

A Review of Loading & Unloading on Intermediate Casting for Effective Support in Drilling Machine

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Abstract— Casing design is one of the most important aspects of drilling Engineering. It is a way of analysing stress for the wellbore. This paper aimed at providing a new method for optimal design of intermediate casing that can withstand a variety of external, internal, thermal, and self-weight loading, while at the same time being subjected to wear and corrosion for optimal well delivery. The methodology employed involves the assessment of pore pressure and fracture pressures for optimal casing seats selection, designing for burst, collapse and tension while considering other external loads. From the simulation carried out for the intermediate section of the well, it was only casing J9 for the case study well that satisfied the load conditions in terms of burst and collapse pressures. This study showed that casings should never be designed to their yield strength or tensile strength limits; instead a design factor should be used to estimate the strength of the casing so that the casing would not be loaded beyond its capacity.

Key words: Burst Pressure Design, Casing Setting Depth, Collapse Pressure Design, Intermediate Casing, Tensile Loading Design

I. INTRODUCTION

Casing design is simply a stress analysis procedure of the wellbore [1]. It predominantly has to do with selecting the appropriate casing size, appropriate setting depth, detection of the operational cases that will lead to collapse, burst or axial loading on the casing, calculating the magnitude of the loads and lastly for selecting the correct weight and grade of casings[2]. Ideally the drilling engineers would prefer to drill from surface to the target depth without setting casing at all because of time and cost, but in reality, many casing strings would be required to get to TD. The geology and the anticipated pore pressure in that locality go a long way in influencing the sizes and the setting depths of casings. [2].

The earth does not allow vacuum in nature. It is therefore important to fortify the well of an open hole drilled to lift oil and gas to the surface in order to avoid numerous hole problems such as caving-in, collapse, fallout, erosion etc. The fortification of the well bore is done using steel pipe, known as casing lowered to the drilled hole during drilling operation. Casings are rated and graded according to known standard. It is very important for the engineer to always bear in mind the risk involved in designing a specific hole section with the wrong casing weight and grade. From experience, we can deduce that the maximum number of different casing grades most rigs can comfortably handle is three. [3].

The challenge in getting a proper casing design is a challenge that needs to be handled with great importance because; a poor casing design leads to poor well performance; the cost of casing (usually 20-40% of the total cost of a well) contributes immensely to the overall cost of a well; poor

casing design places the well and personnel at risk as casing failure could be catastrophic; low reservoir productivity and poor well delivery have been linked in several occasions to poor casing design. The main cause of casing failure from collapse pressure has been suspected to be the fluid in the annulus between two casings [4], [5]. Southon in [5] discussed the modes of casing failure in geothermal wells and highlighted the importance of a careful and thorough implementation of the well design. He also stated that pre-tension loads need to be determined to avoid compression yielding when using buttress threaded couplings. Leaver in [6] discussed the helical buckling and Euler buckling. He highlighted how analyses were done. Euler buckling was also addressed by Richard and Schuler [7] where buckling models were produced. Kane [8] evaluated corrosion problems involving in-service failures of geothermal well production casings where high thermally induced tensile stress in the presence of hydrogen sulfide leads to sulfide stress cracking. A two dimensional (2-D) finite element model of the cross section of a double cased geothermal well was created for representing the behavior of the cement/sealant by Philippacopoulos and Berndt in [9]. It was shown that the compressive strength alone was not adequate in the design of geothermal well

A. Casing Design Process

The casing design process is summarized in fig. 1 below

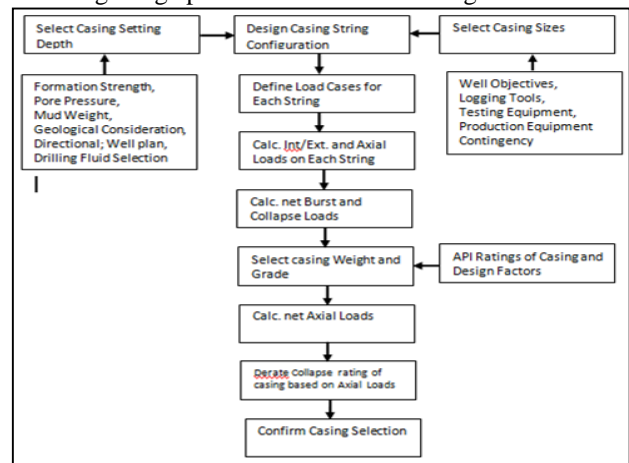


Fig. 1: A Typical Casing Design Process

B. Design Factors (DF) Application

The API bulletin clearly specifies tubing and casing minimum performance properties and they are used to ascertain if selected casing falls within the design factor. Normally the design factor is used in burst, collapse and tension design.

1.3. Burst Model

In general, Burst Pressure σ_p is given by:

$$\sigma_p = \sigma_i - \sigma_e \quad (1)$$

1) Burst Model for Each Individual Casing String

At the top of the hole, the external pressure is zero and the internal pressure must be supported entirely by the casing body.

Therefore, burst pressure is highest at the top and lowest at the casing shoe where internal pressures are resisted by the external pressure originating from fluids on the outer part of the string.

a) Intermediate Casing

The equations for the internal and external pressures will be highlighted below

(1) Internal Pressure

In surface wellheads;

$$BP_{@ \text{ wellhead}} = \frac{60}{100} * (FP_{@ \text{ shoe}} - GCP_{@ \text{ wellhead}}) \quad (2)$$

OR

$$BP_{@ \text{ surface}} = 0.6(\text{Internal Pressure} - \text{External Pressure}) \quad (3)$$

Since the external Pressure @ the surface =0;

Then

$$\text{Surface Burst Pressure} = \sigma_{i(\text{surface})}$$

Where

$$\sigma_{i(\text{surface})} = P_f - G * TD \quad (4)$$

In subsea wellheads;

$$BP_{@ \text{ wellhead}} = \left[\frac{60}{100} * (FP_{@ \text{ shoe}} - GCP_{@ \text{ wellhead}}) \right] - \sigma_{\text{seawater}} \quad (5)$$

OR

$$BP_{@ \text{ wellhead}} = \sigma_{i(\text{surface})} - \sigma_{\text{seawater}} \quad (6)$$

Where;

$$\sigma_{i(\text{surface})} = (P_f - G * TD) = \text{Burst Pressure @ the surface}$$

Note that external pressure at the surface = 0

P_f = Formation Pore pressure @ casing seat (Psi)

The burst pressure limit at the bottom of the hole is equivalent to fracture gradient that was predicted for the hole section below the casing shoe.

Bottom Hole Burst Pressure = (Fracture Gradient) predicted @ shoe

Or

$$\sigma_{\text{burst @ shoe}} = \sigma_{i(\text{casing shoe})} - \sigma_{\text{back up}} \quad (7)$$

$$\sigma_{\text{back up}} = 0.465 * CSD \quad (8)$$

Where;

$$\sigma_{i(\text{casing shoe})} = P_f - \{G * (TD - CSD)\} \quad (9)$$

$$\sigma_{\text{burst @ shoe}} = [P_f - \{G * (TD - CSD)\}] - (0.465 * CSD) \quad (10)$$

(2) External Pressure

This pressure is equivalent to the formation pressure. If a subsea wellhead is installed, then the seawater hydrostatic pressure is to be taken into consideration.

$$\sigma_{\text{netburst}} = (\sigma_{\text{internal}} - \sigma_{\text{external}}) @ \text{ each depth} \quad (11)$$

C. Collapse Model

The following simplified procedure was used for collapse design; the casing was taken to be empty due to losses at the casing setting depth; the internal casing pressure is assumed to be zero (0); the external pressure is mainly due to the drilling fluid lastly it was assumed that there was cement on the outer part of the casing.

$$\text{Collapse pressure} = 0.052 * \rho_m * CSD \quad (12)$$

1) Intermediate Casing

The equations for the internal and external pressures will be highlighted below

a) Internal Pressure

Complete evacuation in intermediate casing is virtually impossible. Casing collapse is most likely to occur where there is mud losses as we drill into a new hole section using the maximum allowed mud density. This will bring about a drastic fall in the level of mud inside the casing. H will be taken as the height of the new low level of mud in the casing.

$$(H_{\text{loss}} - H) * \rho_m = H_{\text{loss}} * G_p \quad (13)$$

Where;

$$H = H_{\text{loss}} * \frac{(\rho_m - G_p)}{\rho_m} \quad (14)$$

If $G_p = 1.03$ (Kg / cm² /10m)

Then

$$H = H_{\text{loss}} * \frac{(\rho_m - 1.03)}{\rho_m} \quad (15)$$

b) External Pressure

At Surface:

Collapse pressure = 0

At depth (CSD-L)

$$\text{Collapse Pressure}_{@ \text{ CDS-L}} = (0.052 * CDS * \rho_m) \quad (16)$$

At depth CSD

$$\text{Collapse Pressure}_{@ \text{ CDS}} = (0.052 * CDS * \rho_m) - (0.052 * L * \rho_{m-\text{next}}) \quad (17)$$

$\rho_{m-\text{next}}$ = mud weight in which casing was run in.

L = CSD - h = Length of mud column inside the casing (ft)

h = depth of top of mud inside casing after loss circulation

$$h = \left(\frac{\rho_{m1-\text{next}} - \rho_f}{\rho_{m1-\text{next}}} \right) * D_{Lz} \quad (18)$$

Hence

Net Collapse Pressure

$$\sigma_{\text{Collapse}} = \sigma_{\text{external pressure}} - \sigma_{\text{internal pressure}} \quad (19)$$

Tables 1 and 2 show the recommended design factors for the different design criteria.

| Design Criteria | Recommended Design Factors |
|-----------------|----------------------------|
| Collapse | 1.0 |
| Burst | 1.1 |
| Tension | 1.6-1.8 |
| Compression | 1.0 |
| Triaxial Design | 1.1 |

Table 1: Recommended Design Factors

| Design Criteria | Recommended Design Factors |
|-----------------|----------------------------|
| Collapse | 1.0-1.1 |
| Burst | 1.1-1.25 |
| Tension | 1.3-1.8 |
| Compression | 1.0 |
| Triaxial Design | 1.1-1.2 |

Table 2: Industrial Range from Various Operators

D. Tension Design Model

When designing for tension, information on the casing grade and weight is very essential. Some forces must be considered when tension is being discussed. They are: the buoyancy force, the buoyant weight of casing, the bending force and the shock load.

1) Load Cases

There are three load cases for which the total tensile force should be calculated for: running conditions, pressure testing

& static conditions. These load cases are sometimes described as Installation Load cases.

a) Load Case I: Running Conditions

This is simply a case of running the casing inside the drilled hole section before the cement job.

$$Total\ tensile\ force = buoyant\ weight + bending\ force + shock\ load \quad (20)$$

b) Load Case II: Pressure Testing Conditions

This is simply when the casing is sent down to the target depth. Cement has just being pumped, hence not dry.

$$Total\ tensile\ force = bending\ force + buoyant\ weight + pressure\ testing\ force \quad (21)$$

c) Load Case III: Static Conditions

In this case, the casing has already been sent down, cement is set and the wellhead mounted.

$$Total\ tensile\ force = bending\ force + buoyant\ weight + miscellaneous\ forces \quad (22)$$

Again, it is imperative for the design factor in tension during pressure testing to be greater than 1.6, i.e.

$$DF - T = \frac{YieldStrength}{TotalTensiltforceduringPressureTesting} \quad (23)$$

E. Service Loads during Drilling & Production Operation

Once the casing is landed and cemented, it will be subjected to additional forces if drilling is continued beyond this casing or if this casing is used as a production casing. These service loads represent extra set of load cases which must be checked before the casing is selected. To calculate the tensile load on the casing, the base load must first be calculated:

$$F_{base\ load} = Air\ weight - Buoyancy\ force + bending\ force + Pressure\ testing\ force + landing\ force\ (if\ applied) \quad (24)$$

The additional forces that must be added include ballooning force, compression load, biaxial stress and temperature force.

F. Casing Wear

1) Volumetric Casing Wear

During string rotation, we can estimate the volume of casing wear by using equation 25 below:

$$V = \frac{Input\ Energy}{Specific\ Energy} \quad (25)$$

$$V = \frac{60\pi FLDNS}{P} \quad (26)$$

Note:

Accepted limit of casing wear is < or = 7%.

II. RESULTS & DISCUSSION

A. Formation Pore Pressure & Fracture Gradient Data Sources

Formation pore pressure and formation fracture pressure data were gathered from offset wells and well logs in the Niger Delta as shown in Table 3. Figure 2 shows the profile of the data shown in table 3. Well summary is shown in table 4

| Depth(ft) | Pore Pressure (Emw,ppg) | Fracture pressure (Emw,ppg) |
|-----------|-------------------------|-----------------------------|
| 1000 | 5.8 | 9.3 |
| 2000 | 5.8 | 9.3 |
| 3000 | 5.8 | 9.8 |
| 4000 | 5.9 | 10.2 |
| 5000 | 6.9 | 10.8 |
| 6000 | 7.4 | 11.8 |
| 7000 | 8.8 | 12.4 |

| | | |
|-------|------|------|
| 8000 | 10.6 | 12.9 |
| 9000 | 11.4 | 13.6 |
| 10000 | 12.2 | 14.3 |
| 11000 | 13 | 14.5 |
| 12000 | 13.3 | 14.8 |
| 13000 | 13.6 | 14.9 |
| 14000 | 13.6 | 15.2 |

Table 3: XXX Formation Pressure data from the Niger Delta

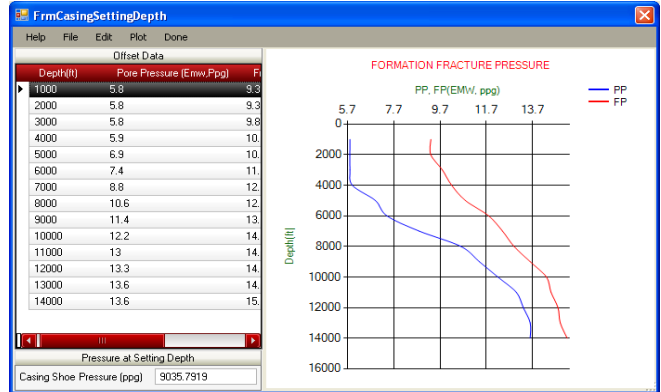


Fig. 2: formation Pore Pressure & Fracture Pressure Profile

B. Geological Overview and the Well Brief

Table 4 shows the well summary.

| | |
|-------------------------------|--|
| Well Name and Location | XXX, OML – XXX, Niger of Nigeria Nigeria |
| Surface Coordinate: | Nigeria Fed (XXX Belt) Coordinates XXX, YYYmN; ZZZmE |
| Proposed Bottom Coordinate | XXXmN; YYYmE |
| Ground Level | 120Feet (XXmeters) |
| Drilling Floor Elevation(DFE) | 510 Feet (XXXmeters) |
| Depth | 12,294ft MD (3617.8m); 11,500ft TVD (3617.8m) |
| Expected Spud Date | March, 2014 |
| Well Type | Deviated |
| Primary Objective | Develop X1, Y1, Y2and Y4 sand for Gas |
| Secondary Objective | Appraise G5 and others |

Table 4: Well Summary

Analysis of the data provided in Tables 3 and 4 and the subsequent ones shall be presented with the aid of WRENCH software developed for this purpose.

C. Casing Setting Depth

The formation data provided in Table 3 were uploaded into a software. This process was necessary to obtain casing setting depth and casing shoe pressure required for the design of burst and collapse strength criteria. The knowledge of casing shoe pressure provided possible maximum anticipated external force on the casing. Figure 3 below shows the plot of the casing setting depth.

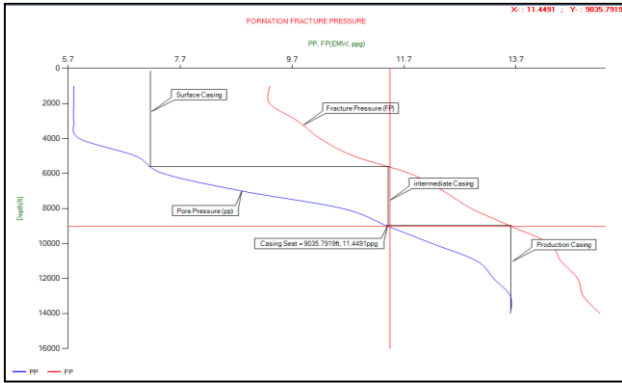


Fig. 3: Casing Setting Depth Analysis

D. Casing Burst Design Criteria

Figure 4 and Table 5 shows the input parameters and calculated result for casing burst design criteria respectively. Figure 5 is the burst design chart.

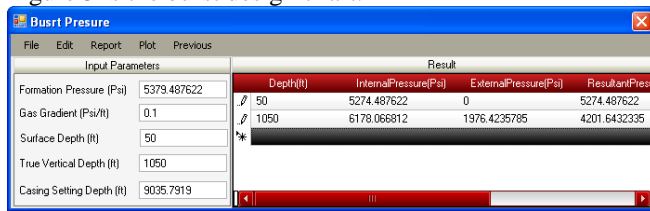


Fig. 4: Graphic User Interface (GUI) for input parameters for burst design criteria.

| Depth(ft) | InternalPressure(Psi) | ExternalPressure(Psi) | ResultantPressure(Psi) | Design(Psi) | Rating(Psi) |
|-----------|-----------------------|-----------------------|------------------------|---------------|--------------|
| 50 | 5274.487622 | 0 | 5274.487622 | 5274.487622 | 5917.4363842 |
| 1050 | 6178.066812 | 1976.4235785 | 4201.6432335 | 4621.80755685 | 5917.4363842 |

Table 5: Calculated result for burst design criteria

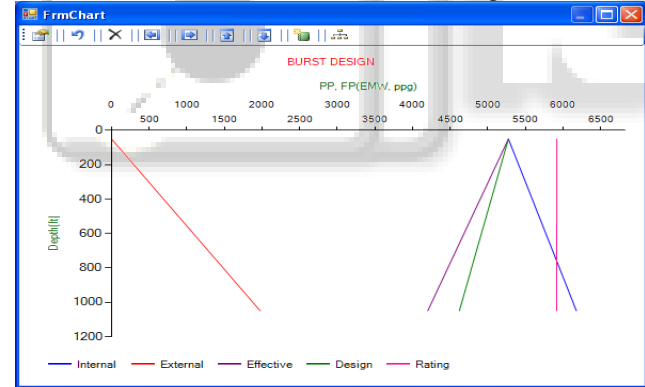


Fig. 5: Burst Design Chart

E. Casing Collapse design Criteria

Figure 6 and Table 6 present the input parameters and calculated result for casing collapse design criteria respectively. Figure 7 shows the collapse design chart

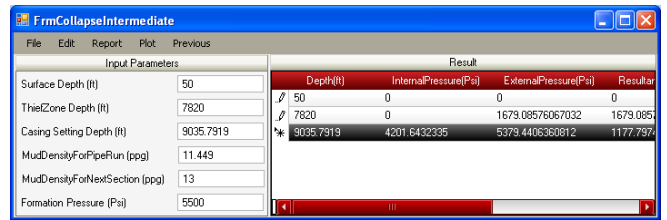


Figure 6: Graphic User Interface (GUI) Input Parameters for Collapse Design Criteria

| Depth(ft) | InternalPressure(Psi) | ExternalPressure(Psi) | ResultantPressure(Psi) | Design(Psi) | Rating(Psi) |
|-----------|-----------------------|-----------------------|------------------------|------------------|-------------|
| 50 | 0 | 0 | 0 | 0 | 6050 |
| 7820 | 0 | 1679.08576067032 | 1679.08576067032 | 1846.99433673735 | 6050 |
| 9035.7919 | 4201.6432335 | 5379.4406360812 | 1177.7974025812 | 1295.57714283932 | 6050 |

Table 6: Calculated result for Collapse design criteria

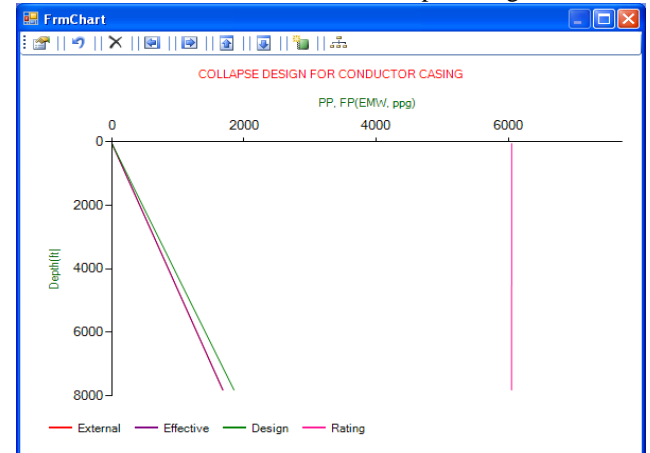


Fig. 7: Collapse Design Chart

F. Casing Tension Design Criteria

Figure 8 and Table 7 present the input parameters and calculated result for casing tension design criteria respectively.

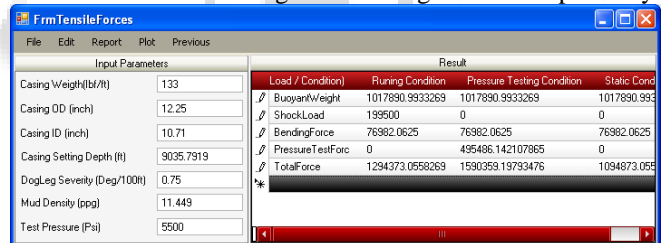


Fig. 8: Graphic User Interface (GUI) Input Parameters for Tension Design Criteria

| Load / Condition | Running Condition | Pressure Testing Condition | Static Condition |
|-------------------|-------------------|----------------------------|------------------|
| BuoyantWeight | 1017890.9933269 | 1017890.9933269 | 1017890.9933269 |
| ShockLoad | 199500 | 0 | 0 |
| BendingForce | 76982.0625 | 76982.0625 | 76982.0625 |
| PressureTestForce | 0 | 495486.142107865 | 0 |
| TotalForce | 1294373.0558269 | 1590359.19793476 | 1094873.0558269 |

Table 7: Calculated Result for Tension Design Criteria

G. Casing Selection

Table 8 provides the specification of the available casing while Figures to follow provides the initial selection. But before ever a load case is to be applied, we must first select the grade and weight of the casing based on the collapse and burst pressures. 2.8. Analysis of the available casing grade

| Tubular | Depth (ft) | Size (in) | Weight (Ib/ft) | Grade | Thread | Burst/Collapse (Psi) | Tensile Body/Joint (X1000Ibs) |
|--------------|------------|-----------|----------------|-------|--------|----------------------|-------------------------------|
| Intermediate | 0- 10,000 | 9-5/8 | 43 | J5 | ST&C | 5434/6720 | 541/322 |
| Intermediate | 0- 10,000 | 9-5/8 | 42 | J6 | ST&C | 5500/6920 | 425/392 |
| Intermediate | 0- 10,000 | 9-5/8 | 36 | J7 | ST&C | 5500/7520 | 564/394 |

| | | | | | | | |
|--------------|-----------|-------|----|----|------|------------|---------|
| Intermediate | 0- 10,000 | 9-5/8 | 40 | J8 | ST&C | 5300/9000 | 524/392 |
| Intermediate | 0- 10,000 | 9-5/8 | 40 | J9 | ST&C | 5300/11320 | 544/390 |

Table 8: Specification of Available Casing

Fig. 9: shows that casing grade J5 only satisfied burst pressure but does not satisfy collapse pressure and therefore not suitable for the operation

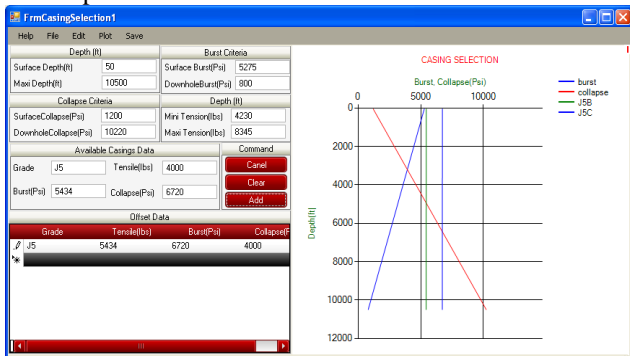


Fig. 9: Input parameters for Burst and Collapse analysis of Casing Grade J5

Figure 10 shows that casing grade J6 only satisfies burst pressure but does not satisfy collapse pressure and therefore not suitable for the operation.

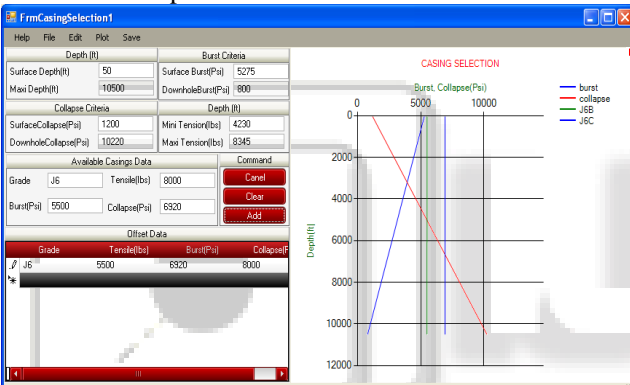


Fig. 10: Input Parameters for Burst and Collapse Analysis of casing grade J6

Figure 11 shows that casing grade J7 only satisfied burst pressure but does not satisfy collapse pressure and therefore not suitable for the operation.

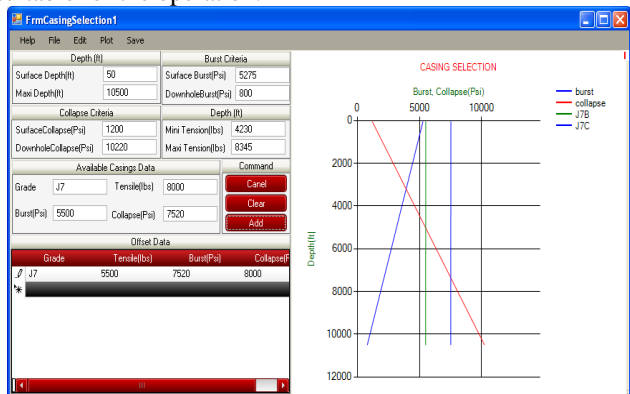


Fig. 11: Input Parameters for Burst and Collapse Analysis of Casing Grade J7

Figure 12 showed that casing grade J8 only satisfied burst pressure but does not satisfy collapse pressure and therefore not suitable for the operation.

III. CONCLUSION

The efficiency of casing design depends on the accuracy of the data acquired. A misleading data set could lead to over design or an under design. Casing should first be designed for burst and collapse and after which, tension, wear and tri-axial before other external factors may be considered. From the analysis presented in this study, it is recommended that Casing grade J9, having met both the burst and collapse pressure is recommended for the intermediate section of the case study well in the Niger Delta.

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