A More Natural Model for Nonlinear Soil/Structure Interaction

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ABSTRACT

In traditional structural models of slender member structures, such as pipes, cables, moorings and guys, the interface between slender structures and soil is often represented rather incorrectly as a hard contact boundary. This paper demonstrates how a nonlinear geometric fluid representation can produce more natural and more realistic soil/structure interactions within a traditional structural simulation.

KEY WORDS: Nonlinear; structure; soil, dynamic; cable, coulomb.

INTRODUCTION

Interactions with soil can often be a very important modeling aspect for the analysis or simulation of fabricated structures. The broadest representation of such structure/soil interactions would be to model the combined structure and soil problem with a three-dimensional (3D) array of solid finite elements, each deformable in three dimensions. LS-Dyna [LSTC, 2013] is an excellent example of a modern computer program that utilizes such a broad soil/structure interaction model.

With potentially thousands of nodes representing the soil, these broad models are often numerically very large. As such, the computational burden is often out of proportion with the desired understanding of the few key structural nodes. This is particularly true for slender structures.

Focus on Slender Structures

Let’s focus on the following types of slender structures:

- Tower guy
- Tension leg tendon
- Drill string or riser
- Vessel mooring
- Marine cable
- Slender pipeline
- Tethered plow or grapple

All of these slender structures have similar overall features including a lack of globally significant bending stiffness. As such, all of these types of slender structures can be globally modeled with essentially the same generic finite element model. Fig. 1 shows this model (not to proper scale) in a straight horizontal orientation, as if the slender structure is lying flat on a straight hard soil surface.

Fig. 1. Generic finite element model for common simulation.

This generic model consists of 29 axial elements serially connected by 30 nodes. Table 1 presents the common structural parameters of the generic model that will be used for all simulations in this paper, irrespective of the type of slender structure being modeled. Depending on the type of slender structure being modeled, element one (1) can represent an anchor, a grapple, a sled, a plow or other end object.

Table 1. Structural modeling parameters for common simulation.

<table>
<thead>
<tr>
<th>Element numbers</th>
<th>Effective Diameter (mm)</th>
<th>Axial Stiffness Factor EA (N)</th>
<th>Wet Unit Weight (N/m)</th>
<th>Dry Unit Weight (N/m)</th>
<th>Element length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76</td>
<td>1.44E8</td>
<td>120</td>
<td>138</td>
<td>3</td>
</tr>
<tr>
<td>2-10</td>
<td>38</td>
<td>1.44E8</td>
<td>60</td>
<td>69</td>
<td>30</td>
</tr>
<tr>
<td>11-29</td>
<td>38</td>
<td>1.44E8</td>
<td>60</td>
<td>69</td>
<td>300</td>
</tr>
</tbody>
</table>

The number of elements and the distribution of element lengths are specifically chosen to assure good overall 3D geometric definition. In particular, the smaller elements (near element one) provide better soil/structure interaction where it will be needed the most.

In this paper, we will show that by adding a new fluid-based soil sub-model to this simple generic finite element structural model, we can easily generate complex 3D results that are not otherwise so easily obtained. In particular, we will present simulation results for two of the