ANALYSIS OF FRICTION & TORQUE AND CASING RUNNING MEASURES OF A WELL IN THE SOUTH CHINA SEA CONSIDERING JOINT EFFECT

by

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The mechanical properties of the rotary drilling system are analyzed in depth and the complex mechanical behaviors of integral tubular strings and the effects of joints are studied. The results show that before the mechanical calculation of the drilling string, the inversion of the friction coefficient by the near-well data can improve the calculation accuracy of the friction and torque of the string. Rotating casing can ensure smooth running in the extended well. The injection of light medium can alleviate the axial force, but it is not enough to ensure safe running, which needs to be combined with the rotating casing method. By increasing the rotation per minute and reducing the weight on bit, the buckle of drill string can be avoided.

Key words*: extended well, friction, torque, casing running, joint effect*

Introduction

Horizontal well and extended-reach drilling technology is one of the cutting-edge technologies in today's oil and gas engineering operations. Compared with vertical wells and or-dinary directional wells, large-displacement horizontal wells have a larger contact area with the reservoir, and therefore, have higher oil and gas production [1, 2]. The application of large-reach horizontal well technology can effectively develop oil and gas resources in areas such as beaches, lakes, and deep seas.

At present, the most classic and widely used downhole drill string friction & torque model is the soft rope model proposed by Johancsik [3]. Sheppard [4] established the Johancsik model in the form of a differential equation. Maidla and Wojtanowicz [5] further considered the influence of drilling fluid viscosity and compared the 2-D analytical model and the 3-D soft rope model. Lesage *et al.* [6] used the soft rope model and combined with actual drilling data to inversely calculate the friction coefficient to identify drilling anomalies. Brett *et al.* [7] applied the soft rope model in pre-drilling design, real-time monitoring and analysis during drilling. This paper considers the influence of the joint effect to conduct relevant research on the friction and torque of the extended-reach well.

Numerical model and validation

Assuming that the stress and deformation of the drill string are within the elastic range, and that there is a rigid support between the well wall and the drill string, the elastic

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deformation-line of the drill string coincides with the wellbore axis, and the effects of shear deformation and vibration damping are ignored, the model of the drill string friction torque reads:

$$\begin{gathered}\frac{\mathrm{d}F_e}{\mathrm{d}s} + EIk\frac{\mathrm{d}k}{\mathrm{d}s} + w_{\mathrm{bp}}t_z - \mu_d(w_{\mathrm{c}} + w_{\mathrm{br}})(1 - kr_{\mathrm{o}}\cos\theta) = 0 \\ \frac{\mathrm{d}M_t}{\mathrm{d}s} - \mu_t r_{\mathrm{o}}(w_{\mathrm{c}} + w_{\mathrm{bp}}) = 0\end{gathered} \tag{1}$$

where E is the elastic modulus, F_e – the axial force, I – the moment of inertia, k – the wellbore curvature, M_t – the torque, r_{o} – the outer diameter of the drill string, t_z – the vertical component of the unit tangent vector of the drill string element, w_{c} – the contact force of the unit length drill string, w_{br} – the additional contact force caused by the discontinuity of the wellbore curvature, w_{bp} – the buoyancy weight of the unit length of the drill string, θ – the angle between the contact direction-line between the drill string and the well wall and the main normal direction, μ_d – the axial friction coefficient, and μ_t – the circumferential friction coefficient. The boundary conditions of eq. (1) are given:

$$F_e(0) = W_{\mathrm{ob}},\ M_t(0) = T_{\mathrm{ob}} \tag{2}$$

where W_{ob} is the weight on bit and T_{ob} – the torque at the drill bit.

Suppose the friction coefficient of the casing section is μ_1 and the friction coefficient of the open hole section is μ_2. The inversion problem is to find the appropriate μ_1 and μ_2 to minimize the deviation between the measured value of the hook load or ground torque and the calculated value.

Taking the extended-reach well X as an example, as shown in fig. 2, the changes in friction coefficient were inverted and the trend of torque was predicted. Since there is noise in the measurement data, the measurement data needs to be smoothed. First, the measurement data within the 30 m well section are averaged, and then the *nine-point cubic polynomial* is used for smoothing. The processed torque data and inversion results are shown in fig. 1.

The prediction error using segmented friction coefficient is low. For extended-reach wells or horizontal wells, using segmented friction coefficient can obtain higher-precision friction coefficients. The friction coefficient of the casing section is about 0.23, and the friction coefficient of the wellhole section is about 0.31. Since the depths of the 8-1/2″ casing section and 7″ casing section both exceed 2400 m, so in the subsequent calculation, the friction coefficient of 0.31 was selected.

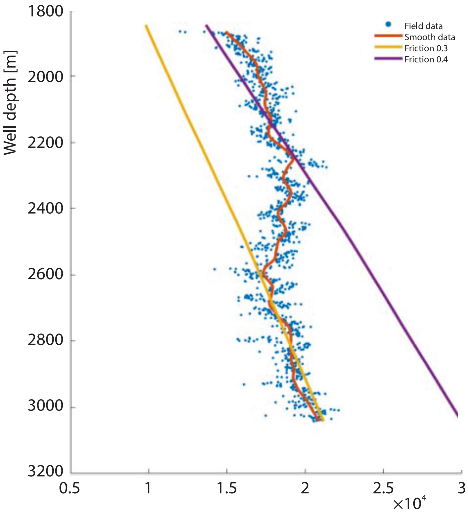

Figure 1. Friction torque inversion

Friction & torque analysis

It can be seen from fig. 3 that the velocity of run in hole has little effect on the axial force of the drill string. When the rotation per minute (RPM) is greater than 40, the drill string will not buckle, so the buckling risk of the drill string can be reduced by increasing RPM.

It can be seen from fig. 4 that the lifting velocity has little effect on the axial force of the drill string. In the case of rotary drilling, the axial force of the string will be reduced. In general, the axial force is less than the yield limit when the drill string is lifted within the casing section.

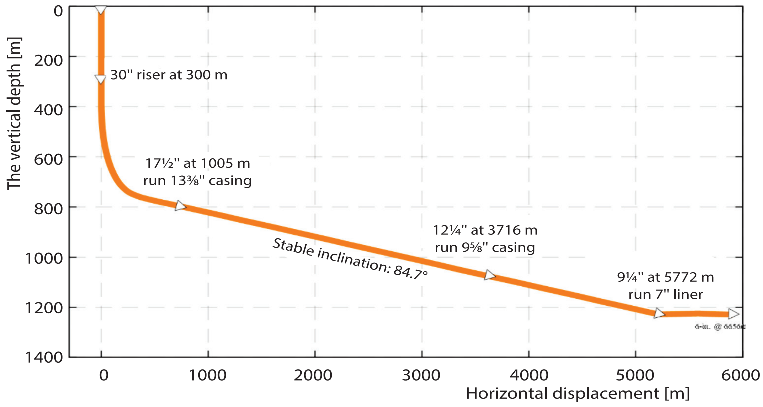

Figure 2. Section of a well in the South China Sea

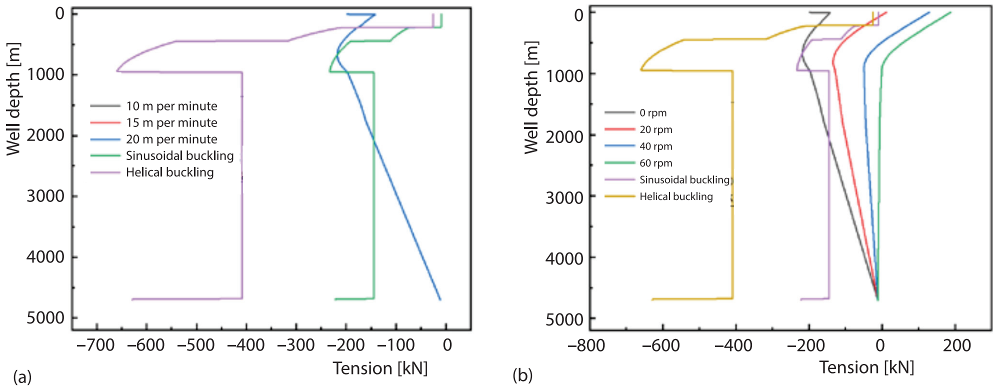

Figure 3. Influence of RPM in run in hole; (a) run in hole and (b) RPM

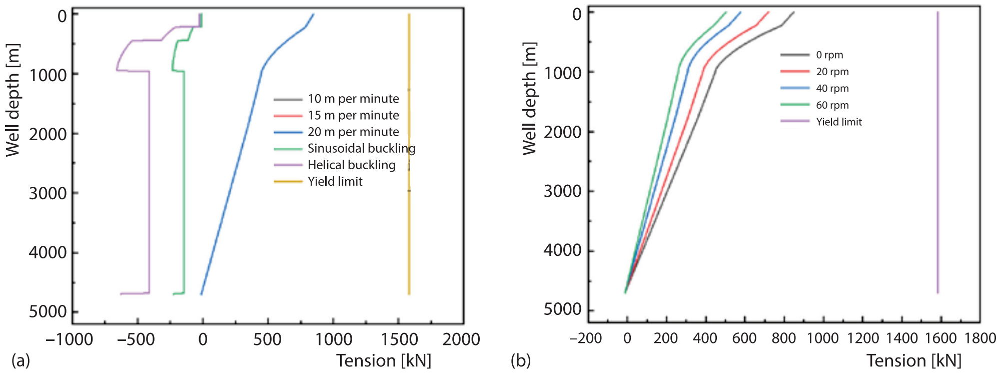

Figure 4. Influence of RPM in put out of hole; (a) put out of hole and (b) RPM

It can be seen from fig. 5 that during the compound drilling process the risk of helical buckling of the drill string during the running process increases. When the weight on bit (WOB) is higher than 15 tonne, the drill string undergoes sinusoidal buckling. As the torque at the drill bit increases, the overall torque of the drill string tends to increase, but it is still far below the torque limit, and high torque can be used for drilling.

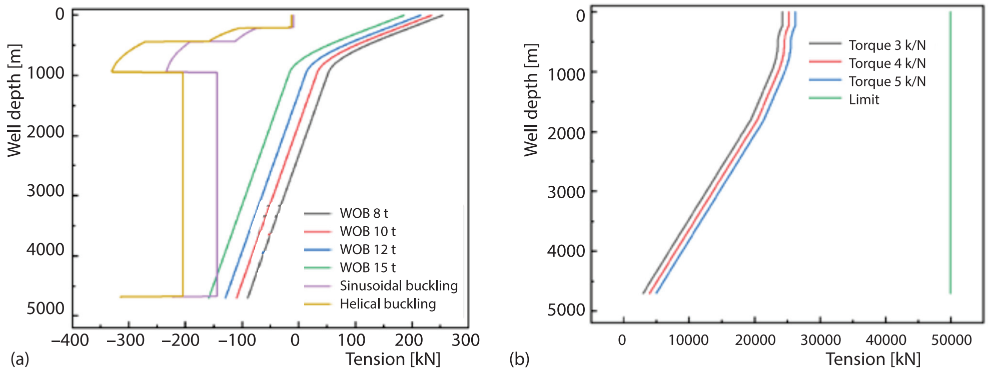

Figure 5. Rotary drilling; (a) tension and (b) torque

The calculation parameters are shown in tab. 1.

Table 1. Calculation parameters

Parameters	Numbers
Friction coefficient	0.28 casing 0.31 wellbore
Viscosity of drilling fluid	20 mPa·s
Density of drilling fluid	1100 kg/m^3
Run in hole	10 m per minute
RPM	20 rpm
Flow rate	3.8 m^3 per minute

In general, in the 8-1/2″ casing section, if the drill string does not rotate, the drill string will buckle above 1000 m, which will cause the drill string to be locked and difficult to run in. Increasing RPM can reduce the axial force of the drill string. When the RPM is greater than 40, the drill string will not buckle during the run-in hole process and can be installed normally. In the drilling conditions, when sliding drilling is used, no matter how to reduce the WOB, the string will buckle in the vertical section above 1000 m and thesteady inclined section of 1000-2000 m. When the compound drilling is used, the sinusoidal buckling occurs when the drilling pressure is greater than 15 tonne.

It can be seen from fig. 6 that the lifting speed has little effect on the axial force of the drill string. In the case of rotary drilling, the axial force of the string will be reduced. In general, the axial force is less than the yield limit when the casing string is lifted under the casing structure.

It can be seen from fig. 7 that with the increase of WOB, the risk of helical buckling in the running process of drill string increases. When the WOB is higher than 15 tonne, the drill string occurs sinusoidal buckling. Therefore, in order to increase drilling efficiency and ensure drilling safety, the WOB can be appropriately increased from 8-12 tonne. With the increase of the torque at the drill bit, the overall torque of the drill string tends to increase, but it is still far below the torque limit. Therefore, high torque can be used for drilling in the field construction.

In general, in the 7″ casing section of the *X* well, if the drill string does not rotate, the spiral buckling occurs in the well depth of above 1000 m, which makes it difficult to lower the drill string. Rotary run in hole process can reduce the axial force of the drill string. When the

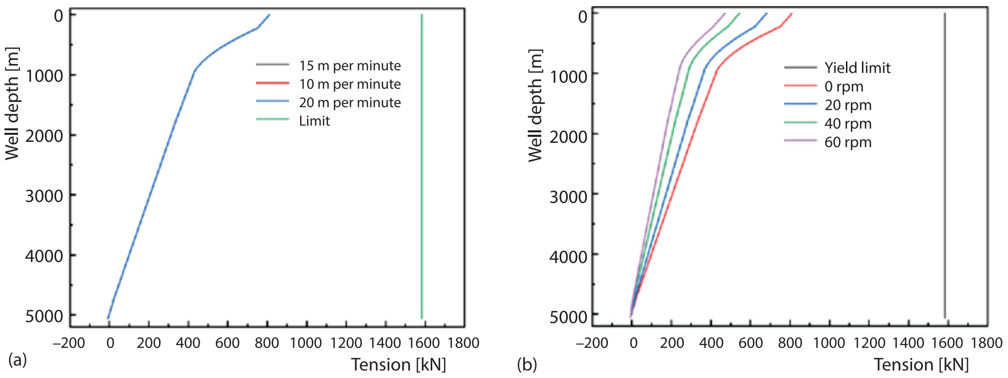

Figure 6. Influence of RPM in put out of hole; (a) put out of hole and (b) RPM

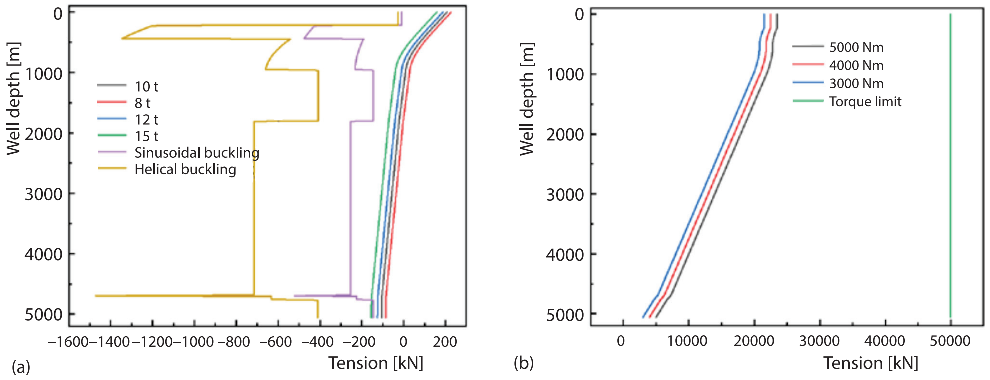

Figure 7. Drilling; (a) WOB and (b) torque

RPM is greater than 40, the drill string will not buckle. In the drilling condition, when sliding drilling is used, the string will not buckle when the WOB is reduced to 3 tonne and below, while drilling with WOB of 3 tonne will greatly affect the efficiency. When the compound drilling is used, the sinusoidal buckling occurs when the drilling pressure is greater than 15 tonne. In general, when using compound drilling, the design drilling pressure can be increased from 8-12 tonne, which cannot only improve drilling efficiency, but also avoid buckling.

Conclusion

Based on the beam equation, buckling differential equation and energy method, the local mechanical behavior of drill string under the influence of wellbore geometry, boundary conditions and joints is established. Rotary run-in hole process can reduce the axial force of the drill string. In general, the use of compound drilling cannot only improve the drilling efficiency, but also avoid the buckling. When the RPM is greater than 40, the buckling can be avoided. In the drilling condition, when the compound drilling is used, the sinusoidal buckling will occur when WOB exceeds 12 tonne.

Nomenclature

E – elastic modulus, [Nm^{-2}]
F_e – axial force, [N]
I – moment of inertia, [m^4]
k – wellbore curvature, [m^{-1}]
M_t – torque, [Nm]
r_o – radius of drill string, [m]

t_z – unit tangent vector
w_c – contact force, [Nm^{-1}]
w_{br} – additional contact force, [Nm^{-1}]
w_c – contact force, [Nm^{-1}]
w_{bp} – buoyancy weight, [Nm^{-1}]

Greek symbols

μ_d – axial friction coefficient
μ_t – circumferential friction coefficient

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