

A New and Simplified Method for Determination of Conductor Surface Casing Setting Depths in Shallow Marine Sediments (SMS)

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Abstract

The common practice in casing design is based on using the pore pressure and fracture pressure gradients plots. In Shallow Marine Sediments (SMS), because of uncertainties in prediction of formation fracture and pore gradients, the conductor and surface casing setting depths have always been subject to debate.^{1,2}

Two of the most important factors in any design are safety and cost. Since safety is one of the most important concerns during drilling an offshore well, planning a design based on the well control aspects would be an appropriate approach to come up with a safe and better design.³⁻⁵ A safe design based on the optimum lengths of conductor and surface casing would enable the operator to handle possible formation kicks.

A well control simulator was used to plan for well control situations. Many design parameters such as water depth, total depth, casing size, bottom-hole assembly (BHA), hole diameter, mud weight, kick tolerance, kick intensity, circulation rate, and kill rate were taken into account in several simulations. Pressure at the casing seat is combined with the well depth, well diameter, and kick volume to define the casing setting depth as a function of fracture gradient. In this paper, the results were generalized for different design scenarios and a simple design method is presented in a series of graphs.

Extension of this method to well design in general suggests the potential for safer drilling operations and cost optimization.

Introduction

Because of geopolitical and global economic uncertainties, some leading oil and gas corporations are likely to place deliberate emphasis on marketing their shallow water and economically volatile assets to small independent oil and gas companies. Nevertheless, because of recent technological advancements, small independent oil and gas companies are able to pursue these assets as part of own portfolio.⁶

It is anticipated that small oil and gas companies will introduce new wells into developed fields to perform further well testing and exploration to the acquired assets. Selection of conductor and surface casing setting depths has, in the past, been based on tradition as much as sound engineering practices.

The suggestion of the methodology described in this paper provides a simple casing seat selection tool based on well control aspects that assure the casing shoe will withstand formation influx during a well control event.

When would it be plausible to attempt to circulate a kick with only conductor casing set? Only when the operator is reasonably sure that the formation fracture pressure (as well as cement bond) and predicted formation pressure are such that there is sufficient kick tolerance that a well kick can be successfully killed. The only way to be sure if the formation fracture pressure is sufficient and the cement bond between cement and casing and cement and formation is intact is to perform a LOT on the conductor shoe.⁷ To be able to shut-in a well and circulate the kick out of hole, the well control team must have knowledge of maximum yield point of the formation and integrity of the casing shoe.

This study presents a framework which highlights the casing design checks that should be made to ensure that rig system, well design, and well control operational procedure are safe.

Use of a Well Control Simulator as a Well Planning Tool

A study by Spencer *et al.*⁴ suggests that "The HSE's work on kick control has made a significant contribution to well design and kick management. The industry indicates that they feel more confident in their ability to predict kick pressures and manage kick incidents as a result of the use of kick simulator software".

A well control simulator is used to plan for well control situations. Many design parameters such as; water depth, total depth, casing size, bottom-hole assembly (BHA), hole diameter, mud weight, kick volume, kick intensity, circulation rate, and kill rate are taken into account. The results are generalized for different design scenarios and a simple design method is presented in a series of graphs.

Basic Design Assumptions

The well control simulator allows specific design issues to be introduced. In order to obtain consistent comparative results some basic assumptions are needed. The basic assumptions introduced to the simulator are presented in **Fig. 1**.

The main goal of running the simulations is to record the pressure at the casing seat when the top of the kick reaches the casing shoe. Prediction of the shoe pressure would depend on the size of the open-hole not the casing. Hence, the results are independent of the casing size. Mud plastic viscosity and yield stress values are adjusted based on the weight of the mud.

Since the kick pressure is assumed to be determined by the mud weight and kick intensity, the formation properties such as; permeability, porosity, and skin are not considered.

In this study, the term “depth” applies to the sum of the water depth and the depth below the mud line. It is clear therefore, if such an assumption is made, then the casing shoe pressure while circulating the kick out of the hole would be an independent variable of the water depth. Note that the water depth would only alter pore and fracture gradients.

The estimation of shut-in pressures is one of the most important measurements that would be made in well control situations. Hence, in all simulations both the standpipe and the casing shut-in pressures are taken into account. Also, the fact that in shallow wells because of the relatively high formation permeability values, the shut-in pressures quickly reach a stable value is taken into account.

Additional input data to implement the kick simulation are presented in **Table 1**.

Design Parameters

In general, casing design, like any other design process, should be justified and planned in advance. An optimal design solution is sought, by finding the best compromise to satisfy the design requirements. The factors considered for a casing design based on the well control issues include:

- Casing shoe depth
- Hole size
- Kick volume
- Mud weight

As it is shown in **Fig. 2**, a design scenario begins with the selection of the existing casing depth. All simulations were performed under three different preset depths of 1000, 1500, and 2000 ft. The next step is to select the size of the hole below the casing shoe. Similarly, three different preset wellbore diameters of 17.5, 14.75, and 12.25 in., are offered for each depth. When the desired depth and hole size are selected, one should decide between 10 or 20 bbl kick tolerance. Knowing the three mentioned parameters, with a wide range of mud weights, the decision-making process becomes much less onerous. In the next section, the methodology and decision-making process will be explained in more detail.

Methodology

All the possible design scenarios shown in **Fig. 2** are presented in a series of graphs. In order to generate a typical pressure versus depth graph, three out of the four parameters, are held constant during the simulations. In other words, for

each set of different mud weights the simulations are performed at a constant casing depth, hole diameter, and kick volume.

The resulting graphs are developed in a way that, any point on the mud weight line would address a depth and a pressure. The depth indicates where the kick is entered into the well. The pressure indicates the pressure at the casing shoe when the top of the kick reaches there. To avoid complexity, the lines would be referred as casing shoe failure pressure lines. For example, point A in **Fig. 3** shows that; while drilling a well with 10 ppg mud, at a depth of 1800 feet, if a 10 barrel kick enters into the wellbore, killing the well with an 11 ppg mud would yield 650 psi pressure at the casing shoe.

The methodology and the application of the graphs are described by two examples. The first example is presented to analyze a simple design scenario and the second one to analyze a more complicated case.

Example 1:

The Aggie Oil Company is drilling an offshore well in the GOM. The water depth is 500 ft and the last casing string is set at 1000 ft below the mud line (BML) for a total depth of 1500 ft. A 17 ½ inch hole is to be drilled using 10 ppg water-based mud. A LOT test is performed and the fracture pressure at the casing shoe turned out to be 950 psi. The decision-making steps, shown in **Fig. 3** are described as follows:

- The first step is to choose a graph with the same hole diameter as of the example above.
- Choose between the 10 bbl and the 20 bbl kick tolerance.
- Calculate the TVD of the casing shoe.
- Mark the casing shoe fracture pressure on the horizontal axis of the graph and then draw a vertical line to intersect with the desired mud weight line.
- From the point of intersection draw a line perpendicular to the vertical axis, read the depth at the intersection point.

The depth value found from the procedure above is the maximum depth that can be drilled without losing the control of the well during the scenario mentioned above. In this case, in order to be able to circulate out a 10 barrel kick, the next casing string should be set at the TVD of 2600 ft. Note that considering the formation pore pressure in the region if the well was to drill with a 9.5 ppg mud, the next casing string could be set at the TVD of 3300 ft.

Example 2:

The water depth is 200 ft and the last casing string is set at 1550 ft BML. A LOT test is performed and the fracture pressure at the casing shoe is found to be 1175 psi. Using a 10.5 ppg mud, an operator decides to drill a 14 ¾ inch hole. Considering a 20 barrel kick tolerance, what is the maximum depth that can be drilled? The graphical solution shown in **Fig. 4** can be described as below;

- The first step is to choose a graph with the same hole diameter and kick tolerance as of the example above.
- Calculate the TVD of the casing shoe.
- Since there is no mud line for a TVD of 1750 ft, a mud line should be interpolated between the values on the left and right.
- In this case, the 10.5 ppg mud line lies on the 12 ppg mud line of the shallower casing set.
- Mark the casing shoe fracture pressure on the horizontal axis of the graph and then draw a vertical line to intersect with the 10.5 ppg mud line.
- From the point of intersection draw a line perpendicular to the vertical axis, read the depth at the intersection point.

The TVD of 2500 ft found from the procedure above is the maximum depth that can be drilled without losing the control of the well.

Conclusions

1. For a constant well geometry, as the depth increases, there would be a linear increase in the casing shoe failure pressure.
2. At a specific casing shoe depth the shoe failure pressure lines are parallel.
3. As the depth of the casing shoe increases the angle between the failure pressure line and the vertical axis decreases. The decrease in the angle shows that the deeper the shoe setting depth the lower increase in the failure pressure.
4. As the depth of the casing shoe increases the buffer window between the failure pressure lines increases.
5. The graphs are generated in a way that allows us to interpolate between the different casing setting depths and also extrapolate the failure pressure lines.
6. An essential requirement for a safe design is to perform Leak-off Tests (LOT) or Pressure Integrity Tests (PIT) to evaluate cement jobs and estimate the formation fracture pressure at the casing shoe.
7. Extension of this method to well design in general suggests the potential for safer drilling operations and cost optimization.

Acknowledgments

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Nomenclature

<i>BHA</i>	=Bottom-Hole Assembly
<i>BML</i>	=Below Mud Line
<i>HSE</i>	=Health and Safety Executive
<i>LOT</i>	=Leak-Off Test
<i>PIT</i>	=Pressure Integrity Test
<i>SMS</i>	= Shallow Marine Sediments

TVD =True Vertical Depth

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Table 1-Simulation Input Data

Well and Drill String Data	
OD of drill pipe, in	5
ID of drill pipe, in	4.214
Length of heavy weight drill pipe , ft	250
OD of heavy weight drill pipe, in	5.5
ID of heavy weight drill pipe, in	3
Length of drill collars, ft	200
OD of drill collars, in	7.5
ID of drill collars, in	2
Fluid Data	
Mud type	Water based
Mud property input data type	Plastic viscosity and yield stress
Mud compressibility, 1/psi	0.000006
Critical Reynolds number	2100
Surface temperature, °F	70
Mud temperature gradient, °F/100ft	1.1
Gas Kick Data	
Gas Specific gravity (Air = 1.0)	0.65
Mole fraction of CO ₂ in the gas kick	0
Mole fraction of H ₂ S in the gas kick	0
Kick intensity, ppg	1.0
Pump Data	
Pump type	Triplex
Liner diameter, in	6
Stroke length, in	18
Pump efficiency, fraction	0.85
While drilling pump strokes per min.	60
While drilling flow rate, gpm	337.1
While kill operation pump strokes per min.	30
While kill operation flow rate, gpm	168.5
Bit Data	
Nozzle diameter, in/32nd	12, 12, 12
Rate of penetration (ROP), ft/hr	60

Well Location <input type="radio"/> Onshore <input checked="" type="radio"/> Offshore	Number of Well Trajectories <input checked="" type="radio"/> Single well (including ERD well) <input type="radio"/> Multi-Lateral well
Selected Method <input type="radio"/> Driller's Method <input checked="" type="radio"/> Engineer's Method (Wait and Weight Method)	Frictional Pressure Loss in the Annulus <input checked="" type="radio"/> Consider <input type="radio"/> Ignore
Fluid Model <input type="radio"/> API RP 13D (4 readings) <input type="radio"/> Power-law (2 readings) <input type="radio"/> Newtonian <input checked="" type="radio"/> Bingham plastic	Mud Compressibility for Well Stabilization <input checked="" type="radio"/> Considered <input type="radio"/> Ignored
Blowout Animation <input type="radio"/> Consider <input checked="" type="radio"/> Ignore	Gas Deviation Factor <input checked="" type="radio"/> Consider <input type="radio"/> Ignore

Figure 1-Basic Assumptions

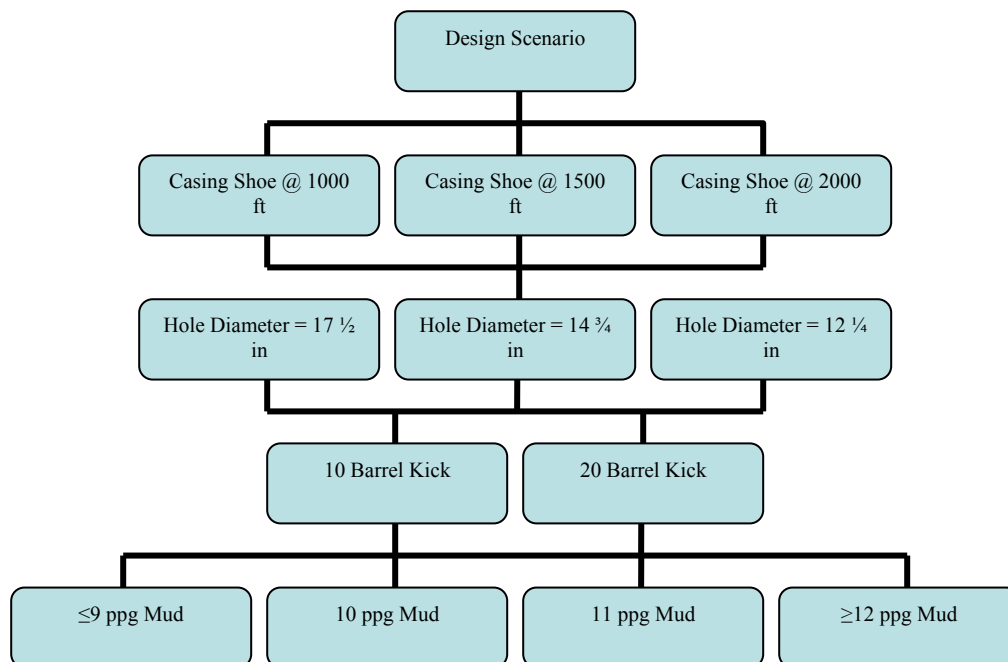


Figure 2-Design Diagram

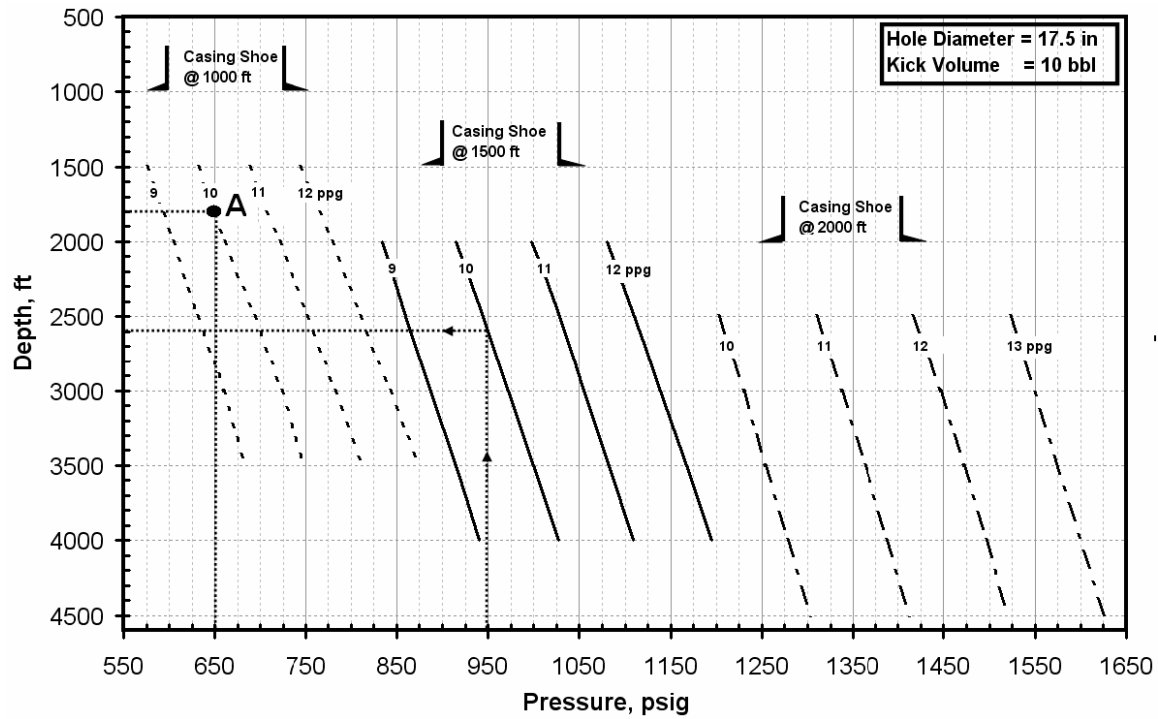


Figure 3-Example 1

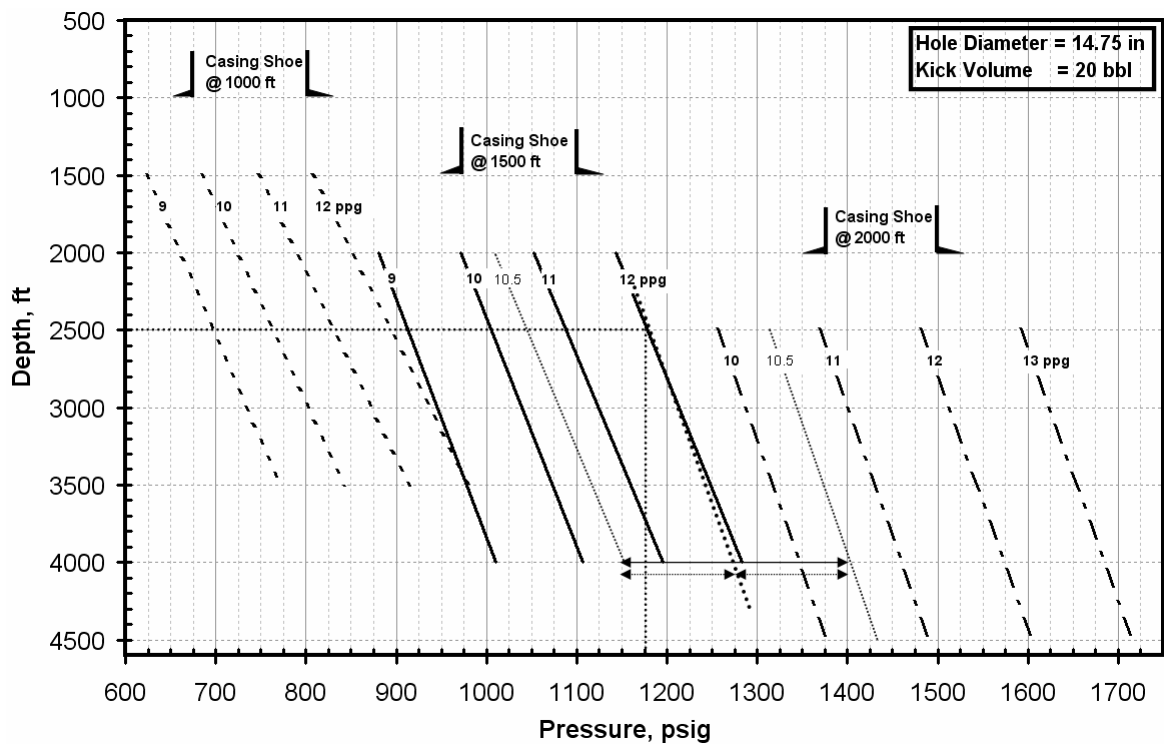


Figure 4-Example 2

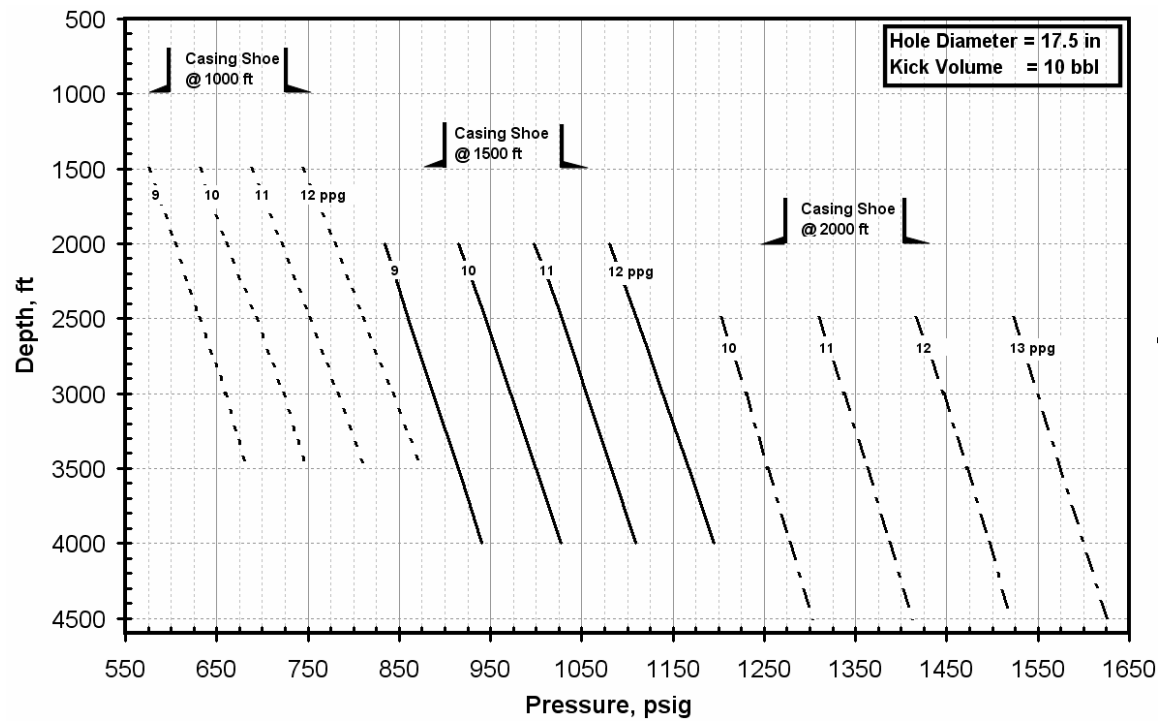


Figure 5-Casing Shoe Pressure While Circulating 10 bbl Kick Out of a 17 1/2 in. Hole

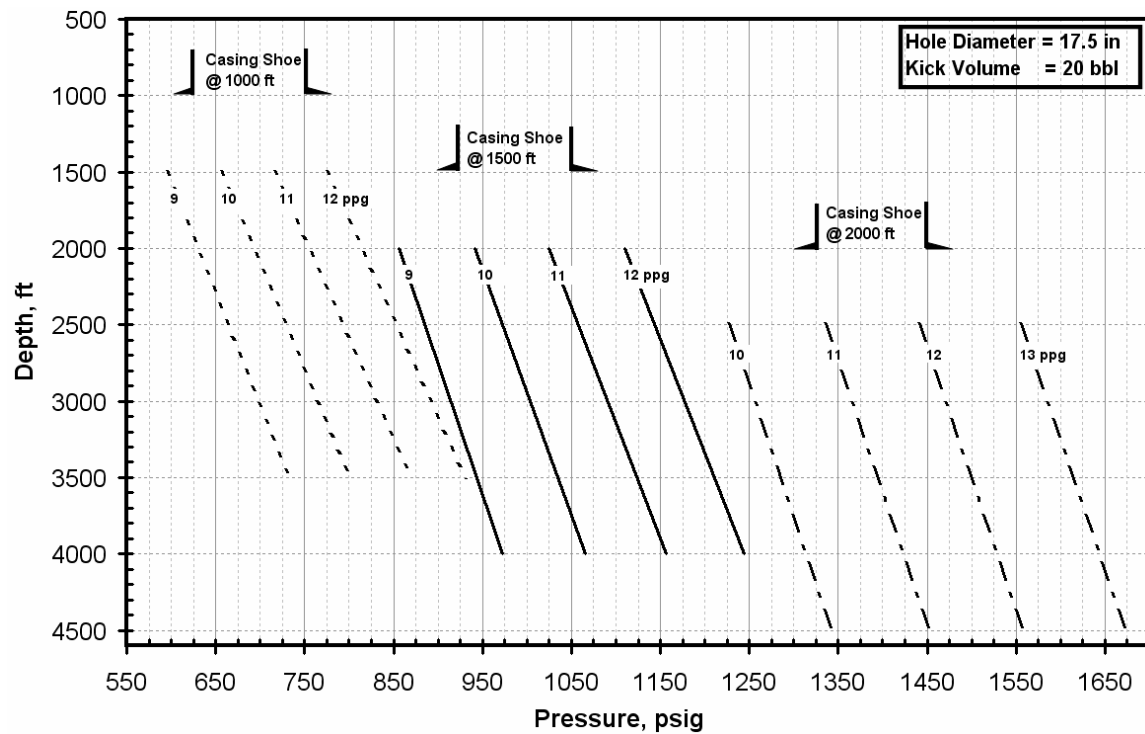


Figure 6-Casing Shoe Pressure While Circulating 20 bbl Kick Out of a 17 1/2 in. Hole

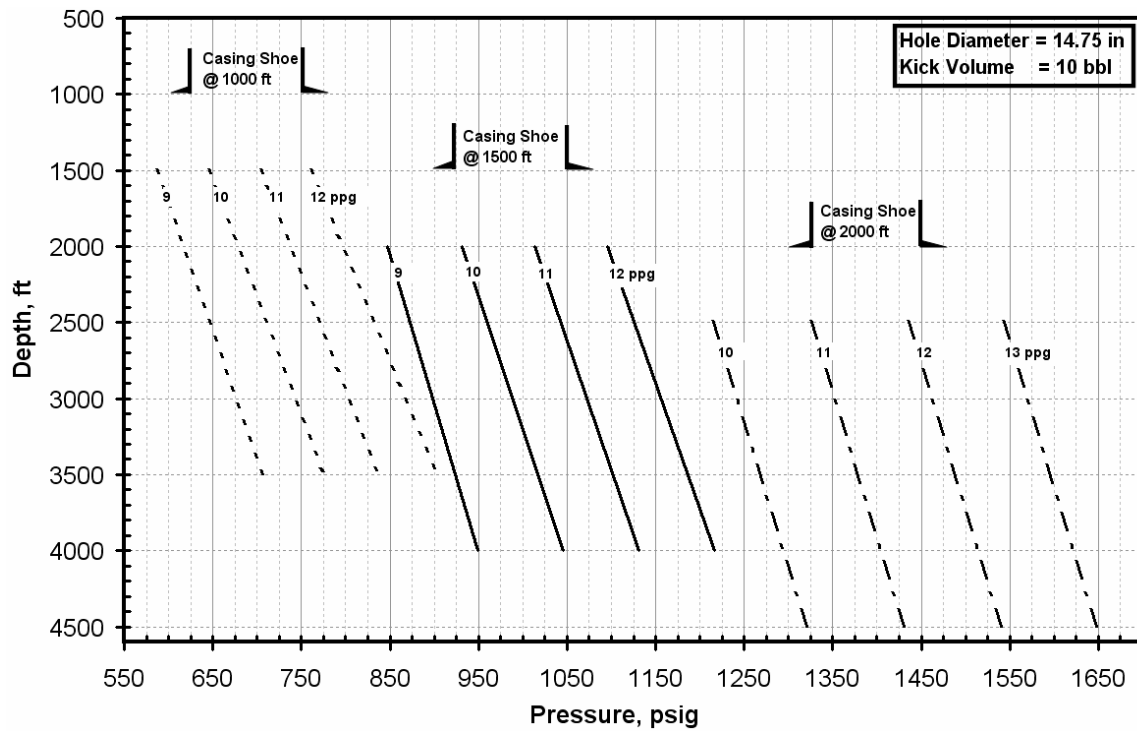


Figure 7-Casing Shoe Pressure While Circulating 10 bbl Kick Out of a 14 3/4 in. Hole

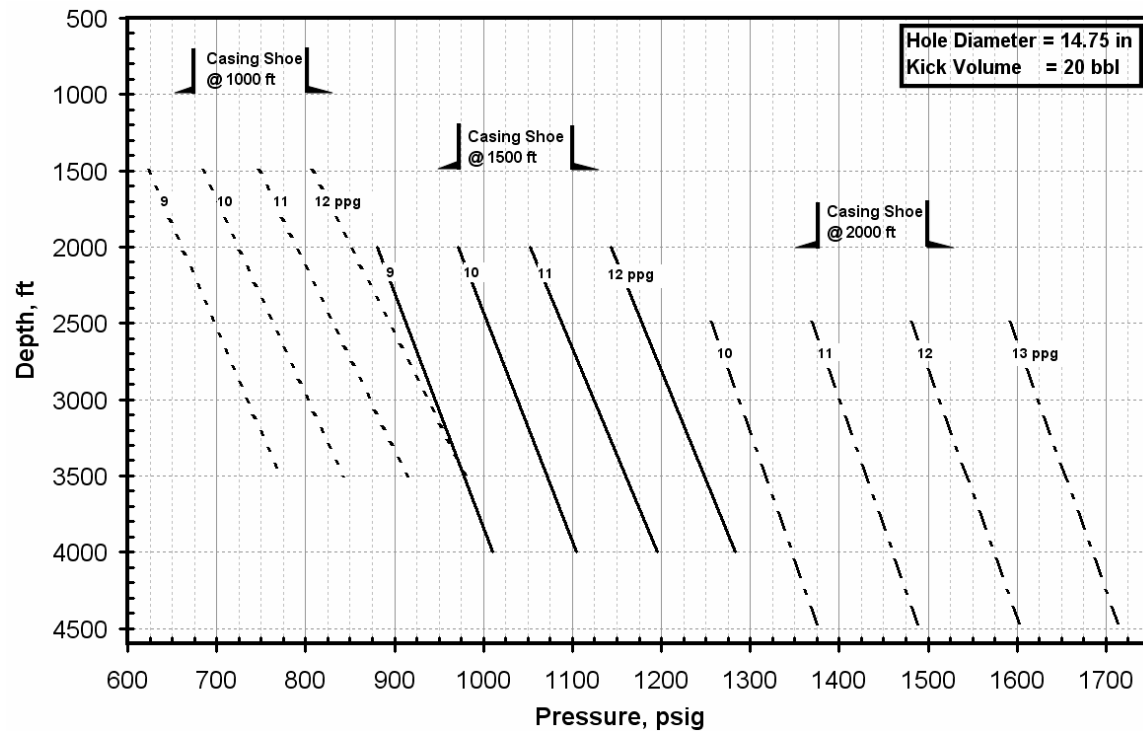


Figure 8-Casing Shoe Pressure While Circulating 20 bbl Kick Out of a 14 3/4 in. Hole

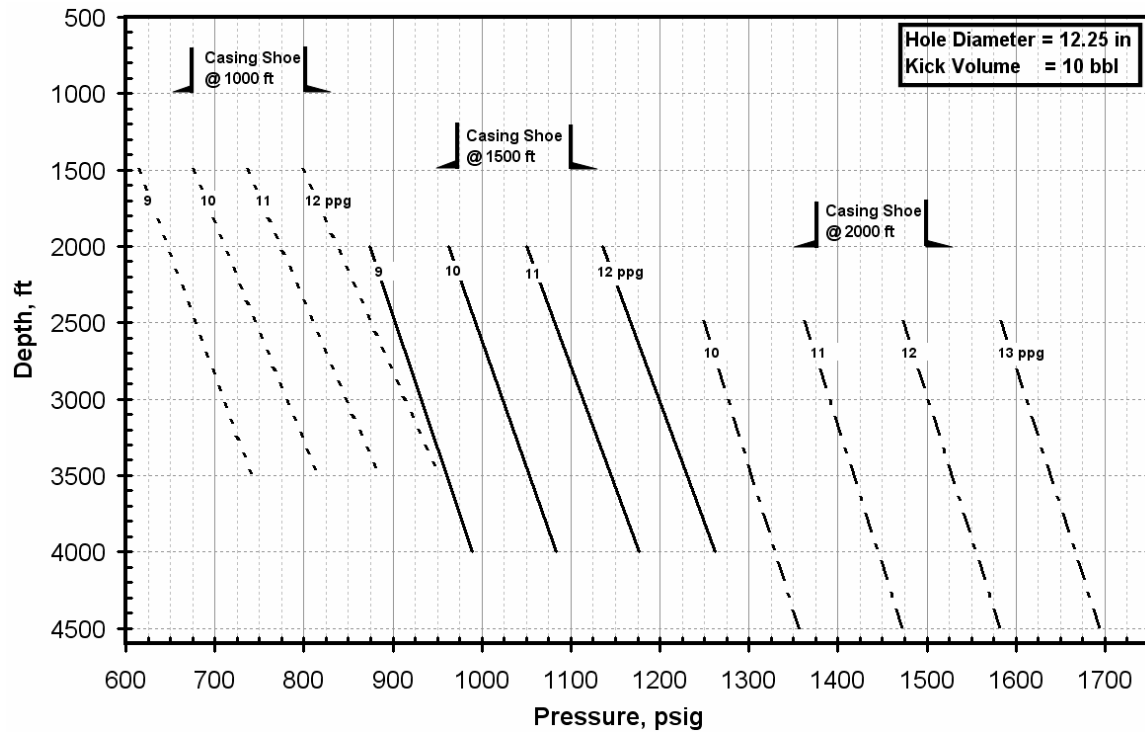


Figure 9-Casing Shoe Pressure While Circulating 10 bbl Kick Out of a 12 1/4 in. Hole

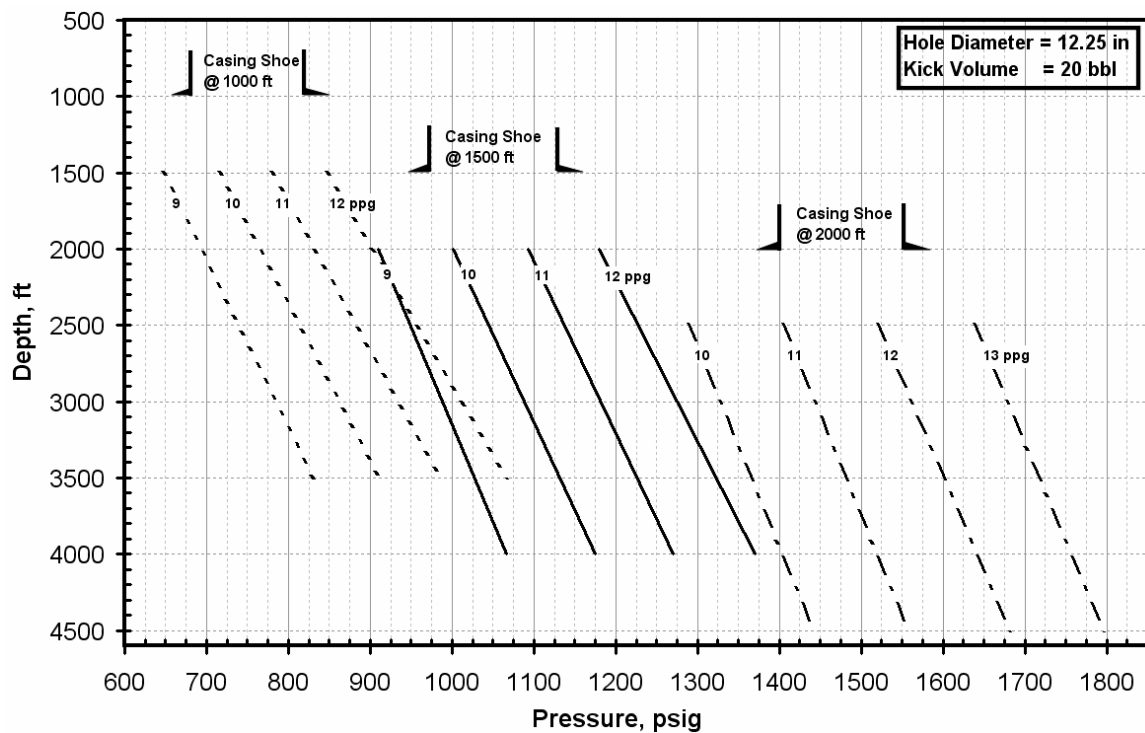


Figure 10-Casing Shoe Pressure While Circulating 20 bbl Kick Out of a 12 1/4 in. Hole