# ASPECTS CONCERNING THE BEHAVIOUR OF DRILL STRINGS ON VERTICAL AND DEVIED WELL

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**Abstract:** *The paper presents an analysis of critical buckling forces and critical lengths for drilling wells and weight on bit. Buckling leads to increased frictional forces and rotational moments as a result of the contact pressures of the drilling string with the walls of the well holes.*

**Key words:** *vertical well, tilt, drill string, buckling, push on the sole.*

## 1. Introduction

The drill string is a tubular material that connects the installation's surface and the drilling rig. For a vertical well, the classic string consists of drill rods, intermediate rods and a drill collar.

Pressing on the drill bit is done by the weight of the drill collar, which is in a compression state on a small portion/surface (Fig. 1). The tendency of deviation of the vertical well is reduced (Fig. 1a).

In the case of inclined wells, the heavy stumps/rods rest against the wall of the wellbore and some of its own weight is transported to the holes. At the horizontal well, pressing on the holes is done by placing the drill collar and some of the intermediate ones in a small, even vertical area (Figure 1b).

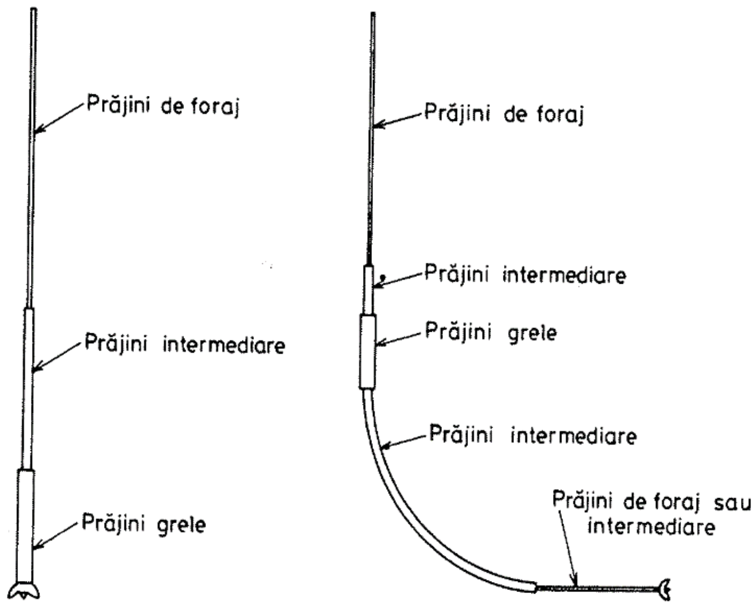


**Fig. 1.** *Composition of the drill string [3]*

Weight on bit is done by means of normal rods that bear large compression loads. Sometimes the drill collar may be missing, so that the whole depth assembly can be made up of intermediate rods that allow high deviation intensities.

## 2. The behavior of drilling strings inside wells

The phenomenon appearing in vertical, inclined or horizontal well is called buckling.

Buckling occurs as a result of loss of the drill string's stability and due to the well's curvature. The buckling is determined by the action of the rods' own weight, the centrifugal forces occurring during rotation, the internal pressure and the flow rate of the drilling fluid within the string. Under the action of the weight left on the sole, the rods begin to lose their stability and move from a right shape to a curved shape. The higher the push on the spline, the

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more critical buckling pressure can be overcome and a loop with a support point on the T1 well wall takes shape. If pressing continues to grow, the drill collar forms the second loop by making two support points: T1 and T2.

In the same way, the third loop and the support points T1, T2 and T3 can also appear. (Fig. 2).

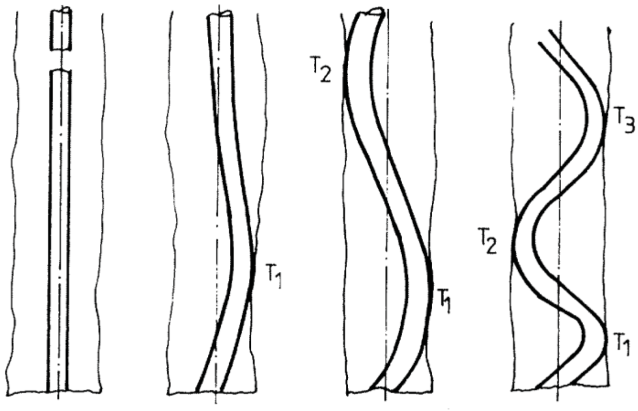


**Fig. 2.** *The buckling of drill collar [3].*
*a. straight form; b. a loop; c. two loops; d. three loops.*

In a vertical well, after the loss of stability, the drill string can take a helical shape.

The critical force of Loss of Stability after Timoshenko is:

$$F_{cr} = 2{,}65\sqrt[3]{EI\, f^2 q^2 g^2} \qquad (1)$$

where: $E$ is the modulus of longitudinal elasticity of the rods' material;

$I$ – the axial inertia module;

$f$ – the buoyancy factor;

$$f = 1 - \frac{\rho_f}{\rho_0} \qquad (1.1)$$

$g$ – the gravitational acceleration;

q – is the mass per linear meter of the rods.

$\rho_f$ – drilling fluid density;

$\rho_0$ – steel density.

The critical length of buckling for drill collar under its own weight can be calculated using the following formula:

$$l_{cr} = 2{,}65\sqrt[3]{\frac{EI}{qfg}} \qquad (2)$$

In the case of inclined and horizontal well, the rods buckle sinusoidally at the beginning and then they take a helical shape. The critical force at which the drill string loses its stability in a steep well with constant angle of inclination is:

$$F_{cr} = 2\sqrt{\frac{EI\, f\, q\, g \sin\alpha}{j_r}} \qquad (3)$$

where: $j_r$ – is the radial play between the well and the rods:

$$j_r = \frac{D_s - D_p}{2} \qquad (3.1)$$

$D_s$ – diameter of the drill bit

$D_p$ – the rods' diameter

$\alpha$ – the angle of inclination or the inclination of the well

The critical buckling length of the constant slope well is:

$$l_{cr} = \frac{F_{cr}}{q\, g\, f} \qquad (4)$$

In sloping well with a rising angle of inclination, the critical buckling force is:

$$F_{cr} = \frac{2\,EI}{R\ j_r}\left[\,1 + \sqrt{1 + \frac{R^2 j_r\ f\ q\ g \sin\alpha}{EI}}\right. \qquad (5)$$

where: $\alpha$ – is the medium inclination angle;

$R$ – is the radius of the curvature of the well;

$$R = \frac{180^0}{\pi\ i} \qquad (5.1)$$

$i$ – is the deviation's intensity.

În During the process of turning of the drill string, buckling occurs due to centrifugal forces. Over a certain speed value, the drill string takes the form of a propeller with step h after Lubinski:

$$h = \pi\sqrt{\frac{8\,E\,I}{F_z}} \qquad (6)$$

where $F_z$ is the axial force.

The bending moment, $M_{inc}$ in a section of the spiral string (Figure 3) is:

$$M_{inc} = \frac{E\, I_0}{R_e} \qquad (7)$$

where: $R_e$ – is the radius of curvature of the propeller;

$$R_e = \frac{1}{c_e}$$

$c_e$ – the curve of the propeller.

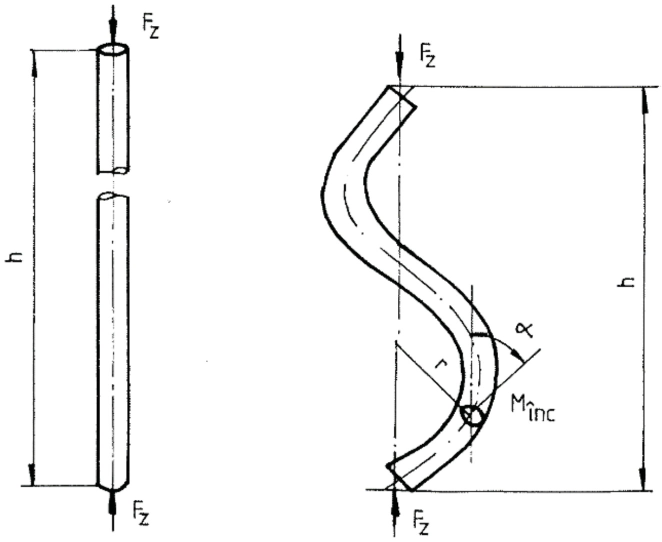


**Fig. 3.** *Compressed area in the form of a spiral*

## 3. Weight on drill bit

In the case of vertical wells, pressure on the screed is a reaction force of the well's foot and it is determined by the weight of the drill collar at the bottom of the drill string.

Thus, practically 70-80% of the weight of the drill collar provides the pressure on the screed.

It is an important mechanical parameter of the drilling regime that can be calculated with the following formula:

$$G_s = \frac{1}{c_s}\, l_g\, q_g\, g\, f \tag{8}$$

where: $c_s$ is the safety coefficient;

$l_g$ – is the length of the drill collar;

$q_g$ – is the mass per linear meter of the drill collar.

In sloping well with a profile like the one shown in Figure 4, with three intervals: one vertical, one curvilinear and one inclined straight, with a routing assembly located above the scaffold, the weight on bit can be calculated as follows [2]:

$$G_s = F_{es} + G_c' \tag{9}$$

where: $G_c'$ - is the weight of the assembly that creates pressure on the bit submerged in the mud. Rods do not buckle if:

$$G_s \leq F_{cr} + l_a\, q_a\, f\, g \cos\alpha \tag{10}$$

where: $l_a$ is the length of the deviation assembly;

$q_a$ the mass per linear meter of the assembly.

When replacing the critical buckling force with formula (3) results are as follows:

$$G_s = 2\sqrt{\frac{EI\, f\, q\, g \sin\alpha}{j_r}} + l_a q_a f\, g \cos\alpha \tag{11}$$

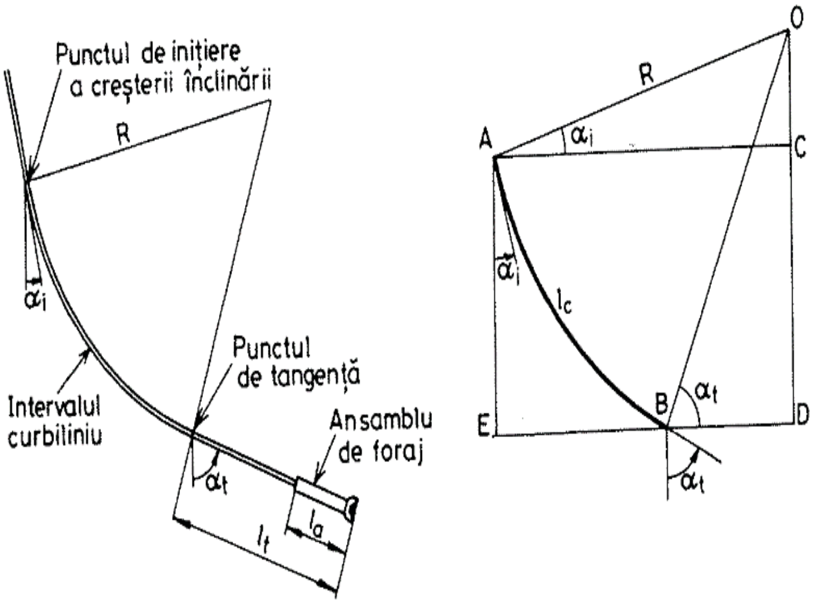


**Fig. 4** *The profile of an inclined well [3]*

In order to avoid buckling of the rods above the curvature range:

$$G_s = f \cdot q_p \cdot g \frac{\sin\alpha}{c} + f \cdot g\left[\left(l_t - l_a\right)q_p + l_a \cdot q_a\right]\cos\alpha \qquad (12)$$

where: $l_t$ is the length of the sloping range;

$c$ – the bend of the well: $c = \frac{1}{R}$

$R$ – is the radius of well's curvature.

## 4. Calculation of buckling forces and lengths and lengths

Buckling forces and lengths and pressure on the drill bit are determined for the following types of well:

a. Vertical well;

b. Slope well with tilt angle $\alpha = 60^0$;

c. Increasing inclination well with deviation intensity $i = 1^0/10\,m$.

Table 1 presents the initial calculation data and the results obtained.

## 5. Conclusions

- The rods located at the bottom of the drill string are in compression and some of them can buckle.
- Problems that may arise may lead to increase friction forces and increase rotational moments due to high contact pressures with the well's walls. Dangerous bending stresses may occur.
- With vertical wells, the forces and critical buckling lengths are lower than in the case of inclined wells. The tapping on the vertical wells depends on the weight of the drill collar, and with inclined wells it is influenced by the critical buckling force.

**Table 1.** *Initial data and results obtained*

| | | |
|---|---|---|
| Vertical well | Initial data | External diameter of drill pipes, $D_p = 5\ 1/2\ in$ |
| | | Thickness of wall of drill pipes, $t = 9{,}17\ mm$ |
| | | The unitary mass of the drill pipes, $q_p = 32{,}59\ kg/m$ |
| | | The length of drill collars, $l_g = 150\ m$ |
| | | External diameter of drill collars, $D_g = 8\ in$ |
| | | The unitary mass of the drill collars, $q_g = 223{,}10\ kg/m$ |
| | | Density of the drilling mud, $\rho_f = 1300\ kg/m^3$ |
| | | Safety factor, $c_s = 1{,}50$ |
| | The results obtained | Critical buckling force, $F_{cr} = 13{,}086\ kN$ |
| | | The critical length of buckling, $l_{cr} = 48{,}550\ m$ |
| | | Weight on drill bit, $G_s = 184{,}499\ kN$ |
| Slope well | Initial data | Angle of slope, $\alpha = 60^0$ |
| | | The length of the deviation assembly, $l_a = 30\ m$ |
| | | The unitary mass of the deviation assembly, $q_a = 133 kg/m$ |
| | | Length of the inclined interval, $l_t = 500\ m$ |
| | | The diameter of the drill bit, $D_s = 295\ mm$ |
| | The results obtained | Critical buckling force, $F_{cr} = 141{,}186\ kN$ |
| | | The critical length of buckling, $l_{cr} = 523{,}850\ m$ |
| | | Weight on drill bit, $G_s = 184{,}499\ kN$ |
| Increasing inclination well | Initial data | Deviation intensity, $i = 1^0/10\ m$ |
| | | Angle of slope, $\alpha = 60^0$ |
| | The results obtained | Critical buckling force, $F_{cr} = 13{,}086\ kN$ |
| | | The critical length of buckling, $l_{cr} = 48{,}550\ m$ |
| | | Weight on drill bit, $G_s = 184{,}499\ kN$ |

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