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Time Domain Soil-Structure Interaction Analysis of a Buried Tank Containing Fluid
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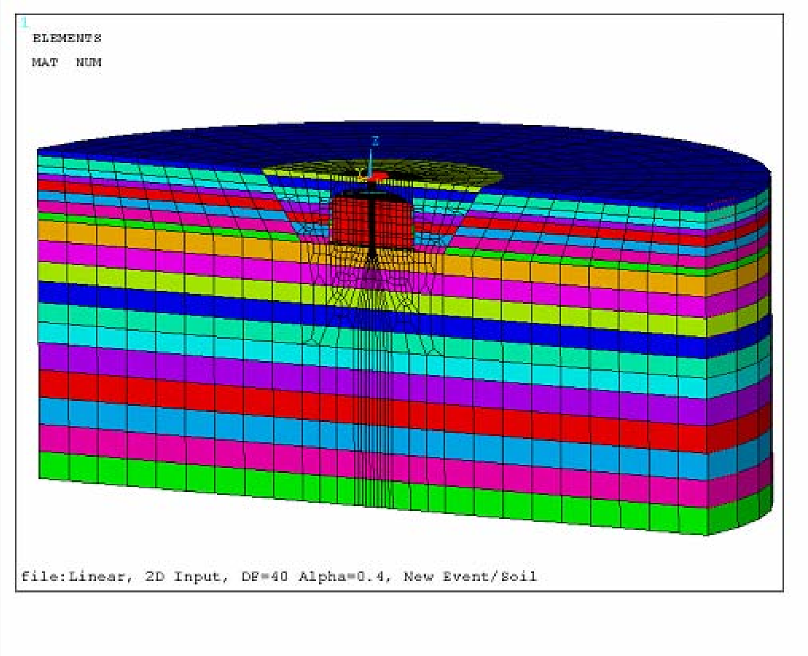
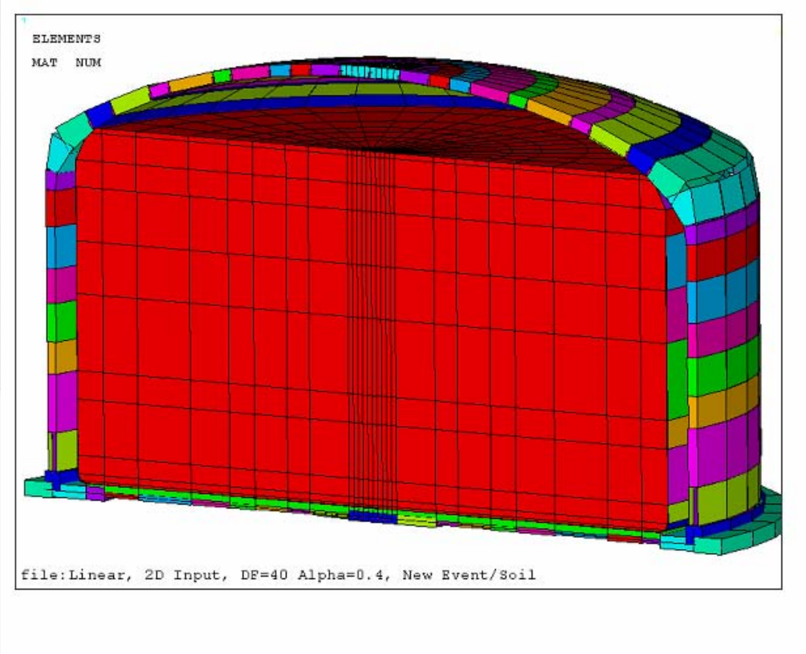
F.G. Abatt B. G. Carpenter C.A. Hendrix

M&D Professional Services, Inc., Richland, Washington

Problem Statement

- Perform a nonlinear seismic soil-structure interaction (SSI) analysis of a buried tank containing liquid.
- The analysis must account for potential sliding at several structural interfaces.
- The analysis must account for the hydrodynamic response of the liquid including the sloshing at the free surface.





Considerations

- SSI analysis is typically performed in the frequency domain, but is limited to linear response and cannot account for contact surfaces.
- Inclusion of sliding interfaces *requires* a time-domain SSI analysis.
- A complete SSI analysis will be performed in the time domain. The soil and structure will be included in a single coupled model.
- Implicit finite element codes are typically used for seismic analysis of structures, but have limited capability for fluid-structure interaction and sloshing analysis.
- Explicit finite element codes have extensive capability for fluid-structure interaction and sloshing analysis, especially with complex geometries.
- Both implicit and explicit codes have advantages and disadvantages, which tend to be complementary.
- How does one decide between the implicit and explicit approach for this problem?

Required Steps to Justify the Use of a Time Domain Code

- Must demonstrate the ability of the selected time domain code to perform site response analysis.
- Must demonstrate the ability of the selected time domain code to perform SSI analysis.
- Must demonstrate the ability of the selected time domain code to perform fluid-structure interaction (FSI) analysis.

Site Response Analysis in the Time Domain

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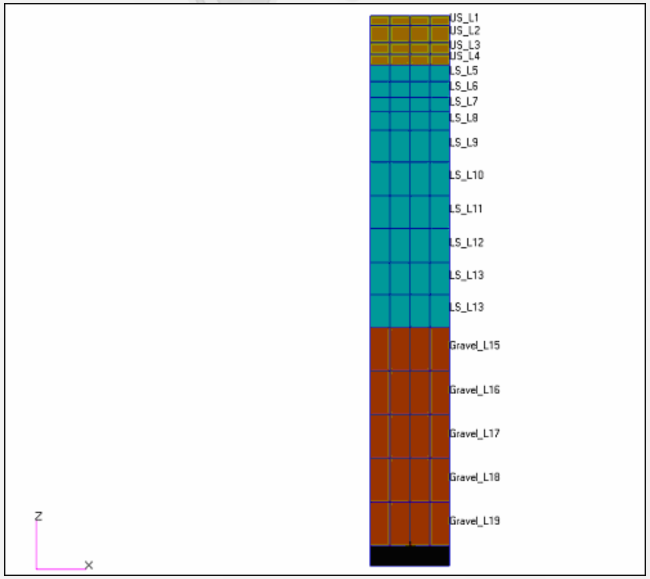
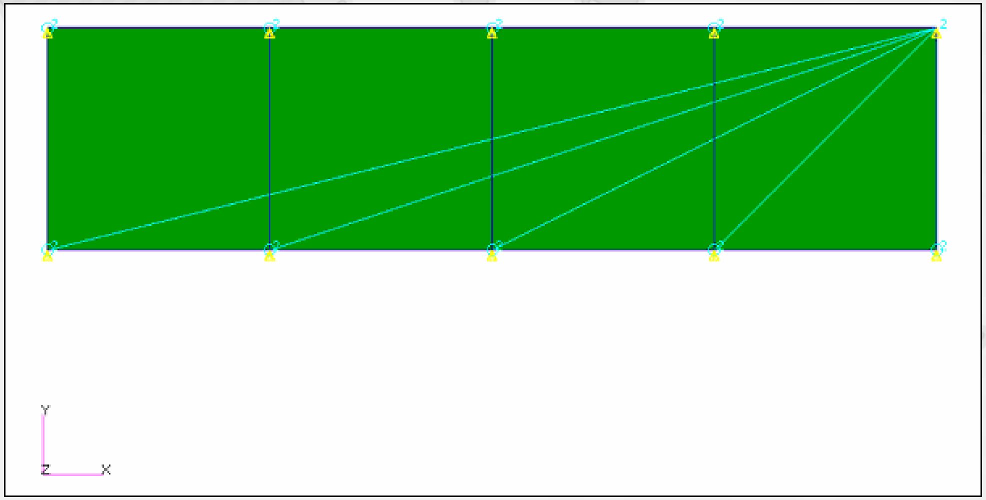
- Fundamental differences between site response analysis in the frequency domain using the complex response method SHAKE (Schnabel et al. 1972) and time-domain site response analysis are the formulation of boundary conditions and damping.
- Site response analysis in the time domain was benchmarked against more traditional frequency-domain analysis by reproducing desired responses in a soil column models subjected to seismic excitation.
- Create soil column models in Dytran and implicit code using “slaved” boundary conditions to enforce shear beam response in the soil column.
- Input to soil column models are the time histories from SHAKE at the base of the soil column.

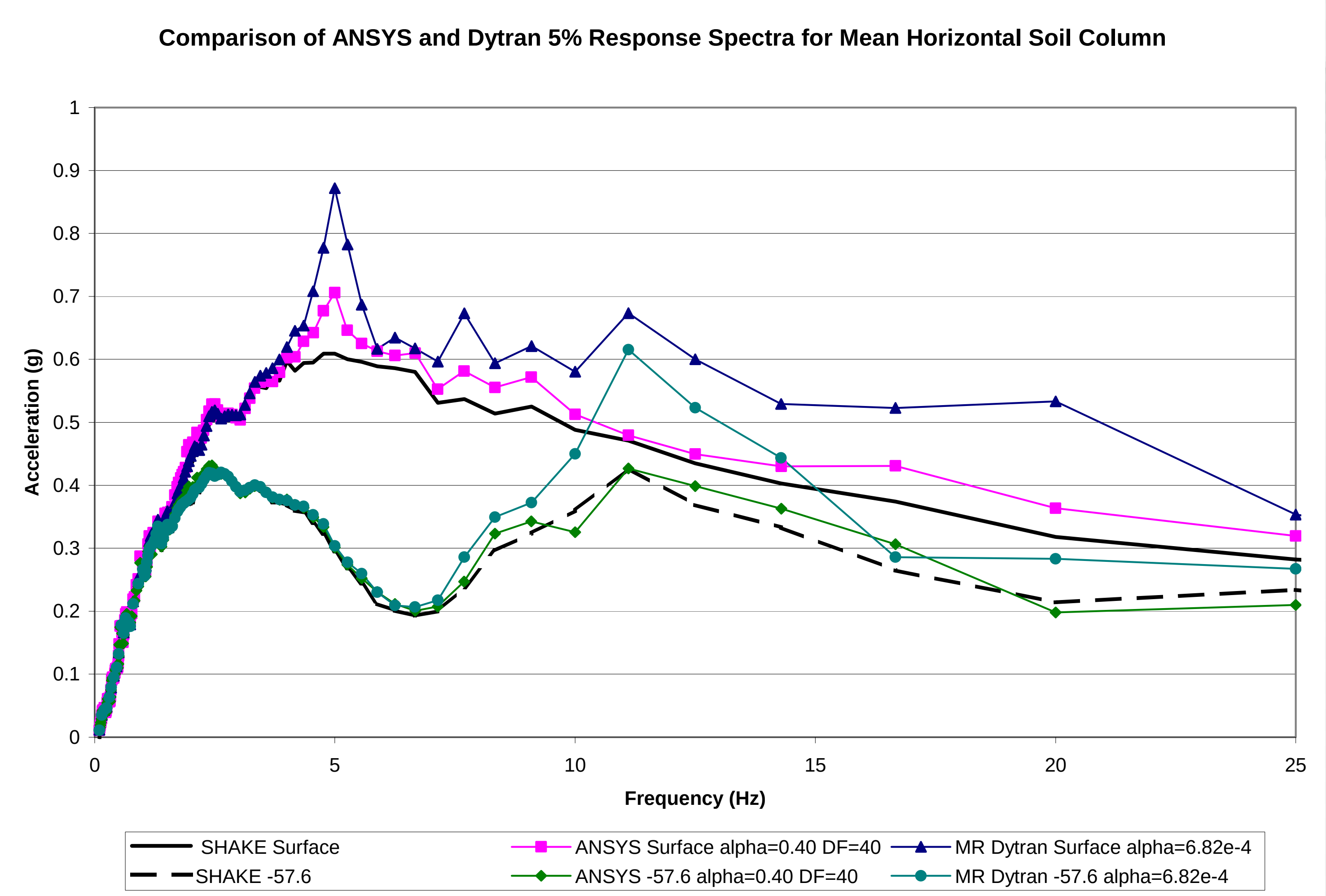
Site Response Analysis in the Time Domain (con't.)

- Adjust damping parameters in MSC Dytran and implicit code to provide best match to SHAKE response at the surface and tank foundation level.
- Two free damping parameters available in typical implicit code (Rayleigh damping) .
- One free damping parameter available in Dytran (VISCDMP).





Results of Site Response Analysis



Results of Site Response Analysis (con't.)

- Both Dytran and the implicit code show excellent matches to the target spectra at frequencies below the second modal frequency of the underlying soil column.
- Dytran begins to show peaks in the surface response spectra beginning at the second modal frequency of the underlying soil column.
- This tendency also occurs with the implicit code, but more flexibility is available to control or tune the response due to the availability of a second Rayleigh damping parameter.
- Generally, the stiffer the soil, the better the match at higher frequencies, especially with Dytran.
- If higher frequencies are important to the problem, an implicit code with Rayleigh damping offers more flexibility for spectral matching.
- The key to the implicit approach appears to be the two Rayleigh damping parameters that can be specified at the material or element level. It is expected that the soil column results could be duplicated with other implicit codes (e.g. MSC Marc).

SSI Analysis in the Time Domain

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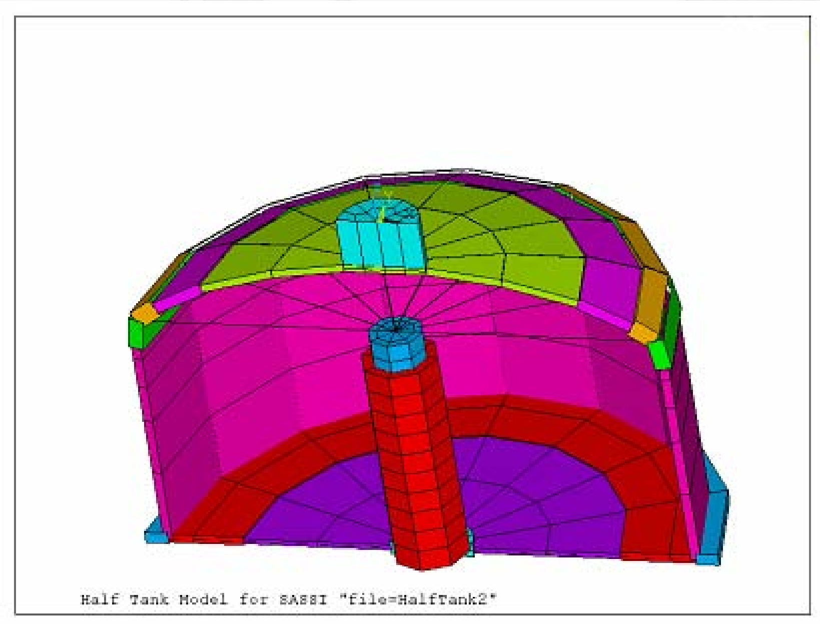
- Compare the structural responses of a simplified tank model using both the frequency domain code SASSI (Lysmer et al. 1999) and an implicit time domain code.
- Create a model of a simplified tank in SASSI in which the impulsive hydrodynamic response is modeled with two cantilever beams per BNL (1995).
- Create a coupled soil-structure model in an implicit code using the same tank configuration as in SASSI.
- Maximum accelerations and response spectra at various locations in the tank structure were compared between the SASSI model and an implicit time domain model.
- Comparisons were made using mean, lower, and upper bound soil properties for horizontal and vertical excitation.

SSI Analysis in the Time Domain (con't.)

- Results from the implicit time domain models and SASSI models were similar, with implicit time domain results tending to bound the SASSI results, though this did not occur in all cases and all locations.
- The results were sufficiently good to proceed with the time domain SSI analysis of the tanks.



Fluid-Structure Interaction Analysis

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- Dytran was developed as a fluid-structure interaction code and has robust capabilities for analyzing FSI and sloshing behavior.
- Typical implicit codes have more limited capabilities for FSI analysis and sloshing behavior. However, the implicit approach still appears to be the better choice for the global analysis of this problem.
- In lieu of a global Dytran model, the comparison of FSI analyses of simplified sub-models of the primary tank and contained fluid using Dytran and an implicit code provides the necessary link to more accurately evaluate the FSI behavior.
- Results from the simplified Dytran models are used to supplement results from the global implicit model.

Fluid-Structure Interaction Analysis (con't.)

- Both Dytran and implicit models were evaluated using a step-by-step approach in which several problems of increasing complexity were analyzed.
- Both rigid and flexible wall tank models were analyzed.
- Parameters of interest were the impulsive and convective mode frequencies, the total hydrodynamic reaction forces, waste pressure distributions, slosh heights, and tank wall stresses.
- Implementation and calibration of the damping in Dytran was a trial and error process to achieve the desired effective damping.
- Rayleigh damping in the implicit model was largely inherited from (dictated by) soil column studies and the effective damping for fluid response was quantified, but not adjusted.

Fluid-Structure Interaction Analysis (con't.)

- The results of the Dytran analyses of the rigid and flexible wall tanks agree well with known theoretical solutions.
- The implicit model showed reasonably good agreement with theoretical results for impulsive and convective frequencies and overall reaction forces, and the model generally tends to over-predict the reaction forces.
- The Dytran model has much better capabilities than the implicit model for predicting slosh heights, and for predicting waste pressures and tank stresses near the free surface of the waste.
- At lower liquid levels where interaction with the dome was minimal, the global implicit model is sufficient for the seismic evaluation of all tank components except for local areas of the primary tank containing the liquid.
- The evaluation of primary tank stresses near the liquid free surface were supplemented by results from the Dytran FSI model.

Fluid-Structure Interaction Analysis (con't.)

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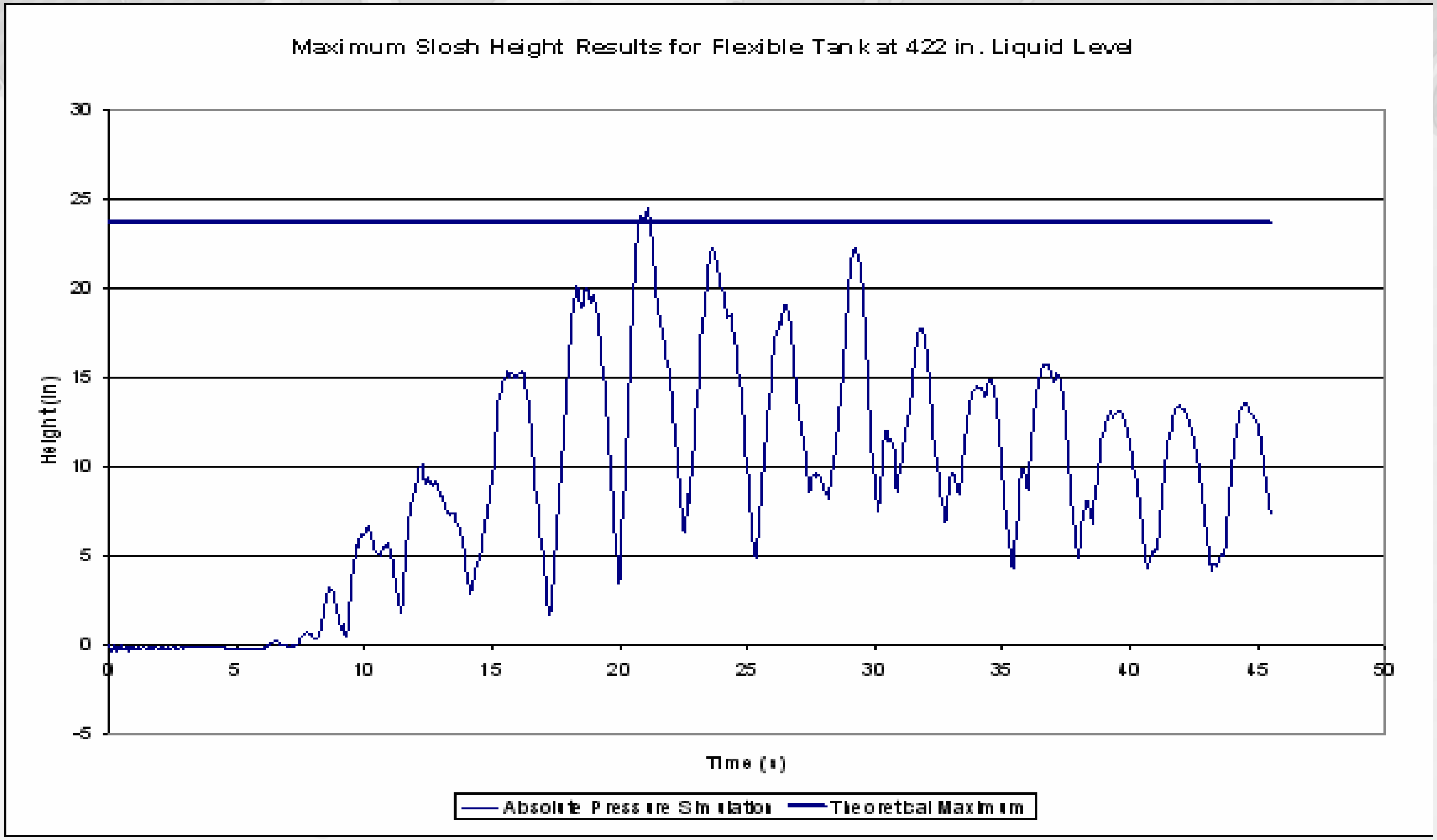

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Conclusions

- Dytran shows excellent spectral matches for the site response problem at lower frequencies, but the spectral match begins to break down at frequencies above the second modal frequency of the soil column due to the availability of only one free damping parameter.
- The availability of two free Rayleigh damping parameters that can be specified at the material or element level is the key that allows spectral matching to higher frequencies using an implicit code.
- The presence of important structural frequencies above the second modal frequency of the soil column drove the decision to use an implicit code for the global model in this problem.
- The implicit code was able to capture the impulsive response of the primary tank and liquid system, but had limited capability to capture the convective response.

Conclusions

- Dytran played a crucial role in evaluating the FSI response of the primary tank, especially near the free surface.
- As geometries become more complex (higher liquid levels and associated interaction with the curved dome) and excitation levels increase, the strengths of Dytran and the limitations of the implicit approach to FSI become more pronounced.

Acknowledgements

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