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## Safely Exceeding Buckling Loads in Long Horizontal Wells: Case Study in Shale Plays

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### Abstract

Drilling operations face several limits that intensify uncertainty and risks. Due to the deeper or/and longer wells, drilling equipment is pushed to its mechanical and endurance limits. The general industry perception is that when drill strings or casing strings exceeding conventional helical buckling criteria, they cannot be operated safely in the hole as the risk of failure or lock-up is too high. However, some theoretical, experimental, and field case studies have shown that tubular may be run in the hole even in a buckling state, within safe limits. This paper shows a case study in long horizontal wells for which helical buckling load has been exceeded without compromising the success of the operations.

Drilling data from Bakken field in North Dakota have been gathered, analyzed and compared to an advanced drill string mechanics model that enables simultaneous calculation of torque, drag, and buckling. A strong focus has been placed on the comparison between conventional buckling criteria and drill pipe or tubular bending stresses. Field results supported by drill string modeling suggest that the helical buckling load has been exceeded during operation at some locations along the drill string during slide drilling and liner running but with bending stresses at an acceptable level. However, in rotary drilling, buckling should be avoided because it will create high vibrations. In this case study, the effect of drill string dynamics is not considered.

### Introduction

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 (constrained buckling). It is worth noting that these two special shapes are a particular case for a given situation. Depending on the hole geometry, the shape of the buckled drill strings may take different forms (Menand et al. 2009; Menand et al. 2008; Menand et al. 2011). The sinusoidal buckling (first mode of buckling) corresponds to a tube that snaps into a sinusoidal shape and 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). Lubinski initiated the first work dedicated to the buckling behavior of pipes in oil well operation (Lubinski 1950; Lubinski 1961). Since then, many theoretical works and/or experimental studies (see all references) have been developed to better understand and model the buckling phenomenon and to take into account the effects due to wellbore geometry, dog leg severity, torque/torsion, tool-joint, friction, and rotation. The standard equation used to predict the occurrence of helical buckling in a straight deviated wellbore is given by:

$$F_{hel} = \lambda \sqrt{\frac{EI\omega \sin(Inc)}{r}} \dots\dots\dots \text{Eq. (1)}$$

The  $\lambda$  number varies from 2.83 to 5.65 depending on the author and on the different assumptions made. In conducting laboratory experiments and numerical analyses in a perfect horizontal well without rotation, Menand et al (2006) and Thikonov et al (2006) found similar results on the relationship between  $\lambda$  and the deformed shape of the drill pipes:  $\lambda$  close to 2.83 predicts the onset of the first helix, and  $\lambda$  close to 5.65 predicts the full helical drill string deformation in a perfect wellbore geometry (without rotation).