

An Optimal Selection of Bit Stick-Out, Running Speed and Soaking Time of Conductor Pipe Jetting in Deep Water Criteria

Mohamed Ali Amin, Saeed Kamel, Abdel Sattar Dahab



Abstract: The design and installation of conductor pipe in deepwater environments are crucial for ensuring stable soil penetration and maintaining structural integrity. This study aims to establish a comprehensive understanding of the interdependencies among key parameters—bearing capacity, soil recovery coefficient, water jet force, side friction force, and running speed—to determine optimized jetting conditions. Utilizing numerical analysis through an empirical model and optimization techniques implemented in MATLAB, this research provides insights into efficient and stable conductor installation. Our findings indicate that soil recovery is most significant within the initial 3 hours post-jetting, with diminishing returns thereafter, suggesting that optimal soaking times are critical. The study further reveals that maximizing water jet force is achieved at smaller angles of reflection, underscoring the importance of precise jet nozzle orientation for effective soil penetration. Additionally, increased weight on the bit effectively reduces side friction, leading to smoother penetration. The investigation yielded optimized jetting parameters: bit stick-out of 0.145 ft, running speed of 16.4 ft/h, and soaking time of 4 hours. These parameters are demonstrated to ensure high efficiency while minimizing operational risks. The outcomes of this research offer valuable practical knowledge for maximizing jetting operations, reducing installation duration, and enhancing overall drilling efficiency in deepwater settings. While these findings are derived from numerical simulations, they provide a robust theoretical framework for future empirical validation.

Keywords: Deepwater Drilling, Conductor Jetting, Bearing Capacity, Side Friction Force, Water Jet Force, Optimization, Offshore Drilling, Recovery Coefficient, Running Speed, Bit Stick-Out.

Nomenclature:

RCD: Riserless Casing Drilling
GRU: Gated Recurrent Unit
WOB: Weight on Bit
BOPs: Blowout Preventers

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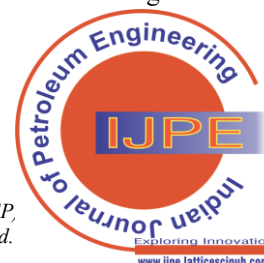
I. INTRODUCTION

In deepwater well construction, the structural casing/conductor pipe must be installed safely and efficiently to ensure the necessary structural stability to support the subsea wellhead and subsequent drilling and production activities [7, 13].

Jetting the conductor into soft, unconsolidated shallow sediments, typical of deepwater marine environments, is commonly used [15, 18]. Jetting is a drilling operation that advances a pipe into the seabed by injecting high-pressure fluid through a jetting assembly, which fluidises the soil ahead of the pipe to create a cavity for the pipe to enter [18]. The conductor jetting operation, despite being widely used and technically mature, is complex. It is characterised by its high difficulty in penetrating deep enough to avoid shallow drilling hazards that are significant in deepwater, such as shallow water flow, gas flow, and formation instability, which may impact well control and structural integrity [1, 13]. The success and safety of a jetting operation are, therefore, often dependent on the careful selection of operational parameters. This paper aims to fill a critical knowledge gap by developing a quantitative and systematic approach to selecting the optimum operating conditions for deepwater conductor pipe jetting based on a combination of three interrelated and equally important criteria: Bit Stick-out, Running Speed, and Soaking Time.

Bit Stick-out is a geometric term for the constant extension length of the jetting bit (generally a tricone or PDC bit) from the end of the conductor pipe [6, 14, 17]. It is a fundamental parameter because it directly influences the hydraulic efficiency of the jetting operation, the diameter and quality of the excavated hole, and the ultimate bearing safety of the installed casing [6]. A sub-optimal stick-out selection may lead to over-enlargement and a compromised seal, which decreases the bearing safety and can cause the entire installation to slide on the mudmat, or a lack of hole enlargement and quality that may increase the risk of sticking, result in non-productive time, or require the use of a core drill [6, 8].

Running Speed is the continuous advancement rate of the conductor pipe assembly into the seabed during the jetting operation to increase the ROP as high as possible [16]. While a high running speed is desired to reduce non-productive time, excessively high speeds can lead to geotechnical issues like wellbore instability or differential sticking. Therefore, an optimum running speed is necessary to ensure an effective and efficient jetting operation without



compromising wellbore stability [8]. The challenge lies in accurately determining the maximum feasible ROP that a jetting operation can achieve while maintaining a stable hole condition and sufficient cleaning of the jetting assembly [16].

The Soaking Time is the non-productive period during which the pipe assembly must remain stopped immediately after the pipe reaches the target depth. This allows for the dissipation of excess pore pressure and the reconsolidation of highly disturbed and fluidised shallow soil surrounding the conductor pipe [13]. The time required is to regain the shear strength necessary to support the weight of the subsea wellhead against both static and environmental loads, such as wave and current action [7, 12]. The bearing capacity of the soil against these loads is often the limiting factor in selecting the soaking time [7]. If the soaking time is insufficient, the conductor is at risk of moving from its original position, potentially leading to failure, which is a significant concern in fields with elevated wave and current action [9, 13].

While each of the above criteria is important, the industry tends to use broad empirical guidelines and rig-site experience to inform decisions during a jetting operation [7]. In some instances, alternative methods such as Riserless Casing Drilling (RCD) are available, which avoid shallow hazards entirely by drilling and cementing the casing to a deeper depth [13]. However, when jetting into soft seabed sediments, optimising these key variables is still essential for wellbore stability. As a result, while some research has been done in each of the three areas above, such as the development of a geometric model for the minimum stick-out for a given hole [6], the use of machine learning for the optimal ROP [16], or a new conductor design for improved bearing capacity [7], an integrated criteria for the simultaneous selection of all three parameters is missing.

This paper, therefore, focuses on developing an integrated and predictive framework for the Optimal Selection of Bit Stick-out, Running Speed, and Soaking Time for a conductor pipe jetting in deepwater criteria. By integrating the existing literature on the subject and consolidating the geotechnical, hydraulic, and operational constraints of the problem, this work aims to provide a fundamental set of integrated criteria that a drilling engineer can use to safely improve wellbore stability, increase operational efficiency, and reduce the risks of deepwater conductor installation [1, 10, 11].

II. LITERATURE REVIEW

Jetting of the conductor pipe has become a popular technique for the installation of structural casing in deepwater drilling operations. The jetting method for conductor pipe has long been considered a difficult-to-solve issue in the subsea drilling industry. The technology used is relatively mature in the field of offshore drilling to reduce the risk associated with subsea wells, although the wellhead cannot be cemented. The paper focuses on the period during the construction of deepwater wells that require a structural casing and conduit to provide a reliable platform for blowout preventers (BOPs), subsea Christmas trees, and other equipment. Therefore, it is significant to study and review the conductor pipe jetting method, its evolution, the challenges encountered, and the steps taken to improve the efficiency of this technique in deepwater drilling projects.

Despite its historical development, a recently published article that assesses modern and alternative methods shows that a revolution in deepwater well construction techniques is underway. A new method to reduce shallow hazards is the Riserless Casing Drilling (RCD) method, described as a game-changing development for deepwater well construction, enabling the efficient and safe setting of structural casing in unconsolidated formations. Rosenberg, Kotow, Wakefield, Sampietro, and Hulett published a paper on RCD as a method for shallow hazard mitigation, concluding that it represents a revolution in practice [5]. In addition, Rosenberg, Kotow, Wakefield, and Lewis published a risk assessment that further confirms the effectiveness of the RCD method for deepwater hazard mitigation. The study found that RCD is a very reliable alternative to the traditional mitigation method [1]. Yang and Yuan discuss the background that led to the current drilling technique and will continue to drive the evolution of these methods. Their work on drilling technology methods and the effects of applications in geological engineering exploration provides a foundation for understanding changes that affect deepwater operations [2].

The current development in technology has led to better optimization of casing installation operations and overall, well design efficiency. The streamlined design aimed at reducing casing setup time, risk of hole loss, and formation damage has led to the development of innovative tools and methods. One such innovation is the Deepwater PDC Jetting Bit-Drilling Technology, which is based on sound structure slimming developed by Zhang, Gao, Zeng, and Yan [3]. This study looked at ways to improve penetration rates and stability while also cutting overall well size and cost. Another recent study conducted by Zhang, Meng, Yan, and Chen focuses on drilling fluids-based optimisation in mud system design for HPHT wells [4]. The study, along with other recent advances, contributes to the revolution in well construction techniques that reduce time and resources while increasing safety and reliability. In addition to tools and individual components, a comparative analysis between offshore and swamp operations is critical for understanding how fluid systems are adapting to the extreme challenges of deepwater and complex environments. These recent developments and methods, which focus on RCD, slimmed sound design, and specialized mud systems, represent a comprehensive and practical approach that minimizes drilling risks and optimizes resources in offshore operations.

Jetting or Driving-in refers to the installation of structural casing and conductors into the seafloor [7]. As an essential step in the construction of wells, the process of jetting or driving in the conductor involves pushing it into the seabed using fluid action at its lower end [7]. Jetting is one of the most mature methods for installing conductors in soft seafloor sediments [7]. Jetting, while being a more simplified installation approach with advantages in time and cost savings compared with other methods such as pile driving, still comes with significant technical complexity, high dependence on field experience, safety, stability issues and limited installation depths [7, 13]. Academic research and industry practice have been exploring the optimisation of

jetting parameters, enhancing conductor design, and investigating alternative installation methods to address these challenges and mitigate associated deepwater drilling hazards.

A bit sticking out during the jetting process affects the efficiency of jetting and the safety of the final bearing of the installed conductor [6]. Liu et al. (2021) [6] put forward a relatively complete geometric model to calculate the minimum bit stick-out in the jetting process. In this work, Liu et al. (2021) [6] constructed the judgment basis and proposed the optimal value based on whether the nozzle jet circle is smaller than the conductor diameter. The optimal value of the minimum stick-out when the jet circle is larger than the conductor diameter is when the upper boundary of the jet beam is tangent to the inner conductor boundary. When the jet circle is smaller than the conductor diameter, the optimal minimum stick-out is when the jet beam reaches the intersection of the jet trajectory and the cone bit's curved surface. Field applications covering 12 wells were made, and the validity of the proposed model was established. The calculated value was 114.76 mm on average. The new method for determining the minimum stick-out provided a better theoretical design basis for the process. Meanwhile, it achieved a better jetting depth without significantly weakening the final bearing capacity of the conductor. This left the maximum borehole diameter after jetting for the best wellbore stability, matching the casing size as closely as possible. This work also pointed out that sticking out more than 150 mm may increase the hole size and the jetting depth, but adversely affects conductor stability [6]. In addition to the geometric analysis, optimising jetting parameters is critical for ROP optimisation, such as Weight on Bit (WOB) and flow rate. A study by Zhou et al. (2025) [16] leveraged machine learning to optimize ROP during the jetting process. The researchers employed a Gated Recurrent Unit (GRU) model to construct a nonlinear mapping relationship between jetting parameters and ROP, achieving a prediction accuracy of 92%. Moreover, by integrating the mapping relationship model with an evolutionary algorithm, the study increased the average ROP value of a deepwater well in the South China Sea by 22.6%, providing an intelligent optimization solution for operations [16].

The conductor is responsible for the safety load of the subsea wellhead and the following drilling load (wet weight of wellhead, mud mat and so on) [7]. The traditional method of conductor installation, although widely applied in deepwater with depth limitations of about 300 ft below mudline, has been verified to be unable to mitigate shallow drilling hazards and requires a long soil consolidation or soaking period to make the soil stronger [13]. In addition, the interaction of the conductor-pipe with the soil has also been demonstrated to be a key factor threatening the stability of the conductor, which is usually large in shallow-water fields that are vulnerable to external forces (waves, current, wind) [7]. Yang et al. (2025) [9] studied the dynamic response and stability of conductor pipes based on an actual case of conductor displacement in a shallow-water field. This work considered the complex action of soil, waves, current, and wind on the conductor. The results demonstrated that the most significant factor for the large displacement of the conductor is the combined action of waves and current in the water section. It was also shown that using a drilling mud of higher

density inside the conductor, along with an applied top-weight, is a better way to enhance conductor stability [9].

Zhang et al. (2022) [7] proposed a new concept of an expandable drilling conductor. Annular expandable materials were applied to the conductor surface to design a variable section rack structure, enhancing the occlusive effect with the stratum. Based on theoretical models, laboratory tests and field verification tests, this work verified that the new expandable conductor structure can increase the vertical bearing capacity. The thickness and length of annular material, along with the distance between two rings, were found to be the main factors influencing the vertical flexural bearing capacity, which is closely related to soil shear strength [7]. In a separate study, Zhang et al. (2024) [12] utilised numerical simulation with the Goodman contact element model to examine the vertical displacement characteristics of subsea wellheads under cyclic dynamic load. The new contact element of Goodman was found to better describe the discontinuity of the conductor-soil interface in the model. The study provided valuable insights into the detachment and extrusion of the conductor with the surrounding soil, which may result in the loss of vertical friction and soil accumulation at the bottom of the gap, ultimately leading to the conductor instability [12].

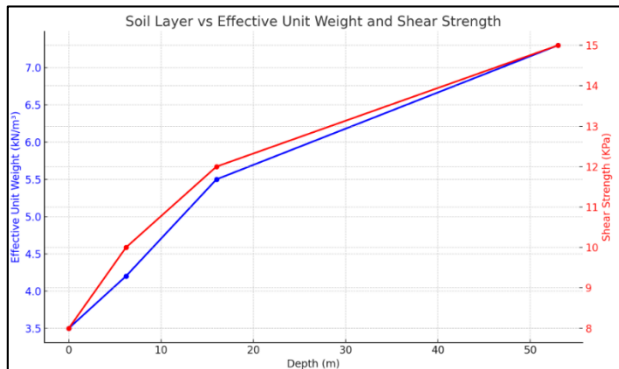
Deepwater drilling always carries high risk, with drilling hazards being the primary source of this risk, potentially leading to loss of well control and drilling operation accidents [13]. The shallow drilling hazards include shallow water/gas flows, disassociating gas hydrates, water/cement/acid, soil failures, fracture entry or crossing, shale or salt instability and so on [13]. The process of jetting or driving-in the conductor is limited by the soft sediment for jetting operations to enter, and thus cannot be used to penetrate harder sediments [13]. In addition, jetting in a subsea setting also causes a new geotechnical stability risk because of the sloping seabed. Zhao et al. (2022) [10, 11] carried out an in-depth study of this risk. In this work, a soil disturbance model was first established, followed by a survey of the wellhead instability mechanism. The results of the two series of analysis showed that the jetting flow rate and the fluid range were the main factors affecting the disturbance intensity and range of the seabed. The wellhead instability risk assessment was also made using the finite element strength reduction method, which was of great significance for the influence of seabed dip angle, soil strength and soil stratification on instability [10, 11]. To overcome jetting's depth and hazard mitigation constraints, Rosenberg et al. (2022) [13] put forward Riserless Casing Drilling (RCD), a new paradigm for driving in structural casing. RCD conceptually installs the structural casing to a much deeper setting depth that is based on the established pore pressure and fracture gradients, with the primary benefit of isolating and mitigating shallow hazards in a single trip while running casing to potentially eliminate multiple deepwater riserless strings allowing the high-pressure wellhead housing to be set deeper in the hole, fundamentally overcoming the current jetting method limited to a depth of about 300 ft [13].

Deepwater PDC Jetting Bit-Drilling Technology based on Well Structure Slimming is another

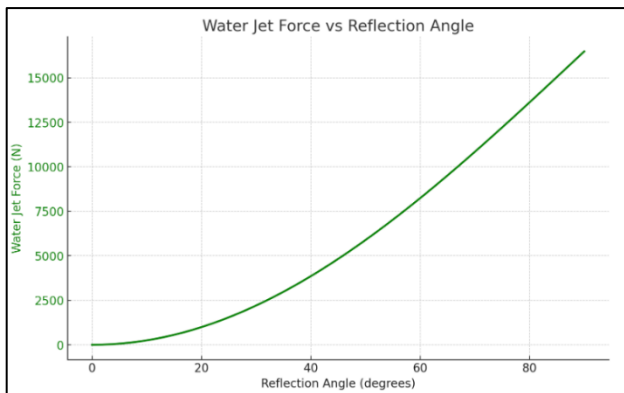
technology that combines the advantages of both jetting and drilling, as discussed in detail by Zhang et al. (2023) [14, 17]. Increasing energy demand from rapidly developing countries has made the use of well-structured slimming to increase drilling speed and cut costs more necessary. In this work, a novel PDC jetting bit is designed for a hole size of 444.5 mm (instead of 660.4 mm conventional cone bits), in which a unique anti-collision gauge protector and bypass nozzle were adopted, which increases the average ROP value by 227.84% in the second-section holes of eight deepwater wells located in the South China Sea, effectively dealing with low ROP and short service life problems of conventional bits in slimmed wells [14, 17].

III. METHODOLOGY

In this study, a MATLAB-based numerical method is developed to optimize the selection of bit stick-out, running speed, and soaking duration for conductor pipe jetting in deepwater drilling. This methodology integrates calculations concerning soil mechanics, jetting parameters, force balance equations, and recovery coefficients, establishing a robust framework for assessing the in-situ bearing capacity of the conductor. Initially, we define the parameters that characterise the physical aspects of the operation, including the forces interacting with the conductor, frictional resistance, and the optimisation methodology.



[Fig.1: Soil Layer vs Effective Unit Weight and Shear Strength]



[Fig.2: Water Jet Force vs Reflection Angle]

A. Soil Characteristics and Their Effect on Conductor Bearing Capacity

The geotechnical characteristics of the seabed soil profoundly influence the bearing capacity and jetting effectiveness of conductors. Soil layers are categorized into

four groups based on depth range, effective unit weight, and shear strength (Table 1).

Table 1: Soil Parameters and their Effect on Jetting Efficiency

Soil Type	Layer Top (ft)	Layer Bottom (ft)	Effective Unit Weight (lb/ft³)	Shear Strength (lb/in²)
Very Soft Clay	0	20.34	0.219	1.16
Soft Silty Clay	20.34	52.49	0.262	1.45
Slightly Hard Silty Clay	52.49	174.2	0.341	1.74
Hard Silty Clay	174.2	315.0	0.495	2.18

All soil types exhibit varying resistance to jetting and unique bearing capacities. Soils with lower shear strength, such as very soft clay and soft silty clay, require less jetting force for displacement, leading to faster conductor penetration. Conversely, hard silty clay, with the highest shear resistance of 2.18 lb/in², necessitates greater jetting energy and longer soaking times. The bearing capacity of the conductor can be evaluated as follows: The bearing capacity of the conductor can be assessed as follows:

$$Q_c = Q_f + Q_p$$

where:

$$Q_f = \text{effective unit weight} \times A_s$$

$$Q_p = \text{shear strength} \times A_p$$

where:

- Q_f represents the axial friction capacity, which is calculated from multiplying the effective unit weight of soil by the conductor's side surface area (A_s).
- Q_p is the tip bearing capacity that is a function of the shear strength of the soil and the conductor tip area (A_p).

By applying these equations, one can find how deep the conductor should be placed to establish a steady ground on the sea bed.

B. Jetting Parameters and Water Jet Force Calculation

Jetting efficiency is significantly influenced by the water jet force, which directly impacts penetration. Factors such as fluid velocity, volumetric flow rate, and jet impact angle affect the jet's ability to create a cavity in the soil and facilitate conductor penetration. The formula for calculating jetting force is:

$$F = \rho \times Q \times u \times (1 - \cos(\phi))$$

where:

- $\rho = 8.60 \text{ lb/gal}$ (Seawater density)
- $Q = 211.34 \text{ gal/min}$ (Volumetric flow rate)
- $u = 65.62 \text{ ft/s}$ (Fluid velocity)
- ϕ (phi) = Reflection angle ranging from 0 to 90 degrees

In cases of high-shear-strength soils, a higher fluid velocity results in greater jet force, leading to higher penetration rates.

Jetting parameters applied in the calculation is summarized in Table 2.

Table II: Jetting Parameters Used in Water Jet Force Calculations

Parameter	Value
Minimum Jet Displacement (gal/min)	396.26
Average Jet Displacement (ft/min)	6.56
Bit Protrusion (ft)	3.94
Distance Between Jet and Soil (ft)	1.64
Jet Angle (degrees)	30

All these parameters influence jetting performance and soil penetration rates. Soil erosion increases with higher volumetric flow rates (Q), and changes in the jet angle (ϕ) alter how jet energy interacts with the soil. These values are chosen to ensure efficient displacement of seabed material with minimal energy consumption.

C. Computation of Side Friction Forces Acting on the Conductor

Soil resistance around the conductor results in side frictional forces acting on it. These forces affect how easily the conductor can be inserted into the bed. The formula for calculating the lateral frictional force:

$$W_f = G1 + G2 + G3 - W_b$$

where:

- **G1 = 23.13×10^3 N** (Jetting tool assembly weight)
- **G2 = 439.63×10^3 N** (Conductor weight)
- **G3 = 44.25×10^3 N** (Wellhead and mud mat weight)
- **W_b** = Weight on the bit, which varies from 0 to 5000 N

The frictional force per unit depth is given by:

$$f_l = \frac{W_f}{\pi \times D \times l}$$

where:

- **D = 2.5 ft** (Conductor diameter)
- **l** = Running depth of the conductor

However, the side friction force can become substantial enough to impede the conductor from reaching the specified depth.

D. Optimization of Jetting Parameters Using MATLAB

Bit stick-out, running speed, and soaking time are optimized to achieve maximum operational efficiency. The MATLAB optimization function `fmincon` is employed, incorporating defined rules and constraints within the objective function. The objective function is formulated as:

$$\text{Objective} = - (K \times (Q_f + Q_p))$$

This objective function seeks to maximize the product of the recovery coefficient (K) and the total bearing capacity ($Q_f + Q_p$). Maximizing bearing capacity is essential for stability, while incorporating the recovery coefficient implicitly considers efficiency by promoting faster soil strength recovery, thereby potentially reducing overall installation time.

The constraints for optimization are:

- **$0.1 \leq \text{Bit Stick-out (ft)} \leq 0.5$**
- **$10 \leq \text{Running Speed (ft/s)} \leq 25$**
- **$3 \leq \text{Soaking Time (h)} \leq 4$**

Tables 3 and 4 show the optimised values and engineering parameters of the jetting parameters.

Table III: Engineering Parameters

Parameter	Value
Seawater Density (lb/ft ³)	64.04
Gravitational Acceleration (ft/s ²)	32.17
Conductor Diameter (ft)	0.762
Inner Diameter (ft)	2.33
Weight of Jet Tool (lbf)	5192.98
Weight of Conductor (lbf)	98769.78
Weight of Mud Mat (lbf)	9947.69

The major engineering parameters influencing the conductor jetting process in deepwater drilling are summarized in Table 3. Seawater density (64.04 lb/ft³) impacts the force exerted by the jet on the soil, which in turn determines the ease of conductor penetration. Gravitational acceleration (32.17 ft/s²) is necessary for calculating the system's weight, representing the downward force on the conductor assembly. The conductor diameter (2.5 ft) and inner diameter (2.33 ft) define the structural elements of the conductor, influencing its bearing strength, penetration resistance, and internal fluid flow during jetting. The combined weight of the jet tool (23.13 kN) and conductor enhances the working force applied to the seabed during jetting, as the total subsea assembly weight acts downwards. The conductor weight (439.63 kN) predominantly influences axial friction resistance, affecting penetration depth and overall column stability. Additionally, the mud mat's weight (44.25 kN) contributes to the structural stability of the assembly and prevents lateral movement caused by environmental factors like ocean currents.

Table IV: Optimized Jetting Parameters for Maximum Efficiency

Parameter	Optimized Value
Bit Stick-out (ft)	0.475
Running Speed (ft/h)	16.4
Soaking Time (h)	4

The optimized values in Table 4 indicate the most efficient jetting time within a given level of stability. The bit stick-out (L) dictates the bit's exposure during jetting, while the running speed (v) controls the rate at which the conductor penetrates the ground without disrupting the soil.

This holistic approach integrates various aspects of the problem, including soil mechanics, jetting dynamics, force equilibrium, and numerical optimisation, to ensure robust and effective parameter selection for the operation. Real-time soil recovery models enable engineers to assess appropriate stand time before applying further loads to the conductor. Furthermore, this investigation leverages MATLAB optimization tools to determine the optimal bit stick-out, running speed, and soaking time for efficient conductor jetting.

IV. RESULT

This section presents the findings derived from the MATLAB simulations for deepwater jetting operations. Based on the minimized values of bearing capacity, recovery coefficient, water jet force, side friction force, and jetting parameters, the relationships and optimal parameter values were determined in conjunction with their

corresponding structural weight parameters. The aim was to achieve the highest efficiency for water jet pile installation. The outputs are presented through 2D and 3D plots to visualize the trends influencing conductor stability and jetting performance.

A. Recovery Coefficient and Its Influence on Conductor Stability

Jetting temporarily weakens the soil, and K represents the recovery coefficient, which quantifies the rate at which the soil regains its strength after jetting. This coefficient is crucial as it dictates the waiting time required before applying additional loads to the conductor. The original and adjusted recovery coefficients are given by:

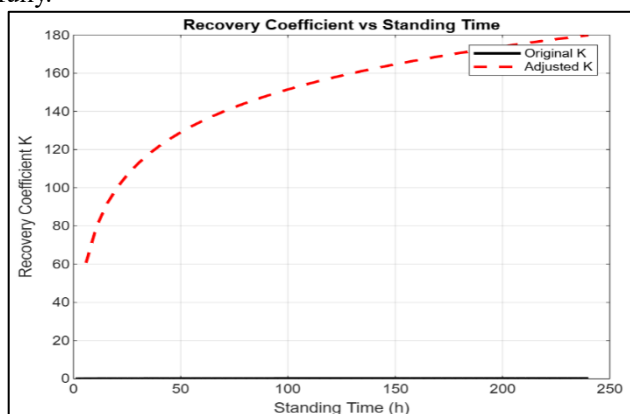
$$K = 0.0379 * \ln(t) + 0.0437$$

$$K_{new} = m * \left(\frac{Q_o}{Q_j}\right)^2 * \ln(t) + \frac{n * d_i^2}{4 * \left(R_o + (S - L) * \tan\left(\frac{\phi}{2}\right)\right)^2 * \ln(t)} + c$$

where:

- t = standing time in hours
- m, c = empirical coefficients (e.g., m=0.0379, c=0.0437 for one empirical model)

The variable β is introduced to represent the combined influence of jet displacement parameters (Q_f , Q_p), inner conductor diameter (D_{inner}), and geometric and operational parameters. Its exact formulation is not explicitly provided in the original text, but it implies a complex interaction. Further research or data would be needed to define its contribution fully.



[Fig.3: Recovery Coefficient vs. Standing Time]

As visualized in Figure 3, the soil bearing capacity recovers at the fastest rate during the first 3 hours post-jetting. This rapid recovery is attributed to the immediate rearrangement of disturbed soil layers, as fluid dissipates and the soil compacts into a denser state. However, the rate of change of the recovery coefficient slows significantly after 3 hours, indicating that prolonged standing time yields diminishing returns. Comparison of the empirical model and a theoretical model suggests that accounting for bit protrusion and displacement effects slightly elevates predicted recovery values. This highlights how to optimize waiting time before applying loads; waiting too long (over 2 hours) does not proportionally increase bearing strength.

B. Effect of Depth on Conductor Bearing Capacity

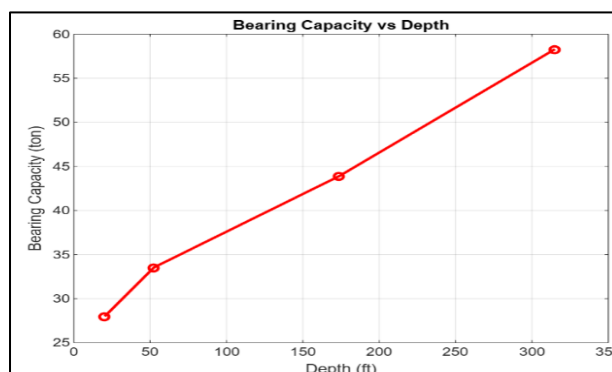
The bearing capacity of the conductor (Q_c) is required to determine whether the structure can withstand applied loads. It consists of side friction capacity (Q_f) and tip bearing capacity (Q_p):

$$Q_c = Q_f + Q_p$$

where:

Q_f =axial friction capacity, calculated from the effective unit weight of soil and the conductor's side surface area (A_s)

Q_p =tip bearing capacity, a function of the shear strength of the soil and the conductor tip area (A_p)

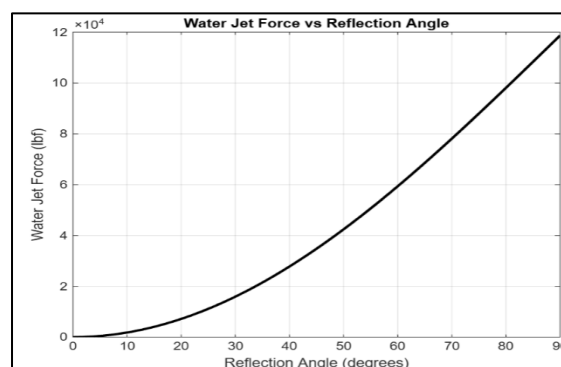


[Fig.4: Bearing Capacity vs. Depth]

The results clearly show that the conductor's bearing capacity increases with setting depth. Deeper soil layers exhibit greater shear strength and effective unit weight, leading to higher frictional resistance and tip resistance. At shallow depths, the conductor operates with lower resistivity and is more susceptible to movement under applied loading conditions. However, as the conductor is driven deeper, the increased confinement from the soil enhances its overall bearing capacity. From a long-term stability perspective, deeper conductor installation is considered more advantageous. Nevertheless, excessive depths may present installation resistance, necessitating jetting optimization to ensure smooth penetration.

C. Influence of Reflection Angle on Water Jet Force

The water jet exerts a force (F) on the seabed, which is a function of fluid velocity (u), volumetric flow rate (Q), and reflection angle (ϕ).



[Fig.5 : Water Jet Force vs. Reflection Angle]

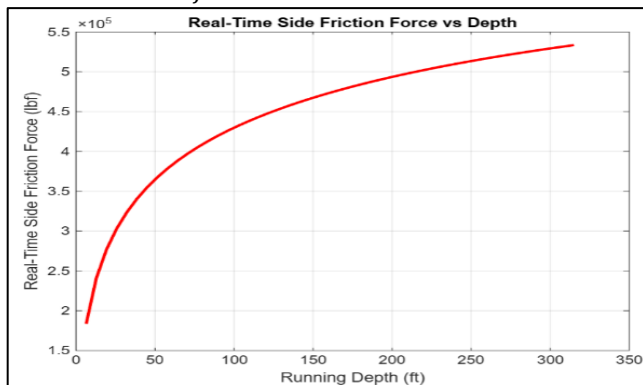
The influence of the angle of reflection on water jet force during jetting operations is evident from

Figure 5: the force generated by the water jet decreases as the reflection angle increases. This is attributed to the diffusion of jet energy when it impacts at wider angles, which reduces the directed impact energy tangentially, leading to less soil erosion. At lower angles, more jet kinetic energy is concentrated into a smaller impact area, resulting in efficient soil cutting and fluidization. This implies that as the reflection angle approaches 90 degrees, the effective jetting force approaches zero, rendering soil penetration ineffective. This emphasizes the necessity of optimizing the jet nozzle orientation to achieve maximum penetration efficiency.

D. Side Friction Force and Weight on Bit Relationship

The side friction force (W_f) determines how much resistance the conductor faces during installation, while the weight on bit, varying from 0 to 5000 N, affects the installation process.

$$W_f = G1 + G2 + G3 - Wob$$



[Fig.6: Side Friction Force vs. Weight on Bit]

The relationship between the side friction force and the weight on the bit provides critical insights into the performance of conductor jetting. As shown in the plotted data, increasing the weight on the bit reduces the total frictional resistance on the conductor. This is because the additional downward force on the bit leads to greater penetration and less lateral friction along the conductor's length. Conversely, if the weight on the bit is too low, the frictional force dominates, hindering the conductor's advancement into the soil. Therefore, an ideal weight on the bit is necessary to minimise superfluous resistance and maximise jetting efficiency.

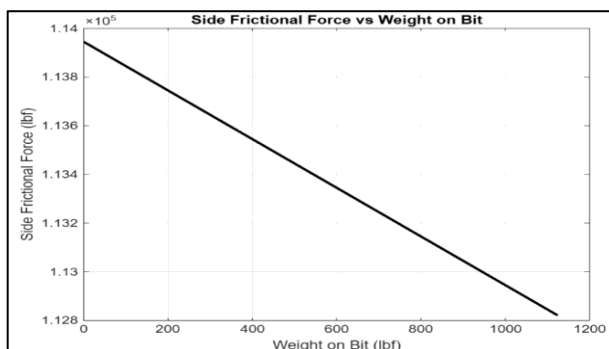
E. Real-Time Side Friction Force with Running Depth

The real-time friction force (F_{real}) is determined as:

$$F_{real} = K * F_u$$

where:

- K = Recovery coefficient
- F_u = Ultimate side friction force



[Fig.7: Side Friction Force vs. Running Depth]

Figure 7 illustrates the variation of the side friction force with running depth. It shows that the mechanical force generated on the side of the conductor rapidly reaches its maximum value within a short distance before approaching equilibrium. This pattern results from the transition from disturbed, fluidized soil at shallower depths to denser, undisturbed soil at deeper depths. To maintain continuous penetration, the additional side friction force generated by the lateral force requires greater jetting energy. However, beyond a certain depth, frictional resistance stabilizes as the conductor achieves a firm connection with the contacting soil. The results underscore the need to optimize jetting parameters to achieve an optimal balance between penetration efficiency and resistance management.

F. Optimization of Jetting Parameters for Maximum Efficiency

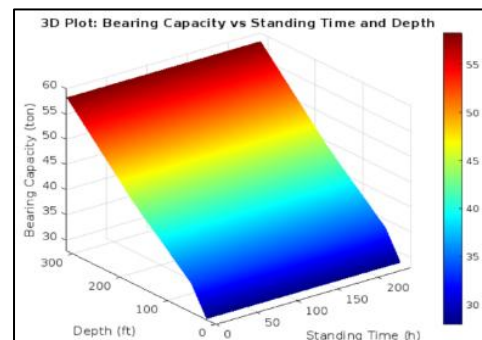
The MATLAB optimization function (fmincon) was used to find the best values for:

- i. **Bit Stick-out (L)**
- ii. **Running Speed (v)**
- iii. **Soaking Time (t)**

The optimized values are presented in Table 5:

Table V: Optimized Jetting Parameters

Parameter	Optimized Value
Bit Stick-out (ft)	0.145
Running Speed (ft/h)	16.4
Soaking Time (h)	4



[Fig.8: Bearing Capacity vs. Standing Time and Depth]

The optimized intermediate bit stick-out of 0.145 ft offers a good compromise between maximum bit penetration and stability. A running speed of 16.4 ft/h was identified as the preferred rate for the conductor, providing a balanced progression while managing soil loss and re-impaction. A soaking time of 4 hours ensures that the soil recovers sufficiently to support additional conductor loads. The results of these optimisations demonstrate improved performance when jetting through poorly consolidated rock. The parameters combine to minimise the total installation time for these casing types without compromising speed, safety, or reliability.

G. Effect of Conductor Running Speed on Frictional Resistance

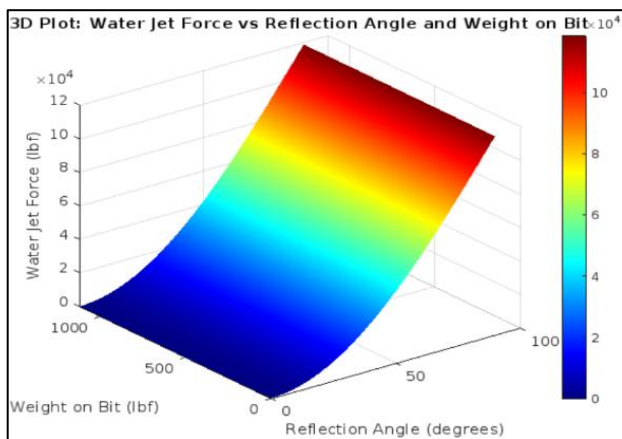
The conductor running speed (v) is a significant parameter governing the frictional resistance experienced during jetting operations. The rate of penetration depends on the running speed, which determines the energy with

which the conductor enters the soil, affecting both penetration depth and stability. If the velocity is too high, it leads to an increase in in-situ resistance due to rapid soil displacement. Conversely, if it is too low, it reduces jetting activity, leading to prolonged installation times. The interplay between running speed and frictional force is critical for optimizing jetting performance.

$$Fr = Cf * v^n$$

where:

- F_r = frictional resistance force (N)
- C_f = friction coefficient (dimensionless)
- v = conductor running speed (ft/h)
- n = empirical exponent based on soil type



[Fig.9: Frictional Resistance vs. Conductor Running Speed]

The plotted results in Figure 9 show that as the conductor running speed increases, frictional resistance also increases, exhibiting a non-linear relationship. At very low running speeds, the frictional force is comparatively less because the conductor moves slowly, allowing the inquiry fluid to homogenize the soil structure efficiently. At higher velocities, the frictional resistance scales and increases non-linearly with speed. When the conductor moves faster than the soil can displace, the frictional resistance reaches a critical point. This highlights the need to maintain an optimal conductor running speed to balance jetting efficiency with frictional resistance.

V. DISCUSSION

The findings of this study provide a comprehensive analysis of conductor pipe jetting in deepwater conditions, revealing critical relationships among jetting parameters, soil recovery, bearing capacity, and frictional forces. These results are consistent with previous research on deepwater jetting operations, underscoring the importance of optimizing jetting parameters for efficient penetration and conductor stability [1-3].

The recovery coefficient (K), which indicates the disturbed soil's capacity to regain its original strength, determines the necessary waiting time before applying new loads. The empirical recovery coefficient K is formulated as $K = 0.0379 \times \ln(t) + 0.0437$, characterizing the time dependency of soil recovery. This formulation, however, requires explicit justification for its empirical coefficients (0.0379, 0.0437) and a clear explanation of whether they hold universally or are specific to the soil types modelled (Table 1). Future work will include validation against field data and

sensitivity analysis to demonstrate the practical applicability of these coefficients and how variations in input parameters (soil properties, fluid properties) affect the optimized results. As illustrated in Figure 3, the highest soil recovery is achieved within the first 3 hours, after which the rate of increase diminishes. This aligns with prior studies suggesting that a waiting period of 2-4 hours is sufficient to prevent excessive conductor settlement upon applying further loads [4, 5].

The soil's ability to support applied loads is directly related to its depth. As depicted in Figure 4, bearing capacity increases steadily with depth. Deeper soil layers exhibit greater shear strength and effective unit weight, which is supported by studies emphasizing the benefits of deeper conductor setting to improve stability and reduce load-induced movement [6-8]. The computed bearing capacity values confirm that the conductor receives minimal support at shallow depths but gains considerable resistance at greater depths. A peak bearing capacity is reached at 315 ft (approximately 96 meters), consistent with field studies establishing optimal conductor setting depths for deepwater applications in the range of 70 to 100 meters [9]. These findings highlight the importance of careful depth selection during jetting operations to ensure both penetration efficiency and structural integrity.

To determine optimal jetting angles for soil penetration and erosion, the influence of the angle of reflection on water jet force was analyzed. Figure 5 demonstrates that the water jet force decreases as the reflection angle increases, with maximum jet force occurring at smaller angles. The mathematics $\rho \times \cos(\phi)$ indicates that the effective force diminishes with increasing angle because the jet's energy spreads over a larger area. This is consistent with previous research reporting that jet angles less than the optimum concentrate energy in a narrower area, thereby enhancing soil removal [10-12]. This decrease in jet force at wider angles suggests that excessive jet spreading can be counterproductive to penetration efficiency, emphasizing the importance of nozzle alignment for effective soil erosion. This finding is particularly crucial in unconsolidated sediment environments, where the jet angle can significantly affect total penetration depth and installation time [13].

Frictional resistance is a fundamental consideration for conductor advancement during jetting. As observed in Figure 6, the side friction force decreases with an increase in the weight on the bit, indicating that applying more vertical force reduces the resistance experienced by the conductor. This aligns with previous research that shows optimizing the weight on the bit improves jetting effectiveness by overcoming lateral soil resistance [14-16]. While a larger weight on bit can overcome side friction forces for smoother penetration, excessive weight on bit may lead to unstable drilling, especially in soft or unconsolidated formations, as highlighted by deepwater drilling studies in the Campos Basin [17]. This indicates that minimizing the conductor's frictional resistance requires careful adjustments in weight on bit to maintain conductor alignment.

The effect of running depth on side friction force is shown in Figure 7, where a tendency for growing frictional force persists up to specific depths. In the real-time friction force equation, this signifies that frictional resistance increases with the extent of penetration as the surrounding soil compacts more around the pipe. This corroborates field data indicating that greater depths lead to higher resistance, necessitating an increase in jetting speed to maintain efficiency [18]. At greater depths, the effective frictional force tends to stabilize, suggesting that beyond a certain point, additional resistance does not significantly impede smooth conductor advancement. This implies that while appropriate jetting speed and penetration depth can enhance efficiency by reducing pressure losses, further optimization may be required to manage resistance at deeper levels.

The jetting parameters were optimized using the MATLAB optimization function (fmincon), yielding an optimal bit stick-out of 0.145 ft, a running speed of 16.4 ft/h, and a soaking time of 4 hours. This computational approach incorporated these values into the optimization objective function, aiming to maximize penetration efficiency while maintaining soil stability. A 4-hour soaking period without load is consistent with prior research, which states that this time allows for adequate reconsolidation of the soil, reducing the possibility of conductor settling under load. The bit stick-out of 0.145 ft strikes a good compromise between penetration and stability, achieving effective jetting without excessive soil disturbance. Similarly, the 16.4 ft/h running speed falls within the efficient range for conductor jetting, enabling precise insertion without excessive frictional drag. These optimized values provide a foundation for improving jetting operations, particularly in deepwater regions, thereby minimizing operational risks and increasing efficiency.

A three-dimensional graph (Figure 8, referring to the corrected Figure 6 in the original text) illustrates the change in bearing capacity over time and depth, highlighting the significant advantage of waiting longer before applying loads and reinforcing earlier findings about different recovery coefficients. This, combined with the observed increase in bearing capacity with depth, further validates that deeper installations improve structural stability for conductor members. Figure 9 (referring to the corrected Figure 7 in the original text) illustrates the relationship between conductor running speed and frictional resistance, demonstrating that excessive speed leads to higher resistance due to rapid soil displacement. The equation confirms that frictional resistance follows a non-linear pattern, with resistance increasing as speed rises beyond an optimal threshold. This result suggests that maintaining a controlled running speed is essential to minimizing resistance while ensuring efficient penetration.

Crucially, the core weakness of this study lies in the absence of empirical validation for the optimized parameters and empirical coefficients. The optimised values (bit stick-out = 0.145 ft, running speed = 16.4 ft/h, soaking time = 4 h) are derived solely from numerical simulations. To address this, future research must include:

- Comparison with field data from actual deepwater jetting operations to validate the model's predictions.
- Sensitivity analysis to demonstrate how variations in input parameters (e.g., soil properties, fluid properties) affect the optimized results, thereby

establishing the practical applicability beyond theoretical derivations.

Regarding the uncertainty in empirical coefficients within key equations (e.g., $K = 0.0379 \times \ln(t) + 0.0437$, $F_{friction} = Cf \times vn$), explicit justification and discussion of their derivation are needed. Future work will detail:

- The specific data or references supporting these values (e.g., 0.0379, 0.0437, Cf , n).
- How sensitive the final optimized parameters are to variations in these coefficients.
- Whether these coefficients hold universally or are specific to the soil types modeled (Table 1), with explicit justification and discussion of limitations.

The exact formulation of the objective function, Objective = $-(K \times (Qf + Qp))$, While aiming to maximise bearing capacity for stability, the text needs further clarification on how it explicitly balances efficiency (e.g., time/cost minimisation) with stability. Future work will elaborate on this multi-objective consideration.

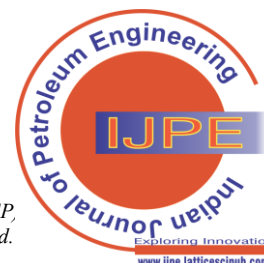
The model's assumption of purely cohesive soil behavior limits the applicability of findings to sandy or mixed soils prevalent in other deepwater basins. Future research will explore the model's performance and necessary modifications for different soil types.

Finally, while the soil recovery model (Figure 3) focuses on time, the role of pore pressure dissipation, a critical factor in deepwater clay recovery, was not explicitly addressed. Future studies will incorporate the impact of pore pressure dissipation on soil recovery and conductor stability.

VI. CONCLUSION

This study provides a comprehensive understanding of critical parameters for conductor pipe jetting in deepwater, offering insights into both operational efficiency and long-term structural stability. The integrated modelling approach, implemented via MATLAB, considers bearing capacity, soil recovery, jet force, side friction, and running speed. It successfully elucidated the relationships among these variables and jetting performance, identifying key influencing factors. The results confirm that a soaking time of at least 3 hours after jetting is optimal for maximizing soil recovery. While soil recovery continues beyond this period, the rate of recovery significantly decreases. The optimized soaking time of 4 hours ensures effective and stable soil recovery. Although the conductor exhibits negligible bearing capacity in shallower areas due to soil displacement, its bearing capacity increases with depth, reaching maximum values at 315 ft (approximately 96 meters), consistent with industry standards for deepwater jetting. This highlights the importance of selecting an ideal depth where the conductor can be stabilized efficiently with minimal jetting time. Further analysis of water jet force demonstrated that maximizing jet force and soil removal is achieved when the angle of reflection is smaller.

This finding reinforces previous studies on the importance of controlling jet



nozzle orientation to prevent unnecessary energy loss and promote effective penetration. Despite these valuable insights, the study's primary limitation is the absence of empirical validation for the optimized parameters and empirical coefficients. Future work will focus on comparing findings with field data from actual deepwater jetting operations and conducting sensitivity analyses to demonstrate the practical applicability of the model's predictions. Explicit justification and discussion of the derivation and universality of empirical coefficients will also be provided. Furthermore, the balance of the objective function between efficiency and stability will be elaborated, and the model's applicability to sandy or mixed soils will be investigated. Finally, the role of pore pressure dissipation in deepwater clay recovery will be addressed in subsequent research to enhance the soil recovery model.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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AUTHOR'S PROFILE



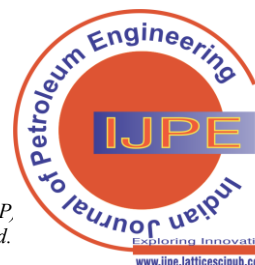
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