Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.6, No.3, 2015

Casing Design for High Pressure/High Temperature Wells

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Abstract

A satisfactorily and economically viable Surface and Intermediate Casing are designed for a high pressure, high temperature (HPHT) well (Nini-55) in the Niger Delta Basin. Based on the estimated parameters (Pore Pressure, Fracture Gradient, and Pressure Gradient) the Burst, Collapse and Tension loads were calculated employing their various design and safety factors. Based on the design calculations, the relevant physical properties (weight, grade, connector, and diameter) were selected from tables or Casing Catalogues. These properties were matched onto each design and the best combination strings were used. The numerical values of these design loads were plotted on a graph and interpreted. Also, treated in this work are the possible remedies for high pressure, high temperature wells.

Keywords: surface casing, intermediate casing, burst pressure, collapse pressure, axial tension

INTRODUCTION

Design for casing string calls for knowledge of the operating conditions imposed on the casing as well as the concepts related to pipe properties. Drilling of an oil well is a very risky venture. To drill a well safely and economically requires specialist talent. The venture is very cost intensive and also depends on the analysis of seismic, geological or reports collated which may indicate the presence of hydrocarbon deposits. Presence of hydrocarbon deposits can only be confirmed by drilling of a well. When the Driller is lucky to strike oil, the other question is whether it is in commercial quantity to justify the huge investments involved.

Various subsurface problems are faced during drilling operations due to some abnormally pressured formations. Some of these problems can be eliminated; others contained or controlled in the process, by use of appropriate design considerations. The problems could vary form lost circulation, over balanced mud system that can fracture the formation, to kick or presence of abnormal pressure**.**

Kick is an initial stage of blow out. It occurs when the formation pressure is in excess of the hydrostatic pressure of the drilling fluid. “When a bit penetrates a permeable formation that has fluid pressure in excess of hydrostatic pressure exerted by the drilling fluid, formation fluid will begin replacing the drilling fluid from the well. The flow of formation fluid into the well in the presence of drilling fluid is called a ***kick.*** Application of appropriate casing string and treatment of the drilling fluid could help in subduing the problem of a kick, which if not checked could lead to a more serious situation of blow out.

Casing situation requires that the formation pressure at various sections of the well should be determined. This is important, if appropriate calculations of burst, collapse and tension forces could be made.

It is often impossible to predict the various loading conditions that a casing string will be subjected to during the life of a well. Thus, casing design is based on an assumed loading condition. The assumed design load therefore, must be severe enough that there is a very low possibility of a more severe situation actually occurring and causing casing failure. Pre-spud calculations and actual conditions of the formations are the determinant for exact locations of the casing depth.

Depending on the geological conditions several casing strings could be used to reach the target depth. The various types of casing string are: drive/Conductor casing string, surface casing string, intermediate/protective casing string, production casing/oil string, liners.

They main reasons for casing off the open hole are: to prevent unstable formations from caving in, to prevent weak formations from mud weights that may cause these zones to break done, to isolate abnormal pressure zones, To seal off any lost circulation zones, to complete and produce the well efficiently, to provide structural support for BOPs and well heads,to prevent fresh water sand’s form possible contamination by drilling mud or oil, gas and salt water from lower zones[1].

METHODOLOGY

The information below gives the well location, depth to be drilled, operator and ownership. The well location was selected on the basis of obtaining data for the entire aerial and vertical extent. The following key operational procedure was followed.

- Well bottom hole locations were picked from Seismic data correlation.

Well name	-	Nini – 55
Well type	-	Exploratory well
Country	-	Nigeria
Block	-	20/12

Surface Coordinates-
* Target size - 20 ft radius
* Target depth (TVD) - 15,092 ft
* Operator - --
* Owner - --

Design Calculation

Calculation of casing design is based on assumed loading condition as correct details of the borehole conditions cannot be predicted. In this light, some assumptions were made in calculating the important parameters (pore pressure, fracture gradient, mind gradient etc.), required for the design. These parameters were then used to calculate the loading conditions imposed on the casing string. The calculations for burst and collapse forces were made by first considering the casing string as empty and with the casing string assumed filled with drilling fluid. The difference between the two results gives the resultant force, which is multiplied by a safety factor to give the design load line. Design load line values guide the selection of the suitable casing pipes[2].

Assumptions

1. The sands of the oligocene zone in the Benin formation has the potential of hydrocarbon deposit.
2. The upper middle Eocene sands are commonly oil bearing in block 20/12 area of the Agbada formation.
3. Top of cement in the 9 $^{5}/_{8}$ “and 13 $3/_{8}$” casing strings will be to 1,746 feet below the previous casing strings.
   i. To prevent risk of cementing up the well head.
   ii. Provide an opportunity to side track the well should need arise
   iii. Allow the bleed off of pressure build up due to thermal expansion in the annuli.
   iv. Could ease recovering of 9 $^{5}/_{8}$ “casing in case the well is dry.

Surface Casing Design

Burst Design Calculation: The maximum internal pressure at the bottom of the casing is determined from the fracture strength of the formation at the casing shoe. In addition to a safety margin, (usually 1ppg equivalent mud weight). This is the ***“injection pressure”.*** The worst case is where a column of gas fills the casing, and so the internal pressure at surface can be calculated from the gas density ***(i.e. surface pressure = injection pressure – gas hydrostatic).*** The back up fluid in the annulus is usually taken to be formation water since this has the lowest density and therefore, gives the highest resultant burst loading[3].

Design Assumption for 13 $^{S}/_{8}$” Casing

- Casing setting depth = 3,500 ft.; Formation fluid density = 9 ppg.; Formation gradient at 3,500 ft = 0.78 psi/ft.
- Mud weight when casing is run = 9.5 ppg.; Cement density (Back to surface) = 12 ppg.
- Gas gradient expected = 0.115 psi/ft.
- *Design factors*

* Burst = 1.1; * Collapse = 1.1; * Tension = 1.6 plus 100,000 lbs pull.

Internal pressure: The achievable maximum pressure at the bottom of the casing string is dependent on the fracture gradient of the formation. To make the formation the desire weak link in the system, a safety factor (SF) is added to the formation fracture gradient. The maximum internal burst loading pressure at the surface casing shoe is the injection pressure, P_{inj}, which is calculated by:

$P_{inj} = 0.052\ (FG + SF).\ Ds$ ------------------------------ (1)

The maximum internal burst loading pressure at surface is a function of pressure, and is given by:

$P_s = P_{inj} - G_g\ D_s$ -- (2)

External pressure: The external pressure on the surface casing due to the annular drilling fluid helps to resist the burst pressure; however, drilling fluid deteriorates with time, and its weight drops to that of saturated salt water. The external back up pressure at any surface hole section depth is assumed a normal hydrostatic pressure of a full column of native fluid, which is given as:

$P_e = G_f\ D$--(3)

Therefore, the external backup pressure at surface is zero, and the external backup pressure at surface casing setting depth is given as:

$P_{e-s-shoe} = G_f D_s$ ---(4)

Design Burst Pressure: The net effective pressure tending to burst the pipe is the resultant given by:

$(P_{br}) = (P_i - P_e)$ -- (5)

Theoretically, P_{br} could be used to select casing for the string. However, a design safety factor is normally applied to account for unforeseen occurrences.

$P_b = P_{br}\ DF_b$ -- (6)

TABLE 1: Burst Loadings for Surface Casing String.

Depth (Ft)	Internal Loading (psi)	Back-up Loading (psi)	Resultant Load (psi)	Design Loading (x 1.1) (psi)
0	2,510	0	2,510	2,761
3,500	2,912	1,638	1,272	1,399

The design loading can now be plotted on a pressure – depth graph (Fig .3.7).

Collapse Design Calculation: The maximum external pressure on the casing is due to the hydrostatic head of the mud or cement in the annulus when the casing was set. Generally, no fluid is considered to be acting on the inside of the casing as a backup (i.e. casing is empty).

External Pressure: The collapse load is the hydrostatic pressure of the heaviest fluid(s) to be left behind the casing. Cement is commonly used to provide the worst load condition. For surface casing, cement is normally returned to surface. The external collapse load is calculated as following:

$P_e = 0.052 \times \rho_c \times H$ -- (7)

TABLE 3.2: Collapse Loadings for Surface Casing String.

Depth (Ft)	External Loading (psi)	Back-up Loading (psi)	Resultant Load (psi)	Design Loading (x 1.1) (psi)
0	0	0	0	0
3,500	2,184	0	2,184	2,402

This design load can also be plotted on a pressure-depth graph (Fig. 3.8)

Choice of Casing: Base on the design loading lines for both burst and collapse, the following strings can be selected.

TABLE3: Selected Casing for Surface Casing String.

Grade	Wt Ib/ft	10 In	Burst Psi	Collapse Psi	Tension STC	1000Ibs BTC	Pipe Body Yield 1000 Ibs
K– 55	54.5	12.615	2730	1130	547	1038	853
K – 55	68.0	12.415	3450	1950	718	1300	1069
N – 80	72.0	12.347	5380	2670	1040	1693	1661

Joint Strength Design for Surface Casing

Beginning from bottom. **Section 3,500 ft to 2,500 ft N – 80, STC, 72.0 Ibs,** Weight of casing for section 3,500 to 2,500

= 72.0 x 1,000 = 72,000 Ibs

Minimum joint strength = 1,040,000 Ibs.; Design factor = 1.6

Design joint strength = $\frac{\text{Joint Strength}}{\text{Safety Factor}}$ ………………………… (8)

=1040000/2.6 = 650,000 Ibs, :. 72,000 Ibs < 650,000 Ibs

Therefore, the pipe grade, N – 80, STC, 72.0 Ibs/ft satisfies the tension requirement.

Section 2,500ft to ft, K – 55, STC, 68 Ibs. Weight of casing for section 2,500 to 0 ft

= 68 x 2,500 = 170,000 Ibs

Minimum joint strength = 718,000 Ibs; Design factor = 1.6; Design joint strength = 718,000/1.6 = 448,750 Ibs

Total casing weight from 3500 to 0 ft = 72,000 + 170,000 = 242,000 Ibs :. 242,000 Ibs < 448,750 Ibs

Thus, the casing K – 55, STC, 68 Ibs/ft can sustain the weight of the entire surface casing string from bottom to surface.

Axial Tension for Surface Casing

*Tension Condition***:** Once the choice of casing has been made for burst and collapse criteria the tensile loadings can be determined from the weight of the casing itself; considering buoyancy[1]. Generally the tensional force is calculated by the formula:

$(F_a)_n = \sum W_i L_i - P_i A_{si} + \sum P_i \triangle A_{si}$ ……………………………………… (9)

For section one, starting from bottom, the axial tensional force Fa can be calculated with the following formulae:

From 3500ft – 2500ft, L = 1000ft, W = 72.0lbs, LTC

$F_{a1} = P_1 A_{s1}$ --(10)

$P_1 = 0.052 \times \rho_m \times D$ --(11)

$A = \pi/4\ (OD^2 - ID^2)$ --(12)

$F_{a2} = W_1 L_1 - P_1 A_{s1}$ -- (13) From 2500ft – 0 ft

$F_{a3} = W_1 L_1 - P_1 A_{s1} + P_2 \triangle A_{s2}$ -------------------------------- (14)

$Fa_4 = W_1L_1+W_2L_2 - P_1A_{s1} + P_2 \triangle A_{s2}$ ----------------- (15)

The Axial Tension at the bottom of section 2 and 3 are shown in figure 3.1 and 3.2.

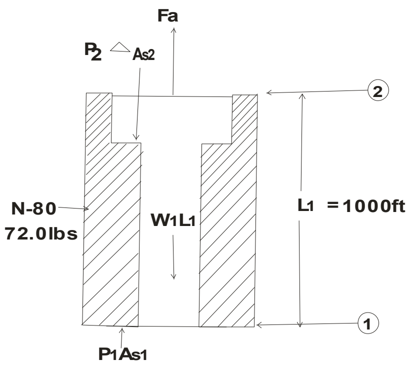


Fig 3.1: Axial Tension at the bottom of section 2 for surface casing

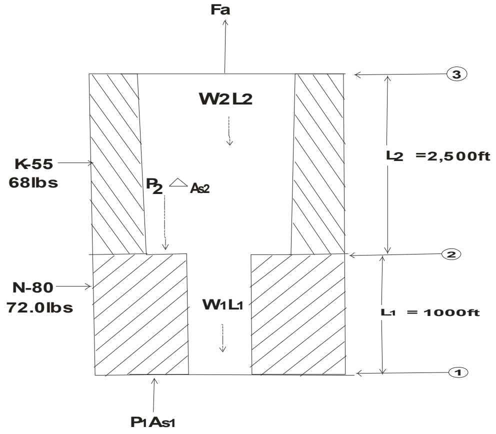


Fig 3.2: Axial Tension at the bottom of section 3 for surface casing

Table 4: Axial Tension for Surface Casing String

Section	Depth (ft)	Weight (lbs)	Tension (lbs)	Over pull (100000lbs)	Design factor (1.6)
N-80	3500	72.0	-35,911	64089	---
	2500		36,089	136089	57,742.4
K-55	2500	68	37722	137722	60355.2
	0		207722	307722	332355.2

The Axial Tension at the bottom of section 2 and 3 for surface casing is plotted in fig. 3.9

Intermediate Casing Design

Mud Assumptions

1. From surface to 295ft; mud weight = 9ppg (formation gradient + 200psi for safety factor, swab and surge)
2. From 295ft, to 2,953ft; mud weight = 9.6ppg (formation gradient + 200psi for safety factor, swab and surge)
3. From 2,953ft, to 9,843ft mud weight = 10.0ppg (formation gradient + 200psi for safety factor, swab and surge)
4. From 9,843ft to 13,353ft, mud weight = 10.4ppg (formation gradient + 200psi for safety factor, swab and surge)

Determination of Formation Pressure

Formation fluid gradient = 0.465psi/ft. Overburden stress gradient = 1.0psi/ft.

Expected formation pressure at 15,092ft is given by the equation:

$P = (0.465\text{psi/ft} \times D_{b)} + 1.0\text{psi/ft.} \times (D_t - D_b)$ -- (16)

Determination of Fracture Pressure: Using the equation below

$$D_t\frac{P_f}{D_t} = \frac{1}{3}\left(1+\frac{2p}{D_t}\right) \quad \text{-- (17)}$$

$G_f = 1/3\ (D_f+ 2p)$ -- (18)

Determination of Fracture Gradient

$G_f = P_f/D_t$ -- (19)

Determination of Pressure Gradient

When D_t and D_b are known, the pressure gradient can be obtained using the formula:

$P_g \times D_t= 1\text{psi/ft} \times D_b - 0.538\ (D_t - D_b)$ --- (20)

Determination of Mud Gradient

Mud gradient = formation gradient + 200psi/total depth

$$G_m = \frac{(P_g+ 200)}{Dt} \quad \text{--- (21)}$$

Assumptions For 9 5/8"Intermediate Casing

Casing Setting Depth = 13,353ft. ; Formation Fluid Gradient = 0.465psi/ft as backup; Mud Weight set in =

0.54psi/ft
Maximum Weight below Casing = 0.62psi/ft.
Cement Density (13,355 – 9,843) = 0.572psi/ft.; Gas Density = 0.115psi/ft.; Fracture Gradient = 0.684psi/ft
Design Factors:
Burst = 1.1 Collapse = 1.1 Tension = 2.0

Burst Design Calculation

The maximum pressure at casing shoe = injection pressure.

Injection pressure = (fracture gradient + safety factor)

$P_{inj} = (G_f + SF) \times 0.052 \times SD$ -- (22)

Lengths of mud and gas column are calculated using the formulae:

$P_{inj} = P_s + X (G_m) + Y (G_g)$ -- (23)

$SD = X + Y$ --- (24)

$X = SD - Y$ --- (25)

Equations 24 and 25 are solved simultaneously

Burst Resultant

Burst Resultant = Burst Load – Burst Back up ---------------------------------- (26)

Burst Design Load

Burst design = Burst resultant x Design factor ---------------------------------- (27)

Table3.5: Burst Loadings for Intermediate Casing Strings.

Depth (ft)	Internal Loading (psi)	Back-up Loading (psi)	Resultant Load (psi)	Design loading (x 1.1) (psi)
0	7,948	0	7,948	8,743
682	8,371	317	8,054	8,859
13,353	9,775	6,209	3,565	3,922

These loadings can now be plotted on a pressure – depth graph. Fig (3.10)

Collapse Design Calculation

Collapse Design Assumptions
Mud weight set in = 10.4ppg; Mud/completion fluid gradient = 11.9ppg ; Gas gradient = 2.21ppg
Fracture gradient = 13.1ppg; Safety factor = 0.3ppg.; Cement density (13, 3531 to 9, 8431) = 11ppg
Anticipated mud weight = 10.4+0.3 = 10.7ppg
Collapse Load
Collapse load is due to 10.7ppg anticipated mud weight and 11ppg cement at (13,353 to 9,843)

Collapse Resultant.

Collapse resultant = Collapse loading –collapse backup

Collapse Design

Collapse design = Collapse resultant x Design factor -- (28)

Table 6 Collapse Loading for Intermediate Casing String

Depth (Ft)	External Loading (psi)	Back-up Loading (psi)	Resultant Load (psi)	Design Loading (x 1.1) (psi)
0	0	0	0	0
682	379	0	379	417
3,338	-	0	1,856	2,042
9,843	5,473	4,025	1,448	1,593
13,353	7,481	6.197	1,284	1,412

These loading can now be plotted on a pressure – depth diagram. Fig (3.11)

Choice of Casing: Based on the design loading lines for both burst and collapse loadings the following strings can be selected

Table 7 Table of selected Casing for Intermediate Casing String

Grade	Wt Ib/ft	ID. In	Burst Psi	Collapse Psi	Tension 1000 Ibs		Pipe body yield 1,000 Ibs
					STC	BTC	
P– 110	43.5	8.755	8,700	4,420	-	1,106	1,318
P– 110	47.0	8.6181	9,400	5300	-	5,300	1493
P– 110	53.5	8.535	10,900	7,500	-	7,950	1,710

Joint strength Design for intermediate casing beginning from Bottom
Section 13, 353ft – 6400, P – 1105 53.5 lbs, LTC

Weight of casing for section 13,353 – 6400ft. Weight = 53.5×6953 = 371,985.5 lbs.

Minimum Joint Strength = $\frac{\text{Joint Strength}}{\text{Safety Factor}}$ -- (29)

Minimum joint strength = 1,423000 lbs; Design factor = 2; Design joint strength = 1,422,000 /2 = 711,000 lbs

Therefore, 371,985.5 lbs$\angle$711,000 lbs. Thus, the pipe grade, P – 110,LTC, 53.5 lbs/ft – satisfies the tension requirement

Section 6400 – 3000ft,p – 110,47.0 lbs, LTC.

Weight of casing for section 6953 – 3000f t = 3,400 × 47.0 = 159,800 lbs. Minimum joint strength = 1,213.000

Design factor = 2.0; Design joint strength = 1,213,000/2 = 606,500 lbs. 159,800 lbs $\angle$ 606,500 lbs

Thus, P – 110 LTC 47.0 lbs satisfies the tension design.

Section 3000ft –0ft, P – 110, 53.5 lbs, LTC

Weight of casing = 53.5 × 3000 = 160,500 lbs. Minimum joint strength = 1,422,000 lbs; Design factor =2

Design joint strength = 711000 lbs. .: 160, 500 $\angle$ 711,000 lbs.

Total weight of casing string = $\sum W_1L_1$ = 371985.5+159,800+160,500 = 692,285.5 lbs $\angle$ 711,000 lbs

Thus the total weight of the Casing Strings is less than the joint strength of the upper most casing

This satisfies the joint strength condition.

Axial Tension for Intermediate Casing

Beginning from bottom, the axial tensional force F_a is calculated using the formula below:

$(F_a)_n = \sum W_iL_i - P_iA_i + \sum P_i \triangle A_{si}$ …………………………………………………………………… (30)

For section 13,353ft – 6,400ft, P – 110, LTC, 53.5 lbs.

ID = 8.535''; OD=9.625''; t = 0.545''

OD=ID + 2t -- (31)

The tensional force, F_a, is calculated as F_a, = $P_1A_{s1}P_1 = 0.052 \times \rho_m \times D$

$A_{si} = \pi/4\ (OD^2 - ID^2)$ -------------------------------------- (32)

The tensional force Fa_2 at section (2) is calculated as

$F_{a2} = W1L1 - P1As1$ -------------------------------------- (33)

For section 6400ft – 3000ft, P – 110, 47.0 lbs LTC

$F_{a3} = W1L1 - P1A1 + P2 \triangle As2$ ----------------------- (34)

For P – 110, 47.0 lbs,

ID = 8.681 (in), t = 0.427 in

OD = 8.681 + 2(0.427) = 9.535 (in)

$\triangle As2 = \pi/4\ (OD^2 - ID^2)$ --------------------------------- (35)

For section 3000ft – 0 ft, P- 110,53.5 lbs,LTC

$Fa_4 = W_1L_1 - P_1As_1 + P_2 \triangle As_2 + W_2L_2$ ----------------------------- (36)

$Fa_5 = W_1L_1 - P_1As_1 + P_2 \triangle As_2 - P_3 \triangle As_3 + W_2L_2$ ---------------- (37)

$Fa_6 = W_1L_1 - P_1As_1 + P_2 \triangle As_2 - P_3 \triangle As_3 + W_2L_2 + W_3L_3 + P_4 \triangle As_4$ ------------------ (38)

The Axial Tension at the bottom of section 2, 3 and 4 are shown figure 3.3, 3.4 and 3.5 and plotted in fig. 3.12

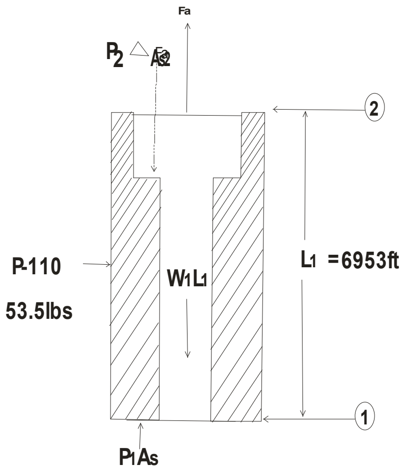


Fig 3.3: Axial Tension at the bottom of section 2 for intermediate casing

Table 8: Axial Tension Load for Intermediate Casing

Section	**Depth (ft)**	**Weight (lbs)**	**Tension (lbs)**	**Over pull (+100000 lbs)**	**Design factor (x2.0)lbs**
P-110	**13353** **6400**	**53.5**	**-118988.2** **252998**	**18988** **532998**	**--** **505996**
P-110	**6400** **3000**	**47.0**	**256672** **416529**	**356672** **516529**	**513334** **833058**
p-110	**3000** **0**	**53.5**	**416529** **432579**	**516529** **532579**	**833058** **865158**

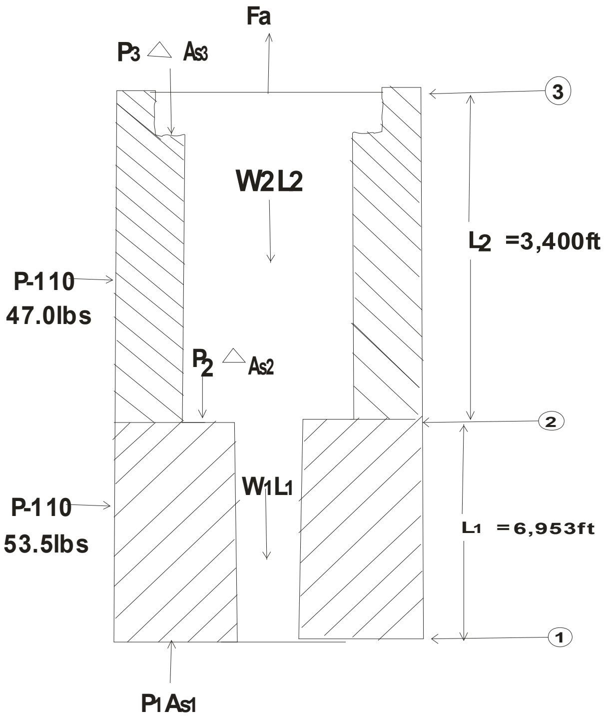


Fig 3.4: Axial Tension at the bottom of section 3 for intermediate casing

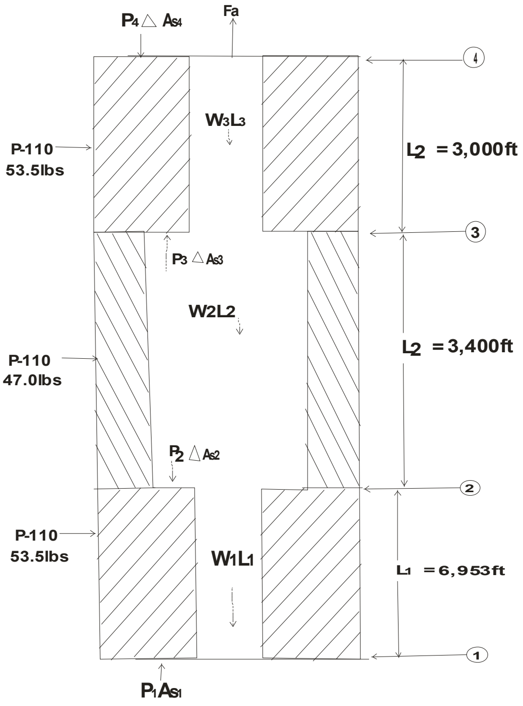


Fig 3.5: Axial Tension at the bottom of section 4 for intermediate casing

DISCUSSION OF CALCULATIONS / RESULTS / GRAPHS

General Overview

With increase in areas where there are high pressures, high temperatures, lost returns and differential sticking problems, there emerged the need for stronger, better-designed casing. The attainable, optimum condition is to design casing to withstand these problem-imposed loads for the minimum cost. This work has properly evaluated the loads imposed on the surface and intermediate casing strings. The loadings were considered separately. The loadings for burst were considered first, since burst will indicate the design for most of the string. Next, the collapse loads were evaluated and the string section up graded if needed. Once the weights, grades and section lengths have been determined to satisfy burst and collapse loadings, the tension load was evaluated. The pipe can then be up graded if necessary, and the pipe coupling types determined. The final step is to check on biaxial reductions in burst strength and collapse resistance caused by compression and tension loads, respectively. But this was limited in this research.

> *By initially choosing the least expensive weights and grades of casing that will satisfy the burst loading, and upgrading only as called for by the prescribed sequence, the resulting design will be the most inexpensive possible that can fulfil the maximum loading requirements.*

Surface Casing Design

The Burst Load Lines: It can be seen from the table 3.1 that the internal or injection pressure increases from the bottom (casing seat) and decreases progressively to the surface.

The Back-up Load Line: This is the load exerted on the outside of the casing, at this time it is the hydrostatic pressure of a column of formation fluid. This external load serves to back up the casing during burst loading. At the surface, the hydrostatic pressure of formation fluid is zero. Therefore, the net burst load is the difference between the pressure inside the casing and the pressure outside. The point of maximum burst loading in this case is therefore at the top (surface) of the casing string where there is a high gas pressure and zero back-up.

Design Load Line: The design load line is obtained by multiplying the actual design (Resultant) by an arbitrary figure (safety factor) of 1.1.This factor is applied to account for unexpected loading conditions, and the selection of suitable casing from the casing catalogue is based on this design line.

Collapse Load Line: For the collapse design, the pipe was considered emptied of fluid, thus the worst collapse situation exists. With no internal hydrostatic pressure of mud, the entire formation pressure is exerted on the casing at the shoe; see figure 5.3, in this case it is represented as 2,184 psi on the collapse design chart. At surface, the collapse pressure is clearly zero since only atmospheric pressure is acting on the casing. Since back up load is zero, the resultant load is the same as the actual load. The collapse design line is drawn as shown in figure5.3.

Based on the design loading lines for both burst and collapse, the following strings on table 2 can be chosen for the design: 0 to 2,500ft k-55 68 lb/ft ; 2,500ft to 3,500ft N-80 72 lb/ft . Also, a short length of K-55, 54 .5 lb/ft could be used between the K-55, 68lb/ft at the top and the N-80, 72 lb/ft at the bottom. However this design is kept as simple as possible (minimum length of section is 1000ft).

Tension Design Calculations: tensile loading is applied to this casing as a result of its own weight and is at a maximum underneath the casing hanger at the surface. Buoyancy reduces the tensile loading on casing.

Collapse and burst on casing are both affected by tensile loading. Tensile loading tends to reduce the collapse resistance of casing. This is a particular problem in deep wells with long strings. However, tensile loading has the reverse effect on burst resistance. Burst resistance is increased. An over pull of 100,000lbs is applied to the tension design in order to allow for the retrieving of the casing in sticky formations or landing of the casing after wait-on-cement (WOC).

Or the actual tension is multiplied by a safety factor of 2 to obtain the design line.

From the graph; figure 4, it can be seen that the pipe body yield strength of the selected casings exceeds the tension design lines. STC couplings will allow sufficient joint strength.

Intermediate Casing Design

The results of the calculations shown in chapter 3 are shown in tables 3.5to3.8 for burst, collapse and tension.

In the design of intermediate casing string, the maximum load will occur when the end points are satisfied simultaneously; the loading will necessarily be pounded by kick conditions. A characteristic of kick loading is the existence of two or more fluids in the borehole the mud being drilled with at the time of the kick, and the influx fluid. Since we are dealing only with maximum loads, the fluids considered will be those with the heaviest mud weight projected for use below the casing string, and gas as the single influx fluid. The position of these fluids in the borehole is important .In this case, the configuration indicate that the heaviest mud weight is at the top, gas is at the bottom, and the end points are satisfied these will simultaneously constitute the maximum load line. The backup fluid for collapse considerations also adheres to the maximum load concept. The maximum collapse loading will occur when attendant with loss of circulation, the mud level inside the casing drops. At the intermediate casing shoe it is improbable that the hydrostatic pressure exerted by a full column of salt water. For the tension design, knowing the weights, grades, and section lengths based on burst and collapse design; the tension load (both positive and negative) can be evaluated.

Burst Load Lines: From tables 3.5 and graph 5.5, it can be seen that pressure and depth correlation indicating burst load line. It shows that pressure increase progressively with depth. From burst back up line, it is assumed that the pressure gradient is equal to the native formation pressure acting as backup. This thus reduces the burst load. On the burst resultant load line, this is the burst load less backup pressure. It is assumed to be the actual burst loading condition to which the casing is subjected. It shows that burst pressure is greater at the surface and so dictates that a high grade of casing pipe should be used for this section.

The burst design line: This is the product of burst resultant and a 1.1 factor of safety. This is the design load for the casing which is used for selection of casing grades , weight and connecters. It is kept aside pending the calculation of the collapse load in order to find out if upgrading of the casing is needed. It also as stated in table 5.5, shows that burst pressure is greater at the surface.

Collapse Load Lines: Here, four different depths are considered instead of three as in the case of burst design. This is a result of the weight of the cementing job between sections 9,843 to 13,353 feet. This is considered since the weight of the cement increases the hydrostatic pressure .Pressure here, also increases with depth. For the collapsed back-up line, at three intervals (0, 682 and 3,338) back-up pressure is considered to be zero. Back–up pressure starts from 9,843 ft, where cementation started. Also, for the collapse resultant since there is no back–up collapse at 0,682 and 3,338 ft the resultant pressure at this interval are equal to the collapse load line. This shows that pressure gradient is independent of depth.

Tension Design Line: Knowing the weights, grades, and section lengths based on burst and collapse design, the tension load (both positive and negative) can be evaluated .Tensile loading is calculated from the bottom of strain due to buoyancy .The effect of buoyancy is thought to be the reduction in the weight of the string when it is run in liquid as compared with the weight when it is run in air. The buoyancy or reduction in string weight, as noted on the surface is actually the result of forces acting on all the exposed horizontally oriented areas of the casing string. The forces are equal to the hydrostatic pressure at each depth times the number of exposed areas, and are defined as negative if acting upwards. The areas referred to are the tube end areas, the shoulders at points of changing casing weights, and to a small degree, the shoulders on collars.

Figure 3.3 to 3.5 shows the forces acting at each exposed area of a casing string, with the resultant loading indicated as negative tension (compression). (The forces acting on the areas of collars shoulders are for practical purposes. negligible in casing design).Once the magnitude and location of the forces are determined, the tension load may be constructed graphically, (figure 5.5) it is note worthy that more than one section of the casing string may be loaded in compression. The design line for tension is obtained by multiplying with a safety factor of 2 and a minimum over pull of 100,000lbs added to the actual tension. This minimum over pull allows for safely pulling on stuck casing or landing of casing after WOC. The graphical representation of design load is shown in figure 5.5, and is labelled as the "tension design line". With a few exceptions, the weakest part of a joint of casing in tension is the coupling; therefore, the tension design line is used primarily to determine the type of coupling to be used. The least expensive coupling strengths that satisfy the design are plotted and the proper couplings determined. At this point the entire string is designed for burst, collapse and tension, and the weights, grades, section lengths, and coupling types are known. Remaining to be checked is the reduction in burst resistance and collapse resistance caused by biaxial effect or loading, but this is limited to this work.

CONCLUSION

When planning a drilling programme, the possibilities of lost circulation should be considered and all practical measures for preventing such losses should be taken. Every effort should be made to maintain optimum conditions of the mud coupled with good drilling practices. The considerations should be adopted:

1. The casing programme should be planed to protect weak potential loss zones before high mud weight become necessary.
2. The mud programme should be planned and maintained with minimum weight to insure a safe merging above expected formation pressure.
3. Viscosity and gel strength should be carried out at such values that they not promote lost circulation.
4. A good selection of lost circulation materials of the proper particle size distribution should be provided to combat the problem if and when it occurs.
5. Determine differential sticking pressure at setting depth before setting the casing.
6. Constant analysis of the drilling fluid properties is required to be able to characterise the formation since the only potential source of information concerning the field is the seismic result. This is necessary as fluid type and density of fluid is the major contributing factor of borehole instability.
7. Mud alone will not solve all the shale problems. Good mud practices along with good drilling practices can do much to alleviate the trouble. Several good drilling practices helpful in nearly any type of shale are as follows:
   (a) Avoid abnormally high annular velocities. This helps to minimize hole enlargement caused by erosion.
   (b) The drilling string should be kept in tension to avoid pipe whipping.
   (c) Avoid pressure surges by running pipe too fast into the hole to prevent it from fracturing the formation.
   (d) Pull slowly through troublesome shale sections when tripping out of hole to avoid swabbing.
8. Select casing pipes for burst, collapse and tension loads, must have higher yield strength as the calculated pressures are only a guide.

RECOMMENDATION

The design has shown that several different weights and grades will be used in a casing string. A check must always be made to make sure that the tensile yield strength of the casing is not exceeded. It also can be seen that loading casing string of different weights and grades can be a logistical nightmare! For this reason, the number of casing weights and grades changes is restricted to ensure that the casing is picked up and run in the hole in the correct order. Thus, for a satisfactory design, a combination string for the Surface Casing should require the following physical properties of casing: Weight 72.0 lbs/ft, Grade N-80, Connector STC and diameter of 13 $^{3}/_{8}$", are ideal for the sections concerned.

Also, for the Intermediate Casing, an economic design however, recommend a combination string of different weights i.e. Grade P-110, 53.5 lbs/ft weight, LTC Connector and P-110 Grade, 47.0 lbs/ft weight, LTC Connector and 9 $^{5}/_{8}$" diameter are ideal for the section concerned.

THE WAY AHEAD

In no time the conventional drilling and casing will be abolished, this is due to the advent of a drilling technology referred as "Casing While Drilling" (CWD). The fundamental value of casing, while drilling, lies in improving drilling efficiency by eliminating "flat spots" in the drilling curve. It also has the advantage of extending open hole sections to reach deeper casing points with smaller diameters, thus, eliminating contingency intermediate strings .One of the key factors leading operators to CWD technology is the removal of " non productive time"(i.e. problem time, and time associated with tool failures and inefficiencies). From the drilling curve, when drilling with casing, non-productive time can be referred to as any time spent not making hole or securing the well for further drilling or production [4].

The procedures for rotary drilling with casing are relatively simple, and involve little extra equipment that is not normally present in a typical rig. For example, Weatherford internationals Drilling Shoe ^{TM} Tool and float collar normally would be made up to a casing joint prior to shipping offshore. When TD is reached and circulating bottoms-up, cementing can begin immediately, since a float collar is present in the string throughout the drilling operation.

To allow casing while drilling, a number of technologies had to be developed to enable safe, efficient and problem free operations. For example, Weather ford’s initial work revolved round a drill bit referred to as the Drill Shoe TM. Tool, other technologies include:[5]

- Improved casing drive system.
- Tubular and connections.
- Centralization
- Time Reduction
- Problem Reduction
- Improved Rig Requirements
- Fluid Requirements.

CASING PROGRAMME FOR NINI – 55 WELL

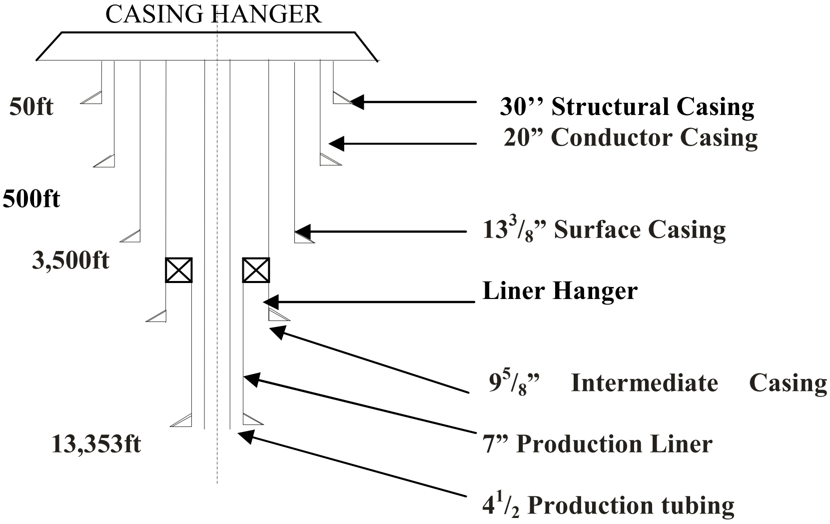


Fig. 3.6 Proposed Casing Design for Nini – 55 Well

(Graphs of Burst, Collapse and Axial Tension)

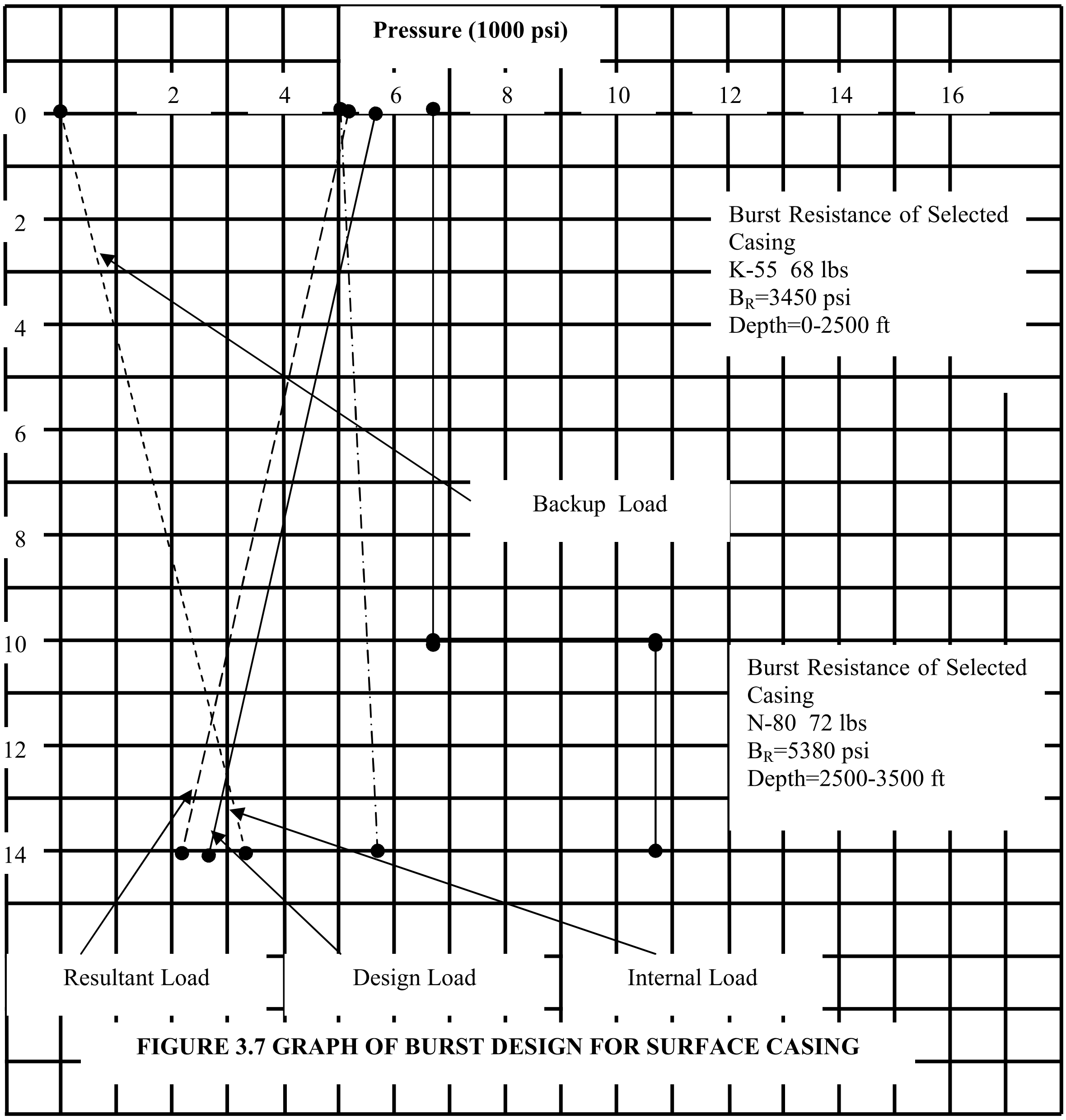


FIGURE 3.7 GRAPH OF BURST DESIGN FOR SURFACE CASING

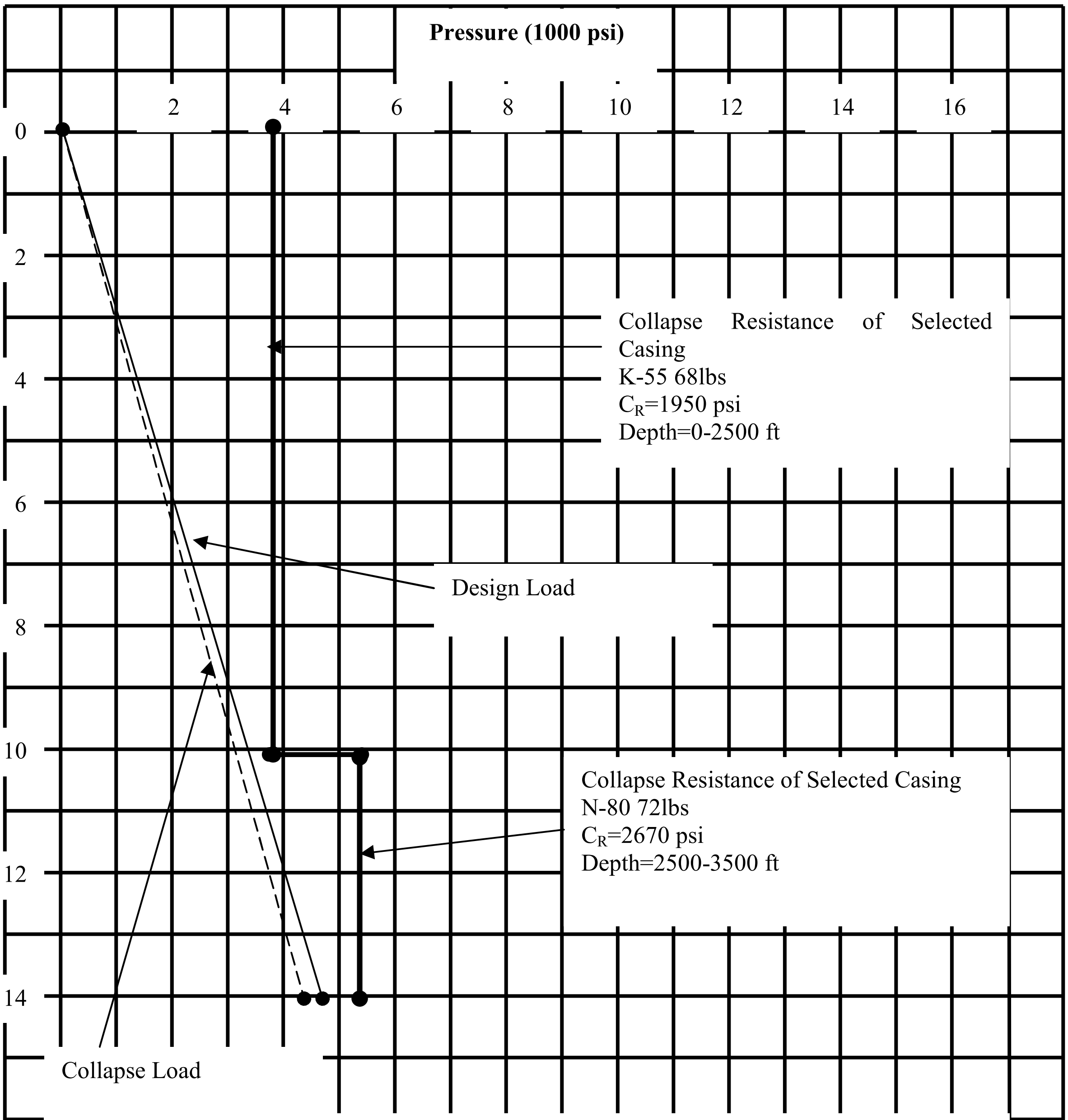


FIGURE 3.8 GRAPH OF COLLAPSE DESIGN FOR SURFACE CASING

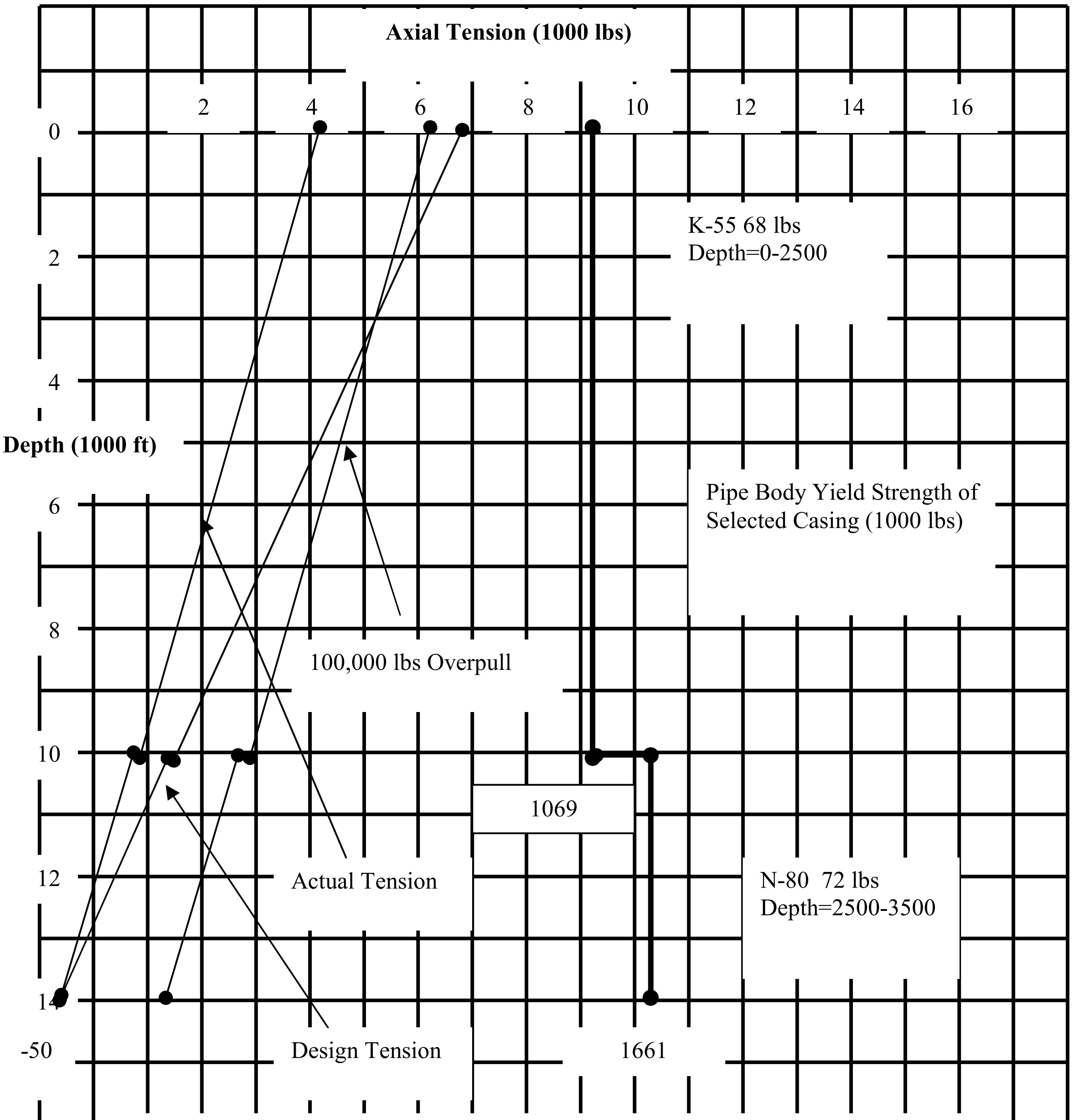


FIGURE 3.9 GRAPH OF AXIAL TENSION FOR SURFACE CASING

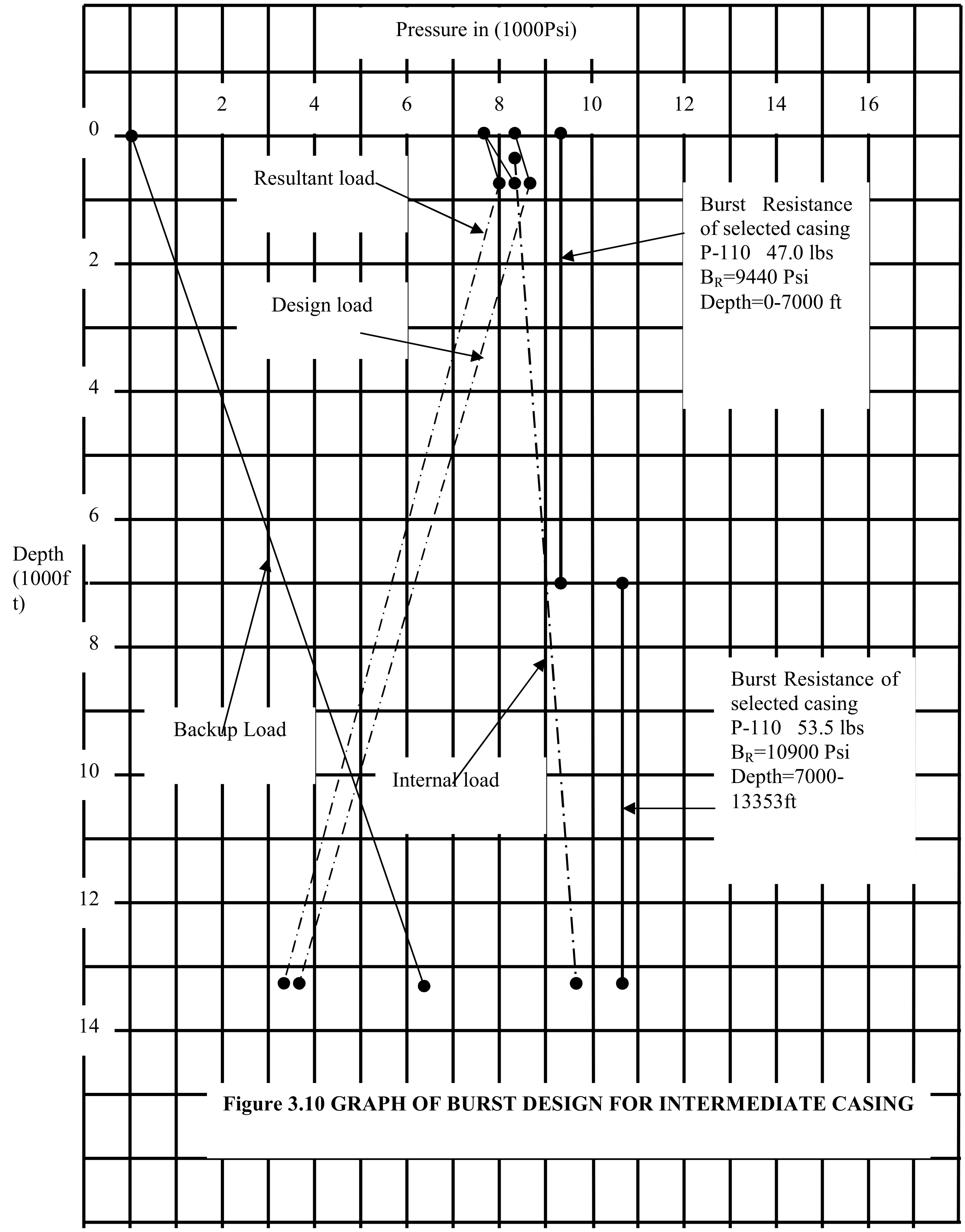
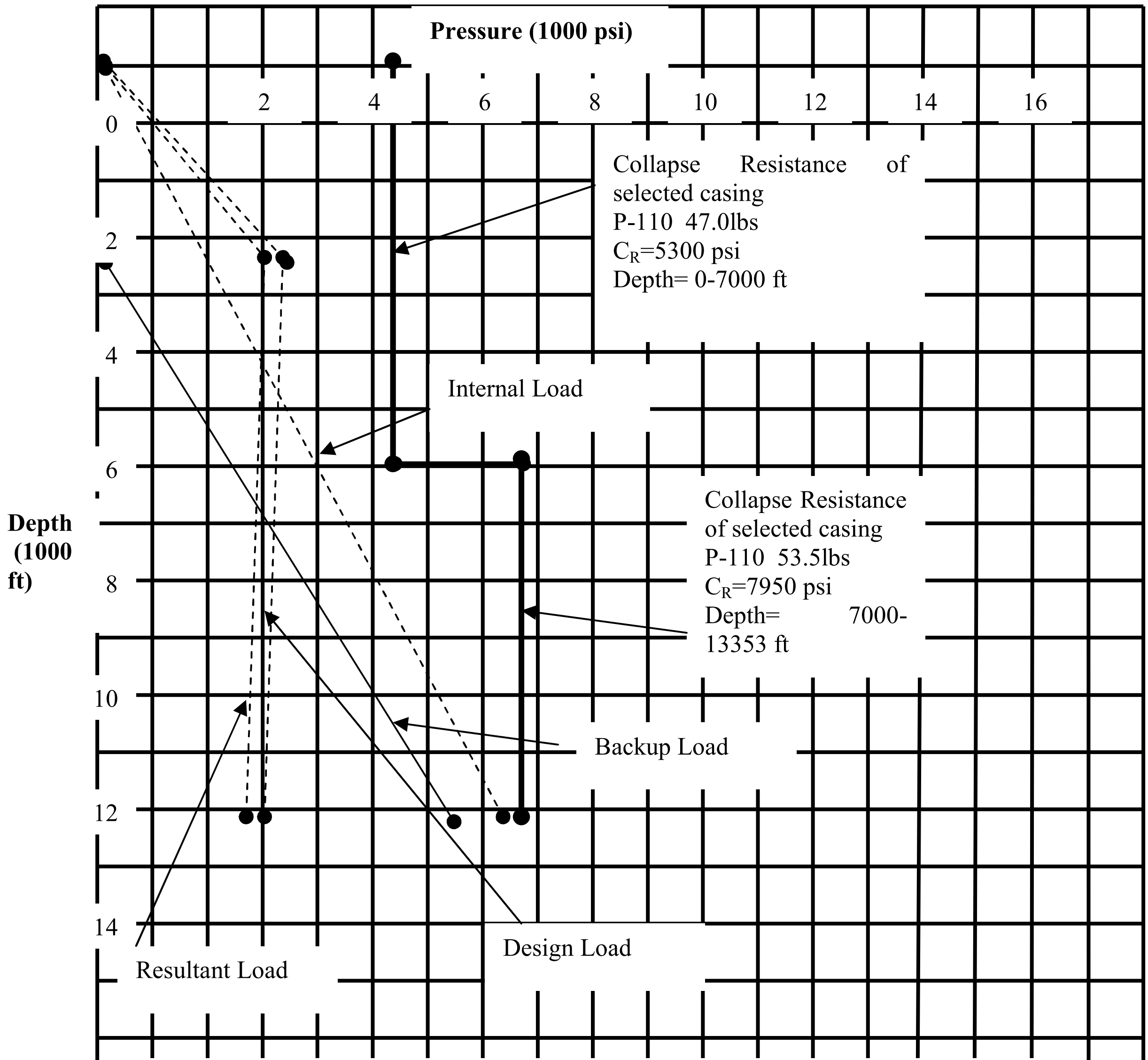


Figure 3.10 GRAPH OF BURST DESIGN FOR INTERMEDIATE CASING



Collapse Resistance of selected casing
P-110 47.0lbs
C_R=5300 psi
Depth= 0-7000 ft

Collapse Resistance of selected casing
P-110 53.5lbs
C_R=7950 psi
Depth= 7000-13353 ft

FIGURE 3.11 GRAPH OF COLLAPSE DESIGN FOR INTERMEDIATE CASING

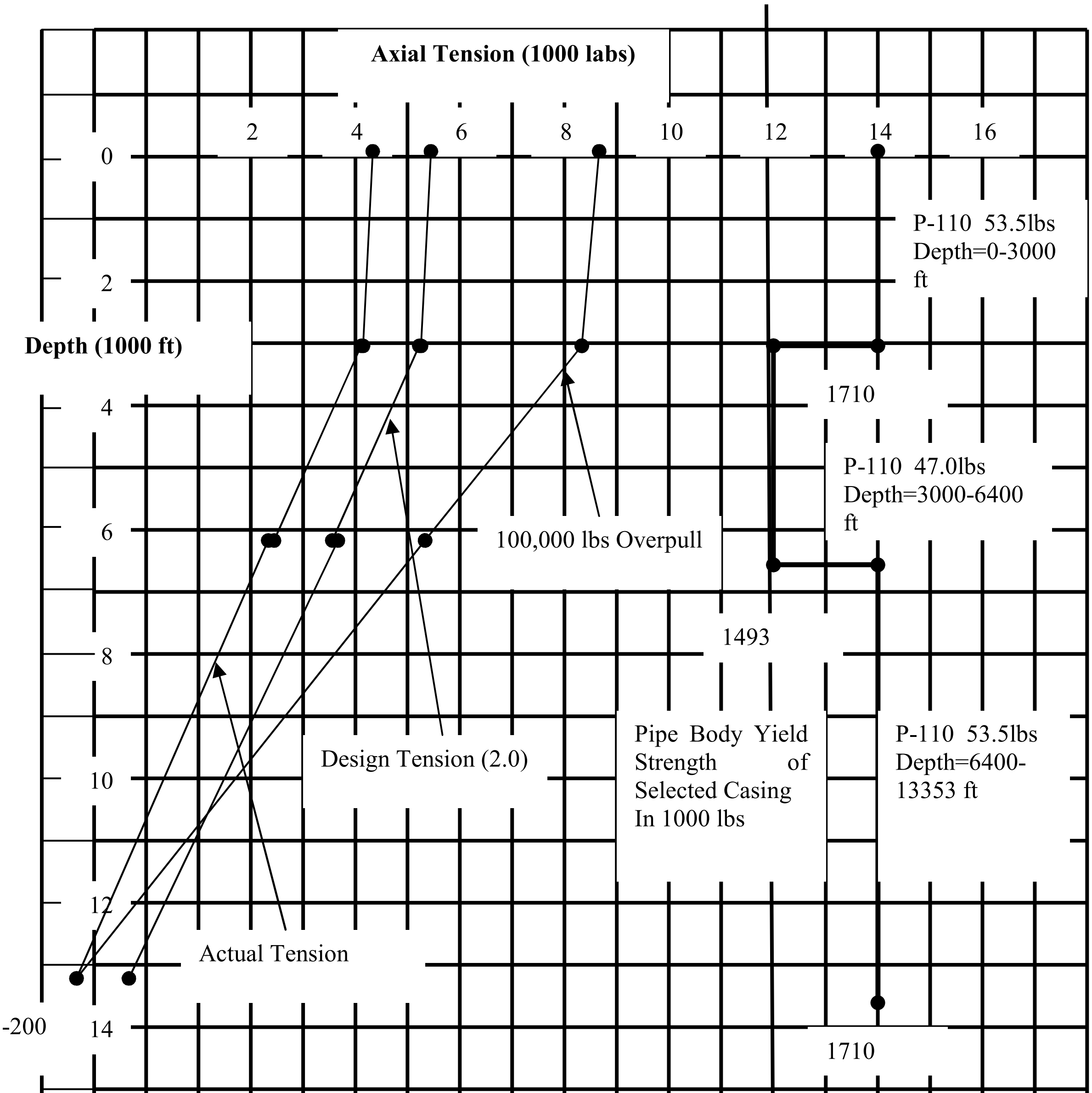


FIGURE 3.12 AXIAL TENSION FOR INERMEDISATE CASING STRING

Nomenclature

Ai = inner pipe area enclosed by ID, inch
A_s = steel cross sectional area, square inch
A_{si} = cross sectional area of ith section of pipe, square inch
D_t = total vertivacal depth, foot
D_s = sub surface depth, foot
F_a = axial tensional force, pound
F_b = design burst safety factor
FG = fracture gradient, psi
G_g = gas gradient, psi
H = hydrostatic pressure, pound per square inch per foot
ID = internal diamedter of pipe, inch
L_i = length of ith section of pipe, foot
P_{br} = in ternal burst pressure, pound per square inch
P_e = external pressure, pound per square inch

$P_{e\text{-}s\text{-}shoe}$ = external backup pressure at casing shoe, pound per square inch
P_f = fracture pressure, pound per square inch
P_i = pressure in ith section of pipe, psi
P_{inj} = injection pressure, pound per square inch
OD = outer diameter of pipe, inch
W_i = weight of ith section of pip

REFERENCES

1.Bourgoyne, A.T., Millheim, K.K., Chenevert, M.E. and Young, F.S.: *Applied Drilling Engineering.* 1991, Richardson, TX. : Society of Petroleum Engineers.
2.Adams, N.J.: *Drilling Engineering (A Complete Well Planning Approach).* 1985, Tulsa, Oklahoma. : Penn Well Books- Penn Well Publishing Company.
3.Schlumberger Anadrill. 2002, Houston, TX. *"Schlumberger Casing Design Manual".* (2002).
4.Prentice, C.M. : "Maximum Load Casing Design". paper SPE 2560, presented at the SPE Technical Conference and Exhibition, Denver, CO. September 28-October 1, 1970.
5.Weatherford Drilling and Well Services. 2003, Houston, TX. *World Oil Casing While Drilling Handbook* . Weatherford.