VESSEL WAKE INDUCED DYNAMICS IN A SHALLOW-BAY ENVIRONMENT

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INTRODUCTION

Ship wakes generated by large deep-draft vessels as well as those generated by smaller barges have the potential to cause significant compounding erosion and sedimentation issues, especially along high-traffic waterways. Yet, long-term in situ measurements of the actual hydrodynamics initiated by ship wakes are rare. These data, however, are needed to optimize the design of erosion mitigation structures, to plan dredging efforts, to validate numerical modeling efforts, and to establish a basis from which the erosion and sedimentation potential of projected ship traffic can be estimated. This study is intended to help close some of these existing knowledge gaps through detailed analyses of measured velocity, water free-surface elevation change, and suspended sediment concentration caused by wind waves and ship wakes in the shallow-bay environment of Galveston Bay, Texas (GBT). In addition, numerical modeling efforts are being presented using the Boussinesq-type wave model FUNWAVE-TVD (Shi et al., 2012) to simulate individual vessel wake hydrodynamics and sediment-related dynamics and interactions with the local bathymetry and wetland edges based on the collected field data.

Ship wake patterns typically include multiple components that are generated as the vessel moves through the water (Figure 1). Both transvers and divergent wave patterns can emanate from the moving vessel. The generated waves then propagate away from the vessel and interact with the surrounding body of water and bathymetry. The formed surface fluctuation pattern is known as a Kelvin wave pattern with an envelope that forms an angle of 19.47 Degrees with the vessel track.

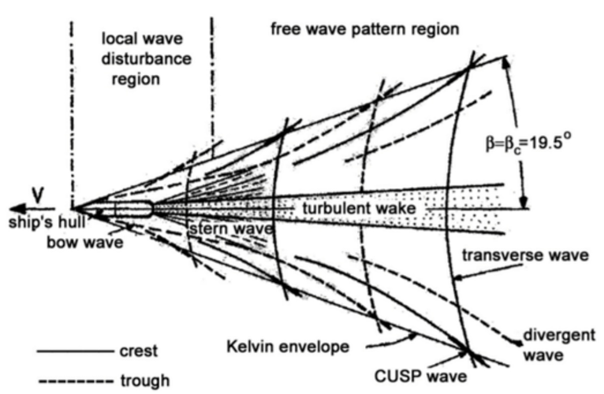

Figure 1 - Geometry of Kelvin ship wake components including bow, stern, transverse, and divergent waves (Hennings et al., 1999).

At some point a distance away from the vessel track, the water surface fluctuation produced by the ship wave takes on a characteristic form as shown in Figure 2. It includes a slight increase in water surface characterized as the bow wave, followed by a substantial drop in water level (drawdown) before the stern wave and secondary ship wakes appear.

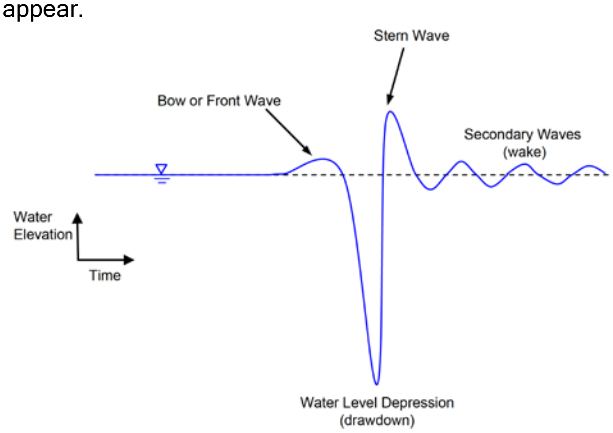

Figure 2 - Typical time series of water free surface fluctuation produced by a large moving vessel (Hennings et al., 1999).

If these vessel-induced water level fluctuations interact with the bed or nearby embankments, sediment suspension and erosion can result. This problem is particularly important in shallow bay systems with high volumes of ship traffic since bank erosion and vessel-induced movement of sediment can lead to increased dredging costs and loss of habitat or protective embankments.

FIELD DATA COLLECTION

Multiple field campaigns provided in-situ data for this effort. A one-year-long field measurement campaign initiated in November 2017 was conducted along the Houston Ship Channel (HSC) in GBT to quantify vessel-induced hydrodynamics near a mixed-sediment embankment approximately 1 km away from the main shipping lane. The embankment is part of a protective dike structure around a newly created dredge material placement area that is designed to turn into a wetland ecosystem after project completion. Measurements were collected via multiple instruments mounted on two temporary platforms along the newly constructed embankment in approximately 2 m water depth (Figure 3). Water level fluctuations were recorded by submerged pressure transducers (PT) with a sampling frequency of 2 Hz. Water velocities were measured using acoustic Doppler current profilers (ADCP, Nortek Aquadopp) in burst configuration (up to 2 Hz sampling). Optical backscatter sensors (OBS) were collecting data on suspended sediment concentrations in concert with the Aquadopp systems. A fixed camera mounted on the platform closest to the HSC took images of the water surface and passing vessels looking east at a frequency of one image per minute. An example of a deep-draft crude oil tanker sailing toward the Port of Houston is shown in Figure 4 alongside the produced wake pattern near the field site a few minutes later. In addition to the in-situ measuring effort, AIS (automated information system) data for the entire duration of the project were collected and critical vessel parameters such as forward speed, track, and various geometric parameters (draft, length, beam width, etc.) were extracted and analyzed.

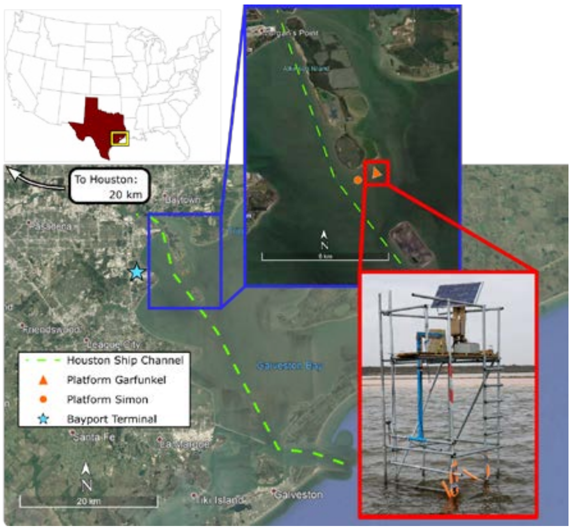

Figure 3 – Location map and instrument platform setup.

A second, 1.5-year data collection effort is currently underway at multiple field sites throughout GBT near exposed wetland edges. Two of these sites are directly impacted by Gulf Intracoastal Waterway (GIW) barge traffic and associated wake dynamics. Analysis of data from both field efforts is ongoing alongside numerical modeling efforts for comparisons. Here progress from the HSC effort related to measured and simulated free-surface fluctuations is presented in more detail.

DATA ANALYSIS & NUMERICAL MODELING

Free-surface fluctuations, water velocities, and suspended sediment concentrations measured via pressure transducers, ADCP, and OBS, respectively, are analyzed with a focus on better understanding vessel-generated dynamics and sedimentation. The hydrodynamics varied based on vessel-related parameters such as draft, beam width, speed, etc. that can affect the governing Froude conditions (e.g., Torsvik et al., 2006). Wavelet analysis was employed to quantify energy contributions of initial drawdown and wake components. Vessel-generated hydrodynamics are linked to actual vessel characteristics using available AIS data and video footage and compared with fetch-limited wind wave effects during calm and energetic conditions.

Figure 4 – Top panel: Photo of inbound deep-draft crude oil tanker (GSTAAD GRACE, MMSI: 240953000); Bottom panel: Photo of produced wake field recorded a few minutes later near one of the measuring stations.

Individual vessel passages were simulated using the FUNWAVE numerical model and its ship module on a 1-m resolution grid that was manually updated with bathymetry and topography data from the newly constructed dredge material placement area PA10 and its new protective embankment built from dredge material. Figure 5 shows a snapshot in time of a FUNWAVE simulation where color indicates free-surface elevation generated from the vessel (black shape) moving northward (upward in the figure) through the HSC. In this figure the ship wakes have just reached the measuring station.

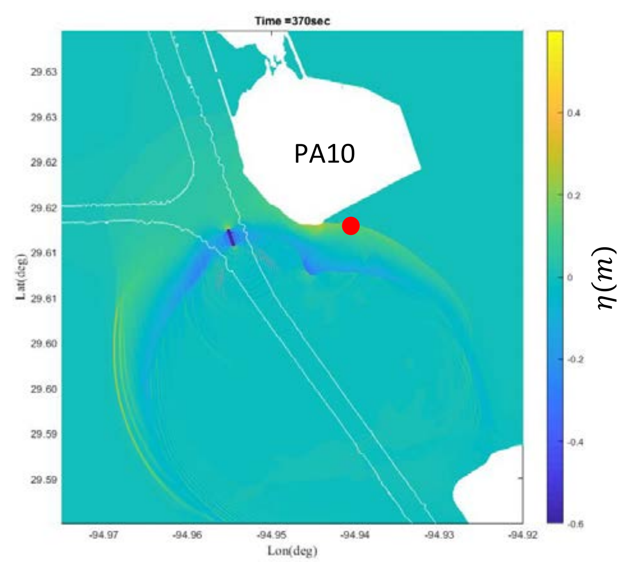

Figure 5 - Screen shot of FUNWAVE simulation results for free-surface elevation η generated by the same inbound deep-draft oil tanker shown in Figure 4 (L: 244m, B: 42m, D: 10m, U=10m/s). The location of the field measuring station is indicated by the red dot.

RESULTS

Results from the analysis of the one-year field data collected near the HSC show a clear dominance of vessel-induced wake energy compared to wind-generated waves at that location and will help with design efforts for erosion mitigation strategies and embankments in light of planned HSC and dredging projects and the intended creation of new placement areas nearby.

FUNWAVE simulation results for individual vessel passages indicate good overall resemblance with measured hydrodynamics at the location of the measuring station. An example comparison is shown in Figure 6 for the same deep-draft crude oil tanker dynamics depicted in the previous figures. The measured free-surface elevation shows a slight and gradual increase of the water level (bow wave or "surge") by a few centimeters before the drawdown significantly lowers the water surface by about 40 centimeters over a period of approximately 100 seconds. This is followed by an abrupt jump in water level as the stern wave and trailing secondary wake packets appear in the measurement with a peak wave elevation of nearly 40 centimeters above still water. Wave transformations over the shallow bay bottom between the vessel track and the measuring location have already occurred at this point and interactions with the nearby embankment (breaking, refraction, etc.) add to the complexity of the measured signal.

The FUNWAVE simulation result also shows a surge, drawdown, and stern wave component with timing comparable to the measured data. In particular, timing and extent of the drawdown and the onset of the trailing transverse wake pattern led by the stern wave are well represented.

However, the magnitude of the leading surge wave is slightly overpredicted and the details of the trailing transverse wake signal are not resolved (Figure 6) which can be attributed to the simplified way vessels are simulated in FUNWAVE.

Simulated and measured suspended sediment concentrations show that vessel wakes can create similar magnitude suspension events as energetic wind wave induced hydrodynamics. It must be noted, however, that the results presented here do not include wind-generated waves or tidal fluctuations. Further analysis will focus on potential improvements to the numerical simulations and expansion of the single-vessel results to multi-vessel effects and extended periods of time based on marine traffic forecasts for the HSC region.

REFERENCES

Hennings, Romeiser, Alpers, Viola (1999): Radar imaging of Kelvin arms of ship wakes. International Journal of Remote Sensing, vol. 20, p. 2519-2543.

Shi, Kirby, Harris, Geiman, Grilli (2012): A highorder adaptive time-stepping TVD solver for Boussinesq modeling of breaking waves and coastal inundation, Ocean Modeling, vol. 43-44, p. 36-51.

Torsvik, Dysthe, Pedersen (2006): Influence of variable Froude number on waves generated by ships in shallow water, Physics of Fluids, AIP, vol. 18(6), p. 11.

Tschirky, Pinkster, Rollings, Smith (2010): Modeling moored ship response to a passing ship, Proceedings of the 12th Triannual International Conference on Ports 2010, p. 10.

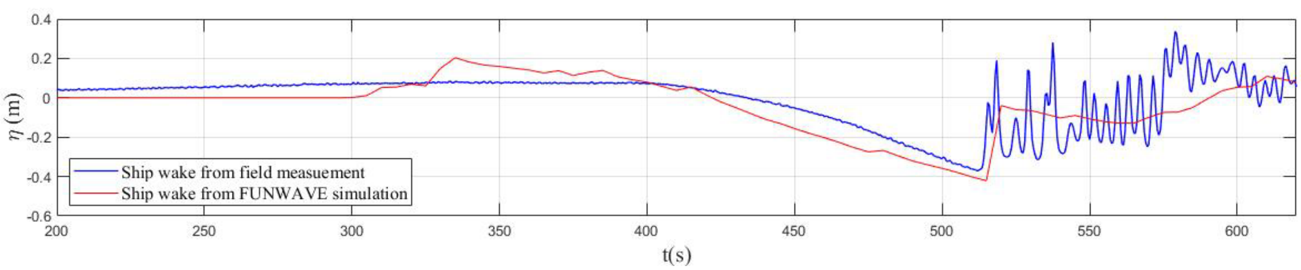

Figure 6 – Comparison of measured (blue) and numerically simulated (red) ship wake free-surface fluctuation signal over 400 seconds duration at the location of the field measuring station closest to the HSC.