3623

HSE
Health & Safety
Executive

OFFSHORE TECHNOLOGY REPORT - OTO 98 029

Ship Impact Resistance of Jack-Up Conductors

Date of Issue : August 1998

Health & Safety Executive

Executive Summary

During the HSE/MaTSU review of Safety Cases a number of generic issues with regard to accidental events were identified. A particular issue was boat impact from visiting crafts and this report considered the implication of boat impact with jack-up conductors.

Jack-ups are common in the North Sea and are used both for exploration and development drilling. For exploration drilling, conductors are (almost) free-standing, only supported at the top by the jack-up. This is also the case for pre-drilling of wells in the development of offshore oil and gas fields. This report addresses a number of aspects on this topic.

An Excel spreadsheet has been developed to obtain elastic and plastic analysis estimates of the conductor impact problem. The details of the methodology are explained and three typical cases, for 10, 50 and 100m water depths, are addressed in more detail, including sensitivity of important parameters. The results of these cases show that the maximum impact force on conductors is relatively low, the supply boat itself will not absorb any impact energy; but due to the large (acceptable) deflections, the conductors have a useful amount of impact energy resistance. At these levels of deflection, the accidental release of hydrocarbons from an impact, such as that from a supply boat on a marine conductor, is rather unlikely.

For the three typical cases the impact resistance increases with waterdepth. In all cases considered the ultimate impact capacity was in excess of 0.5MJ, ranging from 0.75-2.50MJ.

Table of Contents

Executive Summary ---------- i

List of Figures ---------- iv

List of Tables ---------- iv

Glossary of Terms ---------- v

1 Introduction ---------- 1

2 Technical Aspects of Jack-up, Conductors and Casings ---------- 3

2.1 Jack-ups ---------- 3
2.2 Conductors ---------- 3
2.3 Casings ---------- 4
2.4 Well Testing ---------- 4
2.5 Boat Characteristics ---------- 5
2.6 Conductor Failure Mode ---------- 5

3 General Description of The Elastic, Plastic and Elasto-plastic Analyses ---------- 6

3.1 Elastic Analysis ---------- 6
3.2 Plastic Analysis ---------- 7
3.3 Combined Elasto-plastic Analysis ---------- 8
3.4 Denting ---------- 8
3.5 The Spreadsheet ---------- 9

4 Description of Test Cases ---------- 10

4.1 Case 1 - A Conductor in 10m Water depth ---------- 10
4.2 Case 2 - A Conductor in 50m Water depth ---------- 10
4.3 Case 3 - A Conductor in 100m Water depth ---------- 11
4.4 Concluding Remark ---------- 12

5 Conclusions ---------- 13

5.1 On Jack-up Conductors ---------- 13
5.2 On The Methodology ---------- 13

5.3 On The Test Cases -- 13

6 References -- **15**

7 Appendices

A. Description of Input/Output

B. Details of The Elastic Solution

C. Details of The Plastic Solution

Contents

List of Figures

Figure 1 - Jack-up Drilling Conductor. --16

Figure 2 - Typical Conductor, BOP, Tubing head Arrangement During Well Testing. 17

Figure 3 - Three End Conditions for Beam Bending Conductor Models.----------------18

Figure 4 - Load - Displacement Characteristics. ---19

List of Tables

Table 1 - Conductor in 10m Waterdepth, Free Top End.---------------------------------20

Table 2 - Conductor in 50m Waterdepth, Pinned Top End. ------------------------------21

Table 3 - Conductor in 100m Waterdepth, Pinned Top End.-----------------------------22

Glossary of Terms

A	cross-sectional area
BOP	blow-out preventer
D	conductor diameter
E	Young's modulus
E_{compr}	energy due to compressive load
E_{pl}	plastic energy absorption
$E_{pl,dent}$	plastic energy absorption with dent
I_{total}	total moment of inertia
M	moment
M_0	bending moment for $N=0$
N	(effective) tensile force
N_{crit}	Euler buckling load
P	lateral (impact) force
R	support reactions
S	plastic section modulus
SCSV	surface controlled subsurface safety valve
SSIV	subsea isolation valve
Z	elastic section modulus

a	point of impact
h	height of drill floor
h_{bottom}	point of maximum moment at or below sea bed

Contents

h_{top}	height form point of impact to top support
h_{tot}	total height
q	gravity load per unit length
t	thickness
w	lateral displacement
w_0	lateral deflection for N=0
$\tilde{w}$	approximate shape of w
x	dimensionless distance from the top

α	ratio between height of impact over total height
δ	dent depth
$ø$	angle of internal friction for sand
φ	(finite plastic) rotation
λ	eigen value
$\sigma_{ax\text{-}cond.}$	axial stress in conductor
$\sigma_{b\text{-}all}$	allowable bending stress
σ_y	yield stress

Contents

1 Introduction

During assessments of safety cases, a number of generic issues with regard to accidental events were identified. One in particular, was the event of boat impact on a fixed or mobile installation from a visiting support or supply vessel. Other aspects on boat impact can be found in review reports which give an overview of this topic[1,2,3&4].

Jack-ups and Semi-submersibles are commonly used in the North Sea for both exploration and development drilling in water depths ranging from 10m, in the Liverpool Bay area, to over 100m in the Central North Sea. For exploration, the conductors are almost free-standing and only supported at the top by the mobile rig. This is also the case for pre-drilling of wells in the development of offshore fields.

For deepwater, tension is sometimes applied to the conductors to ensure that bending stresses, during extreme environmental conditions, remain within allowable limits. Semi-submersibles provide their conductors with some element of protection due to cross bracing between pontoons and damage avoidance procedures for the pontoons and the mooring anchors.

Jack-ups, on the other hand, have to stay on station permanently during operations and as such are more exposed to the risk of collision. Furthermore, they have large exposed areas, depending on their leg configuration, where access to conductor sites is possible.

Unprotected access to conductor sites is not unique to mobile rigs, the conductors of the BP Harding platform and some other concrete platforms (e.g. Shell Expro's Dunlin-A) are also exposed, and do not have the normal steelwork frames as a first line of defence.

There are a number of phases during exploration and development drilling:

- commencement of drilling (without any casing string), but marine conductor installed;
- drilling after setting the surface casing;
- subsequent drilling and placing casings as required, including production casing;
- the installation of a production tubing;
- the extended production test.

It is during this final phase, most particularly, that boat impact could result in conductor damage and subsequent hydrocarbon release.

The underlying aim of this study was to try and develop some understanding of the energy absorption of the conductor string. As this was a rather unchartered area of investigation, it was thought more convenient, by the author and HSE, to stay with a simplified methodology in order to obtain good basic understanding of the topic. The use of a specifically developed spreadsheet lends itself particularly well to such a study since checks can be made to verify if conductor/casing strings are able to resist the operational impact of 0.5MJ as identified in the

Contents

HSE Guidance Notes[5]. Consideration was also given to the impact energy of the impacting vessel. This relates to supply boats in a typical size range of 1500-5000 tonnes displacement, operating in the vicinity of an operational conductor.

On this issue of conductor analysis, further references are worth mentioning. The OTC paper by Stahl, B. and Baur, M.P[6] is a leading reference in conductor design; it supports the clear distinction between compression in the conductor due to top loads resulting in buckling and compression in the conductor which is the result of tension in the casing. Another reference is an in-house (Visser Consultancy) review note addressing various aspects of conductors[7]; in this note the following topics were also identified as having an effect on the strength of conductor:

- centraliser distance;
- conductor connectors;
- steel strength;
- top tension (generally not more than 5.0 MN);
- mud weight;
- BOP weight;
- thermal stress;
- conductor setting depth.

The objective of the study is to address the realistic resistance of conductor/casing string assemblies under boat impact, using a simple impact analysis methodology. The spreadsheet to developed will be in an Excel format which will allow calculations and parameter variations, to be efficiently carried out.

The following aspects will be covered:

- impact energy at which hydrocarbon release is likely as a result of damage to conductor/casing;
- consideration of the energy absorbed by the impacting vessel as well as the conductor;
- a range of water depths from 10m to 100m and the influence that any conductor tension may have on the energy absorption capacity of the conductor;
- a range of 2 or 3 typical conductor/casing string configurations.

This report describes various aspects of jack-ups, conductors and casings of relevance for this study (Section 2); it highlights in general terms the methodology (Section 3) while the full details of the Excel spreadsheet are provided in the Appendices A-C; the test cases are described in Section 4 and the main conclusions summarised in Section 5.

Contents

2 Technical Aspects of Jack-up, Conductors and Casings

This section deals with technical aspects related to jack-ups and the use of conductors and casings. It was, however, not a comprehensive review on the technical aspects, as this would have been outside the scope and budget of this study. Particular attention was given to the boundary conditions and the combined section properties of conductor/casing combination.

2.1 Jack-ups

Jack-ups are used for a number of different operations; for example, drilling of exploration and development wells or for the repair of wells. For this study, only the case of free-standing conductors is to be considered, since if the conductor is within the protection of a wellhead jacket then the case of a direct hit of the conductor by a supply boat can be disregarded.

The jack-up provides a platform for drilling operations and for conductors in deeper water, it also provides lateral support at that level. The jack-up is, laterally, much stiffer than the conductor and hence a top support can be regarded as fixed or pinned. The conductor can only be free at the top in shallow water; this argument can be demonstrated by considering the wave loading on the conductor during the design storm event.

The jack-up can drive the conductor in the seabed or it can use a well head template at the seabed. In the first case, the soil conditions must be considered. Correspondingly a number of soil conditions have been approximated in the spreadsheet. For the alternative of a seabed template with a tie-back conductor, the bottom boundary condition can be considered as fixed.

The top support of the conductor is provided by an arrangement which allows axial displacements but no lateral displacements: hence a pinned connection is obtained, although for shallow water this connection may not be required from an environmental force point of view.

2.2 Conductors

The conductor itself is a tubular of constant wall thickness with a diameter of either 0.762m (30") or 0.660m (26"). The wall thickness depends on the water depth and can be from 0.020m (0.75") to 0.038m (1.50"). This high thickness is governed by the maximum cold rolling dimension requiring a $D/t \geq 20$, and helps provide lateral stiffness and protection against the environment. It is commonly made from a normal grade steel (Grade 345).

The three cases to be considered, as far as the top boundary conditions are concerned, can be summarised as follows:

- conductors in shallow water: free top end
- the normal top condition: pinned top end

Contents

- during well testing: clamped top end

The inclusion of conductor connectors in the context of this study can be disregarded for two reasons: (a) the chance of the conductor connector being in the critical zone is very remote and (b) conductor connectors are designed to be as strong as the conductor sections being connected.

2.3 Casings

Casings are a set of concentric tubulars which serve many functions. For this study the more important functions are as follows:

- to support wellhead equipment including providing anchorage for the BOP stack;
- a means of containing well bore pressures either expected or unexpected. For this a mud with a certain specific gravity, contained within the casing, is required;
- in order to ensure that the rock formation closer to the surface will not fracture, a steel protection (i.e. casing) is required;
- for deep drilling, a set of casings is needed before the production tubing can be installed.

As weight and cost is of a premium, the casings, except the surface casing, are generally made of a high strength steel, typically of 500MPa. Furthermore, as they must be manufactured in transportable lengths, casings contain screwed connections which are designed to be stronger than the casing itself.

2.4 Well Testing

During well testing, a separate high pressure riser is used (see Figure 2). The riser is a heavy walled, high strength tubular which is not only able to resist the full wellhead pressure but is also much stronger than the conductor. The riser is supported by the drill floor and thus a fixed top end condition is obtained. It is also important to note that the connections in the wellhead, BOP and riser are designed to be stronger than the tubular which they connect.

Hence, it can be concluded that, during well testing, the top of the conductor looks more like a clamped connection than a pinned connection. Therefore this case has also been included in the spreadsheet.

During well testing it is a fairly common practice to install a surfaced controlled subsea safety valve (SCSV) or subsea isolation valve (SSIV) as they are sometimes known. This implies that, in case of an accident of any sort, including boat impact, the uncontrolled release of hydrocarbons is minimised. It then depends on the reliability of the SSIV to function on demand.

Contents

2.5 Boat Characteristics

The boat characteristics are commonly taken as those described by DnV in TN 202[8]. From the graph in this document it can be concluded that the energy absorption taken by the boat can be disregarded for the following conditions:

- under bow impact for forces below 3 MN;
- under stern and broadside impact for forces below 7 MN.

The latter is the most likely boat impact scenario for the conductor. Secondly, it is found in all the test cases that the impact force on the conductor is of the order of 1 MN or less; hence boat impact energy absorption can be disregarded for the case of conductor impact.

2.6 Conductor Failure Mode

The aim here is not to provide a comprehensive and complicated failure mode and effect analysis. However, for proper understanding of the topic, some consequences are addressed in this section.

In the analysis it has been assumed that excessive bending of the conductor, or a finite local rotation in excess of a limiting value, corresponds with conductor failure. However, the ultimate failure load will be well in excess of the load corresponding to this limiting value for the rotation. This excessive bending will at least result in stopping of the drilling operation as the drill string would get stuck and no further rotation of the rotary table would be possible. This could also give rise to further conductor failure conditions occurring in unseen areas below the mudline. These conditions are non-critical as far as personnel safety is concerned.

For deepwater, at a critical drilling situation, a failure of the bottom connection could lead to mud loss and reduction of the control pressure in the well. Secondly, during well testing, the combination of boat impact should be combined with either an absence of a SSIV or with the failure of the SSIV to operate.

Boat/conductor impact is a rare event and therefore it is not necessary to combine this impact scenario with other events of either short duration or of low probability.

One of the outputs is the vertical top displacement. If rigid piping is applied, it may be that excessive vertical displacements could cause failure in the associated high pressure piping, particularly during well testing.

3 General Description of The Elastic, Plastic and Elasto-plastic Analyses

In the absence of any stress concentration, the design and analyses of conductors are commonly carried out using beam bending equations. For deepwater conductors, once the buckling load becomes of the same order of magnitude as the weight of the BOP stack and/or the pre-tensioning, then column buckling behaviour has to be considered.

Two primary methods are considered namely elastic methods and plastic methods; these are described in detail in Appendices B and C. The salient points are summarised in the following sub-sections. Once plastic deformation was apparent it was found that the elastic deformations may form a significant part in the energy absorption; hence in Section 3.4 the procedure for combining the elastic and plastic solutions is described as well.

3.1 Elastic Analysis

The elastic analysis, as given in Appendix B, starts with giving due consideration to:

- the various heights;
- the bottom boundary condition;
- the moment of inertia and section modulus of the combined conductor/casing string.

The displacements of the conductor were found to be an order of magnitude larger than the gaps between the conductor and the surface casing and between the casings. Therefore the gaps can be disregarded.

For the elastic solution, without the contribution due to the axial force, the equations adopted are found in a book by Roark[9] and are given in Appendix B. It gives a first order approximation of the displacements at the point of impact when maximum stress in the cross section is equal to the yield stress.

Substantial attention is given to the contribution of the various weights which have to be allowed for.

These are:

- weights of the BOP stack;
- weight of the conductors and casings, including the mud;
- top tension.

The weight of the conductor, casings and mud would only contribute in part as explained in Appendix B. Particularly if these weights or tensioning are of the order of the Euler buckling load, corrections would have to be applied. This is illustrated in Figure 4, 4.1. In the presence of compression, the conductor/casing combination is more flexible and can absorb lower impact force, whereas under tension the impact force can be higher before the yield stress in the conductor is reached.

In this context, attention should be given to any tensioning in the casing, supported by the conductor. The net tension/compression in the conductor/casing combination is zero; therefore, as explained in detail in Stahl et. al[6] this effect can be disregarded as far as buckling is concerned.

This tension may affect (modestly) the stresses in the conductor and therefore the maximum allowable bending stress; however, this applied casing tension is normally a short operation and therefore the correction can be disregarded.

Tensioning increases the resistance and has therefore been accommodated as a first approximation.

As explained in Section 2 there are three top boundary condition to be considered. These are:

free top end:	for shallow water conductors
pinned top end:	the normal case
fixed top end:	in case of well testing

These three cases are sketched in Figure 3 and addressed in Appendix B.

3.2 Plastic Analysis

The plastic analysis addresses the topic from a virtual displacements point of view. After the calculation of the plastic moments, necessary to generate a failure mode, the impact force can be calculated.

In this case the difficulty lies with the calculation of the maximum displacement. A number of norms have been proposed as reflected in Appendix C. The following norms have been considered:

- the Marshall minimum rotation[10], which is unrealistic and should not be used;
- the Marshall maximum rotation;
- a mean Marshall rotation;
- an allowable rotation using strain hardening[2];
- a maximum rotation of 15°.

Contents

All equations have been incorporated in the spreadsheet and the following conclusions reached:

- the Marshall maximum rotation comes close to the strain hardening rotation;
- a Marshall mean rotation comes close to a maximum slope of 15°.

Therefore, in the spreadsheet, the minimum value of the Marshall mean and the maximum slope is used. It is noted that rotations at, or in excess of, this value do not necessarily correspond with actual conductor failure; there is still an unquantifiable reserve at this point but this conservatism is disregarded in the analysis.

Just as in the elastic case, a top load has a similar effect in the plastic case. However, the treatment in the analysis is completely different: the effect on the impact force and energy depends on pure equilibrium conditions (see Appendix C). Therefore, as shown in Figure 4, 4.2 a compression leads to a softening load-displacement characteristic whereas tension leads to hardening. And as illustrated the softening may be so severe that the impact force becomes zero before the maximum allowable deflection is reached; at this point the situation becomes unstable.

3.3 Combined Elasto-plastic Analysis

The appendices only deal with the details of the elastic solution and of the plastic solution. However, the combined elasto-plastic solution is also required.

The procedure is difficult to explain and is best illustrated through Figures 4, 4.1-4.2 with the outcome in Figure 4.3. This last figure gives the load-displacement curve. The area underneath this curve is the maximum conductor/casing impact energy absorption.

3.4 Denting

There are two equations in common use as far as denting is concerned; they are those by Ellinas & Walker[11] and by Furnes & Amdahl[12]. The two equations have been implemented and the maximum of the two results is given as the output. Note that in the plastic case the impact force depends on the deflection itself; and is shown in Appendix C. For compression the impact force is the highest for zero conductor deflection, therefore, this maximum impact force at zero deflection is used to calculate the dent depth in the compression case for the plastic analysis.

The dent depth was normally small, i.e. less than 50% of the conductor wall thickness. If it was substantially larger than this value, then the dent would affect the section properties. As a first approximation the following equation can be used to assess the consequence of the dent on the impact energy:

$$E_{pl,dent} = E_{pl} \cdot \left\{ 1 - \sqrt{\frac{\delta}{2 \cdot D}} \right\}$$

where δ is the dent depth and D the diameter of the conductor.

Contents

3.5 The Spreadsheet

In addition, to Appendix A, where some comments on the input are given, technical details of the spreadsheet are also described in Appendix B and C, while examples of input/output for the three test cases considered in Section 5, are given in Tables 1-3.

Contents

4 Description of Test Cases

Three typical cases will be considered here, namely in 10m, 50m and 100m water depth. The numbers used in the examples are typical but can be varied without any difficulty. Since the fixed top boundary, during well testing, is a more realistic condition than pinned, during normal operation, only the latter is considered here, as the principal case.

For all cases the following initial assumptions have been made:

- 30" conductor of 1" thickness of a yield strength of 340 MPa
- the weight of the BOP stack of 0.70 MN
- the mud weight ratio of 2.0 (as compared with water)
- a single surface casing
- a deck height of 15m

The details of the input and output of the analyses can be found in Tables 1-3.

4.1 Case 1 - A Conductor in 10m Water depth

This very shallow water case is a good example to test the free top condition; a medium soil was assumed. The input/output parameters are given in Table 1 and show that in terms of displacement and energy, plastic energy absorption is essential. The impact force is of the order of 0.5-1.0MN and the maximum non-elastic deformation at the point of impact is of the order of 0.6m.

The amount of energy which can be absorbed is 0.6MJ; it is in excess of the 0.5MJ operational impact[5]. Although the resulting dent depth was substantial it would have no effect on the energy absorption because the point of the highest moment is at the sea bed.

The two parameter changes which have been made are:

- soft soil:	the impact energy increases because of increased flexibility;
- a 26"conductor:	the impact energy increases because of larger allowable displacements.

4.2 Case 2 - A Conductor in 50m Water depth

This waterdepth can be considered as a good mean value; it is the prime area for jack-up drilling. The top condition is pinned and a hard soil condition is assumed.

Contents

The input/output, given in Table 2, confirms that in terms of displacement and energy, the plastic energy absorption provides valuable reserve capacity. The impact force was of the order of 1MN and the maximum non-elastic deformation at the point of impact was of the order of 1m.

The amount of energy which can be absorbed elastically is 0.2MJ; therefore it evidently required some plastic deformation to reach the 0.5MJ. The dent depth in the plastic range here could be of some concern; if the first order correction, as given in Section 3.5 was applied, the plastic energy absorption in Table 2 would turn out to be non-conservative by some 20%. Because of the high value of plastic energy absorption, which has been calculated to be in the order of 1.7MJ, there is no need to address this in more detail.

The two parameter changes which have been made are:

- a 30" x 1.5"conductor: the impact energy increases because of the larger thickness;
- a clamped top: the elastic impact energy decreases because of the additional fixity but the total plastic and elastic capacity increases modestly.

4.3 Case 3 - A Conductor in 100m Water depth

For the deepwater application top tension was required and a low value of 2.0MN has been assumed; this top tension would be reduced in the input to 1.3MN due to the weight of the BOP.

The output given in Table 3, confirms that in terms of displacement and energy, plastic energy absorption provides valuable reserve capacity that is not necessarily required. The impact force is of the order of 1MN and the maximum elastic deformation at the point of impact is of the order of 2m.

Here the amount of energy which could be absorbed elastically was 0.7MJ and therefore no plastic deformation was necessary to reach the 0.5MJ. The dent depth in the elastic range was arround 9mm and was of no concern.

The two parameter changes which have been made are:

- top tension 1MN: the elastic impact energy decreases by 70%, hence plastic deformation is essential;
- no surface casing: the elastic impact energy decreases by 50% to 0.4 MJ.

Contents

4.4 Concluding Remark

Finally, it was noted that the conductors of the BP Harding platform[1] and some of the concrete gravity platforms (e.g. Shell Expro Dunlin-A) are also exposed, i.e. there is no protected steel framework in the splash zone as a first line of defence. The methods as developed in this report would also be suitable to address these conductors as well.

Contents

5 Conclusions

5.1 On Jack-up Conductors

Jack-up conductors are exposed to boat impact only under the following conditions:

- during exploration activities;
- during development drilling of template wells.

Particularly from a general lay-out point of view, the conductors appear to be quite vulnerable in their exposure.

It can be demonstrated that conductor connectors, if used, are not a prime concern for the impact energy assessment. The casing string, if installed, provides a valuable additional strength in case of boat impact.

5.2 On The Methodology

The elastic solutions of the conductor impact problem show large displacements; this is the prime reason that conductors do have a significant impact energy resistance.

- The plastic solution shows that conductors have a substantial amount of reserve capacity against boat impact.
- Tension/compression for a slender structure such as a conductor should be given careful consideration.
- Denting can be significant, but for the cases considered, its inclusion does not alter the major conclusions.
- A spreadsheet is an easy tool to use. Variations in input parameters, in terms of boundary conditions, water depth and conductor/casing properties, can easily be accommodated.

5.3 On The Test Cases

Three different test cases have been considered, namely for 10, 50 and 100m water depth.

The main conclusions **from these three cases** are:

- 0.5 MJ operational impact energy can be absorbed, provided due consideration to plasticity is given.
- for the deepwater case pre-tension is essential, not only for ensuring adequate impact energy absorption but also to resist the environmental loading of ± 1MN.

Contents

Other conclusions are:

- soft soil has an advantage over hard soil, in terms of allowing the conductor to deflect more;
- the capacity of a 26" conductor is higher than for a 30" conductor;
- an increased conductor thickness leads to a higher impact absorption capacity;
- finally, the clamping at the top end of the conductor, as in the case for well testing, reduces the elastic energy capacity but increases the ultimate capacity.

From the test cases and the parameter variations it was concluded that in all cases considered the ultimate impact energy capacity was in excess of 0.5MJ, ranging from 0.75-2.50MJ. Therefore, the accidental release of hydrocarbons, in the case of a supply boat impacting on a marine conductor, was considered unlikely.

Contents

6 References

1 Visser, W., Capacity of installations to withstand ship impact: Phase 1: Review of Safety Cases; Study carried out for HSE OSD, Contract MaTSU/8800/3451, 1997.

2 Visser, W., Capacity of installations to withstand ship impact: Phase 2: Brace impact resistance; Study carried out for HSE OSD, Contract MaTSU/8800/3451, 1997.

3 Nichols, N.W. and Vaughan, D.A., A review of recent research on the effects of collision with offshore structures, Study carried out for HSE OSD, MaTSU report number MaTR 113, Dec. 1992.

4 AME, Vessel impact on fixed platforms, Final Report Joint Industry Project, HSE number OTN 92 176, Feb. 1992.

5 Offshore Installations: Guidance on Design Construction and Certification, Fourth Edition, UK Health & Safety Executive, London, 1990.

6 Stahl B. and Baur M.P., Design methodology for offshore platform conductors, OTC 3902, 1980.

7 Visser W., Some background notes on conductors, Internal Note 1990.

8 Det Norske Veritas, Technical Note Fixed Offshore Installations, TN A 202, Impact loads from boats, May 1981.

9 Roark R.J., Formulas for stress and strain, fourth edition, McGraw Hill, New York, 1965.

10 Marshall P.W., Gates W.E. and Anagnostopoulos S., Inelastic dynamic analysis of tubular structures, OTC 2908, 1977.

11 Ellinas C.P. and Walker A.C., Damage on offshore tubular bracing members, IABSE Colloquium, Copenhagen 1983.

12 Furnes O. and Amdahl J., Ship collision with offshore platforms, Intermaritec '80,1980.

Contents

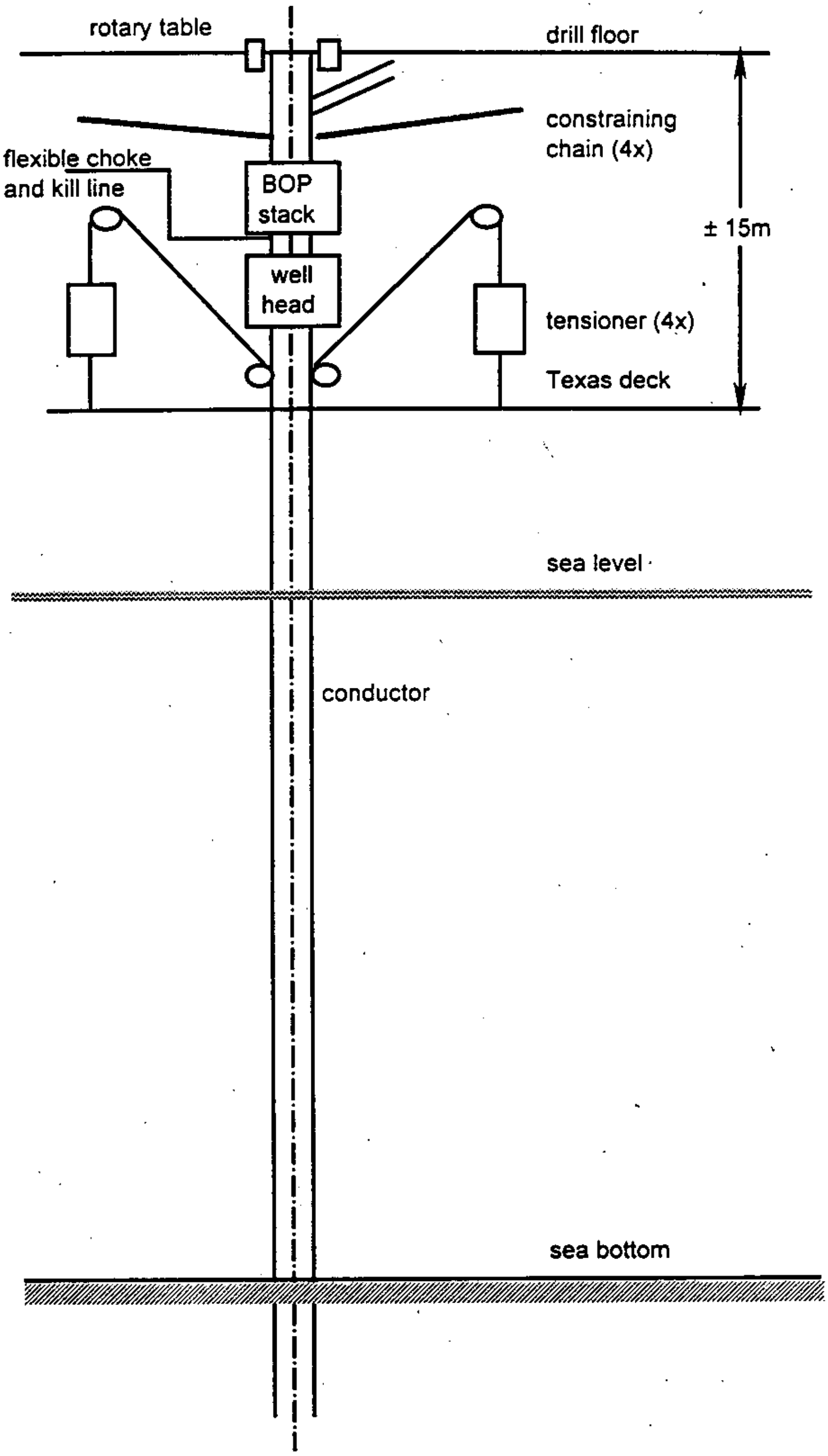


Figure 1 - Jack-up Drilling Conductor.

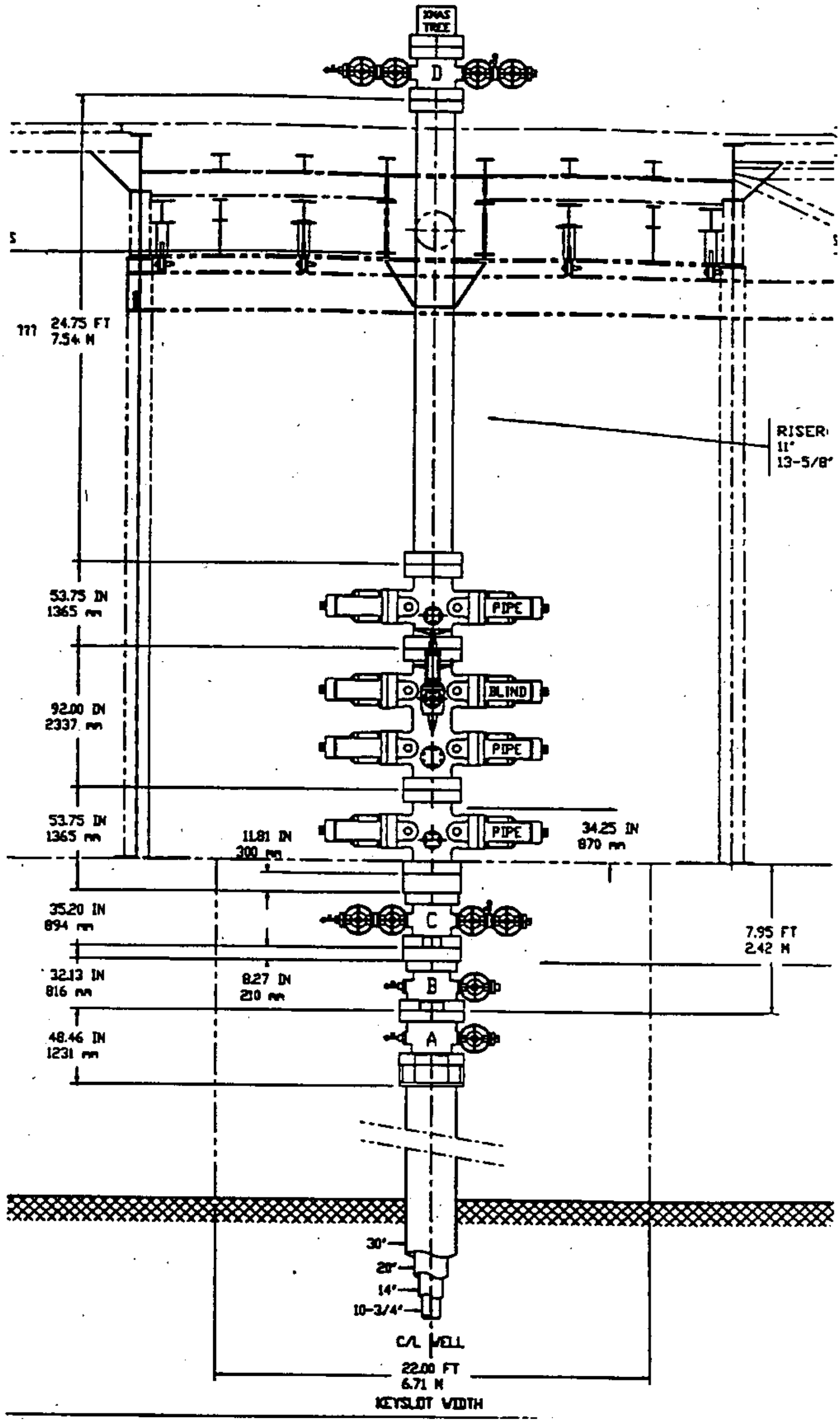


Figure 2 - Typical Conductor, BOP, Tubing head Arrangement During Well Testing.

Contents

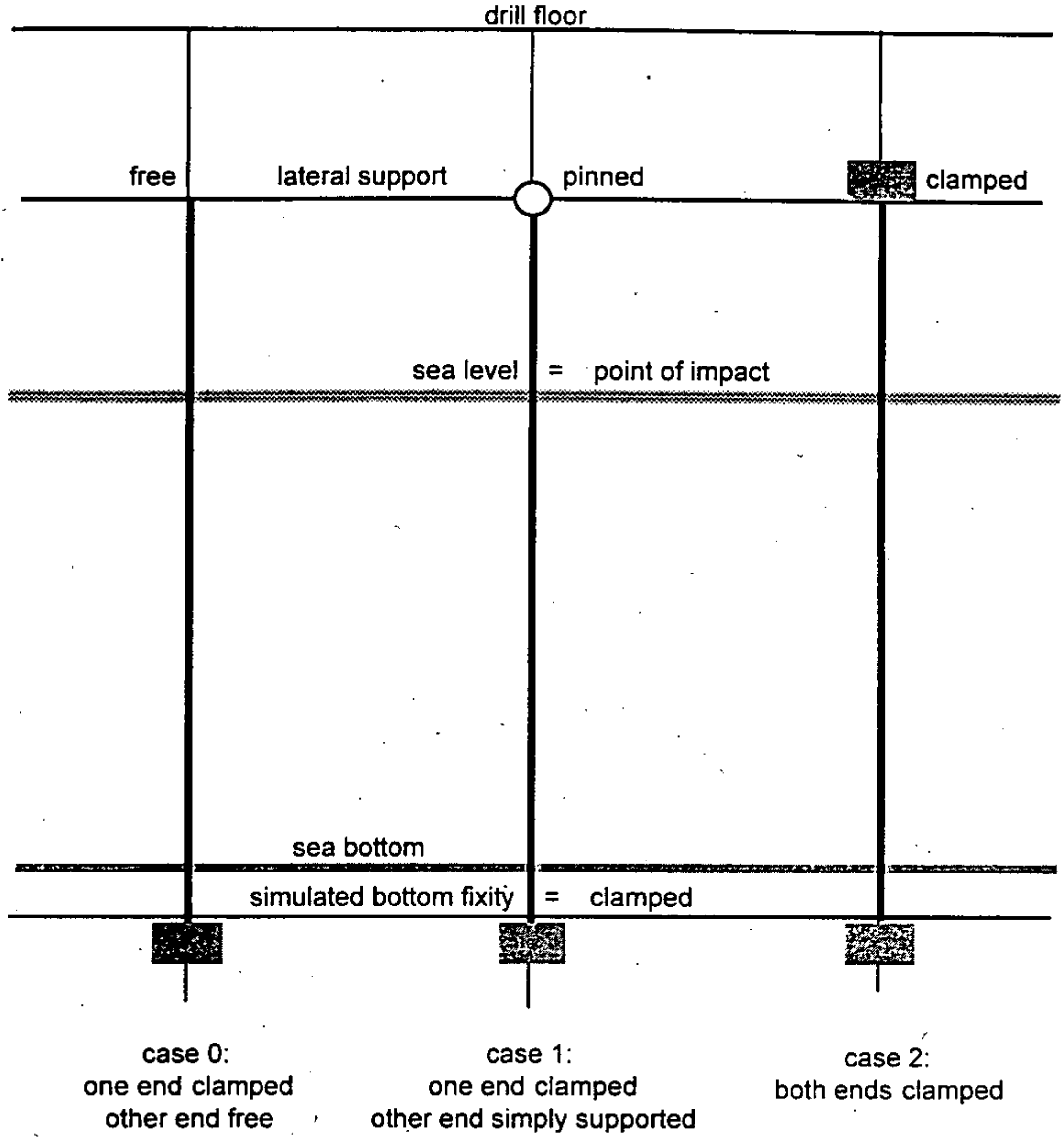


Figure 3 - Three End Conditions for Beam Bending Conductor Models.

Contents

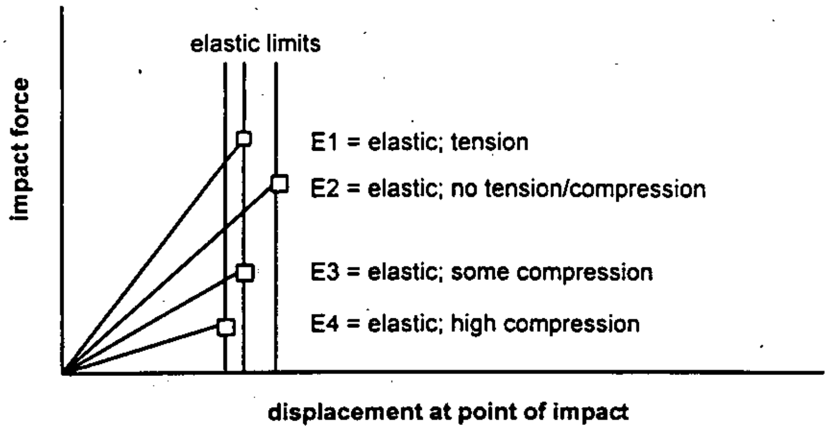


Figure 4.1 Elastic load-displacement characteristics

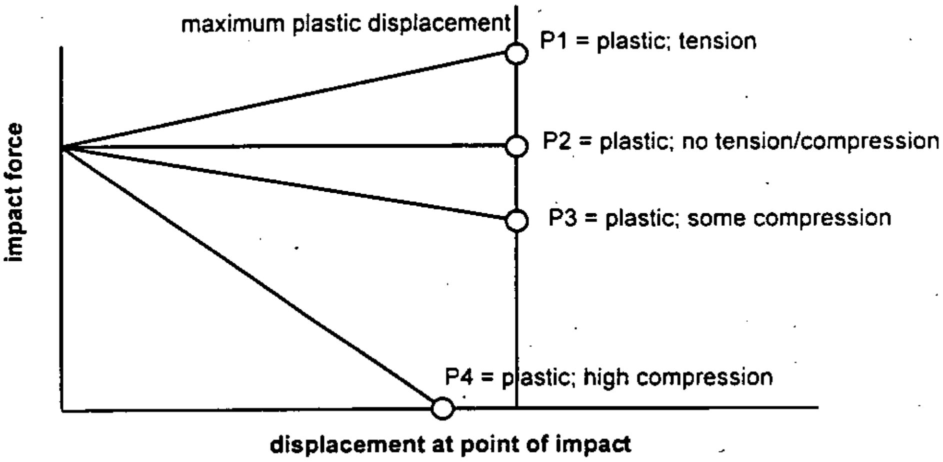


Figure 4.2 Plastic load-displacement characteristics

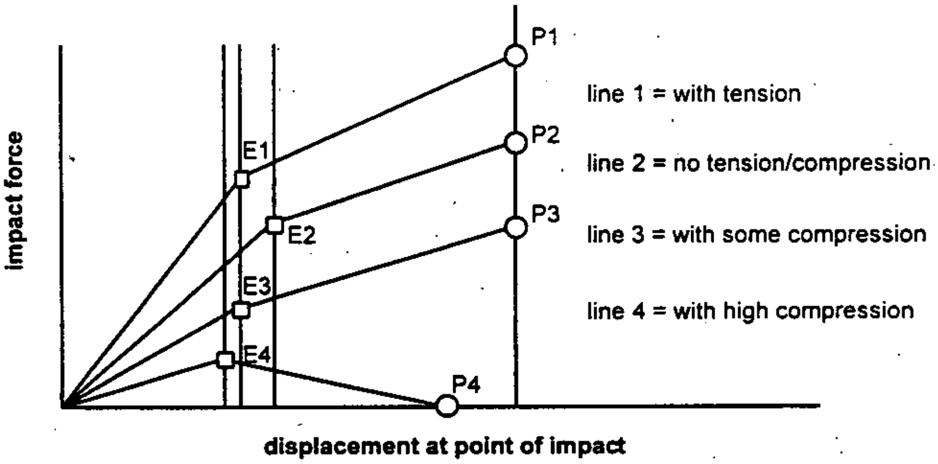


Figure 4.3 Combined elasto-plastic load-displacement characteristics

Figure 4 - Load - Displacement Characteristics.

EXCEL SPREADSHEET FOR CONDUCTOR IMPACT

input data

conductor	case 1	
diameter	0.750	m
thickness	0.025	m
yield str.	340.00	MPa
top tension	-0.70	MN
constraint (0, 1 or 2)	0	
0 = free top		
1 = pinned top		
2 =clamped top		
s.g. mud / s.g.water	2.0	
casing 1		
diameter	0.500	m
thickness	0.150	m
yield str.	340.00	MPa
casing 2		
diameter	0.300	m
thickness	0.000	m
yield str.	500.00	MPa
casing 3		
diameter	0.160	m
thickness	0.000	m
yield str.	500.00	MPa
waterdepth	10.00	m
deck height	15.00	m
deck height to mudline	25.00	m
bottom boundary cond.	2	option
0 = clamped	medium soil	
1 = hard soil		
2 = medium soil		
3 = soft soil		
>3 = own choice (m)		

output data

various parameters		
bottom boundary length	6.0	m
total length	31.00	m
impact height ratio (α)	0.52	
top constraint	free top	
Euler buckling load	3.35	MN
submerged / air weight	0.94	
ratio contr. distr. mass	0.29	
effective top tension	-0.93	MN
tension/P-Euler	-0.28	

displacements at point of impact (m)

	elastic	plastic
excl. tension/compr.	0.04	0.88
with compression	0.04	0.88

max. allowable impact energy absorption (MJ)

	elastic	plastic
excl. tension/compr.	0.01	0.75
with compression	0.01	0.62

vertical top displacement (m)

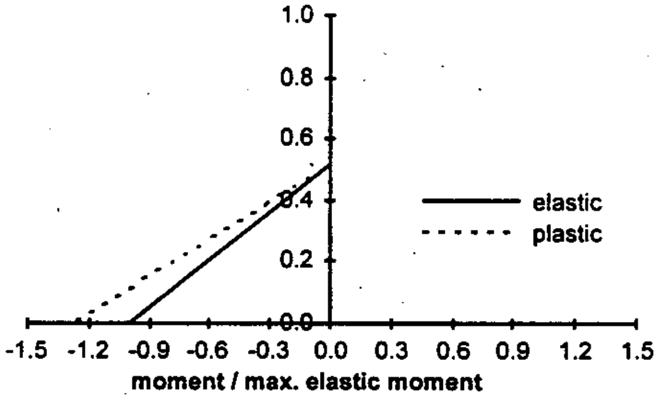
	elastic	plastic
excl. tension/compr.	0.01	0.11
with compression	0.01	0.11

impact force at max. displacement (MN)

	elastic	plastic
excl. tension/compr.	0.65	1.10
with compression	0.45	0.99

dent depth (mm)

	elastic	plastic
excl. tension/compr.	8.36	23.61
with compression	4.06	23.61



Moment distribution as a function of relative height

23-02-1998

Table 1 - Conductor in 10m Waterdepth, Free Top End.

Contents

EXCEL SPREADSHEET FOR CONDUCTOR IMPACT

input data

conductor	case 2	
diameter	0.750	m
thickness	0.025	m
yield str.	340.00	MPa
top tension	-0.70	MN
constraint (0, 1 or 2)	1	
0 = free top		
1 = pinned top		
2 =clamped top		
s.g. mud / s.g.water	2.0	
casing 1		
diameter	0.500	m
thickness	0.150	m
yield str.	340.00	MPa
casing 2		
diameter	0.300	m
thickness	0.000	m
yield str.	500.00	MPa
casing 3		
diameter	0.160	m
thickness	0.000	m
yield str.	500.00	MPa
waterdepth	50.00	m
deck height	15.00	m
deck height to mudline	65.00	m
bottom boundary cond.	1	option
0 = clamped	hard soil	
1 = hard soil		
2 = medium soil		
3 = soft soil		
>3 = own choice (m)		

output data

various parameters		
bottom boundary length	4.0	m
total length	69.00	m
impact height ratio (α)	0.78	
top constraint	pinned top	
Euler buckling load	4.05	MN
submerged / air weight	0.94	
ratio contr. distr. mass	0.34	
effective top tension	-1.29	MN
tension/P-Euler	-0.32	

displacements at point of impact (m)

	elastic	plastic
excl. tension/compr.	0.72	2.00
with compression	0.70	2.00

max. allowable impact energy absorption (MJ)

	elastic	plastic
excl. tension/compr.	0.37	2.18
with compression	0.24	1.73

vertical top displacement (m)

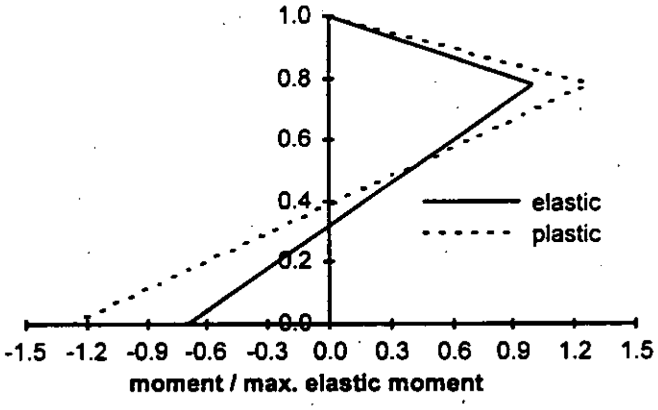
	elastic	plastic
excl. tension/compr.	0.03	0.21
with compression	0.03	0.21

impact force at max. displacement (MN)

	elastic	plastic
excl. tension/compr.	1.02	1.82
with compression	0.67	1.68

dent depth (mm)

	elastic	plastic
excl. tension/compr.	20.62	65.00
with compression	8.93	65.00



Moment distribution as a function of relative height

23-02-1998

Table 2 - Conductor in 50m Waterdepth, Pinned Top End.

Contents

EXCEL SPREADSHEET FOR CONDUCTOR IMPACT

input data		
conductor	case 3	
diameter	0.750	m
thickness	0.025	m
yield str.	340.00	MPa
top tension	1.30	MN
constraint (0, 1 or 2)	1	
0 = free top		
1 = pinned top		
2 =clamped top		
s.g. mud / s.g.water	2.0	
casing 1		
diameter	0.500	m
thickness	0.150	m
yield str.	340.00	MPa
casing 2		
diameter	0.300	m
thickness	0.000	m
yield str.	500.00	MPa
casing 3		
diameter	0.160	m
thickness	0.000	m
yield str.	500.00	MPa
waterdepth	100.00	m
deck height	20.00	m
deck height to mudline	120.00	m
bottom boundary cond.	1	option
0 = clamped	hard soil	
1 = hard soil		
2 = medium soil		
3 = soft soil		
>3 = own choice (m)		

output data		
various parameters		
bottom boundary length	4.0	m
total length	124.00	m
impact height ratio (α)	0.84	
top constraint	pinned top	
Euler buckling load	1.19	MN
submerged / air weight	0.94	
ratio contr. distr. mass	0.33	
effective top tension	0.25	MN
tension/P-Euler	0.21	

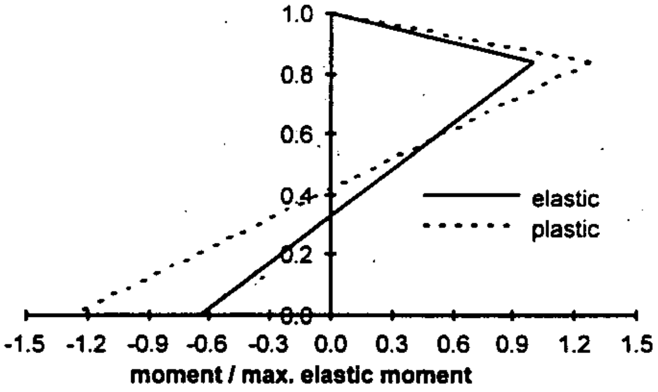
displacements at point of impact (m)	elastic	plastic
excl. tension/compr.	2.03	3.85
with tension	1.90	3.85

max. allowable impact energy absorption (MJ)	elastic	plastic
excl. tension/compr.	0.70	2.42
with tension	0.74	2.57

vertical top displacement (m)	elastic	plastic
excl. tension/compr.	0.14	0.51
with tension	0.13	0.51

impact force at max. displacement (MN)	elastic	plastic
excl. tension/compr.	0.69	1.21
with tension	0.78	1.24

dent depth (mm)	elastic	plastic
excl. tension/compr.	9.26	28.97
with tension	11.82	30.26



Moment distribution as a function of relative height

23-02-1998

Table 3 - Conductor in 100m Waterdepth, Pinned Top End.

Contents

Appendices

CONTENTS

Appendix A Description of Input / Output

Appendix B Details of The Elastic Solution

Appendix C Details of The Plastic Solution

Contents

Appendix A

Description of input and output

CONTENTS

A.1 Input Data

  A.1.1 Part 1: Conductor Related Input

  A.1.2 Part 2: Mud Related Input

  A.1.3 Part 3: Casing Related Input

  A.1.4 Other Geometric Parameters

A.2 Output Data

  A.2.1 Intermediate Results

  A.2.2 Final Results

A.3 Commentary on the Blocks of Output Data

  A.3.1 Displacement at Point of Impact (m)

  A.3.2 Impact Energy Absorption (MJ)

  A.3.3 Length Reduction (m)

  A.3.4 Impact Force (MN)

  A.3.5 Dent Depth (mm)

A.4 Input Data for the Three Test Cases

Contents

APPENDIX A - DESCRIPTION OF INPUT AND OUTPUT

A.1 INPUT DATA

A.1.1 Part 1: Conductor related input

For the conductor the following information is requited:

conductor diameter
thickness
yield strength
top tension — the top tension includes the weight of the BOP
constraint at the top (0, 1 or 2)

0 = free top

1 = pinned top

2 = clamped top

A.1.2 Part 2: Mud related input

s.g. mud / s.g.water — this is the specific gravity as compared with the s.g. of water

A.1.3 Part 3: Casing related input

For each casing string the following input is required:

diameter

thickness

yield strength

A total of three casing strings can be accommodated. It can be demonstrated, through variation in the input parameters that the effect of the third (and any subsequent) casing string(s) can be disregarded.

A.1.4 Other geometric parameters

Important parameters are the water depth and the deck height:

waterdepth

Contents

deck height

Also, as mentioned in Appendix B, the bottom boundary condition should be given proper attention. A number of options can be investigated:

bottom boundary condition:

0 = clamped

1 = hard soil

2 = medium soil

3 = soft soil

>3 = own choice (m)

The following characterisations can be made depending on the top soil condition over the first 5-10m:

hard soil:	medium to dense sand (ø> 25°) or heavily overconsolidated clay
medium soil:	rather loose sand (ø< 25°) or overconsolidated clay
soft soil:	normally consolidated clay

The consequence and importance of the bottom boundary condition can easily be verified by parameter variation.

A.2 OUTPUT DATA

A.2.1 Intermediate results

Various parameters

bottom boundary length	
total effective length	
ratio (α)	this is equal to the ratio between height of impact over total height
top constraint	a reflection of the top boundary
Euler buckling load	

Contents

submerged / air weight	this is calculated for the conductor/casing string combination, completely filled with mud.
ratio contr. distr. mass	this quantity is calculated for the elastic condition and reflects the gravity load due to the conductor/casing string combination (partly submerged, but filled with mud)
effective top tension	this is the top tension as corrected by the gravity contribution of the conductor/casing string
tension/P-Euler	an indicative result: if $\lvert \text{value} \rvert > 0.50$ "warning" is given if value = -1.0 "ERROR" is shown

A.2.2 Final results

The final results are given in a set of five blocks of data which address subsequently:

displacements at point of impact (m)

impact energy absorption (MJ)

length reduction (m)

impact force (MN)

dent depth (mm)

Each block gives the value for:

elastic or plastic

and excluding tension or compression effects

with tension or compresion effects

A.3 COMMENTARY ON THE BLOCKS OF OUTPUT DATA

A.3.1 Displacements at point of impact (m)

Contents

The allowable elastic displacement with tension is less than the allowable elastic displacement without tension because the tension reduces the allowable bending stress.

The plastic displacement is always larger than the elastic displacement. In this case the deflection is governed by the allowable rotation and hence the values for this displacement are independent of the top tension.

A.3.2 Impact energy absorption (MJ)

The impact energy absorption depends on the effective tension; hence the difference between without and with tension results depends on the sign of the top tension.

A.3.3 Vertical Top Displacement (m)

Length reduction may cause a general failure mode, (e.g. failure of the topside piping), hence it is given as one of the output parameters.

A.3.4 Impact force (MN)

The impact force is an important parameter. Only for impact forces in excess of 7.0MN will the supply boat take some of the impact energy. As is apparent from the examples, the impact force is < 7.0MN for most cases.

A.3.5 Dent depth (mm)

The dent depth depends directly on the impact force. As long as the dent is less than 50% of the conductor thickness the dent depth can be ignored. For larger depth the equation for the allowable elastic and plastic moment at the point of impact should be corrected, (see Section 3.4).

A.4 INPUT DATA FOR THE THREE TEST CASES

The three test cases can be run by copying:

for case 1:	H6 - H37
for case 2:	I6 - I37
for case 3:	J6 - J37
and pasting it in the area:	B6 - B37.

Contents

The text underneath the graph (cells A61-F61) is then automatically adjusted as well.

If the input in cell B6 differs from "case 1", "case 2" or case 3" there is no automatic text underneath the graph but the cells A60-F60 are available for user specific text input.

Contents

Appendix B

Details of the Elastic Solution

CONTENTS

- B.1 Input Parameters Excluding Gravity Loads
    - B.1.1 Bottom Boundary Condition
    - B.1.2 Top Boundary Condition
    - B.1.3 Moment of Inertia and Elastic Section Modulus
    - B.1.4 Point of Impact
- B.2 Elastic Solution
- B.3 Effect of Top Load
    - B.3.1 Exact and Approximate Solutions
    - B.3.2 Distributed Gravity Loads
    - B.3.3 Change in Allowable Stress
- B.4 Stiffness Effects of the Casing String
- B.5 Denting
- B.6 Free Top End
- B.7 Fixed Top Support

Contents

APPENDIX B - DETAILS OF THE ELASTIC SOLUTION

The first approximation to the conductor impact problem can be found through the application of the elastic beam bending equations.

B.1 INPUT PARAMETERS EXCLUDING GRAVITY LOADS

If gravity loads are excluded then the conventional beam bending solution can be used. It is then necessary to have information on the following parameters:

- height drill floor	(h)
- bottom boundary condition	
- top boundary condition	
- moment of inertia	(I_{total})
- point of impact	(a)

Some comments on the above parameters are described below.

B.1.1 Bottom boundary condition

Five options for the bottom boundary condition are available; they depend on the soil condition or on the use of a sea bottom template (clamped condition). It is an old method to determine the point where the pile bending moment reaches its maximum; this distance below the mudline is called h_{bottom}. This is the point taken as the bottom fixed boundary condition. The following choices can be made (Ref. 1):

0.	clamped	0m
1.	hard soil	4m
2.	medium soil	6m
3.	soft soil	8m
>3.	own choice	distance (m)

In case of uncertainty the sensitivity of the results as a function of the bottom boundary condition can be considered. Hence the total length is given by:

$$h_{tot} = h + h_{bottom}$$

Contents

B.1.2 Top boundary condition

The top of the conductor is normally simply supported at some point of the jack-up. Therefore this is the first choice and equations will be derived in detail for this case. Other cases are addressed in Section B.6 for the free top end, which can occur in shallow water) and Section B.7 for the fixed condition (during well testing).

B.1.3 Moment of inertia and elastic section modulus

The moment of inertia and other parameters will first of all depend on the conductor itself. Combined with the casing string the elastic section modulus becomes:

$$Z_{tot} = \frac{I_{cond.} + \sum I_{casings}}{D_{cond.} / 2}$$

where: $$I = \frac{\pi}{8} \cdot D^3 \cdot t$$

B.1.4 Point of impact (a)

For the sake of this study the point of impact is assumed to take place at the mean Sea level (MSL) which is related to the LAT (low astronomical tide) by:

$$\text{MSL} \approx \text{LAT} + 2.0\text{m}$$

Other points of impact can be simulated by variation in the input parameters. For the calculations this distance (a) has to be corrected by the distance h_{bottom} described in Section B.1.1.

B.2 ELASTIC SOLUTION

The elastic solution for this problem in terms of the maximum displacement (w_{impact}) and the bending moments at the point of impact (M_1) and at the bottom boundary (M_2) as a function of the transverse force (P) can be found in Roark[9].

Note: the displacement at the point of impact is not necessarily the point where the maximum displacement value is reached.

Contents

The elastic solutions are:

with: $$\alpha = \frac{a + h_{bottom}}{h_{tot}}$$

support reactions:

$$R_1 = \tfrac{1}{2} \cdot N \cdot \left(3\alpha^2 - \alpha^3\right)$$

$$R_2 = N - R_1$$

bending moments:

$$M_2 = \tfrac{1}{2} \cdot N \cdot h_{tot} \cdot \left(\alpha^3 + 2\alpha - 3\alpha^2\right)$$

$$M_{imp} = \tfrac{1}{2} \cdot N \cdot h_{tot} \cdot (1 - \alpha) \cdot \left(3\alpha^2 - \alpha^3\right)$$

lateral displacements:

$$w_{imp} = \frac{N \cdot h_{tot}^3}{96\, E\, I}\left(5 \cdot (1 - \alpha)^3 - 3 \cdot (1 - \alpha)\right)$$

For later use the displacement distribution is also required which can be expressed in terms of x where:

$$x = (\text{distance from the top}) / h_{tot}$$

For $x < 1 - \alpha$:

$$w(x) = \frac{N \cdot h_{tot}^3}{96\, E\, I}\left(5 \cdot x^3 - 3 \cdot x\right)$$

For $x > 1 - \alpha$:

$$w(x) = \frac{N \cdot h_{tot}^3}{96\, E\, I}\left(5 \cdot x^3 - 16\,(x - 0.5)^3 - 3 \cdot (1 - \alpha)\right)$$

Contents

The allowable deflection is a function of the moment of inertia (I) which, for a tubular, can be approximated by:

$$I_0 = I_{conductor} = \frac{\pi}{8} \cdot D^3 \cdot t$$

and of the maximum elastic moment (M_{max}) where:

$$M_{max} = \sigma_y \cdot Z \approx \frac{\pi}{4} \cdot D^2\, t \cdot \sigma_y$$

where D and t are the diameter and wall thickness of the conductor.

The elastic energy ($E_{elastic}$) can be found from the above equations using:

$$E_{elastic} = \tfrac{1}{2} \cdot P \cdot w_{impact}$$

B.3 EFFECT OF TOP LOAD

The top load can be both tension or compression for the following reasons:

- weight of the BOP	-50t	(-0.5 MN)
- maximum constant tension	500t	(5.0 MN)

In addition the following two top loads could be considered:

- weight of the casing string before cementing		
- maximum pull during drilling:	500t	(5.0 MN)

These two elements are addressed in the main report. In addition the weights of the conductor, the casing string and the mud have to be considered. These elements will be translated in an equivalent top load and will then be added to the existing top load but only for its contribution in the column buckling behaviour.

Contents

Any weights on the top of conductor will have a de-stabilising effect whereas any tension has a stabilising effect. These effects are dependent on the ratio of these loads with respect to the first buckling load.

Here an interesting problem arises because different text books gave different numbers:.

Roark: $$N_{crit} = \frac{\pi^2 E I}{(0.7 h_{tot})^2} = 20.1 \cdot \frac{E I}{h_{tot}^2}$$

Hütte: $$N_{crit} = \frac{2 \pi^2 E I}{h_{tot}^2} = 19.7 \cdot \frac{E I}{h_{tot}^2}$$

The exact solution can be found by solving the equation:

$\lambda \cos\lambda - \sin\lambda = 0$ with the solution: $\lambda = 4.493$

and: $$N_{crit} = \frac{\lambda^2 E I}{h_{tot}^2} = 20.2 \cdot \frac{E I}{h_{tot}^2}$$

As a first approximation the effect of tension (positive) or compression (negative) on the deflection (w_p) at the point of impact is:

$$w_p = \frac{w_0}{1 + \frac{N}{N_{crit}}} \quad \text{and } M_p = \frac{M_0}{1 + \frac{N}{N_{crit}}}$$

where w_0 and M_0 are the deflection and bending moment for N = 0.

Due to the top load the maximum elastic moment is somewhat reduced. Using the approximate equation for the cross-sectional area:

$$A = \pi D t$$

the reduced elastic bending moment is:

$$M = M_0 - \frac{|N|}{\pi D t}$$

Contents

In summary, in the presence of a compressive or tensile force in the conductor, the allowable moments are reduced because of the presence of the axial stress.

Hence the procedure becomes:

- calculate the maximum deflection for the elastic solution without tension or compression;
- reduce the deflection taking account of the reduced bending moment as a result of tension or compression;
- secondly reduce/increase N by the factor: $1 + \frac{N}{N_{crit}}$

B.3.1 Exact and approximate solutions

The exact solution for the buckling problem in terms of the distance (y) is of the following shape:

$$w(y) = 1 - y - \cos(\lambda y) + \frac{\sin(\lambda y)}{\lambda}$$

where :

$y = 1 - x$; is a measure for the distance from the bottom fixity.

It leads to the (exact) solution for $\lambda = 4.493$.

Useful insight can also be obtained from approximate solutions ($\tilde{w}$) and the following have been tested:

$$\tilde{w}(y) = \left(y^2 - y^3\right) \quad \text{resulting in} \quad \lambda = 5.48$$

$$\tilde{w}(y) = \left(y^2 - y^3\right) + \mu \cdot \left(y^3 - y^4\right) \quad \text{resulting in} \quad \lambda = 4.57$$

The first approximate solution is too inaccurate in the buckling load which is proportional with λ^2, but the second one is acceptable if an alternative for the exact solution is required. For $\lambda = 4.57$ the corresponding value for $\mu = -0.635$, leading to the following approximate shape:

Contents

$$\tilde{w}(y) = \left(y^2 - 1.635\,y^3 + 0.635\,y^4\right)$$

B.3.2 Distributed gravity loads

This problem of the mode shapes is important in order to calculate the effects of distributed gravity loads. Therefore it is necessary to go back to some fundamental aspects of buckling which can be described as follows:

1. Assume a realistic mode shape ($\tilde{w}$) with a single linear parameter;
2. Calculate the bending strain energy associated with this mode shape;
3. Calculate the potential energy of the compressive load;
4. For the actual buckling load, the two energies are identical.

Note that the bending strain energy is quadratic in the linear parameter; and some examples of mode shapes are given above. The energy due to compressive load is also quadratic in this linear parameter and is calculated through the equation:

$$E_{comp} = N \int_0^{h_{tot}} \tfrac{1}{2}\left(\frac{dw}{dx}\right)^2 dx = a^2 N \int_0^{h_{tot}} \tfrac{1}{2}\left(\frac{d\tilde{w}}{dx}\right)^2 dx$$

This integral reflects the distance over which the compressive load moves and generates energy.

Similarly the contribution of uniformly distributed gravity loads over the entire length of the conductor can be established. In this case it becomes a double integral because N has to be replaced by q(x) or:

$$E_{comp} = \tfrac{1}{2} a^2 \int_0^{h_{tot}} q(z) \left(\int_0^z \left(\frac{d\tilde{w}}{dy}\right)^2 dy \right) dz$$

By comparing this double integral with the single integral for the compressive end load the (de)stabilising effect of the distributed gravity load can be established.

For a conductor in water the gravity load above and below the waterline will be different; this can be reflected by the choice of q(z).

And if q(z) is constant then for the mode shape given above its contribution in the de-stabilising effect is equivalent to a force (N_{eq}) as follows:

$$N_{eq} = 0.351 \cdot q \cdot h_{tot}$$

This factor 0.351, or its comparing number for varying values of q(z), is one of the output parameters in the spreadsheet.

B.3.3 Change in allowable stress

In the elastic regime the top load reduces the allowable maximum bending stress in the conductor. Hence some allowance should be made for this effect. With:

$$\sigma_{ax\text{-}cond.} = \frac{N_{top}}{A_{cond.}}$$

and the allowable bending stress is:

$$\sigma_{b\text{-}all} = \sigma_y - \sigma_{ax-cond.}$$

B.4 STIFFNESS EFFECTS OF THE CASING STRING

In the elastic range the effects by the casing string can be established as follows. Let's first assume a single outer casing. The two terms which have to be considered are the effects on the moment of inertia (I) and the effect on the section modulus.

These can be determined as follows:

$$A_1 = A_{casing} = \pi \, D_{casing} \, t_{casing}$$

Contents

$$I_1 = I_{casing} = \frac{\pi}{8} \cdot D^3_{casing} \cdot t_{casing}$$

It is also noted that the axial stress in the casing and conductor can well be different from the stress which has to be incorporated in establishing the buckling load. Hence it is recommended not to determine A_{tot}.

On the other hand, I_{tot} and Z_{tot} have to be determined as follows:

$$I_{tot} = I_{cond} + \Sigma I_{casing}$$

$$Z_{tot} = \frac{2 \cdot I_{tot}}{D_{cond}}$$

B.5 DENTING

In order to get some understanding on the effects of denting the two recognised equations by Amdahl and Ellinas & Walker have been implemented. These equations are:

Amdahl: $$\delta = 0.00222 \cdot t \cdot \left[\frac{P}{(\sigma_y \cdot t^2 / 4)}\right]^2$$

Ellinas & Walker: $$\delta = D \cdot \left[\frac{P}{(150 \cdot \sigma_y \cdot t^2 / 4)}\right]^2$$

In the output table of results the maximum of these two values are given. If $\delta/t << 1$ the effects of denting can be ignored.

Only if the dent depth is greater than 50% of the wall thickness is it recommended to apply a correction for the elastic and plastic moment capacity. However, this correction may well be small in comparison with other approximations in the derivation of the governing equations.

B.6 FREE TOP END

Contents

The free top end may occur for drilling in shallow water, say less than 20m water depth. The equations for the free top end will be given where they affect the results and they are:

Euler buckling load: $$N_{crit} = \frac{\pi^2 E I}{4 \cdot h_{tot}^2}$$

the corresponding shape: $$w(y) = 1 - \cos(\pi \cdot y/2)$$

Finally, the elastic displacement in the absence of tension/compression, at the point of impact is given by:

$$w(\alpha) = \frac{P \cdot (\alpha \cdot h_{tot})^3}{3 E I}$$

B.7 FIXED TOP SUPPORT

The fixed top end may occur during well testing. The equations for the free top end will be given where they affect the results and they are:

Euler buckling load: $$N_{crit} = \frac{4 \cdot \pi^2 E I}{h_{tot}^2}$$

the corresponding shape: $$w(y) = 1 - \cos(2 \pi y)$$

Finally, the elastic displacement in the absence of tension/compression, at the point of impact is given by:

$$w(\alpha) = -\frac{P \cdot h_{tot}^3}{6 E I} \cdot \alpha^2 \cdot (1-\alpha)^2 \left\{ \left(3 (1-\alpha)^2 + \alpha^2 - 3 (1-\alpha) \right) \right\}$$

Contents

Appendix C

Details of the Plastic Solution

CONTENTS

C.1 Input Parameters Excluding Gravity Loads

C.2 Plastic Solution

  C.2.1 Moment Distribution
  C.2.2 Maximum Rotation

C.3 Effect of Top Load

  C.3.1 Moment due to Axial Force
  C.3.2 Distributed Gravity Loads
  C.3.3 Effect of Top Tension on M_p

C.4 Denting

C.5 Free Top End

C.6 Fixed Top Support

Contents

APPENDIX C - DETAILS OF THE PLASTIC SOLUTION

The second approximation to the conductor impact problem can be found through the application of the plastic beam bending equations, using the failure mode description.

C.1 INPUT PARAMETERS EXCLUDING GRAVITY LOADS

The input description is identical for the elastic and the plastic solutions. The only difference is in the beam properties for the conductor-casing string combination.

In the elastic situation the elastic section modulus is found by:

$$Z_{tot} = \frac{I_{cond.} + \sum I_{casings}}{D_{cond.}/2}$$

where: $I = \frac{\pi}{8} \cdot D^3 \cdot t$

Similarly for the plastic regime the plastic section modulus is given by:

$$S_{tot} = S_{cond.} + \sum\left(\frac{S_{casing} \cdot \sigma_{casing}}{\sigma_{cond.}}\right)$$

where: $S = D^2 \cdot t$

C.2 PLASTIC SOLUTION

The plastic solution to the problem consists of two parts:

- the moment distribution resulting in the maximum impact force
- the maximum rotation resulting in the maximum deflection

These will be addressed in subsequent section.

Contents

C.2.1 Moment distribution

The moment distribution in the plastic regime for the problem with a pin top connection is as follows:

- at the top end: $M = 0$
- at the point of impact: $M = M_{pl}$
- at the bottom connection: $M = -M_{pl}$

For a total length, h_{tot}, and the relative point of impact, α, the lateral force at the point of impact is:

$$P = \frac{M_{pl}}{h_{tot}} \cdot \left(\frac{1}{1-\alpha} + \frac{2}{\alpha} \right)$$

C.2.2 Maximum rotation

A number of norms for the maximum rotation can be identified and the following have been incorporated:

a. Marshall minimum: $\varphi_1 = 122 \cdot \left(\frac{t}{D} \right)^{2.5}$

b. Marshall maximum: $\varphi_2 = 12800 \cdot \left(\frac{t}{D} \right)^{3.0}$

c. Marshall (log) mean: $\varphi_3 = 1250 \cdot \left(\frac{t}{D} \right)^{2.75}$

d. Strain hardening rotation: $\varphi_4 = \varepsilon_{all} \cdot \frac{\sigma_u - \sigma_y}{\sigma_u} \cdot \left(\frac{h_{top}}{D_{cond.}} \right)$

$$0.1 \cdot 0.2 \cdot \left(\frac{h_{top}}{D_{cond.}} \right)$$

Contents

e. maximum slope: φ_5 = a value (say 15°)

All equation have been incorporated in the spreadsheet and the following conclusions were drawn:

- the Marshall max. rotation comes close to the strain hardening rotation
- the Marshall mean rotation comes close to a maximum slope of 15°

Therefore, in the program, the minimum value of the Marshall mean value and the maximum slope is used.

C.3 EFFECT OF TOP LOAD

The top load can be both tension or compression for the following reasons:

- weight of the BOP	-50t	(-0.5 MN)
- maximum constant tension	500t	(5.0 MN)

In addition the following two top loads could be considered:

- weight of the casing string before cementing		
- maximum pull during drilling:	500t	(5.0 MN)

These two elements will be addressed in the main report. In addition the weights of the conductor, the casing string and the mud have to be considered in a manner which is similar to the method described in Appendix B. These elements will be translated in an equivalent top load and will then be added to the existing top load but only for its contribution in the column buckling behaviour.

The contribution of the top load in case of plastic behaviour is completely different from those in the elastic regime both as for as buckling is concerned and allowable bending moment is concerned.

C.3.1 Moment due to top axial force

The situation has been sketched in Figure C.1. An assumption is that large deflections are assumed in a linear fashion. Hence elastic deformations can be disregarded. Plastic hinges occur, for the pinned top, at the point of impact and at the bottom boundary.

Contents

The two equilibrium equations, at points A and B are:

- at A: $-D\cdot h_{tot} + P\cdot a = M_p$
- at B: $-D\cdot b + N\cdot w = -M_p$

Using: $\alpha = a/h_{tot}$

and after elimination of D the equation for P is:

$$P = \frac{M_p}{h_{tot}}\cdot\frac{2-\alpha}{\alpha\cdot(1-\alpha)} + N\cdot\frac{w}{h_{tot}}\cdot\frac{1}{\alpha\cdot(1-\alpha)}$$

The first part is the force in the absence of tension and the second term the tension correction.

It is apparent that the contribution is dependent on the deflection, i.e. for large deflections the correction is large.

Alternatively, there is a critical compressive force which leads to a value P = 0; or:

$$N_{crit} = -\frac{M_p}{w}\cdot(2-\alpha)$$

C.3.2 Distributed gravity loads

The distributed gravity load has an effect on the lateral force (P) similar to that in the elastic range. There are some differences because the deformed shape is different. These differences are small in comparison with other assumptions in the analysis; therefore the same contribution is used in the plastic as in the elastic range which is modestly conservative.

C.3.3 Effect of top tension on M_p

In the elastic range the axial stress has a significant effect on the allowable bending stress. However, for the plastic range it has been demonstrated through Figure C.2 that a modest axial stress ($\sigma_{ax} \leq 20\%$ of σ_y) can be disregarded.

Contents

C.4 DENTING

The denting equations are given in Section B.5.

C.5 FREE TOP END

The equations for the free top end will be given where they affect the results. The main item is that there is only a single plastic hinge at the bottom end. Since there is only a single plastic hinge, it is for this hinge that the maximum rotation as described under C.2.2 above applies.

The equation for the lateral force (P) in the absence of an axial force becomes:

$$P = \frac{M_p}{\alpha \cdot h_{tot}}$$

In the presence of the axial force N, see Figure C1, the equilibrium equation at point A is

- at A: $$-N \cdot \frac{w}{a} + P \cdot a = M_p$$

Using: $\alpha = a/h_{tot}$

the equation for P is:

$$P = \frac{M_p}{\alpha \cdot h_{tot}} + N \cdot \frac{w}{h_{tot}} \cdot \frac{1}{\alpha^2}$$

The first part is the force in the absence of tension and the second term the tension correction.

It is apparent that the contribution is dependent on the deflection, i.e. for large deflections the correction is large.

Alternatively, there is a critical compressive force which leads to a value P = 0; or:

$$N_{crit} = -\frac{M_p}{w} \cdot \alpha$$

C.6 FIXED TOP SUPPORT

The equations for the fixed top end will be given where they affect the results. The main difference is that a third plastic hinge occurs at the top end.

The equation for the lateral force (P) in the absence of an axial force becomes:

$$P = \frac{2 \cdot M_p}{\alpha \cdot (1-\alpha) \cdot h_{tot}}$$

In the presence of the axial force N, see Figure C1, the two equilibrium equations, at points A and B are:

- at A: $-D \cdot h_{tot} + P \cdot a + M_p = M_p$
- at B: $-D \cdot b + N \cdot w + M_p = -M_p$

Using: $\alpha = a/h_{tot}$

and after elimination of D the equation for P is:

$$P = \frac{2 \cdot M_p + N \cdot w}{\alpha \cdot (1-\alpha) \cdot h_{tot}}$$

The first part is the force in the absence of tension and the second term the tension correction.

It is apparent that the contribution is dependent on the deflection, i.e. for large deflections the correction is large.

Alternatively, there is a critical compressive force which leads to a value P = 0; or:

$$N_{crit} = -\frac{2 \cdot M_p}{w}$$

Contents

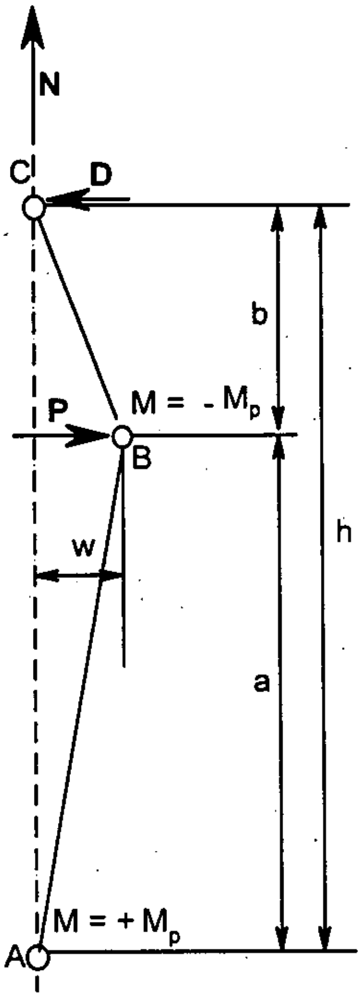


Figure C.1 Equilibrium in deformed shape for a hinge at the top

Contents

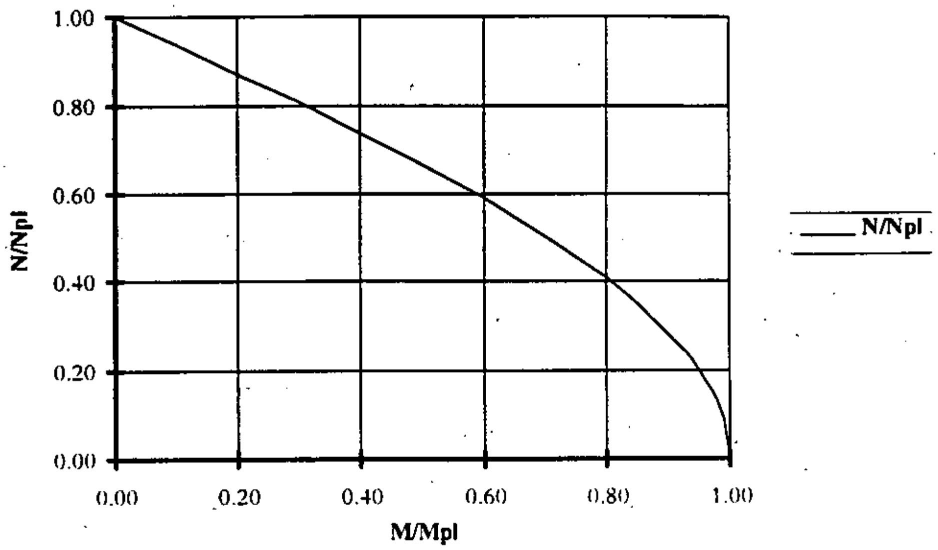


Figure C.2 Plastic moment-force diagram

Contents

Contents