CASING DESIGN FOR EXTENDED REACH WELLS BY USING CASINGSEAT AND STRESSCHECK SOFTWARE

By

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CERTIFICATION OF APPROVAL

Casing Design for Extended Reach Wells by using
Casing Seat and StressCheck software

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(TIMUR TASHKENBAEV)

ABSTRACT

Today, the wells drilled by the petroleum and other energy development industries cover a wide range of drilling conditions. Significant advances in drilling technology have been made it possible to drill horizontally in almost any situation by using specialized tools. Highly deviated and even directional wells with high horizontal departure (ERD wells) are being drilled to complete reservoirs which otherwise could not be produced economically. These types of wells require substantial engineering work compared to conventional directional drilling. Besides that, there are some inherent weaknesses still exist, like casing design. Because, severe drilling and borehole conditions place additional requirements on casing design. As a result, it is often difficult to meet API requirements for principal design loads such as collapse, burst and tension.

In this report author have tried to capture the best of casing design practices and available technologies for extended reach wells. Author have done a thorough analyzes about this topic from various sources such as books, SPE papers and from International Oil and Gas Companies casing design manuals. From the reading, it was observed that horizontal section of Extended Reach wells requires higher collapse and axial strength.

Author has conducted a software simulation in CasingSeat and StressCheck and compared the design with manual calculation from MS Excel. Author has also proposed a methodology for successfully designing an Extended Reach Wells. This document encompasses a background of the study, a problem statement, the objectives and scope of study, the outline of the research methodology, the results and discussion and a conclusion.

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Words are inadequate in offering thanks to my Supervisor, Dr. Reza Ettehadi Osgouei, for the guidance, technical knowledge and valuable advice provided throughout my project. With the motivations and the guidance of the Supervisor I have gained an extra technical knowledge such as MS Excel Macro programming and the Landmark software from Halliburton which helped me to make my project successful.

My salutation would be incomplete without giving credit to UTP, especially the Geoscience and Petroleum Engineering Department who has organized a Landmark training program in UTP for Final Year students.

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INTRODUCTION

1.1 BACKGROUND

Extended-Reach Drilling (ERD) is an advanced form of directional drilling that employs both directional and horizontal drilling techniques. It has the ability to achieve horizontal well departures beyond the conventional directional drilling. The use of ERD wells results in less surface disturbance because fewer wells are needed and surface sites have a smaller footprint. Long ERD wells have been characterized as wells with greater than eight (8) kilometers of horizontal displacement.

Moreover ERD wells has many benefits, such as preventing water and gas coning, achieving inaccessible reservoirs, increasing production, etc. Many companies goes for ERD wells in order to eliminated the high capital cost of a second platform, to intersect more of the formation with near horizontal wellbores, and to demonstrate conclusively that such difficult wells could be drilled and completed economically.

1.2 PROBLEM STATEMENT

Nowadays the significant advances in drilling technology have made it possible to drill ERD wells in almost in any situation by using very specialized tools. But some inherent weaknesses to this technique still exist, like casing design. Casing used in horizontal drilling is subject to load not found in vertical wells that requires careful planning and loads analyzes. An insufficient casing design (e.g., wall thickness too small or material strength (grade) not adequately chosen) can cause – casing collapse, casing burst, parting of the string (mainly casing connections) resulting in loss of time which is economically not preferable, sometimes in a loss of part or even whole borehole. Especially in Extended Reach wells where an uncertainty of the formation to be drilled is very high.

1.3 OBJECTIVES OF REPORT

1. To analyze various loads (external and internal) for Extended Reach wells by manual calculation and by utilizing StressCheck and Casing Seat software of Landmark.

2. To design a casing program for Extended Reach Well with the help of StressCheck and Casing Seat software of Landmark.
3. To develop an Excel Macro for determining of casing setting depth.

1.4 SCOPE OF STUDY

The scope of this study is to understand the parameters of casing design for ER well. The study in this project contains two main parts:

1. To recognize various loads that exists in Extended Reach wells;
2. To apply and to design the casing program that complies with all safety standards for ER wells.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Theory

Casing Design is a process which seeks to have a balance between needs of the subsurface formations and casing strings to be run in hole and cemented in place. Thus the walls of an oil/gas well is usually lined with steel tubes called casing, in order to seal off fluids from the bore hole and to prevent the walls of hole from sloughing off or caving. Sections of individual casings that are screwed together and cemented in hole are called casing strings.

The objective of the design is to ensure that the casing design intent is not exceeded by the predicted and subsequent actual, operating envelope.

The design of a casing program involves the selection of setting depths, casing sizes and grades of steel that will allow for the safe drilling and completion of a well to the desired producing configuration. The selection of these design parameters is controlled by a number of factors, such as geological conditions, hole problems, number and sizes of production tubing, types of artificial lift, equipment that may eventually be placed in the well, company policy, and in many cases government regulations.

2.1.1 Casing classification:

We can classify casing according to its length, outside Diameter (OD), weight per foot, grade of steel and its connections. These parameters are listed below:

- ✓ *Length* (as per API): Range-1: 4.88 – 7.62 m, Range-2: 7.62 – 10.36 m Range-3: 10.36 – 14.63 m (Casing is run most often in R-3 to reduce the number of connections in the string.) Pup-Joints: 0.61 – 3.66 m;
- ✓ *Outside Diameter* (OD): API Casing sizes range from 4 ½” to 20” inclusive. Most commons are: 20”, 13 3/8”, 9 5/8” and 7” (4 ½” or 5” is contingency);

- ✓ *Weight per unit length*: Casing dimension can be specified by nominal wall thickness. The plain-end weight per foot is the weight per foot of the pipe body, excluding the threaded portion and coupling weight. Most design calculations are performed with the nominal weight per foot (an approximate average weight per foot);
- ✓ *Grade of steel*: Casing is manufactured of mild steel (carbon), normalized with small amounts of manganese. Strength can also be increased with Q&T (Quenching and Tempering). API adapted a casing "grade" designation. The adapted grade letter is followed by a number which designates the minimum yield strength of the steel in ksi (10^3 psi). Some grades: J-55, N-80, P-110, Q-125. There are also non- API Steel Grades: e.g. V-150.
- ✓ *Connection:* A connection is a system for joining individual lengths of casing and plays a critical role in determining the overall technical integrity of the casing strings. Connections are rated to their joint efficiency, which is the tensile strength of the joint divided by the tensile strength of the pipe body. Connections fall into two categories: API and proprietary. Connections recognized by API: Buttress Thread Casing(BC), Round Thread – Long and Short, Extreme Line, Line Pipe.

The design process involves the prediction of possible loads and conditions within the wellbore. Then we design our casing based on load bearing capacities that meet the predicted loads in both open and cased-hole sections. The predicted loads include a variety of external and internal pressures, thermal loads and loads related to the self-weight of the casing. Wear, corrosion and fatigue loads should be accounted for as well.

The most important performance properties of casing include its rated values for:

- ➢ ***Axial tension;***
- ➢ ***Burst pressure;***
- ➢ ***Collapse pressure.***

2.1.2 Defining loads

Collapse Criteria

Collapse pressure arises from the differential pressure between the hydrostatic heads of fluid in the annulus and the casing; it is a maximum at the casing shoe and zero at the surface. The most severe collapse pressures occur if the casing is run empty or if a lost circulation zone is encountered during the drilling of the next interval.

There are 2 assumptions are made:

- ✓ 100 percent evacuation (complete loss);
- ✓ Partial loss.

For manual calculation author assumes the complete loss case in order to have a worst case scenario. Because once our design passes through the worst case we can be sure that it can withstand any other loads.

$$\mathbf{P_{int} = atmospheric\ pressure}$$

$$\mathbf{P_{ext} = 0.052 * MW * CSD}$$

where:

MW = mud weight, ppg

CSD = casing setting depth, ft

Burst Load criteria

The burst in the casing occurs when the effective internal pressure inside the casing (internal pressure minus external pressure) exceeds the casing burst strength.

Burst Pressure, B is given by:

B = internal pressure – external pressure

Burst pressures occur when formation fluids enter the casing while drilling or producing next hole. The Figure below shows that in most cases the maximum formation pressure will be encountered when reaching the TD of the next hole section. For the burst criterion, two cases can be designed for:

1. Unlimited kick
2. Limited kick

Unlimited kick was applied for the calculation since it represents the worst case scenario for burst case in the wellbore.

$$\mathbf{P_{int@top} = P_{pore@TD} - (Gas\ Gradient * TD)}$$

$$\mathbf{P_{int@csd} = P_{pore@TD} - Gas\ Gradient\ (TD\text{-}CSD)}$$

$$\mathbf{P_{ext@top} = 0}$$

$$\mathbf{P_{ext@csd} = 0.052*Depth_{TOC} + 0.052*ECD_{cement}*(CSD\text{-}\ Depth_{TOC})}$$

where:

Gas Gradient = 0.1 psi/ft

$MW_{above\ TOC}$ = 8.9 ppg

ECD_{cement} is different for each hole section.

Tension criteria

Most axial tension arises from the weight of the casing itself. Other tension loadings can arise due to: bending, drag, shock loading and during pressure testing of casing. In casing design, the uppermost joint of the string is considered the weakest in tension, as it has to carry the total weight of the casing string. Selection is based on a design factor of 1.6 to 1.8 for the top joint.

In general, the tensile forces are determined as follows:

1. Calculate weight of casing in air using true vertical depth;
2. Calculate buoyancy force;
3. Calculate bending force in deviated wells;
4. Calculate pressure testing forces

The following forces must be considered:

Buoyant Weight of Casing

The buoyant weight is determined as the difference between casing air weight and buoyancy
force.

Casing air weight = casing weight (lb/ft) x hole TVD

Buoyancy force = $P_e (A_e – A_i)$

P_e = external hydrostatic pressure, psi

A_e and A_i are external and internal areas of the casing

There are three load cases for which the total tensile force should be calculated for: running conditions, pressure testing and static conditions. These load cases are sometimes described as Installation Load cases. The maximum force that the top casing joint sees is during pressure testing.

Bending force

The bending force is given by:

Bending force = 63 Wn x OD x θ

where

Wn = weight of casing lb/ft (positive force)

θ= dogleg severity, degrees/100 ft

Pressure testing

The casing should be tested to the maximum pressure which it sees during drilling and production operations (together with a suitable rounding margin).

$$F_t = \frac{\pi(ID^2)}{4} \text{ x test pressure}$$

where

Ft = pressure test force, lb

ID = inside diameter of casing, in

When deciding on a pressure test value, the resulting force must not be allowed to exceed 80% of the rated burst strength.

Total tensile force = buoyant weight + pressure testing force +bending force

As for safety factor for tensional loads we can take 1.3 as many companies practices this as a design factor.

The kick tolerance is widely used nowadays in order to determine casing setting depth. Author has developed an Excel Macros to determine casing setting depth. The formula used in the macro is based on the following:

$$H = \frac{0.052\,x\,\rho m(TD - CSD) + (FG\,x\,CSD\,x\,0.052 - Pf)}{0.052\,x\,\rho m - G}$$

where:

H – represents the height of kick at casing setting depth, ft

TD - total depth, ft

CSD – casing setting depth, ft

FG – fracture gradient at casing setting depth, ppg

G - gas gradient , psi/ft

ρ_m - density of mud for next hole section, ppg

2.1.3 Casing Size selection

Casing and bit sizes are selected using the chart. The deepest casing is chosen first and the bit and casing program is built in reverse sequence towards surface. There are some design factors that is used by International Oil Companies, National oil companies:

TABLE OF DESIGN FACTORS

CASING	BURST	COLLAPSE	TENSION§	STABILITY	TORSION	VON MISES
CONDUCTOR	1.0	1.0	1.6	1.25	1.5	1.25
SURFACE	1.0	1.0	1.6	1.25	1.5	1.25
INTERMEDIATE	1.0	1.0	1.6	1.25	1.5	1.25
PRODUCTION	1.25	1.0	1.6	1.25	1.5	1.25
LINER	1.25	1.2	1.6	1.25	1.5	1.25
WORK & FISHING	1.25	1.25	1.6	1.25	1.5	1.50

§ Body and joint unless joint skinny; then use 2.0 rather than 1.6.

Table 1. Design Factor for casing strings [14]

These three loads are further discussed in methodology part of the report. After performing a design based on burst, collapse and axial considerations an initial design is achieved. Before a final design is reached, design issues (connection selection, wear, corrosion) must be addressed.

2.2 Literature Review

There were enough literatures found about casing design for extended reach wells. Some article addresses an issue of determination of traditional loads such as collapse, burst and tensional loads while others specifies non-traditional loads such as poor cementing job criteria, bending loads and effect of perforations. Some authors states that effect of combined stresses must be considered.

Nowadays there are several approaches have been developed for the casing design, most are based on the concept, of maximum load [15]. In this method, a casing string is designed to withstand the parting of casing, burst, collapse, corrosion and other problems associated with the drilling conditions. To obtain the most economical design, casing strings often consist of multiple sections of different steel grades, wall thicknesses, and coupling types.

Selection of the number of casing strings and their respective setting depths are determined historically by the mud weight, fracture gradient and geological condition. This is also true about Landmark Casing Seat software.

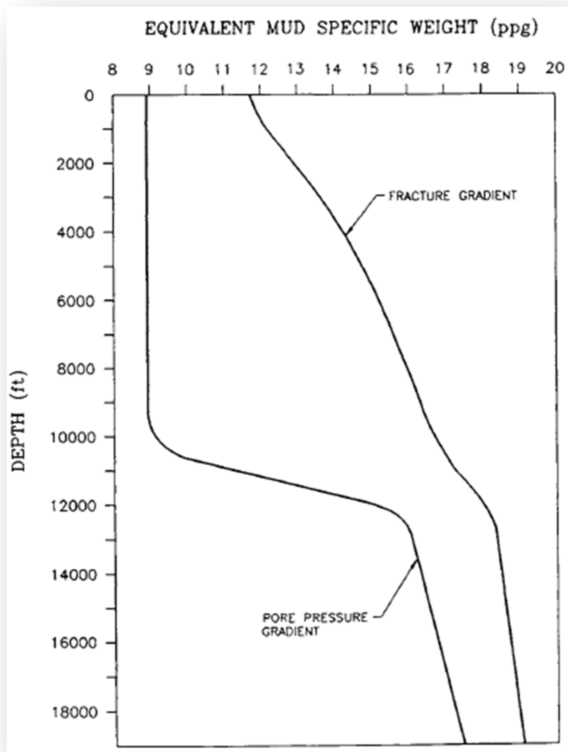


Figure1. Typical pore pressure and fracture gradient data for different depths. [14]

Selection of casing seats for the purpose of pressure control requires knowledge of pore pressure and fracture gradient of the formation to be penetrated. Once this information is available, casing setting depth should be determined for the deepest string to be run in the well. Design of successive setting depths can be followed from the bottom string to the surface.

A number of factors can affect the shoe depth selection:

- *Regulatory requirements.*
- *Kick tolerance.* A specified gas influx volume is used to calculate the maximum length of the open hole section such that the kick volume can be circulated up to the surface without fracturing the formation. In the CasingSeat software, the kick tolerance is determined by assuming the gas as a single, continuous bubble of methane.
- *Hole stability.* This can be a function of mud weight, deviation and stress at the wellbore wall. The plastic flowing behavior of salt zones also needs to be considered.
- *Differential sticking*. The probability of differential stuck increases with increasing differential pressure between the wellbore and formation, increasing permeability of formation and increasing fluid loss of the drilling fluid.
- *Zonal isolation*. Shallow fresh water sands need to be isolated before a formation of higher pressure is penetrated.
- *Directional drilling concerns*. A casing string usually run after an angle building section has been drilled. This avoids key seating problems in the curved portion of the wellbore due to increased normal force between the wall and pipe.
- *Uncertainty in predicted formation properties*. Exploration wells require additional strings to compensate for the uncertainty in pore pressure and fracture pressure.

We need to consider differential sticking problem when we run the casing. The maximum differential pressures at which the casing can be run without severe pipe sticking problems are: 2,000 - 2.300 psi for a normally pressured zone and 3,000 - 3,300 psi for an abnormally pressured zone.

Performance properties of the casing deteriorate with time due to wear and corrosion. A safety factor is used, therefore, to allow for such uncertainties and to ensure that the rated performance of the casing is always greater than the expected loading. Safety factors vary according to the operator and have been developed over many years of drilling and production experience.

2.2.1. Conventional loads

The increasing step out of extended reach wells has resulted in increased loads on the well tubular and therefore engineers are required to verify that the acceptable design factor is met with the additional constraints.

The most important performance properties of casing include its rated values for *axial tension*, *burst pressure*, and *collapse pressure* [13]. Design load for collapse and burst should be considered first. Once the weight, grade and sectional lengths which satisfy burst and collapse loads have been determined the tension load can be evaluated and the pipe section can be upgraded if it is necessary [16].

There are some factors that casing loads are depends on [3]:

- ✓ Casing geometry(wall thickness affects tension);
- ✓ The type of material (density affects tension);
- ✓ The well trajectory (for bending and drag calculation that affect tension);
- ✓ The wellbore fluid (buoyancy affects tension);
- ✓ The fluid in the casing (buoyancy).

2.2.2. Other loads

Beside the three basic condition (burst, collapse and axial loads or tension), casing design in Extended Reach wells can be depend upon various other loads which are depend upon a number of factors [1, 11]:

- ✓ Casing wear – usually it is a minor concern in ER wells due to the fact that much lower surface pipe tension exists to generate normal forces in the well. Casing wear can be an issue if prolonged periods of backreaming are used in the well operations. Water based mud environment is much worse than oil based mud for the casing wear problem.

- ✓ Well trajectory – it dictates the availability of slack-off weight at the surface for the running the casing. Flotation technique is commonly used in ERD.
- ✓ Buckling;
- ✓ Wellbore confining stress;
- ✓ Thermal and dynamic stress;
- ✓ Changing internal pressure caused by production or stimulation operations;
- ✓ Changing external pressure caused by plastic formation creep;
- ✓ Subsidence effects and the effect of bending in crooked holes.

Several other special casing program modifications have been pursued or evaluated for ERD wells. The use of heavier weight and/or higher strength casing through intervals of possible casing wears. [10]

Calculation of the axial loads is the most challenging part of directional-well casing design. Using the maximum load principle, the concept of the maximum pulling load is applied. This concept states that the greatest value of tensile stress in directional-well casing occurs during the casing running operation. [15]

A deviation of the string in the borehole resulting from side tracking, build ups and drop-offs may cause a *bending*. Since bending load increases the total tensile load, it must be deducted from the usable rated tensile strength of the pipe. [11]

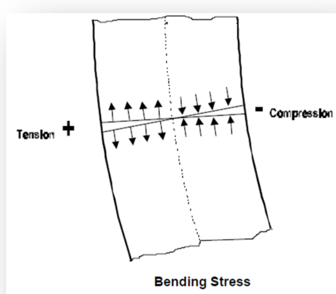


Figure 2. Bending stress for deviated string [13]

In deviated wells there is a casing wear problems also need to be encountered. We usually face this in build-up and drop-off sections. It may result in decreasing in burst and collapse values which are proportional to the reduction in wall thickness.

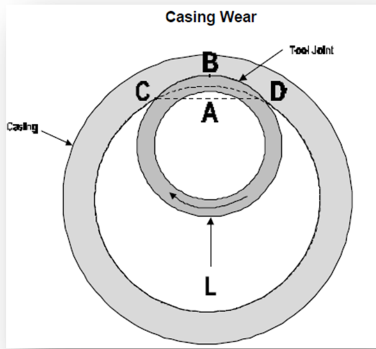


Figure 3. Casing wears problem in the deviated section of the casing string. [13]

The major factors affecting casing wear are:

- Rotary speed;
- Tool joint lateral load and diameter;
- Drilling rate;
- Inclination of the hole;
- Severity of dog legs;
- Casing wear factor.

2.2.3. Hole size selection

Hole and casing diameters are based on the following requirements:

- Production – production equipment requirements, including tubing, subsurface safety valve, submersible pumps and gas lift mandrel size; completion requirements.
- Evaluation – logging interpretation requirements and toll diameters

- Drilling - minimum bit diameter for adequate directional control and drilling performance, available downhole equipment, rig specifications, and available BOP equipment.

Large cost saving are possible by becoming more aggressive during this portion of the preliminary design phase.

In extended reach well we can use 13 ½ ” and 9 7/8” hole sizes (as an alternative to traditional 17 ½’’ x 12 ¼’’x 8 ½’’design) [1]. The smaller hole size requires less flow rate to keep them clean or can be cleaned faster with the same flow rate thereby allowing for the faster penetration rate. The smaller hole size are also inherently more stable and ECD’s in pay-zone are much less.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

In order to ensure that the project can be accomplished within the given timeframe, there are certain procedures to be followed. The project is accomplished within two steps:

- Casing design for ERD well with manual calculation;
- Casing design by using StressCheck and CasingSeat software of Landmark.

Thereafter appropriate recommendations will be done based on the results from both steps.

There are four PRINCIPAL STEPS for an effective casing design of a casing string is:

- Determine the length and size of all casing strings that are needed to produce the well to its maximum potential.
- Calculate the pressure and loads from predicted production and operations such as stimulation, thermal application and secondary recovery.
- Determine any corrosive atmosphere that the casing string will be subjected to and either selects alloys which can resist corrosion or design an alternate corrosion control system.
- Determine the weight and grade of casing that will satisfactorily resist all of the mechanical, hydraulic and chemical forces applied.

3.2 Data research and gathering

For this research following field data were obtained for evaluation purpose:

Reservoir Targets

SANDS	DEPTH	
	TVDDF (m)	**MDDF (m)**
SURFACE LOCATION	-	-
PRIMARY TARGET Sandstone	1,602.00	4,560.00
TD	1,647.00	4,771.00

Total Depth: 4773m (1647m TVD)

Formation Tops / Pressure & Mud Weight Prognosis

Vertical Depth (ft)	Pore Pressure/EMW		Fracture Pressure/EMW	
Depth (ft)	(psi)	(ppg)	(psi)	(ppg)
338.9	132.04	7.5	167.25	9.5
2473	1132	8.81	1427	11.11
3000	1404	9.01	1771	11.36
3500	1674	9.21	2071	11.39
4028	1937	9.26	2524	12.06
4226	2088	9.51	2659	12.11
4321	2294	10.22	2809	12.51
4360	2347	10.36	2857	12.61
4400	2393	10.47	2906	12.71
4764	2651	10.71	3146	12.71
5017	2752	10.56	3261	12.51
5099	2789	10.53	3341	12.61
5118	2795	10.51	3353	12.61

Table 2. Formation Tops / Pressure & Mud Weight Prognosis

<u>Well trajectory:</u>

- Kick off well with 2.5°/30m , Azi 230° at 330m. Build angle from 0° to 73° from 330m to 1100m at 230° Azimuth.
- Hold at 73° Tangent at 230° Azimuth to well TD at 4771m

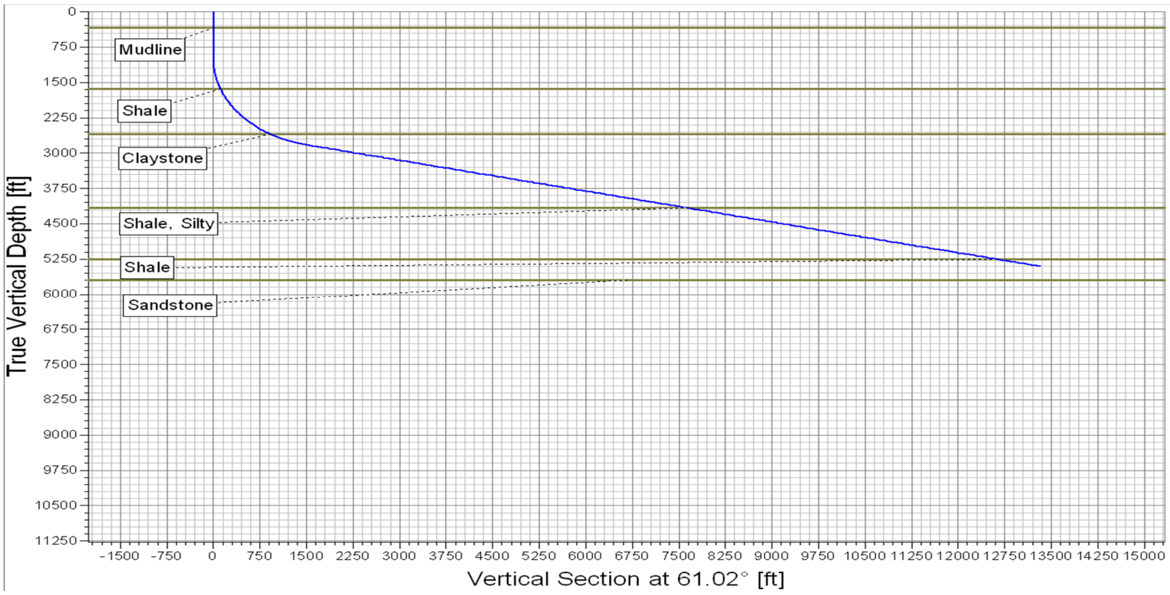


Figure 4. Section View Eshqurbon-2 well

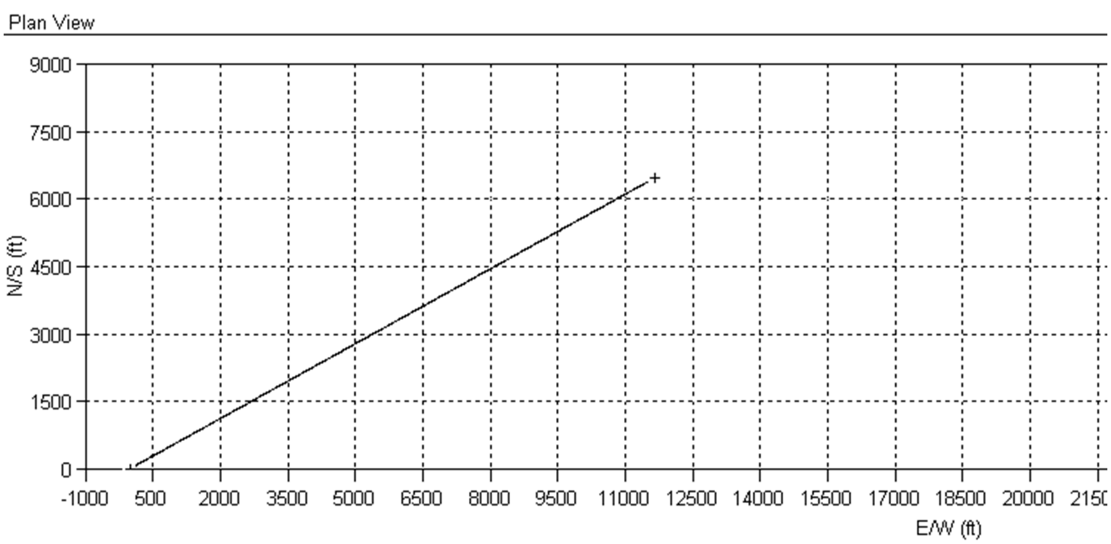


Figure 5. Plan View Eshqurbon-2 well

Data is based on real field information and the names and coordinates were changed due to confidentiality.

3.3. Manual calculation

After obtaining all relevant data we can start to construct our casing design by applying the theories and formulas. The manual calculation procedure will follow as per stated above steps. Briefly we can list those steps again:

1. Selection of shoe depth by using pore pressure and fracture gradient;
2. Selection of hole size and casing size based on production requirements;
3. Mud designing;
4. Selection of casing weight and grades for each casing string based on loads encountered while designing.

For the selection of the casing seat requires a knowledge of pore pressure and fracture gradient of the formation to be penetrated. Based on the pore pressure and fracture pressure we can construct a graph below:

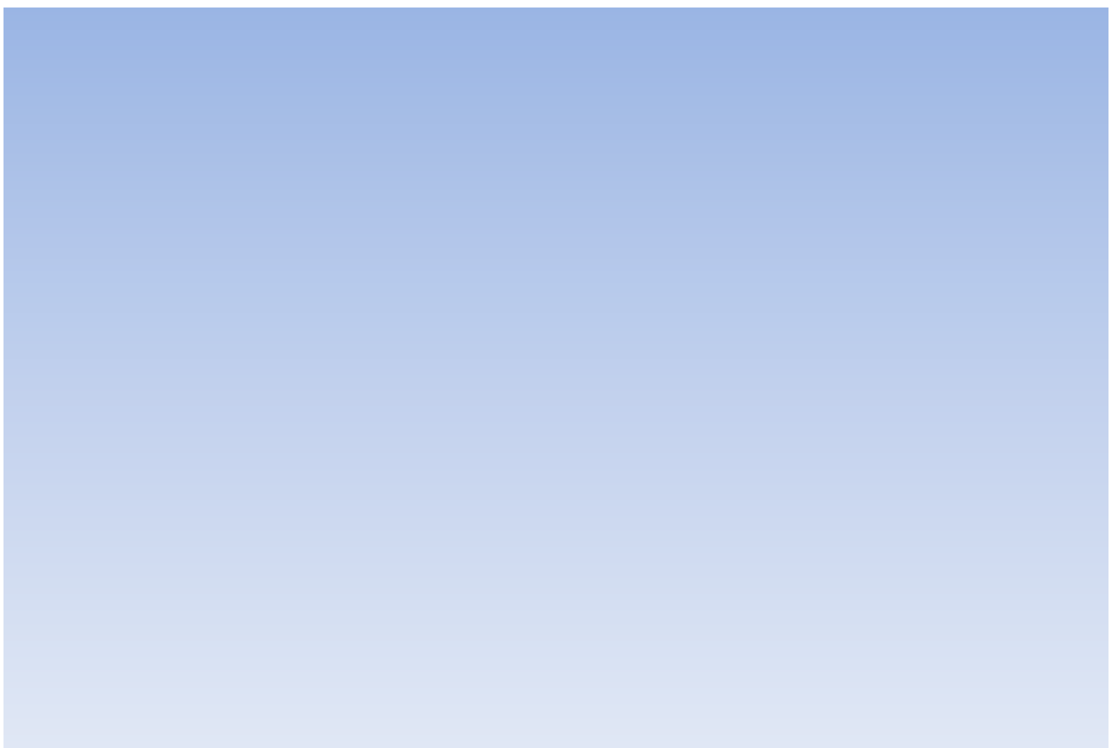
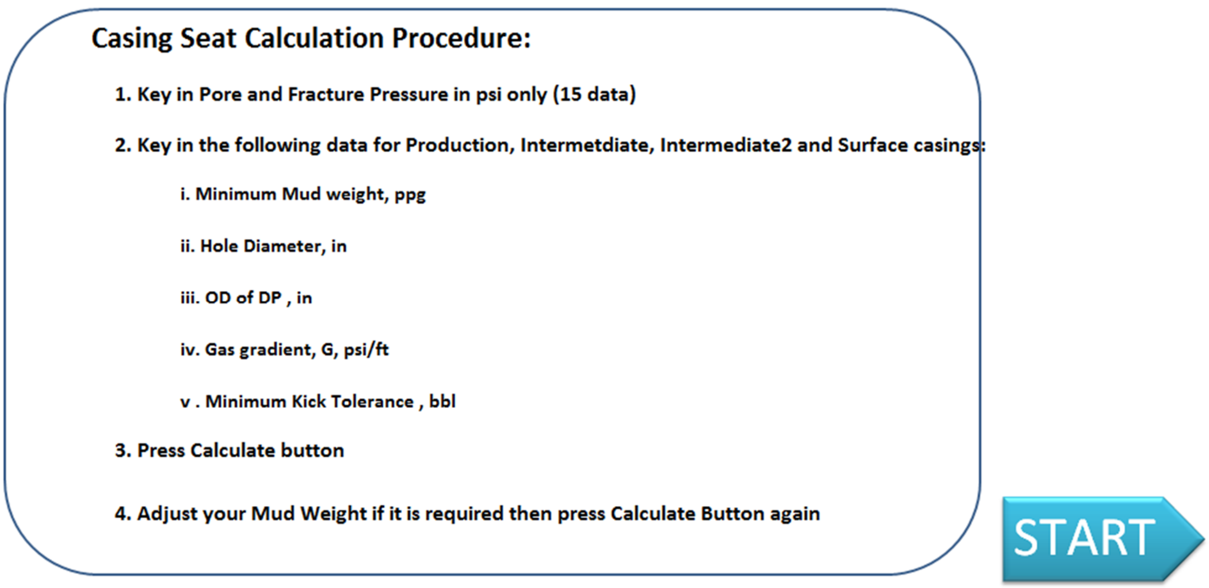


Figure 6. Design Plot in MS Excel for Eshqurbon2 well.

The design will follow from the bottom string to the surface. We also need to consider differential sticking problem when we run the casing by take as a maximum differential pressures to be 2,000 - 2.300 psi.

3.3.1 Excel Macro Calculation

As a part of manual calculation, author has also developed an Excel Macro for determination of casing setting depth. The procedure of calculation is given below:



The Macro will ask from User to key in all relevant data (section 2) for 4 (four) hole section and press Calculate to start calculation. The calculation is based on the following formula given in theory section. The macro calculates from bottom to top and once the first depth is found, macro set that depth to be Total depth for upper hole sections and iterations will continue until it reaches the surface. The macro will convert it into Equivalent Mud Weight (ppg) automatically when the user key in pore and fracture pressures in psi. The kick and trip margin is considered to be 0.5 ppg from pore and fracture pressure data. There may be variation in finding Mud weight program after first calculation. User may refer to the plot on right corner of the Excel in order to correct his/her mud weight so that it will not exceed pore and fracture pressure curves. After adjusting with new Mud weight user need to press Calculate bottom in order to get an accurate data with depth and relevant mud program.

The Macro will set first Total Depth to be 15^{th} value and first Casing Setting Depth will be 14^{th} data. The iteration will continue until it satisfies the kick tolerance requirement for each hole section. The User may key in data with different intervals, but macro was developed in such way that it will interpolate the interval and gives an exact depth that hole can tolerate the kick that has been specified by user.

Author continuously working on this macro to make it more user friendly and handy to use. In later upgrades author planning to include geological hole problems that enable the user to define any depth manually and kick calculation will be done for each hole section separately.

As an industry standards practices, author have used the following kick tolerance for this project:

- ✓ 25 bbl of kick tolerance is assumed at 8 ½’’ hole section;
- ✓ 50 bbl of kick tolerance is applied for 12 ¼ ’’ hole and above sections.

After establishing the setting depths and the outside diameters, one must select the nominal weight, steel grade, and couplings of each of these strings. Each casing string should be designed to withstand the maximal load that is anticipated during casing landing, drilling, and production operations.

At first we need to consider the design load for collapse and burst. Once the weight, grade and sectional lengths which satisfy burst and collapse loads have been determined the tension load can be evaluated and the pipe section can be upgraded if it is necessary.

3.4. Software based design (StressCheck™, CasingSeat™)

Throughout the process author will use software from Landmark: StressCheck™ and CasingSeat™. The design process in Landmark can be divided into two distinct phases:

- ✓ Preliminary design (Casing Seat):
  - Data gathering and interpretation;
  - Determination of shoe depths and number of strings;
  - Selection of hole and casing sizes;
  - Mud weight design;
  - Directional design.
- ✓ Detailed design (StressCheck):
  - Selection of pipe weights and grades for each casing string;
  - Connection selection.

3.4.1. *CasingSeat™* - is a casing seat selection tool that provides rigorous shoe selection calculation to optimize shoe locations, based on pore pressure and fracture gradients and user-defined design constraints. It is a preliminary design tools that support selection of casing and hole sizes, setting depth for the casings, determination of the highest allowable cement tops.

All required data will be entered to perform a CasingSeat analysis and interpretation will be done based on results. At the end of interpretation we will obtain casing *shoe depths, number of strings, hole and casing sizes, and mud weight programs.*

A workflow used in the *CasingSeat™* software is shown below:

1. Enter general information: well name and vertical section definition;
2. Enter wellpath data;
3. Enter hole sizes allowed below casing OD for drill-through ops;
4. Enter the casing ODs allowed for the hole size;
5. Enter general parameters used for calculating the casing design;
6. Define the lithology;

7. Define the pore pressure;
8. Define the fracture pressure;
9. Define the temperature profile;
10. Calculate results;
11. Select the case type to view results;
12. View results of the analyzed case.

Top of Cement Depths (TOC) for each casing string will be selected in the preliminary design phase, because this selection influences axial load distribution and external pressure profiles used during the detailed design phase.

After determining the casing shoe depth, the CasingSeat software calculates the TOC depth such that the formation will not fracture. The cement slurry is assumed to be **16 ppg** for this calculation.

In the CasingSeat software, the kick tolerance is determined by assuming the gas as a single, continuous bubble of methane. The allowable gas-kick volume can be specified or calculated. Gas bubble volume is depth-dependent; it is calculated as a function of local pressure, temperature, volume and compressibility. Kick tolerance therefore depends on the maximum kick size, maximum formation pressure at next TD and the maximum mud weight which can be tolerated without fracturing the weakest point in the open hole, usually the previous casing shoe. Other factors which affect kick tolerance include density of the invading fluid and the circulating temperatures.

HOLE SIZE (inch)	KICK VOLUME (bbl)
6"and smaller	10-25
8.5"	25-50
12¼"	50-100
17.5"	100-150
23"	250

Table 3. Typical Values of Kick Tolerances From various Operators [15]

3.4.2. *StressCheck^{TM}*

The next software that author have used to analyze the loads is ***StressCheck^{TM}*.** It is a powerful tool for the design and analysis of casing strings. With the Custom Loads features, the StressCheck software also provides an easy-to-use spreadsheet facility for specifying in exact detail, user-defined internal pressure, and external pressure and temperature profiles when more unique load-case formulations are required.

The following displays a list of StressCheck features that follows a casing design methodology:

i. Mechanical Design
   - Burst loads
   - Collapse loads
   - Axial loads
   - Load lines
   - Design factors

ii. Weight and grade selection
   - Tubular properties
   - Pipe inventory
   - Connections spreadsheet

iii. Special conditions
   - Connections
   - Stuck pipe
   - Casing wear
   - Buckling
   - Temperature
   - Combined loading
   - Corrosive environment
   - Squeezing salt and shale

The StressCheck software can be used to design casing string that meet or exceed all relevant design criteria from top to bottom. It can yield significant savings in total casing costs by providing a variety of automated formulations for specifying realistic burst, collapse and axial loads rather than traditional worst case maximum load profiles and by optimizing the number and length of the casing string sections.

For experienced engineers who understand requirements of casing design it can facilitate more sophisticated design issues. These issues include:

- ✓ Running, installation and service loads for more comprehensive axial design
- ✓ Gas kick loads
- ✓ External pressure profiles for good and poor cement
- ✓ Permeable zones
- ✓ Annulus mud drop
- ✓ Worst case or user entered temperature profiles
- ✓ Overpull limits
- ✓ Allowable wear
- ✓ Pressure testing

<u>Buckling</u>

All service loads should be evaluated for changes in the axial load profiles, triaxial stress, pipe movement and the degree of buckling. Buckling occur if the buckling force is greater than a threshold force known as the Paslay buckling force.

Buckling should be avoided in drilling operations to minimize casing wear. Buckling can only occur in the uncemented portion of a casing string between the hanger and the TOC, and the onset of buckling is influenced by the pickup or slackoff force, as well as changes in temperature, changes in internal and external pressure, and the local wellbore inclination. Increases in temperature and internal pressure both tend to increase buckling, while the tendency to buckle is suppressed at greater wellbore inclinations. Buckling can be reduced or eliminated by:

- Applying a pickup force after cementation before landing the casing.
- Raising the TOC.
- Using centralizers

- Increasing pipe stiffness.

In high temperature applications, the intermediate and surface casings should be checked for possible buckling occurring.

API Connection Rating

Connection rating for 8 round (STC and LTC) and butters (BTC) casing connections are based on four failure criteria given in API Bulletin 5C3:

- Burst - the internal pressure which will initiate yield at the root of the coupling based on connection geometry and yield strength.
- Leak – the internal pressure which exceeds the contact pressure between the connection's seal flanks.
- Fracture –the axial force which causes either the pin or coupling to fracture based on the ultimate tensile strength.
- Jump out – the axial force at which an 8 round pin "jumps" or "pulls" out of the box without fracturing. This criteria only applies to STC and LTC connections.

3.4.2.1 Detailed Mechanical Design

Design load represent the worst case loads that a particular casing string could experience during the life of a well.

Burst Loads

- ✓ Drilling loads:
    - Limited Gas/Oil Kick;
    - Full displacement/Evacuation to Gas;
    - Lost returns with water;
    - Pressure Test
- ✓ Production loads:
    - Tubing Leak
    - Stimulation surface Leak
    - Injection Down Casing

Collapse Loads

- ✓ Drilling loads
  - Full or partial Evacuation to Air
  - Lost returns with Mud Drop
  - Cementing
- ✓ Production loads
  - Full Evacuation to Atmospheric Pressure
  - Above/Below Packer

Axial Loads

- ✓ Running in Hole (Shock Loading)
- ✓ Overpull Force
- ✓ Buoyed Weight in Mud
- ✓ Buoyed Weight in Cement Slurry
- ✓ Service Loads

In StressCheck , a load line consisting of the maximum differential pressure with depth is formed from the two load cases.

3.4.2.2. External Pressure Profiles

In StressCheck the following pressure profiles are available:

- ✓ Mud and Cement Mix Water External pressure profile
- ✓ Permeable zones
- ✓ Minimum formation pore pressure
- ✓ Pore pressure with Seawater gradient
- ✓ Mud and Cement Slurry
- ✓ Frac @ Prior shoe with Gas gradient above

uring the casing grade selections author have used an appropriate casing loads for burst, collapse and axial loads calculation in StressCheck. In result section of this report we will further describes and analyze our selection of loads for each hole section.

Design parameters for all casing sections calculations are based on the following pipe and connection design factors as per below:

- Pipe body
  - Burst 1.1
  - Collapse 1.0 - 1.5
  - Axial 1.3
  - Triaxial 1.25

- Connection
  - Burst/Leak 1.1
  - Axial 1.3

In order to begin with StressCheck we need to set a data structure first if it is not specified in CasingSeat. Landmark has an EDM database hierarchical data structure that supports different level of data required by drilling suite applications.

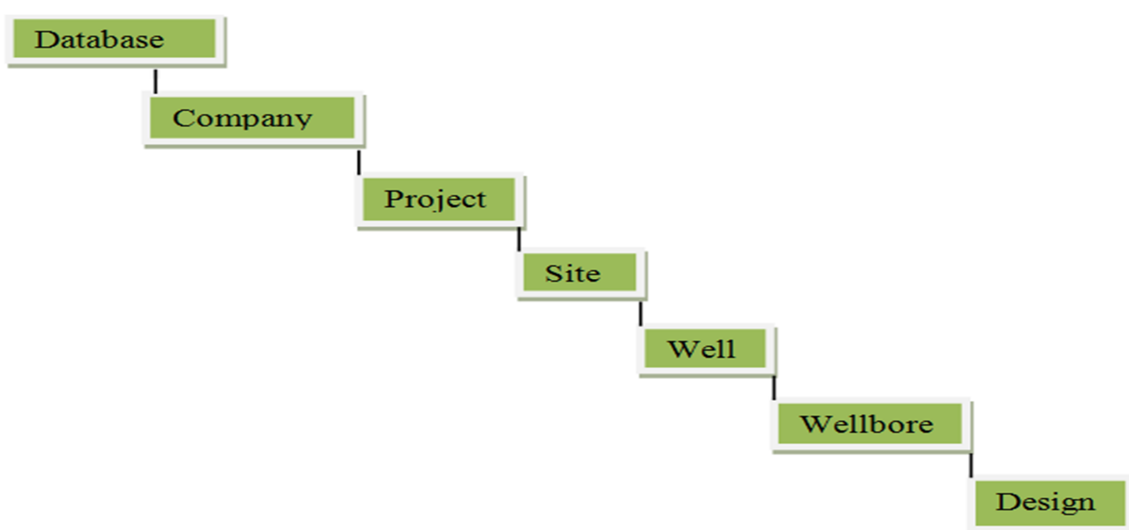


Figure 7. Hierarchical database structure of the EDM database

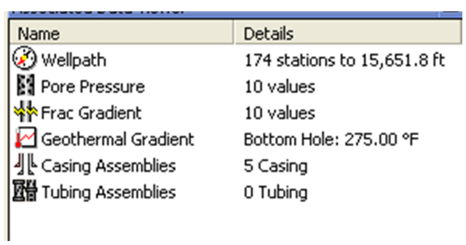
CHAPTER 4
RUSULTS AND DISCUSSION

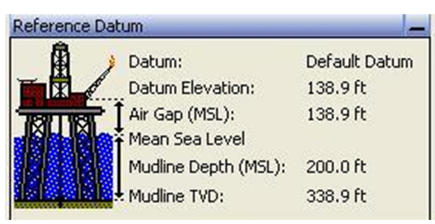
At initial stage of this project author has used the software from Landmark: StressCheck™ and CasingSeat™. As a manual calculation author has developed an Excel Macro in order to compare and analyze the results with the one obtained from Landmark.

<u>CasingSeat</u>

The following steps were accomplished for *Eshqurbon-2* well using CasingSeat:

- Entered general well information:





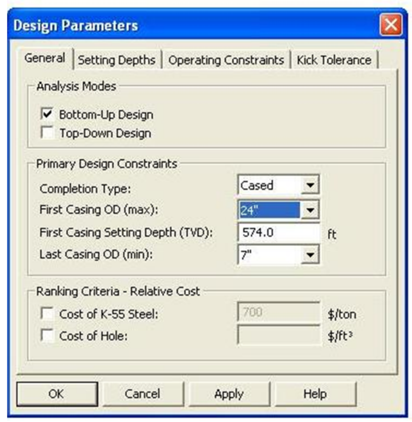
Figures 8. General Well Information

From the information above we can see that it is a Jack-Up platform with shallow water depth of 200 ft and depth from rig floor until sea bed is 338.9 ft. The design has 10 values of Pore and 10 values of Fracture pressure data and bottom-hole pressure is 275^0F.

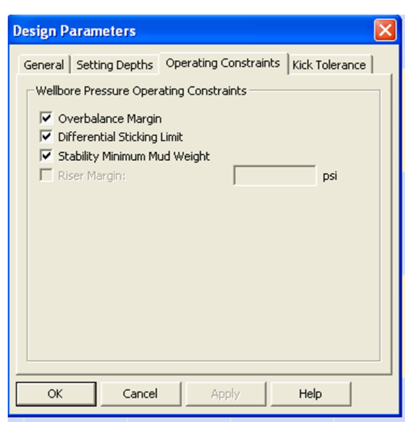
- Defined the well trajectory: The trajectory was obtained from real field data (see Figure 1 in Appendix A).

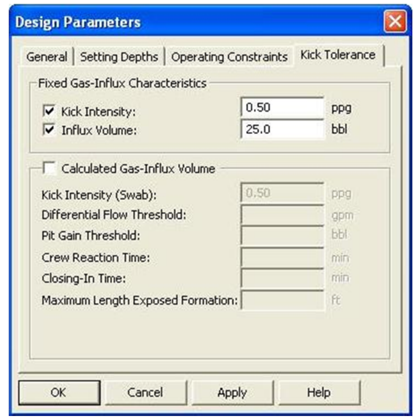
The trajectory was obtained from real field data for Eshqurbon-2 well.

- Defined allowable hole sizes using the spreadsheet (see Figure 2 in Appendix A) Author has used a default Landmark Catalog in order to get first results and as for later simulations author have reduced the catalog so that it meets traditional casing grades.
- Specified a design parameters for Eshqurbor-2 well as below:



A design can be performed in two ways: Bottom-Up or Top-Down Design for analysis modes. The CasingSeat software can use these options individually or use both simultaneously. We would like our casing to be 7'' for production liner and first casing depth to be at 574 ft and it is driven well. We also can select the completion to be open or cased hole. For this project author have chosen the first casing OD to be 24''.





As an operating constraints author have chosen *Overbalance Margin*, *Differential Sticking limit* and *Stability Minimum Mud Weight* as a design constraints. From offset data it has been observed that we have a Stability Minimum Mud Weight that we need to consider in designing of the well. This minimum is required in order to keep our hole stable during drilling operation. Author has also designed a well without using Stability Minimum Mud Weight in order to check its influence on final well schematic. This Stability Minimum Mud Weight can shift the lower constraint curve to the right.

The differential sticking limit was taken to be 2000 psi because the pore pressure and fracture pressure is not relatively high enough.

At kick tolerance tab author have specified the intensity of the kick volume of gas influx, and to calculate the gas influx volume for a swab kick. In this project author took **20 bbl** of influx volume ensures that a kick of the specified magnitude can be circulated out without exceeding the Upper constraint Curve.

- Defining the lithology in Casing Seat (see Figure 3 in Appendix A)

Lithological description above specifies Layers Top, Layers Type, Competent Layer (competent to set the casing), Overbalance Margin (ppg), Differential Sticking Limits (psi) and Stability Minimum Mud Weight (ppg). The stability Minimum Mud Weight (ppg) is obtained from offset wells and will be used as a minimum design constraint. We are checking our design with 2000 psi Differential sticking limits. The competent layer checkbox indicates whether the casing can be set at this layer or not. CasingSeat will not set the casing at the layer where it is indicated as a not competent layer. Overbalance Margin is needed to specify the minimum mud weight that will prevent the formation from caving in inside the Wellbore.

- Defining Pore pressure and Fracture Pressure (see Figure 4 in Appendix A)

From the given pore pressure, fracture pressure and Minimum Stability Mud weight we can construct a Design Plot in CasingSeat. Based on this plot CasingSeat will calculate a setting depth with taking into consideration various constraints (Kick tolerance, First Casing Setting Depth, Stability Min. MW).

<u>Result Analyzes:</u>

After specifying all relevant constraints and data we press F8 button to let CasingSeat calculate the setting depth.

For the parameters that author has initially specified, the CasingSeat has generated more than 3000 casing options of casing seats and ODs. This is mainly due to the using default Halliburton catalog. In order to squeeze the options, author have adjusted the catalog by having only traditional casing ODs (24'', 20'', 13 3/8'', 9 5/8'' and 7''). After that the casing was recalculated and finally we had 30 casing design options with different combinations of OD's specified. For ERD well we need to have smaller OD casing strings because it enables us efficient hole cleaning which is crucial in this type of wells (see Figure 5 in Appendix A). As a result of this calculation we have 6 string completions and 5 string completion options available (see Figure 6 in Appendix A).

We can see from the above two results, bottom-up design, at left side there is a 6 string completion (option #21) design and at right side we have 5 string completion (option #12) bottom-up designs. The kick tolerance is the same for this both casing designs which is 25 bbl. We can refer to bottom part of this result that gives reasons for setting the casing at specific depth. It can be observed that due to change in hole diameter from 17 ½" hole to 14 ¾" we have to set one more casing above 13 3/8'' casing which is 16'' because fixed kick tolerance (25 bbl) is exceeded. In both cases we can check that Stability Min. MW is applied (see Figure 7 in Appendix A).

Author has also tried to compare Top–down design with Bottom-up designs. From figure 8 in Appendix, author has selected 5 string completions for both cases with identical OD's. We can see that Top-down design will give deeper casing setting depth compare to Bottom-Up design (9 5/8'' was set at 10533 ft compare to 7820 ft in bottom-up design).

Author has also checked the impact of Stability Min. MW on casing seat selection (see Figure 9 in Appendix A). We can see from this plot that Stability Min. MW will not influence much on casing setting depth and the only minor change was on setting of 20'' surface casing (871 ft in No Stability MW vs 747 ft have Stability MW).

If we use Stability Min. MW we could increase our minimum kick tolerance limit from 20bbl to 25 bbl and with top-down design plus Stability Min. MW we can increase kick tolerance up to 30 bbl (see Figure 11 in Appendix A).

From this analyzes we can conclude the final decision is based on of what we need from this design? What kind of results we are expecting? Because it may give a hundred results, but best choice is based on our needs. For ERD wells major concern is OD of the casing strings. We need to go for lower diameter strings because small diameter gives less cuttings and easier to transmit it to the surface. Moreover, less hydraulic horse power is need at surface to clean the bottom hole.

In order to have a feasible design for ERD well author has chosen less casing stings completion which is 5 strings with bottom-up design and including Stability Min. MW. Hence final completion has the following configurations:

- 24'' conductor casing (driven),
- 20'' surface casing is drilling with 22'' Bit,
- 13 3/8'' intermediate casing is drilled with 17 1/5'' Bit
- 9 5/8'' intermediate casing is drilled with 12 ¼'' Bit
- 7'' production liner is drilled with 8 1/5'' Bit

The final casing schematic is shown below (Option #12b):

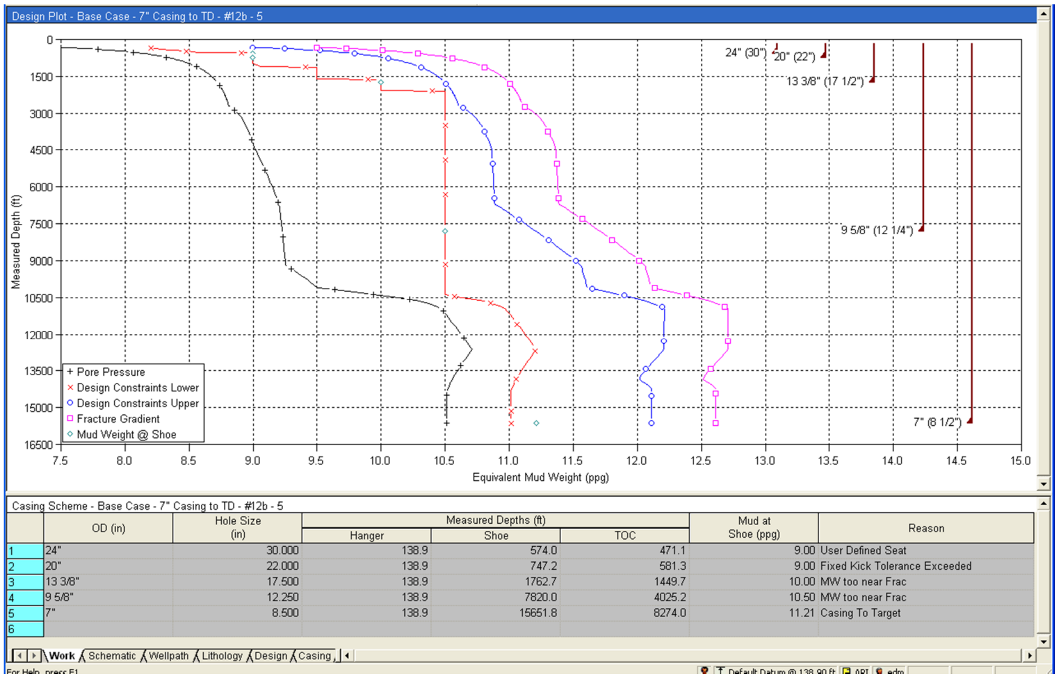


Figure 9. Final Casing Schematic for Eshqurbon2 well, option #12b.

CasingSeat does not give an option to select a liner for any hole sections. But for later considerations author suggests to use 7'' production liner, in order to save a cost.

<u>StressCheck</u>

To access our casing schematic we need to open Project from EDM database in Well Explorer.

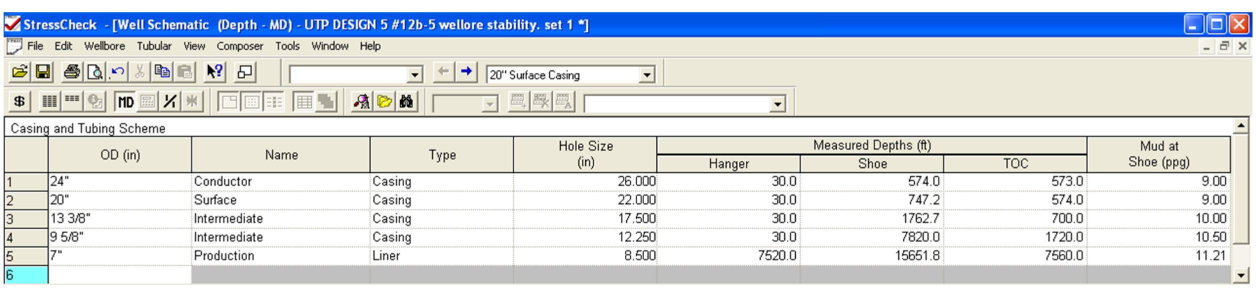
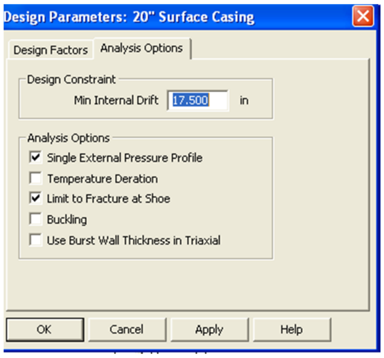


Figure 10. Casing and Tubing Scheme in StressCheck.

We can change now our 7'' production casing to production liner and also to specify Top of Cement depth and Top of Liner depth here. The Mud at Shoe represents the density values of the mud in which the casing string was run and cemented. The loads analyzes is carried out one by one for each hole sections, because different hole section will experience different loads.

Analysis Options for 20" surface casing

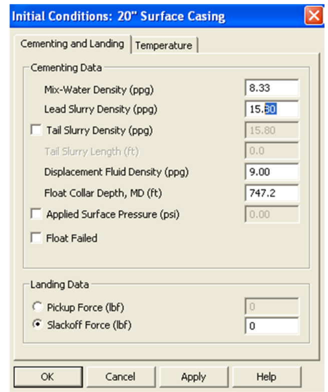


Single External Pressure Profile was chosen to use the same external pressure profile, as selected in the respective dialog. *Limit to Fracture at Shoe* causes a boundary condition to be imposed on load case pressure profiles such that the fracture pressure at a casing shoe is not exceeded. The same analysis was applied for 13 3/8" intermediate casing.
But for 9-5/8" intermediate casing and 7" production liner, we need to consider also *Temperature deration* and *Buckling.*

Temperature deration will causes the minimum yield strength (MYS) for all string sections to be reduced as a function of temperature according to the deration schedule in the Pipe Grade Properties spreadsheet.

Buckling enables the analysis of buckling onset and extent for all load cases selected on the Select tab of the Burst Loads, Collapse Loads, or Axial Loads dialogs.

After that author have specified Initial Conditions for 20’’ Surface casing as per below:



- ✓ For 20’’surface casing and for 13 3/8” intermediate casing strings we have used 15.8 ppg and 15.6 ppg cement slurry respectively. This value is taken from real field data and their accuracy is beyond the topic of this paper. Thus we consider that this cement slurry will not fracture our casing shoe.
- ✓ For 9 5/8” intermediate casing uses 12.4 ppg lead slurry and 15.8 tail slurry with depth of 1100ft. Displacement fluid density is 10.5 ppg.
- ✓ For 7’’ production liner we have used 15.2 ppg of lead slurry with displacement fluid of 11.21 ppg.

This data will be used to define a load cases, determine initial state of the casing, and dictate design and analysis logic. The default slurry densities are based on Class G neat cement.

<u>Defining Burst Load</u>

The design load is determined from aggregate worst case burst loading as a function of depth, with design factor and temperature deration of minimum yield strength considered for all selected burst load.

The burst loads selection for 20’’ surface casing is shown below:

- Displacement to Gas
- Lost Returns with Water
- Pressure Test
- Drill Ahead loads.

External Profile: Fluid Gradient w/Pore Pressure (This external pressure profile is constructed from a mud density above the TOC, a fluid gradient from the TOC to the prior shoe and in open hole, either the fluid gradient below the TOC or the pore pressure profile.)

Author assumes worst case scenario and thus we took Displacement to Gas to see what is the maximum burst load for this hole section.

For 13 3/8'' and 9 5/8'' casings the burst load selection are as follows:

- Displacement to Gas
- Lost Returns with Water
- Pressure Test
- Green Cement Pressure test
- Drill Ahead loads.

External Profile: Fluid Gradient w/Pore Pressure.

For 7" production liner loads are as per below:

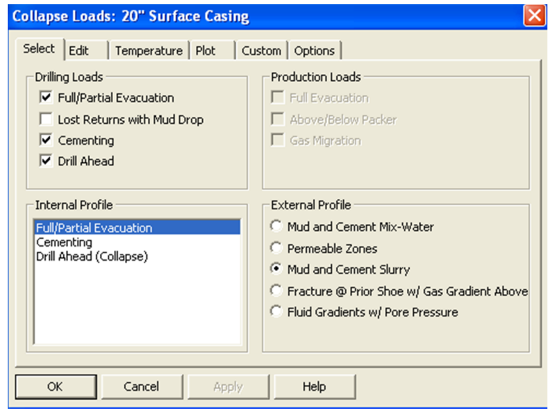
- Pressure test
- Green cement pressure test
- Tubing Leak

External Profile: Fluid Gradient w/Pore Pressure.

From the figure 12 in Appendix for 7'' Production liner's Burst Load plot, it can be determined that from surface until depth of 14890 ft the Tubing Leak is contributing to burst load line and from 14890 ft to TD the acting load is Pressure test that we applied in amount of 1000 psi.

There are two burst loads contributing to burst load line for 9 5/8" and 13 3/8" intermediate casing (see Figure 13 and 14 in Appendix A), which is Displacement to Gas and Pressure test. For 20" surface casing, since it sets at shallower depth compare to next hole sections, the dominating force is Pressure test only which is 1000 psi.

Defining Collapse Load



For all casing string section we apply:

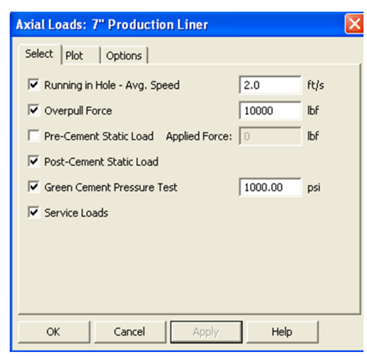
- Full/Partial Evacuation;
- Cementing;
- Drill Ahead

External Profile: Mud and Cement Slurry

Author have applied additional safety factor

For all casing sections the critical Collapse load is Full/Partial Evacuation that contributes to design load line (see Figure 16, 17 and 18 in Appendix casing collapse load plot). This safety factor is determined from the various literature reviews. It was determined that horizontal section is influenced by formation subsidence that produces non-uniform overburden load with 25% of reduction and perforation technique results 10% to 60% of crushing resistance. Accurate determination of this safety factor requires addition study of the formation and its characteristics in Eshqurbon2 well.

Defining Axial Loads



From the Triaxial Design Limit Plot in Appendix A (Figure 19, 20, 21 and 22) we can see that all loads for each hole section are within the envelop which means that our casing can withstand to the combined loads experienced by casing as a function of depth, based on current string load cases selected on the Burst Loads, Collapse Loads, and Axial Loads Dialog boxes.

From Design Plot that is given in Appendix A Figure 23 we can clearly observe that Collapse pressure is critical load for all of them. The same procedure will be followed to check the rest of the casing section.

Casing Strings	Running in hole	Overpull Force	Post Cement Static Load	Green Cement Pressure Test	Service Loads
7” production liner	2	100000	+	1000	+
9 5/8” intermediate casing	3	100000	+	1000	+
13 3/8” intermediate casing	3.5	100000	+	1000	+
20” surface casing	4	-	+	-	+

Table 4. Axial loads selection for Eshqurbon2 well.

The **<u>Well Summary</u>** is given below:

Well Summary

	String	OD/Weight/Grade	Connection	MD Interval (ft)	Drift Dia. (in)	Minimum Safety Factor (Abs)				Design Cost ($)
						Burst	Collapse	Axial	Triaxial	
1	Conductor Casing	24", 125.500 ppf, X-42	N/A	30.0-574.0	22.813	N/A	N/A	N/A	N/A	23,892
2										Total = 23,892
3										
4	Surface Casing	20", 94.000 ppf, H-40	BTC, VM-130	30.0-747.2	18.936	1.52	1.26	3.08	1.92	62,571
5										Total = 62,571
6										
7	Intermediate Casing	13 3/8", 68.000 ppf, J-55	BTC, J-55	30.0-1762.7	12.259	3.13	1.62	2.74	2.35	52,874
8										Total = 52,874
9										
10	Intermediate Casing	9 5/8", 43.500 ppf, C-75	BTC, C-75	30.0-7820.0	8.625 A	3.10	1.62	3.12	2.50	198,465
11										Total = 198,465
12										
13	Production Liner	7", 26.000 ppf, C-90	BTC, C-90	7520.0-15651.8	6.151	4.10	1.59	(4.30)	2.35	135,439
14										Total = 135,439
15										
16										Total = 473,241
17	A Alternate Drift									
18	( ) Compression									
19										

Figure 11. Well Summary for Eshqurbon 2 well.

From Well summary we can conclude that we met all design criteria and our casing grade can withstand all anticipated loads. Hence, our final well schematic is shown below:

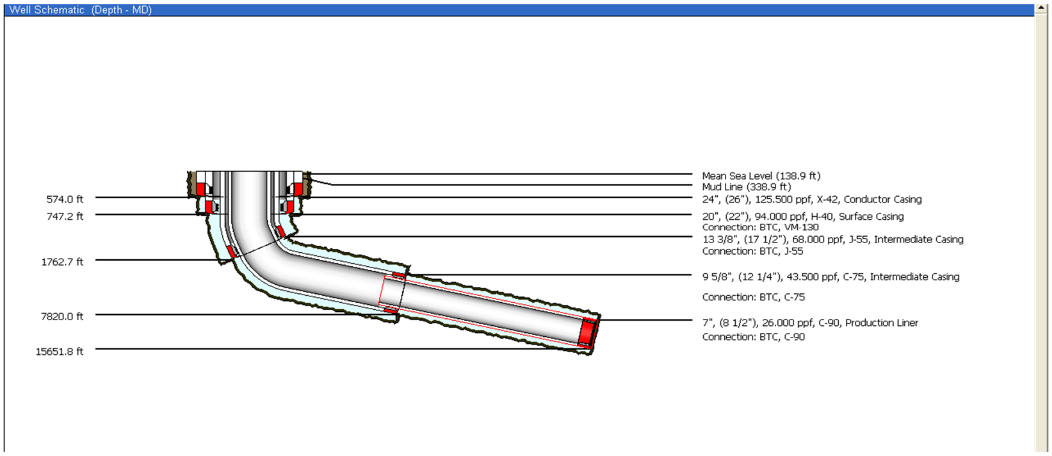


Figure 12. Well Schematic for Eshqurbon 2 well

Excel Macro

The User is asked to enter a Pore and Fracture pressure with corresponding depth in Microsoft Excel (see Figure 24 in Appendix B). Trip and Kick Margin will be calculated once a Pore and Fracture Pressures are specified. The date is limited with 15 data only. For this project the following hole sections' parameters have been specified:

1. Production Casing	
Planned Mud Weight at TD of next hole, ppg	**11.30**
Hole diameter, in	**8.50**
OD of DP, in	**5.50**
Gradient of gas, G, psi/ft	**0.10**
Minimum Kick Tolerance	**25**
2. INTERMEDIATE CSG	
Planned Mud Weight at TD of next hole, ppg	**10.60**
Hole diameter, in	**12.25**
OD of DP, in	**5.50**
Gradient of gas, G, psi/ft	**0.10**
Minimum Kick Tolerance	**50**
3. INTERMEDIATE 2 CSG	
Planned Mud Weight at TD of next hole, ppg	**9.80**
Hole diameter, in	**17.50**
OD of DP, in	**5.50**
Gradient of gas, G, psi/ft	**0.10**
Minimum Kick Tolerance	**50**
4. SURFACE CSG	
Planned Mud Weight at TD of next hole, ppg	**9.50**
Hole diameter, in	**22.00**
OD of DP, in	**5.50**
Gradient of gas, G, psi/ft	**0.10**
Minimum Kick Tolerance	**50**

After that User can press Calculate button to launch the calculation and author have got the following casing scheme for Eshqurbon-2 well (see Figure 25 in Appendix B).

5. FINAL CSG SCHEME

Casing String	Interval, ft From	Interval, ft To	Expected Kick at CSD
Production	5404	4068	25
Intermetdiate	4068	2886	50
Intermetdiate 2	2886	1281	50
Surface	1281	748	50

CALCULATE

The design is based on PETRONAS standards requirement that has been dictated by kick tolerance which is 25 bbl for 8 ½'' hole section and 50 bbl for upper hole sections. We can see from the plot that first conductor casing must be at depth of 793 ft and OD must be greater than surface casing. The table below shows casing scheme and mud weight prognoses:

	Casing strings	Depth		Hole Size	Estimated Formation Pressure @CSD		Mud Weight	Overbalance
		from	to	in	psi	ppg	ppg	psi
1	Conductor casing	0	748	26	344			
2	Surface casing	748	1280	22	587	8.82	9.50	45
3	Intermediate csg	1280	2880	17 1/2	1342	8.96	9.50	81
4	Intermediate csg 2	2880	4060	12 1/4	1962	9.29	10.00	149
5	Production liner	3910	5404	8 1/5	2879	10.25	11.30	296

Table 5. Casing schematic and Mud design for Eshqurbon 2 well.

In determining of the setting depth author have taken into consideration 2000 psi differential sticking limits and also 0.5 ppg of kick and trip margins. There is no geological problems such as shallow gas or salt creeps, have been found based on offset wells. Once casing setting depth has been determined we can proceed with load calculation analyzes.

Collapse loads:

Selection of casing weight and grades for each casing string based on loads encountered while designing. Author has assumed the complete loss case for each hole section in order to have a worst case scenario (see Appendix B for Collapse Loads). Collapse rating for inclined section of the well is determined by multiplying the collapse load by

1.5. This safety factor was calculated from the reduction due perforation technique results with 20% and 60% reduction from formation subsidence due to non-uniform overburden load which act as a point line load on the pipe. Hence by taking into account these two loads reduction author have chosen to increase the collapse resistance up to 50% and have used 1.5 as a safety factor while designing a collapse load for inclined section of the well. The loads are summarized in following table:

	Collapse loads			
	Casing String	Depth, ft	TOP, psi	BOTTOM, psi
1	Conductor casing	748		
2	20'' Surface casing	1280	0	632
3	13 3/8'' Intermediate csg	2880	0	1423
4	9 5/8''Intermediate csg 2	4060	0	2111
5	7 ''Production liner	5404	2298	3175

Table 6. Collapse Loads summary

Burst Loads:

For calculation of burst load 1.1 Safety factor was applied for all sections. The design of the grades is based on unlimited kick since it represents the worst case scenario for burst case in the wellbore. External loads were calculated based on the formula above sections. Initial Cementing program were also carried out in order to calculate burst loads and it is given as below table:

	Cementing Program	Depth		Cemend Density
		from	to	ECD, ppg
1	24'' Conductor casing	0	748	
2	20'' Surface casing	590	1280	12
3	13 3/8'' Intermediate csg	1130	2880	12
4	9 5/8''Intermediate csg 2	2730	4060	14
5	7 ''Production liner	3910	5404	14

Table 7. Primary design for cementing density

The cementing calculation is done based on the fracture pressure at the casing shoe. The burst loads are summarized in following table:

Burst Loads

			Internal Loads		External Loads	
	Casing String	Depth, ft	Top of casing	Bottom of casing	Top of Casing	Bottom of Casing
1	24'' Conductor casing	748				
2	20'' Surface casing	1280	1054	1182	0	557
3	13 3/8'' Intermediate csg	2880	1556	1844	0	1615
4	9 5/8''Intermediate csg 2	4060	2339	2656	0	2232
5	7 ''Production liner	5404	2730	2879	0	1088

Table 8. Burst loads summary

After finding relevant internal and external loads we can find a burst load by subtracting internal load from external load. The plots for each hole section are given in Appendix B (see Collapse and Burst Loads section).

Tensional loads:

Casing buoyant weights were determined based on its air weights and pressure test of 1000 psi were conducted for each casing sections. Bending force was applied on curved sections only and shock loads also calculated from top to bottom of the string.

Tensional Load

	Casing strings	Buoyancy Factor	Air Weight	Buoyant Weight	Calculated Tension	Pressure Testing	Bending Force	Shock Load
1	24'' Conductor casing							
2	20'' Surface casing	0.85	136320	116340	149952	298496	0	159750
3	13 3/8'' Intermediate csg	0.85	195840	167137	215424	132665	174760	102000
4	9 5/8''Intermediate csg 2	0.85	162400	137358	178640	66804	72765	60000
5	7 ''Production liner	0.83	38844	32083	42728	214966	0	39000

Table 9. Tensional loads summary

After that author consider three load cases for which total tensile force should be calculated: running conditions, pressure testing and static conditions. These are summarized in table below (see also Appendix B for Tension loads section):

	Casing Strings	Running Condition	Pressure Testing condition	Static Condition
1	24'' Conductor casing			
2	20'' Surface casing	276090	414837	116340
3	13 3/8'' Intermediate csg	269137	474562	341897
4	9 5/8''Intermediate csg 2	197358	276927	210123
5	7 ''Production liner	71083	247049	32083

Table 10. Load cases scenario for Tensional Loads in Eshqurbon 2 well

From the above table, it can be seen the maximum force that the top casing joint sees is in fact during pressure testing. Hence this load was taken as a base for design of Axial loads.

<u>From the plots we can observe that the critical loads that impacting on our design is collapse loads.</u>

Eventually we can select the casing weight and grades for each casing string based on loads encountered while designing of the Eshqurbon-2 well. The table below summarizes the selection:

Casing string	OD, in	Grades	Casing Specification			Safety Factor		
			(psi)	(psi)	('000)lbs	1.0-1.5	1.1	1.3
20" Surface casing	20	J-55, 106.5 ppf	770	2410	1685	1.22	2.29	4.06
13 3/8"Intermediate casing	13 3/8	L-80, 68 ppf	2260	5020	1556	1.59	3.23	3.28
9 5/8" Intermediate casing 2	9 5/8	C-90, 40 ppf	3250	6460	1031	1.54	2.76	3.72
7" Production Liner	7	N-80, 26 ppf	5410	7240	604	1.70	2.65	2.44

Table 11. Well Summary for Eshqurbon 2 well by using MS Excel.

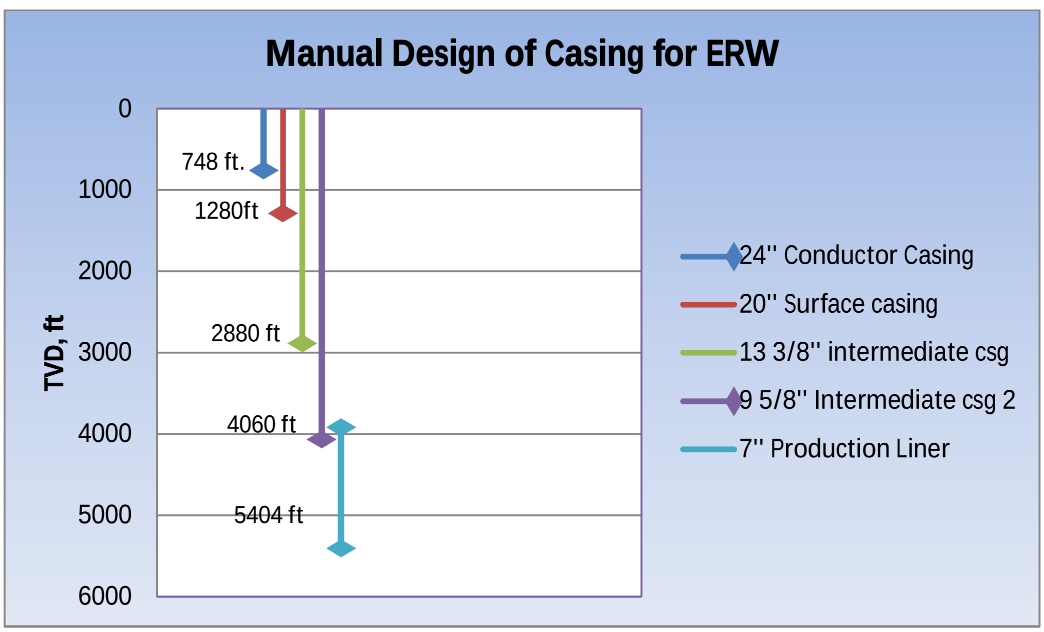


Figure 13. Well Schematic for Eshqurbon 2 well by using MS Excel.

Comparison:

- **Casing Setting Depth, ft. Bottom up design**

Casing String	Manual Calculation		Using CasingSeat and StressCheck*	
	TVD, ft	Kick tolerance bbl	TVD, ft	Kick tolerance bbl
24''Conductor casing	748	**50**	574	25
20'' Surface casing	1280	**50**	747	25
13 3/8'' Intermediate csg	2880	**50**	1680	25
9 5/8'' Intermediate csg 2	4060	**50**	3490	25
7'' Production Liner	5404	**25**	5110	25

* Author would like to specify here that CasingSeat software has a certain limitation regarding a selection of kick tolerance. It accepts only one kick tolerance for entire hole sections from bottom to top. If the entered kick tolerance cannot be tolerated for that amount it will not give a result. Author has developed an Excel Macro in order to overcome this limitation and result is shown in table above.

Casing String	Manual Calculation		Using CasingSeat and StressCheck	
	TVD, ft	Kick tolerance bbl	TVD, ft	Kick tolerance bbl
24''Conductor casing	494	**25**	574	25
20'' Surface casing	655	**25**	747	25
13 3/8'' Intermediate csg	1970	**25**	1680	25
9 5/8'' Intermediate csg 2	4070	**25**	3490	25
7'' Production Liner	5404	**25**	5404	25

As we can see that the results obtained by manual calculation and the calculation using by Landmark CasingSeat Software, the difference is less than 20% and can be considered as accurate result. This difference is basically due to consideration of temperature and formation compatibility factors in CasingSeat while Excel Macros consider only allowable kick tolerance limits as a design factor. As a final choice for manual calculation author have chosen a first case which is 25 bbl for 8 1/5'' hole and 50 bbls for upper sections.

- **Casing Weight and Grades**

Casing String	**Manual Calculation**		**Using CasingSeat and StressCheck**	
	Grade	**Weight, ppf**	**Grade**	**Weight, ppf**
24''Conductor casing	X-42	125.5	X-42	125.5
20'' Surface casing	J-55	106.5	H-40	94
13 3/8'' Intermediate csg	L-80	68	J-55	68
9 5/8'' Intermediate csg 2	C-90	40	C-75	43.5
7'' Production Liner	N-80	26	C-90	26

The result obtained from Manual calculation and by using Landmark's software was given in above table shows that the loads encountered in Eshqurbon-2 well can be solved using Landmark software also. Based on this table we can conclude that we might have save the cost due to lower configuration that Landmark gave.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Casing used in horizontal drilling is subject to load not found in vertical wells that requires careful planning and loads analyzes. Successful casing design can be accomplished when we can determine the loads as accurate as possible. In this report author is proposing a casing design with some procedures to be followed for successfully designing ERD wells. Author had gone through several literature reviews and case studies in order to understand nature of loads that exists in long horizontal wells. As a recommendation, first of all it is very important to have as much data as possible from offset wells. Pore and Fracture pressures together with geological information and possible Stability Min. Mud Weight information are important for casing design, especially for determination of casing setting depth. There are some formation that we cannot set our casing or there may be excessive pressure differential between wellbore and formation pressure. Thus much effort need to be taken for primary data gathering and it is very important for casing design. Yet we need to specify what kind of design we want? Because using Landmark software may give you hundred or even thousand results. Thus the final choice is from the drilling engineer who is design a well.

Moreover for ERD wells it is preferable to have smaller OD's of the casing. The smaller diameter will generate less cutting and it will help to clean bottom hole efficiently. As for load determinations author has found that StressCheck can give an accurate load calculation compare to manual one. Author also suggest to use StressCheck for casing grade selection because it much faster and very user friendly. For Extended Reach Wells author recommends to use worst case scenario for Burst Load use Full Displacement to Gas and for Collapse Load use Full/Partial Evacuation load. The safety factor for horizontal section must be 1.5 for collapse loads. This will help the designer to be sure that if the casing grade passes through this worst case scenario it will withstand to any other loads. Furthermore, the StressCheck has extra loads consideration such as Pressure Test, Green Cement Tests, and Service Loads which generates more accurate design compare to manual one.

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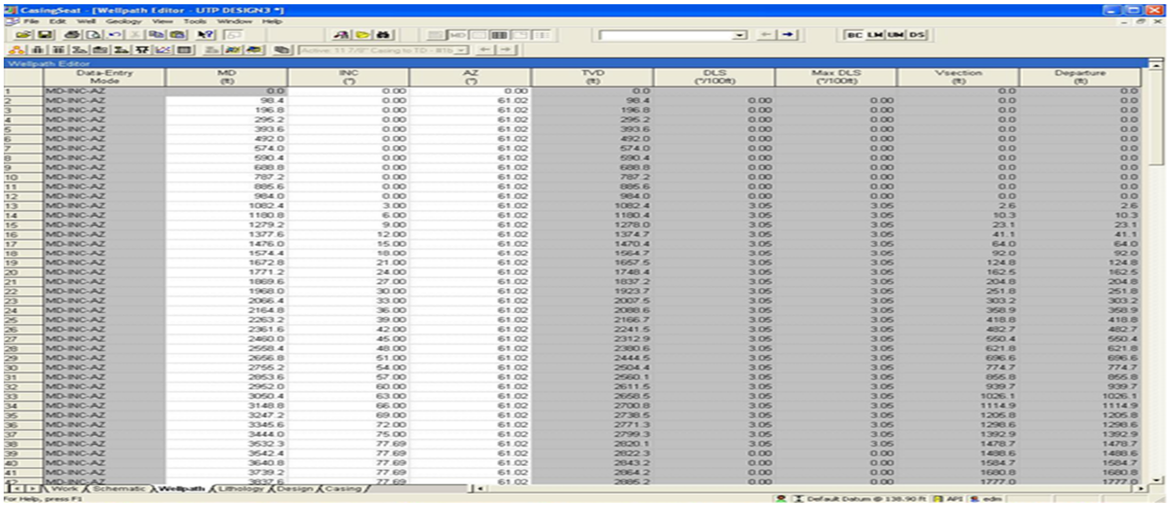
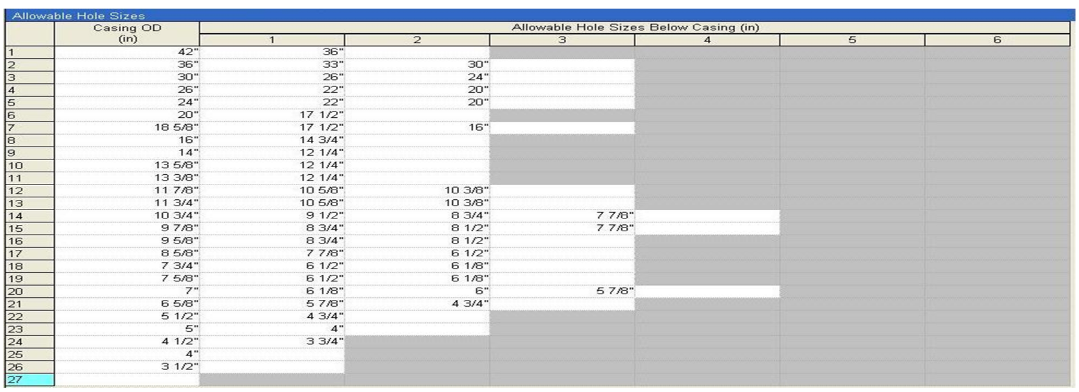
APPENDIX A



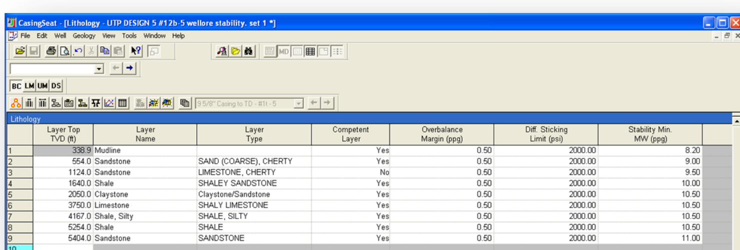
	Data-Entry Mode	MD (ft)	INC (°)	AZ (°)	TVD (ft)	DLS (°/100ft)	Max DLS (°/100ft)	Vsection (ft)	Departure (ft)
1	MD-INC-AZ	0.0	0.00	0.00	0.0			0.0	0.0
2	MD-INC-AZ	98.4	0.00	61.02	98.4	0.00	0.00	0.0	0.0
3	MD-INC-AZ	196.8	0.00	61.02	196.8	0.00	0.00	0.0	0.0
4	MD-INC-AZ	295.2	0.00	61.02	295.2	0.00	0.00	0.0	0.0
5	MD-INC-AZ	393.6	0.00	61.02	393.6	0.00	0.00	0.0	0.0
6	MD-INC-AZ	492.0	0.00	61.02	492.0	0.00	0.00	0.0	0.0
7	MD-INC-AZ	574.0	0.00	61.02	574.0	0.00	0.00	0.0	0.0
8	MD-INC-AZ	590.4	0.00	61.02	590.4	0.00	0.00	0.0	0.0
9	MD-INC-AZ	688.8	0.00	61.02	688.8	0.00	0.00	0.0	0.0
10	MD-INC-AZ	787.2	0.00	61.02	787.2	0.00	0.00	0.0	0.0
11	MD-INC-AZ	885.6	0.00	61.02	885.6	0.00	0.00	0.0	0.0
12	MD-INC-AZ	984.0	0.00	61.02	984.0	0.00	0.00	0.0	0.0
13	MD-INC-AZ	1082.4	3.00	61.02	1082.4	3.05	3.05	2.6	2.6
14	MD-INC-AZ	1180.8	6.00	61.02	1180.4	3.05	3.05	10.3	10.3
15	MD-INC-AZ	1279.2	9.00	61.02	1278.0	3.05	3.05	23.1	23.1
16	MD-INC-AZ	1377.6	12.00	61.02	1374.7	3.05	3.05	41.1	41.1
17	MD-INC-AZ	1476.0	15.00	61.02	1470.4	3.05	3.05	64.0	64.0
18	MD-INC-AZ	1574.4	18.00	61.02	1564.7	3.05	3.05	92.0	92.0
19	MD-INC-AZ	1672.8	21.00	61.02	1657.5	3.05	3.05	124.8	124.8
20	MD-INC-AZ	1771.2	24.00	61.02	1748.4	3.05	3.05	162.5	162.5
21	MD-INC-AZ	1869.6	27.00	61.02	1837.2	3.05	3.05	204.8	204.8
22	MD-INC-AZ	1968.0	30.00	61.02	1923.7	3.05	3.05	251.8	251.8
23	MD-INC-AZ	2066.4	33.00	61.02	2007.5	3.05	3.05	303.2	303.2
24	MD-INC-AZ	2164.8	36.00	61.02	2088.6	3.05	3.05	358.9	358.9
25	MD-INC-AZ	2263.2	39.00	61.02	2166.7	3.05	3.05	418.8	418.8
26	MD-INC-AZ	2361.6	42.00	61.02	2241.5	3.05	3.05	482.7	482.7
27	MD-INC-AZ	2460.0	45.00	61.02	2312.9	3.05	3.05	550.4	550.4
28	MD-INC-AZ	2558.4	48.00	61.02	2380.6	3.05	3.05	621.8	621.8
29	MD-INC-AZ	2656.8	51.00	61.02	2444.5	3.05	3.05	696.6	696.6
30	MD-INC-AZ	2755.2	54.00	61.02	2504.4	3.05	3.05	774.7	774.7
31	MD-INC-AZ	2853.6	57.00	61.02	2560.1	3.05	3.05	855.8	855.8
32	MD-INC-AZ	2952.0	60.00	61.02	2611.5	3.05	3.05	939.7	939.7
33	MD-INC-AZ	3050.4	63.00	61.02	2658.5	3.05	3.05	1026.1	1026.1
34	MD-INC-AZ	3148.8	66.00	61.02	2700.8	3.05	3.05	1114.9	1114.9
35	MD-INC-AZ	3247.2	69.00	61.02	2738.5	3.05	3.05	1205.8	1205.8
36	MD-INC-AZ	3345.6	72.00	61.02	2771.3	3.05	3.05	1298.6	1298.6
37	MD-INC-AZ	3444.0	75.00	61.02	2799.3	3.05	3.05	1392.9	1392.9
38	MD-INC-AZ	3532.3	77.69	61.02	2820.1	3.05	3.05	1478.7	1478.7
39	MD-INC-AZ	3542.4	77.69	61.02	2822.3	0.00	0.00	1488.6	1488.6
40	MD-INC-AZ	3640.8	77.69	61.02	2843.2	0.00	0.00	1584.7	1584.7
41	MD-INC-AZ	3739.2	77.69	61.02	2864.2	0.00	0.00	1680.8	1680.8
42	MD-INC-AZ	3837.6	77.69	61.02	2885.2	0.00	0.00	1777.0	1777.0

Figure 1. Well Trajectory for Eshqurbon 2 well.



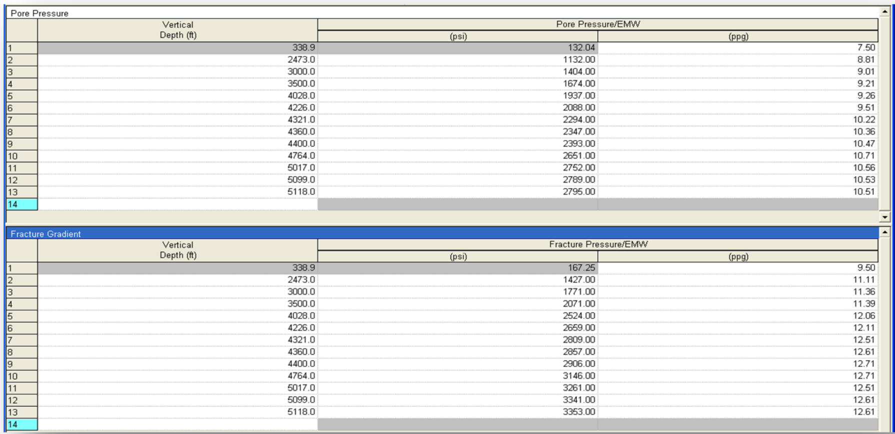
	Casing OD (in)	Allowable Hole Sizes Below Casing (in)					
		1	2	3	4	5	6
1	42"	36"					
2	36"	33"	30"				
3	30"	26"	24"				
4	26"	22"	20"				
5	24"	22"	20"				
6	20"	17 1/2"					
7	18 5/8"	17 1/2"	16"				
8	16"	14 3/4"					
9	14"	12 1/4"					
10	13 5/8"	12 1/4"					
11	13 3/8"	12 1/4"					
12	11 7/8"	10 5/8"	10 3/8"				
13	11 3/4"	10 5/8"	10 3/8"				
14	10 3/4"	9 1/2"	8 3/4"	7 7/8"			
15	9 7/8"	8 3/4"	8 1/2"	7 7/8"			
16	9 5/8"	8 3/4"	8 1/2"				
17	8 5/8"	7 7/8"	6 1/2"				
18	7 3/4"	6 1/2"	6 1/8"				
19	7 5/8"	6 1/2"	6 1/8"				
20	7"	6 1/8"	6"	5 7/8"			
21	6 5/8"	5 7/8"	4 3/4"				
22	5 1/2"	4 3/4"					
23	5"	4"					
24	4 1/2"	3 3/4"					
25	4"						
26	3 1/2"						
27							

Figure 2. Allowable Hole Size



	Layer Top TVD (ft)	Layer Name	Layer Type	Competent Layer	Overbalance Margin (ppg)	Diff. Sticking Limit (psi)	Stability Min. MW (ppg)
1	338.9	Mudline		Yes	0.50	2000.00	8.20
2	554.0	Sandstone	SAND (COARSE), CHERTY	Yes	0.50	2000.00	9.00
3	1124.0	Sandstone	LIMESTONE, CHERTY	No	0.50	2000.00	9.50
4	1640.0	Shale	SHALEY SANDSTONE	Yes	0.50	2000.00	10.00
5	2050.0	Claystone	Claystone/Sandstone	Yes	0.50	2000.00	10.50
6	3750.0	Limestone	SHALY LIMESTONE	Yes	0.50	2000.00	10.50
7	4167.0	Shale, Silty	SHALE, SILTY	Yes	0.50	2000.00	10.50
8	5254.0	Shale	SHALE	Yes	0.50	2000.00	10.50
9	5404.0	Sandstone	SANDSTONE	Yes	0.50	2000.00	11.00
10							

Figure 3. Lithology Description in CasingSeat



Pore Pressure

	Vertical Depth (ft)	Pore Pressure/EMW (psi)	(ppg)
1	338.9	132.04	7.50
2	2473.0	1132.00	8.81
3	3000.0	1404.00	9.01
4	3500.0	1674.00	9.21
5	4028.0	1937.00	9.26
6	4226.0	2088.00	9.51
7	4321.0	2294.00	10.22
8	4360.0	2347.00	10.36
9	4400.0	2393.00	10.47
10	4764.0	2651.00	10.71
11	5017.0	2752.00	10.56
12	5099.0	2789.00	10.53
13	5118.0	2795.00	10.51
14			

Fracture Gradient

	Vertical Depth (ft)	Fracture Pressure/EMW (psi)	(ppg)
1	338.9	167.25	9.50
2	2473.0	1427.00	11.11
3	3000.0	1771.00	11.36
4	3500.0	2071.00	11.39
5	4028.0	2524.00	12.06
6	4226.0	2659.00	12.11
7	4321.0	2809.00	12.51
8	4360.0	2857.00	12.61
9	4400.0	2906.00	12.71
10	4764.0	3146.00	12.71
11	5017.0	3261.00	12.51
12	5099.0	3341.00	12.61
13	5118.0	3353.00	12.61
14			

Figure 4. Pore and Fracture in CasingSeat

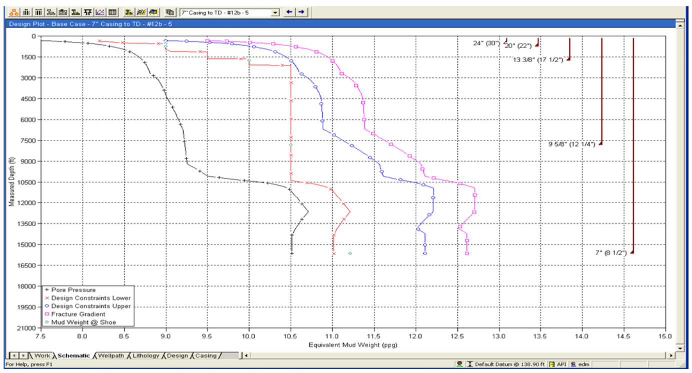
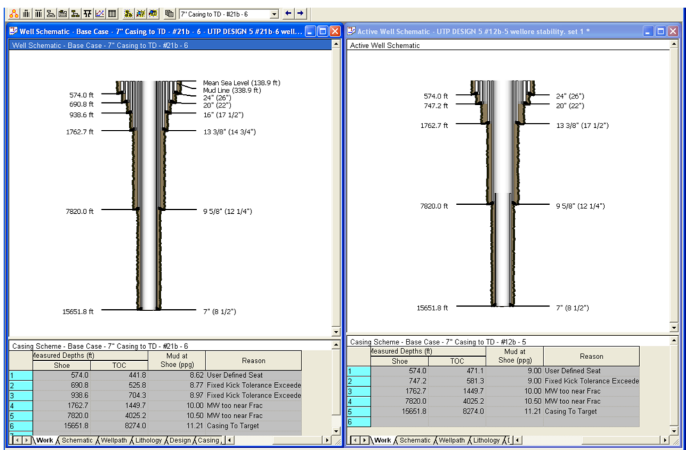


Figure 5. Design Plot in CasingSeat.



Casing Scheme - Base Case - 7" Casing to TD - #21b - 6

	Measured Depths (ft) Shoe	TOC	Mud at Shoe (ppg)	Reason
1	574.0	441.8	8.62	User Defined Seat
2	690.8	525.8	8.77	Fixed Kick Tolerance Exceede
3	938.6	704.3	8.97	Fixed Kick Tolerance Exceede
4	1762.7	1449.7	10.00	MW too near Frac
5	7820.0	4025.2	10.50	MW too near Frac
6	15651.8	8274.0	11.21	Casing To Target

Casing Scheme - Base Case - 7" Casing to TD - #12b - 5

	Measured Depths (ft) Shoe	TOC	Mud at Shoe (ppg)	Reason
1	574.0	471.1	9.00	User Defined Seat
2	747.2	581.3	9.00	Fixed Kick Tolerance Exceede
3	1762.7	1449.7	10.00	MW too near Frac
4	7820.0	4025.2	10.50	MW too near Frac
5	15651.8	8274.0	11.21	Casing To Target
6				

Figure 6. 6 string completions and 5 string completion options

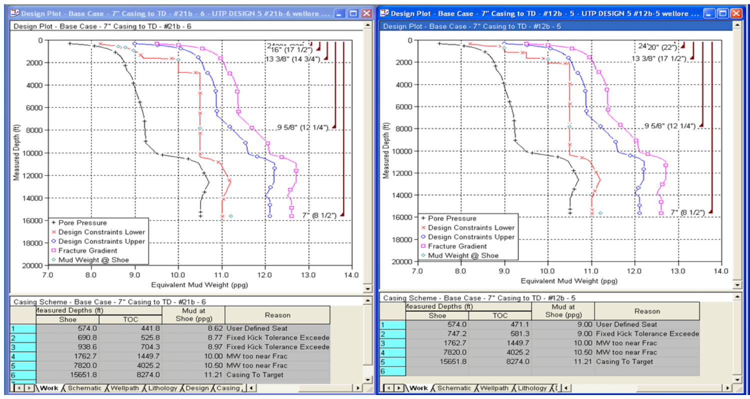


Figure 7. 6 string completions and 5 string completion options with Min Stability applied

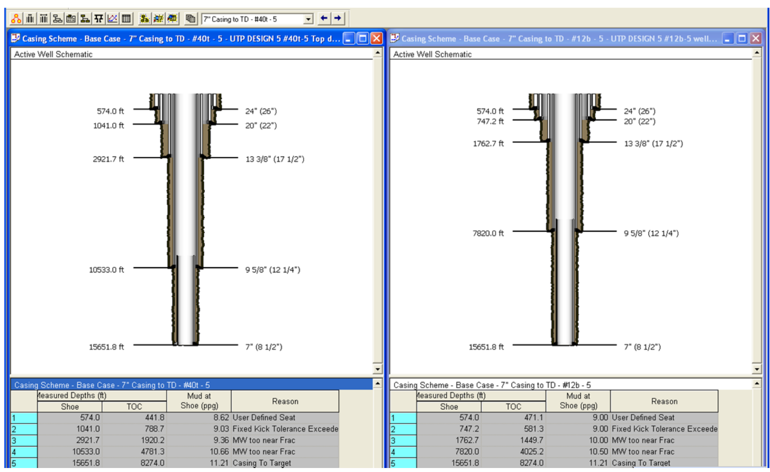


Figure 8. Top –down design vs Bottom-up designs

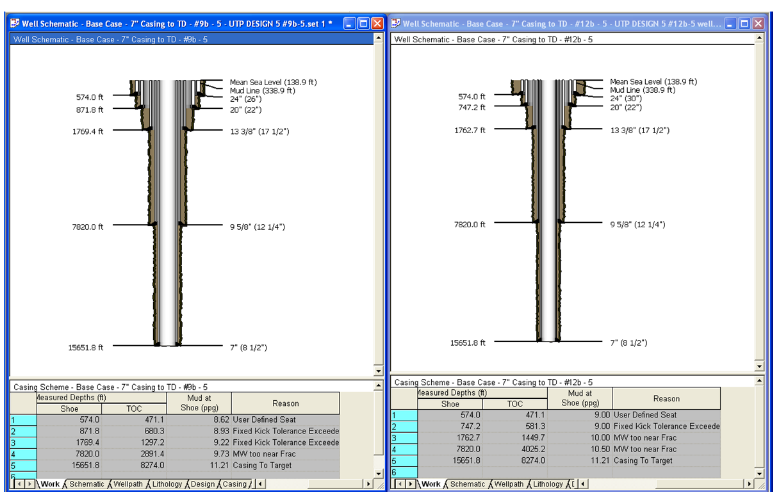


Figure 9. Effect of Stability Min. MW

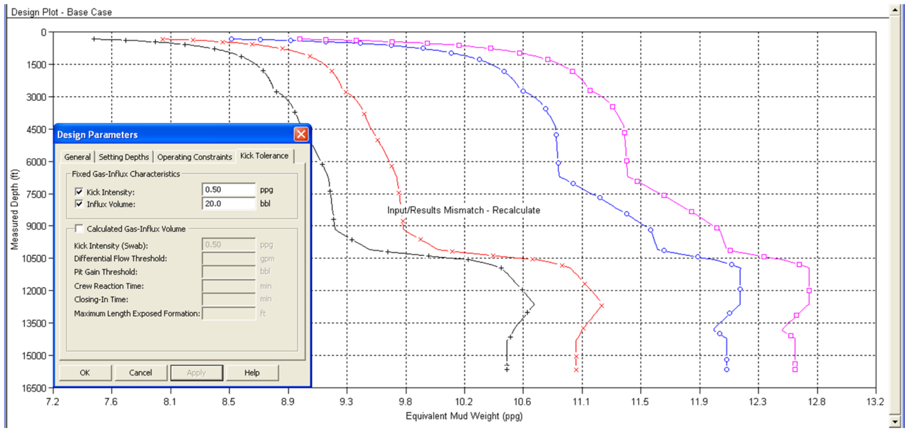


Figure 10. Option #9b: bottom-up design that gave no result if we increase it up to 20bbl

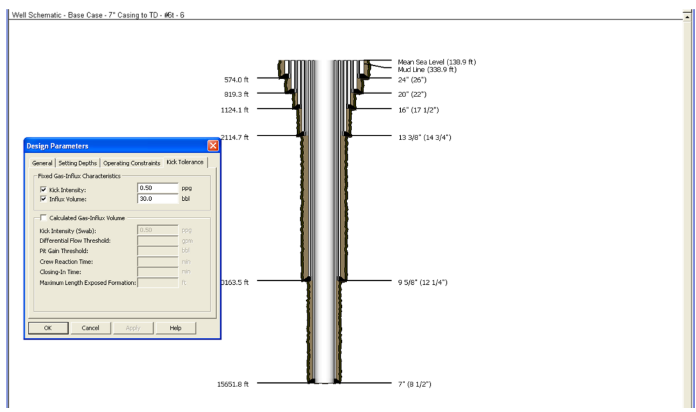


Figure 11. Option #6t: Top-down design that gave result with 30 bbl.

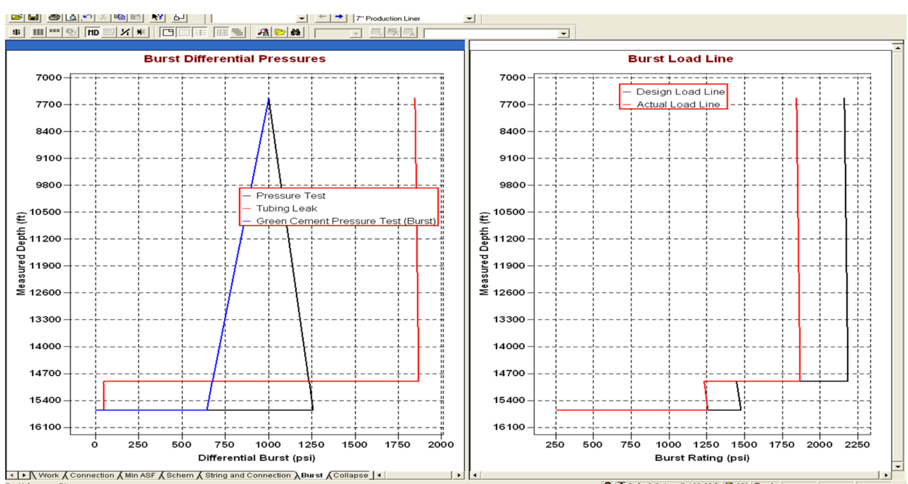


Figure 12. 7'' Production liner's Burst Load plot

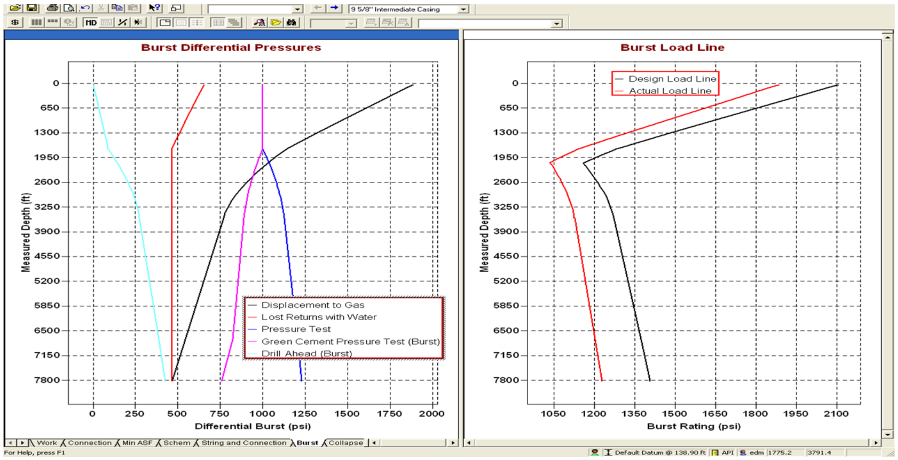


Figure 13. 9 5/8'' Intermediate casing Burst Load plot

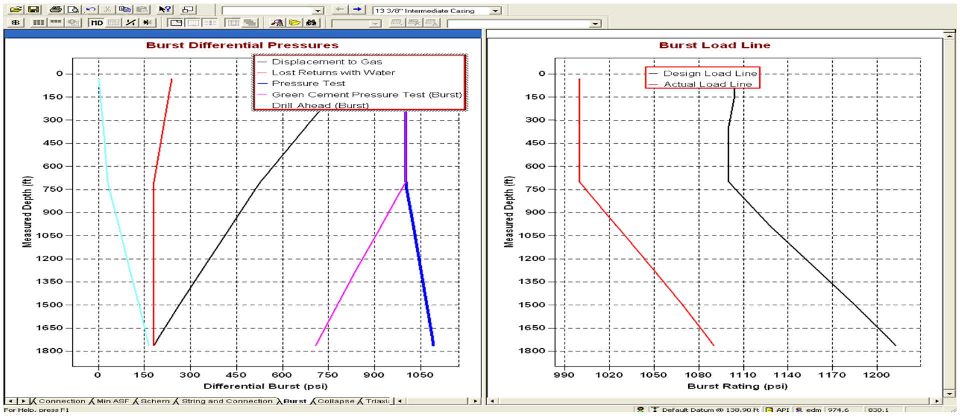


Figure 14. 13 3/8'' Intermediate casing Burst Load plot

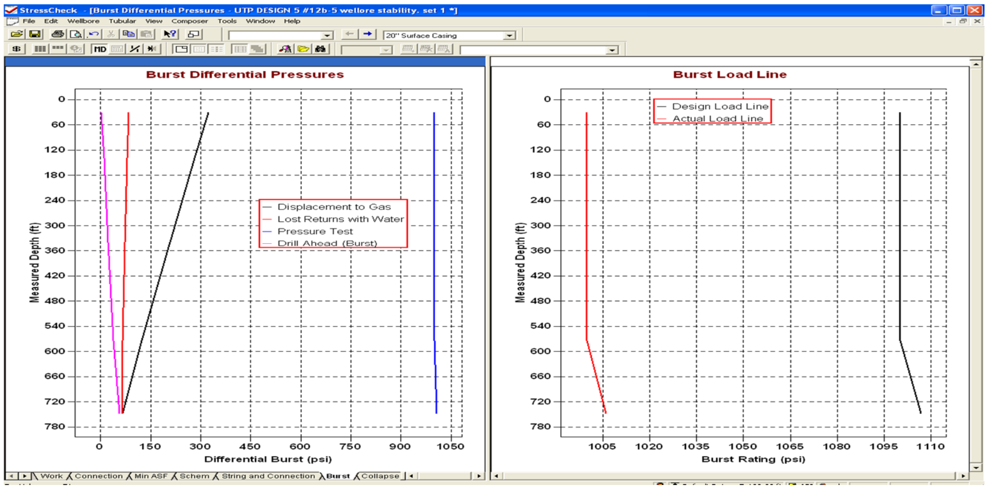


Figure 15. 20'' Surface casing Burst Load Plot

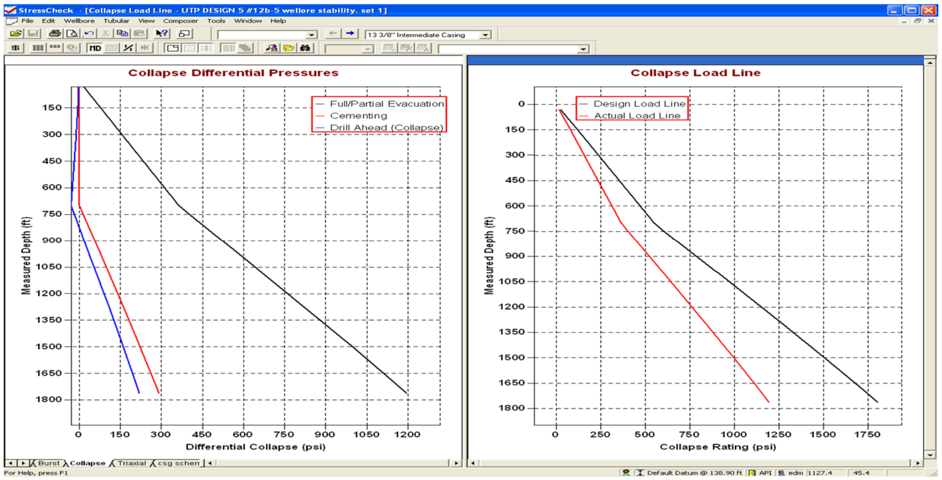


Figure 16. 13 3/8'' Intermediate casing Collapse Load Plot

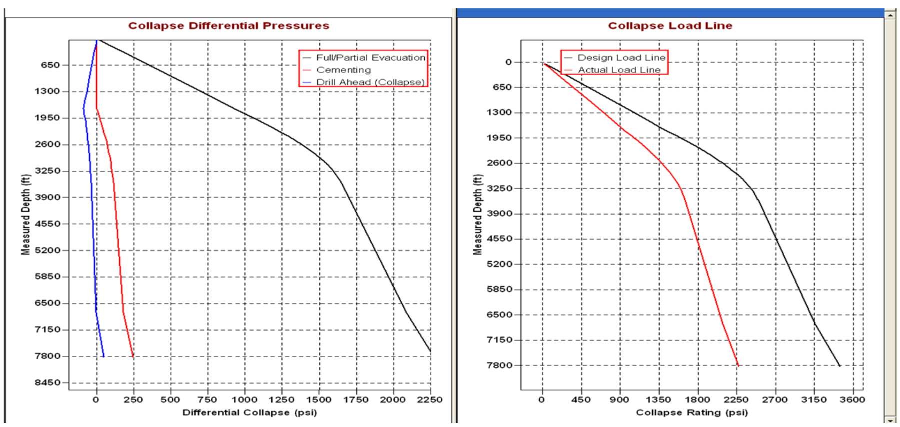


Figure 17. 9 5/8'' Intermediate casing 2 Collapse Load Plot

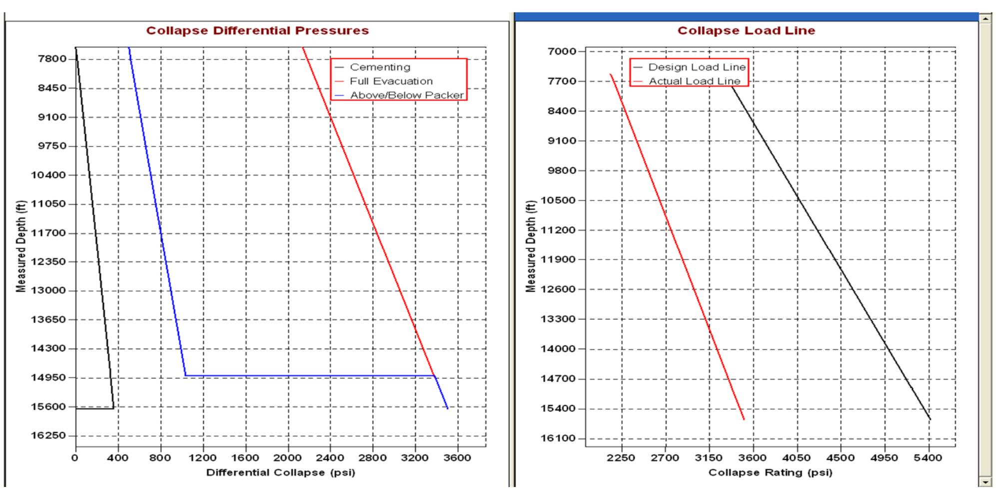


Figure 18. 7'' Production Liner Collapse Load Plot

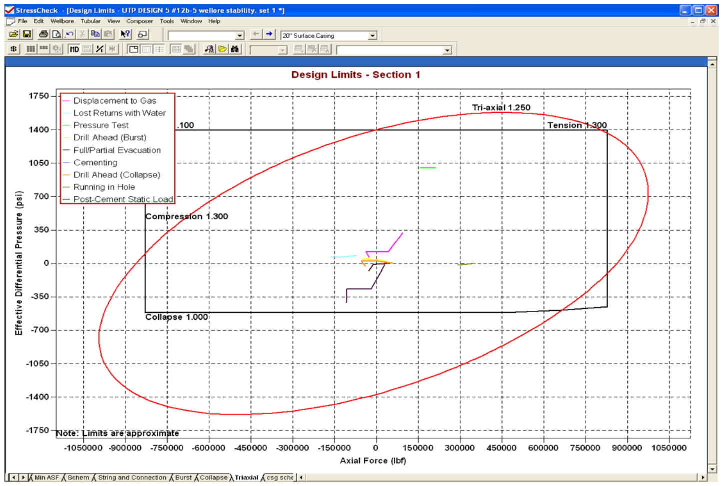


Figure 19. 20’’ Surface casing Triaxial Design Limit Plot

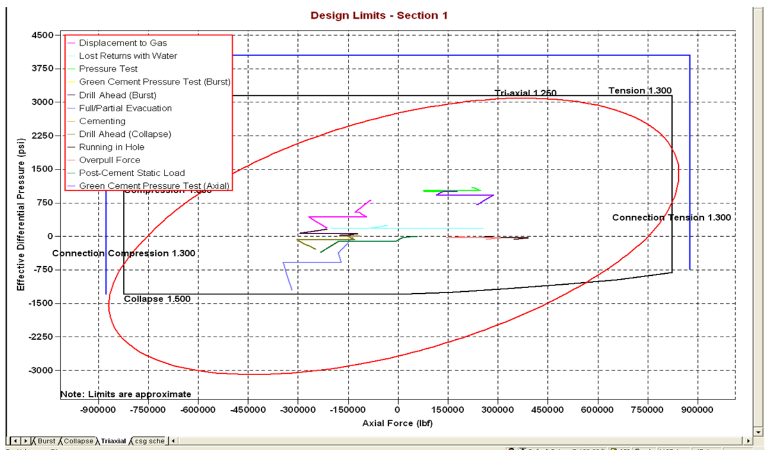


Figure 20. 13 3/8’’ intermediate casing Triaxial Design Limit Plot

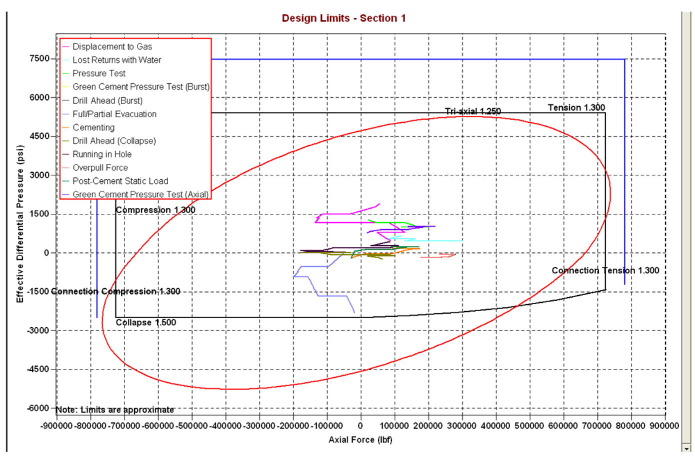


Figure 21. 9 5/8 intermediate casing 2 Triaxial Design Limit Plot

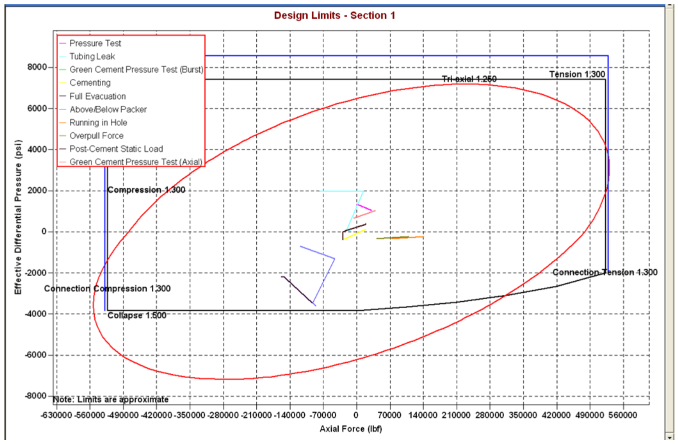


Figure 22. 7'' Production Liner Triaxial Design Limit Plot

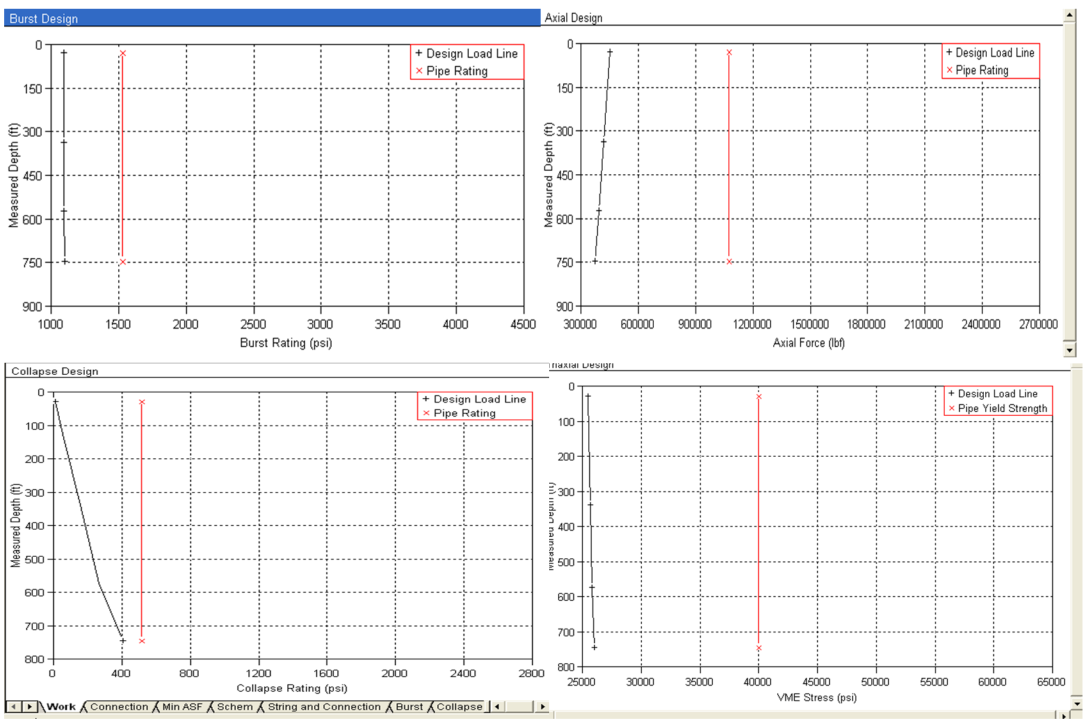


Figure 23. Design Loads for 20'' casing string

APPENDIX B

Excel Macro:

	BOTTOM TO TOP DESIGN				
	Input				
	Depth, ft	Pressure, psi	EMW, trip margin	Fracture Pressure, psi	EMW, Kick Margin
1	339	132	7.99	167	8.99
2	1134	521	9.34	641	10.37
3	2473	1132	9.30	1427	10.60
4	3000	1404	9.50	1771	10.85
5	3500	1674	9.70	2071	10.88
6	4028	1937	9.75	2524	11.55
7	4226	2088	10.00	2659	11.60
8	4321	2294	10.71	2809	12.00
9	4360	2347	10.85	2857	12.10
10	4400	2393	10.96	2906	12.20
11	4764	2651	11.20	3146	12.20
12	5017	2752	11.05	3261	12.00
13	5099	2789	11.02	3341	12.10
14	5118	2795	11.00	3353	12.10
15	5404	2879	10.75	3413	11.65

Figure 24. Data specification in Excel

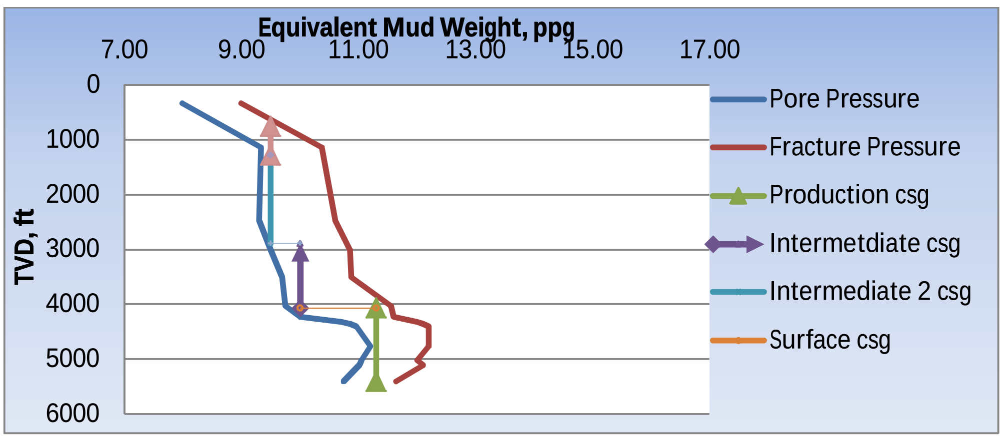


Figure 25. Design Plot for Eshqurbon2 well

Collapse and Burst Loads:

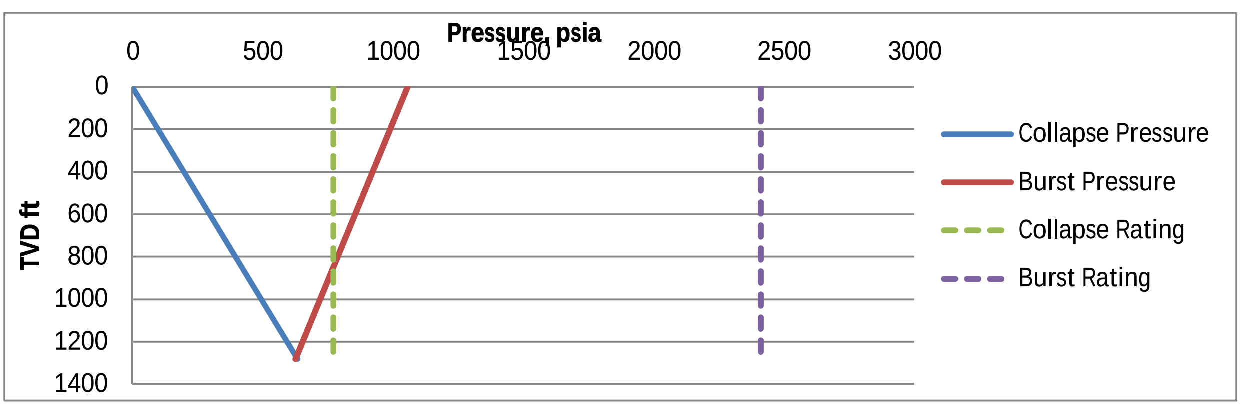


Figure 26. 20'' Surface casing load lines, J-55 #106.5 ppf

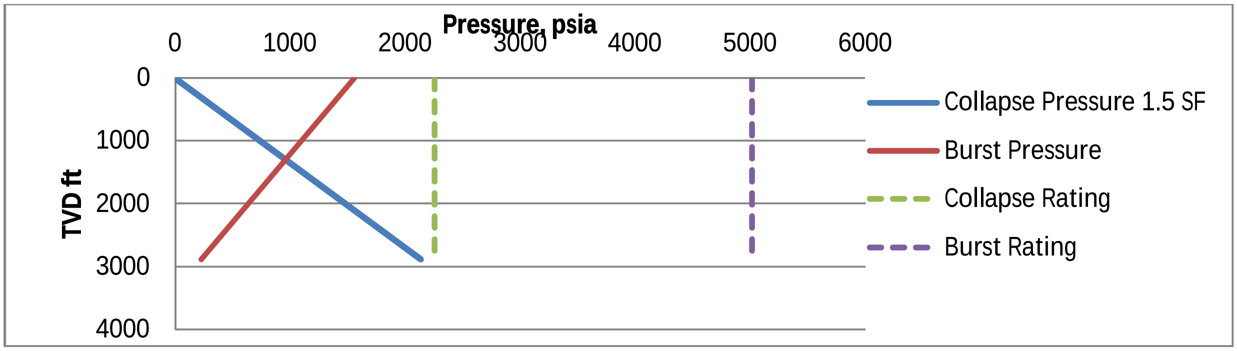


Figure 27. 13 3/8'' Intermediate casing load lines, L-80 #68ppf

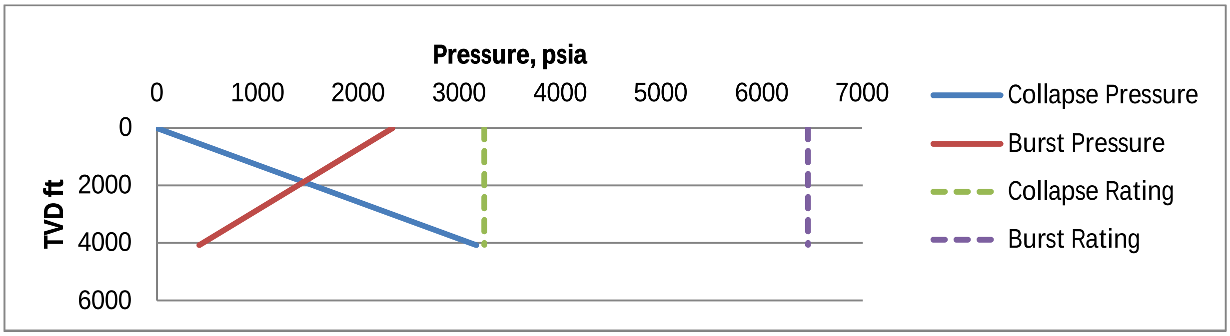


Figure 28. 9 5/8'' Intermediate casing load lines, C-90 # 40 ppf

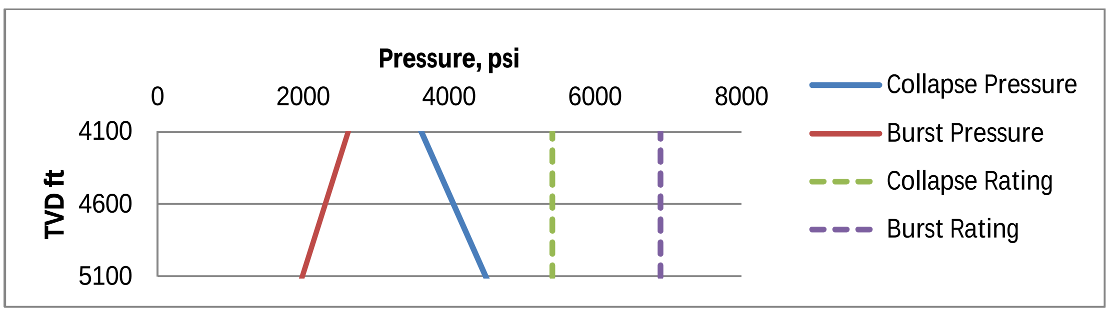


Figure 29. 7'' Production liner load lines, N-80 #26 ppf

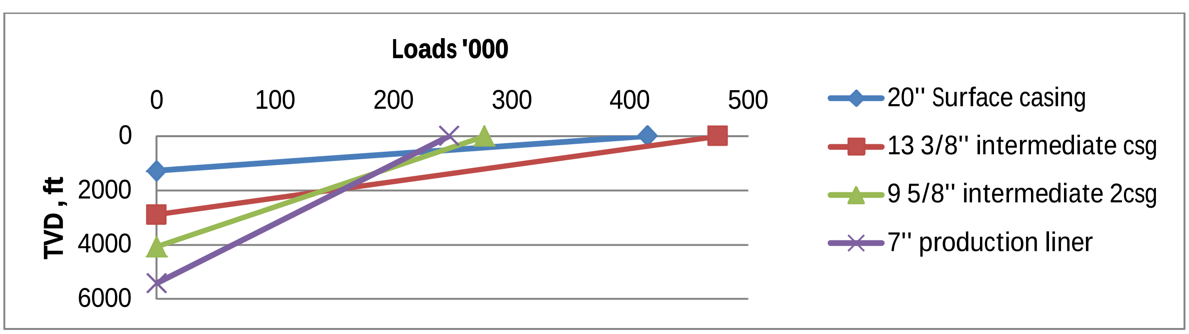


Figure 30. Tensional loads for all casing string for Eshqurbon2 well.