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Dynamic Buckling and Snaking Motion of Rotating Drilling Pipe in a Horizontal Well

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Abstract

This paper is focused theoretical and experimental study on the dynamic buckling and the snaking motion of rotating pipe in a horizontal well. Firstly, a comprehensive dynamic buckling model, a group of fourth order non-linear partial differential equations were derived and discussed. Then, a perturbation solution of the model was obtained, which represents the snaking motion of the rotating pipe. Based the perturbation solution, critical dynamic buckling load and dynamic behavior of rotating pipe were analyzed. It has been found that there are two different kinds of snaking motion. One type is that the pipe moves up and down around its static buckling configuration. The other is that the pipe moves from one to another side of wellbore.

The authors also conducted experimental study with a small scale experimental facility. Depending upon axial compressive load and rotating speed, different motion patterns of drilling pipe were observed. Measurements of axial load at both ends and axial displacement at the loaded-end are recorded. Theses observations and measurements provide us with very important information about the dynamic behavior of rotating pipe in a horizontal well. Observations also show that the pipe may take two different patterns of snaking motions. Both critical static buckling load and dynamic buckling load were measured with this facility. Both theoretical and experimental results showed that the pipe rotation does not affect the critical load of sinusoidal static buckling and snaking dynamic buckling. Experiment also showed that there exist two different snaking motions, which support the analytical solution of the dynamic model presented in this paper. The results are useful for practical design applications related to calculating buckling loads, selection of BHA elements and pipe rotational speeds.

Introduction

Drilling pipe is used to transfer torque and motion from the kelly to the bit, and convey drilling fluid. While drilling the drillpipe is subjected to the combined action of axial and lateral loads, torque, pressure, frictional and viscous drags, and its motion is constrained by the wall of the wellbore. Due to the nature of the drilling process, most of these loads are dynamic loads. They excite axial, lateral, and torsional vibrations. Under some critical conditions, the drill pipe may lose its stability, and develops into very complicated snaking and whirling motions, which in turn may result in serious problems such as fatigue damage of pipe, excessive wear of downhole tools, failure of MWD, excessive drill bit wear, bit bounce and stick-slip motion, wellbore instability and washout, and inefficiency of drilling, etc. So, understanding the mechanisms of dynamic stability and dynamic post-buckling behavior of rotating drilling pipe in a horizontal well is crucially important for successful drilling. However, there are only few papers that attempt to address the above mentioned issues.

Static stability and post-buckling behavior of pipe in vertical, inclined, horizontal and curved wellbores have been investigated by different authors. Lubinski, A., et al. (1950, 1962) studied the stability and helical buckling of tubing in vertical wells. Later, Paslay, P.R., et al. (1964) and Dawson, R. and Paslay, P.R. (1984) studied the stability and sinusoidal buckling of tubing constrained in an inclined borehole. Chen, Y., et al. (1990) investigated helical buckling of pipe in a horizontal well. Mitchell, R.F. presented a group of fourth order non-linear differential equations that describe the post-buckling behavior of tubing in inclined wells (Mitchell, R.F., 1988), and analyzed the post-buckling behaviors (Mitchell, R.F., 1997, 1999, 2002, 2006). Kyllingstad, A. (1995) investigated buckling of tubing constrained in a 3D curved well with energy method. Gao (1996a) derived a general buckling equations of pipe constrained in 3D curved wells, which can be simplified as the same buckling equations proposed by Mitchell, R.F. (1988) under the condition of zero curvature of wellbore trajectory. Gao obtained perturbation solution of the buckling equation, derived the critical loads, investigated effects of boundary conditions (Gao, G., 1995, 1996a), effects of curvature (Gao, G., 1996a, 1996b), and lock-up conditions (Zhang, F., Gao, G., et al. 2000). Miska, S., et al. (Miska, S. and Cunha, J.C., 1995, Miska, S., et al., 1996, Qiu, W., et al.,