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# A New Buckling Model Successfully Validated with Full-Scale Buckling Tests

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## Abstract

Buckling of tubulars inside wellbores has been the subject of many researches and articles in the past. An increasing number of observations in the field suggest that existing buckling theories have to be challenged, as they fail to predict the buckling phenomenon, such as lockup. Indeed, existing buckling theories assume generally that the wellbore is idealistically perfect without any dog legs. Recent advancements in drillstring mechanics modelling have demonstrated that dog legs, friction and rotation greatly affect the buckling phenomenon. For the first time, this paper compares results of full-scale buckling tests with a new buckling model that takes into account the actual tortuosity of the wellbore.

Full-scale buckling tests have been performed in a 2000 m depth well in testing two (2) different drill string configurations. Various weights on bit have been applied for buckling drill pipe in the wellbore, and then a high accuracy continuous gyroscope has been run into the drill pipe to estimate its deformed geometry. This paper shows for each drill string and weight on bit experimental and theoretical results in terms of weight transfer (lockup prediction) and buckling state (sinusoidal or helical). Although existing models failed to predict observed buckling behaviour, the new buckling model has given excellent predictions for each full-scale buckling test performed, not only in terms of deformed buckling shape, but also in terms of weight transfer.

This paper shows for the first time to the drilling industry that a new buckling model has been derived and successfully validated in the field. This model has proved its ability to realistically predict the onset and severity of buckling in any kind of 3D trajectory.

## Buckling theories

Buckling occurs when the compressive load in a tubular exceeds a critical value, beyond which the tubular is no longer stable and deforms into a sinusoidal or helical shape. The sinusoidal buckling (first mode of buckling) corresponds to a tube that snaps into a sinusoidal shape. This first mode of buckling is sometimes called lateral buckling, snaking or two-dimensional buckling. The helical buckling (second mode of buckling) corresponds to a tube that snaps into a helical shape (spiral shape).

The first work dedicated to the buckling behavior of pipes in oil well operation was initiated by Lubinski[1,2]. Since then, many theoretical works and/or experimental studies have been developed to better understand the buckling phenomenon. First theories were developed for perfect vertical wellbores without friction by Lubinski[1]. Then, the buckling behavior of drill pipes in inclined wellbores was first proposed by Dawson & Paslay[3], based on earlier work by Paslay & Bogy[4]. The authors came to the following known critical buckling load for sinusoidal mode:

$$F_{sin} = 2\sqrt{\frac{EI\,\omega\, sin(Inc)}{r}} \quad (1)$$

where EI is pipe stiffness, ω is the buoyed linear weight of the pipe, Inc is the wellbore inclination and r is the radial clearance between the pipe and the wellbore. The critical force given by Eq. (1) is considered by the authors as the onset of buckling in an inclined hole, and is widely used in the drilling industry.

Although there seems to be a general consensus for the onset of buckling (sinusoidal mode) in a perfect wellbore geometry, there is some controversy regarding the solution for the critical helical buckling load[5,6]. Indeed, the equation for critical helical buckling in a straight deviated wellbore is given by:

$$F_{hel} = \lambda \sqrt{\frac{EI\omega \sin(Inc)}{r}} \quad (2)$$

where λ varies from 2.83 to 5.65 depending on the authors[5,6] and different assumptions taken into account. In conducting laboratory experiments and numerical analysis in a perfect horizontal well without rotation, Menand et al[7] and Thikonov et al[8] found similar results about the relationship between λ number and the deformed shape of the drill pipes: λ close to 2.83 enables to predict the onset of the first helix, and λ close to 5.65 enables to predict the full helical drillstring deformation in a perfect wellbore geometry (without rotation).