Petroleum and Coal

Article **Open Access**

An Assessment of Slip Crushing in Drillstring Tension Design

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Received November 2, 2023; Accepted February 19, 2024

Abstract

Among other forces considered during the design of drillstring, the effects of collapse pressure due to the presence of drilling fluids and tensile stress due to the length of the drillstring, both in a vertical wellbore, are the primary considerations in this work. Field data, drilling fluid specifications, wellbore geometry and American Petroleum Institute tubular specifications were applied. Recommended design procedures for bottom-top approach, with pressure-area force considerations were used to account for the effects of buoyancy. It was observed that all the initial designs were revised due to slip crushing safety element and margin-of-overpull. Nonetheless, the slip crushing problem was the most prevalent in the design conditions considered. The revised designs included replacement of some sections of the original 5-in. grade E drillpipes with similar E grade pipe, but with greater weight per foot types which had higher tensile strength. The maximum allowable load was used as an indicator of a properly designed drillstring, with tensile capacity of the pipes as basis for design. It is deduced that slip crushing might be expected in every first-pass assessment of drillstring design for tensile failure.

Keywords: *Drillstring design; Collapse loading; Tension loading; Slip crushing factor; Margin-of-overpull.*

1. Introduction

Drilling with drillstring has been in used since the invention of the rotary drilling system. Both drilling for conventional and drilling processes for the industrial production of unconventional oil and gas must include drillstring for steering wells. Also, horizontal wells, and rotating steering systems (RSS) are applicable for industrial production [1]. Drillstring design is a critical component of the every well planning process in rotary drilling [2].

However, failure in drill string designs can stiffen the optimization of drilling performance, which is an important problem for optimization of trajectories, improved design, improved drill life and smart drilling. Deep water, deep wells, hard rocks and fragile shell formations, directed wells and other specialized pathways are often used. Every year, drillstring-related nonproductive time (NPT) accounts for 25% of total NPT, severely limiting the development of automated drilling and penetration rates (ROP). The use of drill string, on the other hand, may provide the oil sector with incalculable economic benefits [1]. As a result, drillstring study and inquiry are an essential and fascinating topic. Over the last 70 years, a growing number of scholars have devoted time and effort to studying the drillstring's fundamental causes, modeling, assessment, control, and applications.

However, the drillstring is an integral part of the rotary drilling mechanism and a key component. Drill stem and drillstring are used interchangeably. It's the link between the drilling rig and the drill bit. Kelly, drill pipe, drill collars, tools, and a drill bit make up a standard drillstring. It is designed to accomplish functions [3], which include two main goals which include to serve as a conduit for drilling fluid to be poured down through it and then circulated back up the annulus, and to give torque to the drill bit in order to cut the rock.

The drilling string can also perform certain unique features, such as enabling for the formation assessment and testing if logging instruments cannot be used at the open hole, giving some stability for the bottom hole assembly, which reduces vibration and bit hopping [1].

Among other components, the drill pipe is the most significant component of the drillstring, and it accounts for the majority of the top part of the drillstring. The drill pipe is suspended in the slips or elevators by these tool joints, which create a shoulder. The forces on the slips can crush it; hence, slip crushing is usually designed into drillstrings. The most frequent length range is 27 to 30 feet (API range 2). Alternative length ranges are 18 to 22 feet (API Range 1) and 38 to 45 feet (API Range 3). Because single lengths are not consistent, the precise length of each single must be measured on the rig. During transportation and on the rig, they are usually arranged to prevent damage [4]. There are a variety of drill pipe sizes and wall thicknesses to choose from [5]. A drill pipe can be categorized for identification reasons based on its size (nominal OD), wall thickness (or nominal wall thickness), steel grade, and length ranges [1]. Also, tool joints are placed at the ends of each length of drill pipe. The shoulder-to-shoulder connection between box and pin is the only seal, and it provides the screw thread for connecting drill pipe joints. The end of the drill pipe is fastened with tool joints, which are subsequently strengthened by welding. Tool joints are subjected to the same pressures as drill pipes, but they also have to contend with extra issues like:

i. The elevator maintains the string weight beneath the shoulder of the tool joint when pipe is tripped from the hole,
ii. Repeated engagement of pins and boxes, if done forcefully, can damage threads, and
iii. The threaded pin end of the pipe is often left exposed. If connections are adequately lubricated (dope) and a constant tension is applied, tool joint life can be significantly increased. Thread protectors made of rubber are also utilized.

Moreso, the bottom hole assembly (BHA) is a drill string component that lies beneath the drill pipe and right above the drill bit. In addition to the drill collar, the BHA also includes stabilizers, jars, reamers, crossovers, hole-openers, and various subs such as bit subs and shock subs. Also included are down hole motors, rotary steerable systems (RSS), and measurement and logging while drilling tools (MWD and LWD). However, sometimes the drill bit is regarded a part of the BHA. It is suspended below the drill pipe and provides weight to the drill bit, allowing the teeth to penetrate the formation.

The drill collars are heavy steel pipes with a significantly greater external diameter and typically smaller internal diameter than drill pipes (DC) are heavier steel collars. They are used to weigh bit and stiffness at the bottom of a BHA. The main function of the drill collar is to ensure that the weight is sufficient. The collar weight also guarantees that the boiling pipe remains in tension so that it is not buckled. It is a pipe that is attached at the base of the drill string with thick walls [6]. As a consequence; the wall is significantly thicker than a pipe. Because of its numerous functions, it is usually the first part of the drillstring during design. Hence, the objective of drillstring design is to identify the most durable and cost-effective size and length for various drill string components. The problem's inherent complexity necessitates the employment of an iterative technique. Typically, a design model is expected at the outset [7]. The components of the drillstring are chosen based on the first consideration, and the design is refined by integrating aspects that were neglected during the first stage. During the design phase, a thorough understanding of drillstring performance qualities (available sizes, grades, and so on), past drilling experience in similar circumstances, and drill string component prices is essential. Certain design requirements are often met during design [7].

However, there are a few additional key requirements that must be met at the end of the design process [8]. The following criteria are;

i) every load capacity of the drill string component divided by SF shall be greater or equal to the maximum allowable load;
ii) the adjacent elements must be adequately adapted, which are achieved by choosing elements with a suitable bending stress-ratio; and
iii) the geometrical properties of the drill string should be chosen along with an optimal hydraulic and casing configuration,

iv) the rotation of the boiler string in the deviating pools should not cause excessive damage to the wall and the case and
v) the expense of the line shall be minimized. In short, the design of the drill string includes the length, weight and grades of the drill pipe to be used during drilling, coring or other operations that are affected by the depth of a hole, size of a hole, weight of a mud, safety factor (MOP) and/or length of the DC, and size of the pipe. Tension, collapse and other design elements such as loading shock, torsion, tube and critical rotational velocity all have to be considered [8].

The pipe's burst resistance, on the other hand, is unlikely to be surpassed. Except in the case of a severely deviated well, torsion does not need to be considered [2]. After determining the collapse and tension loads, the suitable weight and grade of drill pipe may be chosen. A graphical approach to drill string design is suggested in general. It is necessary to upgrade a portion of the string if it does not satisfy the standards. Such procedure is given [8-9].

i. choose a pipe weight and grade to satisfy the collapse circumstances,
ii. compute tension loading, taking into account buoyancy effects, and
iii. draw the tension loading line as well as the maximum permissible load line,
iv. change the tension load in (ii) by using a design factor, MOP, or other method.
v. use a design factor, MOP, or other method to change the tension load as shown in (ii).
vi. create three distinct design lines;
vii. If one of these design lines exceeds the maximum allowable load,
viii. it is necessary that a new tension loading line for the new drill string is computed and steps repeated (v) and (vii) for that section of pipes are used (vi).

Irrespective of the collapse loads, the effect of buoyancy on the weight of the drill string and, as a result, the tension, must be considered. On horizontal surfaces that are exposed, buoyancy forces act upwards or downwards. Drillstring uplift also occurs in shut-in wells [10]. Exposed surfaces arise when there is a difference in cross-sectional area between different portions. Buoyancy observed in oil and gas wells has been analyzed [11].

2. Materials and method

Field data, design and API standard pipe specifications were used for the design of the drill strings in vertical well.

2.1. Materials: field data collection and pipe specifications

Tables 1-3 shows the drilling fluid data, tubular data and information on the hypothetical borehole geometry used in the drillstring design.

Table 1. Tubular data.

Specifications	API RP 07G	
Desired safety factors	Collapse	1.125
	Tension	85%
	MOP	100000 lbs
	Design factor	1.3
	Slip crushing factor	1.59
DC length (API Range 2)	30 ft	
DC OD	6 ¼-in.	
DC ID	2 13/14-in.	
Weight per foot	82.6 lb	
New DP length (API Range 2)	30ft	
DP OD	5-in.	
DP ID	4.276-in	
Weight per foot	19.5 and 25.6 lb/ft available	
DP Grade	E	
Length of slips	12-in.	

Table 2. Drilling fluid data.

Type	Water-based mud
Mud Density (ppg)	8.5, 10, 10.5 & 13

Table 3. Hole geometry.

Hole size	8 ½-in.
Anticipated TD with drillstring	12,000 ft &20,000ft

2.2. Method

The drillstrings for the hypothetical well was designed with four different mud weights to account for possible increase and variations in the mud weight as drilling progressed. The wells were proposed to be at the same target depths, and the drillstrings were later re-designed at increased depth. Hence, the depth was adjusted to a possible maximum depth in case it was decided do drill deeper for more zones for increased production of oil and gas. The parameters used for the designs are presented in Tables 1-3 for the scenarios. The total lengths of drillpipes in the drillstring were in the range of 90% to 95% of the total drillstring length [9]. The bottom-top design approach was used. The collapse loading factor for the entire drillstring was initially determined. The calculated value was used and as a basis for selection of the drillpipe with the recommended collapse resistance after it has been de-rated, with data as presented in the Drilling Data Handbook [12]. The Tension Load Line (TL) was determined by considering the pressure-area force, though the appropriate terminology and methods for accurate estimates have been subjects of study [13]. Also, for the drillpipe chosen, the maximum allowable load was chosen from API Tables and the Tension Load factor of 0.85 applied. Other load lines such as (i) design load line, (ii) margin-of-overpull (MOP) line, and (iii) slip crushing factor line were drawn. Finally, points of intersection of the maximum allowable load line and the other design lines were noted. The intersection point signifies the approximate transition point (depth) for connection of drillpipes with greater tensile capacity than the class used for the initial design. At this point, the design lines are redrawn after selection of higher grade pipe. Where, another point of intersection is encountered, a higher grade pipe is selected, and the maximum allowable load line redrawn. As a basis for the design for tension in drillstrings, at no point should the maximum load line intersect with any of the design load lines. For the hypothetical well, designs were made starting with 8.5ppg mud, and the mud density of 13ppg was later applied for a 5-inch outer diameter (19.5lb/ft) drill string using new pipe to reach a total depth of 12,000ft in a vertical hole. The bottom hole assembly consist of 20 drill collars (82.6lb/ft) each 30ft long, with outer diameter of 6.25-inch and inner diameter of 2.812-inch. All the selections were made with ROP as the primary consideration in drilling a well economically [14-15], while preventing drill string damage to the casing due to wear, high torque and drag [16-17].

2.2.1. Design procedure [9]

The drillstring schematic is made with given data as shown (Figure 1).

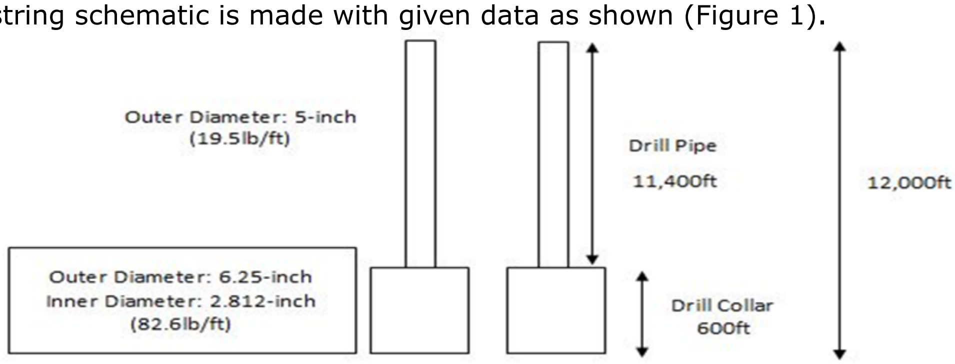

Figure 1. Drill collar and drillpipe connection schematic

When the requirements are not met, the drillstring is re-drawn as shown (Figure 2).

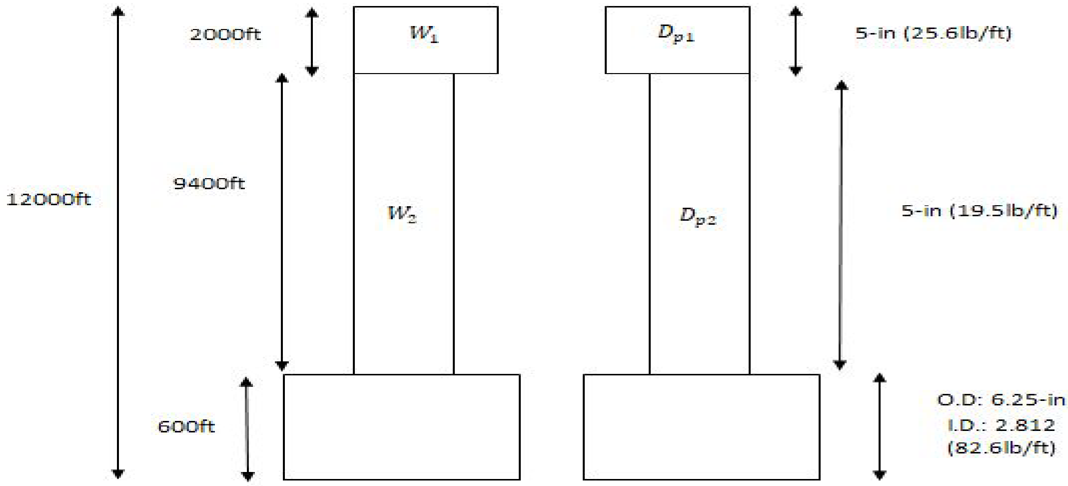

Figure 2. Drill collar and drillpipe connection schematic (re-drawn)

3. Results and discussion

The initially selected drillpipe grade used for the design yielded undesirable result when compared with the available loads. The re-designed and re-drawn graphs are presented to highlight the impact of improperly selected drillpipe section when consideration is made on the tensile load expected during drilling.

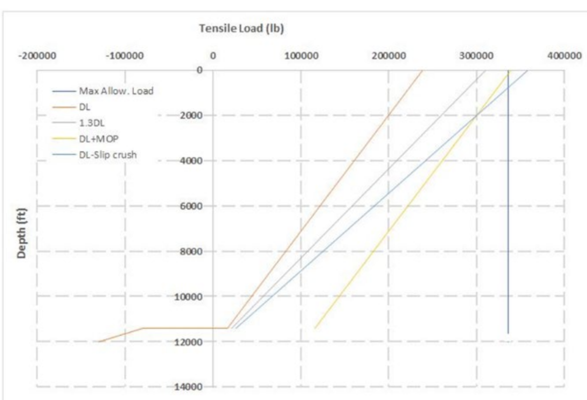

Figure 3. Effects of slip crushing factor and margin-of-overpull on the drillstring design in 8.5ppg mud in hole at 12000ft well depth.

At the expected target depth of 12000ft, with mud weight of 8.5ppg, both slip crushing and margin-of-overpull would have effects on the selected drillpipe grade (Figure 3). A redesign was considered to select drillpipe with appropriate tensile strength to withstand the crushing load and provide a margin-of-overpull in case a stuck pipe incident is encountered.

The consideration resulted in the redrawn graph (Figure 4). Mixed drillpipe was used in the new design to prevent damage and failure due to the expected loads. The point of transition from one pipe grade to another was observed to be appropriate at a depth of about 2000ft from the surface.

Due to the expected increase in mud weight from 8.5 ppg to 13 ppg during the drilling process from well prognosis data, the proposed drillstring was considered for possible redesign with 13ppg in the hole. The results are presented as shown in Figure 5 and Figure 6.

From Figure 5, it is observed that at a depth of 12000ft with increased mud weight of 13ppg, the new 5-in OD, 19.5 lb/ft pipe would not withstand the tensile load when subjected to crushing load due the tool used in making pipe connections possible. The pipe could withstand the design loads from design factor and effect of overpull in case of stuck pipe.

Therefore, the drillstring was redesigned to account for slip crushing. Figure 6 was made by selection of a 5-in OD, 25.6 lb/ft drillpipe which has higher tensile strength than the initial pipe grade used. The new selected pipe has higher maximum allowable load, thus, can withstand the crushing load expected during drilling. As a result, mixed drillpipe design would be necessary to allow drilling to the target depth. The transition depth was observed to be suitable at about 10000ft from the bottom of the wellbore. The design procedures are similar to the steps presented in subsection 2.2.1.

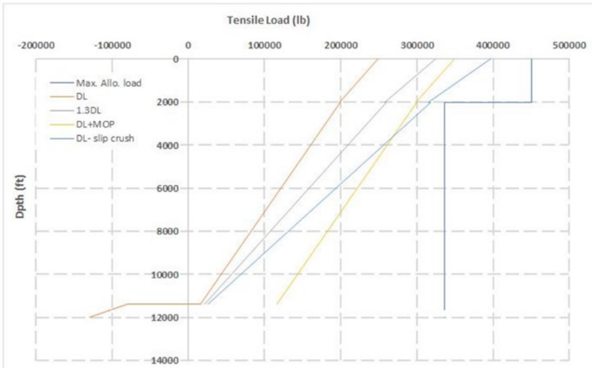

Figure 4. Effects of slip crushing factor and margin-of-overpull on the drillstring design corrected and design load lines re-drawn with 8.5ppg mud in hole at 12000ft well depth.

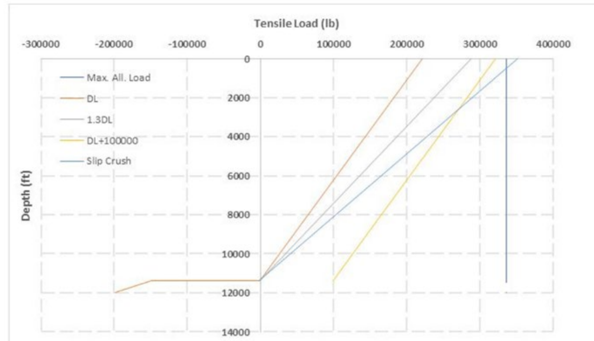

Figure 5. Effect of slip crushing factor on the drillstring design with 13 ppg mud in hole at 12000ft well depth.

The observed differences in the design result were due to the effects of the mud weights on the buoyancy of the drillstring while suspended in the mud filled hole. As expected, the 13ppg mud exerted greater buoyancy force compared with the 8.5 ppg mud. The buoyancy effect from the 13 ppg mud was greater irrespective of the same exposed surface at transition depth of connection from drill collar to drill pipe.

The plots of well depth (TVD, RKB reference point) are shown in Figures 7, 8 and 9 for 12000ft well depth and 10.5ppg mud weight.

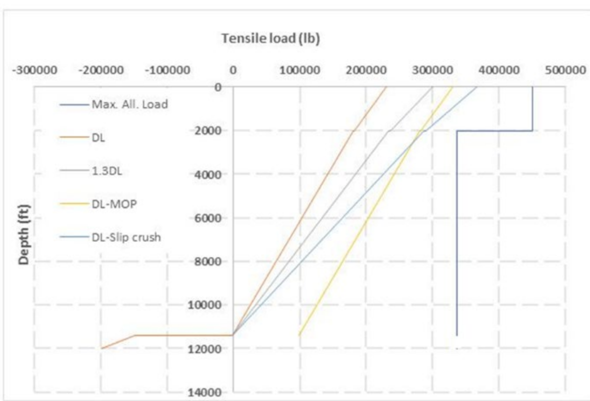

Figure 6. Effect of slip crushing factor on the drillstring design corrected and load design load lines re-drawn with 8.5ppg mud in hole at 12000ft well depth.

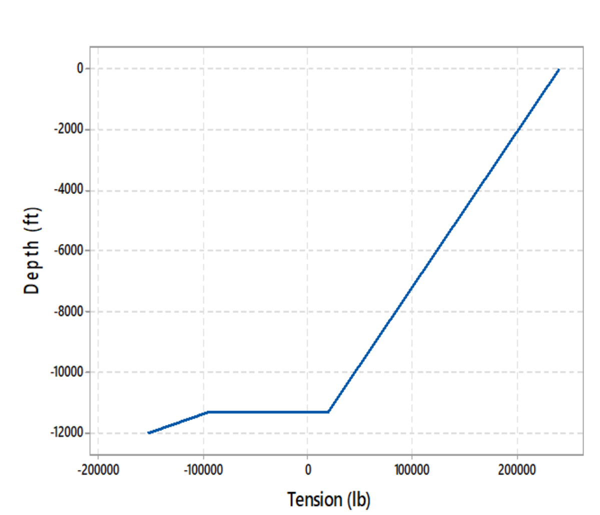

Figure 7. Tension load line for 10.5ppg mud in hole at 12000ft well depth

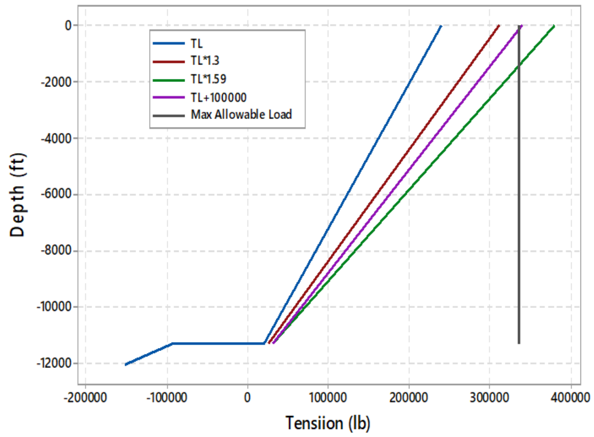

Figure 8. Effects due to slip crushing and margin-of-overpull for 10.5ppg mud in hole at 12000ft well depth.

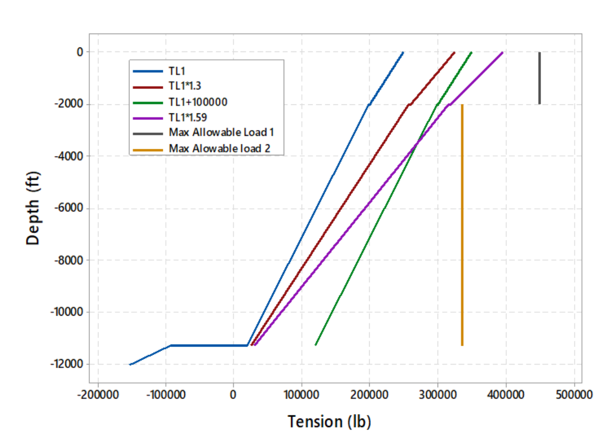

Figure 9. Effects due to slip crushing and margin-of-overpull corrected with mixed drillpipe for 8.5ppg mud in hole at 12000ft well depth.

For comparison, with mud weight of 10.5 ppg in 12000ft hole and at increased depth of 20000ft, with reduced mud weight of 10 ppg, Figure 10 and Figure 11 were observed.

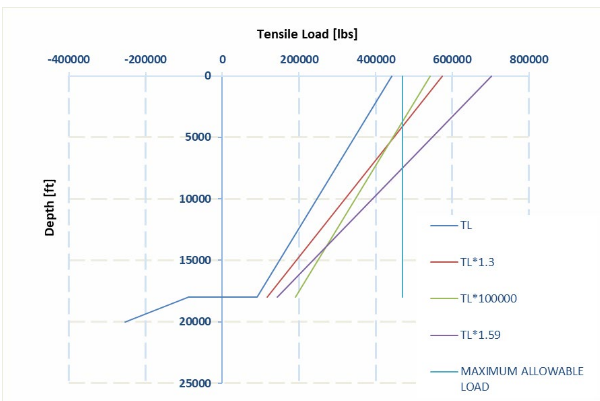

Figure 10. Effects of slip crushing factor, design load line and margin-of-overpull on the drillstring design for 10ppg mud and 20000ft (ultradeep) well depth.

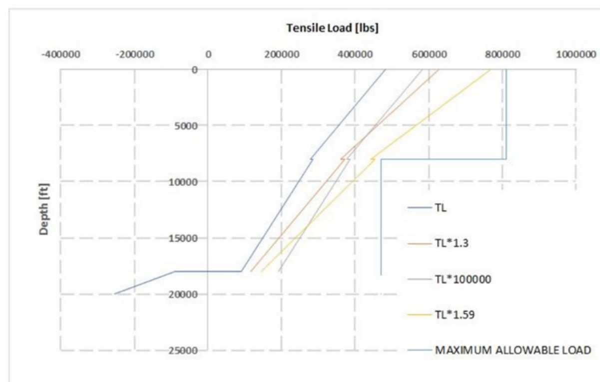

Figure 11. Effects of slip crushing factor, design load line and margin-of-overpull on the drillstring design corrected and design load lines re-drawn for 10ppg mud and 20000ft (ultradeep) well depth.

From Figure 10, it is obvious that the first selected pipe (grade G, 19.5 lb/ft pipe) was not suitable for the whole length of drill pipe required, but only the length between 1500 ft depth and 18000ft depth, because the slip crushing and margin-of-overpull lines intersected the maximum allowable load at that depth. The incapability was corrected in by introducing a stronger pipe (grade S) from depth of intersection. Figure 11 shows that it has the capacity to withstand the expected tensile loads, as none of the design lines exceeded the maximum allowable load. Hence, grade S (25.6 lb/ft) pipe is suitable between 0-8000ft depth and grade G pipe is suitable from 8000ft – 18000ft depth, and with this combination, each grade and section of pipe is able to carry the cumulative weight below it.

4. Conclusion

It was observed from all the design considerations that slip crushing is the most common tension design problem encountered in all mud weights used. It is deduced that slip crushing might be the expected cause of failure in any first-pass assessment of drillstring design for tension. This was followed by the margin-of –overpull consideration. Similarly, from the graphs obtained, it could be deduced that higher weight per foot of the same grade of drillpipes are most efficient for designing drillstring to constitute mixed drillpipe design. However, for the 20000ft well, considered to be ultra-deep, higher grades of drillpipe could be used, such as S and G grades.

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