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Dynamic FEA Models for Snubbing Buckling and Riserless Subsea Wireline Intervention

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Abstract

A dynamic finite element analysis (FEA) calculation engine has been developed and is being used to solve specialized well intervention problems. This paper summarizes the theory used in this engine, and documents two of its applications. The first application is modeling the buckling behavior of pipe (or a bottom hole assembly) being snubbed through a packer. The second application is wireline being run from a boat to a subsea well to perform an intervention. The first step in this intervention is to jar the plug out of the tree.

Introduction

A dynamic FEA engine has been developed for modeling several well drilling and intervention situations. The initial model is for analyzing pipe in a wellbore, discussed in reference 1. The second model is for analyzing well intervention stack stability and stresses, discussed in reference 2. This paper discusses two additional applications which use variations of the same FEA modeling capability. As this powerful calculation technique is refined and applied, many more complicated well drilling and intervention models can be developed.

The theory for this FEA engine has already been discussed in references 1 and 2. The major addition to the theory discussed in this paper involves buckling of a pipe and the large displacements needed to model the behavior of wireline in the ocean between the boat and the subsea well.

When pipe, or a bottom-hole assembly (BHA), is being snubbed into a well, large compressive forces are applied to push it through the packer into the well. These forces often cause the pip to buckle in the surface equipment. Buckling guides are often used to support the buckled pipe, to prevent excessive bending. Failures have occurred, especially when snubbing packers into a well. A modeling tool was developed which calculates the maximum bending and stress in each component of the pipe of BHA.

Intervening in subsea wells from a boat is much less expensive than using a rig to perform the intervention. There are many questions about how the wireline will behave with the ocean currents, especially when performing an operation which requires precise force/displacement control such as operating jars. The current causes a significant lateral displacement of the wireline as it passes through the water. If there is a sudden change in tension of the wireline at surface, will the tension be translated through the wireline to the well, or will the motion of the wireline and its shape in the water absorb the change in tension? Will the operator on the boat be able to determine from his surface tension indicator when the jars have fired, when the plug has released, etc? How should the depth measurement be corrected for the lateral displacement of the wireline in the water? If the boat is moving up and down, how much will the wireline tools move up and down in the well? A modeling tool was developed to answer these types of questions.

Theory

Reference 1 describes the FEA theory used by this calculation engine for a static analysis. Reference 2 shows how this theory is used along with a finite-difference (FD) scheme in time. The FEA model is run for each time step with the dynamic forces included, forming a dynamic model.

Buckling Theory

For the snubbing buckling case, the pipe or BHA starts in a straight vertical position, centered in the lubricator/BOP or other stack structure. A pipe can buckle in such a structure in an infinite number of positions. The helix can be in either direction, the buckling can begin an any rotational position around the structure, etc. This causes a static FEA analysis of pipe buckling to be unstable. However, if a static analysis of the pipe is performed before the compressive load is applies, and then the dynamic analysis is performed while the pipe buckles, the calculation remains stable.

A small destabilizing force must be added to the pipe for the first time step to push it slightly out of line. This destabilizing force is applied at each node along the length of the pipe. The direction at each node is varied helically at a user specified period along the length of the pipe. This destabilizing force determines the configuration of the pipe as it buckles and thus the final buckled solution. Fortunately, the stresses in the buckled pipe tend to be very similar, no matter which buckled solution is reached.

Large Displacement Theory

Figure 1 shows a single beam element with 6 degrees of freedom (DOF) at each node. There are 3 translational DOF along the 3 axis of the local coordinate system, and 3 rotational DOF around each axis of the local coordinate system. Multiple elements are combined as discussed in reference 1 shown in Figure 2 to form the desired structure. In the case of subsea wireline modeling, the wireline is initially assumed to be perfectly vertical in the global coordinate system, as shown in Figure 2. Lateral sea currents cause the wireline to actually be at a significantly different location. Beam elements work fine with large translational displacements, but rotational displacements about the Y and Z axis change the orientation of the stiffness of the element. In this application, the element may be rotated by some significant angle, α. A wireline segment has significant strength in the local x direction when it is oriented along the length of the segment, and almost no strength in the local y and z directions. If the segment is rotated about the y and/or z axis the stiffness in the x direction is no longer accurate.

To handle this problem it is necessary to rotate the local coordinate system from its original position to the new position. Since the wireline will be moving laterally during the dynamic simulation, the local coordinate system is moved after each time step. For purposes of discussion consider the situation shown in Figure 2 with the wireline at one position at time t and moving to another position at time t+Δt. The global displacements, U, for this time step are shown for the X and Y directions. The following points summarize the steps used to perform the coordinate system transformation:

- The sum of all of the global displacements for all the time steps must be stored. U_g is the sum of the global displacements for all time steps. U_t is the global displacements from time t to time t+ Δt.

$$\overline{U}_{g(t+\Delta t)} = \overline{U}_{g(t)} + \overline{U}_t \quad (1.1)$$

- The inclination angle, α and azimuth angle, γ, for the new local coordinate system location is calculated:

$$\alpha_{t+\Delta t} = \tan^{-1}\left[\frac{\sqrt{\Delta y^2 + \Delta z^2}}{L_{x_{t+\Delta t}}}\right] \quad (1.2)$$

where:

$$L_{x_{t+\Delta t}} = L_o + U_{gx_{i+1}} - U_{gx_i} \quad (1.3)$$

$$\Delta y = U_{gy_{i+1}} - U_{gy_i} \quad (1.4)$$

$$\Delta z = U_{gz_{i+1}} - U_{gz_i} \quad (1.5)$$

$$L_{t+\Delta t} = \sqrt{L^2_{x_{t+\Delta t}} + \Delta y^2 + \Delta z^2} \quad (1.6)$$

$$\gamma_{t+\Delta t} = \tan^{-1}\left[\frac{\Delta z}{\Delta y}\right] \quad (1.7)$$

- Once the new values of α and γ have been calculated, a new transformation matrix T must be calculated using the equations given in reference 1.
- The length of the element in the new coordinate system will be different than the original length of the element. This can be compensated for by applying a local force within the element that would restore the element to its original length. This applied local force is:

$$R_x = \frac{\left(L_o - L_{t+\Delta t}\right)AE}{L_o} \quad (1.8)$$

- The dynamic analysis requires the local u displacements in the current local coordinate system for the last 3 time steps. The new T matrix is used to transform the last 3 Ug matrices into the current local coordinates.

Once this process is completed the FEA engine can be called for the next time step, and the process continues through the dynamic calculation.

Snubbing Buckling Example

Subsea Wireline Intervention

A well intervention was to be carried out with 0.125" slickline from a floating mono-hull vessel at a water depth of 3,500'. One of the first steps in this intervention is to jar the plug out of the subsea tree. The FEA model was used to simulate this jarring operation.

Figure 3 shows a schematic of this operation. The stroke length of the spang jars is about 30". For this example it was assumed that there is a 2 knot current in the Y direction for the upper half of the depth and a 1 knot current in the same direction for the lower half of the depth. The drag forces due to the current were added in the FEA model of the slickline. The resulting lateral displacement of the slickline is shown in Figure 4. When the slickline is held at surface with 1,076 lb of tension, the maximum lateral displacement is 106'. Note that the displacement in the upper half of the slickline is greater than in the lower half due to the higher current. In this situation there is 800 lbs of tension at the spang jars.

It was assumed the spang jars would release at a tension of 1,000 lb. A dynamic simulation was run in which the slickline was pulled upwards 30" at surface and then held at that position. Figure 5 shows the result of this simulation. It took 1.5 seconds before the bottom force at the jar reached 1,000 lbs so the jar could release. When it released, the bottom force went to zero and the jar started traveling upward. This release of tension was seen at the surface about 0.2 seconds later. The speed of sound in steel is 22,000 ft per second. Thus, we would expect it to take 0.16 seconds for the force change to travel 3,500 ft. The jar travels upward 30" and hits with its upward impact. The force imparted by this impact depends upon the stiffness of the jar and plug. In this case the stiffness was assumed to be 100,000 lb/in. The resulting impact force was about 20,000 lb.

It was assumed that the plug came free due to this impact force. The weight of the plug was added to the jar weight, and both continued to travel upward through the lubricator. During this simulation the maximum lateral travel of the slickline in the water was only about 3".

For this example, the lateral movement of the slickline in the water did not have a significant impact on the operation of the jar. The operator had a very clear indication on surface when the jar released and when it struck. The upward impact of the jar was greatly enhanced by having a release mechanism. In fact, it would be very difficult to perform this operation without a release mechanism. The ocean currents cause a tension in the slickline. If there was no release mechanism the jar would travel to the top of its stroke due to this tension, and there would be no jarring action.

Conclusions

Acknowledgement

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References

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2. Smalley, Ed, Newman, K.R.: "Modeling and Measuring Dynamic Well Intervention Stack Stress," SPE paper 94233 presented at the SPE/ICoTA Coiled Tubing Conference, The Woodlands, Texas, 12-13 April 2005

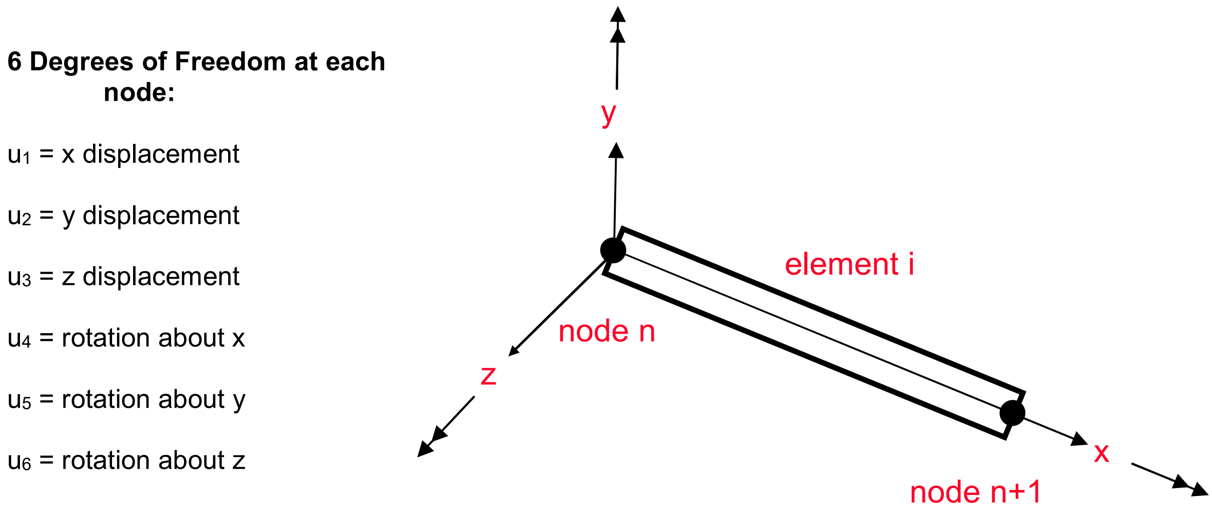

Figure 1 - Elements in a Global Coordinate System

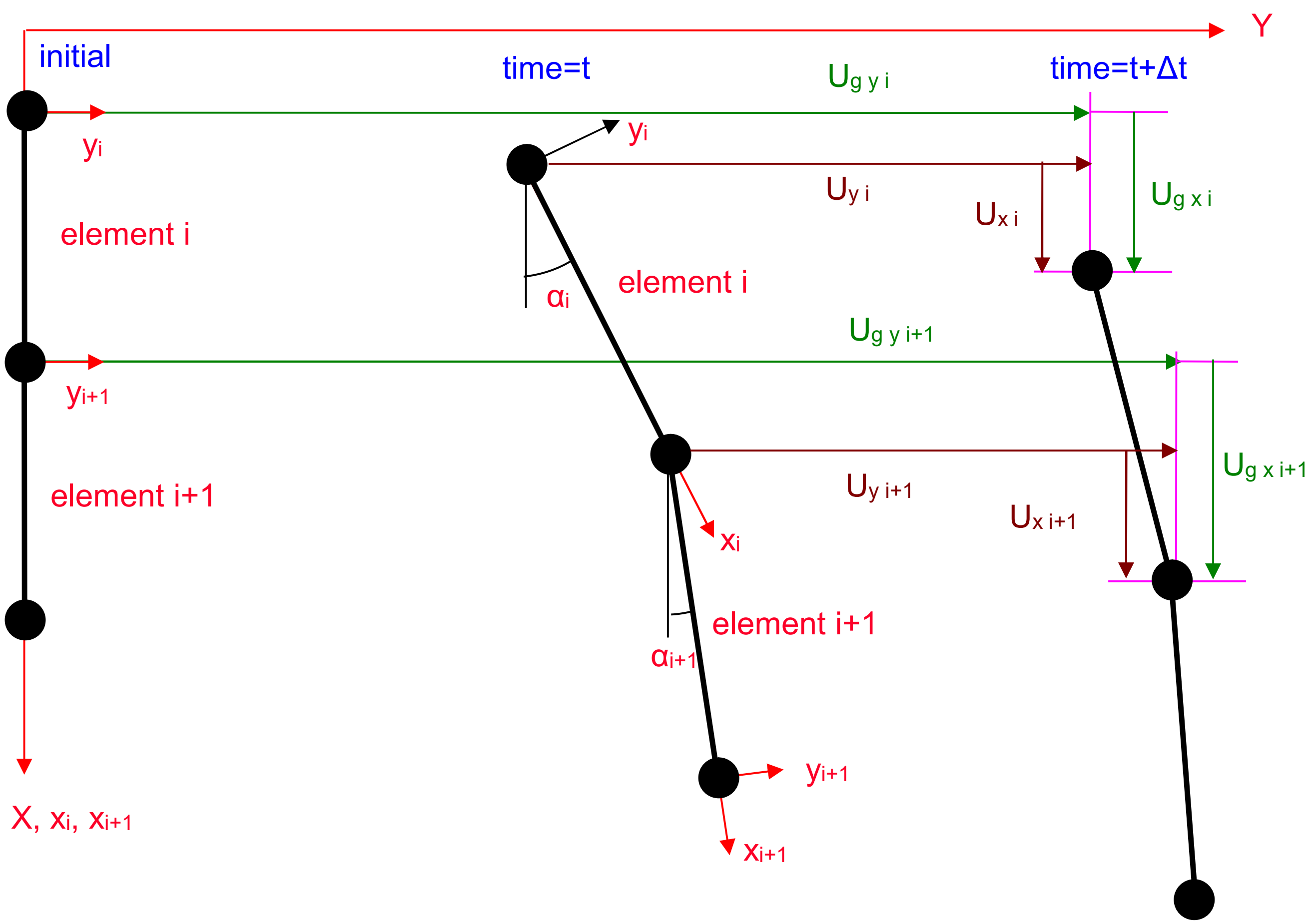

Figure 2 – Two Elements with Large Displacements

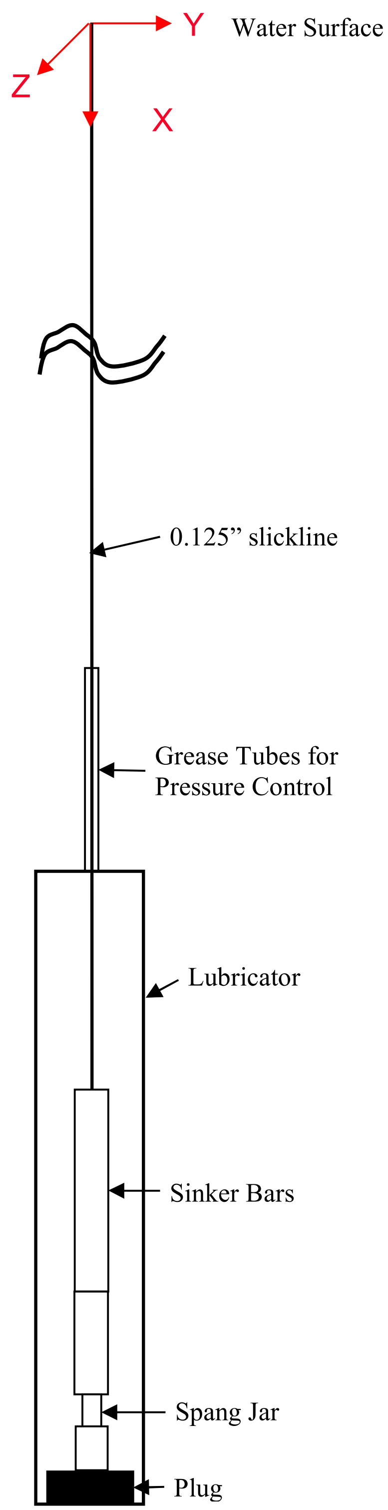

Figure 3 - Slickline Subsea Jarring Schematic

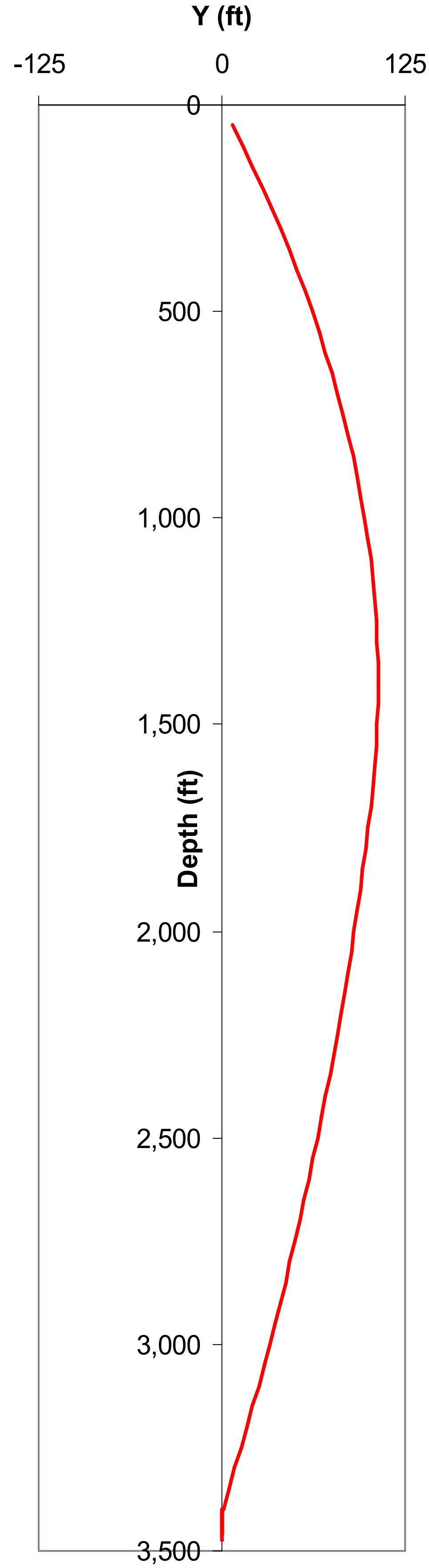

Figure 4 - Slickline Deflection due to Water Current

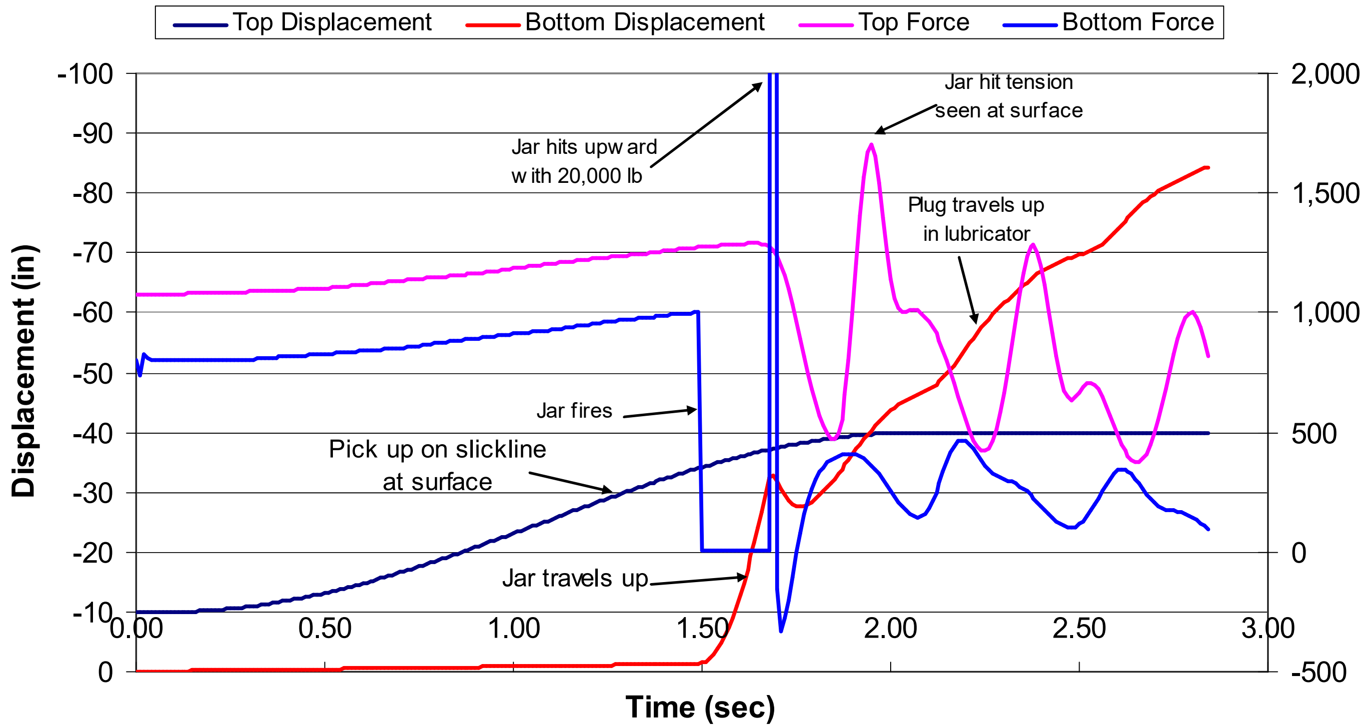

Figure 5 - Dynamic Slickline Jarring Simulation Results