



Analysis of Helical Buckling, Lock-Up, and Drill String Failure in Horizontal Wells: A Case Study from an Oilfield, Libya

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ABSTRACT

Helical buckling in horizontal drilling creates serious risks: high torque, strong drag, poor axial load transfer, and potential string sticking or breakage. Research indicates that friction along the borehole wall governs buckling initiation and growth. Pipe rotation reportedly lowers the helical buckling threshold by roughly half. This study evaluates key factors controlling helical buckling, lock-up conditions, and compressive failure. The case well (A60H-NC169A) lies in Libya's Ghadames Basin. Classical models (Dawson & Paslay, Lubinski) alongside finite element simulations are applied. Parameters examined include pipe size, annular gap, well inclination, torque, and friction coefficient. Findings indicate that axial compression rises with higher friction and inclination. Torque reduces critical buckling load by only 1–3%. Lock-up occurs when helical friction equals applied compression. Threaded connections withstand compression better than the pipe body. These outcomes offer practical guidance for bottomhole assembly optimization, reducing non-productive time, and improving drilling performance in high-angle wells.

تحليل الالتواء الحلزوني، تعليق أنابيب الحفر، وفشل عمود الحفر في الآبار الأفقية: دراسة حالة من حقل نفطي، ليبيا

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المُخلص

يُسبب الالتواء الحلزوني في الحفر الأفقي مخاطر جسيمة، منها: ارتفاع عزم الدوران، وقوة السحب الكبيرة، وضعف نقل الحمولة المحورية، بالإضافة إلى احتمالية تعليق عمود الحفر أو كسره. تشير الأبحاث إلى أن الاحتكاك على طول جدار حفرة البئر هو العامل المتحكم في نشوء الالتواء وتطوره. ويُذكر أن دوران أنابيب الحفر يُخفّض قيمة عتبة الالتواء الحلزوني بحوالي النصف. تهدف هذه الدراسة إلى تقييم العوامل الرئيسية التي تتحكم في الالتواء الحلزوني، وظروف التعليق (أو الاحتجاز)، والفشل الانضغاطي. تقع البئر محل الدراسة (A60H-NC169A) في حوض غدامس بليبيا. تم تطبيق النماذج الكلاسيكية (داوسون وباسلاي، ولوبينسكي) إلى جانب محاكاة طريقة العناصر المحددة. تشمل المتغيرات التي تم فحصها: حجم الأنبوب، والفجوة الحلقية، وزاوية ميل البئر، وعزم الدوران، ومعامل الاحتكاك. تشير النتائج إلى أن الانضغاط المحوري يزداد بازدياد كل من معامل الاحتكاك وزاوية الميل. كما أن عزم الدوران لا يُخفف حمل الالتواء الحرج إلا بنسبة تتراوح بين 1% و3% فقط. ويتحقق التعليق (الاحتجاز) عندما يُصبح الاحتكاك الحلزوني مساوياً لقيمة الانضغاط المسلط. وتجدر الإشارة إلى أن الوصلات الملولبة تتحمل الانضغاط بشكل أفضل من جسم الأنبوب نفسه. تُقدّم هذه النتائج إرشادات عملية لتحسين أداء مجموعة أدوات أسفل البئر، وتقليل الوقت غير المنتج، وتحسين كفاءة الحفر في الآبار

الكلمات المفتاحية: الالتواء الحلزوني، التعليق، فشل عمود الحفر، عزم الدوران والسحب، الحفر الأفقي.

1 Introduction

During the process of horizontal and extended-reach drilling, the drill string is exposed to considerable compressive stresses, which may eventually result in buckling. Broadly, two principal forms of buckling are recognized in the technical literature: the sinusoidal (or lateral) type and the more critical helical (spiral) type. Among these, the helical configuration is particularly harmful as it intensifies the contact forces pressing the pipe against the borehole wall. This intensification leads to excessive frictional drag, obstructs the effective transfer of weight down to the bit, and ultimately produces a lock-up condition where further forward movement of the string ceases [1], [7].

Drill string buckling remains a major industry challenge, worsening with depth [1]. Lubinski pioneered systematic buckling studies of tubulars in drilling [10],[11]. Subsequent experimental and theoretical work advanced understanding and prediction of this phenomenon [12],[13],[14].

Buckling depends on borehole geometry [15], wellbore curvature [16],[17], tool joint dimensions and placement [18], and torque [19]. Rotating the pipe can lower the helical buckling threshold by up to 50% depending on downhole conditions [20],[7].

This study aims to: (1) quantify axial compression for helical buckling onset, (2) assess effects of pipe diameter, radial clearance, wellbore tilt, and torque on buckling, (3) define lock-up conditions versus friction factor, and (4) compare compressive strength of pipe body versus connections.

Materials and Methods

The following steps were performed with their corresponding equations:

Step 1: Data Collection. Well A60H-NC169A (X Field, Libya) was selected. Data included well trajectory, drill pipe sizes (3.5-in. with weights from 10.4 to 17 lb/ft), hole sizes (6 to 26 in.), and casing program.

Step 2: Sinusoidal Buckling Load Calculation (Dawson & Paslay, 1984 [3]).

Step 3: Helical Buckling Load Calculation (Lubinski, Woods & Dawson, as presented in Mitchell, 2005 [4],[12]).

Recent studies using explicit finite element methods have validated these analytical predictions, showing good agreement between theoretical and simulated results for inclined wellbores [8].

Step 4: Helical Buckling in Curved Wellbores (Wu & Juvkam-Wold, 1995 [7]).

Step 5: Influence of Torque on Helical Buckling. Per Miska & Cunha (1995) [2].

Step 6: Calculation of Helical Frictional Force. Per Mitchell & Miska (2004), [6].

Higher friction coefficients delay buckling onset and permit deeper drilling [1].

Step 7: Lock-Up Depth Determination (Wu & Juvkam-Wold, 1995 [7]; Mitchell, 2008 [10]).

Lock-up occurs when the helical frictional force equals the applied axial compression. Lock-up depth was calculated for friction factors of 0.1, 0.2, 0.3, and 0.4. Recent studies have proposed discriminative conditions for lock-up occurrence, noting that increasing axial load can delay lock-up [9].

Step 8: Compression Capacity of Pipe Body and Connections (API / Mason & Chen, 2007 [8]).

Step 9: Numerical Simulation (Halliburton Wellplan, 2001 [11]).

Well trajectory, mud properties, friction factors, and drill string components were input into Wellplan software to generate effective tension, torque, and minimum WOB charts.

Results

Effect of Drill Pipe Size and Weight

Heavier drill pipes require higher axial compression to initiate helical buckling. At 40° inclination, the 3.5-in., 12.7 lb/ft pipe buckles at a higher compression load than the 3.5-in., 10.4 lb/ft pipe (**Figure.1**).

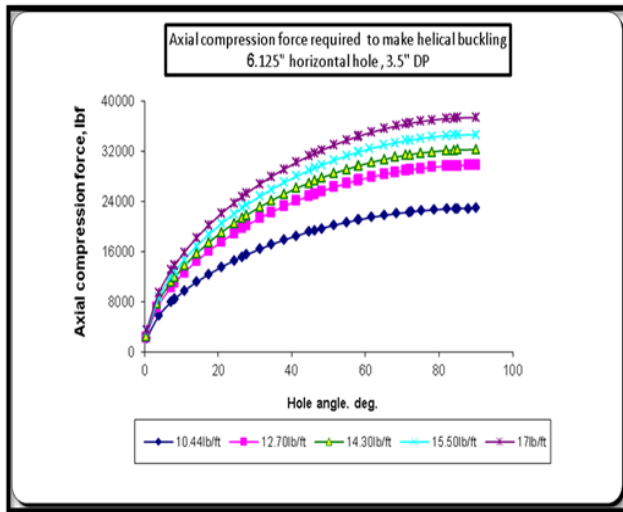


Fig.1: Effect of DP size and weight on helical buckling force.

Impact of Radial Clearance

Larger radial clearance lowers critical buckling force. In an 8.5-in hole, buckling needs higher compression than in 12.25-in, 16-in, or 26-in holes (Figure 2). Friction forces control buckling initiation and growth; reducing friction coefficient postpones buckling [1].

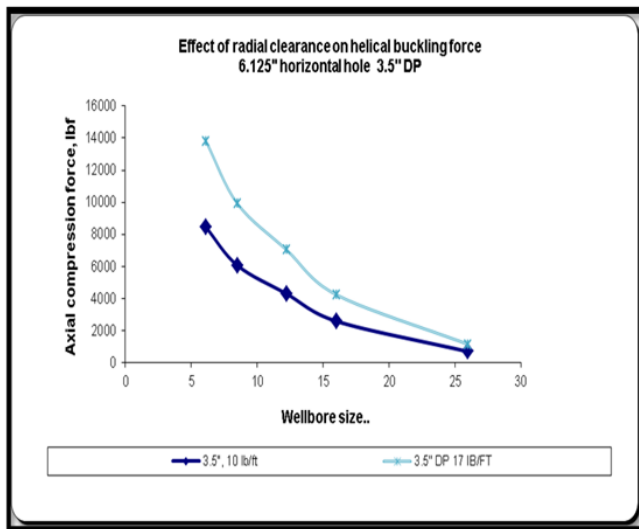


Fig. 2: Effect of radial clearance on helical buckling force.

Effect of Wellbore Inclination

The force required to buckle the pipe increases with inclination up to approximately 60°, after which the increase becomes marginal. At angles above 60°, drag forces dominate (Figure 3). Finite element analyses have shown that theoretical buckling load predictions for different inclination angles agree well with simulation results [8].

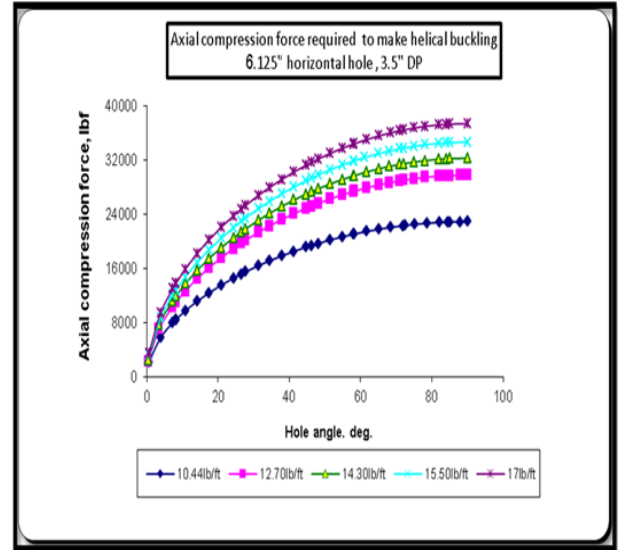


Fig. 3: Effect of deviations on helical buckling force.

Impact of Torque on Helical Buckling

Torque slightly lowers critical buckling load by 1–3%, negligible for field use (Figure 4). Yet, pipe rotation may reduce helical buckling threshold by ~50% under dynamic conditions [7],[2].

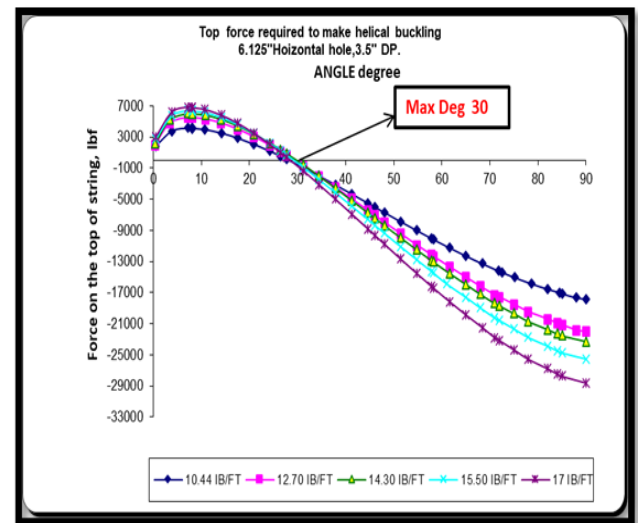


Fig. 4: Max deviation deg for 3.5" Drill pipe before buckling.

Lock-Up Conditions

At friction factor 0.4, lock-up occurs at ~7,200 ft MD; at 0.3, ~7,300 ft; at 0.2, ~7,600 ft; at 0.1, no lock-up occurs. Low-friction mud systems significantly delay lock-up (Figure 5). Recent studies on coiled tubing have proposed discriminative conditions for lock-up, demonstrating that increasing axial load can delay lock-up occurrence [9].

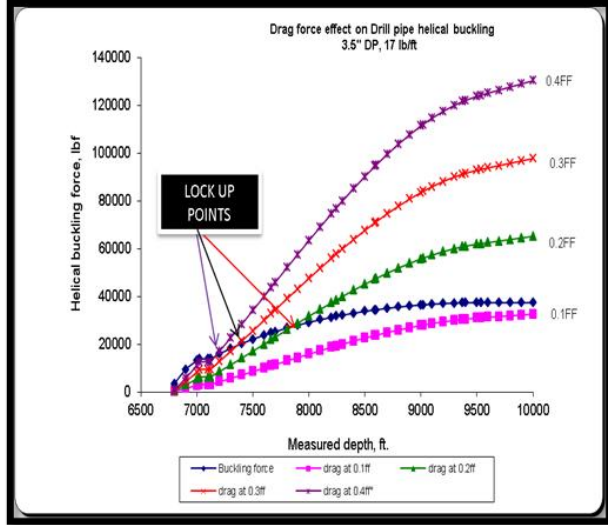


Fig. 5: 3.5” 17lb/ft DP, Frictional force due to helical buckling and lock-up condition.

Compressive Capacity: Pipe Body Versus Connections

Tool joints resist compression better than the pipe body. For 3.5-in, 12 lb/ft pipe, body fails at ~50,000 lbf, connections at ~70,000 lbf (Figure 6). Tool joints stabilize by generating extra contact forces and bending stresses [7],[16].

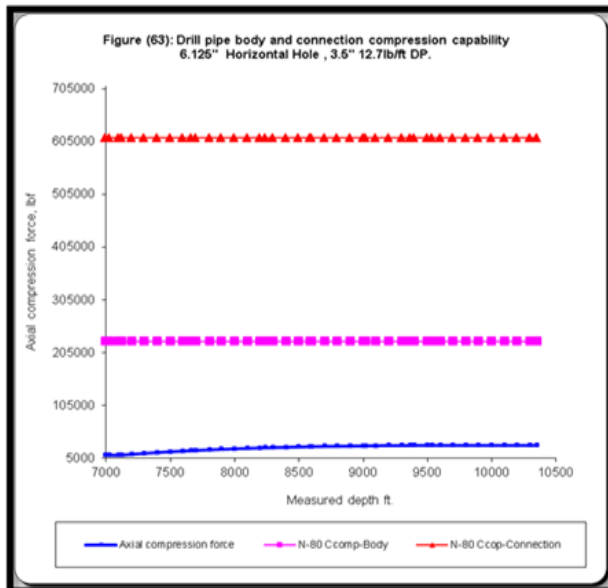


Fig. 6: 3.5”, 12lb/ft, Drill pipe body and connection compression capability.

Wellplan Simulation Results

No buckling is predicted. All torque values remain below makeup limits. At 10,000 ft MD, WOB should not exceed 15,000 lbf (Figures 7, 8, and 9).

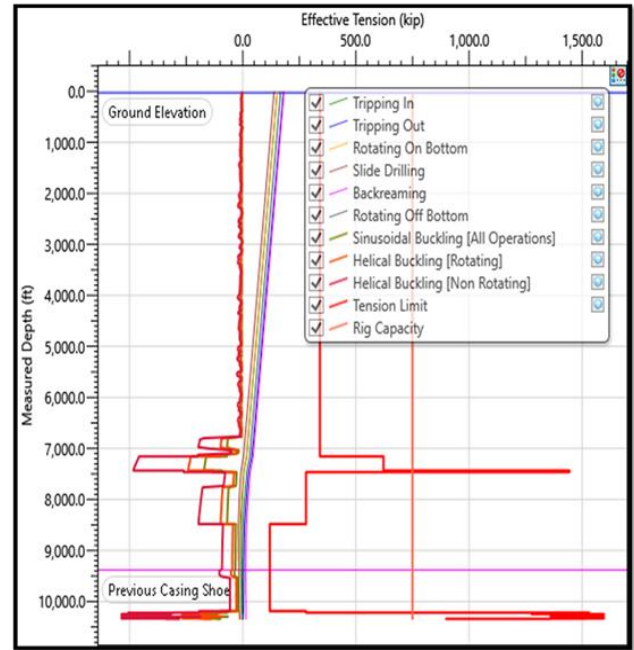


Fig. 7: Effective Tension during Tripping in and Tripping out (Well plan)

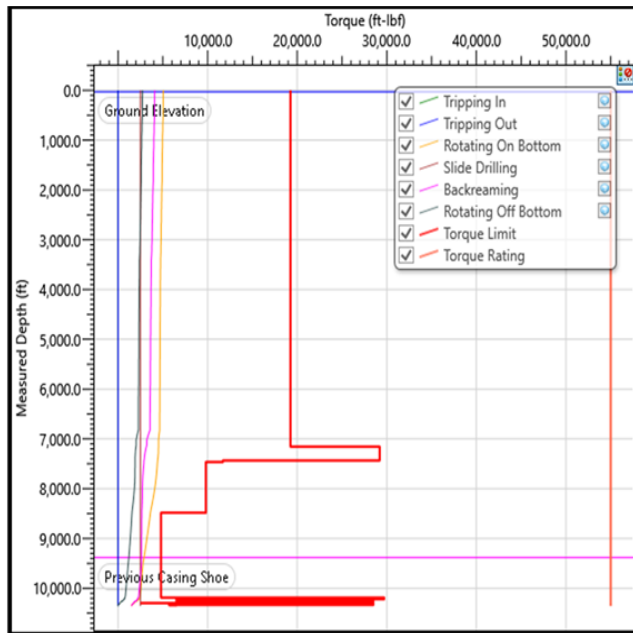


Fig. 8: Torque during Tripping in and tripping out (Well plan).

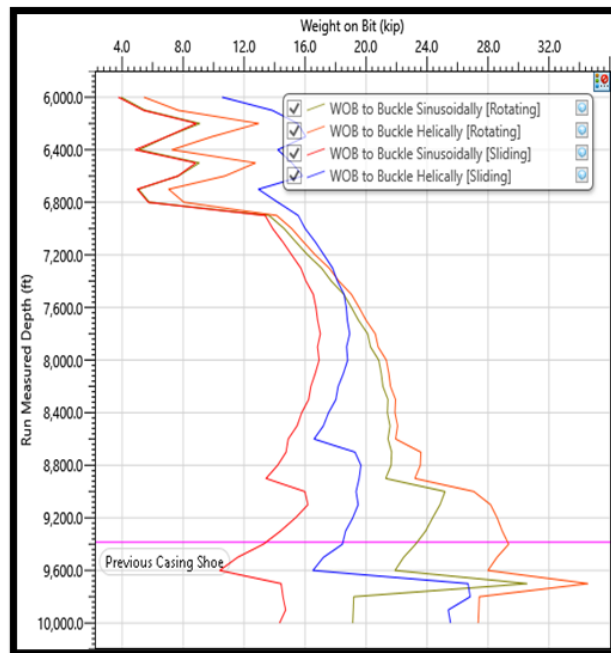


Fig. 9: Minimum Weight on Bit.

Discussion

The results confirm that helical buckling in horizontal wells is primarily governed by pipe weight, radial clearance, wellbore inclination, and friction. Heavier drill pipes and smaller radial clearances significantly increase the critical buckling load, while wellbore inclination strongly influences buckling up to approximately 60°, beyond which frictional forces

dominate. Torque under static conditions has a negligible effect (only 1–3% reduction in buckling load), although dynamic rotation may lower the threshold more substantially. Lock-up depth is highly sensitive to the friction factor: at 0.4, lock-up occurs around 7,200 ft, while no lock-up is observed at 0.1, highlighting the importance of low-friction mud systems, such as those enhanced with nano-additives. Additionally, threaded connections demonstrate superior compressive strength compared to the pipe body, suggesting that failure in buckling-prone sections is more likely to occur in the pipe itself rather than at the joints.

Simulations using Wellplan indicate no buckling risk under standard operating conditions for well A60H-NC169A, provided that weight on bit (WOB) does not exceed 15,000 lbf and torque remains below makeup limits. These findings offer practical guidance for drill string design, including the use of heavier pipes, reduced radial clearance, and real-time torque and drag monitoring. Future field validation and further investigation into dynamic rotation effects are recommended to enhance predictive accuracy and operational safety in high-angle wells.

Conclusions

1. Heavier drill pipes and smaller radial clearances increase critical buckling load.
2. Wellbore inclination strongly affects buckling up to ~60°.
3. Torque reduces critical buckling load by only 1–3% (negligible) under static conditions, though recent studies suggest rotation may have a more significant effect under dynamic conditions.
4. Lock-up depth is strongly dependent on friction factor; nano-additives in drilling fluids can significantly reduce Coefficient of Friction and delay lock-up.
5. Drill pipe connections are stronger in compression than the pipe body.
6. For well A60H-NC169A, no buckling risk is predicted under standard operating conditions.

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Conflict of interest: The authors declare that there are no conflicts of interest

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