

# Torque and Drag Mitigation in Extend Reach Wells: A Case Study of the SUST-X Well, Sudan

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**Abstract** - Extended-Reach Drilling (ERD) is a critical technique for enhancing hydrocarbon recovery from remote and complex reservoirs, yet it poses significant mechanical challenges—most notably, managing torque and drag (T&D) forces in long, deviated wellbores. These forces can reduce drilling efficiency, impede weight transfer, and increase the risk of stuck pipe, particularly in the build-up and horizontal sections. This study presents a detailed mechanical analysis of the SUST-X ERD well in Sudan, integrating actual field data with advanced simulations using WellPlan software. The modeling confirmed the well's ERD profile and identified critical T&D zones. Key findings include sinusoidal and helical buckling thresholds at 98.8 kip and 104.3 kip, respectively; pick-up and slack-off drag values of 35.2 kip and 36.2 kip; and a maximum rotary torque of 13,236.8 ft-lbf during on-bottom drilling. The simulation also predicted a safe overpull margin of 324.0 kip, validating WellPlan's reliability for pre-drill mechanical risk assessment. By combining real-world data with simulation, this work addresses a key knowledge gap in ERD design and execution—specifically the lack of data-driven, case-specific analysis for quantifying mechanical limits. The findings underscore the importance of simulation-based planning and proactive wellbore design in mitigating T&D challenges and improving both the technical performance and economic outcomes of ERD operations. Future research should extend this approach to dynamic drilling effects for a more comprehensive risk management strategy.

**Keywords:** Torque, Drag Mitigation, Extend Reach Wells, SUST-X Well, Extended-Reach Drilling, ERD.

## I. INTRODUCTION

Directional drilling has become a cornerstone of modern oil and gas operations, enabling more efficient hydrocarbon recovery and access to previously inaccessible reservoirs. A key driver for this technology is its ability to increase reservoir contact through horizontal well sections, which is particularly

useful for thin or low-permeability formations. It also allows for onshore-to-offshore drilling, which significantly reduces infrastructure costs and environmental impact, and provides a solution for navigating surface obstructions like urban areas or existing infrastructure. Among the most advanced forms of this technique is Extended-Reach Drilling (ERD), which involves wells where the horizontal distance is at least twice the true vertical depth (TVD). ERD is crucial for developing remote offshore fields and areas with strict surface access limitations. The article highlights two primary technologies for achieving these deviated wellbores: Measurement While Drilling (MWD)/Mud Motor systems and Rotary Steerable Systems (RSS). MWD systems enable real-time trajectory adjustments and data transmission, while RSS provides continuous rotation and precise directional control for improved drilling efficiency. Despite these advancements, ERD presents significant technical challenges, including excessive torque and drag, difficulties with hole cleaning, complex pressure management, and the need for highly accurate trajectory control. The text points out a knowledge gap in the current literature, specifically the lack of case-specific, data-driven analysis that quantifies mechanical limits and operational thresholds in ERD. The innovation lies in the integration of high-resolution field data with advanced simulation platforms to proactively predict and mitigate these risks, ultimately leading to more sustainable and cost-effective hydrocarbon development.

## Problem Statement

In extended-reach and horizontal drilling, torque and drag are significant mechanical challenges. Torque is the rotational resistance on the drill string due to friction with the wellbore, while drag is the axial friction experienced during drill string movement. Both increase with wellbore length and complexity, especially in ERD wells, leading to issues like reduced drilling speed, poor hole cleaning, stuck pipe, and equipment wear. Despite existing research on torque and drag in conventional drilling, their specific impact, quantification, prediction, and management in ERD, particularly in deepwater

and ultra-extended-reach environments, remain insufficiently addressed, highlighting a clear knowledge gap.

## Research Objectives

This research therefore aims to thoroughly investigate the:

1. Limitations imposed by torque and drag in extended-reach drilling (ERD) operations,
2. Identify the principal factors contributing to these limitations,
3. Subsequently develop strategies for effective mitigation.

By systematically addressing this critical research gap, this study endeavors to significantly contribute to the enhancement of efficiency, safety, and cost-effectiveness in ERD operations, ultimately fostering increased productivity in hydrocarbon exploration and development within challenging geological and environmental settings.

## II. LITERATURE REVIEW

Torque and drag are critical mechanical challenges in Extended-Reach Drilling (ERD), a method used to access distant and complex hydrocarbon reservoirs. These forces arise from the friction between the drill string and the wellbore wall, becoming more pronounced in longer, more deviated wells. If not properly managed, they can lead to reduced drilling efficiency, inefficient weight transfer, and major operational issues like stuck pipe. Torque and drag are influenced by the drilling mode. In sliding mode, the drill string is pushed axially without rotation, which minimizes torque but increases axial drag and the risk of "lock-up," where the string buckles and prevents weight from reaching the bit. In rotary drilling mode, the continuous rotation of the string results in higher torque but lower drag and a reduced risk of lock-up. Several key factors contribute to excessive torque and drag such as: Hole Instability, Key Seating, Differential Sticking, Poor Hole Cleaning, Wellbore Friction, Wellbore Tortuosity (Schlumberger, 2024; McCormick et al., 2012; Tona and Evren, 2011; K&M Technology Group – 2003; Weijermans et al., 2001; Vos and Reiber, 2000; Aston et al., 1998; Aarestad and Blikra, 1994; Navarro and Yalcin, 1990; Ho, 1988; and Johancsik et al., 1984).

These issues create a number of operational challenges in ERD, including difficulty with accurate prediction, limited weight transfer to the bit, and high stress on surface equipment. To manage these challenges, the industry uses analytical models and commercial software (METU, 2025; FCEE, 2025; VS, 2024; Bagadi et al., 2012; Mason and Chen, 2007; Samuel, 2007; Azar and Samuel, 2007; Mason, 2000; and Payne and Abbassian, 1997). Soft String Model: This is the most common model used in the industry. It treats the drill

string as a flexible cable, ignoring tubular stiffness, and assumes loads are a result of gravity and friction. Stiff String Model: This more complex model accounts for string bending stiffness and radial clearance, making it more realistic for wells with narrow clearances, high tortuosity, or high Dogleg Severity (DLS). However, there is no industry-standard formulation for it, which makes it less practical. Commercial Software (WellPlan): Tools like WellPlan are widely used for pre-drill planning and real-time monitoring. WellPlan can simulate various drilling scenarios and calculate critical parameters like tension, torque, and side force. A key limitation, however, is a reported mismatch between predicted and actual field results, especially in long horizontal sections over 5,000 meters. This is attributed to simplifying assumptions and uncertainties in input parameters like friction factors.

Mitigating torque and drag requires a multi-faceted approach uses many techniques include:

- **Optimized Well Plan:** Small changes to the directional plan, such as adjusting the build rate and dogleg severity, can reduce surface torque.
- **Drill String Design:** Designing a lighter string with fewer heavy-weight drill pipes (HWDP) can reduce surface torque. Specialized components like Heavy Wall Drill Pipe (HWDP) and Compressive Service Drill Pipe (CSDP) are also used to resist buckling in high-compression zones.
- **Use of Technology:** Rotary Steerable Systems (RSS) allow for continuous string rotation, drilling smoother curves, and reducing torque. A modular motor within an RSS can also minimize string revolution while maintaining bit rotation, further reducing torque and drag.
- **Non-Rotating Drillpipe Protectors (NRDPP):** These tools prevent metal-to-metal contact between the drill pipe and casing, which reduces both torque and casing wear.
- **Mud Additives:** Using oil-based or synthetic-based drilling fluids, or adding friction-reducing additives to water-based muds, can significantly lower surface torque.
- **Proper Hole Cleaning:** Maintaining correct mud properties and regularly pumping slugs and sweeps is crucial to remove cuttings that accumulate and increase frictional resistance.

A clear research gap exists in developing reliable, adaptive models and mitigation strategies for the extreme conditions of ERD wells. Current models have limitations and often a mismatch between predicted and actual field results, especially in very long horizontal sections. The industry lacks

integrated systems that combine real-time data, predictive analytics, and responsive drilling controls. The innovation lies in the growing need for these systems to minimize torque and drag throughout the drilling process.

### III. METHODOLOGY

This study will use a multi-faceted methodology to achieve its research objectives. It will begin with a comprehensive literature review to build a theoretical framework, covering the foundational concepts of torque and drag, the history and challenges of Extended-Reach Drilling (ERD), and current mitigation techniques and simulation tools. Following this, relevant well data from existing ERD operations will be collected, including wellbore trajectories, drill string configurations, and operational parameters, to serve as a basis for validating the models and understanding real-world challenges. The core of the study involves using the WellPlan software to simulate torque and drag in various ERD scenarios. This will include developing well profiles, modelling different drilling components, and running simulations to predict force magnitudes under various conditions, such as tripping in and out, and performing sensitivity analyses. Based on the insights from the literature review and simulations, the research will then propose and evaluate new well profiles and optimized drilling strategies designed to minimize torque and drag. This may involve optimizing trajectory designs, selecting advanced drilling tools, and recommending improved drilling fluid properties. Finally, these proposed strategies will be evaluated against industry benchmarks and, if possible, compared with historical data to assess their potential effectiveness.

### IV. RESULTS AND DISCUSSION

This well profile outlines the design for an Extended-Reach Drilling (ERD) well, which is engineered to access the "Blue Nile" formation. The well's trajectory starts with a vertical section, transitions into a gradual build-up section, and concludes with a long horizontal section. This design is specifically chosen to minimize drilling risks, especially torque and drag, which are critical factors that need to be carefully managed. The well begins at the surface and extends vertically to a True Vertical Depth (TVD) of about 1,200 meters. This vertical section includes a 20" conductor casing and a 13-3/8" surface casing, which provide initial stability and protect against shallow formation collapse. At the Kick-off Point (KOP), located at 1,200 meters TVD, the well begins a smooth, continuous curve. This gradual build-up section, which passes through the "Dindir-2" and "Dindir-3" geological markers, is a key design feature aimed at minimizing the Dogleg Severity (DLS)—the rate of change in

the well's direction. A low DLS is crucial for reducing friction, normal forces, and bending stresses on the drill string.

Once the well reaches its maximum inclination at a TVD of 2,800 meters, a 7" intermediate liner is set. This casing isolates the most curved part of the wellbore, creating a stable base from which to drill the final long, horizontal section. This horizontal section, which enters the target "Blue Nile" formation, is designed to maximize reservoir exposure and enhance hydrocarbon recovery. The final Measured Depth (MD) of the well is significantly greater than its TVD, confirming its status as a long-reach well.

Despite the optimal design, the well trajectory presents several critical points where torque and drag could become problematic. The entire build-up section is a high-risk zone, as the curvature forces the drill string against the wellbore wall, generating high normal forces and friction. The long horizontal section also poses a significant risk, as the extended length of the drill string in contact with the wellbore generates a high cumulative drag force. This makes it difficult to transfer sufficient Weight on Bit (WOB) and increases the risk of the drill string getting stuck. Other critical points include the KOP and the casing shoes, where the drill string transitions between different hole sizes or friction coefficients. The interface between the cased section and the open hole is also a risk, as varying lithology can cause unexpected spikes in friction. To ensure a successful operation, the high torque and drag predicted for this well must be carefully managed to prevent them from exceeding the mechanical limits of the drilling rig's equipment and the tensile and torsional strength of the drill string itself.

#### New 8 ½ in Section Proposed Plan

The plan for the field development is to conduct a side track from the existing vertical hole's 9-5/8" casing, Table (1). This will be done by milling a window in the casing using a whipstock and a milling bottom hole assembly (BHA), Fig. (1) and Table (2). The window will be created at a depth of 910 meters in the 165-degree direction, which is opposite to the original wellbore's direction. A gyro tools will be used to orient the whipstock correctly. After opening the window, drill a pilot hole and then pull out the milling assembly. Next, run a directional bottom hole assembly (BHA) with a Rotary Steerable System (RSS) to build the new hole to an 87-degree inclination, Fig. (2) and Table (3). This will be achieved at a measured depth of 3280.24 meters and a true vertical depth of 2680 meters, which is our landing point.

Table (1): Build Section General Case Information @ 8½ in Section

<b>Company</b>	SUST		
<b>Project</b>	X Field	<b>Site</b>	SUST - X Well
<b>Well</b>	SUST - X Well	<b>Wellbore</b>	ST-ERD Well
<b>Design</b>	ST - ERD Well	<b>Case</b>	SUST
<b>Hole MD</b>	3280.24 m	<b>Hole TVD</b>	2733.00 m
<b>Air Gap</b>	7.50 m	<b>Ground Elevation</b>	435.90 m
<b>Reference Point</b>	RKTB@443.4m	<b>Well Type</b>	Platform

	CI (m)	MD (m)	Inc (°)	Azi (°)	TVD (m)	V. Sec. (m)	Dogleg (°/30m)
1		910.00	1.95	375.74	909.88	-12.26	0.000
2	30.00	940.00	2.00	165.00	939.87	-12.23	3.927
3	600.00	1540.00	2.00	165.00	1539.51	8.71	0.000
4	1740.24	3280.24	87.00	165.00	2670.00	1119.64	1.465

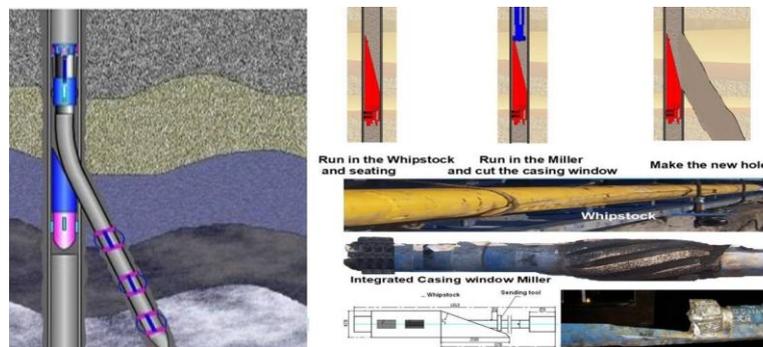


Figure (1): Whipstock and Milling Operation

Table (2): Milling BHA @ 8½ in Section

Item	Name	Qty.	Specification
1	Integrated whipstock, anchor and miller	1	8 1/2"
2	Milling shoe	1	8 1/2"
3	MWD/LWD	1	6 3/4"
4	Gyro	1	1 1/2"
5	Motor	1	6 3/4"
6	NMDC	2	6 3/4"
7	Lead stamp	2	8 1/2"
8	Pear-shaped shaper	1	Φ216-222mm (8.5-8.75")

Table (3): Buildup Section String Details @ 8½ in Section

Tools	Length (m)	Depth (m)	Body		Stabilizer / Tool Joint				Grade
			OD (in)	ID (in)	Avg Joint Length (m)	Length (m)	OD (in)	ID (in)	
Drill Pipe	3042.34	3042.34	5.5	4.778	9.144	0.457	6.719	3.5	G
Heavy Weight	120	3162.34	5.5	3.25	9.144	1.219	7.25	3.313	1340 MOD
Jar	10	3172.34	6.5	2.25	10				15-15LC MOD (1)
Heavy Weight	60	3232.34	5.5	3.25	9.144	1.219	7.25	3.313	1340 MOD
MWD	40	3272.34	6.75	2.5	40				SAE 4145
Stabilizer	1.5	3273.84	5.5	2.813	1.5				4145H MOD
Rotary Steerable System	6	3279.84	6.75	3.5	6				15-15LC MOD (2)
Bit	0.4	3280.24	8.5		0.4				

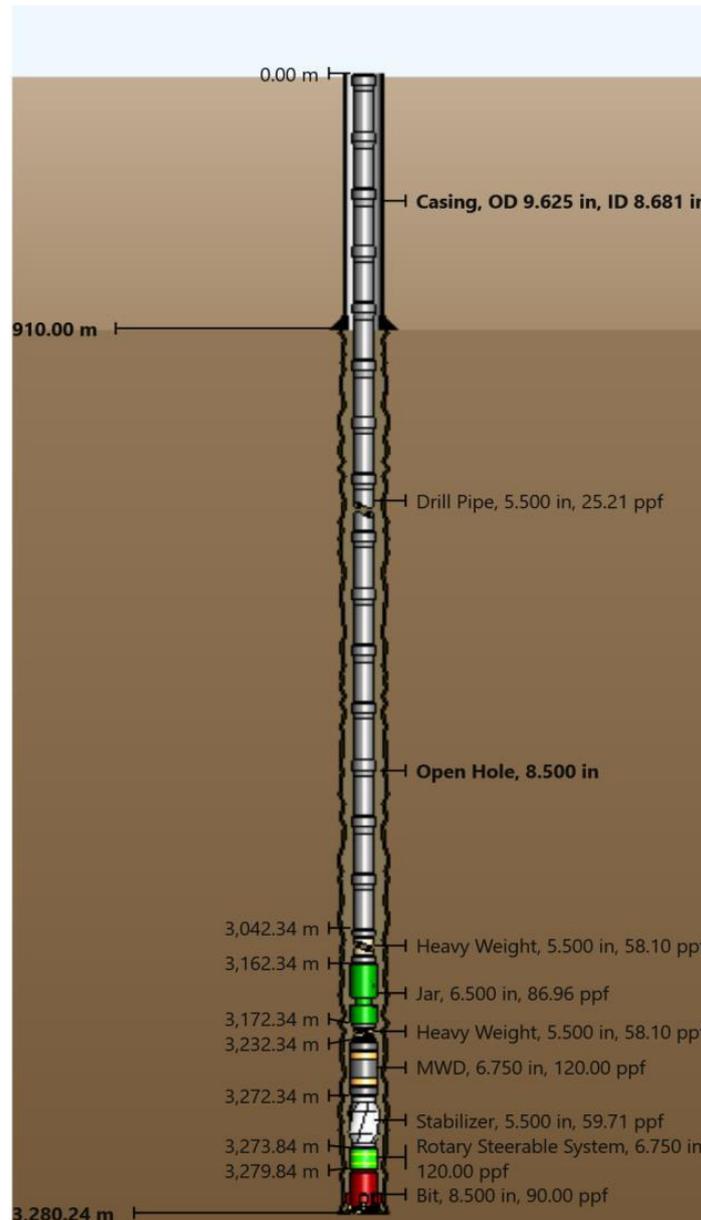


Figure (2): Buildup Section Bottom Hole Assembly @ 8½ in Section

Concentrating on the hydraulics for the SUST - X Well, specifically the ST-ERD Wellbore and design. The mud uses a Bingham Plastic rheology model with a base density of 9.5 ppg, a Plastic Viscosity (PV) of 24 cp, and a Yield Point (YP) of 12 lbf/100ft<sup>2</sup>, all measured at 70°F and 14.7 psi. The bit has three 16/32" nozzles and a total flow area (TFA) of 0.589 in<sup>2</sup>. The hydraulics calculations were performed using the WellPlan model with a pump rate of 550.0 gpm. Key results from the hydraulics analysis include a stand pipe pressure of 2359.65 psi and a bit pressure loss of 762.59 psi. The bit hydraulic power is 244.66 hp, and the bit nozzle velocity is 299.6 ft/s, which results in a bit impact force of 810.8 lbf. The specifies cuttings loading calculation parameters, including a rate of penetration of 10.97 m/hr, rotary speed of 25 rpm, cuttings diameter of 0.240 inches, and cuttings density of 2.145 sg.

The torque and drag results provide key mechanical limitations and a load summary for various operations. The overpull margin during a tripping out operation is 199.2 kip, using 90% of yield. The minimum weight on bit to cause buckling: 98.8 kip for sinusoidal buckling and 104.3 kip for helical buckling, both at 1530.28 m during a rotating on bottom operation. Other key findings from the load summary include a pick-up drag of 35.2 kip and a slack-off drag of 36.2 kip. For a rotating on bottom operation, the torque at the rotary table is 13,236.8 ft-lbf, and the measured weight is 215.3 kip. The provided data for tripping in and tripping out operations, including measured weights and stretch, Fig. 3 and 4.

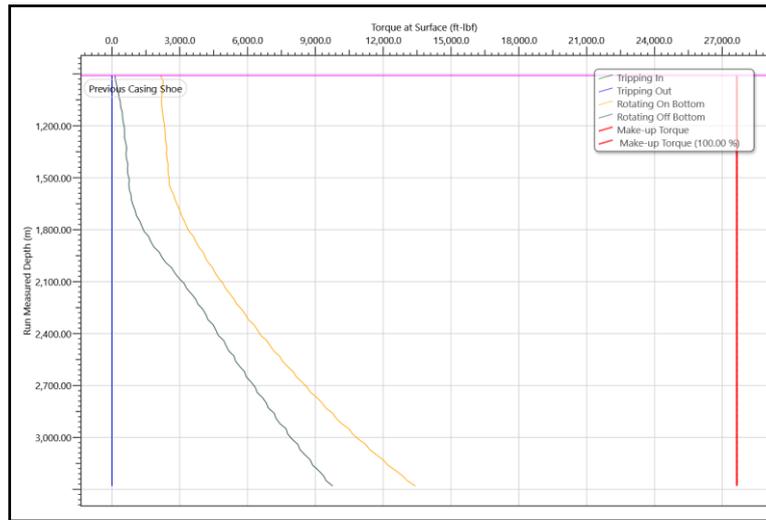


Figure (3): Torque @ 8 1/2 in Section

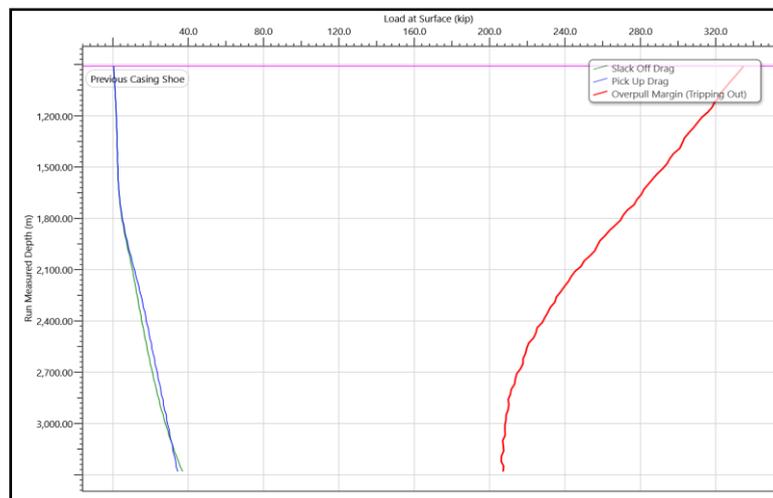


Figure (4): Slack off/Pick Up Drag Force @ 8 1/2 in Section

### New 6 in Section Proposed Plan

Finally, continue to drill a 6-inch hole using a Rotary Steerable System (RSS) BHA with holding inclination and azimuth until reaching the total depth (TD) of 4484 meters, Fig. (5), Table (4 and 5).

Table (4): Build Section General Case Information @ 6 in Section

<b>Company</b>	SUST						
<b>Project</b>	X Field			<b>Site</b>	SUST - X Well		
<b>Well</b>	SUST - X Well			<b>Wellbore</b>	ST-ERD Well		
<b>Design</b>	ST - ERD Well			<b>Case</b>	SUST		
<b>Hole MD</b>	4484.00 m			<b>Hole TVD</b>	2733.00 m		
<b>Air Gap</b>	7.50 m			<b>Ground Elevation</b>	435.90 m		
<b>Reference Point</b>	RKTB@443.4m			<b>Well Type</b>	Platform		
	<b>Cl (m)</b>	<b>MD (m)</b>	<b>Inc (°)</b>	<b>Azi (°)</b>	<b>TVD (m)</b>	<b>V. Sec. (m)</b>	<b>Dogleg (°/30m)</b>
<b>1</b>	0.000	3280.24	87.00	165.00	2670.00	1119.64	1.465
<b>2</b>	1203.76	4484.00	87.00	165.00	3733.00	2321.75	0.000

Table (5): Buildup Section String Details @ 6 in Section

Tools	Length (m)	Depth (m)	Body		Stabilizer / Tool Joint				Grade
			OD (in)	ID (in)	Avg Joint Length (m)	Length (m)	OD (in)	ID (in)	
Drill Pipe	4377.749	4377.749	4.0	2.764	9.144	0.469	4.565	2.438	G
Heavy Weight	30	4407.75	4.5	2.75	9.144	1.219	6	2.875	1340 MOD
Jar	10	4417.75	4.75	2.00	10				15-15LC MOD (1)
Heavy Weight	30	4447.75	4.5	2.75	9.144	1.219	6	2.875	1340 MOD
MWD	30	4477.75	4.5	1.6	30				SAE 4145
Rotary System Steerable	6	4483.75	4.75	1.6	1.6				15-15LC MOD (2)
Bit	0.26749	4484.00	6		0.25				

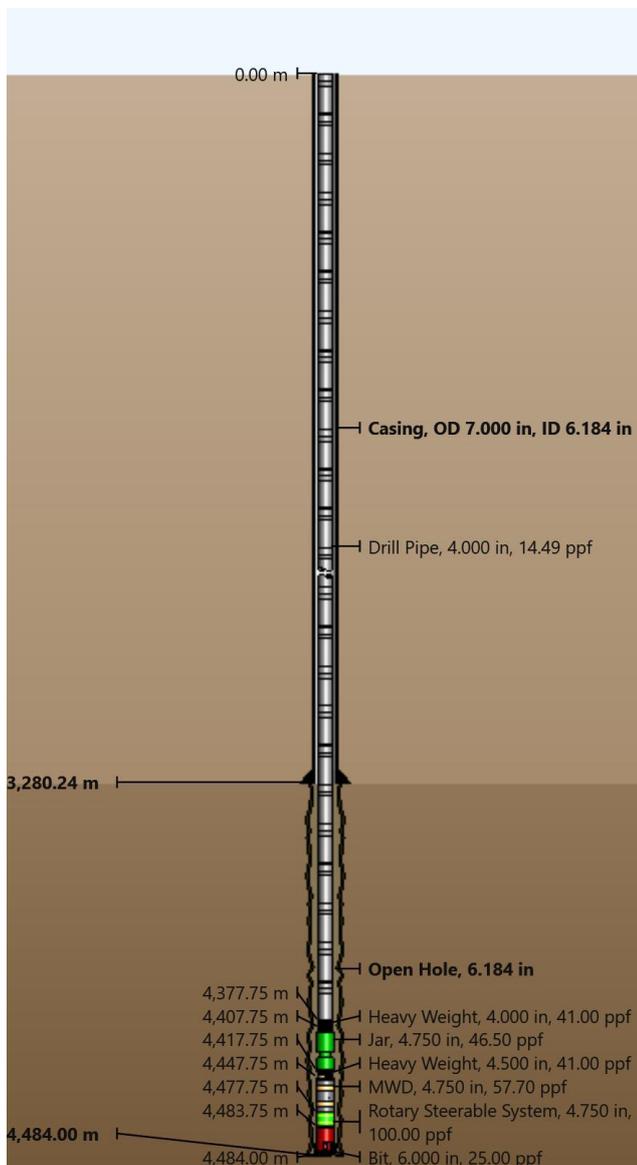


Figure (5): Buildup Section Bottom Hole Assembly @ 6 in Section

The hydraulic performance of the drilling plan and complements the mechanical analysis has provided consistent general information about fluid data, and string details. A key detail is the specification of a Polycrystalline Diamond Bit with a Total Flow Area (TFA) of 0.442 in<sup>2</sup>. The report provides critical hydraulic parameters, including a pump rate of 300.0 gpm and a standpipe pressure of 7157.32 psi. It further breaks down the pressure losses, indicating a bit pressure loss of 411.85 psi, which accounts for 5.75% of the total hydraulic power at the bit. The run parameters for the hydraulic simulation are set from an MD of 3280.24 m to 4484.00 m, with a step size of 30.48 m. This report effectively evaluates the hydraulic efficiency of the proposed drilling fluid and bottom-hole.

Also, thoroughly evaluates the mechanical aspects of the drilling operation. It details the general case information for the SUST - X Well, including a total measured depth (MD) of 4484.00 m and a true vertical depth (TVD) of 2733.00 m. The report outlines the drill string components, such as drill pipe, heavy weight pipe, jar, MWD, and a rotary steerable system. The materials and grades used, along with their minimum yield stress, are clearly specified. The most critical sections of this report are the Torque and Drag Results and the Load Summary. The mechanical limitations are detailed, showing an overpull margin of 324.0 kip during tripping out and minimum weights for sinusoidal and helical buckling. The load summary provides key data points for different operational conditions, such as the measured weight and total stretch for tripping in, tripping out, and rotating on and off bottom. The inclusion of the wellpath calculations via the Minimum Curvature method, with detailed information on inclination, azimuth, and TVD at various depths, adds to the thoroughness of the planning., Fig. (6 and 7).

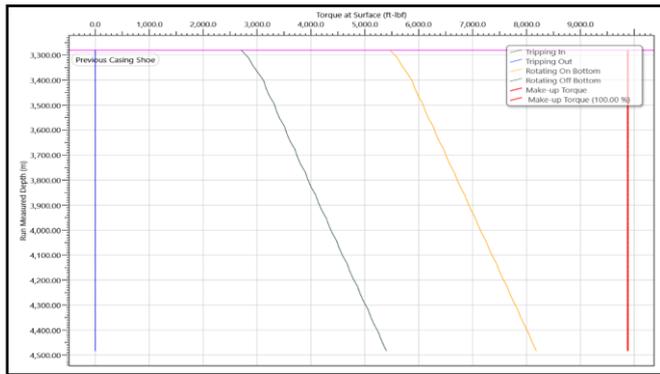


Figure (6): Torque @ 6 in Section

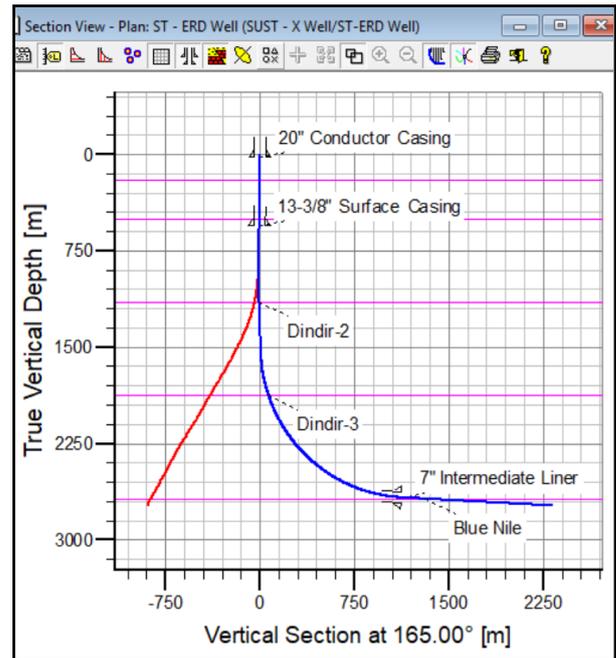


Figure (9): SUST-X Well Vertical Section New Proposed ERD vs. Mother Hole

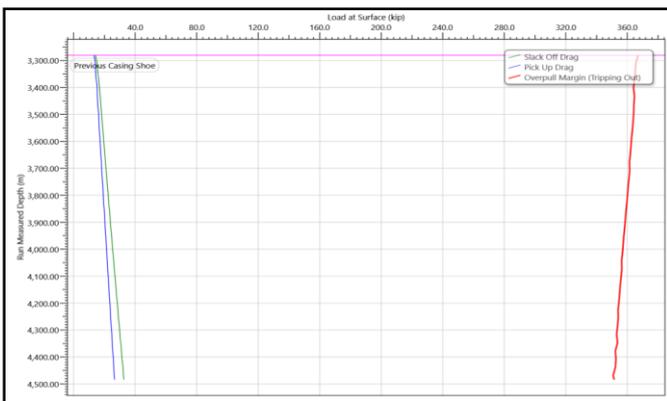


Figure (7): Slack off/Pick Up Drag Force @ 6 in Section

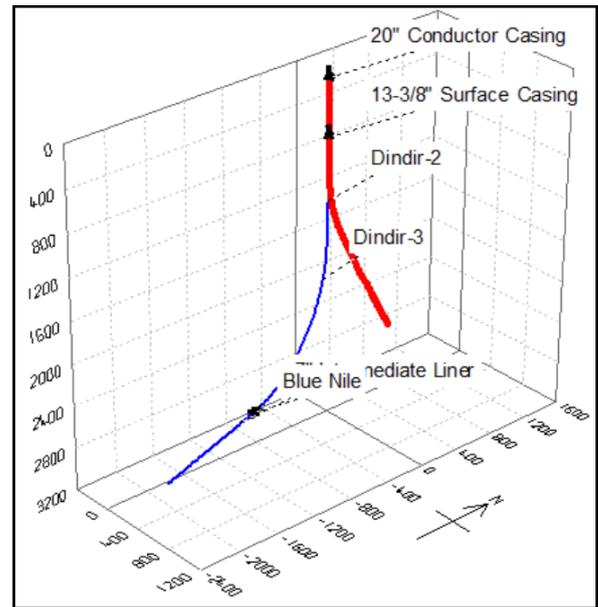


Figure (10): SUST-X Well Three Dimension New Proposed ERD vs. Mother Hole

Technically the data presented is consistent, which is crucial for a cohesive drilling plan. The Torque and Drag comprehensively address the mechanical integrity of the drill string, while the Hydraulics report provides a detailed analysis of fluid performance and pressure management. Together, they form a robust foundation for the drilling operation of the SUST - X Well as shown in Fig. (8, 9 and 10). The level of detail in the provided tables and parameters suggests a thorough and professional engineering approach has been taken.

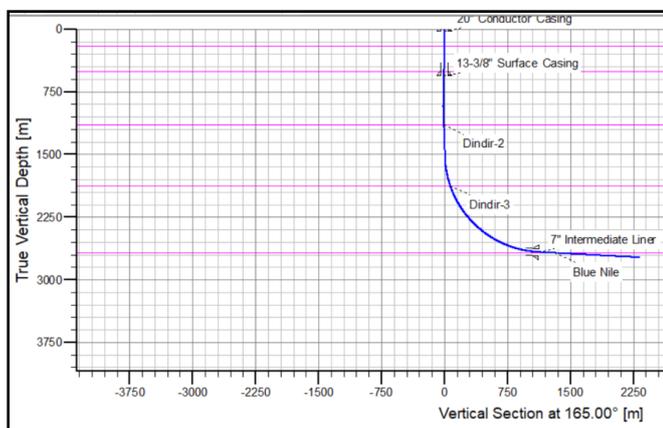


Figure (8): Vertical Section New Proposed ERD SUST-X Well

The Mother Hole (red line), Fig. (9 and 10), exhibits a classic, older style of ERD design. Its trajectory shows a relatively sharp, aggressive build-up section after the vertical segment. This "high dogleg severity" is a major point of concern. While this design does achieve a modest horizontal reach of approximately 1,500 meters, it does so at a significant cost in terms of mechanical stress. A sharp build-up section dramatically increases friction, torque, and drag forces on the drill string, which are the primary enemies of ERD. This design would likely lead to excessive pipe wear, a high risk of

stuck pipe, and could limit the ultimate reach of the well due to the inability to overcome the friction. It's a design that would likely require extensive use of lubricants and still be prone to non-productive time (NPT) events.

In stark contrast, the New Proposed ERD well (blue line), Fig. (9 and 10), represents a modern, optimized approach. The most critical and innovative feature is the much smoother, more gradual build-up section. This design choice is a direct response to the limitations of the Mother Hole. By distributing the change in inclination over a longer measured depth, the dogleg severity is significantly reduced. The result is a dramatic decrease in the friction and drag forces that the drill string must overcome. This smoother trajectory allows the well to achieve a much greater horizontal displacement, reaching approximately 4,000 meters. The lower forces also mean less wear and tear on the drill pipe and surface equipment, improving safety and reliability. Furthermore, this design facilitates better hole cleaning, as a smoother path allows drilling fluid to circulate more efficiently, reducing the risk of cuttings accumulation and stuck pipe. Therefore, the new proposed well is not just an alternative; it is a superior and more innovative solution that directly addresses and mitigates the primary challenges of ERD, promising greater reservoir access and operational efficiency.

## V. CONCLUSIONS AND RECOMMENDATION

The conclusions of this study represent a successful application of theoretical principles to a practical engineering problem in the field of Extended-Reach Drilling (ERD). The study argues that ERD is a well-established and optimized strategy, and its innovation lies in the specific, advanced well design for the SUST-X Well. This design utilized a smooth build-up section and a long horizontal trajectory to proactively mitigate common and costly challenges such as friction and differential sticking. Furthermore, the research validates the use of WellPlan software as a reliable pre-drill planning tool, a conclusion drawn from detailed and consistent simulation results for both the 8.5" and 6" sections of the well. The simulations provided empirical evidence by accurately predicting critical safety margins, including the "overpull margin of 324.0 kip" and the "minimum weights for sinusoidal and helical buckling," which provides confidence in the software's capabilities.

The most significant recommendation is the development of adaptive, real-time models that can continuously update drilling parameters based on downhole data, moving beyond static pre-drill simulations to a prescriptive system for greater automation and safety. A crucial next step is the validation of simulation results with real-world field data to establish a correlation factor and enhance the reliability of pre-drill

planning. The study also recommends investigating dynamic effects like drill string vibration, an area that is currently less understood, which could lead to improvements in drilling speed and equipment longevity. Finally, a comparative study on mitigation techniques is proposed to evaluate the cost and effectiveness of different strategies, providing engineers with a data-driven guide for optimizing future ERD projects.

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