

**Seabed Scour and Buried-Pipeline Deformation
Due to Ice Ridges:
Pipeline Stress and Deformation**

Quarterly Progress Report II

by

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March 27, 2012

Preface

This report summarizes our progress to date (second quarter) in the Project entitled “Seabed Scour and Buried-Pipeline Deformation Due to Ice Ridges: Pipeline Stress and Deformation.” We have continued the development and implementation of a computational procedure based on the finite element method suitable for the analysis of fluid-structure interaction problems. We have encountered difficulties that we had expected. Most of the issues have been resolved. In the third quarter, we will be working towards overcoming the remaining important challenges and improving the performance of the procedure.

The First Quarterly Progress Report highlighted the overall approach chosen in this investigation for modeling a general class of fluid-structure interaction problems. Effort was concentrated on validation and verification of the soundness and robustness of the numerical technique. During the second quarter, we have continued the development of the procedure. One of the difficulties experienced within the adopted framework was divergence of the numerical solutions late into the analysis. We succeeded in resolving this instability while retaining the order of accuracy of results. The instability was circumvented by changing the way the numerical solution is marched forward in time. The velocity vector field along a fluid-structure interface of a model is shown in Figure 1a and Figure 1b before and after the use of the modified time-stepping scheme, respectively.

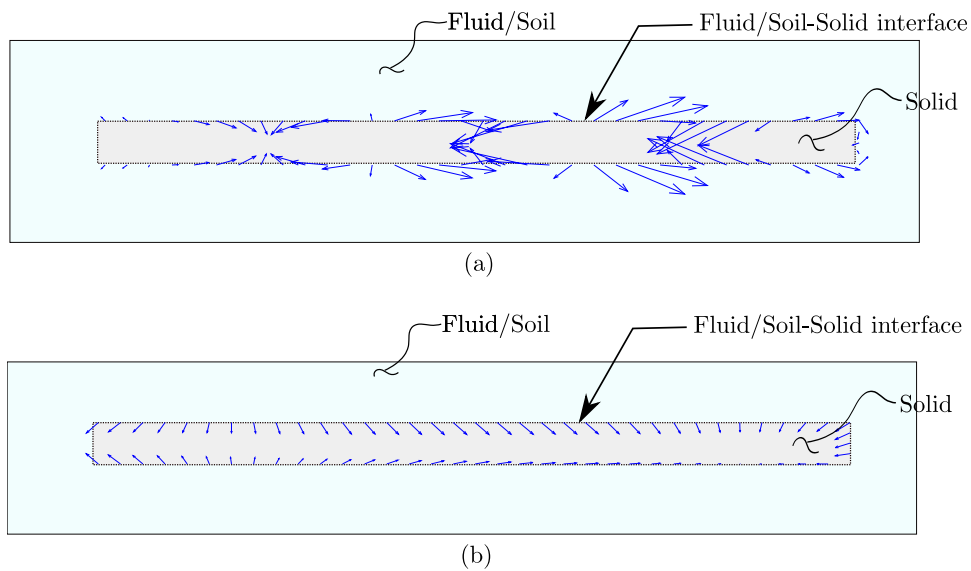


Figure 1: Instability along a fluid/soil-structure interface. Blue arrows show the velocity vector field along the interface. (a) Typical irregular velocity field at onset of instability. (b) Expected smoothly varying velocity field under the new formulation.

Results presented in the First Quarterly Progress Report had been obtained using a direct solver of the system of equations. The robustness of direct solvers makes them very attractive for smaller computational models. However, as the size of computational models becomes larger, direct solvers take a much longer time to produce results and the required computational resources can become excessive. To accommodate larger computational models, we have now incorporated iterative solvers. As

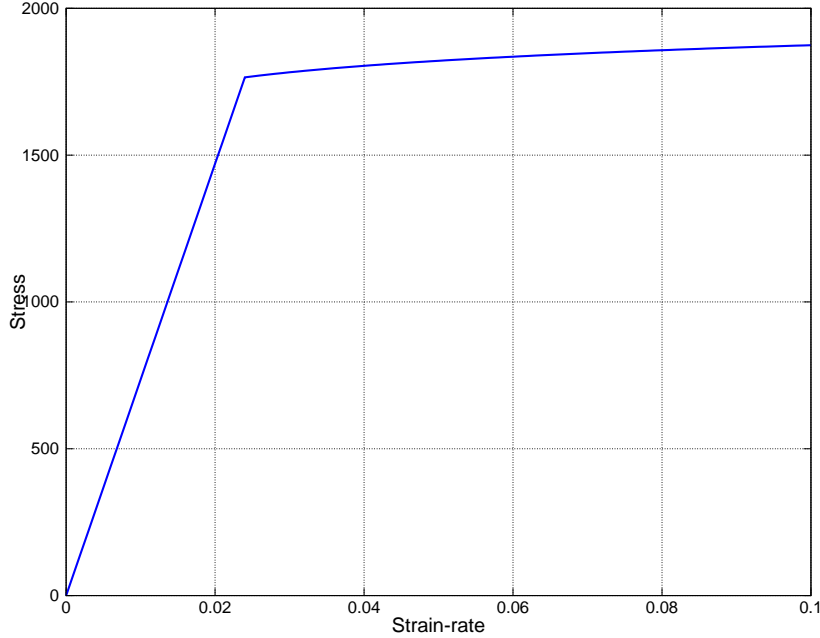


Figure 2: Herschel-Bulkley model.

an example, for a test problem in our studies involving 121,556 unknowns, a direct solver would roughly take 19.5 minutes, while an iterative scheme would reduce this requirement to about 4.5 minutes for a single time-step (with 8 nonlinear iterations).

Our approach of modeling the seabed as a viscous fluid is based on the success of previous studies in which use has been made of the representation of the soil as a Non-Newtonian Bingham fluid with shear thinning. In the present study, we are taking the same approach. More specifically, we have chosen to describe the soil using the Herschel-Bulkley model which aims to simulate the strain-rate effect in the soil correctly. A typical stress-strain rate curve for this model is shown in Figure 2. The calibration of the strain-rate effect of the model has been based on data obtained from a torpedo-anchor installation experiment [1].

In order to investigate the behavior of this material model for the soil, we have considered a sample two-dimensional sea-bed scour problem. A sketch of the system

analyzed is shown in Figure 3. The ice ridge is embedded 2 m into the seabed with an attack-angle of 15° . Starting from rest, the ice-ridge is translating laterally from left to right, gradually reaching a maximum speed of 0.5 m/s. The pipeline considered in this example is rigid and fixed in space. Figure 4 shows the profile of the mound in front of the ice-ridge after it has moved laterally by roughly 2.4 m. The corresponding distortion of the computational mesh representing the ice ridge is shown in Figure 5. Because of this distortion, the analysis was terminated at this level of lateral translation of the ice ridge. Our current efforts are focused on allowing for larger magnitudes of translations while avoiding the distortion of the computational mesh within the vicinity of the ice-ridge.

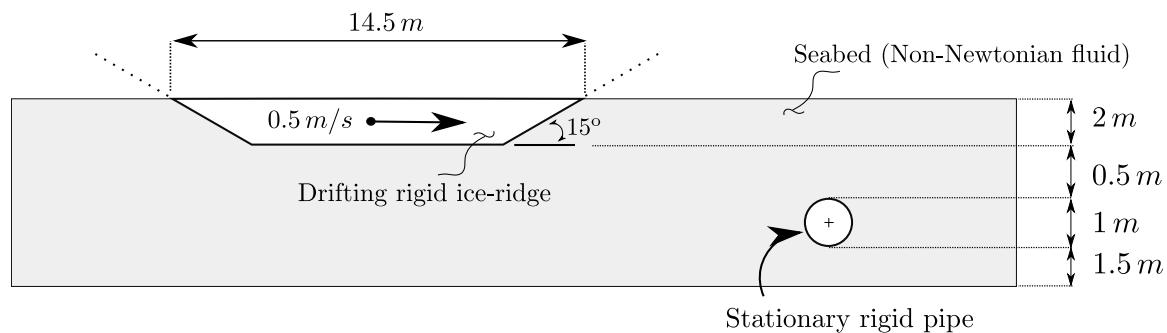


Figure 3: Test sea-bed scour problem.

References

- [1] Mohammad S. Raie and John L. Tassoulas. Installation of torpedo anchors: Numerical modeling. *Journal of Geotechnical and Geoenvironmental Engineering*, 135(12):1805–1813, 2009.

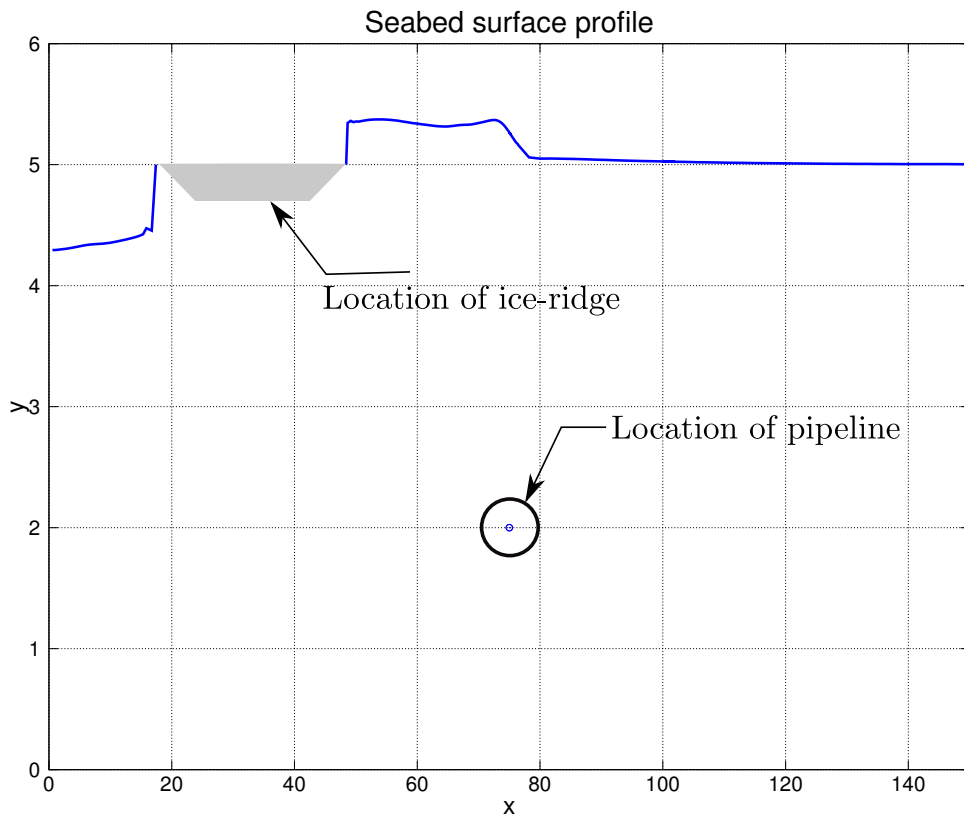


Figure 4: Profile of the sea-bed surface after lateral translation of ice-ridge.

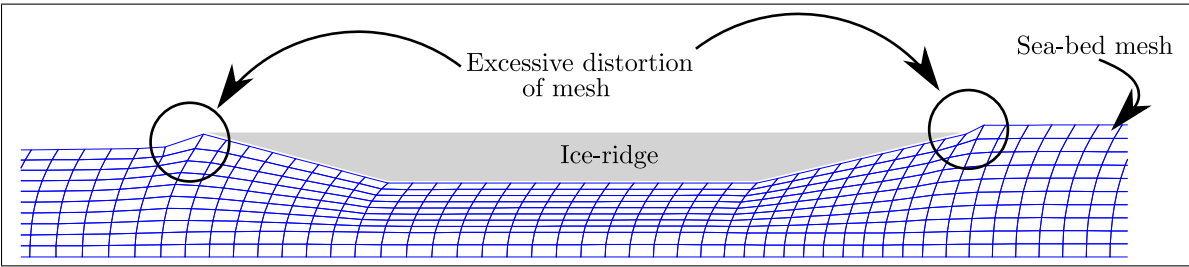


Figure 5: Mesh distortion due to translation of ice-ridge.