Modeling of Sediment Mechanics for Mine Burial Prediction

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LONG-TERM GOALS

The long-term goal of the project is to understand and model the burial of mines and similar objects into the seabed due to processes of liquefaction and mine-induced local sediment deformation.

OBJECTIVES

The specific objectives of this study are:

- Develop a finite element procedure for modeling mine burial as a time-dependent process with a focus on sub-seabed liquefaction and sediment mechanics.
- Collect necessary material parameters, including pore pressure generation characteristics under cyclic loading conditions, from planned field and laboratory tests.
- Integrate findings from this study with parallel modeling efforts underway as part of ONR's Mine Burial Program (MBP), which are exploring burial processes due to bedform migration and local scour.

APPROACH

In the finite element code under development, GEO-CP, the sediment is treated realistically as a porous material using Biot's theory, with the option of selecting among a number of constitutive models ranging from linear elasticity to Cam Clay elasto-plasticity, depending upon the type of sediment of interest. The current modeling is focusing on sub-seabed mechanics, as opposed to above-seabed sediment transport processes and scour. However, the formulation will include the capability to re-mesh the problem domain as a function of time to account for sediment deposition and erosion. The computational framework under development is based on an open architecture design, and hence as new, fully coupled models are developed they can readily be incorporated.

In addition to static and cyclic behavior, the formulation allows for the generation of excess pore pressures due to volume changes in the sediment associated with cyclic shear stress fluctuations resulting from multiple surface water waves and mine loads. The rate of pore pressure generation depends on the type of sediment and the nature of the cyclic loads. It will be determined from laboratory cyclic simple shear tests and from pore pressure generation and dissipation measurements taken during planned field experiments.

WORK COMPLETED

ONR's Mine Burial Program is an ambitious long-term program that has been initiated only recently. Since this study requires data collected from planned field experiments that have not yet taken place, our efforts so far have concentrated on development of the finite element program. We have been modifying our existing code, GEO-CP, for the purposes of this study. We are in the process of verifying the code for a number of simple cases where closed-form solutions are available, such as various 1-D consolidation and elastic deformation problems.

More recently, we have begun the analysis of seabed loading from surface water waves to investigate the generation and dissipation of excess pore pressures in a 1-D column of elastic sediment as described below.

RESULTS

As a first approach to the modeling of pore pressure generation and dissipation, which can result in a liquefied seabed, we considered a 1-D, elastic seabed that is subjected to normal loading at the sediment-water interface due to a single linear, sinusoidal water wave passing overhead (Figure 1).

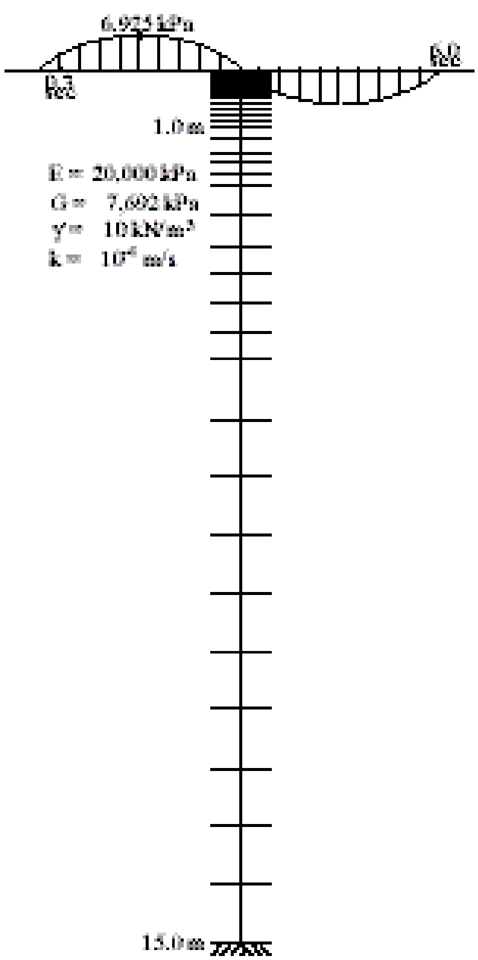

Figure 1. 1-D Finite element discretization of 15 m seabed below sinusoidal seabed pressure

The wave being considered has a period of 6.0 seconds, a wave length of 56 meters, and propagates at the sea surface in 10 meters of water. The resulting normal pressure fluctuation on the seabed has a maximum value of 6.925 kPa. Equal time increments of 0.3 seconds are used in the analysis. The soil column is 15 meters deep and has elastic constants as shown in Figure 1. A total of 40 quadrilateral elements, each with four displacement and four pore pressure nodes, were used. A finer mesh was selected near the seabed surface due to large pore pressure gradients generated during upward diffusion of pore water.

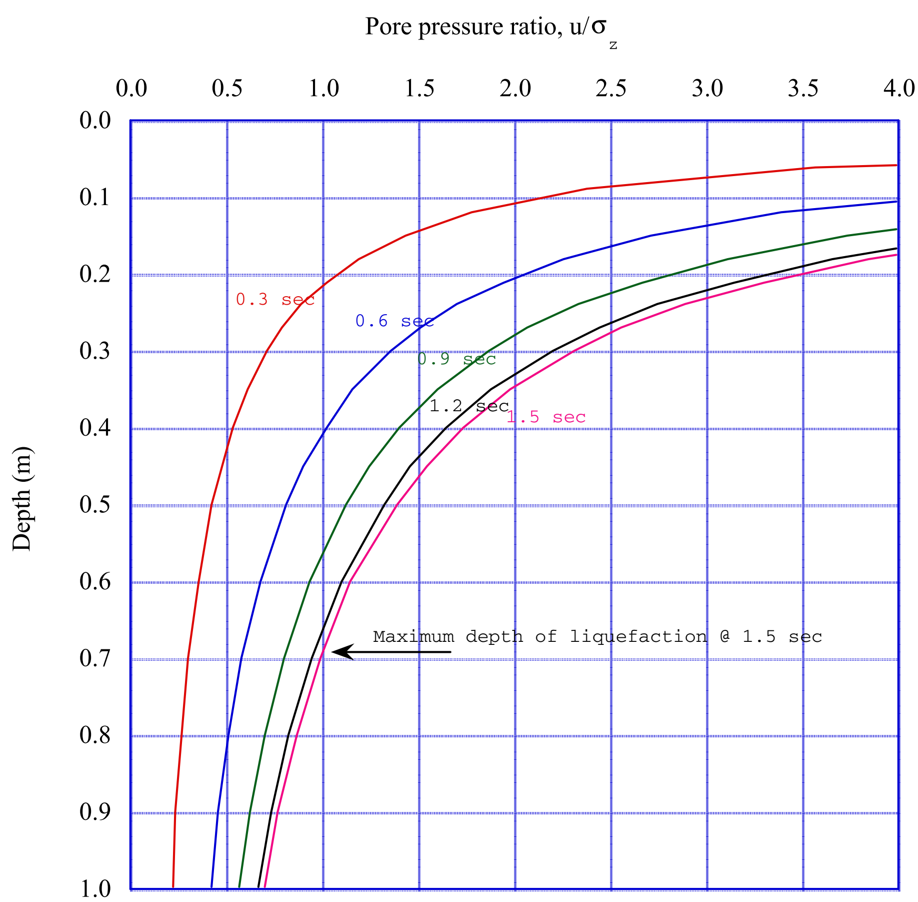

Figure 2. Undrained excess pore pressure distribution with depth [maximum excess pore pressures coincide with the crest of the wave]

The solution was carried forward in time through 2 cycles of the passing wave, i.e. for a total of 12.0 seconds. Two cases were considered: a) where undrained conditions prevail so that no diffusion can take place, and b) where pore water exchange with the overlaying water column is allowed through the seabed surface (drained condition). The results are summarized in Figures 2 and 3 in terms of the predicted pore pressure ratio, where the computed excess pore pressure is normalized by the static, no-wave vertical effective stress. Ratios larger than one indicate a liquefied state in the sense that the resulting effective stress is reduced to zero and hence the sediment is unable to support any external gravity load such as that resulting from a mine. The computed results did not vary significantly from one cycle to the next. From a liquefaction point of view, only the portion of the load cycle that results in positive (compressive) seabed stresses is of interest, since it is the only one that can lead to positive excess pore pressures and a reduced state of effective stress. In the undrained analysis, excess pore pressures rise and fall uniformly throughout the soil column by the same amount as the applied pressure, as one would expect from theory. This confirms that the code is generating accurate predictions, at least for this case. In the drained situation, where water is allowed to leave or enter the soil column through the seabed, the pore pressure ratio fluctuates near the surface due to simultaneous pore pressure generation and dissipation.

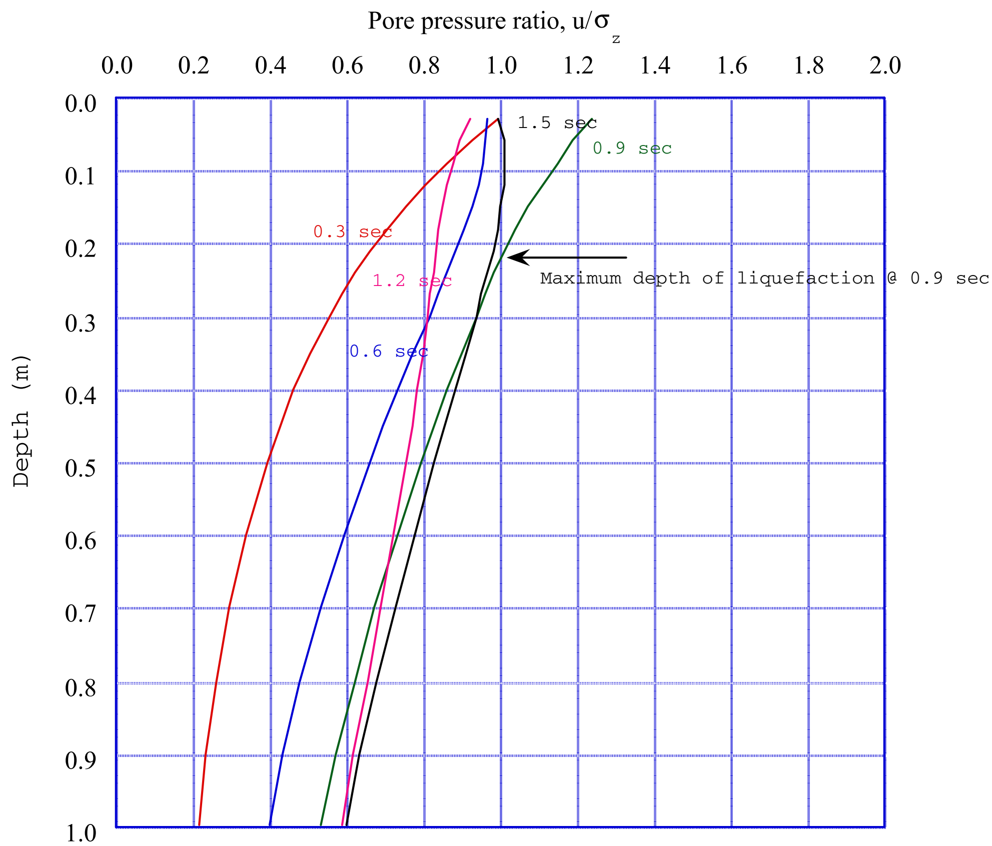

Figure 3. Drained excess pore pressure distribution with depth
[maximum excess pore pressures does not coincide with the crest of the wave]

In both cases there exists a depth below the seabed above which the effective stress is reduced to zero, resulting in a loss of bearing capacity. However, the depth of liquefaction extends deeper in the undrained case (0.70 m) than in the drained case (0.24 m).

IMPACT/APPLICATIONS

Results from this simple case clearly suggest that there may very well exist scenarios in the field where one can expect a zone below the seabed in which bearing capacity is lost due to wave-induced excess pore pressures. A mine or other object resting on such a seabed could be expected to sink under such a condition. Of course, the analysis still needs to be extended to consider 2-D effects, multiple waves, as well as other material parameters and geometries.

TRANSITIONS

The code under development will be made available to researchers of the Mine Burial Program and others. With suitable further development, it may also be useful for military decision making purposes.

RELATED PROJECTS

We intend to interact with other researchers in the Mine Burial Program as we continue to refine our modeling efforts. In particular, Dr. Scott Jenkins at Scripps has agreed to provide information on time series describing scour geometries surrounding mines, as well as hydrodynamic mine loads, which we will use as input to our program. Similarly, Dr. C. C. Mei at M.I.T. has agreed to help develop time series that describe bedform migration processes. This type of input, as well as information regarding in situ sediment properties and pore pressure characteristics, will become available as data is collected from various planned field experiments.

PUBLICATIONS

Brandes, H.G. and Riggs, H.R., FE modeling of liquefaction burial of mines due to surface water waves, 21st International Conference on Offshore Mechanics and Arctic Engineering, Oslo, Norway, June 2002 (abstract submitted 10/2001)

Brandes, H.G. and Riggs, H.R., Time and space discretization issues in modeling of seabed liquefaction due to surface water waves, 12th International Conference of Offshore and Polar Engineering, Kyoto, Japan, May 2002 (abstract submitted 9/2001).