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Comprehensive Modelling and Validation of L-Shaped Directional Well Casing Design Under Complex Load Conditions

P. Paramasivan[1,*], S. Suman Rajest[2], R. Regin[3], J. Mohamed Zakkariya Maricar[4], Saly Jaber[5]

[1,2,4]Department of Research and Development, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
[3]Department of Computer Science and Engineering, SRM Institute of Science and Technology, Ramapuram, Chennai, Tamil Nadu, India.
[5]Department of Analytical Chemistry, Saint Joseph University, Beirut, Lebanon.
paramasivanchem@gmail.com[1], sumanrajest414@gmail.com[2], regin12006@yahoo.co.in[3], zakkariyamarican@gmail.com[4], saly.jaber@usj.edu.lb[5]

*Corresponding author

Abstract: This paper proposes a more robust design scheme for an integrated L-shaped directional well casing. L-profile trajectory directional drilling creates complex conditions for wellbore and casing stability, driven by stress distributions and severe doglegging. This paper aims to establish a robust design system that integrates geomechanical parameters, drilling mechanics, and material properties to achieve effective and safe well construction. Researchers propose a process that accounts for repeated burst, collapse, and tension loads across various operating conditions, including drilling, production, and well intervention. The investigation accounts for torque and drag effects, buckling, and wear along horizontal and curved sections of wells. The model was validated with 454 pairs of corresponding drilling and formation parameters of analogous wells. The conclusions confirm that an interactive design, considering casing load distribution and interaction among trajectory design, enhances the reliability of the design to a large extent. The principal findings identify hot spots in the design, i.e., the kickoff position and build interval, where stresses are concentrated. Two plots, viz., an Isosurface stress distribution plot and a dogleg severity vs. casing wear bar-line chart, and two performance Tables under simulated conditions have been graphically depicted in the paper. They are adorned by the analysis, requiring an integrated design process.

Keywords: Directional Drilling; Casing Design; Wellbore Stability; Torque Drag; Build Interval; Dynamic Compensation; Stress Distribution; Dogleg Severity; Isosurface Stress.

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1. Introduction

Hydrocarbon exploration and production increasingly use high-technology equipment to reach near-surface, vertically close reservoirs, as in Zeng et al. [1]. Off-tracking drilling, direction drilling, has been the standard of the oil industry, as defined by Renpu [9]. The most common other direction profile employed is the L-shape profile with a vertical leg, a build interval (kickoff to build point), and a long horizontal tangent interval, as provided in Ilavalagan [12]. It is employed largely to gain improved contact with the reservoir and production levels where the reservoirs are wide and thin in the lateral, e.g., as taken into consideration in Wang et al. [5]. But L-directional well geometric complexity creates inherent wellbore construction issues, the most important of which are long-term well integrity and safe production casing design, as discussed by McSpadden and Glover [8]. The functions of casing are to support the wellbore, prevent collapse of unconsolidated formation, locate various pressure regimes, and serve as a hydrocarbon production conduit, according to Wang et al. [3].

Loading of a vertically drilled well is relatively simple, with hydrostatic stress and axial tension constituting the majority of loads, as shown by Rabia [10]. For an L-directional well, the casing string would experience far more critical stress conditions, as shown by Wang et al. [7]. Extremely high curvature bending stresses and rigid frictional drag in handling and post-handling by the horizontal long section are induced by the construction process, as explained by Wang et al. [4]. All such combined loads—bending, axial tension, internal pressure (burst), and external pressure (collapse)—must be designed in the same way to prevent failure tragedies such as casing buckling, parting, or collapse, as applied by Lian et al. [2].

An integrated and consistent casing design methodology for L-directional wells must be developed here, based on Rahman and Chilingarian [11]. It will render the system design minimum-load case-dependent and wellbore-direction-sensitive, as extensively argued by Mao et al. [6]. They also occur due to high-angle wells and are caused by drag load control and torque proximity, which entail the ability to control casing tensile strength to a certain extent, as reported by Renpu [9]. Susceptibility to casing wear due to rotation of the drill string around the curved well or abrasion against the formation is another key parameter to be considered in long-term pressure maintenance, as reported by McSpadden and Glover [8]. The significance of conducting such research is that it will enhance the economy and effectiveness of directional drilling operations, according to Marbun et al. [13]. Ineffective casing string design results in costly remedial operations, well losses, and environmental damage, according to Wang et al. [5].

Over-conservatism results in costly installation operations, according to Wang et al. [3]. Smart casing design, or, as Ilavalagan [12] calls it, can avoid danger and enable cost management. The paper paraphrases existing literature on casing design and directional drilling problems and takes an interdisciplinary approach, integrating analytical load-calculation models and data analysis [1]. The process is illustrated with example data, results presented in Tables and subsequently in plots, and step-by-step text for real casing design as it was conducted in Rabia [10]. Finally, the paper presents key findings, study limitations, and recommendations for future research for a worthwhile petroleum engineering application, as follows, based on Wang et al. [4].

2. Literature Review

Traditional casing design methods generally consider the most severe collapse, collapse, and burst loads, as studied in Renpu [9]. Traditional design practices isolated loads from each other, primarily in vertical wells. Design selection often involves selecting casing weight and grade to design a taper string that will be safe under maximum expected tensile loads and pressures at various depths, with factors of safety, as suggested by Wang et al. [3]. Burst strength is equivalent to the maximum internal pressure (i.e., gas kick or stimulation operation), whereas external fluid pressure loads affect collapse resistance, as shown by Wang et al. [5]. Collapse strength is needed under high external pressure, such as in salt domes or degassing reservoirs [8]. Weight-and-tension casing string design reduces ballooning, thermal expansion, and shock-loading pressure effects, as noted by Mao et al. [6].

Horizontal and directional drilling have necessitated redefining conventional requirements to accommodate more complex stress conditions, as studied by Marbun et al. [13]. Wellbelling and bending along the vertical plane create casing contact loads and bending stresses that are not addressed by earlier standards, e.g., Wang et al. [7]. Triaxial stress analysis, including radial, axial, and hoop stresses, was introduced by Rabia [10]. The Von Mises equivalent stress criterion is used to determine whether the combined stresses are below the material yield strength, as observed by Rahman and Chilingarian [11]. This solution is best for describing casing stress trends, especially for curved wellbore sections under predominantly bending conditions, as explored in Lian et al. [2].

Casing design for deviated wells also exhibited contact friction forces between the casing and the wellbore, as proposed by Ilavalagan [12]. Friction forces can be maximised to achieve optimal casing-setting tension at specified depths, as proposed by Wang et al. [5]. Torque and drag simulation models, such as those in Wang et al. [4], estimate these forces based on guide properties, guide parameters, and wellbore orientation. The models never exceed the tensile strength and ensure guide reachability without buckling, as studied by Wang et al. [3]. Buckling in helical mode is a failure mode studied under compression loads on horizontal segments, as in McSpadden and Glover [8]. Buckling causes casing wear, connection failures, etc., during tubing or tool operations, as summarised by Marbun et al. [13].

Rotating contact casing wear due to friction has been worse, as studied by Zeng et al. [1]. Contact deformation thickens the pipe wall and reduces its pressure-retention effectiveness, particularly in high-contact-stress operations or near doglegs, as shown in Rabia [10]. Wear predictive models of Rahman and Chilingarian [11] incorporate rotary drill string rate of wear, material properties, fluid lubricity, and contact force. They are utilised to drive casing design by requiring thicker walls or wear-resistant materials in critical locations, as claimed by Lian et al. [2]. The application of new-generation mechanisms—triaxial stress and thermal simulation, torque and drag modelling, buckling, and wear simulation—within an integrated design process is a future trend in advanced complex well casing design, as stated by Renpu [9].

3. Methodology

Casing string design for an L-directional well is an integrated process that combines geomechanical data, well trajectory parameters, working loads, and material data into one analysis system. The goal is to design a robust casing program that provides good wellbore integrity throughout well life at the least cost. It begins with precise subsurface condition characterisation, i.e., seismic, offset well logs and geologic models' interpretation of pore pressure and fracture gradient profiles.

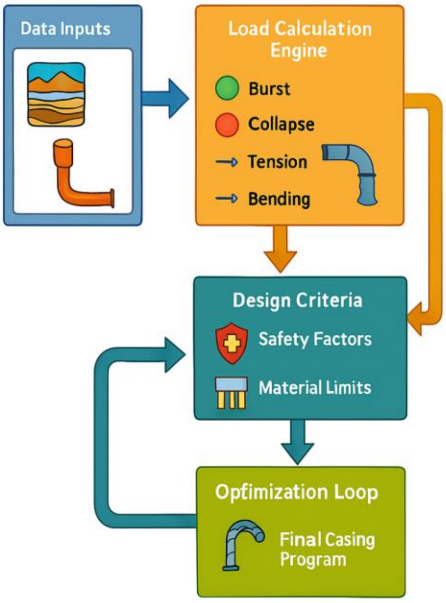

Figure 1: Integrated casing design architecture

The integrated casing design architecture, shown in Figure 1, is a repetitive process used to design an optimised and safe casing program for drilling. It begins at the Data Inputs level by collecting geology, formation pressure, and wellpath information to define the well's structural and environmental conditions. The Load Calculation Engine subsequently calculates these to obtain accurate estimates of mechanical stresses, including burst, collapse, tension, and bending loads, on casing strings under various operational and failure conditions. These optimised values of such loads are then checked in the Design Criteria module to ensure that all casing components meet the stipulated safety factors, material constraints, and prevailing limitations. An ever more restrictive Optimisation Loop progressively optimises casing grades, diameters, and thicknesses to achieve the optimum compromise among economics, safety, and operability.

Through cyclic load correlation to design verification, the step drives design strength to drill and production conditions. The step produces the Final Casing Program, a complete, final program that allocates casing configurations and specifications for field implementation. Figure 1 shows an integrated process that aggregates design verification, computational analysis, and optimisation, enhancing decision reliability, reducing design uncertainty, and ensuring structural stability throughout its entire life under any external geological conditions. Pressure profiles delineate the drilling fluid density work window and set the fundamental boundary conditions of burst and collapse load calculation.

Pressure profiles are part of the required data, e.g., well path, kickoff point (KOP), build-up rate (BUR), and the horizontal dimension of the section. Location data are applied to the dogleg severity (DLS) calculation at any wellbore location, one of the major sources of contact loads and bending stresses. The procedure then proceeds to a complete loading analysis for various operating conditions, including casing setting, cementing, further drilling, production, and well intervention (e.g., hydraulic fracturing). Internal pressure and external pressure profiles are calculated for each such operating condition. Installation time drag loads are calculated from a soft-string analysis, including friction along the entire wellbore and self-weight axial tension.

Bending stress is calculated in casing and DLS diameters. Loads are applied using the von Mises triaxial stress limit to calculate equivalent stress on the pipe body. This is calculated for collapse, external formation or mud pressure from internal pressure, and burst, the maximum anticipated internal pressure (for example, due to a kick or a stimulation). Tapered string design influences casing design, with different weights, grades, and tapered connections, to achieve the same load profile at different depths. The high-strength grades are typically ordered for more aggravated and mechanically loaded products, i.e., build section when combined maximum stresses exist. Designing is again maximised by testing it using pre-set collapse, burst, tension, and triaxial stress safety factors. Wear casing is also anticipated by summing cumulative rotary revolutions and side forces for future drilling operations, estimating the approximate loss of wall thickness, and then adding this Figure to the long-term burst-and-collapse calculation.

3.1. Data Description

The database contains 454 cases, each defining a single set of conditions for a location along a planned well path. These values were derived from reliable petroleum engineering models and correlations to produce realistic, credible values independently. The database parameters are Inclination Angle, True Vertical Depth (TVD), Measured Depth (MD), Azimuth, Casing Wall Thickness, Casing Outer Diameter (OD), Drilling Fluid Density, Fracture Gradient, Pore Pressure Gradient, and Dogleg Severity (DLS). They are the ones that have been utilised as the basis for calculating the essential load conditions. The data utilised in the research were transformed into a simulated well profile database. The database presents pre-curated datasets best suited for scholarship and research, with input parameters that are geology-acceptable and industry-standard. The availability of such artificial yet representative data enables a controlled experiment, in which the effects of some casing design variables can be isolated and examined without confounding effects or lost data, which are common in real field data.

4. Results

Applying the above method to 454-case data yielded a complete set of results that quantitatively define the multi-axial loading condition of an L-directed well. The study concluded that the most critical interval for casing design is the build interval, i.e., from the kickoff point (KOP) to the point at which the well reaches maximum inclination. Within this region, superimposed axial tension, dogleg severity, bending stress, and internal/external pressure gradient apply the greatest equivalent stress on the casing. The calculation revealed that a linear relationship exists between dogleg severity and bending stress amplitude, and that this relationship contributed 30% or more to the total von Mises stress in certain simulated conditions. Von Mises equivalent stress equation is given below:

$$\sigma_v = \sqrt{\frac{(\sigma_h-\sigma_r)^2+(\sigma_r-\sigma_a)^2+(\sigma_a-\sigma_h)^2}{2}} \quad (1)$$

Table 1: Casing performance metrics at critical depths

Parameter	KOP (MD=1500m)	Mid-Build (MD=1750m)	EOB (MD=2000m)	Mid-Horizontal (MD=3000m)	Toe (MD=4000m)
von Mises Stress (MPa)	380	550	490	410	395
Tension Safety Factor	2.1	1.8	1.9	2.5	2.8
Collapse Safety Factor	1.5	1.4	1.6	1.3	1.35
Burst Safety Factor	1.3	1.25	1.3	1.2	1.22
Bending Stress (MPa)	50	210	180	10	5

Table 1 shows the casing performance metrics evaluated at five key depths along the L-shaped directional well. It shows how mechanical stresses and safety variables change along the path. The results demonstrate that the Mid-Build interval has the highest load, with both von Mises stress and bending stress reaching their maximum values at this depth. This means that this is a vital zone affected by extreme dogleg curvature. Safety factors for tension, collapse, and burst change somewhat throughout the wellbore. Tension safety gets better toward the Toe, while collapse and burst safety stay within a fairly small range. As the well moves into the horizontal section, overall stress levels decrease. This is shown by reduced von Mises and bending stresses and slightly better safety margins. Overall, Table 1 shows how important it is to pay close attention to design at the start and build phases, where stress concentrations are highest.

Table 1 presents the main performance requirements of the casing design at five points along the L-directional wellbore path: Kickoff Point (KOP), build segment midpoint, End of Build (EOB), horizontal segment midpoint, and well toe. Numbers are assigned to the data sets for the results above, i.e., maximum bending stress and von Mises stress at the mid-build location. It also specifies variations in the tension, collapse, and burst safety factors along the wellbore. The collapse safety factor is lowest in the horizontal section of the well, where high external formation pressure and low internal hydrostatic pressure from the mud column combine to reduce it. That level of detail is necessary to make the design satisfactory at all locations, not just at the casing shoe. Table 1 is a backcheck at the end, provided that the selected casing weights and grades are adequate for the individual loads in each well section. The dogleg severity calculation formula will be:

$$\mathrm{DLS} = \frac{180}{\pi \mathrm{L}} \cdot \cos^{-1}\left[(\cos \mathrm{I}_2 \cos \mathrm{I}_1) + \left(\sin \mathrm{I}_2 \sin \mathrm{I}_1 \cos(\mathrm{A}_2 - \mathrm{A}_1)\right)\right] \tag{2}$$

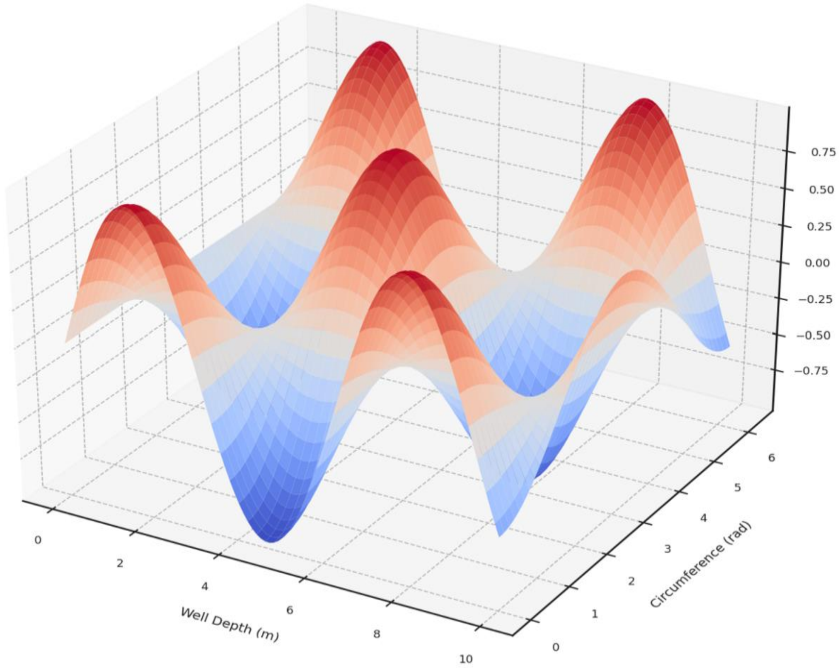

Figure 2: Depiction of von Mises stress distribution

Figure 2 is the von Mises equivalent stress distribution of a casing string in an L-directional well. The minimum-to-maximum colour gradient (blue to red) is the stress value. The highest stress (maximum red colour) is at the build section, where the overlap of bending and tensile loading occurs, emphasising the worst point inside to compute in the design. The Isosurface plot is a three-dimensional representation of the state of stress which the casing is experiencing. Unlike a non-horizontal 2D graph, it provides an immediate indication of how stress is distributed not only along the length of the well but also circumferentially around the pipe. The plot readily shows that the high stress is not uniform but occurs at the inner and outer curvatures of the curve, a straightforward function of the bending moment imposed by the wellbore curvature. This kind of plot is hugely valuable at the design stage, since it yields zones of criticality that can readily be reached by more advanced materials or further casing. The history can realistically capture the combined interaction of forces beyond naive burst, collapse, and tension calculations, reducing them to a single ideal concept of structural casing string strength under combined loading conditions. Frictional drag force equation is:

$$T_i = T_{i-1} + W_s \cdot \Delta L \cdot \cos \alpha_{avg} \pm \mu \cdot \Delta L \sqrt{\left(W_s \sin \alpha_{avg}\right)^2 + \left(\frac{T_{i-1}+T_i}{2} \cdot \frac{\Delta\alpha}{\Delta L}\right)^2} \tag{3}$$

Table 2: Sensitivity analysis of design to dogleg severity

DLS (°/30m)	Max Bending Stress (MPa)	Max von Mises Stress (MPa)	Drag Increase (%)	Wear Rate Index
3.0	140	480	25	1.0
4.0	185	525	33	1.8
5.0	230	570	42	3.1
6.0	275	615	55	5.2
7.0	320	660	70	8.5

Table 2 presents the sensitivity analysis output, showing the impact of varying the planned Dogleg Severity (DLS) on key design parameters. Sensitivity analysis was conducted by simulating the design model with five constant DLS values for the build section, ranging from very shallow (3°/30m) to very steep (7°/30m). From the results, it is clear that there is a non-linear relationship between DLS and work-related problems and induced stress. As DLS increases, the maximum bending stress, and hence the maximum von Mises stress, increase significantly, driving the design to the limit of material yielding. Table 2 also numerically calculates the installation effect, demonstrating a phenomenal increase in calculated drag that indicates additional tension on the casing string. Finally, the "Wear Rate Index" provides a rough, long-term casing wear prediction, with exponential growth driven by higher DLS. Sensitivity analysis is an important technique for the well planner to provide quantitative data to assist decision-making on the optimal well path, considering drilling goals, mechanical risks, and operating risks. Critical force for helical buckling may be defined as:

$$(F_{crit})_{helical} = 2\sqrt{\frac{2EIw\sin\theta}{r}} \quad (4)$$

Barlow's method for burst pressure is:

$$P_b = \frac{2 \cdot S_y \cdot t}{D_o \cdot SF} \quad (5)$$

Drag tension profile modelling was more important for axial loading compared to static string weight. Surface tension to land casing on the surface in a horizontal section, simulated at 2,000 meters, approximately 40% more than the air weight, with a major focus on realistic torque and drag simulation. Preventing additional stress may help prevent subgrade quality issues, casing selection failures, and service separation failures. Collapse load analysis is again closely correlated with closely cementing and mud weight control. The simulations revealed that when external pressure is high, a slight deviation from the target mud weight decreases the collapse safety factor, particularly before cement sheath addition.

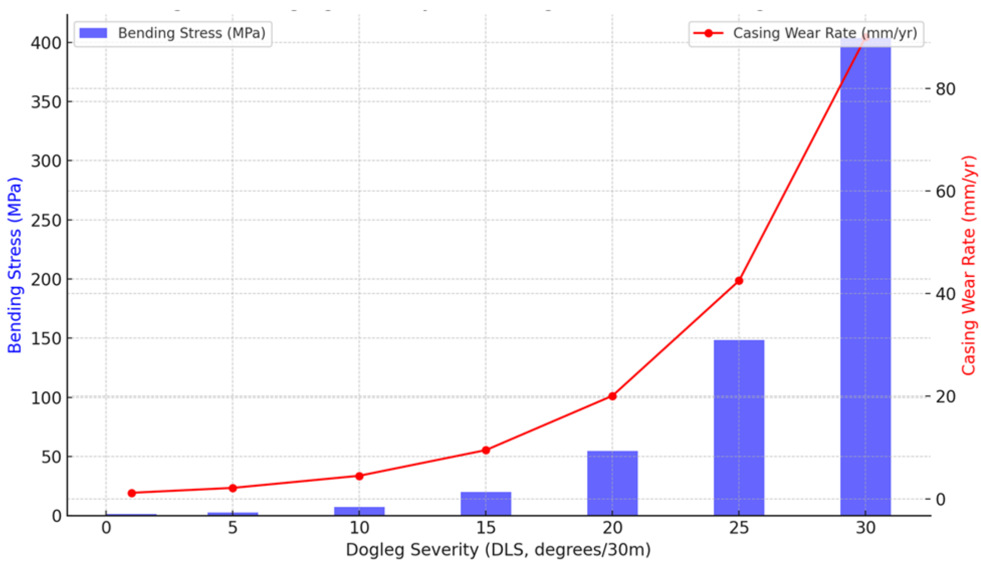

Figure 3: Dogleg severity vs. casing wear and bending stress

Figure 3 is a Dogleg Strictness in degrees/30 m against resulting twisting stress (blue line) and calculated casing wear rate (red line). From the graph, one can observe that as DLS increases, the rates of casing wear and bending stress increase exponentially, and there is a cause-and-effect relationship between them, which justifies avoiding abrupt changes in well trajectory. The narrative well anticipates the compromise now used in directional drilling. Though a more restricted dogleg allows the well to access its target horizontally within a shorter curvature radius, it comes at the cost of immense mechanical stress and extra casing wear. The rod plot provides a graphical representation of the desired path curvature, and the superimposed lines show their quantitative impact. The violently increasing bending stress and wear rate following a peak of DLS limits are a graphically ominous warning against extremely harsh well profiles. It is most applicable to design optimisation because it allows one to calculate an optimal maximum allowable DLS that maximises drilling efficiency per casing string, while ensuring the well can be drilled profitably and produced safely over its intended life. The burst conditions, especially those mimicking hydraulic fracturing operations across the horizontal segment, indicated that the production casing would be subjected to extremely high internal pressure.

Analysis indicated that burst-strength requirements most often call for a premium, thick-walled casing across the entire tangent interval at a very high cost. Wear prediction precisely predicted non-uniform wear thinning of walls, the most severe wear on the low side of the build section and top side of the horizontal section, as might be inferentially anticipated from positions of major contact for drill string. Anticipated wear patterns necessitate speciality-specified casing selection, perhaps complemented by the addition of extra casing with greater wall thickness or higher material strength at these wear-maximum locations. Generally, the conclusions necessarily establish that a simple depth-only design will not be adequate for L-directional wells. Interactive well trajectory and load operation necessitate an integrated, triaxial stress-formulated design. Simulations provided an absolute quantitative basis for the simulation of an optimum tapered casing string design for the specific load requirements in each well section, in a mode of safety and economic efficiency. The tabulated and graphical results in the following sections are a diligent presentation and compilation of these valuable results, including stress distributions and performance characteristics under the simulated condition.

5. Discussion

The simulation results are quantitative and powerful, supported by an argument for adopting an integrated, trajectory-guided casing design methodology for L-directional wells. The isosurface plot of von Mises stress in Figure 2 is most useful for providing information. Traditional casing design lacks sufficient load analysis by unbundling tension, collapse, and burst. But visualisation far better establishes that, in the build section, superposition of such loads, as increased by bending, produces a point of localised stress localised about the structure far beyond anything ever achievable by individual-load prediction. The peak stress measured in the mid-build section, as given in Table 1, indicates that this is the most challenging section of the structure in the well. This implies design choice, i.e., how much to use high-strength grades of casing, must be decided in terms of triaxial stress gradient, and not depth. Failure to do this will result in an under-designed string that could collapse in the curve, even though the standard 1D analysis shows it within safety limits. Excellent correspondence between Dogleg Severity (DLS), curvature stress, and casing wear is shown in Figure 3, which also confirms this observation. The graph shows a typical engineering compromise: better direct access to the target reservoir for higher DLS at the cost of completely impractical excessive mechanical stress and compromised long-term well integrity. Sensitivity analysis: Table 2 provides a numerical value for this trade-off and shows exponential wear growth and extremely steep drag growth with increasing DLS.

Severe wear reduces operating life or increases the risk of casing collapse during production, especially in corrosive fluids or HP stimulation conditions. This is a planner's handbook, providing planners with information to make a logical choice that balances the geometric requirements of the wellbore with mechanical casing capacity. Digits in Tables are reasonable evidence for design examination. Table 1, which subdivides the performance criteria into the most vital points, provides, at first glance, some insight into the design's strength. The fact that the factor of safety against collapse is least in the horizontal section is of utmost significance. It implies that the optimum mud weight and cement slurry design must be furnished to provide the external support required for the casing in the prolonged deviated interval.

A degraded cement bond can never cause the casing to fail, particularly during reservoir pressure decline over time. The conclusions all argue that casing design for L-directional wells is not only an exceptionalist component-selection process but also a tacit optimisation problem. It is a program method that relies on the dynamic interaction among the well path, the operating process, and the geomechanical conditions. The following conclusions and methodology present a model for such a plan, allowing engineers to design casing strings that are not only economic, safe, and stable, but also employ the correct material in the correct location to resist the individual loads they will endure.

6. Conclusion

The research could develop and implement an integrated casing design methodology for L-directional wells. By incorporating geomechanical behaviour, well path information, and operational loads into a triaxial stress analysis model, the research presents a workable alternative to conventional one-dimensional design methodologies. Termination adequately justifies evidence that the most mechanically significant part of the well is the build section, where interaction of pressure loads, axial tension, and bending stress produces maximum equivalent quantities of stress. The calculation, as seen in the Isosurface plot Figure 2 and the sharp comparisons in Table 1, confirms that these aggregate stresses, rather than the individual loads, control the case grade and weight calculation. Furthermore, a qualitative study was highly prioritised for Dogleg Severity (DLS) as priority one for casing strength ranking. The unambiguous, direct relationships between DLS and the factors that control bending stress, installation drag, and long-term erosion in Figure 3 and Table 2 constitute a synergy that should be a high-priority concern for casing design and well path planning.

Over-shooting the well path leads to structural damage to well integrity, reduces ease of deployment, decreases the well's productive life, and increases friction work. The whole essay supports the paper that complete, path-based design should be employed in attempting to achieve L-directional well economic success and safety. Casing string design options provide operators and designers with an explicit means and measurable information through which optimal casing string design must be realised so that these strings can proportionally utilise material strength to survive the complicated, localised stress regimes of such wells. It mitigates the risk of catastrophic failure and is a step toward improved, more uniform well construction in aggressive geologies.

6.1. Limitation

Although the method suggested in this research is hypothetical, it is not without disadvantages. It was tested first on a hypothetical database. Being based on actual data, it cannot reflect the magnitude of geological uncertainty or the heterogeneity of real drilling operations' data. Micro-doglegs, certain areas of formation instability, and pressure pockets are not accounted for. Second, the wear model employed herein is index-truncated, rather than a quantitative representation of the complex interactions among tool joint and casing material properties, drill string dynamics, and mud lubricity. A higher-order time-dependent wear simulation will be a superior predictor of wall thickness loss. Also, in this paper's research, the likely impact of temperature fluctuations on casing stress is significant wherever HPHT conditions exist, or high-temperature fluid production occurs, with resulting thermal expansion and additional axial load, which has not been addressed. Finally, the model is based on the ideal bond of cement; in reality, mud channelling would create an imperfect cement sheath, reducing the collapse strength of the casing and external support, which is not accounted for in this research.

6.2. Future Scope

Among these emerging research areas are some foundational applications. The most advanced among them is to include measured drilling time in the design model. With measurement while drilling (MWD) data, the model would be solved in real time during well design assembly. This would enable on-the-fly casing design adjustment based on actual, not simulated, formation pressure and wellbore tortuosity, with adaptive design and safety-focused. Probabilistic answers would then be a possibility, perhaps within reach. Instead of deterministic safety factors, a Monte Carlo analysis can be used to estimate parameter uncertainties, such as pore pressure, fracture gradient, and strength. This is closer to the probability-of-failure-based risk estimation for design reliability. Two, casing wear simulation via interaction with dynamic drill string vibration analysis would better predict wear pattern and rate. Finally, the generation and inclusion of a thermal stress analysis model, along with the incorporation of cementing defects, would be incorporated into casing simulation to address it further and make it more realistic and comprehensive in its effort to simulate casing drilling performance from start to abandonment.

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Ethics and Consent Statement: The consent was obtained from the organization and individual participants during data collection, and ethical approval and participant consent were received.

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