, and analyzed using the ANSYS finite element analysis package. ANSYS is a self-contained, general purpose, finite element program that is well proven and widely used. ANSYS has an extensive element library and provides the ability to solve a wide range of engineering problems.

5.1. Finite Element Model

5.1.1. FE Model for Load case 1:

The BOP, LMRP, Wellhead housing, conductor and inner (21”/ 20”/13-3/8”) casing were modelled using elastic pipe elements (PIPE16) from ANSYS [4]. PIPE16 is a three-dimensional elastic straight pipe element with tension-compression, torsion, and bending capabilities. The element is defined by two nodes, each having six degrees of freedom. The element also has features stress stiffening and large displacement options and these are applied to the model.

Lateral contact due to the interaction of annular cement between the conductor and casings was modelled using contact elements (CONTA178). Annular cement to the mudline level was assumed. Nodal coupling was used to suspend the inner casing string from the wellhead housing and to represent the lateral contact between the wellhead housings.

The flex joint at the top of the LMRP is modelled using a revolute joint COMBIN7 element, topped with a short BEAM3 element. The tension is applied to the BEAM3 element which was rotated to the appropriate angle. A stiffness of 92kNm/degree has been used for the flex joint. The FE model for Load case 1 is shown in Figure 5-1. The foundation soil below mudline surrounding the 30” conductor was modelled using COMBIN39 non-linear spring elements, set at 1m intervals. The spring P-Y characteristics generated from the soil properties are shown in Figure 5-1 through Figure 5-6.

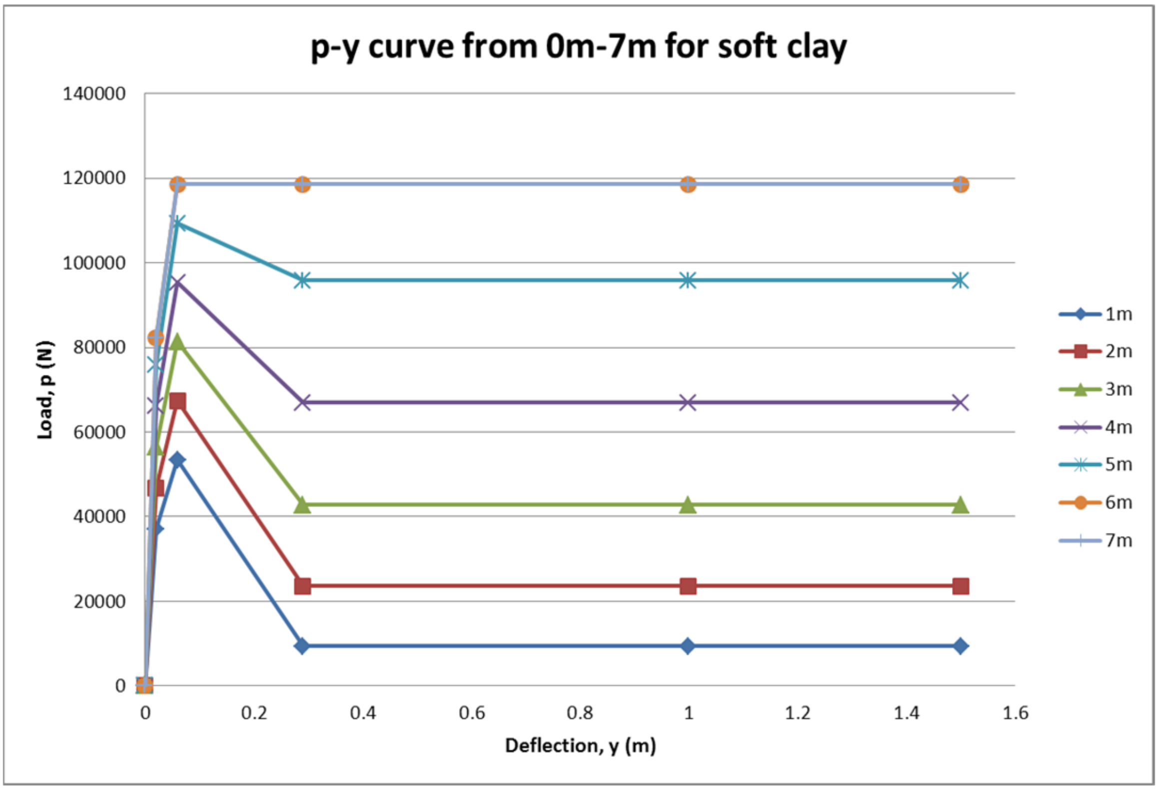


Figure 5-1 Non-Linear Soil Springs for Soft Clay Layer 1

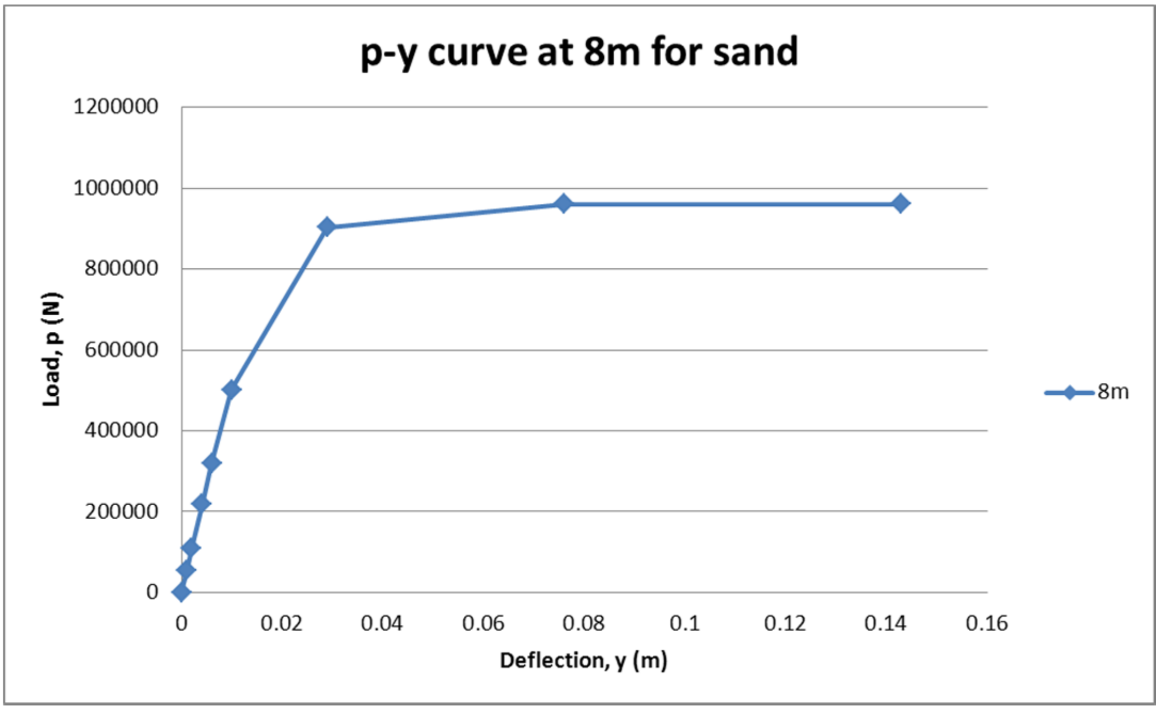


Figure 5-2 Non-Linear Soil Springs for Sand Layer 2

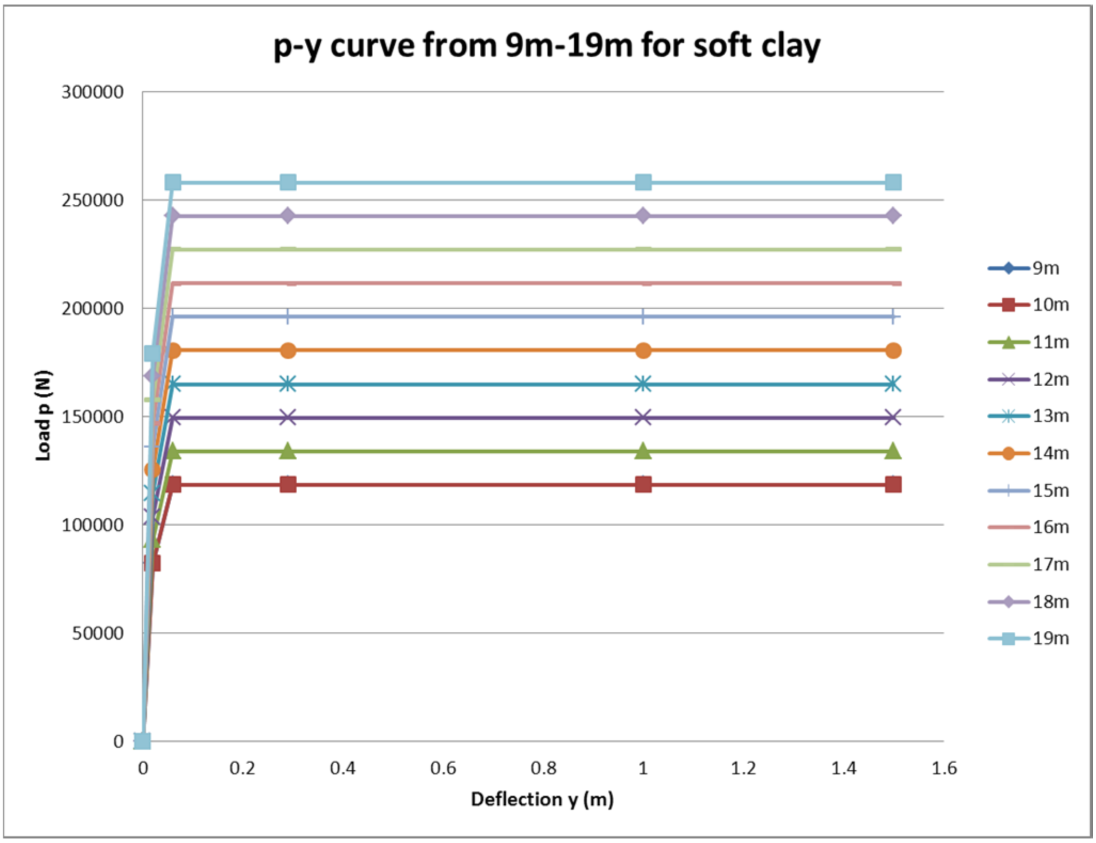


Figure 5-3 Non-Linear Soil Springs for Soft Clay Layer 3

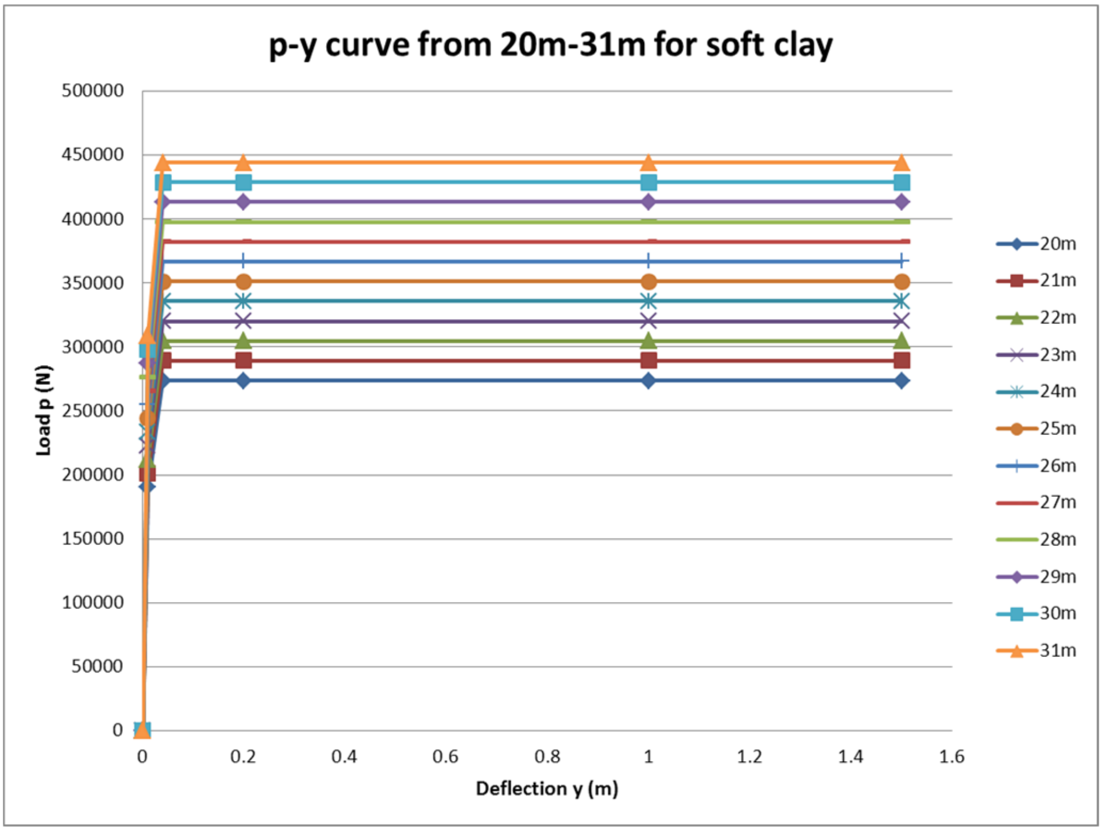


Figure 5-4 Non-Linear Soil Springs for Soft Clay Layer 3

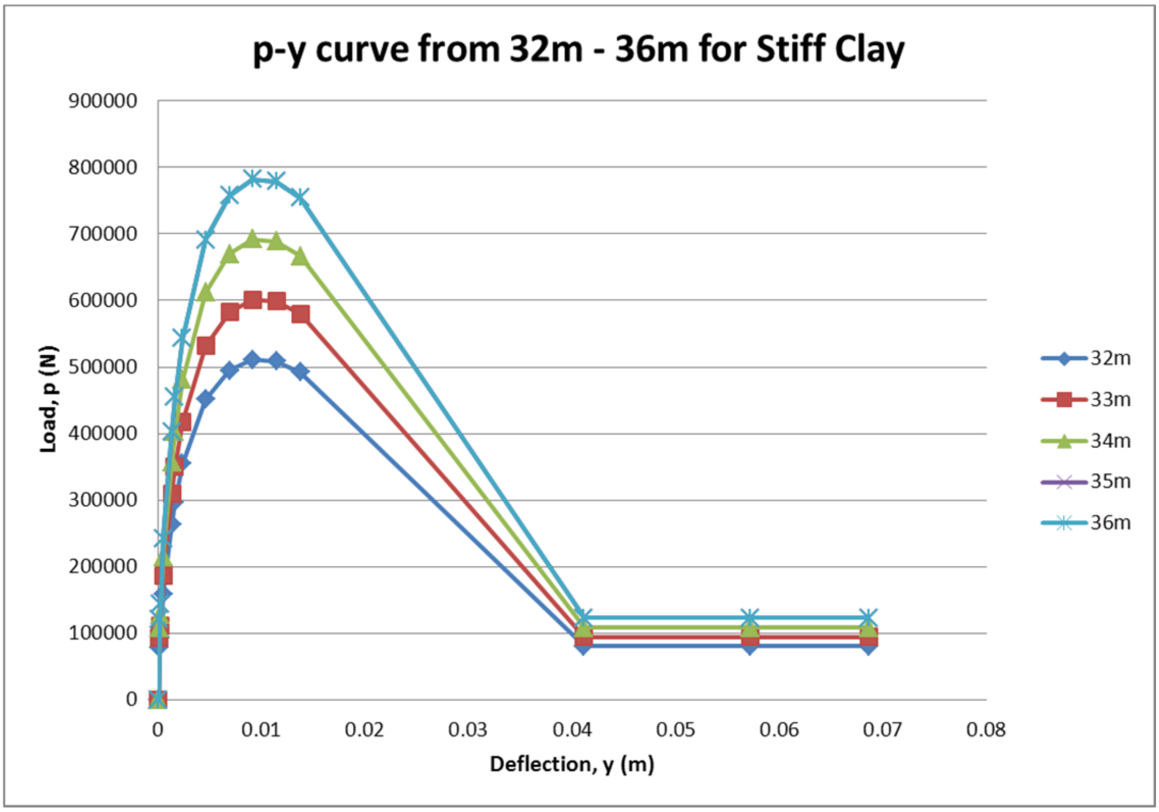


Figure 5-5 Non-Linear Soil Springs for Stiff Clay Layer 4

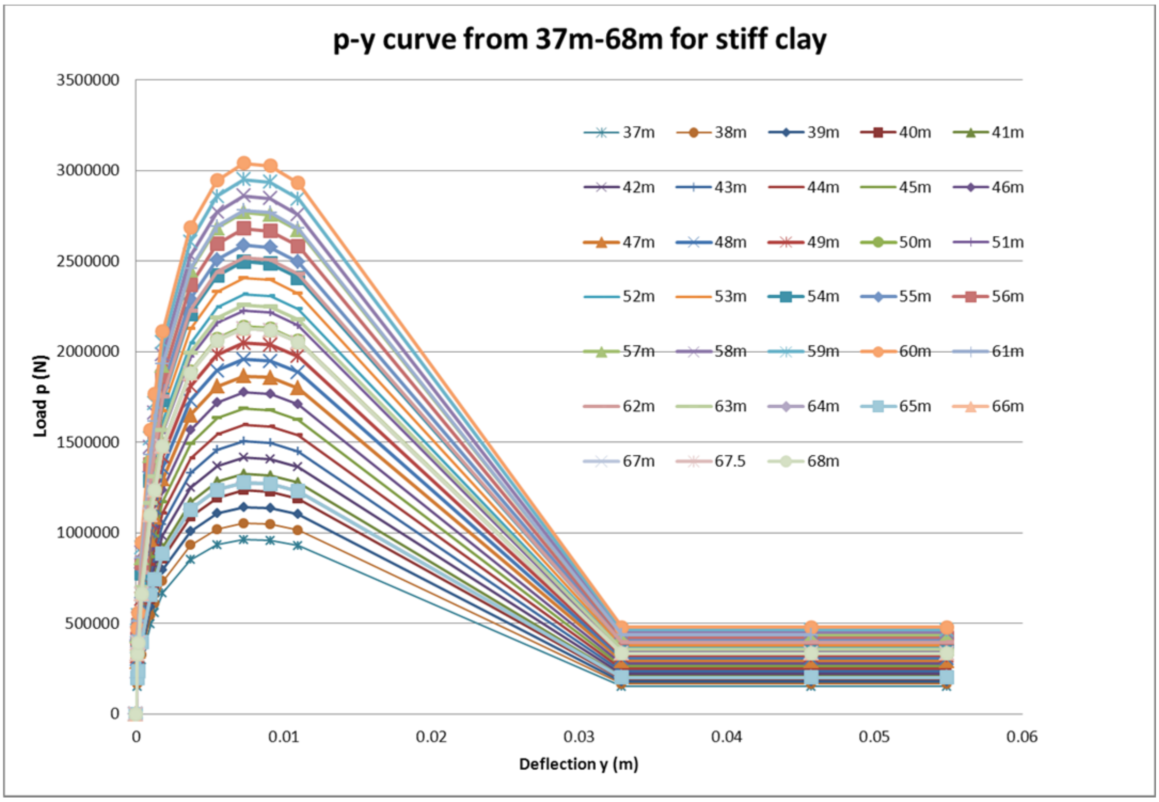


Figure 5-6 Non-Linear Soil Springs for Stiff Clay Layer 4

5.1.2. FEA Model for Load case 2:

Load case 2 is the 30” conductor system with the suction CAN. The CAN was not explicitly modelled but the effect of CAN was modelled by incorporating non-linear spring in the conductor system. The FE model for Load case 2 is shown in Figure 5-7. To account the effect of CAN in the analysis, non-linear spring representing CAN was incorporated in the model. The CAN spring is placed at 1m above the mudline. The relevant stiffness properties of the CAN presented in the Table 4-3 are used in the analysis to resist the loads coming from the 30" wellhead and conductor system.

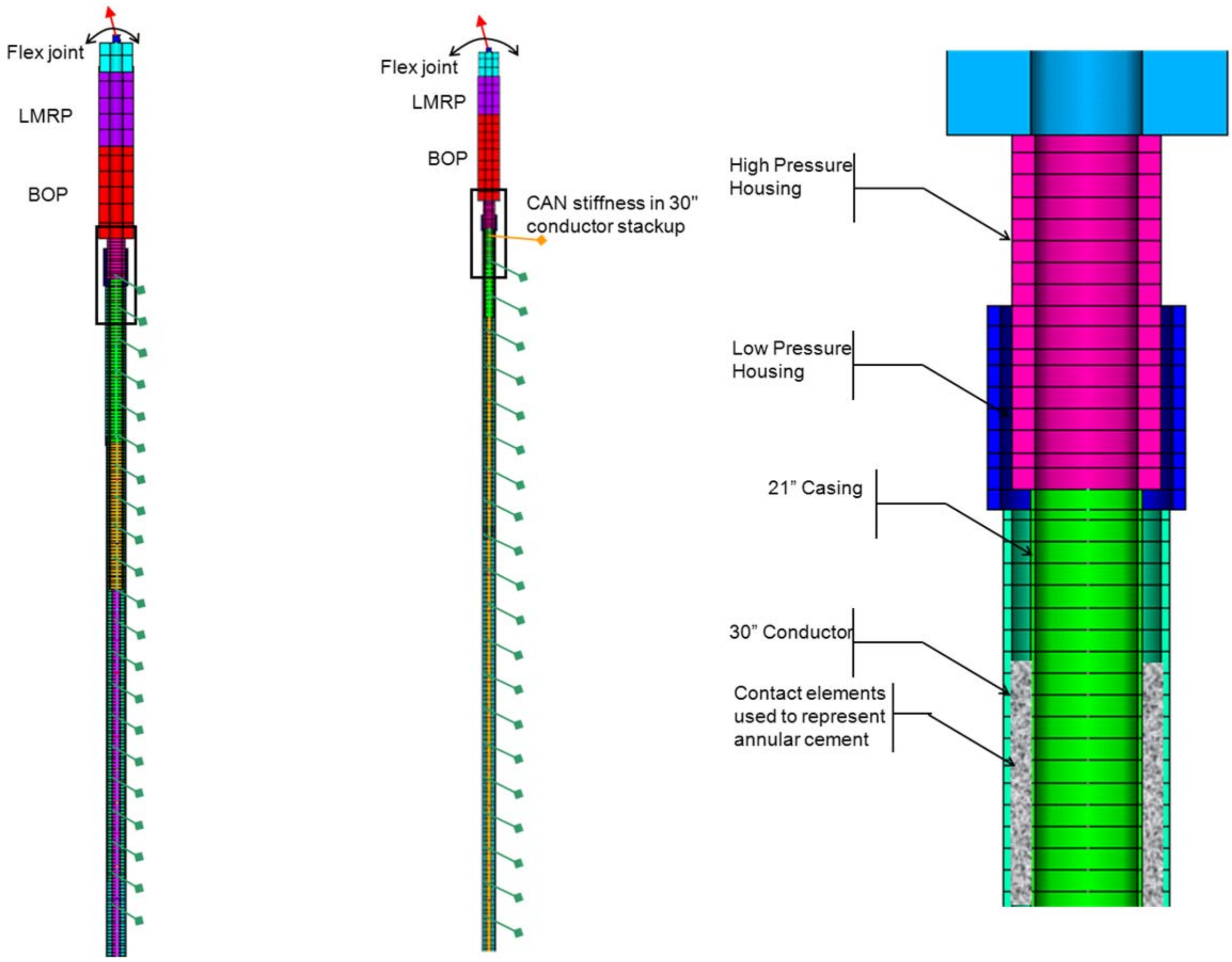


Figure 5-7 FEA Model of the Wellhead Conductor

5.1.3. FEA Model for Load case 3:

Load case 3 is a 30” conductor system with the suction CAN and a Seabed BOP Supporter, this is an extension to the Load case 2. To account the effect of Seabed BOP Supporter in the analysis, a simple pipe model was incorporated in the FE model (see Figure 5-8). The Seabed BOP Supporter is modeled using elastic pipe elements (PIPE16). The characteristics and capabilities of the PIPE16 element have already been explained above.

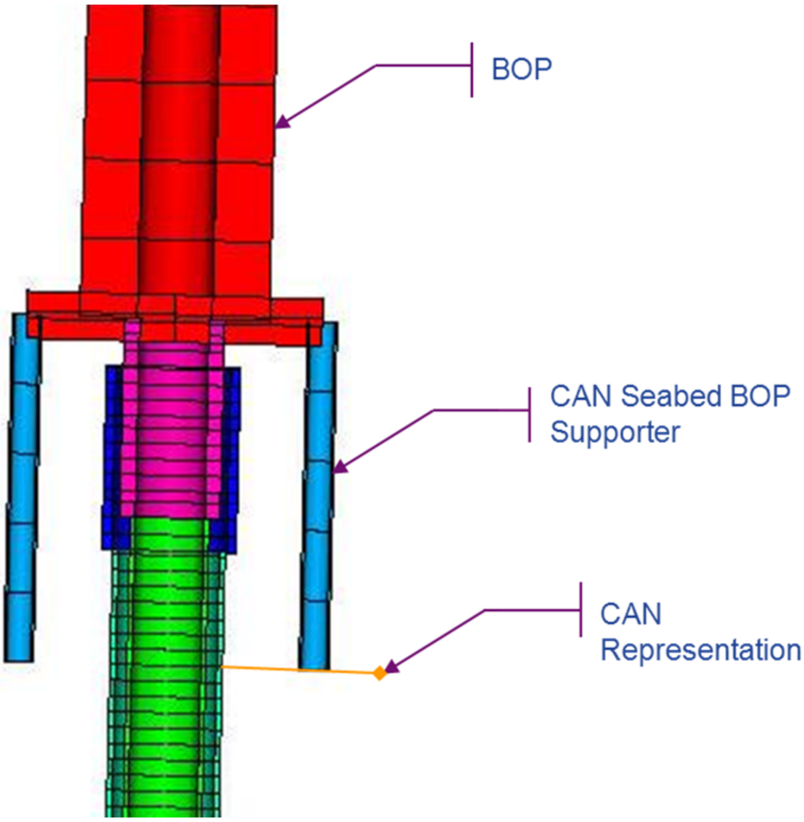


Figure 5-8 FEA model of CAN Seabed BOP Supporter

5.2. Material Properties

The analyses were carried out using linear elastic material properties for all the components:

Modulus of Elasticity = 207×10^9 N/m^2

Poisson Ratio = 0.3

5.3. Applied Loads and Boundary Conditions

The bottom of the conductor string was fixed vertically and rotationally. The free ends of the soil springs were fixed in all degrees of freedom. The angle of inclination of the conductor system was achieved by rotating the complete model through the required angle. Gravity was used so that the mass effects of the BOP etc. would be taken into account. The diameters of pipe elements representing the subsea equipment were based on appropriate values for bending stiffness, with the density of material adjusted to give the correct mass. Riser tension was applied at the flex joint. The variation of flex joint angle was achieved by applying rotation (via bending moment) to the COMBIN7 element. Although 3-dimensional elements are used in this analysis, the model has been constrained so that only 2-dimentional degrees of freedom are active. The CAN stiffness modelled in the 30" stack-up using non-linear spring element is shown in Figure 5-9 and Table 4-3. The values are taken from a thesis submitted to UiS [9].

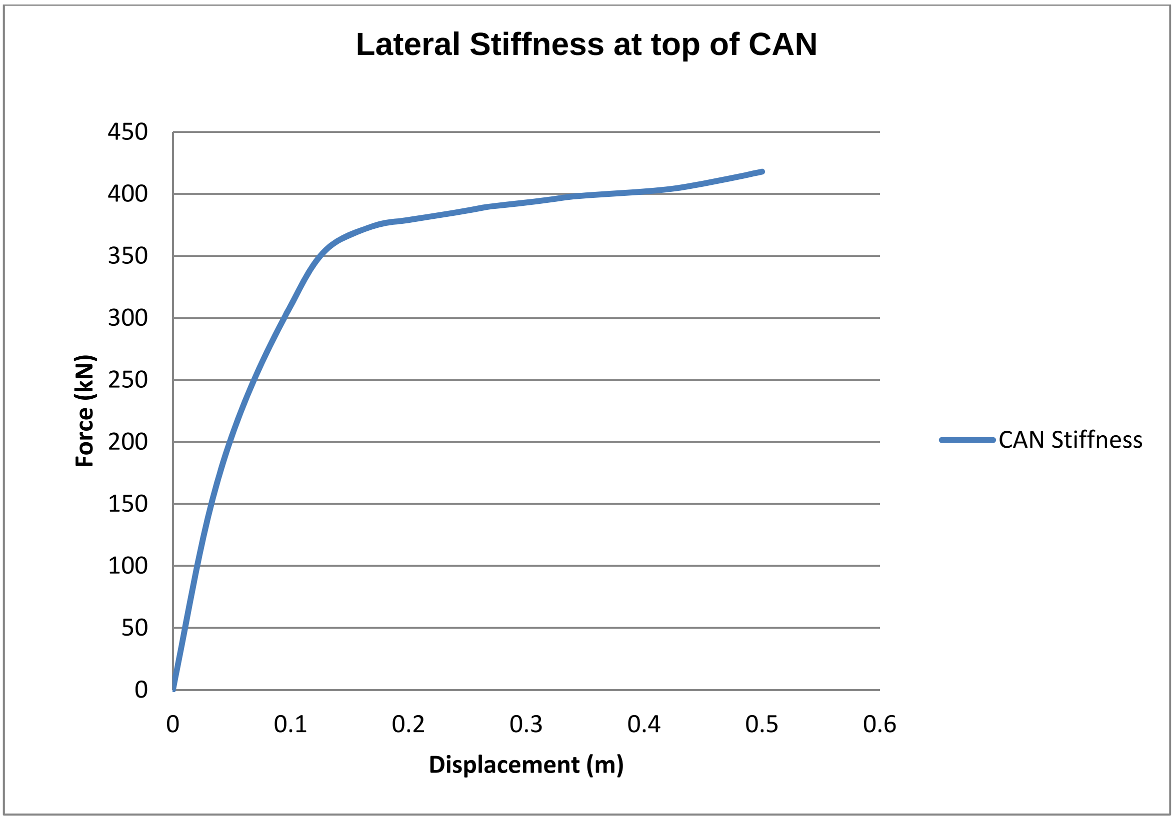


Figure 5-9 CAN Stiffness used for the analysis model [9]

The load on the model was a combined load based on:

- Assumed 50 tonne (490kN) Tension at the flex joint;
- Flex joint Angle (ranging from -10° to +10°);
- BOP/LMRP Weight;
- 511kips (2275kN): 111 kips Internal Casing Load, see Appendix A, plus 400 kips tubing weight (assumed).

5.4. Structural Assessment

The structural bending strength of the system is assessed using the bending moment profile along the conductor with respect to the capacity of the 30" conductor pipe. As mentioned previously, the allowable conductor capacity calculations are in accordance with API RP 2A WSD [2]. Net compression on the conductor due to internal casing and subsea equipment weight is taken into account. Appendix B shows the calculations for conductor capacity.

In accordance with API RP 2A WSD bending stresses are limited to 0.75*yield stress for normal operations and axial stresses are limited to 0.6*yield stress. A 1/3 increase for extreme loading is permitted.

5.5. Allowable Stresses for Conductor

The bending moment induced in the conductor along its length should be lower than the calculated allowable bending capacity as per the API guidelines. The final limiting flex joint rotation angles for the recommended casing program for both working and extreme conditions are determined based on this acceptance criterion. The bending capacity of the conductor is evaluated based on the following equations for the cylindrical members subjected to combined axial and bending loads.
The inelastic buckling stress (F_{xc}) is determined as described below:

5.5.1. Local Buckling

Cylindrical members are investigated for local buckling due to axial compression when the D/t ratio is greater than 60 as per in [2] (Section 3.2.2).
When the D/t ratio is greater than 60 and less than 300 both the elastic (F_{xe}) and inelastic local buckling stress (F_{xc}) due to axial compression are determined from equations given below.

1. Elastic Local Buckling Stress.
   The elastic local buckling stress, F_{xe} is determined from

$$F_{xe} = \frac{2CEt}{D}$$

   Where
   C = critical elastic buckling coefficient, C = 0.3
   D = outside diameter, in (m)
   t = wall thickness, in (m)

2. Inelastic Local Buckling Stress.
   The inelastic local buckling stress, F_{xc}, should be determined from:

$$F_{xc} = \sigma_Y * \left[1.64 - 0.23 \left(\frac{D}{t}\right)^{\frac{1}{4}}\right] \leq F_{xe}$$

$$F_{xc} = \sigma_Y \; for \; (D/t) \leq 60$$

Where σ_Y is Yield strength, ksi (MPa)

5.5.2. Bending

The allowable bending stress, F_b, is determined from:

$$F_b = 0.75 * \sigma_y \ for \ \frac{D}{t} \leq \frac{1500}{\sigma_y}$$

$$F_b = \left[0.84 - 1.74\frac{\sigma_y D}{Et}\right]\sigma_Y \ for \frac{1500}{\sigma_y} < \frac{D}{t} \leq \frac{3000}{\sigma_y}$$

$$F_b = \left[0.72 - 0.58\frac{\sigma_y D}{Et}\right]\sigma_Y \ for \frac{3000}{\sigma_y} < \frac{D}{t} \leq 300$$

Cylindrical members subjected to combined axial and bending loads should be proportioned to satisfy the following requirements at all points along their length.

For the working condition:

$$\frac{f_a}{0.6F_{xc}} + \frac{f_b}{F_b} \leq 1.0$$

After evaluating the bending stress f_b from the above equation, the allowable bending moment is calculated from the equation given below.

The allowable bending moment for the working condition is [15]:

$$ABMW = \frac{2 * f_b * I}{D}$$

For the extreme condition, the stress increases by one third the permitted stress as mentioned in [2] (Section 3.2.2).

For the extreme condition:

$$\frac{f_a}{0.6F_{xc}} + \frac{0.75 * f_b}{F_b} \leq 1.0$$

Therefore, the allowable bending moment for the working condition is [15]:

$$ABME = \frac{2 * f_b * I}{D}$$

6. Results and Discussion

Incremental moment loading was applied to the flex joint. An allowable bending moment for the 30" conductor (52ksi Yield) has been calculated and this can be compared against bending moments generated for each rotation to define allowable flex joint angles [3]. A load of 494kN suspended casing weight has been accounted for in the calculation and it has been assumed that the inner $13^{3/8}$" string does not contribute to the strength of the conductor. For the analysis, the rotational angle of the flex joint has been termed as the angle relative to its initial (point of zero rotational stiffness) position. This relative angle is offset from the vertical by the initial 1.5° well inclination plus the conductor deflection (due to the weight of the subsea equipment etc.) as illustrated below in Figure 6-1.

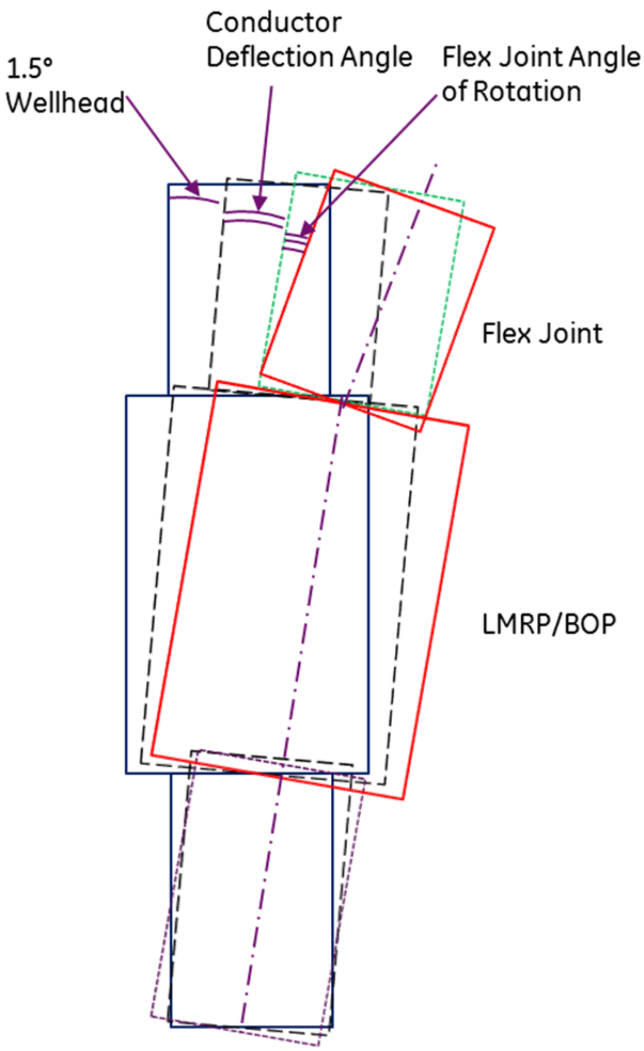


Figure 6-1 Illustration of Conductor and Lower Flex Joint Angles

The responses of bending moment against depth were plotted to assess the load at which the capacity of the 30"x1.5" conductor system is exceeded respectively.

Figure 6-2 through Figure 6-4 show the results for Load Case 1. From the figures, it is seen that the model predictions for bending moment exceeds the allowable bending capacities of the conductor at Flex joint angle of 7° for working conditions.

Similarly, Figure 6-5 through Figure 6-7 presents the results for Load Case 2. The results from the figures show reduced amount of bending moment in the conductor compared to the Load Case 1. Based on the results, it can be concluded that the introduction of CAN in the system influences the response for bending moment to a considerable extent. It is observed that the predicted bending moment of the conductor is within the allowable limit for all the selected range of flex joint angles (-10° through +10°), which is not seen in the Load Case 1.

Further, Figure 6-8 through Figure 6-10 shows the results for Load Case 3. Figures shows the results of reduced amount of bending moments in the wellhead and conductor compared to the above two load cases. It can be concluded that the introduction of Seabed BOP Supporter in the system influences the response for bending moment to a significant extent. Similar to the Load Case 2, also Load Case 3 yields the model predictions that are within the allowable limits for all flex joint angles.

Compared to the introduction of CAN the introduction of Seabed BOP supporter shows profound effect in reducing the bending moment in the overall system. In Figure 6-9 and Figure 6-10 results of bending moment in 30” wellhead conductor and 20” Casing and HP wellhead at 5° of Flex Joint angles have been superimposed for a closer evaluation.

As mentioned, the analysis has been performed by varying the moment load over the selected range of angles. The results for the given range of flex joint angles are extracted for all the three load cases. The results for wellhead conductor are summarized in Table 6-2 for the three load cases. In summary, it is seen from the results that there is, in an average, about 25% reduction of bending moment in the conductor for Load Case 2 compared to Load Case 1. Also Table 6-2 summarizes the results for Load Case 3 in which the introduction of Seabed BOP Supporter causes the reduction of bending moment about 50% to 80% compared to the Load Cases 2 and 1, respectively.

Table 6-3 presents the results for the bending moment extracted for various selected angles in the High Pressure housing and casings. The results follow a similar trend of response as is observed in Low Pressure housing and conductor.

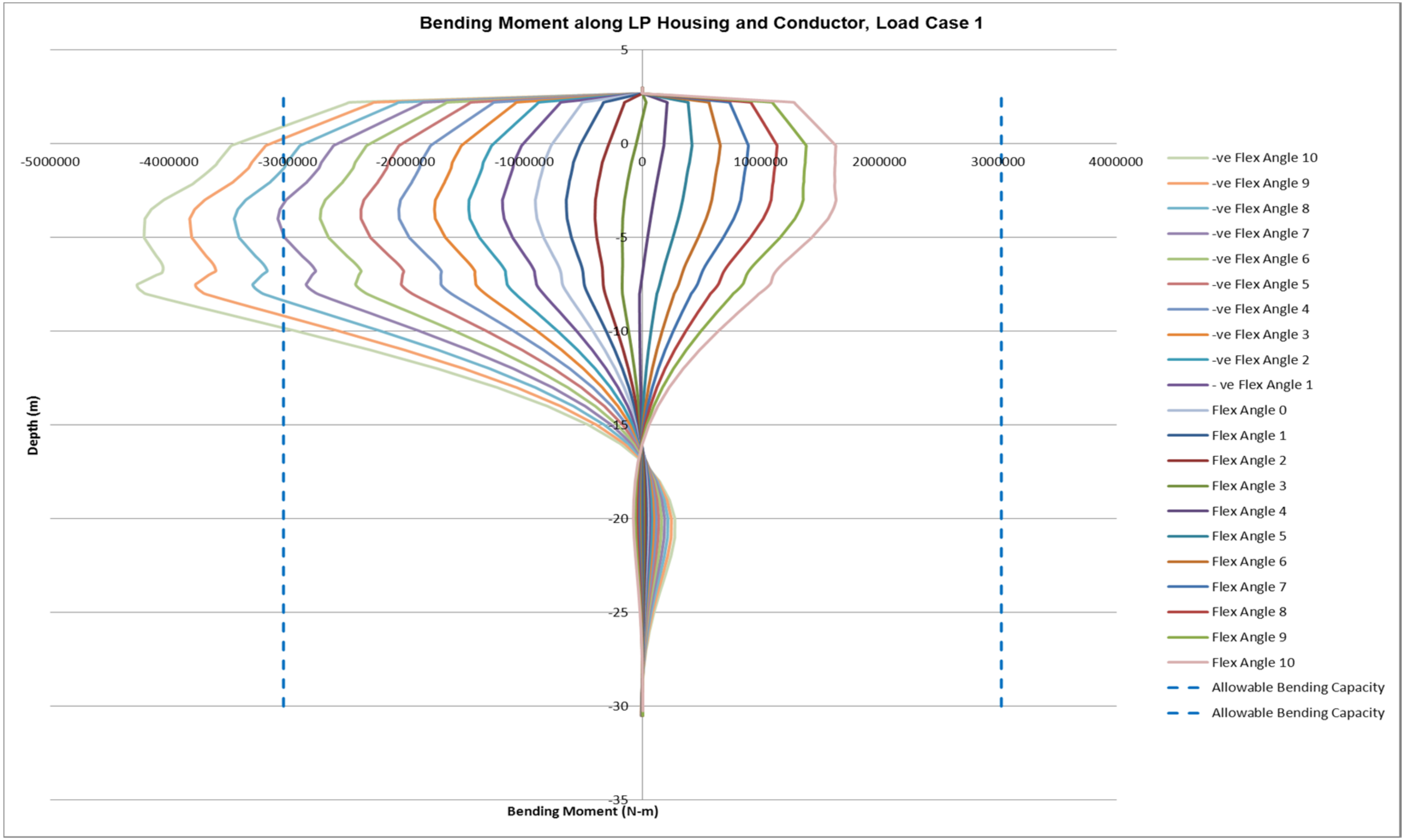


Figure 6-2 Variation of Bending Moment (Nm) with Lower Flex Joint Angle along the Conductor System

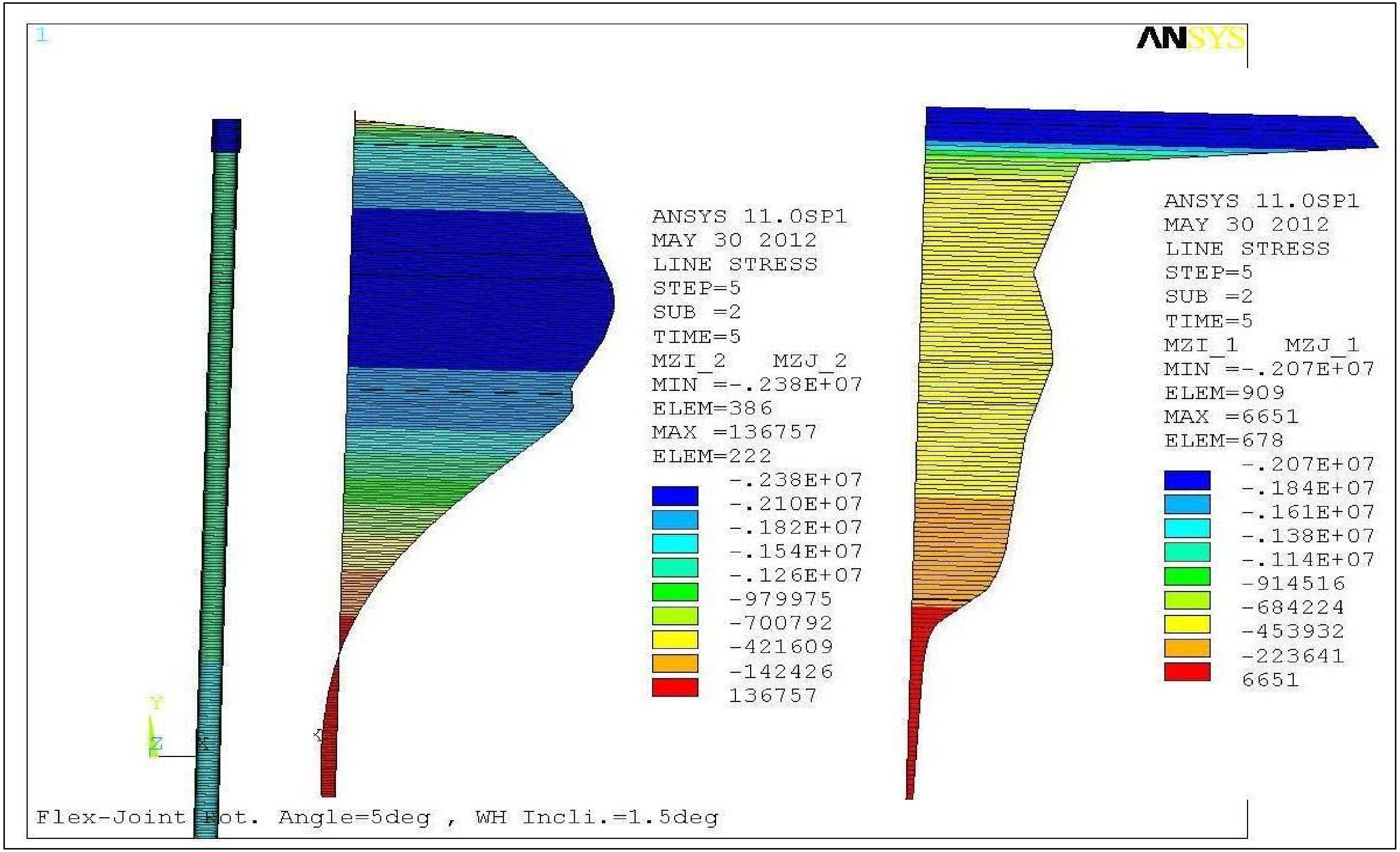


Figure 6-3 Bending Moment (Nm) along the 30” Conductor / 21” Casing at 5° Lower Flex Joint Rotation Angle

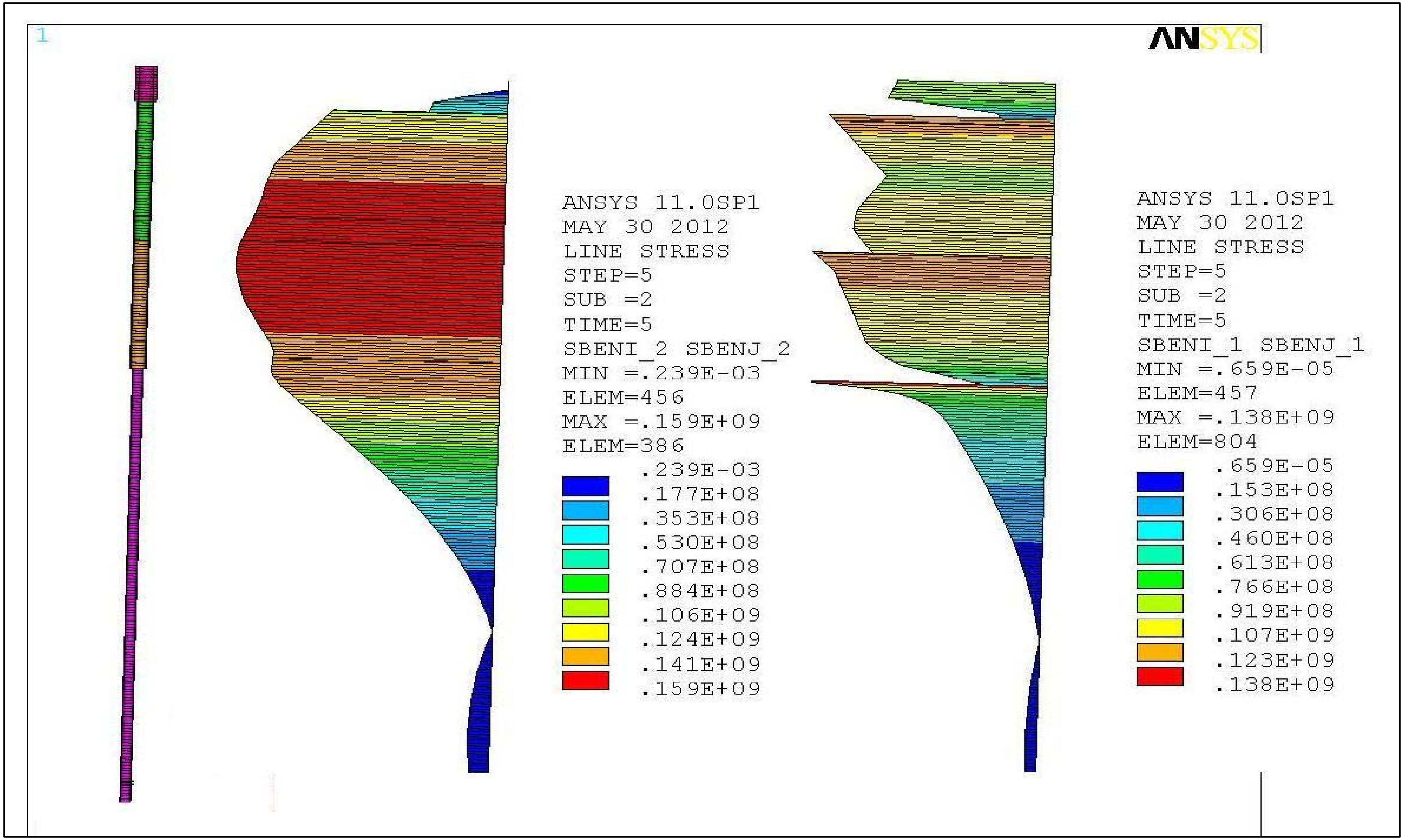


Figure 6-4 Bending Stress (Nm) along the 30” Conductor / 21” Casing at 5° Lower Flex Joint Rotation Angle

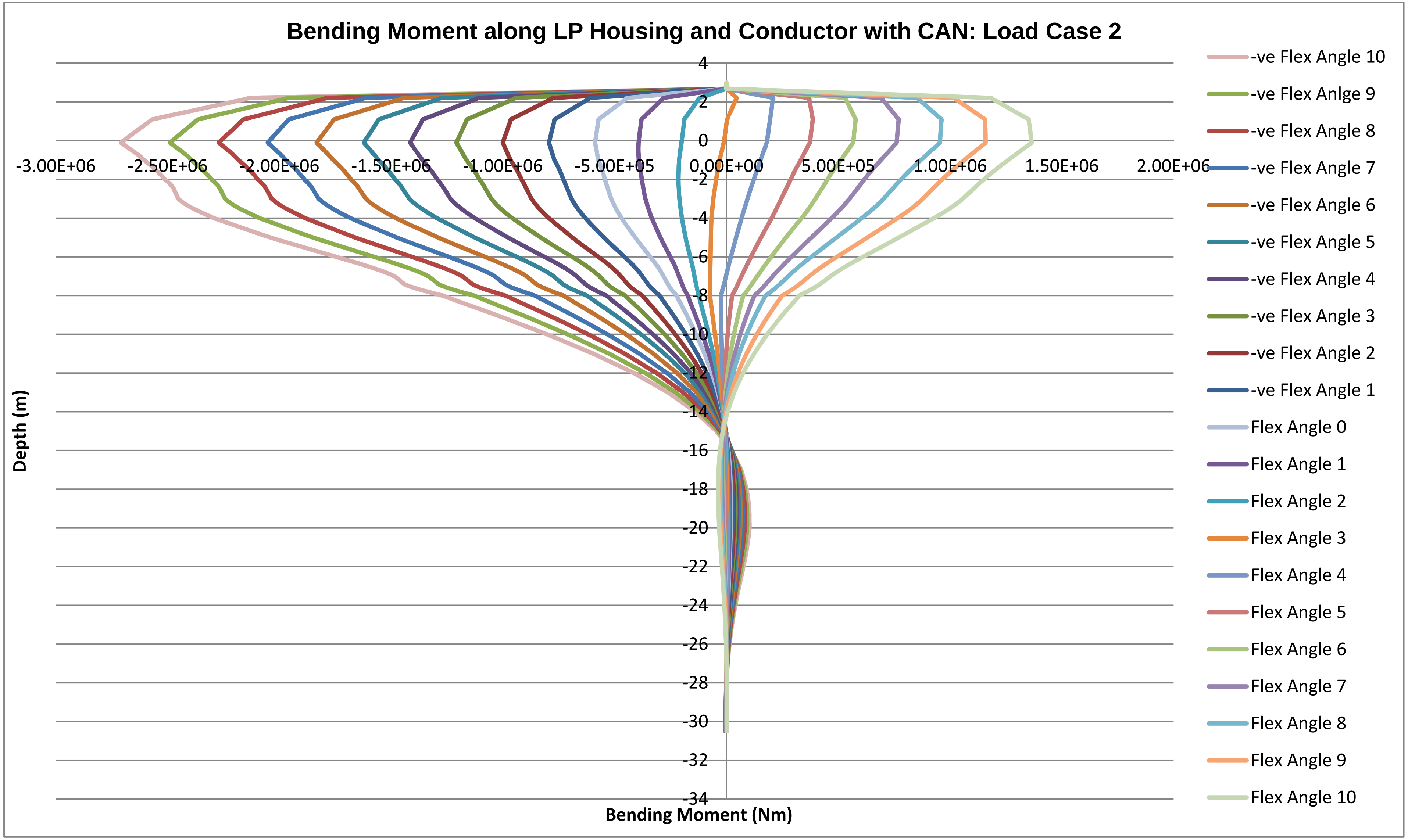


Figure 6-5 Variation of Bending Moment (Nm) with Lower Flex Joint Angle along the Conductor with CAN

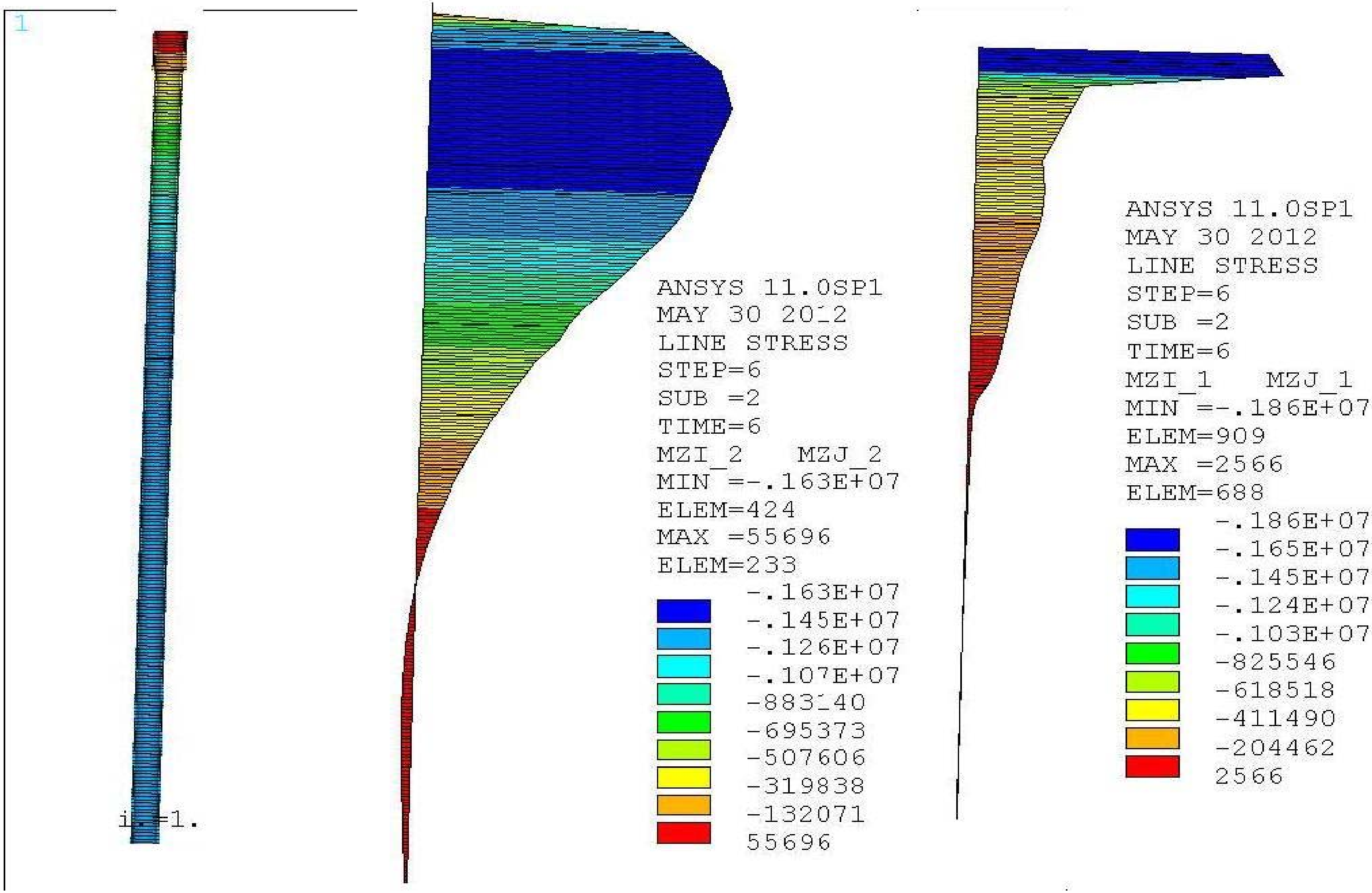


Figure 6-6 Bending Moment (Nm) along the 30" Conductor / 21" Casing with CAN at 5° Lower Flex Joint Rotation Angle, Load Case 2

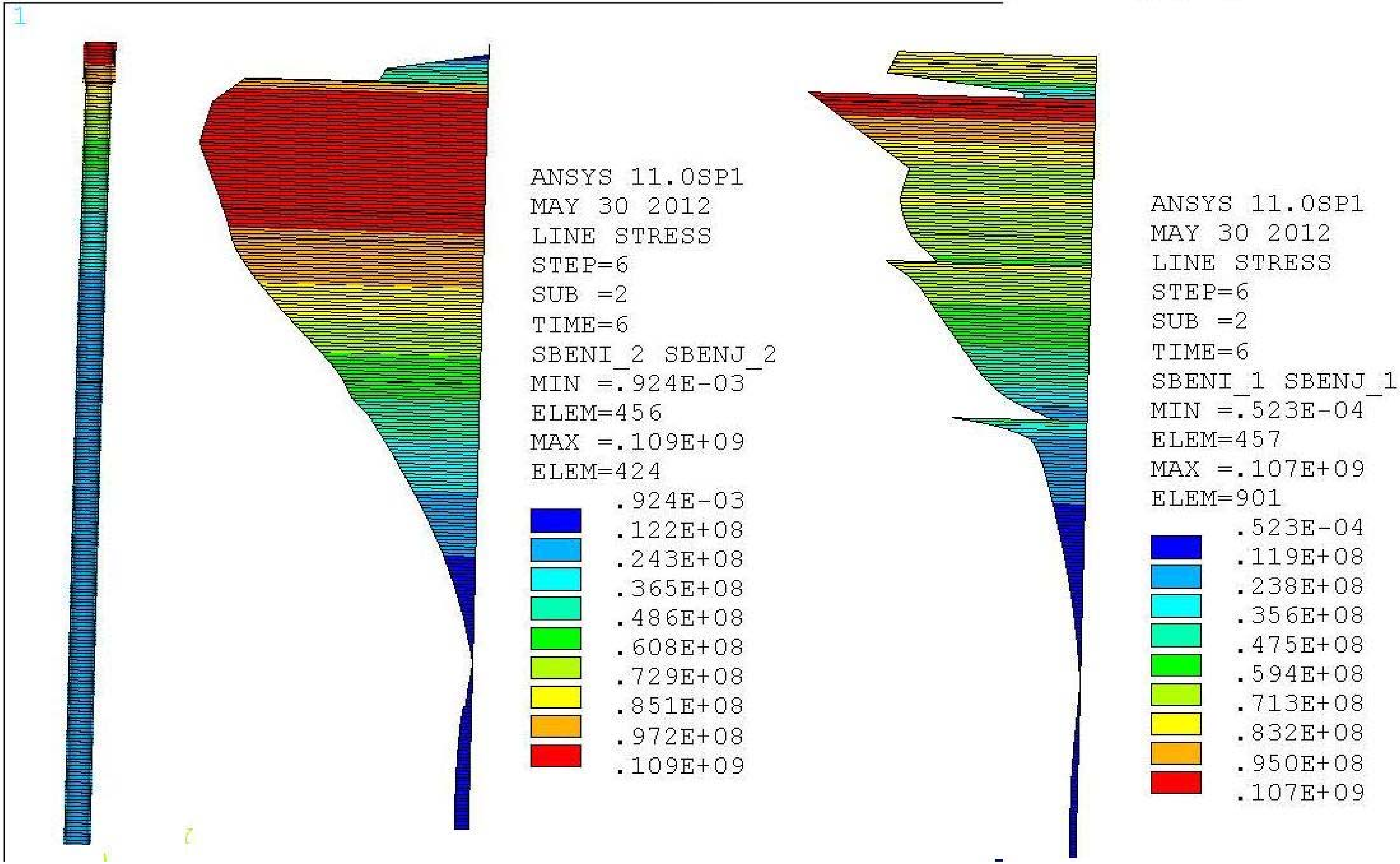


Figure 6-7 Bending Stress (Nm) along the 30” Conductor / 21” Casing with CAN at 5° Lower Flex Joint Rotation Angle, Load Case 2

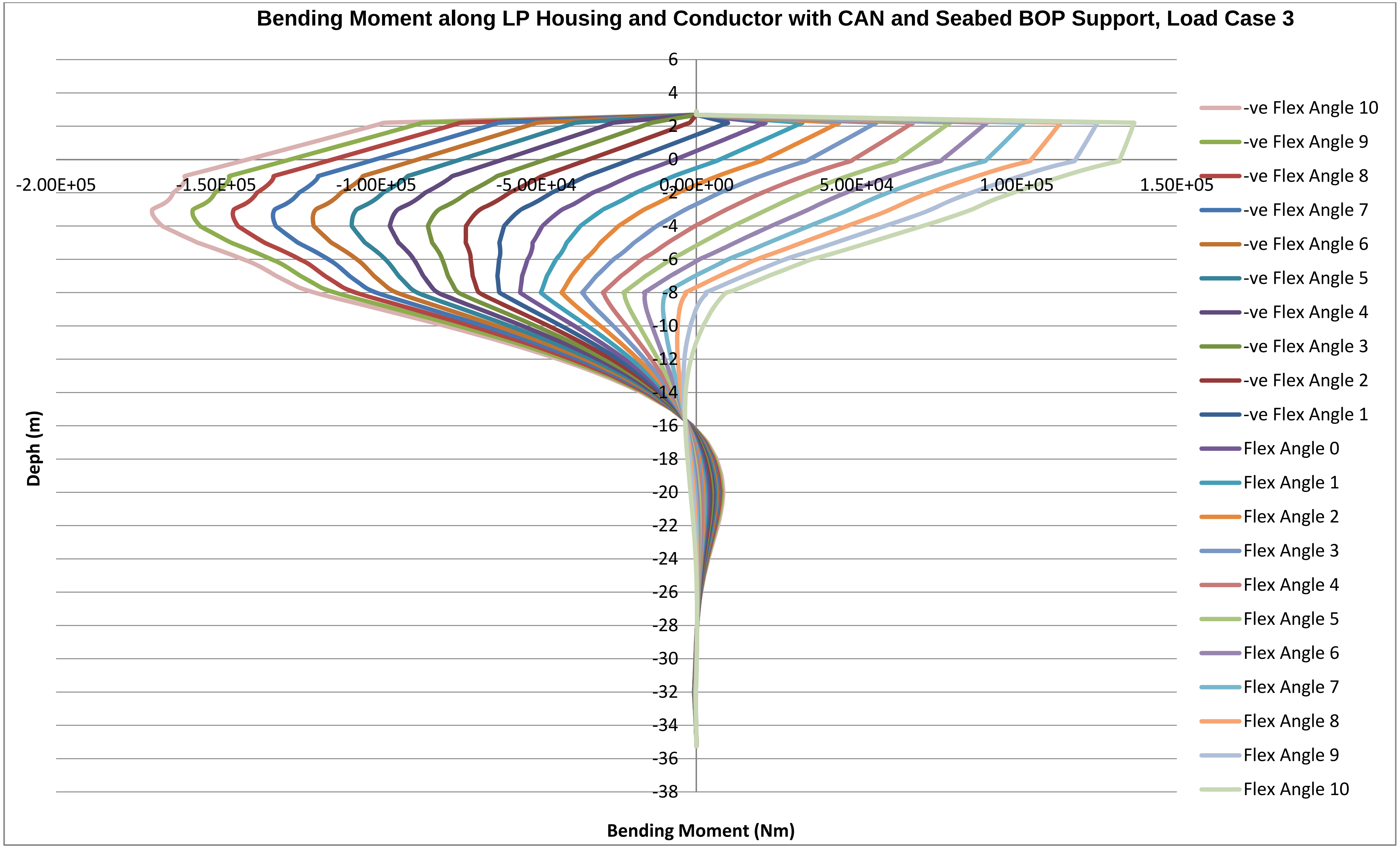


Figure 6-8 Variation of Bending Moment (Nm) with Lower Flex Joint Angle along the Conductor with CAN and Seabed BOP Supporter

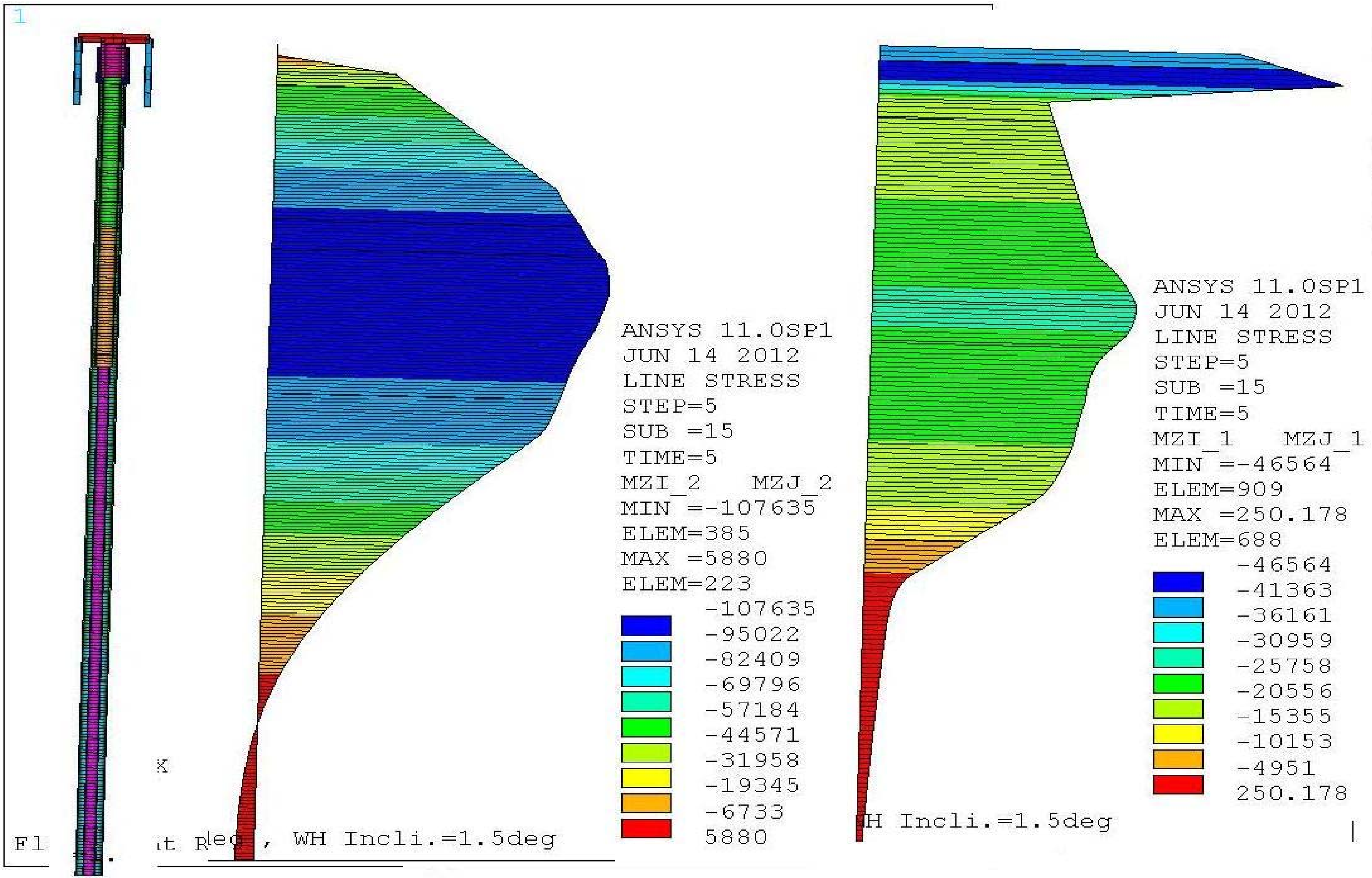


Figure 6-9 Bending Moment (Nm) at 5° Lower Flex Joint Rotation Angle along the 30” Conductor / 21” Casing with CAN and Seabed BOP support, Load Case 3

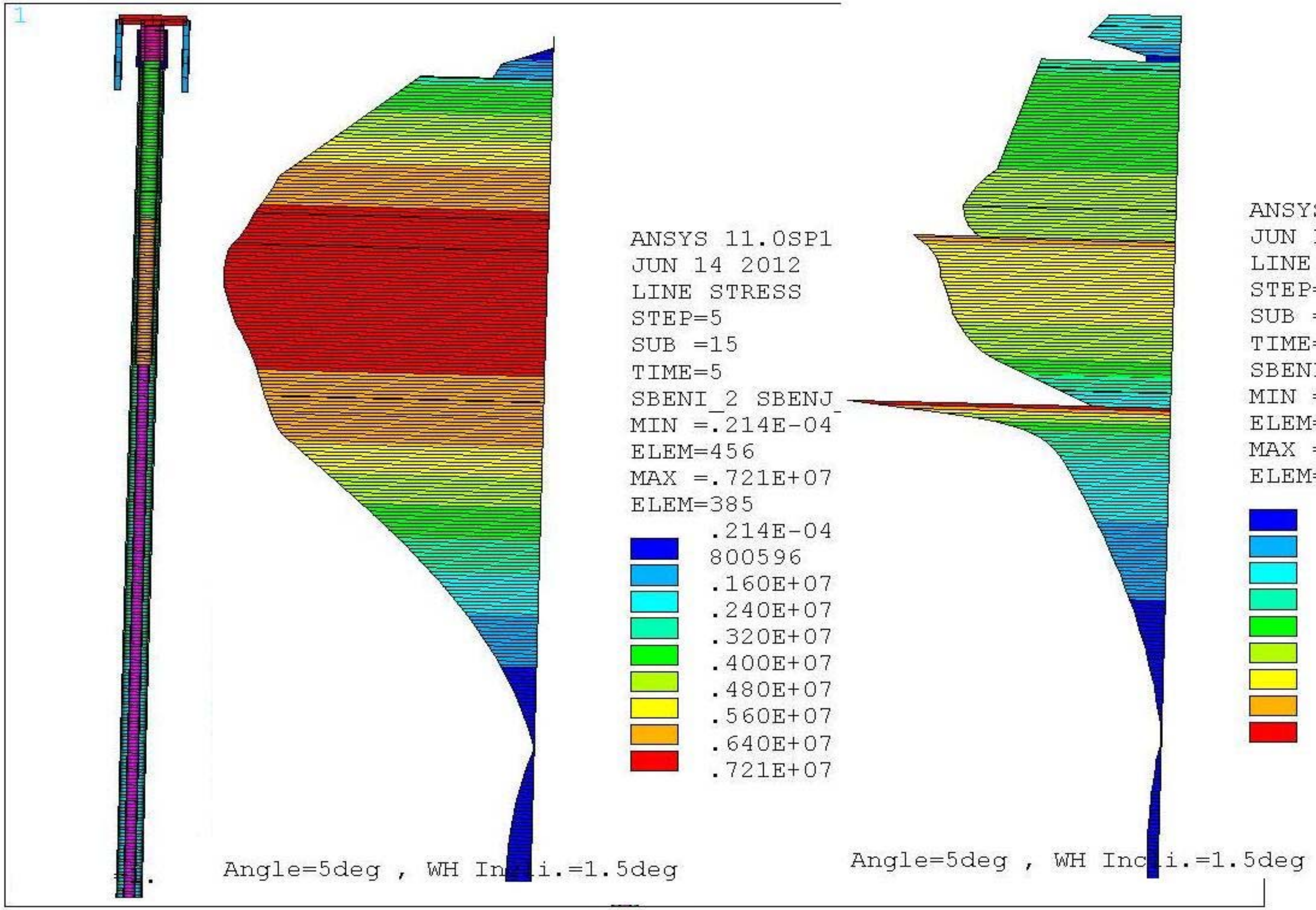


Figure 6-10 Bending Stresses (Nm) at 5° Lower Flex Joint Rotation Angle along the 30” Conductor / 21” Casing with CAN and Seabed BOP Support, Load Case 3

According to API 16 Q standard the recommended allowable limit for the Flex angles is listed in the table below.

Table 6-1 Allowable Flex angles [3]

Working	**4°**
Extreme	**90% of Available = 9°**

The working condition is considered during drilling while extreme condition is considered as non-drilling operation. This is a rig dependent and some of the latest 5th/6th generation rigs can handle more allowable flex angles within the limit of the Flex Joint during drilling operation.

Table 6-2 Variation in maximum bending moment in Low Pressure Housing w.r.t Flex Joint Angles

Flex Angles in (Degrees)	Bending Moment (N-m) for LC1	Bending Moment (N-m) for LC2	Bending Moment (N-m) for LC3	Allowable Bending Capacity WORKING
-10	4265196	2708261	170032	3030000
-9	3821568	2489052	157406	3030000
-8	3445826	2270316	144795	3030000
-7	3077618	2051843	132251	3030000
-6	2720745	1833042	119813	3030000
-5	2375888	1621471	107635	3030000
-4	2057587	1414528	95749	3030000
-3	1756205	1207499	83858	3030000
-2	1466361	1000273	72039	3030000
-1	1181987	794040	62166	3030000
0	904356	587765	21451	3030000
1	643238	393677	48565	3030000
2	400562	215124	44517	3030000
3	171226	73867	56050	3030000
4	208301	208234	67581	3030000
5	418622	386136	79114	3030000
6	657369	577837	90636	3030000
7	894206	770199	102146	3030000
8	1136922	961508	113657	3030000
9	1382759	1159299	125160	3030000
10	1634673	1365033	136649	3030000

Table 6-3 Variation in maximum bending moment in High Pressure Housing w.r.t Flex Joint Angles

Variation in Flex Jt. Angles	Bending Moment (N-m) for LC1	Bending Moment (N-m) for LC2	Bending Moment (N-m) for LC3
-10	3546625	3100727	133048
-9	3244752	2848003	115766
-8	2943626	2596076	98479
-7	2646533	2344993	81182
-6	2354233	2093873	63876
-5	2065970	1846472	46564
-4	1784554	1601603	29246
-3	1508871	1356869	19505
-2	1237256	1112876	16089
-1	967703	869986	12745
0	701998	626248	50737
1	441443	387295	68115
2	184463	149371	85508
3	104133	119671	102896
4	351607	351539	120282
5	598888	581362	137675
6	845925	811922	155053
7	1096603	1044209	172414
8	1356526	1282009	189780
9	1618957	1524195	207138
10	1884393	1766419	224502

7. Conclusion

The present work focuses on investigating the effect of the bending loads on the wellhead systems and evaluating the response of the conductor by introducing CAN and Seabed BOP Supporter. FE Analyses were performed for three different Load Cases for obtaining safe drilling conditions with respect to angle of the action of tension at flex joint by maintaining the structural integrity of the wellhead conductor system. As a first case the wellhead system was analyzed without the CAN and Seabed BOP Supporter. The stiffness contribution due to the CAN and Seabed BOP Supporter has been analyzed in two other different load cases.

The results from the load cases with each of CAN and Seabed BOP Supporter are compared against with the original load case without them. In the first load case results show a significant amount of bending moment transferred to the wellhead conductor and high pressure housing.

For the second load case where CAN is introduced at the sea bed to improve the well foundation, the results show reduced amount of bending moment in the conductor. The reduction in the bending moment is calculated to be in the order of 25%. It has been observed that this reduction is mainly in the part of the conductor below the CAN and considerable amount of high bending loads still exist above the CAN. On other hand when Seabed BOP supporter is introduced as in the Load Case 3, the results show a significantly reduced amount of bending moments in the overall wellhead system, about the order of 80%.

In summary, based on the results from the analysis, it can be conclude that the introduced CAN and Seabed BOP Supporter greatly reduces the response for the bending moment in the subsea wellhead conductor. However the results are purely based on general assumption and are not intended for any specific construction, installation or application purposes.

Finally it can be said that he present work can be challenged to draw improved conclusions by using the realistic material data and design parameters.

8. References

[1] API 17A: Design and Operation of Subsea Production Systems — General Requirements and Recommendations, 4th Edition, 4006.

[2] API RP 2A-WSD (2000): *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design. 21st Edition, December 2000.*

[3] API RP 16Q: *Recommended Practice for Design, Selection, Operation and Maintenance of Marine Drilling Riser Systems, 1st Edition, November 1993 (Reaffirmed Aug 2001)*.

[4] ANSYS11.0 User Manual, ANSYS Inc.

[5] Bai, Y., Bai, Q., *Subsea Engineering Handbook,* Elsevier Inc., 2010, 703-761.

[6] Det Norske Veritas, *Classification Notes No. 30.4*, 1992.

[7] Det Norske Veritas, *Wellhead Fatigue - Method Statement Update*, DNV Reg. No.: 1291V16-21, Revision 02, 2009.

[8] John T. Evans., and John McGrail., *An Evaluation of the Fatigue Performance of Subsea Wellhead Systems and Recommendations for Fatigue Enhancements,* 2H Offshore Engineering Ltd, OTC paper No 21400.

[9] Kwame, T.E., *Investigating Lateral Soil support effects for different types of wellhead systems with an objective to optimize well structural integrity*, Master Thesis, 2011, UiS.

[10] Matlock, H., Reese, L.C., *Generalized Solutions for Laterally Loaded Piles, Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 86, No SM5, 1960, pp. 63–91.

[11] Middleditch, B., *Deepwater Drilling Riser Technical Challenges*, IBC Energy Offshore Drilling Conference, 2011, www.2hoffshore.com/technical-papers

[12] Roger Van Noort, Rob Murray, James Wise, Mark Williamson, Bob Wilde, John Riggs, *Conductor Pre-Installation, Deepwater Brazil,* 2009, OTC Paper No 20005.

[13] Shen, C., Natarajan, S., Lim, F., *"Conductor System Fatigue Excitation and Mitigation",* ISOPE 2010, www.2hoffshore.com/technical-papers

[14] Sivertsen, T., Strand, H., *New Well foundation concept, as used at Norwegian Sea well,* 2011, SPE Arctic and Extreme Environments Conference, paper no. 149548.

[15] Sunkavilli, V.P., Ansari, T., Hashemizadeh, H., *Strength assessment of subsea wellhead conductors, 2012,* International Journal of Oil, Gas and Coal Technology (IJOGCT), in press

[16] Van der Tempel, J., Zaaijer, B., Subroto, H., *The effects of Scour on the design of Offshore Wind Turbines,* http://ocw.tudelft.nl/fileadmin/ocw/courses/OffshoreWindFarmEnergy/res00076/Scour___MAREC_2004.pdf

[17] Xiujuan, Lin., Wensheng, Xiao., Jingbo, Bi., *Subsea Wellhead Mechanical Stability Analysis after Placing Tree in Position,* Journal of Information & Computational Science 8: 10, 2011, 1919–1927.

Appendix A: Casing Weight Calculations

DEFINE VARIABLES

subscript 21 describes the 21" casing string

subscript 22 describes the 20" Casing string

subscript 23 describes the 13 3/8" Casing string

Strings ODs and IDs

$OD_{21} := 21.0 \cdot in$ $\quad ID_{21} := 18.5 \cdot in$

$OD_{22} := 20 \cdot in$ $\quad ID_{22} := 18.0 \cdot in$

$OD_{23} := 13.375 \cdot in$ $\quad ID_{23} := 12.347 \cdot in$

Density of steel $DENS_{st} := 0.287 \cdot \frac{lb}{in^3}$

Density of mud $DENS_{mud} := 12.65 \cdot \frac{lb}{gal}$ $\quad DENS_{mud} = 0.055 \cdot \frac{lb}{in^3}$

Density of cement $DENS_{cmnt} := 16.5 \cdot \frac{lb}{gal}$ $\quad DENS_{cmnt} = 0.071 \cdot \frac{lb}{in^3}$

Density of brine $DENS_{water} := 8.66 \cdot \frac{lb}{gal}$ $\quad DENS_{water} = 0.037 \cdot \frac{lb}{in^3}$

True vertical depth of strings

$TVD_{21} := 15.0 \cdot ft$ $\quad TVD_{21} = 180 \cdot in$ Depth to surface casing xover

$TVD_{22} := 30.0 \cdot ft$ $\quad TVD_{22} = 360 \cdot in$ Depth to surface casing xover

$TVD_{23} := 3607.0 \cdot ft$ $\quad TVD_{23} = 4.328 \times 10^4 \cdot in$ Depth to surface casing shoe

True vertical depth from surface to cement top

$TVDCM_{21} := 0.0 \cdot ft$ $\quad TVDCM_{21} = 0 \cdot in$ Depth to surface casing cement top

$TVDCM_{22} := 15.0 \cdot ft$ $\quad TVDCM_{22} = 180 \cdot in$ Depth to surface casing cement top

$TVDCM_{23} := 30.0 \cdot ft$ $\quad TVDCM_{23} = 360 \cdot in$ Depth to surface casing cement top

START CALCULATION

Section Properties

$AREA_{OD21} := \frac{\pi}{4} \cdot OD_{21}^2$ $\qquad AREA_{OD21} = 346.361 \, in^2$

$AREA_{ID21} := \frac{\pi}{4} \cdot ID_{22}^2$ $\qquad AREA_{ID21} = 254.469 \, in^2$

$AREA_{OD22} := \frac{\pi}{4} \cdot OD_{22}^2$ $\qquad AREA_{OD22} = 314.159 \, in^2$

$AREA_{ID22} := \frac{\pi}{4} \cdot ID_{22}^2$ $\qquad AREA_{ID22} = 254.469 \, in^2$

$AREA_{OD23} := \frac{\pi}{4} \cdot OD_{23}^2$ $\qquad AREA_{OD23} = 140.5 \, in^2$

$AREA_{ID23} := \frac{\pi}{4} \cdot ID_{23}^2$ $\qquad AREA_{ID23} = 119.733 \, in^2$

Strings Metal Areas

$CSA_{21} := AREA_{OD21} - AREA_{ID21}$ $\qquad CSA_{21} = 91.892 \, in^2$

$CSA_{22} := AREA_{OD22} - AREA_{ID22}$ $\qquad CSA_{22} = 59.69 \, in^2$

$CSA_{23} := AREA_{OD23} - AREA_{ID23}$ $\qquad CSA_{23} = 20.768 \, in^2$

String Nominal Weights

$PPF_{21} := CSA_{21} \cdot DENS_{st}$ $\qquad PPF_{21} = 316.475 \frac{lb}{ft}$

$PPF_{22} := CSA_{22} \cdot DENS_{st}$ $\qquad PPF_{22} = 205.573 \frac{lb}{ft}$

$PPF_{23} := CSA_{23} \cdot DENS_{st}$ $\qquad PPF_{23} = 71.524 \frac{lb}{ft}$

1. BUOYANT WEIGHT OF 21" / 20" / 13-3/8” CASING

Calculation of Fluid Forces

$$Wcontents_2 := \left[AREA_{ID21} \cdot TVD_{21} + AREA_{ID22} \cdot (TVD_{22} - TVD_{21}) + AREA_{ID23} \cdot (TVD_{23} - TVD_{22})\right] \cdot DENS_{mud}$$

$$Wcontents_2 = 2.865 \times 10^5 \cdot lb$$

$$Wdisplaced_2 := AREA_{OD23} \cdot DENS_{cmnt} \cdot (TVD_{23} - TVDCM_{23}) + AREA_{OD22} \cdot DENS_{cmnt} \cdot (TVD_{22} - TVDCM_{22}) \ldots + AREA_{OD21} \cdot DENS_{cmnt} \cdot (TVD_{21} - TVDCM_{21})$$

$$Wdisplaced_2 = 4.393 \times 10^5 \cdot lb$$

Casing Weight in Air

$$Winair_2 := PPF_{21} \cdot TVD_{21} + PPF_{22} \cdot \left(TVD_{22} - TVD_{21}\right) + PPF_{23} \cdot \left(TVD_{23} - TVD_{22}\right)$$

$$Winair_2 = 2.637 \times 10^5 \cdot lb$$

Casing Weight When Cemented

$$Wincement_2 := Winair_2 + Wcontents_2 - Wdisplaced_2$$

$$Wincement_2 = 1.109 \times 10^5 \cdot lb$$

Summary of Results

21" / 20" / 13-3/8" casing $Winair_2 = 2.637 \times 10^5 \cdot lb$ $Wincement_2 = 1.109 \times 10^5 \cdot lb$

Appendix B: Conductor Capacity Calculations

Allowable Bending Moment Calculation to API 2A-WSD Section 3.3.1b

Find the allowable moment in column buckling - 30" x 1.5" Outer Conductor

$\sigma_y := 52000\,psi$ Grade X-52 Conductor

$E := 30000000\,psi$ $E = 2.068\times 10^{11}\,Pa$

<u>Outer Conductor</u>

$OD_{30} := 30\cdot in$

$t_{30} := 1.5\cdot in$

$ID_{30} := OD_{30} - 2\cdot t_{30}$

$ID_{30} = 27\,in$

<u>Cross Sectional Areas (Outer Conductor Only):</u>

$A_{30} := \frac{\pi}{4}\cdot\left(OD_{30}^{\;2} - ID_{30}^{\;2}\right)$ $A_{30} = 134.303\,in^2$

<u>I Values</u>

$I_{30} := \frac{\pi}{64}\cdot\left(OD_{30}^{\;4} - ID_{30}^{\;4}\right)$ $I_{30} = 1.367\times 10^4\,in^4$

<u>Outer Conductor Subject to Casing Load</u>

Axial load

$P := [(511000) + 640000 - 178000]\cdot lbf$ (Casing Load+ BOP, LMRP, Flex Joint-Tension)

Axial stress $fa := \frac{P}{A_{30}}$ $fa = 7.245\times 10^3\,psi$

<u>Inelastic buckling stress</u>

$\frac{OD_{30}}{t_{30}} = 20$ (D/t)

$$\mathrm{Fxc} := \begin{cases} \sigma_y & \text{if } \dfrac{OD_{30}}{t_{30}} \le 60 \\ \sigma_y \cdot \left[1.64 - 0.23\left(\dfrac{OD_{30}}{t_{30}}\right)^{\frac{1}{4}}\right] & \text{if } \sigma_y \cdot \left[1.64 - 0.23\left(\dfrac{OD_{30}}{t_{30}}\right)^{\frac{1}{4}}\right] \le 2 \cdot 0.3 \cdot E \cdot \dfrac{t_{30}}{OD_{30}} \wedge \dfrac{OD_{30}}{t_{30}} > 60 \\ 2 \cdot 0.3 \cdot E \cdot \dfrac{t_{30}}{OD_{30}} & \text{otherwise} \end{cases}$$

(3.2.2-4)

$$\mathrm{Fxc} = 52000\mathrm{psi}$$

Allowable Bending Stress (API 2A WSD, Sect.3.2.3

$$\mathrm{Fb} := \begin{cases} 0.75 \cdot \sigma_y & \text{if } \dfrac{OD_{30}}{t_{30}} \le \dfrac{1500000 \cdot \mathrm{psi}}{\sigma_y} \\ \left(0.84 - 1.74 \cdot \dfrac{\sigma_y \cdot OD_{30}}{E \cdot t_{30}}\right) \cdot \sigma_y & \text{if } \dfrac{1500000\mathrm{psi}}{\sigma_y} < \dfrac{OD_{30}}{t_{30}} < \dfrac{3000000 \cdot \mathrm{psi}}{\sigma_y} \\ \left(0.72 - 0.58 \cdot \dfrac{\sigma_y \cdot OD_{30}}{E \cdot t_{30}}\right) \cdot \sigma_y & \text{if } \dfrac{3000000\mathrm{psi}}{\sigma_y} < \dfrac{OD_{30}}{t_{30}} < 300 \end{cases}$$

(3.2.3-1a)

$$\mathrm{Fb} = 39000\mathrm{psi}$$

Combined Axial and Bending for Cylindrical Pile Stress (API 2A WSD, Sect.3.3.1b)

$$\frac{fa}{0.6 \cdot \mathrm{Fxc}} + \frac{fb}{\mathrm{Fb}} \le 1$$

(3.3.1-5)

Rearranging for bending stress (f_b):

$$fb := \left(1 - \frac{fa}{0.6 \cdot \mathrm{Fxc}}\right) \cdot \mathrm{Fb} \qquad fb = 206 \times 10^6\,\mathrm{Pa}$$

Equivalent De-rating factor: $\dfrac{fb}{\sigma_y} = 0.576$

$$fb = 29944\mathrm{psi}$$

Calculate allowable moment using the above bending stress:

2a. Outer Conductor Only (Working)

$$ABM_{1w} := \frac{fb \cdot I_{30} \cdot 2}{OD_{30}}$$

$$ABM_{1w} = 2.275 \times 10^{6}\ lbf \cdot ft$$

$$ABM_{1w} = 3.084 \times 10^{6}\ N \cdot m$$

Section 3.1.2 allows a one third increase in permitted stress for extreme environmental loading:

$$\frac{fa}{0.6 \cdot Fxc} + \frac{0.75 \cdot fb}{Fb} \leq 1$$

Rearranging:

$$fb := \left(1 - \frac{fa}{0.6 \cdot Fxc}\right) \cdot \frac{Fb}{0.75} \qquad fb = 275 \times 10^{6}\ Pa$$

$$fb = 39925 psi$$ Equivalent De rating factor: $\frac{fb}{\sigma_y} = 0.768$

Calculate allowable moment using the above bending stress:

2b. Outer Conductor Only (Extreme)

$$ABM_{1e} := \frac{fb \cdot I_{30} \cdot 2}{OD_{30}}$$

$$ABM_{1e} = 3.033 \times 10^{6}\ lbf \cdot ft$$

$$ABM_{1e} = 4.112 \times 10^{6}\ N \cdot m$$

Appendix C: ANSYS CODE

```
FINISH
/CONFIG,NPROC,2
/CLEAR
*ABBR,INPUT,/INPUT,INPUT,INP
/COLOR,PBAK,OFF
/TITLE,THESIS CASE1
/UNITS,SI
/PREP7

C***  ***********************************
C***  * INPUT PARAMETERS (METRIC UNITS) *
C***  ***********************************

PI=ACOS(-1)
degtorad=pi/180

WHD_ANG=1.5  !    ****   Wellhead Inclination Angle   ****

SNANG=SIN(WHD_ANG*degtorad)

!conductor rotated to 1.5 degree wellhead angle

C***  ***********************
C***  * PIPES AND GAPS SIZES *
C***  ***********************

C***  Flex Joint ********************   !(- *0.254) = inches to meters
ODFJ1=47.50*.0254 !1.206m

THFJ1=14.38*.0254 !0.365m


C*** LMRP *************************
ODLMRP1=50.54*.0254 !1.283m

THLMRP1=15.27*.0254 !0.388m


C*** BOP *************************
ODBOP1=50.54*.0254 !1.283m

THBOP1=15.27*.0254 !0.388m


C***  30" STRING *****************

C***  30" HSG

OD1H1=35.75*0.0254

ID1H1=30.8*0.0254

TH1H1=(OD1H1-ID1H1)/2  !0.06286m 2.47in

C***  30"x1.5" Conductor (OD & WT) X52
OD30EXT=30.0*0.0254

TH30EXT=1.5*0.0254


C***  30" Conductor (OD & WT) X52
OD30=30.0*0.0254
TH30=1.0*0.0254

C***  20" STRING *****************
```

```
C***  18 3/4" HSG

OD2H1=26.8*0.0254

ID2H1=18.5*0.0254

TH2H1=(OD2H1-ID2H1)/2

C***  21" x 1.25" X52 Casing (OD & WT)
OD21=21.0*0.0254
TH21=1.25*0.0254

C***  20" x 1" X52 Casing (OD & WT)
OD20=20.0*0.0254
TH20=1*0.0254

C***  13 3/8" x 0.514" P-110Casing (OD & WT)
OD13=13.375*0.0254
TH13=0.514*0.0254

C***  ****************
C***  * HEIGHT DATA *
C***  ****************
                                !total 40 ft*4 =160ft => 48.768m
C***  Origin at Mudline
MUDL=0.0
C*** Critical locations above mudline

TFLEXJT=(641.52+10)*0.0254  !Top of Flex Joint for Tension Location
FLEXJT=641.52*0.0254    !16.3m Flex Joint Centre of Rotation
LMRP=606.12*0.0254      !15.4m Top of LMRP - 4.5ft below FLEXJT
BOP=456.48*0.0254       !11.6m Top of BOP

THPHSG=130.116*0.0254   !3.3m Top of High Pressure Housing (HPH)
THS30=118.116*0.0254    !3.0m TOP OF 30 HOUSING (LPH) FROM MUDLINE
H1LS=105.67*0.0254      !2.68m MUDLINE TO TOP CONTACT POINT
H2LS=86.92*0.0254       !2.20m MUDLINE TO BOTTOM CONTACT POINT
HWP=80.25*0.0254        !2.03m MUDLINE TO WELD PREP ON HPH (144"-63.75")

TCO30=72*0.0254         !1.83m Top of 30"x1.5in conductor (bottom of LPH)


C*** Critical locations below mudline
BOTST=-68
SPR68=-67
SPR67=-66
SPR66=-65
SPR65=-64
SPR64=-63.5
SPR63=-63
SPR62=-62
SPR61=-61
SPR60=-60
SPR59=-59
SPR58=-58
SPR57=-57
SPR56=-56
SPR55=-55
SPR54=-54 !30"x1" to shoe joint" xover @ 54m
SPR53=-53
SPR52=-52
SPR51=-51
SPR50=-50
SPR49=-49
SPR48=-48
SPR47=-47
SPR46=-46
SPR45=-45
SPR44=-44
```

```
SPR43=-43
SPR42=-42
SPR41=-41
SPR40=-40
SPR39=-39
SPR38=-38
SPR37=-37
SPR36=-36
SPR35=-35
SPR34=-34
SPR33=-33
SPR32=-32
SPR31=-31
SPR30=-30
SPR29=-29
SPR28=-28
SPR27=-27
SPR26=-26
SPR25=-25
SPR24=-24
SPR23=-23
SPR22=-22
SPR21=-21
SPR20=-20
SPR19=-19
SPR18=-18
SPR17=-17
XOVER30=-16.5 !30"x1.5" to 30"x1" xover @ 16.5m
SPR16=-16
SPR15=-15
SPR14=-14
SPR13=-13
SPR12=-12
SPR11=-11
SPR10=-10
SPR9=-9
SPR8=-8
XOVER20=-7.42 !20" to 13 3/8" xover @ 7.42m(24.367 ft from mudline of the
total 15ft length)
SPR7=-7
SPR6=-6
SPR5=-5
SPR4=-4
SPR3=-3
XOVER21=-2.85 !21" to 20" xover @ 2.85m(9.367ft from mudline of the total
15ft length)
SPR2=-2
SPR1=-1
SPR0=0

C***  *****************
C***  * ELEMENT TYPES *
C***  *****************

ET,1,PIPE16,,,,,,1
ET,2,COMBIN39  ! for soil springs
ET,3,BEAM3     ! for short beam to pull tension
ET,4,CONTA178  ! Contact Elements for cement

KEYOPT,4,1,1     !1 for CYLINDRICAL GAP
KEYOPT,4,2,4     !Algorithm Type
KEYOPT,4,3,1     !Weak Spring 0-no 1-yes
KEYOPT,4,4,0     !Initial Gap Status
KEYOPT,4,5,0     !Contact Normal Direction
KEYOPT,4,7,0     !Time step predictions
KEYOPT,4,9,0     !Ramp Initial Gap Size 0-step 1-ramp
KEYOPT,4,10,0    !Contact Behaviour (normal, sticking etc)
KEYOPT,4,12,1    !Monitor Contact Status
```

```
ET,5,COMBIN7    !For flex joint

C***  *****************
C***  * MATERIAL TYPES *
C***  *****************

C***  Standard PIPE16 Elements
EX,1,207.0E9
NUXY,1,0.3
DENS,1,7840

C***  Flex Joint PIPE16 Elements !assumed 15 tonne weight
EX,2,207.0E9
NUXY,2,0.3
DENS,2,13889

C***  LMRP PIPE16 Elements !assumed 100 tonne weight
EX,3,207.0E9
NUXY,3,0.3
DENS,3,23923

C***  BOP PIPE16 Elements !assumed 170 tonne weight
EX,4,207.0E9
NUXY,4,0.3
DENS,4,18975

C***  Zero Mass Elemnts COMBIN39 Elements
EX,6,207.0E9
NUXY,6,0.3
DENS,6,0.0

C***  Gap Elements
MU,7,0.0

C***  Zero Mass BEAM Elemnts WITH HIGIH STIFFNESS FOR LOAD CASE 3
EX,8,207.0E11
NUXY,6,0.3
DENS,6,0.0

C***  ******************
C***  * REAL CONSTANTS *
C***  ******************

C*** 20" String+WHD+BOP+LMRP+FJ
R,1,ODFJ1,THFJ1
R,2,ODLMRP1,THLMRP1
R,3,ODBOP1,THBOP1
!R,4,ODTREE1,THTREE1
R,5,OD2H1,TH2H1
R,6,OD21,TH21
R,7,OD20,TH20
R,8,OD13,TH13 !13 3/8"

C*** 30" String+WHD

R,10,OD1H1,TH1H1
R,11,OD30EXT,TH30EXT
R,12,OD30,TH30
R,13,OD30,TH30
C*** Rotational Stiffness of Flex Joint

rotstf_met=92000                      !in Nm / degree
rotstf=rotstf_met*(1/degtorad)        !in Nm / radian

R,20,1e10,1e10,1e10,rotstf,0,-1  !real constants of combin7 element
R,21,0.0645,100,0.254            ! real constants of beam element at the
top.(A,I,Thickness)

C*** Contact Elements for Annular Cement or Clearance
```

```
GAP1=3*.0254             !30x1.5" to 21" clearance
GAP2=3.5*.0254           !30x1.5" to 20" clearance
GAP3=6.81*.0254          !30x1.5" to 13" clearance
GAP4=7.3*.0254           !30x1.0" to 13 3/8" clearance
GAP5=4.9*.0254           !30"housing to 20" clearance
CMNT=0.00001             ! no clearance - cemented
!178 Contact must be +ve for pipe-in-pipe & -ve for pipe-beside pipe (0 not
allowed)

R,30,-1e12 ,GAP1,0.0 ,0.0, , ,   !30x1.5" to 21"
RMORE,1.0, , ,
R,31,-1e12 ,GAP2,0.0 ,0.0, , ,   !30x1.5" to 20"
RMORE,1.0, , ,
R,32,-1e12 ,GAP3,0.0 ,0.0, , ,   !30x1.5" to 13"
RMORE,1.0, , ,
R,33,-1e12 ,GAP4,0.0 ,0.0, , ,   !30x1.0" to 13"
RMORE,1.0, , ,
R,34,-1e12 ,CMNT,0.0 ,0.0, , ,   !Cemented
RMORE,1.0, , ,
R,35,-1e12 ,GAP5,0.0 ,0.0, , ,   !Cemented
RMORE,1.0, , ,

C***  COMBIN39 Elements (for soil)

!Real No Y1 F1  Y2 F2 Y3 F3
!more    Y4 F4  Y5 F5 Y6 F6
!         m N    m N   m N
r,48,0,0,0.02,0,0.06,0
$RMORE,0.29,0,1,0,1.5,0


r,49,0,0,0.02,37124,0.06,53458
$RMORE,0.29,9379,1,9379,1.5,9379
r,50,0,0,0.02,46816,0.06,67415
$RMORE,0.29,23654,1,23654,1.5,23654
r,51,0,0,0.02,56508,0.06,81371
$RMORE,0.29,42827,1,42827,1.5,42827
r,52,0,0,0.02,66200,0.06,95327
$RMORE,0.29,66896,1,66896,1.5,66896
r,53,0,0,0.02,75891,0.06,109284
$RMORE,0.29,95863,1,95863,1.5,95863
r,54,0,0,0.02,82296,0.06,118506
$RMORE,0.29,118506,1,118506,1.5,118506
r,55,0,0,0.02,82296,0.06,118506
$RMORE,0.29,118506,1,118506,1.5,118506

r,56,0,0,0.001,55487,0.002,110605
$RMORE,0.004,218318,0.006,320546,0.01,500925
$RMORE,0.029,903068,0.076,961051,0.143,9612361


r,57,0,0,0.02,82296,0.06,118506
$RMORE,0.29,118506,1,118506,1.5,118506
r,58,0,0,0.02,82296,0.06,118506
$RMORE,0.29,118506,1,118506,1.5,118506
r,59,0,0,0.02,93072.85714,0.06,134025
$RMORE,0.29,134025,1,134025,1.5,134025
r,60,0,0,0.02,103849.7143,0.06,149544
$RMORE,0.29,149544,1,149544,1.5,149544
r,61,0,0,0.02,114626.5714,0.06,165062
$RMORE,0.29,165062,1,165062,1.5,165062
r,62,0,0,0.02,125403.4286,0.06,180581
$RMORE,0.29,180581,1,180581,1.5,180581
r,63,0,0,0.02,136180.2857,0.06,196100
$RMORE,0.29,196100,1,196100,1.5,196100
r,64,0,0,0.02,146957.1429,0.06,211618
$RMORE,0.29,211618,1,211618,1.5,211618
r,65,0,0,0.02,157734,0.06,227137
```

```
$RMORE,0.29,227137,1,227137,1.5,227137
r,66,0,0,0.02,168510.8571,0.06,242656
$RMORE,0.29,242656,1,242656,1.5,242656
r,67,0,0,0.02,179287.7143,0.06,258174
$RMORE,0.29,258174,1,258174,1.5,258174

r,68,0,0,0.01,190065,0.04,273693
$RMORE,0.2,273693,1,273693,1.5,273693
r,69,0,0,0.01,200841,0.04,289212
$RMORE,0.2,289212,1,289212,1.5,289212
r,70,0,0,0.01,211618,0.04,304730
$RMORE,0.2,304730,1,304730,1.5,304730
r,71,0,0,0.01,222395,0.04,320249
$RMORE,0.2,320249,1,320249,1.5,320249
r,72,0,0,0.01,233172,0.04,335768
$RMORE,0.2,335768,1,335768,1.5,335768
r,73,0,0,0.01,243949,0.04,351286
$RMORE,0.2,351286,1,351286,1.5,351286
r,74,0,0,0.01,254726,0.04,366805
$RMORE,0.2,366805,1,366805,1.5,366805
r,75,0,0,0.01,265503,0.04,382324
$RMORE,0.2,382324,1,382324,1.5,382324
r,76,0,0,0.01,276279,0.04,397842
$RMORE,0.2,397842,1,397842,1.5,397842
r,77,0,0,0.01,287056,0.04,413361
$RMORE,0.2,413361,1,413361,1.5,413361
r,78,0,0,0.01,297833,0.04,428880
$RMORE,0.2,428880,1,428880,1.5,428880
r,79,0,0,0.01,308610,0.04,444398
$RMORE,0.2,444398,1,444398,1.5,444398

r,80,0,0,0.0001,79377,0.0002,93921
$RMORE,0.0005,158755,0.0013,263265,0.0016,297003
$RMORE,0.0023,354987,0.0046,451616,0.0069,494956
$RMORE,0.0091,510938,0.0114,508604,0.0137,492623
$RMORE,0.0411,80368,0.0572,80368,0.0686,80368
r,81,0,0,0.0001,93424,0.0002,110540
$RMORE,0.0005,186847,0.0013,309851,0.0016,349559
$RMORE,0.0023,417803,0.0046,531531,0.0069,582540
$RMORE,0.0091,601351,0.0114,598604,0.0137,579795
$RMORE,0.0411,94590,0.0572,94590,0.0686,94590
r,82,0,0,0.0001,107470,0.0002,127160
$RMORE,0.0005,214940,0.0013,356437,0.0016,402115
$RMORE,0.0023,480620,0.0046,611447,0.0069,670125
$RMORE,0.0091,691764,0.0114,688604,0.0137,666967
$RMORE,0.0411,108811,0.0572,108811,0.0686,108811
r,83,0,0,0.0001,121516,0.0002,143780
$RMORE,0.0005,243032,0.0013,403023,0.0016,454672
$RMORE,0.0023,543436,0.0046,691362,0.0069,757710
$RMORE,0.0091,782176,0.0114,778604,0.0137,754139
$RMORE,0.0411,123033,0.0572,123033,0.0686,123033

r,84,0,0,0.0009525,392444,0.001905,782731
$RMORE,0.00381,1548483,0.005715,2281718,0.009525,3602402
$RMORE,0.028575,6862342,0.0762,7471544,0.142875,7474876

r,85,0,0,0.0001,149557,0.0002,176958
$RMORE,0.0004,299114,0.001,496025,0.0013,559591
$RMORE,0.0018,668840,0.0037,850901,0.0055,932559
$RMORE,0.0073,962671,0.0091,958274,0.011,928163
$RMORE,0.0329,151423,0.0457,151423,0.0549,151423
r,86,0,0,0.0001,163588,0.0002,193560
$RMORE,0.0004,327176,0.001,542561,0.0013,612091
$RMORE,0.0018,731589,0.0037,930730,0.0055,1020049
$RMORE,0.0073,1052987,0.0091,1048177,0.011,1015241
$RMORE,0.0329,165630,0.0457,165630,0.0549,165630
r,87,0,0,0.0001,177619,0.0002,210162
$RMORE,0.0004,355239,0.001,589096,0.0013,664590
$RMORE,0.0018,794338,0.0037,1010559,0.0055,1107540
```

```
$RMORE,0.0073,1143302,0.0091,1138080,0.011,1102320
$RMORE,0.0329,179836,0.0457,179836,0.0549,179836
r,88,0,0,0.0001,191650,0.0002,226764
$RMORE,0.0004,383301,0.001,635632,0.0013,717090
$RMORE,0.0018,857086,0.0037,1090389,0.0055,1195030
$RMORE,0.0073,1233618,0.0091,1227983,0.011,1189398
$RMORE,0.0329,194042,0.0457,194042,0.0549,194042
r,89,0,0,0.0001,205681,0.0002,243366
$RMORE,0.0004,411363,0.001,682168,0.0013,769590
$RMORE,0.0018,919835,0.0037,1170218,0.0055,1282521
$RMORE,0.0073,1323933,0.0091,1317886,0.011,1276476
$RMORE,0.0329,208248,0.0457,208248,0.0549,208248
r,90,0,0,0.0001,219713,0.0002,259967
$RMORE,0.0004,439425,0.001,728704,0.0013,822089
$RMORE,0.0018,982584,0.0037,1250048,0.0055,1370011
$RMORE,0.0073,1414249,0.0091,1407789,0.011,1363554
$RMORE,0.0329,222454,0.0457,222454,0.0549,222454
r,91,0,0,0.0001,233744,0.0002,276569
$RMORE,0.0004,467487,0.001,775240,0.0013,874589
$RMORE,0.0018,1045333,0.0037,1329877,0.0055,1457502
$RMORE,0.0073,1504564,0.0091,1497692,0.011,1450632
$RMORE,0.0329,236661,0.0457,236661,0.0549,236661
r,92,0,0,0.0001,247775,0.0002,293171
$RMORE,0.0004,495549,0.001,821776,0.0013,927088
$RMORE,0.0018,1108082,0.0037,1409707,0.0055,1544992
$RMORE,0.0073,1594880,0.0091,1587595,0.011,1537710
$RMORE,0.0329,250867,0.0457,250867,0.0549,250867
r,93,0,0,0.0001,261806,0.0002,309773
$RMORE,0.0004,523612,0.001,868312,0.0013,979588
$RMORE,0.0018,1170831,0.0037,1489536,0.0055,1632482
$RMORE,0.0073,1685195,0.0091,1677498,0.011,1624788
$RMORE,0.0329,265073,0.0457,265073,0.0549,265073
r,94,0,0,0.0001,275837,0.0002,326375
$RMORE,0.0004,551674,0.001,914847,0.0013,1032087
$RMORE,0.0018,1233580,0.0037,1569366,0.0055,1719973
$RMORE,0.0073,1775511,0.0091,1767401,0.011,1711866
$RMORE,0.0329,279279,0.0457,279279,0.0549,279279
r,95,0,0,0.0001,289868,0.0002,342976
$RMORE,0.0004,579736,0.001,961383,0.0013,1084587
$RMORE,0.0018,1296329,0.0037,1649195,0.0055,1807463
$RMORE,0.0073,1865826,0.0091,1857305,0.011,1798944
$RMORE,0.0329,293485,0.0457,293485,0.0549,293485
r,96,0,0,0.0001,303899,0.0002,359578
$RMORE,0.0004,607798,0.001,1007919,0.0013,1137086
$RMORE,0.0018,1359078,0.0037,1729025,0.0055,1894954
$RMORE,0.0073,1956142,0.0091,1947208,0.011,1886022
$RMORE,0.0329,307692,0.0457,307692,0.0549,307692
r,97,0,0,0.0001,317930,0.0002,376180
$RMORE,0.0004,635860,0.001,1054455,0.0013,1189586
$RMORE,0.0018,1421827,0.0037,1808854,0.0055,1982444
$RMORE,0.0073,2046457,0.0091,2037111,0.011,1973100
$RMORE,0.0329,321898,0.0457,321898,0.0549,321898
r,98,0,0,0.0001,331961,0.0002,392782
$RMORE,0.0004,663923,0.001,1100991,0.0013,1242085
$RMORE,0.0018,1484576,0.0037,1888684,0.0055,2069935
$RMORE,0.0073,2136773,0.0091,2127014,0.011,2060178
$RMORE,0.0329,336104,0.0457,336104,0.0549,336104
r,99,0,0,0.0001,345992,0.0002,409384
$RMORE,0.0004,691985,0.001,1147527,0.0013,1294585
$RMORE,0.0018,1547325,0.0037,1968513,0.0055,2157425
$RMORE,0.0073,2227088,0.0091,2216917,0.011,2147257
$RMORE,0.0329,350310,0.0457,350310,0.0549,350310
r,100,0,0,0.0001,360023,0.0002,425985
$RMORE,0.0004,720047,0.001,1194063,0.0013,1347084
$RMORE,0.0018,1610074,0.0037,2048343,0.0055,2244916
$RMORE,0.0073,2317404,0.0091,2306820,0.011,2234335
$RMORE,0.0329,364516,0.0457,364516,0.0549,364516
r,101,0,0,0.0001,374055,0.0002,442587
$RMORE,0.0004,748109,0.001,1240599,0.0013,1399584
```

```
$RMORE,0.0018,1672823,0.0037,2128172,0.0055,2332406
$RMORE,0.0073,2407719,0.0091,2396723,0.011,2321413
$RMORE,0.0329,378723,0.0457,378723,0.0549,378723
r,102,0,0,0.0001,388086,0.0002,459189
$RMORE,0.0004,776171,0.001,1287134,0.0013,1452083
$RMORE,0.0018,1735572,0.0037,2208002,0.0055,2419897
$RMORE,0.0073,2498035,0.0091,2486626,0.011,2408491
$RMORE,0.0329,392929,0.0457,392929,0.0549,392929
r,103,0,0,0.0001,402117,0.0002,475791
$RMORE,0.0004,804233,0.001,1333670,0.0013,1504583
$RMORE,0.0018,1798321,0.0037,2287831,0.0055,2507387
$RMORE,0.0073,2588351,0.0091,2576529,0.011,2495569
$RMORE,0.0329,407135,0.0457,407135,0.0549,407135
r,104,0,0,0.0001,416148,0.0002,492393
$RMORE,0.0004,832296,0.001,1380206,0.0013,1557082
$RMORE,0.0018,1861070,0.0037,2367660,0.0055,2594877
$RMORE,0.0073,2678666,0.0091,2666432,0.011,2582647
$RMORE,0.0329,421341,0.0457,421341,0.0549,421341
r,105,0,0,0.0001,430179,0.0002,508995
$RMORE,0.0004,860358,0.001,1426742,0.0013,1609582
$RMORE,0.0018,1923818,0.0037,2447490,0.0055,2682368
$RMORE,0.0073,2768982,0.0091,2756335,0.011,2669725
$RMORE,0.0329,435547,0.0457,435547,0.0549,435547
r,106,0,0,0.0001,444210,0.0002,525596
$RMORE,0.0004,888420,0.001,1473278,0.0013,1662082
$RMORE,0.0018,1986567,0.0037,2527319,0.0055,2769858
$RMORE,0.0073,2859297,0.0091,2846238,0.011,2756803
$RMORE,0.0329,449754,0.0457,449754,0.0549,449754
r,107,0,0,0.0001,458241,0.0002,542198
$RMORE,0.0004,916482,0.001,1519814,0.0013,1714581
$RMORE,0.0018,2049316,0.0037,2607149,0.0055,2857349
$RMORE,0.0073,2949613,0.0091,2936141,0.011,2843881
$RMORE,0.0329,463960,0.0457,463960,0.0549,463960
r,108,0,0,0.0001,472272,0.0002,558800
$RMORE,0.0004,944544,0.001,1566350,0.0013,1767081
$RMORE,0.0018,2112065,0.0037,2686978,0.0055,2944839
$RMORE,0.0073,3039928,0.0091,3026044,0.011,2930959
$RMORE,0.0329,478166,0.0457,478166,0.0549,478166
r,109,0,0,0.0001,431788,0.0002,510898
$RMORE,0.0004,863575,0.001,1432077,0.0013,1615601
$RMORE,0.0018,1931013,0.0037,2456642,0.0055,2692399
$RMORE,0.0073,2779336,0.0091,2766642,0.011,2679708
$RMORE,0.0329,437176,0.0457,437176,0.0549,437176
r,110,0,0,0.0001,391303,0.0002,462996
$RMORE,0.0004,782606,0.001,1297805,0.0013,1464121
$RMORE,0.0018,1749960,0.0037,2226306,0.0055,2439958
$RMORE,0.0073,2518744,0.0091,2507240,0.011,2428458
$RMORE,0.0329,396186,0.0457,396186,0.0549,396186
r,111,0,0,0.0001,350818,0.0002,415094
$RMORE,0.0004,701637,0.001,1163533,0.0013,1312642
$RMORE,0.0018,1568907,0.0037,1995970,0.0055,2187517
$RMORE,0.0073,2258152,0.0091,2247838,0.011,2177207
$RMORE,0.0329,355196,0.0457,355196,0.0549,355196
r,112,0,0,0.0001,198346,0.0002,234686
$RMORE,0.0004,396691,0.001,657838,0.0013,742141
$RMORE,0.0018,887028,0.0037,1128481,0.0055,1236778
$RMORE,0.0073,1276714,0.0091,1270883,0.011,1230949
$RMORE,0.0329,200821,0.0457,200821,0.0549,200821
r,113,0,0,0.0001,198346,0.0002,234686
$RMORE,0.0004,396691,0.001,657838,0.0013,742141
$RMORE,0.0018,887028,0.0037,1128481,0.0055,1236778
$RMORE,0.0073,1276714,0.0091,1270883,0.011,1230949
$RMORE,0.0329,200821,0.0457,200821,0.0549,200821
r,114,0,0,0.0001,330576,0.0002,391143
$RMORE,0.0004,661152,0.001,1096397,0.0013,1236902
$RMORE,0.0018,1478381,0.0037,1880802,0.0055,2061297
$RMORE,0.0073,2127856,0.0091,2118138,0.011,2051581
$RMORE,0.0329,334701,0.0457,334701,0.0549,334701
r,115,0,0,0.0001,330576,0.0002,391143
```

```
$RMORE,0.0004,661152,0.001,1096397,0.0013,1236902
$RMORE,0.0018,1478381,0.0037,1880802,0.0055,2061297
$RMORE,0.0073,2127856,0.0091,2118138,0.011,2051581
$RMORE,0.0329,334701,0.0457,334701,0.0549,334701
r,116,0,0,0.0001,330576,0.0002,391143
$RMORE,0.0004,661152,0.001,1096397,0.0013,1236902
$RMORE,0.0018,1478381,0.0037,1880802,0.0055,2061297
$RMORE,0.0073,2127856,0.0091,2118138,0.011,2051581
$RMORE,0.0329,334701,0.0457,334701,0.0549,334701
r,117,0,0,0.0001,330576,0.0002,391143
$RMORE,0.0004,661152,0.001,1096397,0.0013,1236902
$RMORE,0.0018,1478381,0.0037,1880802,0.0055,2061297
$RMORE,0.0073,2127856,0.0091,2118138,0.011,2051581
$RMORE,0.0329,334701,0.0457,334701,0.0549,334701

c***  ***************
c***  * LOAD CASE 2 *
C***  ***************
C***  CAN SPRING STIFFNESS
r,200,0,0,0.03,140000,0.06,230000
$RMORE,0.1,310000,0.17,355000,0.2,379000
$RMORE,0.240,385000,0.3,393000,0.34,398000
$RMORE,0.37,400000,0.4,402000,0.43,405000
$RMORE,0.47,412000,0.5,418000

c***  ***************
c***  * LOAD CASE 3 *
C***  ***************
C***  PIPE ELEMENTS REAL CONSTANTS DEFINED

R,201,0.3,0.125

r,202,0.2,0.015

C***  ********************
C***  * NODES GENERATION *
C***  ********************

C***  30" CONDUCTOR STRING ***********************************
NDNM=1

C***  Element length
NSPCNG=0.25

NBOTST=NDNM
*DO,ELEV,BOTST,SPR68-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR68=NDNM
*DO,ELEV,SPR68,SPR67-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR67=NDNM
*DO,ELEV,SPR67,SPR66-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR66=NDNM
*DO,ELEV,SPR66,SPR65-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR65=NDNM
```

```
*DO,ELEV,SPR65,SPR64-(NSPCNG/5),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR64=NDNM
*DO,ELEV,SPR64,SPR63-(NSPCNG/5),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR63=NDNM
*DO,ELEV,SPR63,SPR62-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR62=NDNM
*DO,ELEV,SPR62,SPR61-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR61=NDNM
*DO,ELEV,SPR61,SPR60-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR60=NDNM
*DO,ELEV,SPR60,SPR59-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NSPR59=NDNM
*DO,ELEV,SPR59,SPR58-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR58=NDNM
*DO,ELEV,SPR58,SPR57-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR57=NDNM
*DO,ELEV,SPR57,SPR56-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR56=NDNM
*DO,ELEV,SPR56,SPR55-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR55=NDNM
*DO,ELEV,SPR55,SPR54-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR54=NDNM !30"x1" to shoe joint" xover @ 54m
*DO,ELEV,SPR54,SPR53-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
```

```
NDNM=NDNM+1
*ENDDO

NSPR53=NDNM
*DO,ELEV,SPR53,SPR52-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR52=NDNM
*DO,ELEV,SPR52,SPR51-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR51=NDNM
*DO,ELEV,SPR51,SPR50-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR50=NDNM
*DO,ELEV,SPR50,SPR49-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR49=NDNM
*DO,ELEV,SPR49,SPR48-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR48=NDNM
*DO,ELEV,SPR48,SPR47-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR47=NDNM
*DO,ELEV,SPR47,SPR46-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR46=NDNM
*DO,ELEV,SPR46,SPR45-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR45=NDNM
*DO,ELEV,SPR45,SPR44-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR44=NDNM
*DO,ELEV,SPR44,SPR43-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR43=NDNM
*DO,ELEV,SPR43,SPR42-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO
```

```
NSPR42=NDNM
*DO,ELEV,SPR42,SPR41-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR41=NDNM
*DO,ELEV,SPR41,SPR40-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR40=NDNM
*DO,ELEV,SPR40,SPR39-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR39=NDNM
*DO,ELEV,SPR39,SPR38-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR38=NDNM
*DO,ELEV,SPR38,SPR37-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR37=NDNM
*DO,ELEV,SPR37,SPR36-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR36=NDNM
*DO,ELEV,SPR36,SPR35-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR35=NDNM
*DO,ELEV,SPR35,SPR34-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR34=NDNM
*DO,ELEV,SPR34,SPR33-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR33=NDNM
*DO,ELEV,SPR33,SPR32-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR32=NDNM
*DO,ELEV,SPR32,SPR31-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR31=NDNM
*DO,ELEV,SPR31,SPR30-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
```

```
NDNM=NDNM+1
*ENDDO
NSPR30=NDNM
*DO,ELEV,SPR30,SPR29-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR29=NDNM
*DO,ELEV,SPR29,SPR28-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR28=NDNM
*DO,ELEV,SPR28,SPR27-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR27=NDNM
*DO,ELEV,SPR27,SPR26-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR26=NDNM
*DO,ELEV,SPR26,SPR25-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPCNG=0.1
NSPR25=NDNM
*DO,ELEV,SPR25,SPR24-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR24=NDNM
*DO,ELEV,SPR24,SPR23-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NSPR23=NDNM
*DO,ELEV,SPR23,SPR22-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR22=NDNM
*DO,ELEV,SPR22,SPR21-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR21=NDNM
*DO,ELEV,SPR21,SPR20-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR20=NDNM
*DO,ELEV,SPR20,SPR19-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO
```

```
NSPR19=NDNM
*DO,ELEV,SPR19,SPR18-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR18=NDNM
*DO,ELEV,SPR18,SPR17-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR17=NDNM
*DO,ELEV,SPR17,XOVER30-(NSPCNG/5),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NXOVER30=NDNM
*DO,ELEV,XOVER30,SPR16-(NSPCNG/5),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR16=NDNM
*DO,ELEV,SPR16,SPR15-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR15=NDNM
*DO,ELEV,SPR15,SPR14-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR14=NDNM
*DO,ELEV,SPR14,SPR13-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR13=NDNM
*DO,ELEV,SPR13,SPR12-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR12=NDNM
*DO,ELEV,SPR12,SPR11-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR11=NDNM
*DO,ELEV,SPR11,SPR10-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR10=NDNM
*DO,ELEV,SPR10,SPR9-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR9=NDNM
*DO,ELEV,SPR9,SPR8-(NSPCNG/10),NSPCNG
```

```
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR8=NDNM
*DO,ELEV,SPR8,XOVER20-(NSPCNG/5),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NXOVER20=NDNM
*DO,ELEV,XOVER20,SPR7-(NSPCNG/5),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NSPR7=NDNM
*DO,ELEV,SPR7,SPR6-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR6=NDNM
*DO,ELEV,SPR6,SPR5-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR5=NDNM
*DO,ELEV,SPR5,SPR4-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NSPR4=NDNM
*DO,ELEV,SPR4,SPR3-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NSPR3=NDNM
*DO,ELEV,SPR3,XOVER21-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NXOVER21=NDNM
*DO,ELEV,XOVER21,SPR2-(NSPCNG/2),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NSPR2=NDNM
*DO,ELEV,SPR2,SPR1-(NSPCNG/8),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NSPR1=NDNM
*DO,ELEV,SPR1,MUDL-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NMUDL=NDNM
```

```
NSPR0=NDNM
NSPCNG=0.1

*DO,ELEV,MUDL,TCO30-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO


NTCO30=NDNM
*DO,ELEV,TCO30,HWP-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NHWP=NDNM
*DO,ELEV,HWP,H2LS-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

!NSPCNG=0.25
NH2LS=NDNM
*DO,ELEV,H2LS,H1LS-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NH1LS=NDNM
*DO,ELEV,H1LS,THS30-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NTHS30=NDNM
N,NDNM,SNANG*THS30,THS30,0.0

C***  20" STRING ***********************************

C*** Create Duplicate sets of Nodes to the mudline
NGEN,2,5000,NBOTST,NMUDL
NDNM=NMUDL+5000

NSPCNG=0.1
C*** Create Duplicate nodes for 20" up to top of 30" HSG
*DO,ELEV,MUDL,TCO30-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

*DO,ELEV,TCO30,HWP-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

*DO,ELEV,HWP,H2LS-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO
!NSPCNG=0.25
*DO,ELEV,H2LS,H1LS-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

*DO,ELEV,H1LS,THS30-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO
```

```
C*** to top of HP HSG
NSPCNG=0.1
*DO,ELEV,THS30,THPHSG-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

NTHPHSG=NDNM

NSPCNG=0.5
C*** to top of BOP
NSPCNG=0.5
NTHPHSG=NDNM
*DO,ELEV,THPHSG,BOP-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO
NTTREE=NDNM

C*** to top of LMRP
NBOP=NDNM
*DO,ELEV,BOP,LMRP-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

C*** to point of rotation on Flex Joint
NLMRP=NDNM
*DO,ELEV,LMRP,FLEXJT-(NSPCNG/10),NSPCNG
N,NDNM,SNANG*ELEV,ELEV,0.0
NDNM=NDNM+1
*ENDDO

C*** nodes for zero length rotational element
NFLEXJT1=NDNM
N,NDNM,SNANG*FLEXJT,FLEXJT,0.0
NDNM=NDNM+100
NFLEXJT2=NDNM
N,NDNM,SNANG*FLEXJT,FLEXJT,0.0

C*** Node at top for tension
NDNM=NDNM+100
NTENSION=NDNM
N,NDNM,SNANG*TFLEXJT,TFLEXJT,0.0  ! top of flex jt beam rotated with
wellhead


C*** NODES FOR SOIL SPRING ELEMENTS

NGEN,2,1000,NSPR68
NGEN,2,1000,NSPR67
NGEN,2,1000,NSPR66
NGEN,2,1000,NSPR65
NGEN,2,1000,NSPR64
NGEN,2,1000,NSPR63
NGEN,2,1000,NSPR62
NGEN,2,1000,NSPR61
NGEN,2,1000,NSPR60
NGEN,2,1000,NSPR59
NGEN,2,1000,NSPR58
NGEN,2,1000,NSPR57
NGEN,2,1000,NSPR56
NGEN,2,1000,NSPR55
NGEN,2,1000,NSPR54
NGEN,2,1000,NSPR53
NGEN,2,1000,NSPR52
NGEN,2,1000,NSPR51
NGEN,2,1000,NSPR50
```

```
NGEN,2,1000,NSPR49
NGEN,2,1000,NSPR48
NGEN,2,1000,NSPR47
NGEN,2,1000,NSPR46
NGEN,2,1000,NSPR45
NGEN,2,1000,NSPR44
NGEN,2,1000,NSPR43
NGEN,2,1000,NSPR42
NGEN,2,1000,NSPR41
NGEN,2,1000,NSPR40
NGEN,2,1000,NSPR39
NGEN,2,1000,NSPR38
NGEN,2,1000,NSPR37
NGEN,2,1000,NSPR36
NGEN,2,1000,NSPR35
NGEN,2,1000,NSPR34
NGEN,2,1000,NSPR33
NGEN,2,1000,NSPR32
NGEN,2,1000,NSPR31
NGEN,2,1000,NSPR30
NGEN,2,1000,NSPR29
NGEN,2,1000,NSPR28
NGEN,2,1000,NSPR27
NGEN,2,1000,NSPR26
NGEN,2,1000,NSPR25
NGEN,2,1000,NSPR24
NGEN,2,1000,NSPR23
NGEN,2,1000,NSPR22
NGEN,2,1000,NSPR21
NGEN,2,1000,NSPR20
NGEN,2,1000,NSPR19
NGEN,2,1000,NSPR18
NGEN,2,1000,NSPR17
NGEN,2,1000,NSPR16
NGEN,2,1000,NSPR15
NGEN,2,1000,NSPR14
NGEN,2,1000,NSPR13
NGEN,2,1000,NSPR12
NGEN,2,1000,NSPR11
NGEN,2,1000,NSPR10
NGEN,2,1000,NSPR9
NGEN,2,1000,NSPR8
NGEN,2,1000,NSPR7
NGEN,2,1000,NSPR6
NGEN,2,1000,NSPR5
NGEN,2,1000,NSPR4
NGEN,2,1000,NSPR3
NGEN,2,1000,NSPR2
NGEN,2,1000,NSPR1
NGEN,2,1000,NSPR0

c***  ***************
c***  * LOAD CASE 2 *
C***  ***************
C***  CAN SPRING NODE GENERATION

CANSPR = 435   ! CAN SPRING ASSIGNED AT THIS NODE

NSEL,S,NODE,,CANSPR

*get,xxn1,NODE,CANSPR,LOC,X
*get,yyn1,NODE,CANSPR,LOC,Y
*get,zzn1,NODE,CANSPR,LOC,Z

N,100000,xxn1,yyn1,zzn1

allsel,all

c***  ***************
```

```
c***  * LOAD CASE 3 *
C***  ***************
C***  PIPE ELEMENTS NODE GENERATION FOR BOP_SUP

BOPSUP = 5460


NSEL,S,NODE,,BOPSUP


*get,xxBOPSUP,NODE,BOPSUP,LOC,X
*get,yyBOPSUP,NODE,BOPSUP,LOC,Y
*get,zzBOPSUP,NODE,BOPSUP,LOC,Z

LNGTH_SUP = 1.0 !EXTREME LOCATION OF BOP SUPPOTER
RANG = (WHD_ANG+90)*degtorad

!N,100001,xxBOPSUP+LNGTH_SUP*SIN(RANG),yyBOPSUP+LNGTH_SUP*COS(RANG),zzBOPSU
P
!N,100002,xxBOPSUP-LNGTH_SUP*SIN(RANG),yyBOPSUP-LNGTH_SUP*COS(RANG),zzBOPSU
P


K,100001,xxBOPSUP+LNGTH_SUP*SIN(RANG),yyBOPSUP+LNGTH_SUP*COS(RANG),zzBOPSUP
K,100002,xxBOPSUP-LNGTH_SUP*SIN(RANG),yyBOPSUP-LNGTH_SUP*COS(RANG),zzBOPSUP



K,100003,xxn1+LNGTH_SUP*SIN(RANG),yyn1+LNGTH_SUP*COS(RANG),zzn1
K,100004,xxn1-LNGTH_SUP*SIN(RANG),yyn1-LNGTH_SUP*COS(RANG),zzn1

L,100001,100003
L,100002,100004

allsel,all


C***  ***********************
C***  * ELEMENTS GENERATION *
C***  ***********************
C***  Generate PIPE16 SHOE JOINT 30" X 1.0" Conductor Elements
***************
TYPE,1
MAT,1
REAL,13

*DO,NDNM,NBOTST,NSPR54-1                                                   !
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 30" X 1" Conductor Elements ***************
REAL,12

*DO,NDNM,NSPR54,NXOVER30-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 30" X 1.5" Conductor Elements ***************
REAL,11


*DO,NDNM,NXOVER30,NTCO30-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 30" Housing Elements
REAL,10

*DO,NDNM,NTCO30,NTHS30-1
```

```
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 13" Casing Elements ***************
MAT,6                    ! density 0 - weight not considered
REAL,8

*DO,NDNM,(NBOTST+5000),(NXOVER20+5000)-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 20" Casing Elements ***************
MAT,6                    ! density 0 - weight not considered
REAL,7

*DO,NDNM,(NXOVER20+5000),(NXOVER21+5000)-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 21" Casing Elements ***************
REAL,6

*DO,NDNM,NXOVER21+5000,NHWP+5000-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 18 3/4" Housing Elements
MAT,1
REAL,5

*DO,NDNM,NHWP+5000,NTHPHSG-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 BOP Elements
REAL,3
MAT,4
*DO,NDNM,NTHPHSG,NBOP-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 LMRP Elements
REAL,2
MAT,3
*DO,NDNM,NBOP,NLMRP-1
E,NDNM,NDNM+1
*ENDDO

C***  Generate PIPE16 Solid Flex Joint Elements
REAL,1
MAT,2
*DO,NDNM,NLMRP,NFLEXJT1-1
E,NDNM,NDNM+1
*ENDDO

C*** Flex Joint Element
MAT,6
TYPE,5
REAL,20
E,NFLEXJT1,NFLEXJT2

C*** Beam on Top of Flex Joint Element
MAT,6
TYPE,3
REAL,21
E,NFLEXJT2,NTENSION

C***  Generate soil spring elements  **********************
TYPE,2
```

```
REAL,48
E,NSPR0,NSPR0+1000
REAL,49
E,NSPR1,NSPR1+1000
REAL,50
E,NSPR2,NSPR2+1000
REAL,51
E,NSPR3,NSPR3+1000
REAL,52
E,NSPR4,NSPR4+1000
REAL,53
E,NSPR5,NSPR5+1000
REAL,54
E,NSPR6,NSPR6+1000
REAL,55
E,NSPR7,NSPR7+1000
REAL,56
E,NSPR8,NSPR8+1000
REAL,57
E,NSPR9,NSPR9+1000
REAL,58
E,NSPR10,NSPR10+1000
REAL,59
E,NSPR11,NSPR11+1000
REAL,60
E,NSPR12,NSPR12+1000
REAL,61
E,NSPR13,NSPR13+1000
REAL,62
E,NSPR14,NSPR14+1000
REAL,63
E,NSPR15,NSPR15+1000
REAL,64
E,NSPR16,NSPR16+1000
REAL,65
E,NSPR17,NSPR17+1000
REAL,66
E,NSPR18,NSPR18+1000
REAL,67
E,NSPR19,NSPR19+1000
REAL,68
E,NSPR20,NSPR20+1000
REAL,69
E,NSPR21,NSPR21+1000
REAL,70
E,NSPR22,NSPR22+1000
REAL,71
E,NSPR23,NSPR23+1000
REAL,72
E,NSPR24,NSPR24+1000
REAL,73
E,NSPR25,NSPR25+1000
REAL,74
E,NSPR26,NSPR26+1000
REAL,75
E,NSPR27,NSPR27+1000
REAL,76
E,NSPR28,NSPR28+1000
REAL,77
E,NSPR29,NSPR29+1000
REAL,78
E,NSPR30,NSPR30+1000
REAL,79
E,NSPR31,NSPR31+1000
REAL,80
E,NSPR32,NSPR32+1000
REAL,81
E,NSPR33,NSPR33+1000
REAL,82
```

```
E,NSPR34,NSPR34+1000
REAL,83
E,NSPR35,NSPR35+1000
REAL,84
E,NSPR36,NSPR36+1000
REAL,85
E,NSPR37,NSPR37+1000
REAL,86
E,NSPR38,NSPR38+1000
REAL,87
E,NSPR39,NSPR39+1000
REAL,88
E,NSPR40,NSPR40+1000
REAL,89
E,NSPR41,NSPR41+1000
REAL,90
E,NSPR42,NSPR42+1000
REAL,91
E,NSPR43,NSPR43+1000
REAL,92
E,NSPR44,NSPR44+1000
REAL,93
E,NSPR45,NSPR45+1000
REAL,94
E,NSPR46,NSPR46+1000
REAL,95
E,NSPR47,NSPR47+1000
REAL,96
E,NSPR48,NSPR48+1000
REAL,97
E,NSPR49,NSPR49+1000
REAL,98
E,NSPR50,NSPR50+1000
REAL,99
E,NSPR51,NSPR51+1000
REAL,100
E,NSPR52,NSPR52+1000
REAL,101
E,NSPR53,NSPR53+1000
REAL,102
E,NSPR54,NSPR54+1000
REAL,103
E,NSPR55,NSPR55+1000
REAL,104
E,NSPR56,NSPR56+1000
REAL,105
E,NSPR57,NSPR57+1000
REAL,106
E,NSPR58,NSPR58+1000
REAL,107
E,NSPR59,NSPR59+1000
REAL,108
E,NSPR60,NSPR60+1000
REAL,109
E,NSPR61,NSPR61+1000
REAL,110
E,NSPR62,NSPR62+1000
REAL,111
E,NSPR63,NSPR63+1000
REAL,112
E,NSPR64,NSPR64+1000
REAL,113
E,NSPR65,NSPR65+1000
REAL,114
E,NSPR66,NSPR66+1000
REAL,115
E,NSPR67,NSPR67+1000
REAL,116
E,NSPR68,NSPR68+1000
```

```
C***  Generate Annulus Gap or Cemented Elements
******************************
TYPE,4

C***  Between 30x1.0" and 14" (from Bottom up)

REAL,34      !if Cemented
! REAL,33      !if gap

*DO,NDNM,NBOTST,NXOVER30-1
E,NDNM,NDNM+5000
*ENDDO

C***  Between 30x1.5" and 14" (from Bottom up)

REAL,34      !if Cemented
!REAL,32      !if gap

*DO,NDNM,NXOVER30,NXOVER20-1
E,NDNM,NDNM+5000
*ENDDO

C***  Between 30x1.5" and 21" (from Bottom up)

REAL,34      !if Cemented
! REAL,31      !if gap

*DO,NDNM,NXOVER20,NXOVER21-1
E,NDNM,NDNM+5000
*ENDDO

C***  Between 30x1.5" and 20" (to mudline)

REAL,34      !if Cemented
! REAL,30      !if gap

*DO,NDNM,NXOVER21,NMUDL-1
E,NDNM,NDNM+5000
*ENDDO

C***  Between 30x1.5" and 20" (up from mudline)

!REAL,34      !if Cemented
REAL,30      !if gap

*DO,NDNM,NMUDL,NTCO30-1
E,NDNM,NDNM+5000
*ENDDO

!REAL,34      !if Cemented
REAL,35      !if gap

*DO,NDNM,NTCO30,NHWP
E,NDNM,NDNM+5000
*ENDDO


C***  CAN SPRING ELEMENT GENERATION
TYPE,2
REAL,200
E,CANSPR,100000

C***  PIPE ELEMENT GENERATION FOR LOAD CASE3

TYPE,1
REAL,202
```

```
NUMSTR, ELEM, 10000
LSEL,S,LINE,,1,2
LESIZE,ALL,0.5
LMESH,ALL

TYPE,1
MAT,8
REAL,201
E,BOPSUP,100001
E,BOPSUP,100007

C*** *****************************************************
C*** PERMANENT BOUNDARY CONDITIONS ************************
C*** *****************************************************


C*** COUPLE NODES AT THE WELLHEAD TO TRANSFER LOADS TO CONDUCTOR

CP,10,UX,NH1LS,NH1LS+5000
CP,11,UX,NH2LS,NH2LS+5000
CP,12,UY,NH1LS,NH1LS+5000
CP,13,UY,NH2LS,NH2LS+5000

C*** GRAVITY
ACEL,,9.81,

C*** MAKE MODEL 2-D
DSYM,SYMM,Z

C*** BOTTOM VERTICAL AND ROTATIONAL FIXITY CONSTRAINTS
! D,NBOTST,ALL,0.0
D,NBOTST,UY,0.0
D,NBOTST,ROTZ,0.0


C*** SOIL SPRING CONSTRAINTS
nsel,S,,,NSPR0+1000
nsel,a,,,NSPR1+1000
nsel,a,,,NSPR2+1000
nsel,a,,,NSPR3+1000
nsel,a,,,NSPR4+1000
nsel,a,,,NSPR5+1000
nsel,a,,,NSPR6+1000
nsel,a,,,NSPR7+1000
nsel,a,,,NSPR8+1000
nsel,a,,,NSPR9+1000
nsel,a,,,NSPR10+1000
nsel,a,,,NSPR11+1000
nsel,a,,,NSPR12+1000
nsel,a,,,NSPR13+1000
nsel,a,,,NSPR14+1000
nsel,a,,,NSPR15+1000
nsel,a,,,NSPR16+1000
nsel,a,,,NSPR17+1000
nsel,a,,,NSPR18+1000
nsel,a,,,NSPR19+1000
nsel,a,,,NSPR20+1000
nsel,a,,,NSPR21+1000
nsel,a,,,NSPR22+1000
nsel,a,,,NSPR23+1000
nsel,a,,,NSPR24+1000
nsel,a,,,NSPR25+1000
nsel,a,,,NSPR26+1000
nsel,a,,,NSPR27+1000
nsel,a,,,NSPR28+1000
nsel,a,,,NSPR29+1000
nsel,a,,,NSPR30+1000
nsel,a,,,NSPR31+1000
nsel,a,,,NSPR32+1000
```

```
nsel,a,,,NSPR33+1000
nsel,a,,,NSPR34+1000
nsel,a,,,NSPR35+1000
nsel,a,,,NSPR36+1000
nsel,a,,,NSPR37+1000
nsel,a,,,NSPR38+1000
nsel,a,,,NSPR39+1000
nsel,a,,,NSPR40+1000
nsel,a,,,NSPR41+1000
nsel,a,,,NSPR42+1000
nsel,a,,,NSPR43+1000
nsel,a,,,NSPR44+1000
nsel,a,,,NSPR45+1000
nsel,a,,,NSPR46+1000
nsel,a,,,NSPR47+1000
nsel,a,,,NSPR48+1000
nsel,a,,,NSPR49+1000
nsel,a,,,NSPR50+1000
nsel,a,,,NSPR51+1000
nsel,a,,,NSPR52+1000
nsel,a,,,NSPR53+1000
nsel,a,,,NSPR54+1000
nsel,a,,,NSPR55+1000
nsel,a,,,NSPR56+1000
nsel,a,,,NSPR57+1000
nsel,a,,,NSPR58+1000
nsel,a,,,NSPR59+1000
nsel,a,,,NSPR60+1000
nsel,a,,,NSPR61+1000
nsel,a,,,NSPR62+1000
nsel,a,,,NSPR63+1000
nsel,a,,,NSPR64+1000
nsel,a,,,NSPR65+1000
nsel,a,,,NSPR66+1000
nsel,a,,,NSPR67+1000
nsel,a,,,NSPR68+1000

nsel,a,,,100000    !CAN SPRING CONSTRAINED

nsel,a,,,100002    !RIGHT BOP SUPPORT CONSTRAINED
nsel,a,,,100008    !LEFT BOP SUPPORT CONSTRAINED

D,ALL,ALL    ! Fix soil spring nodes

ALLSEL

C*** INTRODUCE WELLHEAD / CONDUCTOR INCLINATION ANGLE
/ESHAPE,1.0
WPCSYS,-1,0
c*** wprota,0,90,0
/type,1,7
/cplan,1
/DSCALE,1,OFF
/PNUM,REAL,1
/NUMBER,1

/PLOPTS,INFO,2
/PLOPTS,LEG2,0
/PLOPTS,DATE,1
/TRIAD,LBOT

eplot

C*** ***************************************************
C*** FINISH PREP7 **************************************
C*** ***************************************************
FINISH

C*** ***************************************************
```

```
C*** SOLUTION ***********************************************
C*** *******************************************************

/SOLU

C***  *****************
C***  * ANALYSIS TYPE *
C***  *****************

ANTYPE,STATIC

C***  Large Deflections
NLGEOM,ON
C***  Stress Stiffening
SSTIF,ON
C***  Turn Off Newton-Raphson Convergence Criteria
NROPT,FULL,,OFF


AUTOTS,OFF
NSUBST,1
NEQIT,200
C*** LOAD STEP 1 *********************************
C*** APPLY LOAD & CONSTRAIN 30" IN X
TIME,1.0

C*** Select Beam on top (using top node), then apply tension force to beam
C*** (done this way so tension angle varies with beam angle)
NSEL,S, , ,NTENSION
ESLN,S
f1=490000 !N = 50 Tonne

sfbeam,all,3,pres,f1   ! Note this is an applied tension check to make sure
face no is right

ALLSEL

flex_angle=0                !
lp=-(flex_angle)            !Corrected sign convention + rel to WHD
angtld=lp*degtorad*rotstf
ALLSEL
/TITLE,Flex Joint Rotation Angle=%flex_angle%deg , Wellhead
Inclination=%WHD_ANG%deg

C*** Apply 20" Casing Weight to bottom of (weightless) string
WT_20inch=0 ! 511 kips   (111kips casing and 400 kips tubing weight)
F,NBOTST+5000,FY,WT_20inch
SAVE

C*** FIX CONDUCTOR IN X
C*** NSEL,S,,,NBOTST+1,NHWP
C*** D,ALL,UX,0.0
C*** ALLSEL

*do,flex_angle,1,9,1
autots,off
nsubst,2
neqit,200
lp=-(flex_angle)    !
angtld=lp*degtorad*rotstf
F,NFLEXJT2,mz,angtld  ! Apply moment to rotate flexjoint to required angle
ALLSEL
/TITLE,Flex-Joint Rot. Angle=%flex_angle%deg , WH Incli.=%WHD_ANG%deg

solve
*enddo

FINISH
```