VESSEL HYDRODYNAMIC INVESTIGATIONS

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ABSTRACT

Deep-draft vessels in narrow waterways can generate significant hydrodynamic effects on berthed vessels, wharf structures and shorelines. Pacific International Engineering (PI Engineering) has performed analyses of vessel-generated hydrodynamic effects in various waterways in the United States and overseas using proprietary and commercially available numerical modeling tools. In the present paper, the application of two models to evaluate passing-berthed vessel interaction is presented.

The proprietary Ship-Generated Hydrodynamics (SGH) model can be used to calculate vessel-generated water surface fluctuations, current velocities and vessel wakes. The model incorporates complex channel geometry, hull shapes, variable roughness and variable sailing lines. Water level time histories around the berthed vessel are calculated using the SGH model and used as input into the Multi-Operational Structural Engineering Simulator (MOSES). MOSES calculates berthed vessel motion, mooring line loads and loads/compression in fenders.

These advanced computer technologies have been succesfully and cost-effectively used to analyze waterways in Oakland, CA; Corpus Christi and Sabine-Neches Waterway, TX; Duwamish, WA; Karnafuli River, Bangladesh; and elsewhere.

1. INTRODUCTION

The following paper provides an overview of analysis, numerical modeling and field investigations performed to study problems caused by deep-draft vessels in narrow waterways.

At marine port terminals, loads on berthed vessels due to passing vessels have caused damage to berthed vessels, wharf structural failures (mooring line, fender and bollard failure), operational problems, life safety concerns and fires due to berthed vessel motion during loading/unloading operations. The study of berthed vessel response is quite complicated; the loads on the berthed vessel result from a transfer through a highly variable medium of energy from a passing vessel. The passing vessel loads are dependent upon the speed, geometry and position

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of the passing vessel and the three-dimensional geometry of the moored vessel and the surrounding port. The accurate simulation of these loads can only be achieved if the far-field generation and near-field transformation of the hydrodynamic forcing is correctly modeled. Similarly, sophisticated modeling, which takes into account the geometry of the hull and the mooring arrangement, is required to determine the dynamic response of the moored vessel and the resulting line and fender loads.

2. NUMERICAL MODELING AND ANALYSIS OVERVIEW

Numerical modeling and analysis of loads on berthed vessels due to passing vessels has been investigated using several numerical modeling and analysis tools. Passing-berthed vessel interaction analysis requires coupling of two independent models to evaluate 1) vessel-generated hydrodynamics and 2) dynamic mooring analysis and berthed vessel response.

2.1 Passing Vessel Hydrodynamics

Early investigations were performed following the development of the Vessel-Generated Pressure Field (VGPF) model (Shepsis, et. al.,1998). The VGPF model is an analytical, steady-state, quasi-3D model that predicts the pressure field and water level distribution surrounding a moving ellipsoidal body with specified length, beam and draft in a waterway with specified width and depth. The VGPF model allows efficient *first-cut* approximations of vessel-generated drawdown in narrow waterways. The VGPF model's drawdown predictions were compared with wave pressure data collected in the Inner Harbor Waterway, Port of Oakland, CA. Vessel speed, location, draft and name/size were collected using US Coast Guard vessel tracking radar data and the Lloyd's Register of Ships. Figure 1 shows comparison of measured and predicted water levels for the passing containership "MSC Xingang". The results show that even with the relatively restrictive assumptions used in its derivation, the VGPF model gives an excellent prediction of the period and amplitude of the vessel-induced drawdown. In long straight channels, or other areas where the assumptions of uniformity of depth and channel cross-section are appropriate, the VGPF provides a valuable tool for engineering design purposes.

In many areas, however, the channel geometry is too complicated for these assumptions. Also, vessel hull shape can, in many circumstances, have a significant effect on the resulting hydrodynamics. Next-generation hydrodynamic analysis is performed with the proprietary Ship-Generated Hydrodynamics (SGH) model (MacDonald and Davies, 2002).

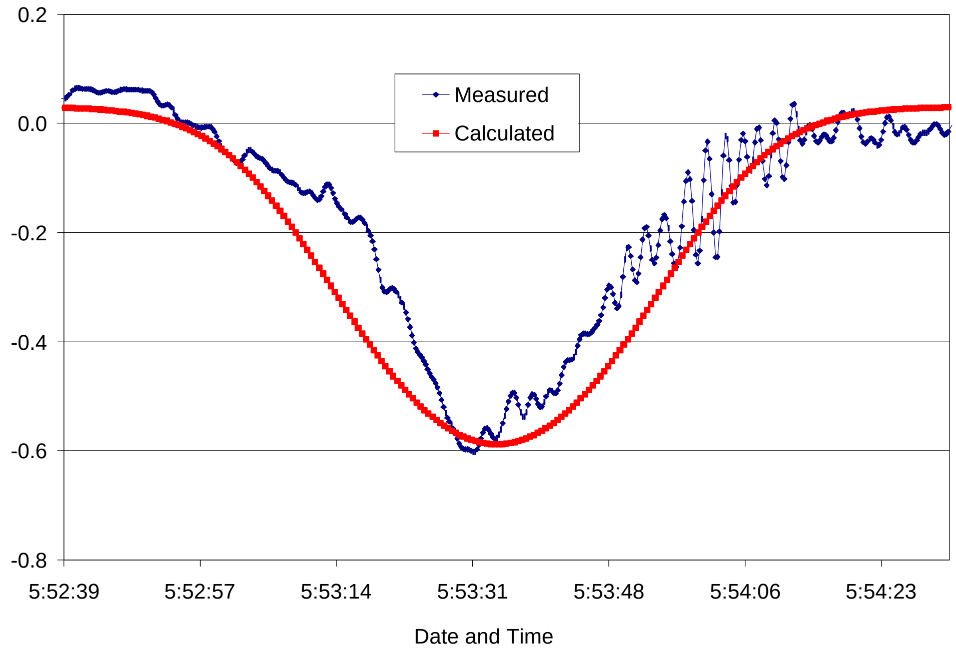

Figure 1. Comparison of measured and predicted water levels. Containership "MSC Xingang", Inner Harbor Waterway, Port of Oakland, CA. Measured (blue); VGPF model (red).

The governing equations of the SGH model are developed using a phase-averaged approach, however, the model is solved in the time domain, enabling contemporaneous predictions of both vessel-generated low frequency drawdown and high frequency wakes. The SGH model uses a finite-difference approach, allowing incorporation of complex three-dimensional channel geometry, variable channel bottom roughness maps, user-specified variable sailing lines within the domain, and three-dimensional user-specified or analytical vessel hull shapes. Vessel hull shapes developed and tested to date include general cargo-type, containership, tanker, barge, and analytical (mathematical) shapes (Figure 2).

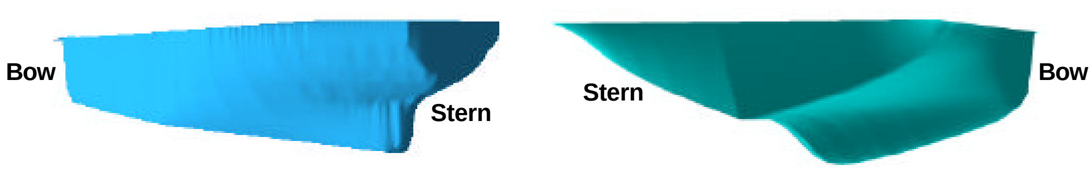

Figure 2. Example model representations of tanker (left) and cargo (right) hulls

The SGH model is capable of reproducing the generation and interaction of low-frequency drawdown induced by any number of vessels simultaneously. At present, high frequency wake modeling is restricted to a single vessel per simulation. Complex ambient flow conditions, for example, from tides or river outflows, can also be included in the model and the interaction of these flows with the vessel-induced flows is computed directly. The versitility of the code also allows the model to be applied to open coastal environments. PI Engineering has several projects presently underway that are using the SGH model to develop design criteria for shoreside structures and to evaluate beach and riverbank erosion problems. All simulations shown in the present paper were performed with the wake module deactivated; only the results of the model's low frequency drawdown (water surface fluctuations and current velocities) module are presented.

The SGH model has been verified using wave pressure data measured in the Corpus Christi Ship Channel, TX. This is a challanging test of the model, since the navigation channel has shallow banks on either side; the main channel depth is 14 m, while the measurements were taken in 2 m of water near the shore. Figure 3 shows a comparison of measured (black) and predicted (blue) water levels for the vessel "Monarch", which was followed using a small craft to obtain approximate vessel speed and position in the channel. The SGH model provides a good prediction of the period and amplitude of the drawdown.

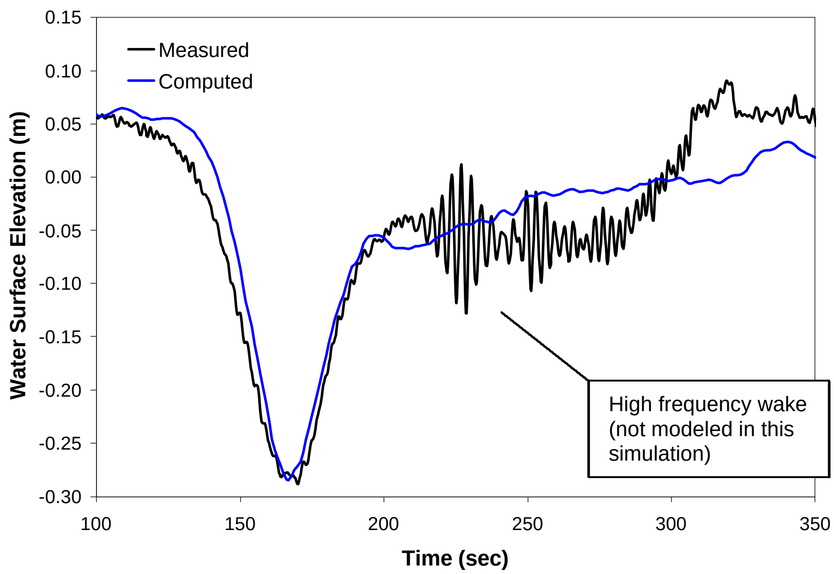

Figure 3. Comparison of measured and predicted water levels. Vessel "Monarch", Corpus Christi Ship Channel at Port Aransas, TX. Measured (black); SGH model (blue).

This Corpus Christi Ship Channel also provides a good case for illustration of the importance of a realistic representation of hull shape, especially in situations with complex channel cross-sections. Figure 4 shows the measured and computed results for two simulations, one with an ellipsoidal hull shape (blue) and with a hypothetical cargo vessel hull shape. While the period is unchanged, the peak drawdown near the shore is significanly under-estimated.

Additional field investigations in both the US and Canada are planned to further verify the model.

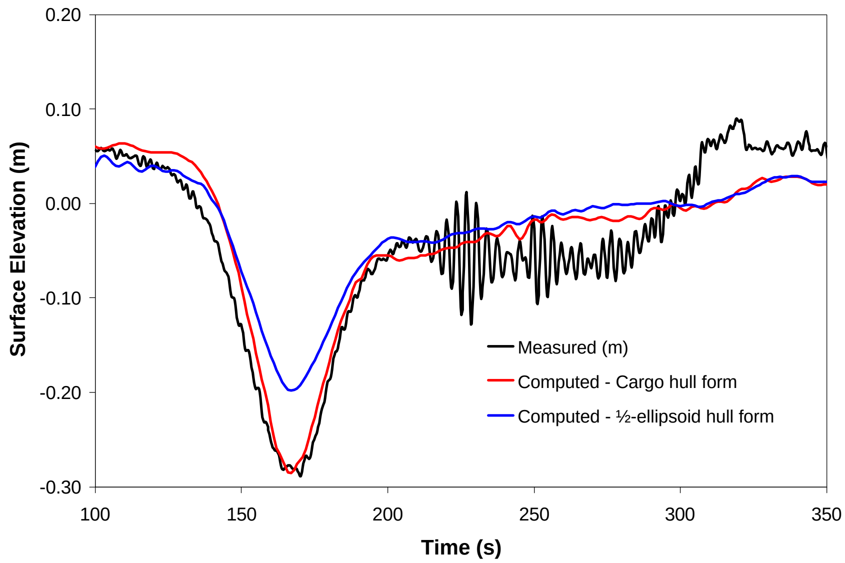

Figure 4. Effect of hull shape on predicted water level results. Vessel "Monarch", Corpus Christi Ship Channel at Port Aransas, TX. Measured (black); SGH model with ellipsoidal hull shape (blue); SGH model with cargo hull shape (red).

2.2 Dynamic Mooring Analysis

Mooring analysis has been performed, both static and dynamic, in both the frequency and time domains. Experience and analysis indicates that in-depth evaluation of berthed vessel response and structural impacts during passing vessel events requires time-domain, dynamic mooring analysis.

Model input to the MOSES from the SGH model can include loading time histories at multiple locations or water level fluctuations at locations surrounding the berthed vessel. MOSES is presently used to develop time histories of mooring line loads, compression and loads in fenders, loads on bollards, and berthed vessel motion in six degrees of freedom. MOSES results can be used to determine which individual lines, fenders, and bollards may be susceptible to long-term wear-and-tear and/or catastrophic failure during particular vessel passing events.

3. VESSEL MOORING ANALYSIS: PRACTICAL APPLICATIONS

Various vessel hydrodynamics studies have been performed by PI Engineering personnel at the Port of Oakland, CA since 1996. Vessel hydrodynamics studies were performed (PI Engineering 2000, Shepsis et. al. 2001) that analyzed the design vessels in the Inner and Outer Harbor Waterways and made recommendations regarding potential impacts to berthed vessels. The Inner Harbor Waterway design vessel was changed from a Maersk "K" Class Containership to a Maersk "S" Class Containership, an increase in length of approximately 100 feet (no change in beam or draft). Analysis showed that the *description)*

Figure 6 shows the time history of motion (longitudinal and transverse only) for the berthed containership “MSC Xingang” due to a passing Maersk “S” Class Containership. The results indicate approximately 10 feet of longitudinal motion for the berthed vessel during the event.

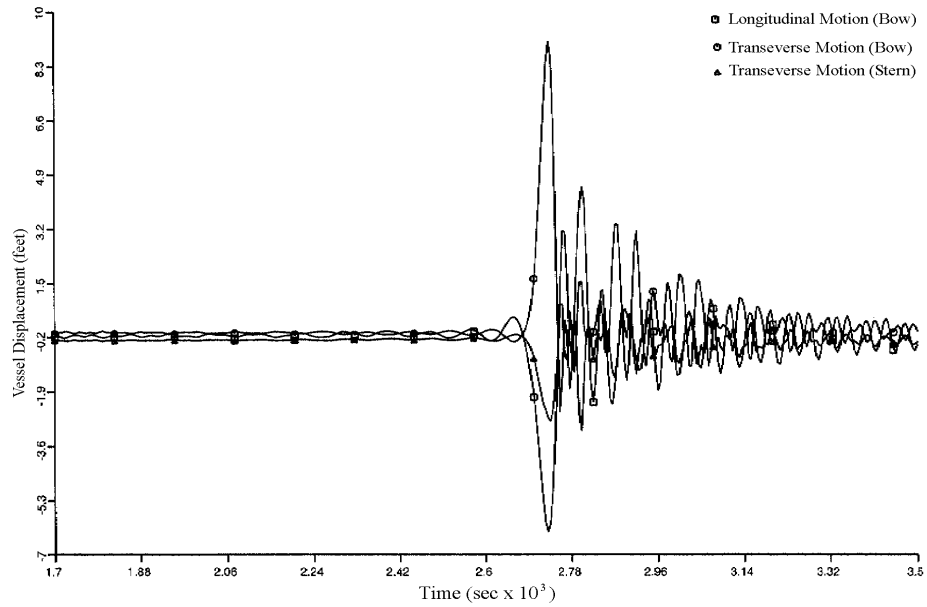

Figure 6. Time histories of motion (longitudinal and transverse only) for berthed containership "MSC Xingang" during passing of Maersk "S" Class Containership

Figure 7 shows the time history of spring mooring line loads for berthed containership "MSC Xingang" due to passing Maersk "S" Class Containership. The results indicate individual line loads of up to approximately 100,000 lbf (100 kips) in the 2.5-inch diameter double-braid nylon lines during the event.

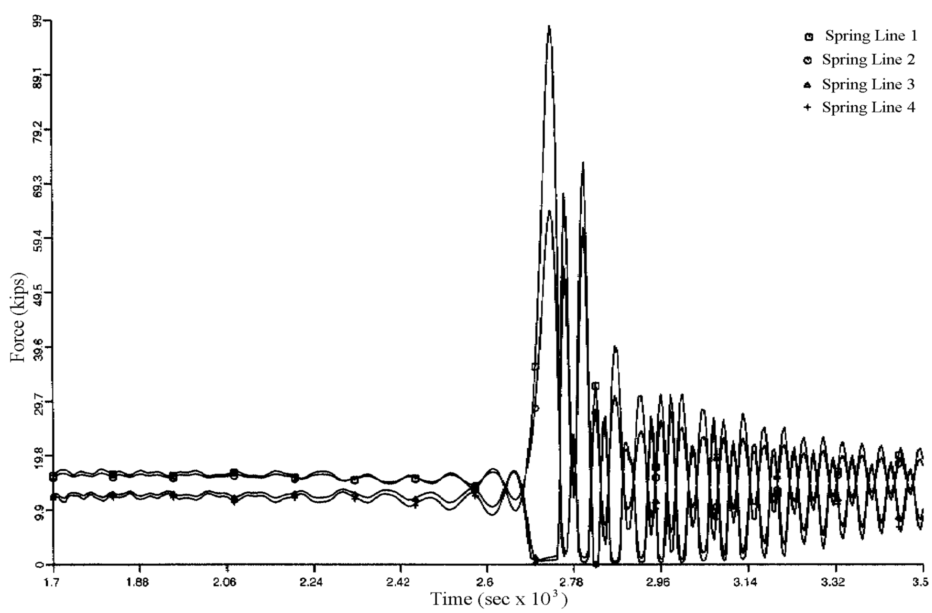

Figure 7. Time histories of spring mooring line loads for berthed containership "MSC Xingang" during passing of Maersk "S" Class Containership

4. SHORELINE IMPACTS ANALYSIS: PRACTICAL APPLICATIONS

Deep-draft vessel hydrodynamic effects have a significant effect on the shorelines of navigation channels. In the Sabine-Neches Waterway, TX, deep-draft tankers and other vessels travel in the relatively narrow waterway, creating significant erosive surge and vessel-generated currents at the shoreline. PI Engineering has used the SGH model to cost-effectively develop site-specific design criteria for shoreline erosion protection structures.

Figure 8 shows the complex channel geometry of the Sabine-Neches Waterway near Port of Port Arthur, TX. The SGH model allows the complex horizontal and vertical geometry of the area to be modeled to a fine scale.

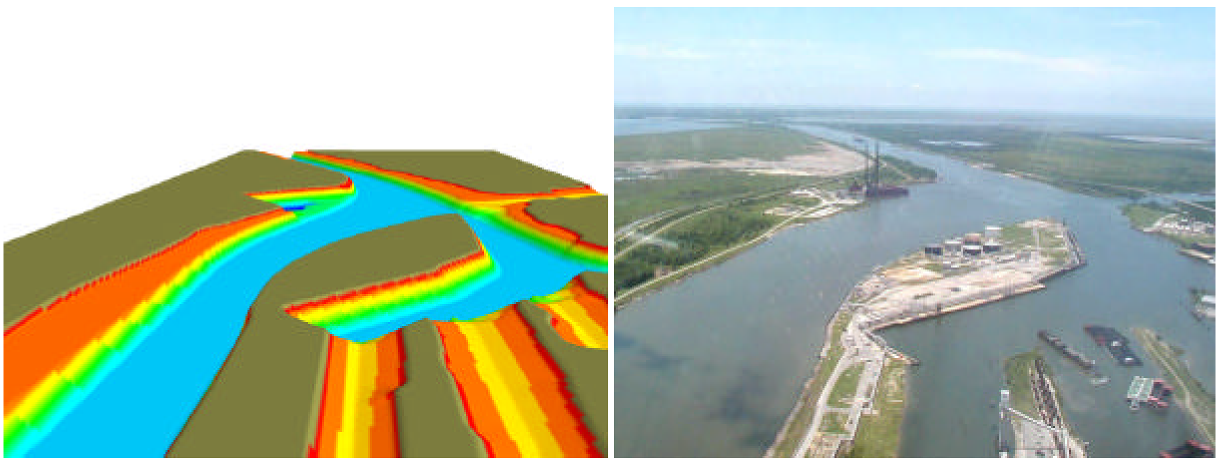

Figure 8. Model geometry (left) and aerial photo (right) of the Sabine-Neches Waterway at Port of Port Arthur, TX

Figure 9 shows vessel-generated current speeds in the channel surrounding a tanker passing at 8 knots. Note how the flow accelerates in the shallow water near the shore, and how the influence of the vessel is felt in the neighboring channel.

Figure 10 shows water level fluctuations surrounding the vessel. As would be expected, the drawdown is greatest in the immediate vicinity of the vessel. However, passage of a vessel can cause seiching in the channel, and this effect is likely a contributing factor to the large drawdown near the shore farthest from the sailing line. Sophisticated algorithms are used in the SGH code to handle flooding and drying of model cells along the shore.

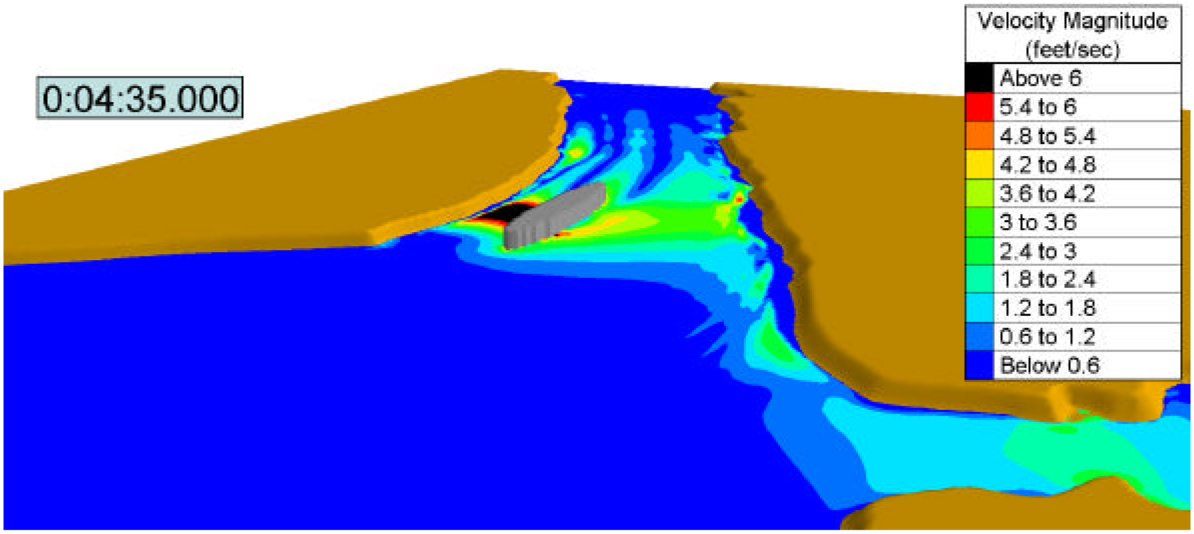

Figure 9. Vessel-generated current velocities surrounding tanker moving at 8 knots in Sabine-Neches Waterway

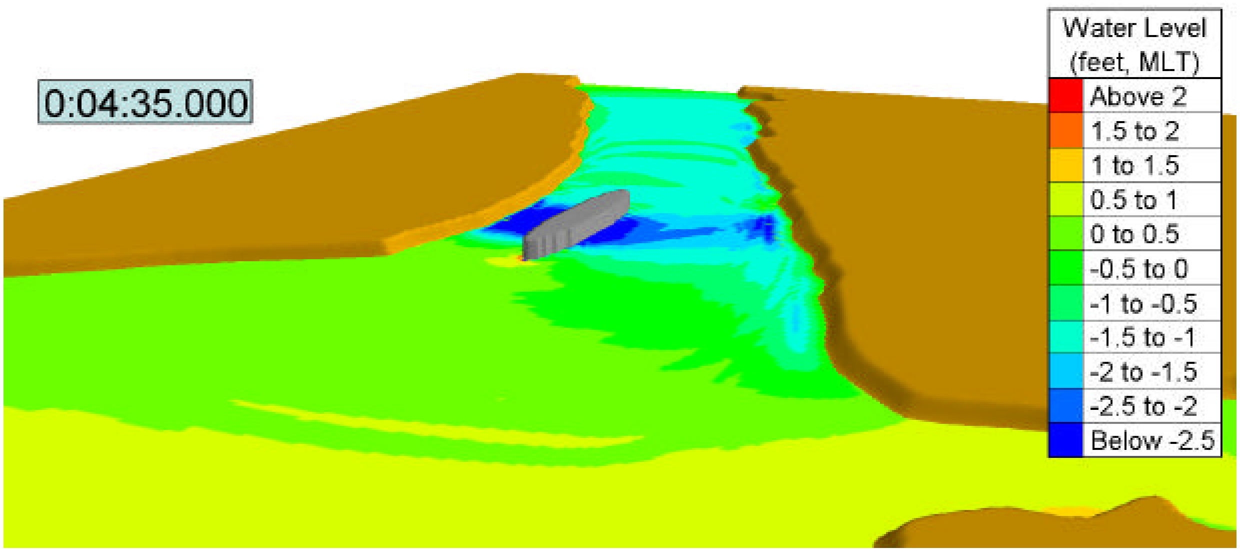

Figure 10. Vessel-generated water level fluctuations surrounding tanker moving at 8 knots in Sabine-Neches Waterway

An overhead view of the instantaneous flow velocity vectors and bottom elevation contours at another point in the simulation are shown in Figure 11. These simulation results were used to evaluate shore protection structure design alternatives (rock revetment and sheetpile bulkhead) and develop design criteria including rock size, structure crest height, and toe scour protection.

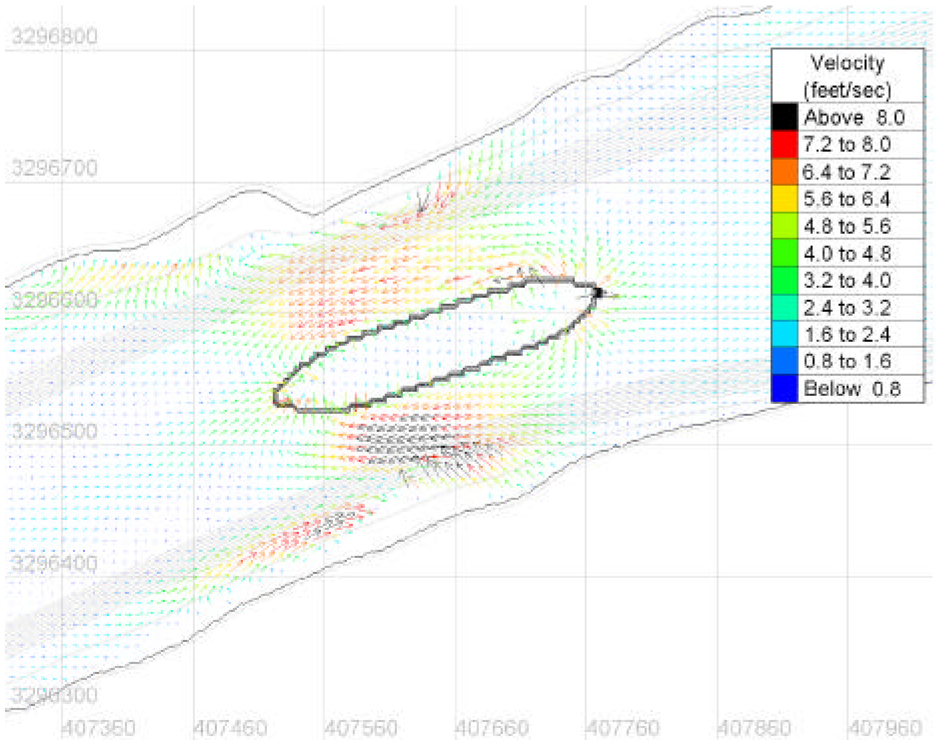

Figure 11. Vessel-generated current velocity vectors surrounding tanker moving at 8 knots in Sabine-Neches Waterway (contour lines are elevation)

5. SUMMARY

Vessel hydrodynamics studies have recently allowed improved analysis and prediction of vessel-generated surge, currents, and vessel wakes surrounding deep-draft vessels. Passing-berthed vessel interaction analysis has been cost-effectively performed to analyze structural and life safety issues associated with berthed vessel motion, and excessive mooring line, fender, and bollard loads. Vessel-generated hydrodynamic analysis has also been efficiently performed for these types of deep-draft vessels to develop design criteria for shoreline erosion and development projects.

Conclusions drawn from modeling results can be used to:

- Evaluate proposed navigation channel improvements
- Evaluate impacts of proposed channel deepening
- Design/evaluate mooring systems
- Evaluate impacts of fleet expansion
- Provide operational guidance to terminal operators and pilots

6. REFERENCES

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