VOL. 21, NO. 5, MARCH 2026 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


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# REDESIGNING CASING PROGRAMS WITH PROTECTION STRINGS AS LINERS TO IMPROVE SAFETY AND COST EFFICIENCY IN DIRECTIONAL WELL CONSTRUCTION

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## ABSTRACT

This study proposes the use of a protection casing string as a liner in low- and medium-pressure zones of directional wells to reduce drilling costs, minimize non-productive time (NPT), and enhance operational safety. Two directional wells were redesigned using Halliburton Landmark software to analyze casing stresses, while Microsoft Excel was employed to model costs. The conventional well design was modified to replace the traditional 9⅝″ production casing with a liner system, supported by single-stage cementing and mechanical hangers. This improved design reduced casing pipe length, eliminated the need for additional wellhead components, and avoided cold cutting operations. Pipe costs decreased by 50–60%, cement costs by 30–50%, and NPT related to the relevant operations was reduced by approximately 90%. Overall, the approach lowered well construction costs by $190,000 to $200,000 per well. Using the protection string as a liner is a technically viable, cost-effective, and safer alternative for directional wells, particularly in depleted reservoirs. This method improves drilling efficiency, reduces operational risks, and offers significant economic benefits in multi-well development scenarios.

**Keywords:** protection casing string, liner casing, casing design, directional drilling, safety improvement, non-productive time (NPT) reduction, drilling cost optimization, well integrity.

Manuscript Received 15 February 2026; Revised 9 March 2026; Published 10 May 2026

## 1. INTRODUCTION

Current casing programs in directional wells often result in elevated costs and increased safety risks. This paper proposes an alternative approach: utilizing the protection string as a liner to mitigate these challenges, to reduce overall costs, and enhance operational safety.

Nonproductive Time (NPT) in the drilling operations is a longstanding inefficiency in the oil and gas industry, leading to well delivery delays, production losses, and reduced profitability. [1] One of the approaches towards reducing rig time is to take measures that avoid wellbore instability during drilling and well completion operations. [2] The focal point of the optimization process is to reduce drilling time and associated cost for each well. [3]

The primary goal of drilling optimization is to minimize drilling time and reduce the associated cost per well. Engineers employ optimization strategies to improve drilling efficiency and enhance the success rate of well construction [4, 5]. Sustaining field-proven drilling technologies and maximizing return on investment (ROI) in mature oil and gas fields remain top priorities for operators worldwide. Financial constraints-such as volatile oil and gas prices, rising drilling costs, and economic uncertainties-should not hinder the pursuit of innovative well-construction solutions. Extending operational limits to unlock new reserves must be balanced with a strong focus on safety and sound engineering practices. In particular, optimizing casing design and well architecture is pivotal to reducing costs, minimizing operational risks, and improving drilling efficiency, ensuring both near-term project success and long-term resource development. [6]

Effective hydrocarbon production from pay zones requires meticulous and systematic well planning. The objective of well planning is to develop a comprehensive program that integrates multiple variables to ensure operational safety, minimize costs, and maintain technical feasibility. [7] However, in low and medium-pressure zones, especially in directional wells, conventional casing programs frequently result in increased non-productive time (NPT), higher material and cement costs, and additional operational hazards. Operational challenges often arise between drilling successive hole sections. These operations are not only time-consuming but also hazardous, increasing the risk of incidents such as dropped objects, falls from height, and lifting-related accidents. These factors contribute to NPT, elevate costs, and jeopardize personnel safety. Implementing the proposed strategy can mitigate these challenges by reducing non-productive time, lowering costs, and enhancing operational safety.

Liner drilling systems have been widely applied in complex drilling environments such as depleted formations, unstable formations, loss zones (thief zones), low-pressure intervals, mobile or swelling formations, and sections prone to excessive hole collapse. [8] In these systems, the liner is suspended from the preceding casing string using a liner hanger and cemented in place. The liner hanger incorporates a sealing element, typically an elastomer, to isolate the annulus and mitigate fluid migration into the wellbore and towards the surface [9]. The cement placed within the casing-liner overlap plays a critical role in maintaining well integrity. The cement sheath serves as the primary barrier against the influx of formation fluid, supplemented by secondary sealing mechanisms, such as elastomeric or metallic seal assemblies in the liner hanger or wellhead [10].

Building on established liner drilling concepts, this study introduces a novel application: employing the protection string (typically a full casing string) as a liner in low and medium-pressure zones of directional wells. To date, this approach has not been systematically assessed in such contexts. The objective of this research is to evaluate its technical feasibility, economic benefits, and safety enhancements, using field case studies conducted on two directional wells. Conductor casing, surface casing, intermediate casing, production casing, and liner casing Figure-1 shows the design of the well before and after modeling.

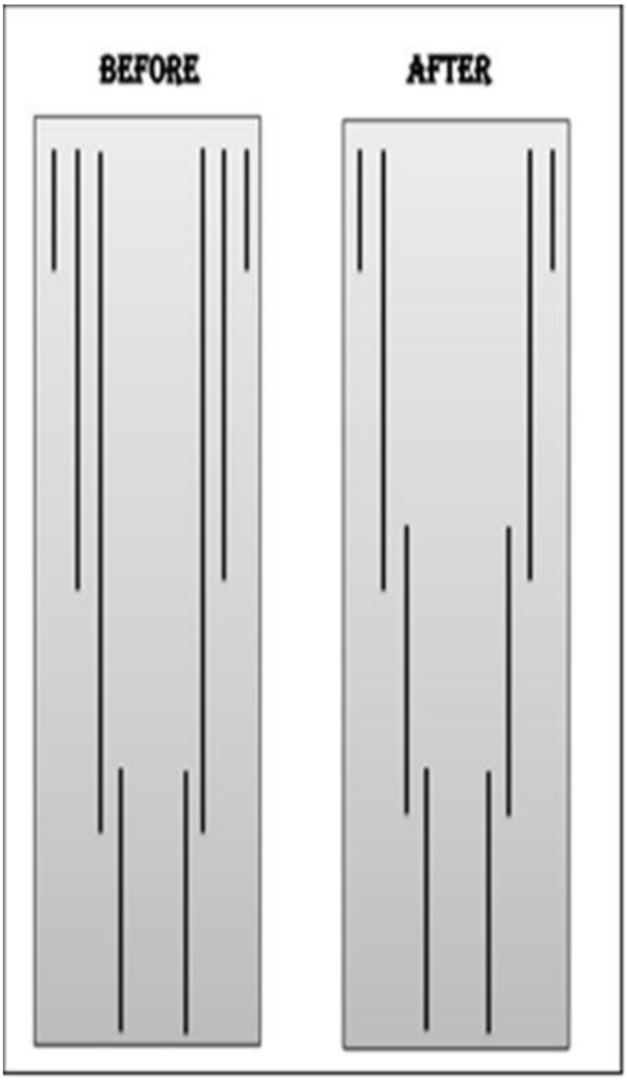


**Figure-1.** The design before and after modeling.

### 1.1 The Installation of Casing

Casing installation is a complex process composed of several sequential operations:

- **Running the casing:** The casing string is lowered into the wellbore using specialized handling equipment.
- **Cementing:** Cement slurry is pumped into the annular space between the casing and the wellbore wall to provide mechanical support and hydraulic isolation.
- **Preparation for the next section:** This stage involves multiple activities: disconnecting the flowline, bill nipple and control line; dismantling scaffolding; setting hanger slips; performing cold cutting operations; welding base flange and rips (post surface casing only); removing diverter or blowout preventer (BOP) as appropriate; installing the next wellhead section; assembling the double stud adaptor and/or riser BOP; lifting the bell nipple under the rotary table; reinstalling the BOP; reassembling scaffolding; reconnecting control and flowlines; realigning BOP; changing BOP rams from casing size to drill pipe size; and testing both BOP rams and wellhead equipment.
- **Casing and cement testing:** After the cement has set, both casing and cement integrity are inspected to ensure they are free of defects and capable of sustaining operational loads.

These extensive operations can reduce drilling efficiency and increase Non-Productive Time (NPT), a significant concern in the capital-intensive petroleum industry. Consequently, the industry continuously seeks technological innovations that can mitigate these inefficiencies. [11]

### 1.2 Justification for Utilizing the Protection String as a Liner

This innovative approach is expected to address many of the challenges inherent in conventional casing programs for directional wells, including elevated costs, increased Non-Productive Time (NPT), and heightened operational risks. By employing the protection string as a liner, operators can streamline well construction processes, enhance well integrity, and optimize project economics, thereby improving both short-term operational outcomes and long-term field development strategies.

Well completion design plays a pivotal role in determining the overall life cycle performance of a well. Operational delays during the completion phase can jeopardize well integrity, defer production startup, and negatively impact the economic viability of the field development plan. [12] Moreover, production inefficiencies often arise when completions involve small-diameter components - a frequent limitation associated with the use of a full protection string. This limitation can be mitigated through the application of the protection string as a liner, which optimizes the well architecture by reducing the length of reduced-diameter sections. Consequently, this approach facilitates the installation of larger production tubing and optimally sized equipment, thereby enhancing production capacity and improving operational flexibility.

Furthermore, ensuring the safety and reliability of critical infrastructure is paramount throughout drilling and completion operations. The Safety Integrity Level (SIL), as defined in IEC 61511, is an established metric for assessing the performance of safety instrumented functions. In shale gas operations, the gas station constitutes a crucial component of the gathering and transportation network. Maintaining the safety and reliability of its instrumentation systems is vital for ensuring the stable and secure operation of the entire infrastructure. [13]

The use of the protection string as a liner also contributes to improved operational safety by eliminating the need for cutting or dressing procedures and obviating the requirement to lift the diverter or Blowout Preventer (BOP) during casing hanger installation. Eliminating the use of casing tongs and casing stabbers during casing installation significantly reduces multiple operational risks. These include the risk of pinch points, stuck pipe incidents, dropped objects, and musculoskeletal injuries such as lower back strain associated with maneuvering heavy drill pipe stands. By simplifying the casing running process, the proposed approach minimizes personnel exposure to high-risk tasks, thereby enhancing both operational efficiency and safety. [14] These process simplifications reduce personnel exposure to high-risk activities, thereby enhancing safety and operational efficiency. [15]

Given the complexity and risks associated with conventional casing programs, the application of the protection string as a liner offers substantial advantages. Failures in well infrastructure, such as those involving wellhead equipment systems, have been significant contributors to operational hazards and safety incidents in oil and gas wells. By adopting this liner-based approach, operators can further streamline well construction, reinforce well integrity, and optimize economic returns. [16] Table-1 summarizes the anticipated benefits of this approach, particularly in suitable low and medium-pressure zones of directional wells.

**Table-1.** Comparative benefits of utilizing a protection string as liner.

| Benefit | Description |
|---|---|
| Cost Reduction - Pipe | Potential reduction of 50-60% in directional wells in terms of pipe costs. |
| Cost Reduction - Cement | Reduction of cement costs by 30-50% for the relevant section. |
| Time Efficiency | 40-50% reduction in running and cementing time; ~90% reduction in preparation time for the next section. |
| Elimination of Cold Cutting Operations | No cold cutting operation required for 9⅝″ casing. |
| Enhanced Safety | Reduced exposure to hazards such as line-of-fire incidents, working at height, scaffolding, and bell-nipple/BOP manipulation - all of which have been associated with injuries and fatalities. |
| Single-Stage Cementing | Cementing performed in a single stage rather than a two-stage process. |
| Improved Sidetracking Feasibility | Easier sidetracking from a single casing pipe, facilitating reservoir development when needed. |
| Optimized Well Architecture | Shorter reduced-diameter sections allow for completions with larger production tubing or optimal equipment sizes. |

## 2. METHODOLOGY

This study evaluates the technical feasibility and cost-effectiveness of using the protection string as a liner by redesigning two directional wells. The methodology combines casing design analysis using industry-standard software with cost modeling to compare conventional and proposed well designs.

The design process may be thought of as a two-step process:

a) Calculate the anticipated loads.

b) Select standard tubes with adequate strength to safely sustain those loads. [8]

Design considerations apply to both the pipe body and connections. The calculation of design factors accounts for all variables influencing material performance, including wall thickness, manufacturing tolerances, corrosion, and tubular wear over the well's lifecycle [17]

### 2.1 Software and Tools

The Halliburton Landmark software suite was used to redesign the actual drilled wells, while Microsoft

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Excel was utilized for cost calculations to compare conventional and redesigned casing programs.

### 2.2 Casing Design Analysis

Casing serves as the structural backbone of oil and gas wells, playing a crucial role in maintaining operational safety, efficiency, and environmental protection. It involves installing a series of steel pipes within the drilled wellbore to provide structural support, prevent borehole collapse, and isolate geological formations. While lighter weights and lower-grade casing materials can lower overall drilling and completion costs, casing designs must ensure that well integrity and safety are uncompromised. Thus, designers must optimize material selection to balance cost efficiency with operational reliability. [15]

Casing stress analysis and well construction simulations were conducted using modules within the Halliburton Landmark suite, specifically Stress Check, WellPlan, and COMPASS. These tools provide advanced stress analyses to simulate casing and tubing integrity under a variety of operational loads, including internal and external pressures, temperature fluctuations, and axial forces.

Key stress check considerations included tensile stress, compressive stress, burst stress, collapse stress, and triaxial stress.

These analyses were employed to redesign the casing program and compare it against the actual well design to assess the feasibility of implementing the protection string as a liner.

#### 2.2.1 Input data

The following key input parameters were incorporated into the analysis:

- Well geometry (coordinates, measured depth [MD], true vertical depth [TVD]).
- Pore and fracture pressures.
- Casing program (outer diameter [OD], hole size, depths, mud weights).
- Design factors (burst, collapse, axial, triaxial).
- Anticipated operational loads.

#### 2.2.2 Stress check parameters

Stress checks included evaluations of:

- Tensile stress.
- Compressive stress.
- Burst stress.
- Collapse stress.
- Triaxial stress.

#### 2.2.3 Software output

Software simulations provided the following outputs:

- Design envelopes and casing string section breakdowns
- Cost estimates for casing programs
- Detailed well schematics

### 2.3 Cost Modeling

A custom-built Excel model was developed to quantify potential cost savings derived from the proposed design changes. The model evaluated:

- Casing pipe cost reductions
- Elimination of wellhead component costs
- Rig time savings (estimated at approximately two days)
- Net cost savings after accounting for liner hanger system expenses

## 3. THE FIELD CASE STUDY

We applied the above workflow to two onshore directional wells: M-10 and M-16. The following subsections detail their pre- and post-redesign casing schemes.

The two directional wells that were drilled with 30" conductor casing, 18 5/8" surface casing, 13 3/8" intermediate casing, 9 5/8" as protective (production) casing, and 7" as production liner.

### 3.1 Well M-10

Well M-10 is a directional, onshore development well with a datum elevation of 10 m. The maximum inclination angle is ±37° with an azimuth variation of ±4°.

Table-2 summarizes the casing scheme, including hole sizes, measured depths, and mud weights. Figure-2 illustrates the initial well schematic.

**Table-2.** Casing Scheme for Well M-10 (Before Modeling).

| OD (in) | Name | Type | Hole Size (in) | MD (ft) | Mud wt (ppg) |
|---|---|---|---|---|---|
| 30″ | Conductor | Casing | 36.000 | 0 - 118 | 9.35 |
| 18⅝″ | Surface | Casing | 23.000 | 0 - 2658 | 9.35 |
| 13⅜″ | Intermediate | Casing | 16.000 | 0 - 5808 | 9.85 |
| 9⅝″ | Production | Casing | 12.250 | 0 - 8327 | 14.60 |
| 7″ | Production liner | Liner | 8.500 | 8104 - 10804 | 9.93 |

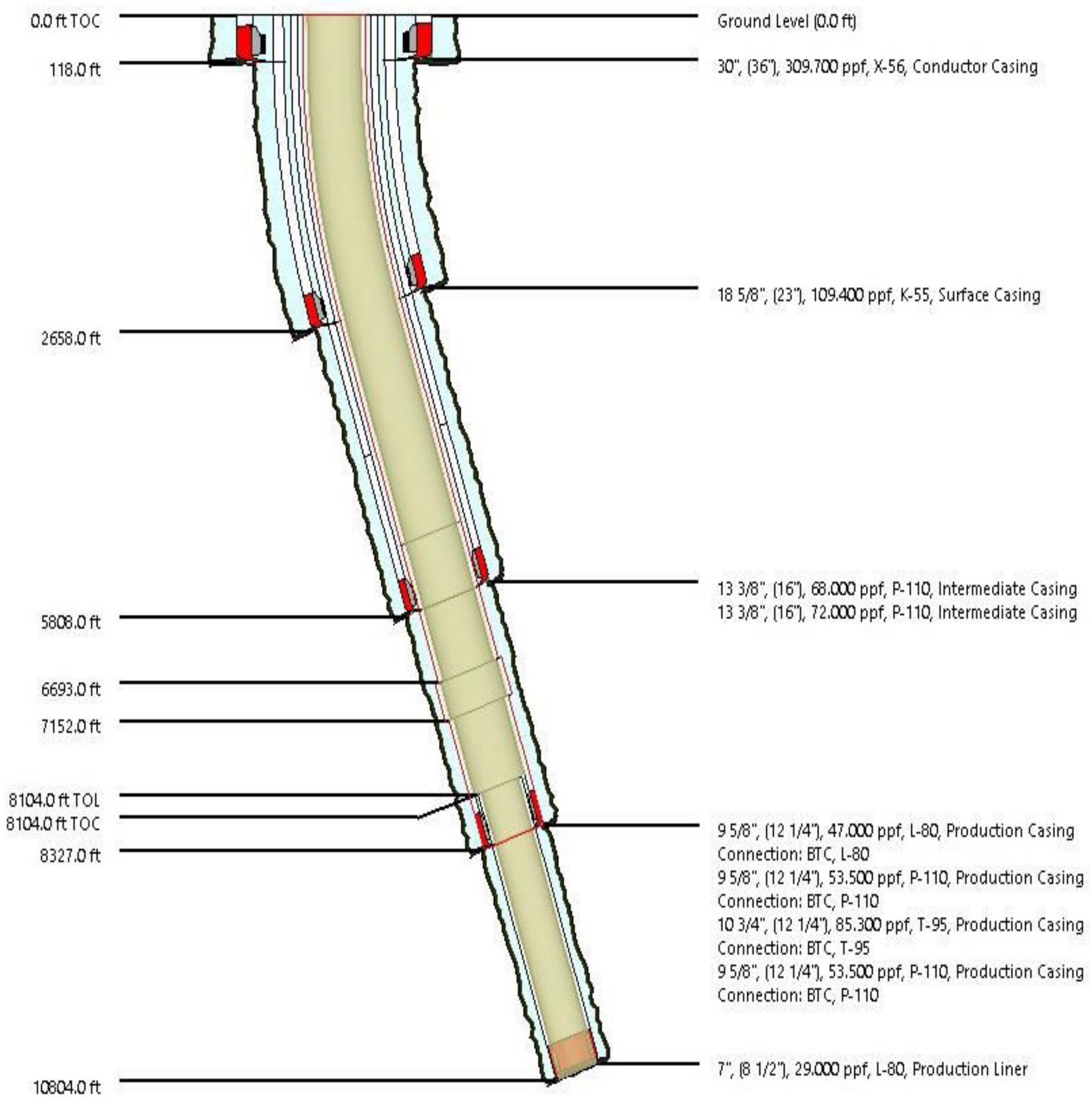


**Figure-2.** Well Schematic for Well M-10 before modeling.

The 13 3/8" intermediate casing utilizes P-110 grade pipe (68 & 72 ppf) due to the design loads. Table-3 shows the string sections and associated costs. Table-3 shows the string sections (13 3/8" Intermediate Casing) and the section cost. Design loads in this area and the suitable pipe rating are shown in Figure-3.

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**Table-3.** String Sections (13 3/8" Intermediate Casing) for Well M-10 before modeling.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 206,385 |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 4265.0 | 13 3/8" | 68.000 | P-110 | 149,232 |
| 2 | 4265.0 | 5808.0 | 13 3/8" | 72.000 | P-110 | 57,153 |

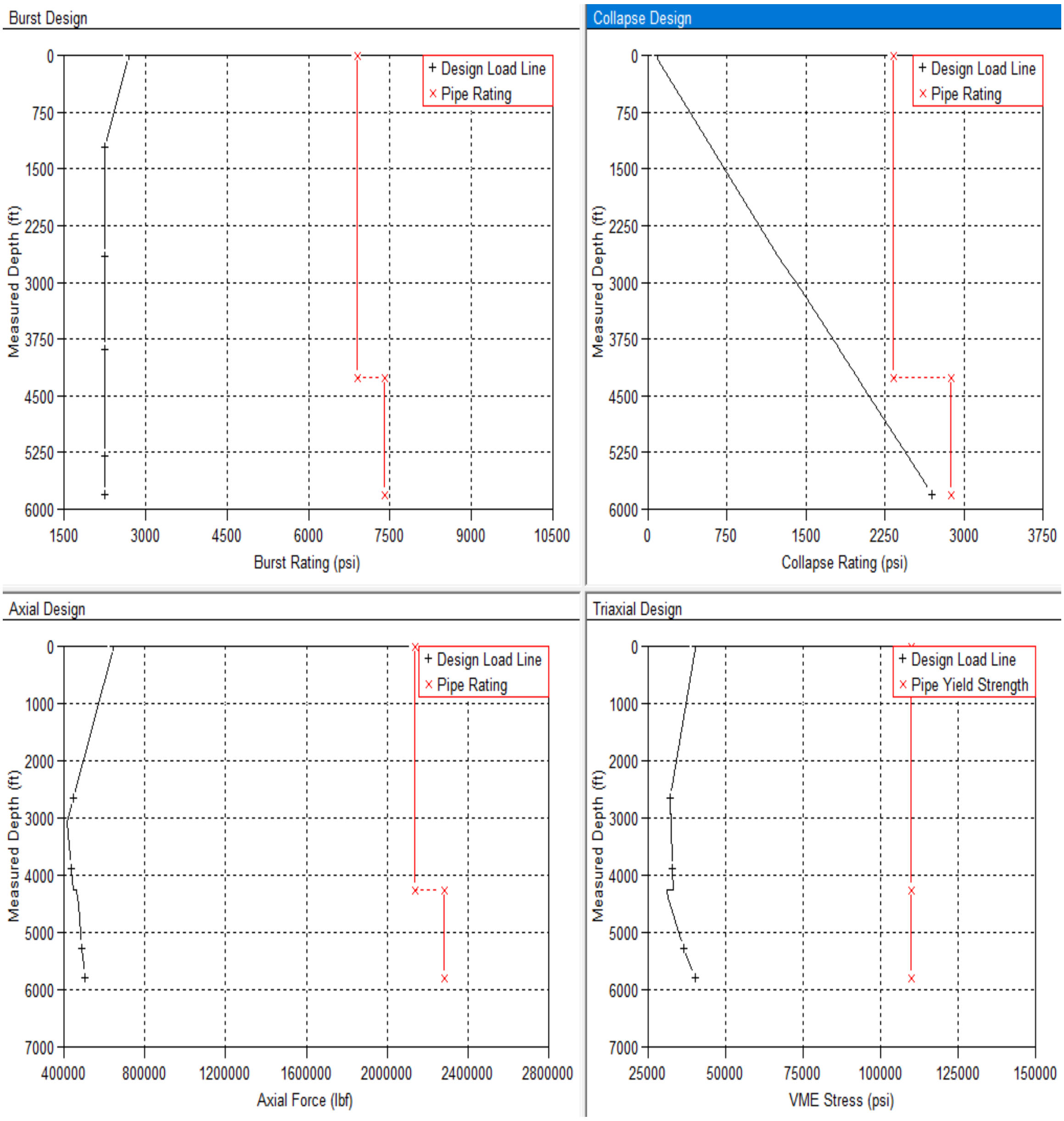


**Figure-3.** Design Loads for 13 3/8" Intermediate Casing for well M-10, before modeling.

The 9 5/8" production casing comprises multiple grades and weights to accommodate variable loads. Table-4 outlines the casing configuration; Figure-4 shows the design loads.

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**Table-4.** String Sections (9 5/8" Production Casing) for Well M-10. Before modeling.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 252,920 |
|---|---|---|---|---|---|---|
| 1 | 0 | 5413 | 9 5/8" | 47 | L-80 | 151,248 |
| 2 | 5413 | 6693 | 9 5/8" | 53.5 | P-110 | 41,579 |
| 3 | 6693 | 7152 | 10 3/4" | 85.3 | T-95 | 21,924 |
| 4 | 7152 | 8327 | 9 5/8" | 53.5 | P-110 | 38,169 |

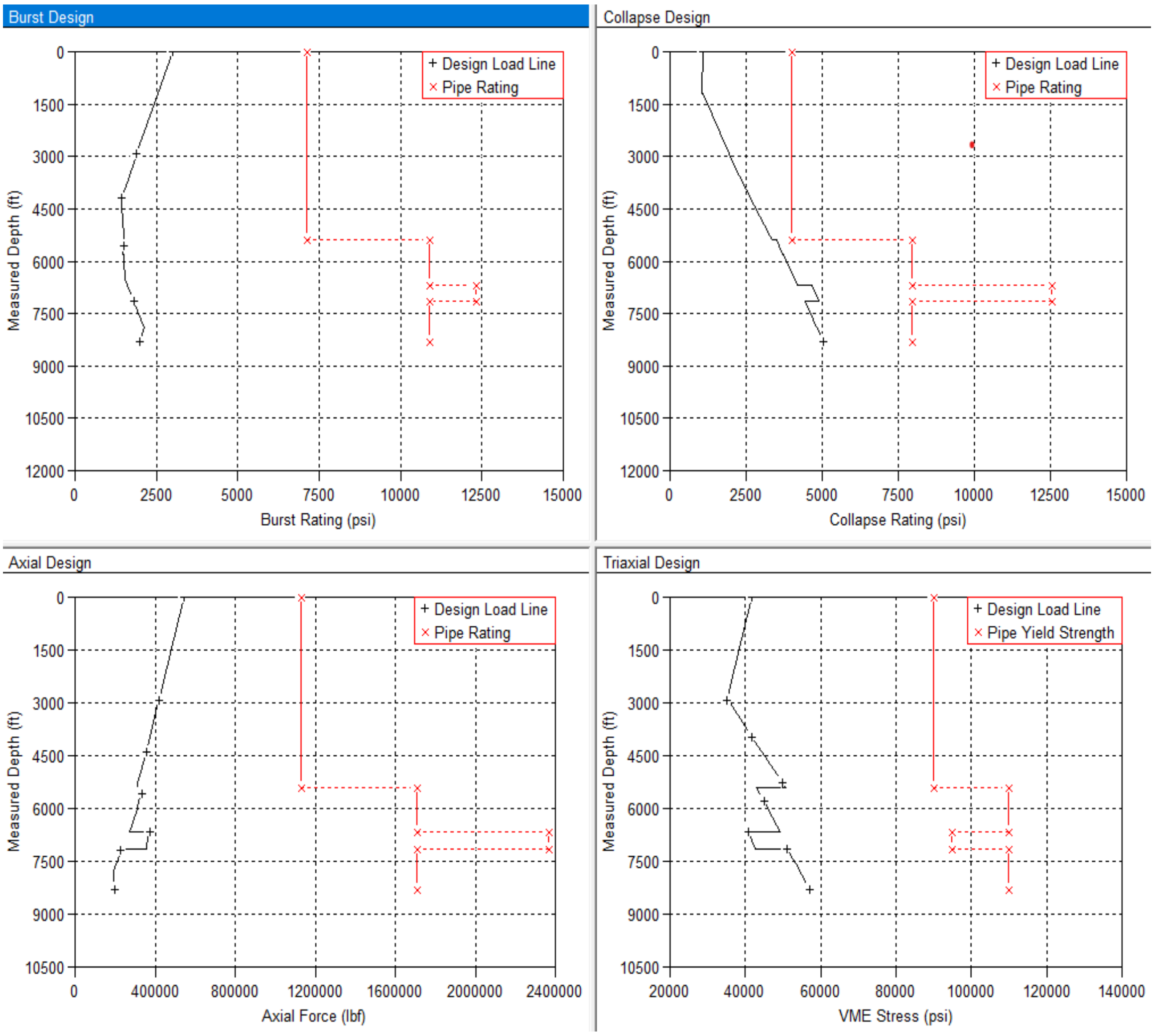


**Figure-4.** Design Loads for 9 5/8" Production Casing for Well M-10 Before.

**3.2 Well M-16**

Well M-16 is also a directional, onshore development well with a datum elevation of 10.5 m. The maximum inclination is ±35° with an azimuth of ±258°.

Table-5 provides the casing scheme, and Figure-5 depicts the initial schematic.

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**Table-5.** The Casing Scheme for well M-16 before modeling.

| OD (in) | Name | Type | Hole Size (in) | MD (ft) | Mud wt (ppg) |
|---|---|---|---|---|---|
| 30″ | Conductor | Casing | 36.000 | 0 - 115 | 8.93 |
| 18⅝″ | Surface | Casing | 23.000 | 0 - 656 | 8.93 |
| 13⅜″ | Intermediate | Casing | 16.000 | 0 - 4823 | 9.85 |
| 9⅝″ | Production | Casing | 12.250 | 0 - 8241 | 14.60 |
| 7″ | Production liner | Liner | 8.500 | 8103 - 12083 | 8.10 |

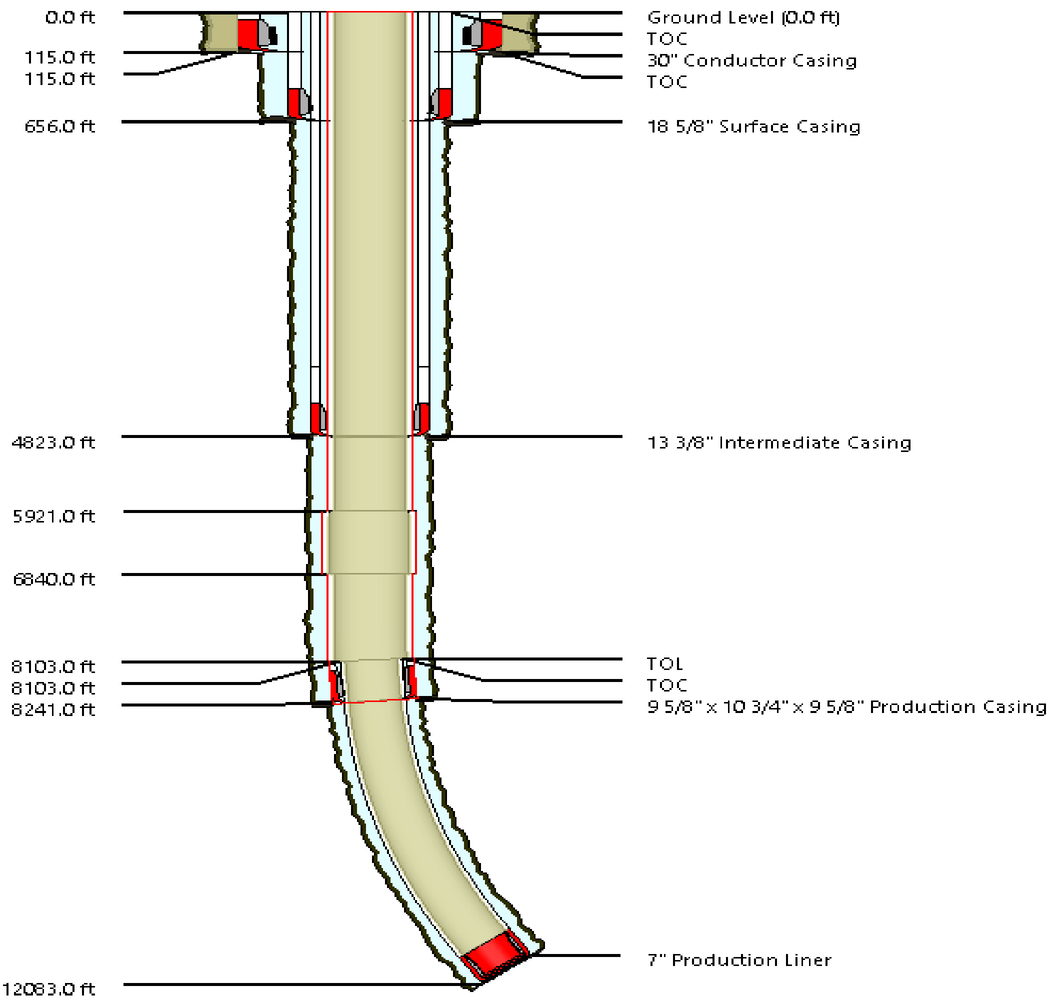


**Figure-5.** Well Schematic for Well M-16 before modeling.

The 13 3/8" intermediate casing again uses P-110 grade (68 & 72 ppf). Table-6 and Figure-6 Outline the pipe sections and loads.

**Table-6.** String Sections (13 3/8" Intermediate Casing) for Well M-16 before modeling.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 169,900 |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 4265.0 | 13 3/8" | 68.000 | P-110 | 149,232 |
| 2 | 4265.0 | 4823.0 | 13 3/8" | 72.000 | P-110 | 20,668 |

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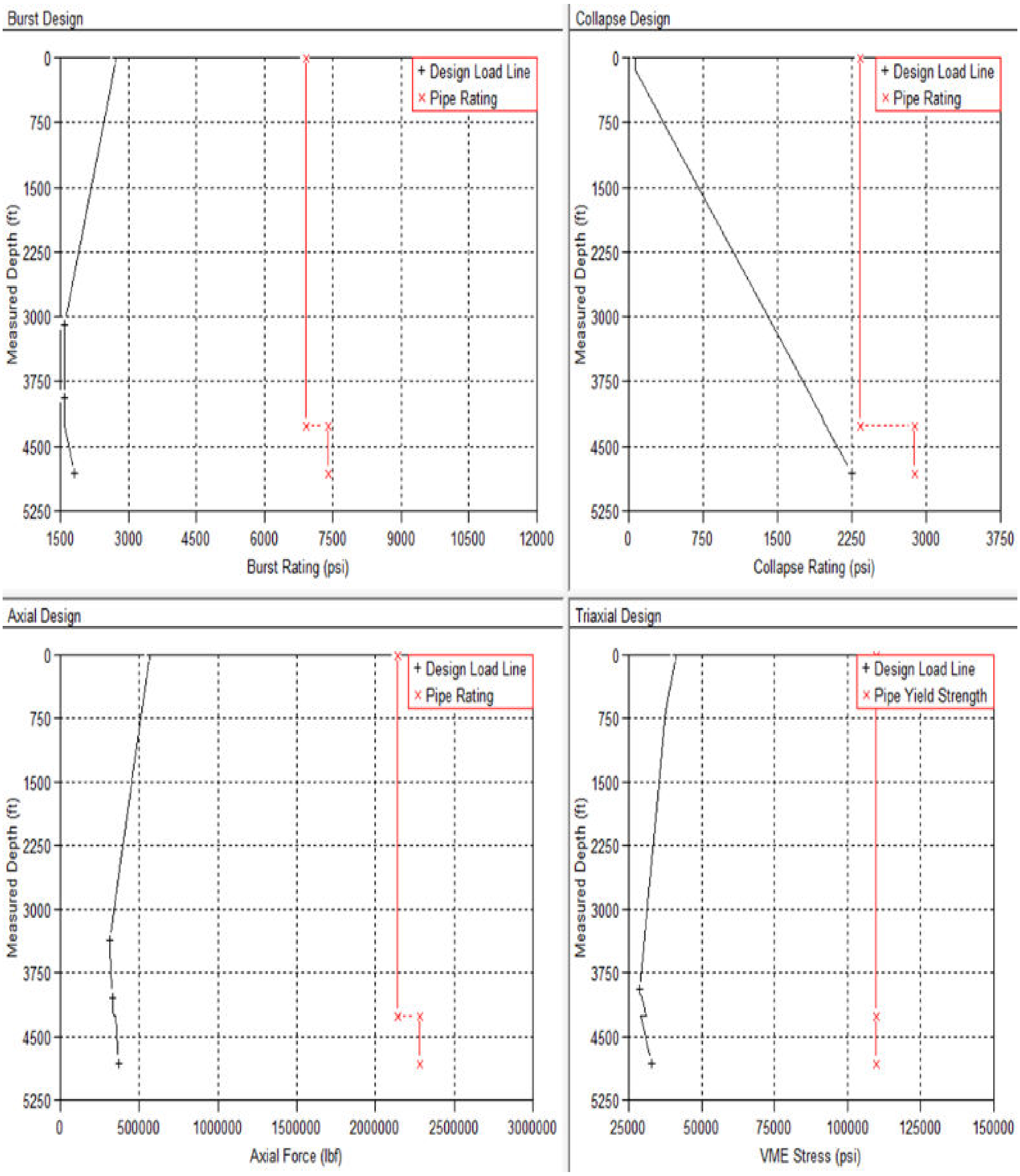


**Figure-6.** Design loads for 13 3/8" Intermediate Casing for Well M-16 before modeling.

The 9 5/8" production casing addresses the risk of mobile formations by incorporating heavier and stronger pipe sections. Table-7 and Figure-7 present the casing details.

**Table-7.** String Sections (9 5/8" Production Casing) for Well M-16 before modeling.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 281,744 |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 5921.0 | 9 5/8" | 53.500 | P-110 | 192,337 |
| 2 | 5921.0 | 6840.0 | 10 3/4" | 85.300 | T-95 | 43,897 |
| 3 | 6840.0 | 8241.0 | 9 5/8" | 53.500 | P-110 | 45,510 |

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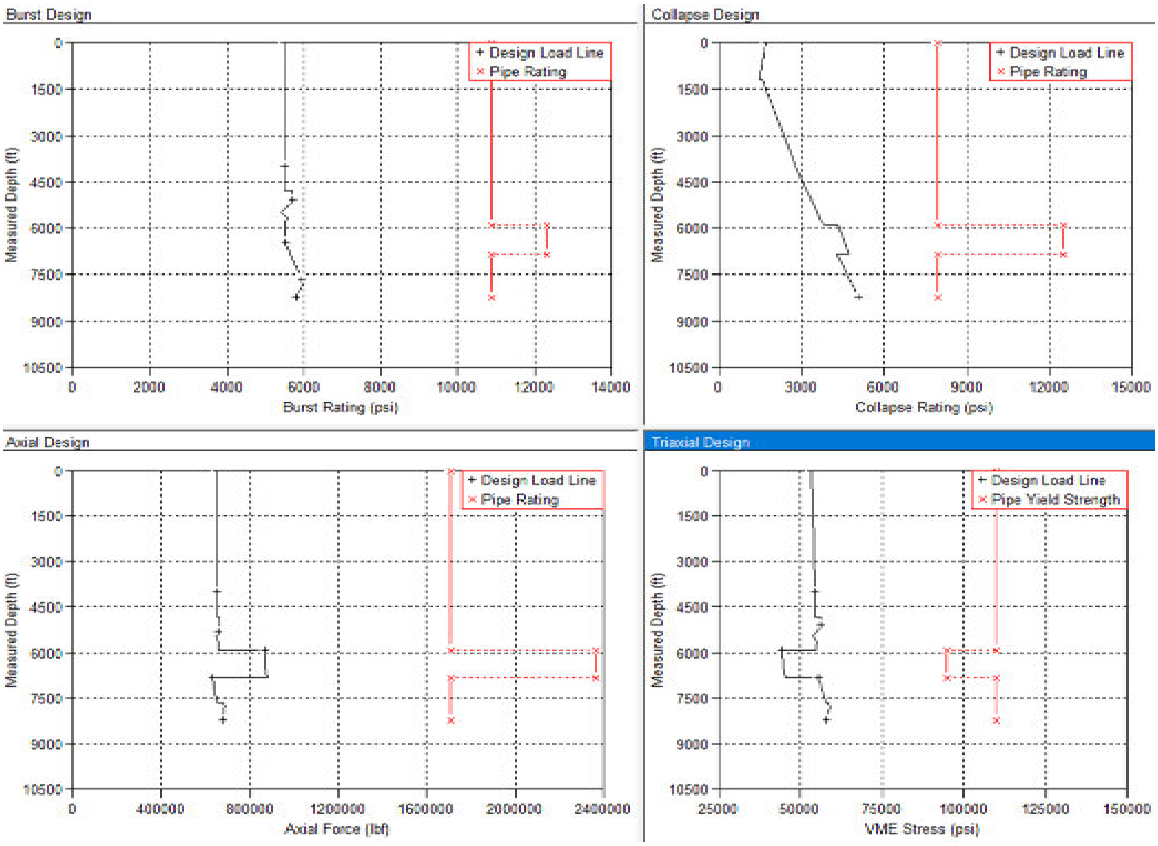


**Figure-7.** Design loads for 9 5/8" Production Casing for Well M-16 before modeling.

## 4. WELL REDESIGN AND MODELING

After the redesign, both wells undergo modifications:

- The 13 3/8" casing is reclassified from intermediate to production casing.
- The 9 5/8" casing is converted into a production liner.
- The liner hang-off depth is positioned ~200-400 ft above the previous shoe depth, maintaining a minimum overlap of 300 ft for integrity in gas influx scenarios. [4]

### 4.1 Well M-10

The final well construction consisted of 30" Conductor, 18 5/8" Surface, 13 3/8" Production string, 9 5/8" first Production liner, and 7" second Production liner. All depths are shown in Table-8 and the well schematic is shown in Figure-8.

**Table-8.** Casing Program Comparison for Well M-10.

| Casing Section | Hole Size (in) | Casing OD (in) | Casing Type | Measured Depth (ft) | Mud Weight (ppg) | Design |
|---|---|---|---|---|---|---|
| Conductor | 36.000 | 30″ | Casing | 0 - 118 | 9.35 | Same (Before & After) |
| Surface | 23.000 | 18 5/8″ | Casing | 0 - 2658 | 9.35 | Same (Before & After) |
| Intermediate / Production | 16.000 | 13 3/8″ | Casing | 0 - 5808 | 9.85 | Reclassified as Production Casing (After) |
| Production | 12.250 | 9 5/8″ | Casing → Liner | 5413 - 8327 | 14.60 | Converted to Liner (After) |
| Production Liner | 8.500 | 7″ | Liner | 8104 - 10804 | 9.93 | Same (Before & After) |

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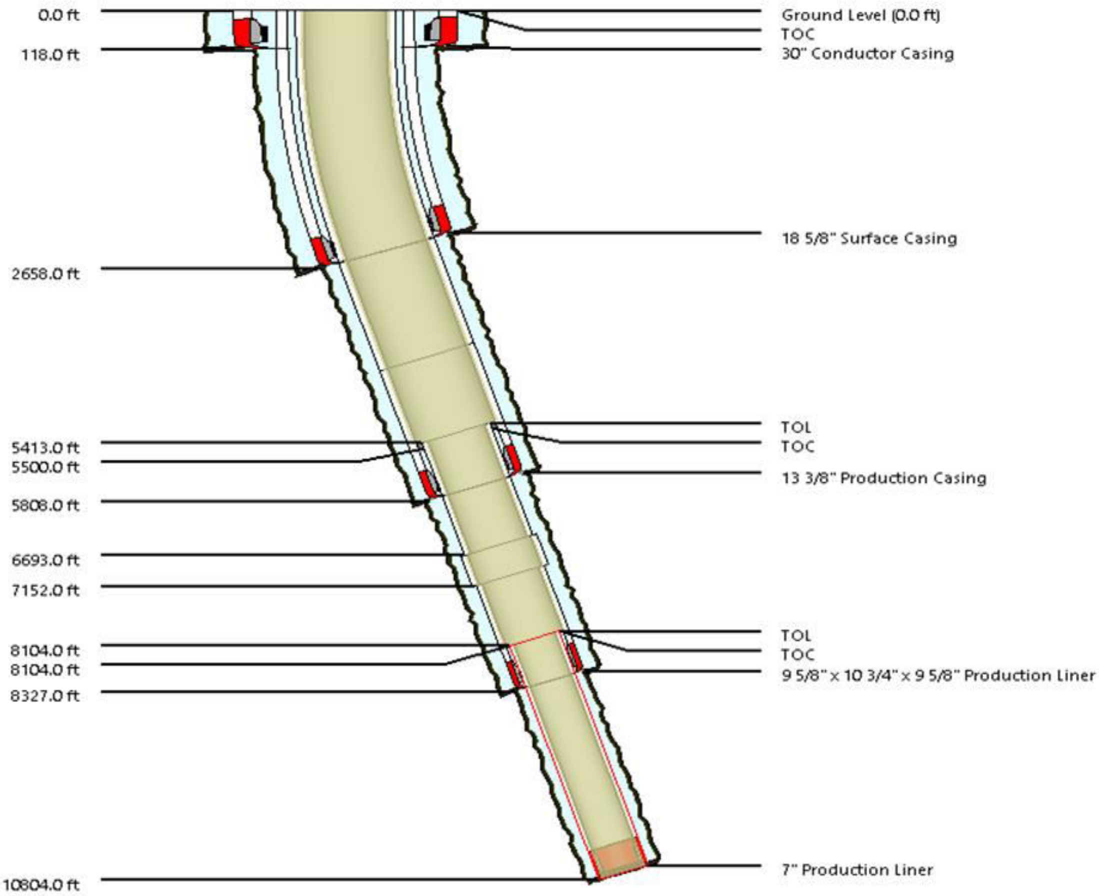


**Figure-8.** Well Schematic for well M-10 after modeling.

The 13⅜″ casing string, reclassified as production casing, experienced increased burst, axial, and triaxial loads, which were sustained by the high-grade casing. The collapse load line remained constant, as shown in Table-9 and Figure-9.

**Table-9.** String Sections (13 3/8" production casing string) for well M-10 after.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 206,385 |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 4265.0 | 13 3/8" | 68.000 | P-110 | 149,232 |
| 2 | 4265.0 | 5808.0 | 13 3/8" | 72.000 | P-110 | 57,153 |

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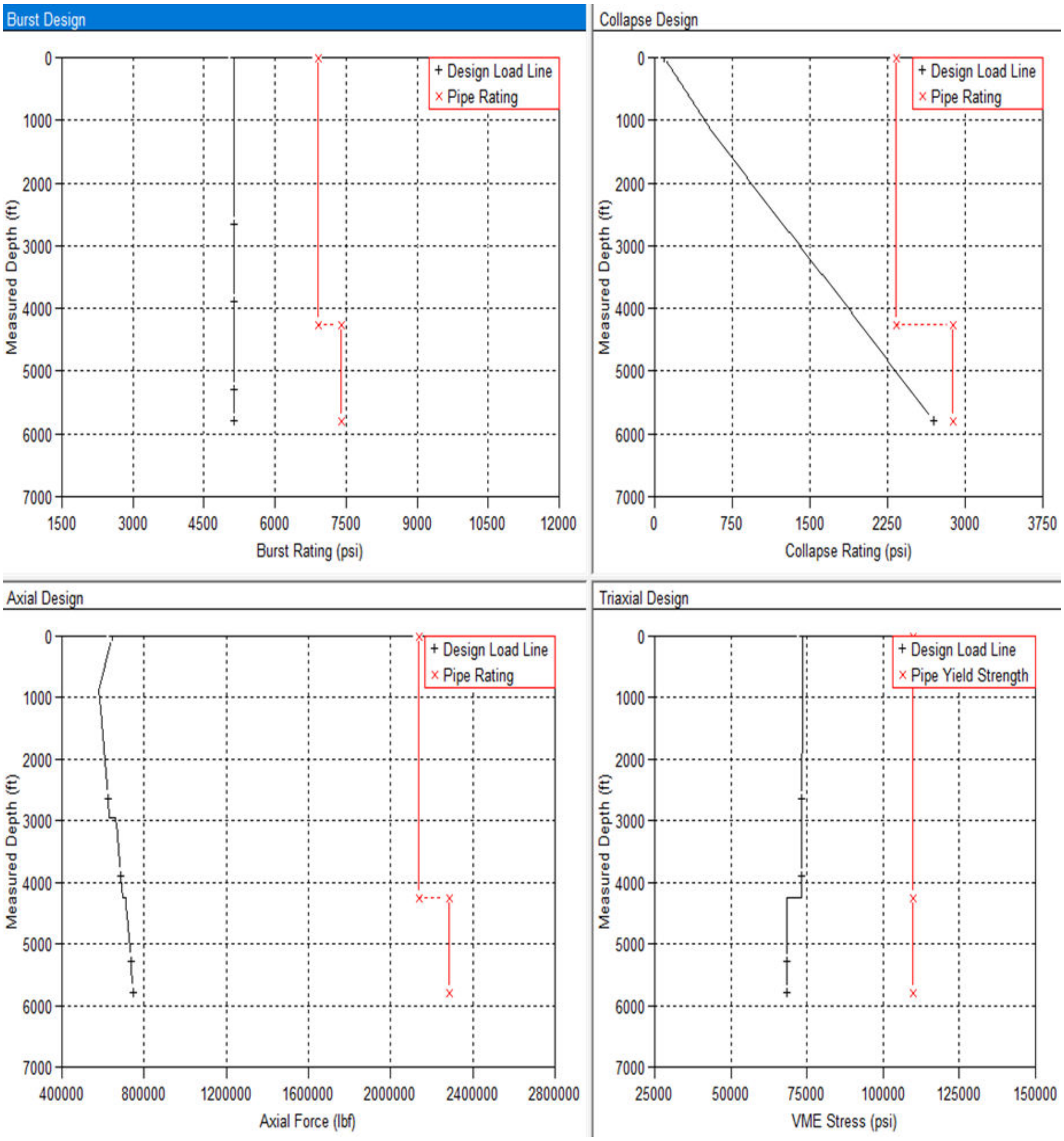


**Figure-9.** Design loads for a 13 3/8" production casing string for well M-10 after modeling.

The length of the 9⅝″ production liner was reduced by 5413ft (grade L-80 weight 47 ppf), and this section was completed using P-110 and T-95 grades, weight 53.5 & 85.3 ppf, and outside diameter 9 5/8" & 10 ¾" respectively are shown in Table-10. Design loads lines versus pipe rating are shown in Figure-10.

**Table-10.** String Sections (9 5/8" Production liner casing) for well M-10 after modeling.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 101,672 |
|---|---|---|---|---|---|---|
| 1 | 5413.0 | 6693.0 | 9 5/8" | 53.500 | P-110 | 41,579 |
| 2 | 6693.0 | 7152.0 | 10 3/4" | 85.300 | T-95 | 21,924 |
| 3 | 7152.0 | 8327.0 | 9 5/8" | 53.500 | P-110 | 38,169 |

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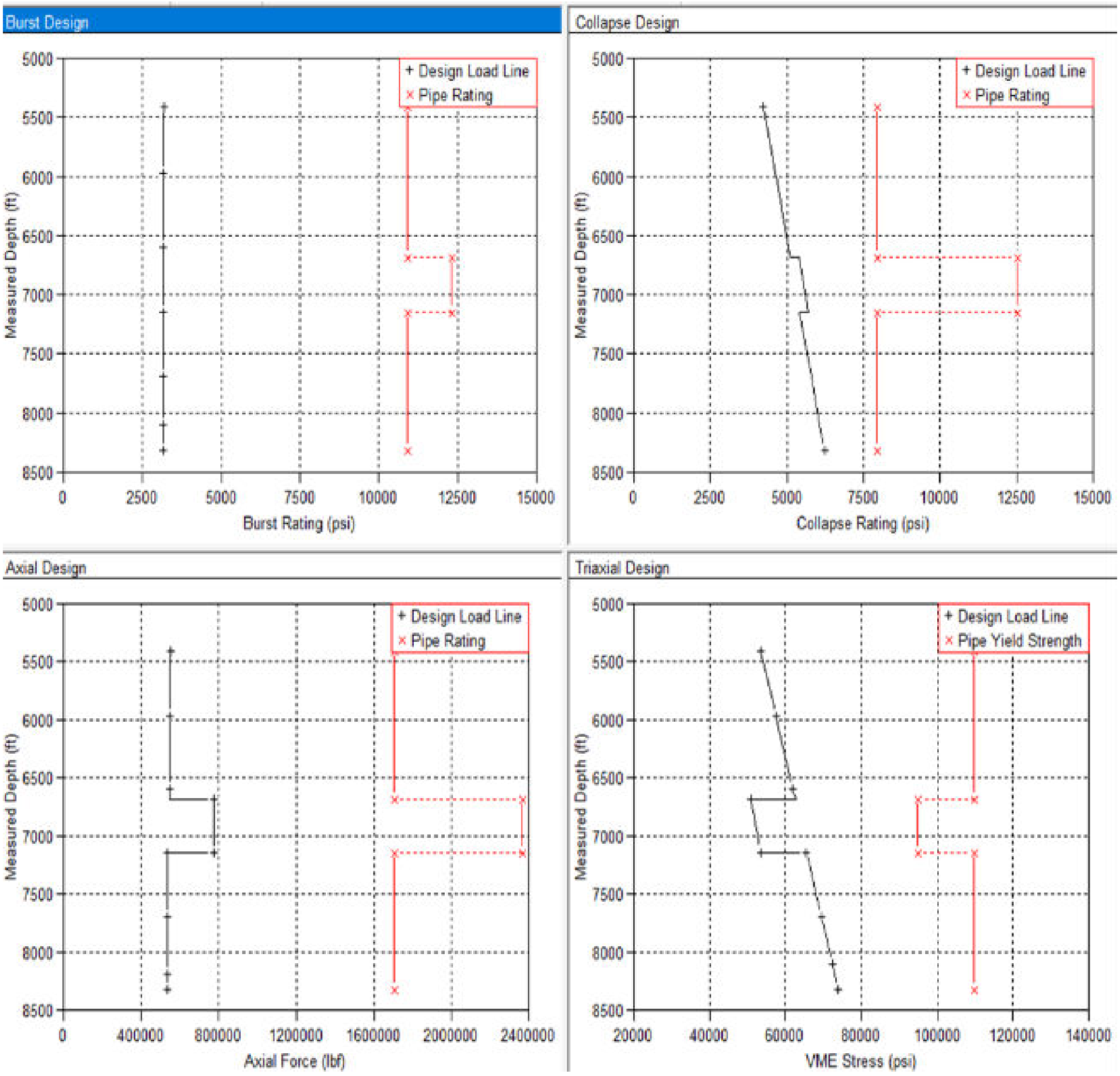


**Figure-10.** Design loads for 9 5/8" Production liner Casing for well M-10 after modeling.

**4.2 Well M-16**

Finally, the construction becomes 30" Conductor, 18 5/8" Surface, 13 3/8" Production string, 9 5/8" first Production liner, and 7” second Production liner. All depths are shown in Table-11 and the well schematics are shown in Figure-11.

**Table-11.** Casing Program Comparison for Well M-16.

| Casing Section | Hole Size (in) | Casing OD (in) | Casing Type | Measured Depth (ft) | Mud Weight (ppg) | Design |
|---|---|---|---|---|---|---|
| Conductor | 36.000 | 30″ | Casing | 0 - 115 | 8.93 | Same (Before & After) |
| Surface | 23.000 | 18 5/8″ | Casing | 0 - 656 | 8.93 | Same (Before & After) |
| Intermediate / Production | 16.000 | 13 3/8″ | Casing | 0 - 4823 | 9.85 | Reclassified as Production Casing (After) |
| Production | 12.250 | 9 5/8″ | Casing → Liner | 4523 - 8241 | 14.60 | Converted to Liner (After) |
| Production Liner | 8.500 | 7″ | Liner | 8103 - 12083 | 8.10 | Same (Before & After) |

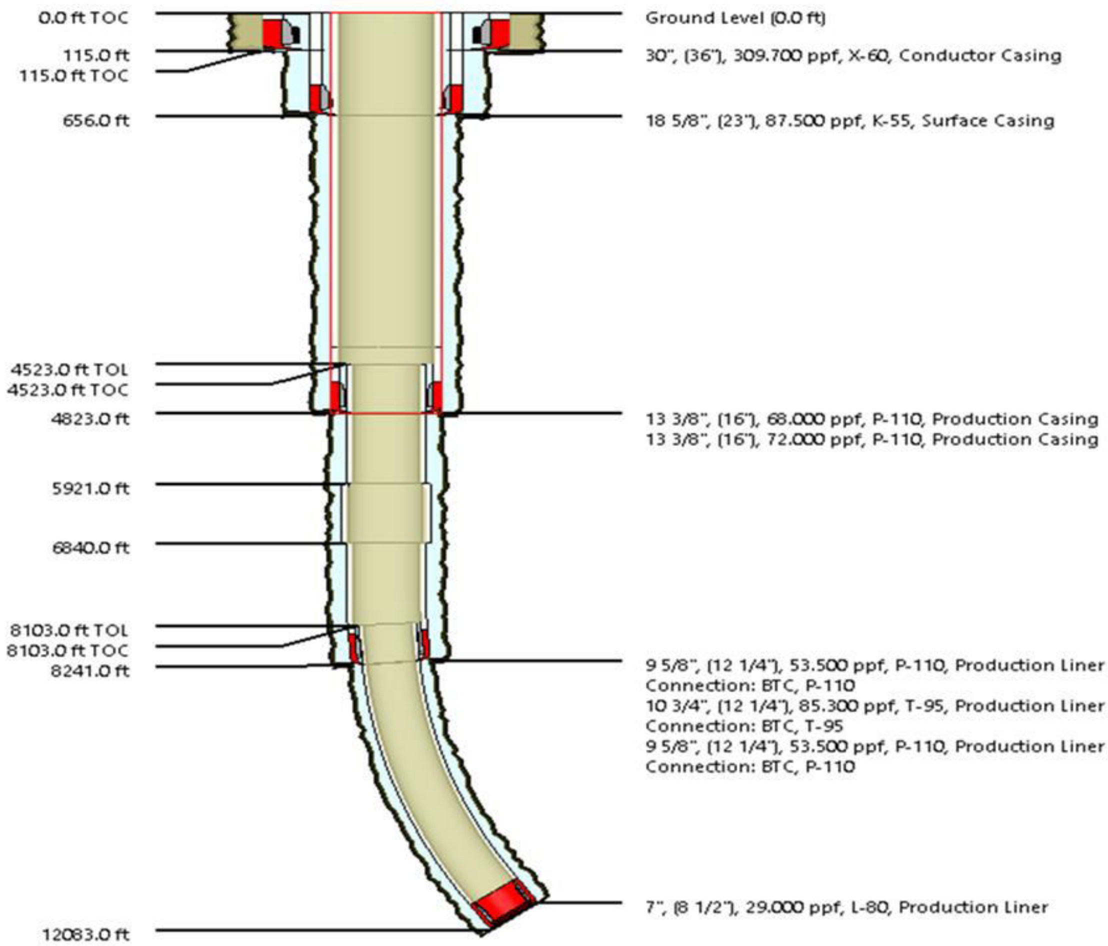


**Figure-11.** Well Schematic for well M-16 after modeling.

The 13⅜″ casing string, reclassified as production casing, experienced increased burst, axial, and triaxial loads, which were sustained by the high-grade casing. The collapse load line remained constant, as shown in Table-12 and Figure-12.

**Table-12.** String Sections (13 3/8" production casing string) for well M-16 after.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 206,385 |
|---|---|---|---|---|---|---|
| 1 | 0.0 | 4265.0 | 13 3/8" | 68.000 | P-110 | 149,232 |
| 2 | 4265.0 | 4823.0 | 13 3/8" | 72.000 | P-110 | 20,668 |

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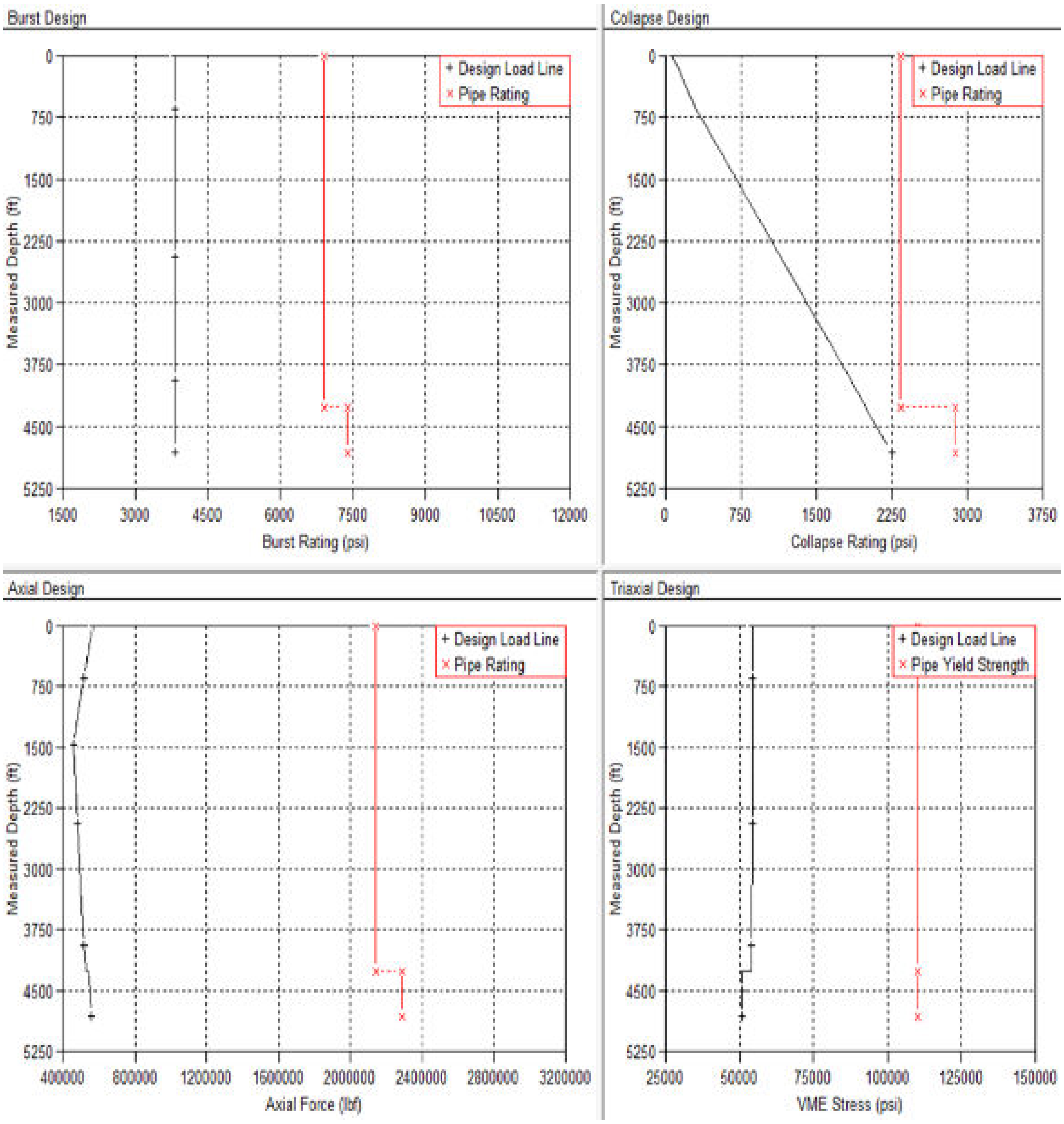


**Figure-12.** Design loads for 13 3/8" production casing string for well M-16 after modeling.

Production liner Casing 9 5/8" was reduced by 4523 ft (grade P-110 weight 53.5ppf), and this section was completed using P-110 and T-95 grades, weight 53.5 & 85.3 ppf, and outside diameter 9 5/8" & 10 ¾" respectively are shown in Table-13. Design loads lines versus pipe rating are shown in Figure-13.

**Table-13.** String Sections (9 5/8" Production liner casing) for well M-16 after modeling.

| | Top, MD (ft) | Base, MD (ft) | OD (in) | Weight (ppf) | Grade | Cost ($) 101,672 |
|---|---|---|---|---|---|---|
| 1 | 4523.0 | 5921.0 | 9 5/8" | 53.500 | P-110 | 45,412 |
| 2 | 5921.0 | 6840.0 | 10 3/4" | 85.300 | T-95 | 43,897 |
| 3 | 6840.0 | 8241.0 | 9 5/8" | 53.500 | P-110 | 45,510 |

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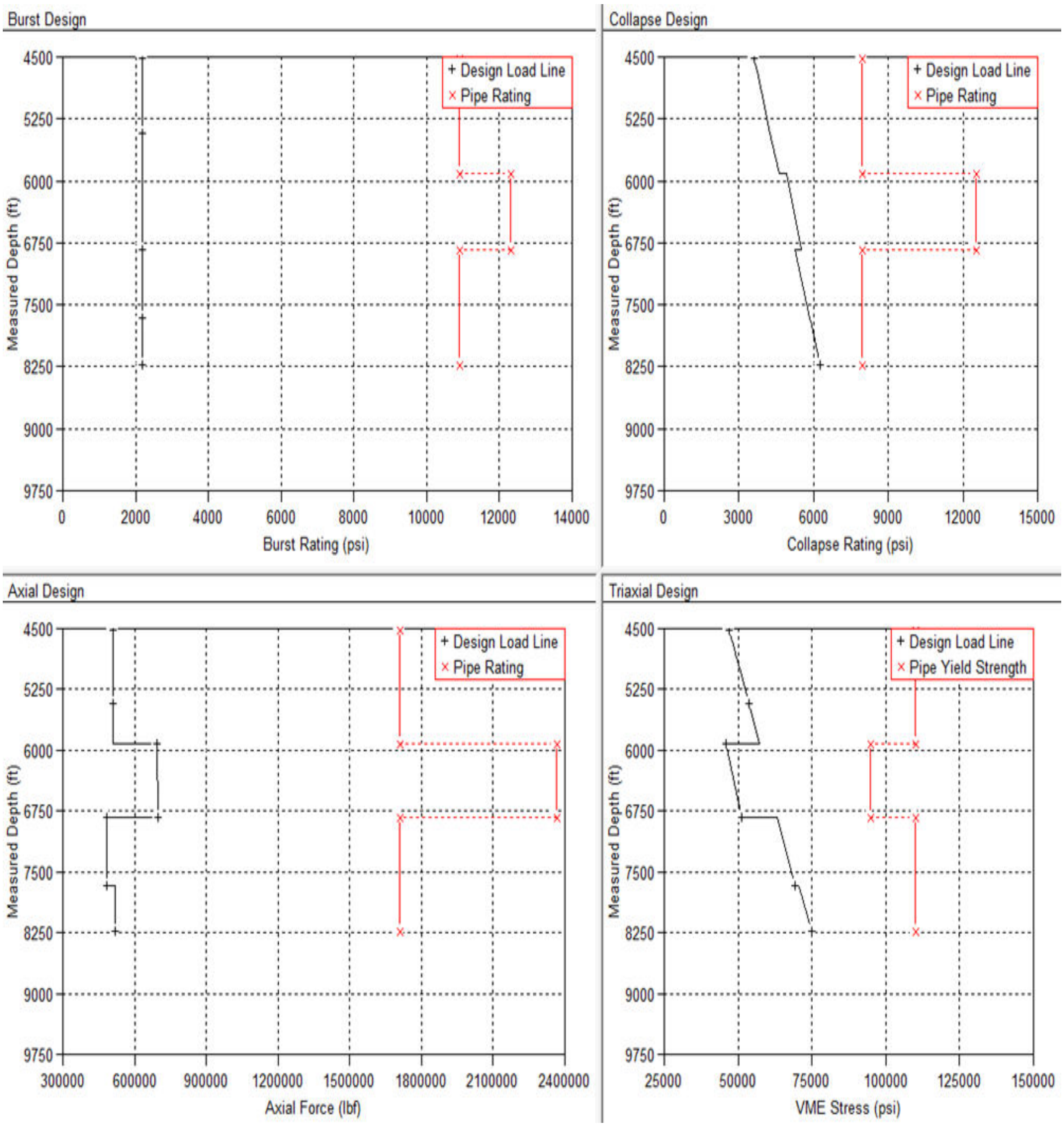


**Figure-13.** Design loads for 9 5/8" Production liner Casing for well M-16 after modeling.

## 5. RESULTS AND DISCUSSIONS

Efficiency and safety are at the core of any field operations in the Oil and Gas industry. [18] This study investigates the innovative application of protective strings as liners in directional drilling operations. The analysis highlights both the potential for cost savings and enhanced safety benefits associated with this technique. By carefully installing protective strings, this approach mitigates several risks commonly encountered during drilling operations, including:

- **Line-of-fire hazards:** Reduce exposure to flying debris or falling equipment, such as hammers or dropped objects.
- **Reduced need for elevated work platforms:** Minimizes height-related risks, including falls, by decreasing reliance on scaffolding and raised platforms.
- **Confined space hazards:** Mitigates risks associated with welding, cutting, and hot work in cellars and other restricted spaces.
- **Heavy machinery risks:** Reduces the need for heavy machinery, such as forklifts, in narrow areas, thereby minimizing accident risks.

Modeling results for applying a 9 5/8" protection casing string as a 9 5/8" liner casing demonstrate the following benefits:

- 45% to 60% cost savings in casing pipe length for this section.
- Reduction of non-productive time (NPT) and rig operation duration by approximately two days.
- Elimination of the 9 5/8" wellhead section.
- No requirement for cold cutting of the 9 5/8" section.
- Only the addition of a liner hanger for the 9 5/8" section.

Overall, this design strategy reduces well costs by approximately $190,000 to $200,000 per well (equivalent to 45% to 65% of the pipe cost). It is particularly advantageous for reservoir development projects involving multiple wells, where the cumulative cost and safety benefits become even more substantial. To complement the tabulated results and numerical simulations, a comparative illustration of the two design approaches is presented in Figure-14. This figure contrasts the conventional full length protection string with the optimized liner-based configuration, highlighting key differences in material usage, cementing strategy, and overall well architecture. By visually summarizing these distinctions, the figure facilitates a clearer understanding of how the liner-based approach enhances safety, reduces operational complexity, and improves cost efficiency.

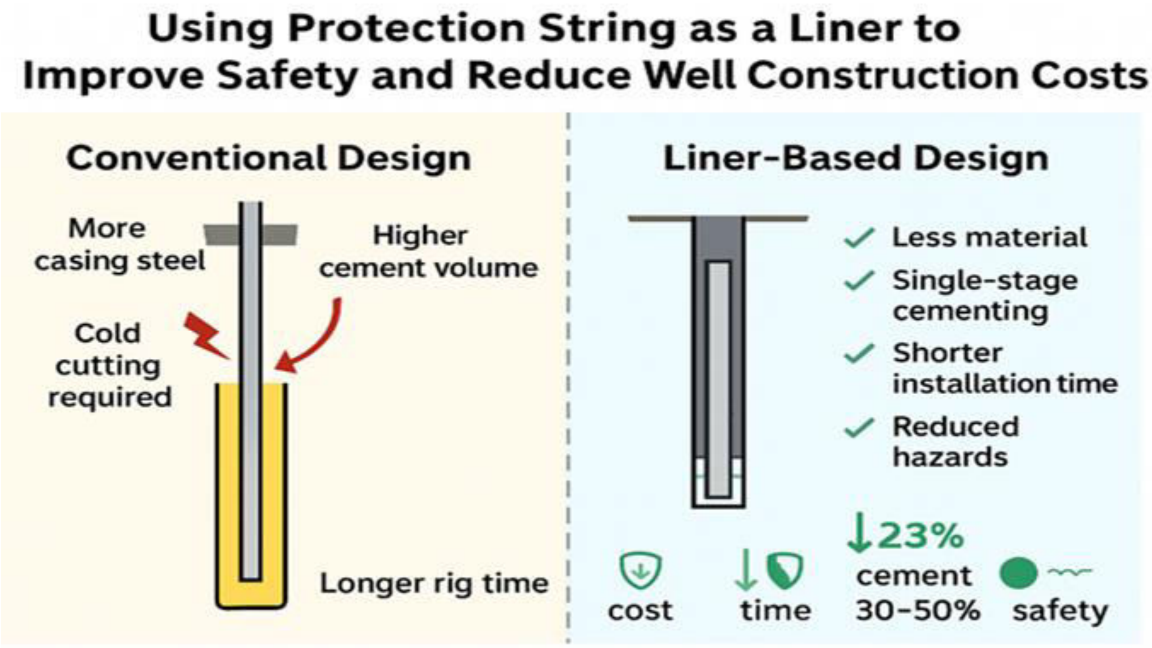


**Figure-14.** Comparison between conventional design and Liner based design.

The financial impact is particularly significant in fields under large-scale development. Table-14 summarizes the cost analysis for Well M-10, comparing the conventional and proposed casing designs.

**Table-14.** Cost Analysis for Well M-10 (Conventional vs. Proposed Design).

| Cost Item | Conventional Design ($) | Proposed Design ($) | Savings ($) |
|---|---|---|---|
| Pipe Cost (9 5/8″ Section) | 252,820 | 101,672 | 151,148 |
| Wellhead Section (9 5/8″) | 32,000 | 0 | 32,000 |
| Cold Cutting (9 5/8″) | 1,000 | 0 | 1,000 |
| Rig Time Savings (~2 days) | — | — | 60,000 |
| Total Gross Savings | — | — | 244,148 |
| Liner Hanger Cost | — | 50,000 | (50,000) |
| Net Cost Saving | - | - | 194,148 |

For Well M-10, the redesigned approach reduced casing length by 65%, yielding a net saving of $194,148 - a 59% reduction in casing section costs. Table-15 summarizes the cost analysis for Well M-16.

**Table-15.** Cost Analysis for Well M-16 (Conventional vs. Proposed Design.

| Cost Item | Conventional Design ($) | Proposed Design ($) | Savings ($) |
|---|---|---|---|
| Pipe Cost (9 5/8″ Section) | 281,774 | 134,879 | 146,895 |
| Wellhead Section (9 5/8″) | 32,000 | 0 | 32,000 |
| Cold Cutting (9 5/8″) | 1,000 | 0 | 1,000 |
| Rig Time Savings (~2 days) | - | - | 60,000 |
| Total Gross Savings | - | - | 239,865 |
| Liner Hanger Cost | - | 50,000 | (50,000) |
| Net Cost Saving | - | - | 189,865 |

For Well M-16, the redesign achieved a 55% casing length reduction, resulting in a net saving of $189, 865-a 52% cost reduction compared to the conventional design.

This demonstrates that the method is particularly beneficial for depleted reservoirs. Now proceeding with Table-16 (Summary of Final Cost Savings Both Wells).

**Table-16.** Summary of Net Cost Savings across Both Wells (M-10 & M-16).

| Well | Net Cost Saving ($) |
|---|---|
| Well M-10 | 194,148 |
| Well M-16 | 189,865 |

Across both wells, the average net saving was approximately $192,000 per well, validating the consistency and robustness of the proposed design in comparable environments.

**Key observations**

- Casing pipe cost becomes increasingly significant with depth.
- The approach is especially effective for development wells in depleted reservoirs.
- The method is advantageous when sourcing 9 5/8" casing is challenging.
- Reservoir properties determine the feasibility of the application.

By implementing this method, operators can anticipate substantial cost savings from reduced non-productive time and material usage while enhancing safety and efficiency. Industry benchmarks suggest a 20-30% reduction in fall and impact-related incidents through minimized use of scaffolding and heavy machinery. These benefits support the broader application of this approach in development drilling, particularly in mature and depleted reservoirs.

**5.1 Limitations and Risk Assessment**

While the proposed method demonstrates clear benefits, several limitations and potential risks should be acknowledged:

- **Liner hanger reliability:** Dependent on mechanical integrity and sealing capability.
- **Cementing challenges:** Single-stage cementing in deviated wells can complicate zonal isolation.
- **Limited applicability:** Most suitable for low to medium-pressure zones; less viable in HPHT wells.
- **Operational complexity:** Requires precise liner running and experienced personnel.
- **Regulatory compliance:** Jurisdictional standards may limit liner applications.

Recognizing these limitations allows operators to conduct appropriate risk assessments and contingency planning to ensure safe, effective implementation.

**5.2 Future Work and Recommendations**

Further studies and activities are recommended to validate and expand this method’s applicability:

- Conduct expanded field trials under varied conditions.
- Undertake advanced liner hanger reliability testing.
- Optimize cement placement techniques for deviated wells.

- Perform economic sensitivity analyses across different reservoir types.

- Engage with regulatory bodies to clarify compliance pathways.

- Conduct adaptation studies to evaluate feasibility and performance in HPHT environments, broadening the method's applicability.

## 6. CONCLUSIONS

The use of a protection string as a liner has been demonstrated to significantly reduce well costs, enhance operational safety, and improve drilling efficiency. The approach offers substantial technical and economic advantages, particularly in the context of development wells and mature or depleted reservoirs. Key conclusions are:

- **Cost Reduction:** Casing pipe length reductions of 45% to 65% yielded average net savings of approximately $192,000 per well.

- **Enhanced Safety:** The method minimizes risks associated with working at heights, confined spaces, and heavy machinery use.

- **Improved Efficiency:** The approach reduced non-productive rig time by approximately two days per well.

- **Technical Feasibility:** The method proved robust when applied to directional wells with comparable load profiles.

Overall, this design strategy provides a cost-effective and operationally sound alternative to conventional casing designs, offering strong potential for widespread adoption in suitable field environments.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Material Research Center (MRC) and Concrete Labs in the Mining and Petroleum Engineering Department, Faculty of Engineering, Al-Azhar University, Cairo, Egypt.

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