APPLICATION OF MULTI-DIMENSIONAL NUMERICAL MODELING TO REAL WORLD COMPLEX HYDRAULIC PROBLEMS

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ABSTRACTS

There is a growing need to have multi-dimensional numerical modeling capability to apply to real world problems. Complex hydraulic problems in rivers, streams and coastal areas require that application tools be available to the practicing engineer for use in developing suitable alternative solutions and to provide more insight to regulators and peer reviewers.

Sediment management with river engineering structures has been successfully performed around the World in both isolated and systematic ways. By proper evaluation and implementation of river engineering projects sediment problems can be alleviated. There are numerous examples of such projects around the World, such as; Lower Mississippi River, Red River Waterway, Arkansas River, and numerous small streams having systems approach applied to reduce sediment transport Additionally, localized projects when properly evaluated can solve sediment problems without causing problems to other areas in the watershed.

Multiple dimensional modeling is now capable of adequately computing the hydrodynamics and sediment transport of a river reach to aid in developing a sustainable solution. The CCHE3D model was applied to the Hudson River in the vicinity of Yonkers, New York and specifically the docking area to evaluate means of moving the sediment through the area, in lieu of annual maintenance dredging. A submerged river dike was evaluated in the 3D model and found to be effective in keeping the sediment moving through the dock area. The river dike will be constructed of sand filled geotextile bags, or a soft dike. The soft dike concept has been utilized in other locations effectively and is less damaging to a commercial or recreational craft than would be a rock structure.

BACKGROUND

The industry has been located on the Hudson River at Yonkers, New York for over a century and

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has operated a docking facility for incoming shipments of goods. Dredging has been performed at the docking facility over the century on a periodic basis and more recently, in the last ten years has increased to requiring annual maintenance dredging. The maintenance dredging now averages between 40,000-80,000 cubic yards annually. To complicate the issues for the industry, the river sediments within the Hudson River are contaminated, primarily due to PCB's from an upstream site.

Figure 1. The Dock at Yonkers, New York.

OBJECTIVE

HYDROLOGY AND FLUVIAL PROCESS

The Hudson River is a large river with both fresh and salinity water. The Lower Hudson River (LHR), from Albany to Battery (153.7miles), is a tidal dominated estuary (Figure 2). This study reach is about 25 miles from the New York Harbor. The flow discharge and direction in the Hudson River near Yonkers oscillates with the tide and the tidal discharge is much higher than that of the base flow.

The main source of fresh water flowing to the LHR is from the Green Island Dam. Water from tributaries to the main channel of LHR is considered secondary in this study. The river channel is straight and is about one mile wide near the study site, Yonkers. The study reach is about five miles; the upstream end is at the USGS gage station Hastings, two and half miles from Yonkers, the other end is two and half mile downstream.

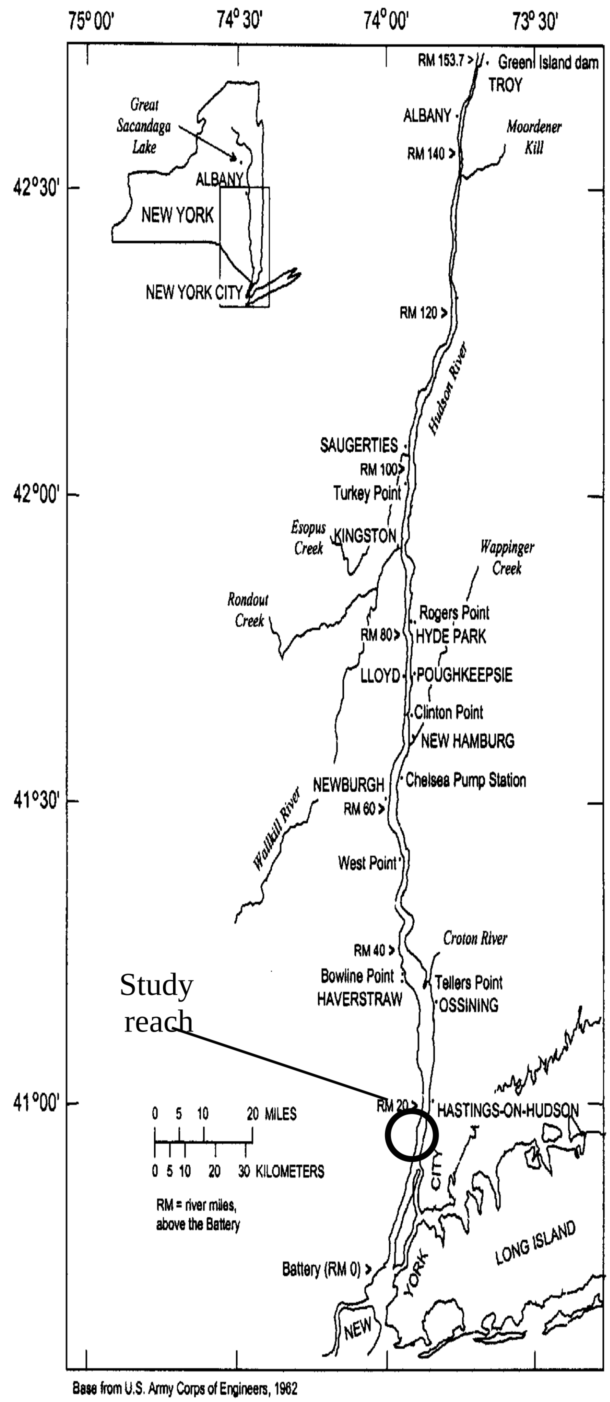

Figure 2. The Lower Hudson River

The sediment in LHR is mainly silt and clay, highly contaminated with PCBs. The exact size distribution of the sediment is unknown, it sediment is treated as cohesive material in our sediment transport study.

Because LHR is an estuary highly influenced by tidal flows, salinity of the river is also high, which also affect the sediment transport processes by forming flocs of cohesive sediment and speed up the fall velocity of the sediment. The studied reach is about 25 miles to the New York Harbor, salinity is high and it certainly is one of the factors to be considered in sediment transport.

The study site is at the left (East) side of the river near Yonkers, the Dock of American Sugar. The Dock is rectangular in shape and is concave in to the bank line.

APPROACH

MODELING

Numerical models have been applied to study the three-dimensional flow in the Dock and related sedimentation problems. Channel bed elevation measured in the study reach is used to generate the 3D grid.

Flow discharge in the LHR is determined by the tidal process: it is always unsteady. As a result, it is difficult to measure the discharges for such a large river continuously. Two-dimensional numerical simulations of tidal flow were conducted in the entire LHR to obtain the flow discharges. Because the 2D simulation was calibrated and validated with the tidal flow boundary conditions, its results also provided information such as bed roughness for the 3D simulation. The two-dimensional simulation for the LHR was based on data collected by the USGS (De Vries and Weiss, 2001). The bed elevation data from this report was for a one-dimensional model, the resolution in longitudinal and transversal direction of these bed elevation data was quite sparse.

Three-dimensional simulations were conducted in the 5 mile Yonkers reach. The final 3D mesh was very fine along the left side of the channel, and the density of cross-sections near the Dock was also much finer than either the upstream or downstream channel. Submerged dikes with different length, height, alignment angle and locations were tested to study if the flow pattern in the Dock can be altered. If yes, identify the dike parameters that can introduce more flow into the dock and therefore could minimize the sedimentation problem. Shear stress distribution is one criterion and the sediment deposition/erosion in the Dock is another. The preliminary simulation of the flow in the Dock indicated a large size eddy (recirculation). This eddy is driven by the main channel flow passing through the Dock opening. The eddy is generally responsible for carrying sediment in to the Dock and depositing in that area. In the shear layer between the main flow and the eddy, the flow velocity reduced dramatically and caused sedimentation along the Dock opening, apparently causing the ridge of the bed elevation. Because the tidal flow is periodical, the flow pattern in the Dock and the size and strength of the eddy vary with the main flow. The deposition in the dock area and at the ridge is an accumulation of the fluvial process. However, this ridge of sediment seems not to be a main concern because it is outside the dredge area. It is assumed that sedimentation outside the ridge would not affect the ship navigation.

The survey conducted at the end of April and early May, 2004 indicates some degree of deposition when compared with the data measured in Nov. 2003, after a dredging. However, resolution of the two surveys presents large differences when comparing along the survey lines of May 2004.

Simplification and approximation

Because the goal of the study is to identify the most effective dike design to reduce or eliminate sedimentation in the Dock, flow patterns of steady state of several flow discharges and corresponding sediment transport conditions are considered, instead of study the dike effect using unsteady tidal flow which could result in excessive computing time.

Because the dock in the Lower Hudson River is about 25 miles from the New York harbor, the wind waves from the sea are mostly damped. The wave effect including the local wind driven waves is assumed to be insignificant to the sediment transport processes and thus can be neglected.

Cohesive sediment transport and deposition are highly affected by the salinity of the water. The formation of flocs of cohesive sediment in the presence of high salinity will increase the settling or fall velocity of the suspended solids and thus accelerate deposition. To fully simulate the saltwater intrusion and related sediment flocculation using rigorous analysis is a more involved task, which is beyond the scope of this study. The flocculation process is approximated by using an empirical effective fall velocity which has been commonly accepted in practical engineering.

Critical shear stress of the cohesive sediment

Critical shear stresses for entrainment (re-suspension) of deposited cohesive sediment or its erosion are important physical parameters for modeling the interaction of the flow, suspended solids and sediment in the bed layers and the bed elevation change processes. The following table (Table 1) listed the values of measured critical erosion and deposition shear stresses and/or used in numerical modeling practices in the literature. These values vary for different cases, but they are quite limited in range. The critical stress measured in the Upper Hudson River from the TLMT Report was adopted for this study. The critical stress for the deposition should be smaller than that of the stress for erosion, which was taken as 0.08 (N/m^2), a rather conservative estimate.

Table 1. Critical shear stress for erosion and deposition of cohesive sediment

	τ_{ce} (N/m^2)	τ_{cd} (N/m^2)	Remarks
Krishnappan and Engel, 1994	0.121	0.0563	Rotating flume
Stoschek, et al. 2003	0.3	0.06	
Ji, et al. 2002	0.3	0.25	
TLMT Report, 2000	0.1		Upper Hudson River Data
The study	0.1	0.08	

Numerical simulations using CCHE3D

As we have pointed out, the flow induced by a submerged structure is highly three-dimensional and the three-dimensionality is important to understand how the submerged dike will change the flow in the dock zone and affect sedimentation processes. The three-dimensional simulations are therefore considered. Although this will significantly increase the efforts, it is necessary to accomplish the objective.

Many dike designs have been tested with uniform flow of Q=2,000, 5,000, 10,000, 15,000 and 20,000 m3/s. These design tests are useful for us to see the qualitative variation of flow in response to the installment of these dikes. These tests are more efficient in computing time, which allow us to examine the effectiveness of alternatives and select the most promising configuration.

The computation mesh has a very high density in the dock; it should be able to resolve needed flow patterns induced by the dike structures. Comparing the mesh used in the earlier study, this new mesh has a more accurate water edge line and bed topography. The bed in the dock zone is after dredging in Nov. 2003. The collapsed pier is preserved in the mesh.

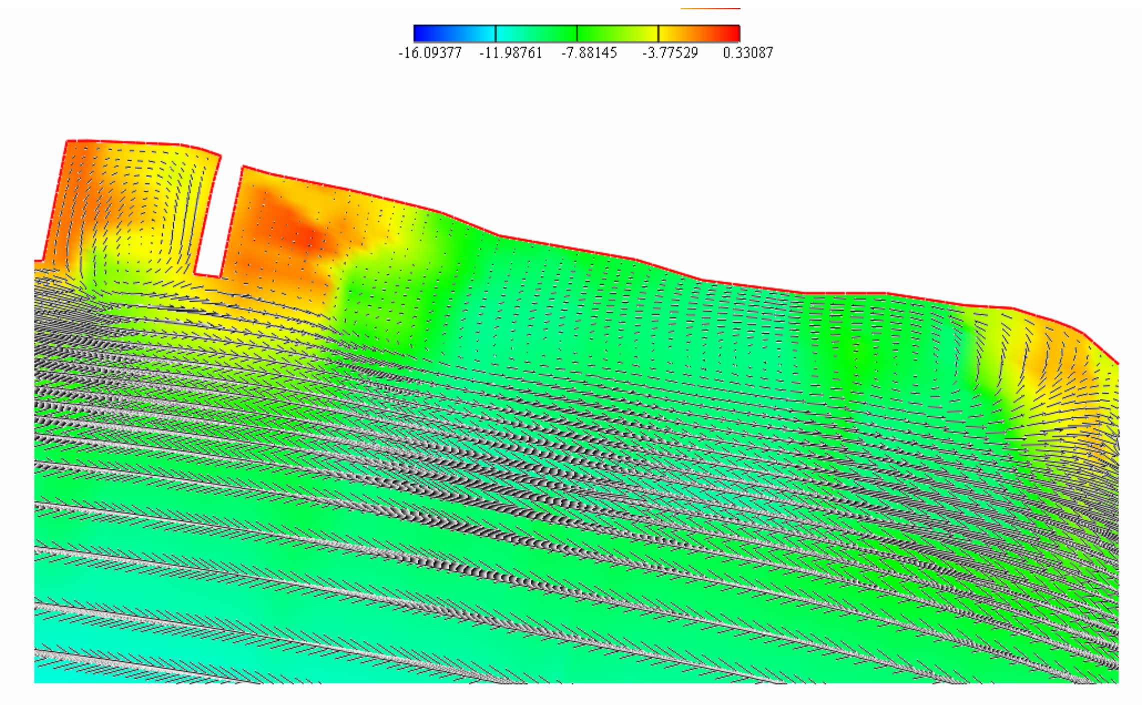

Figure 3 Velocity vector distribution and bed topography (m) in the dock zone

SOFTDIKE DESIGN

Design of a submerged dike with numerical simulations

As mentioned above, the submerged dikes are placed near the Dock and three-dimensional simulations are conducted to seek an optimal design. The study focuses on identifying a dike, which could increase the flow and shear stress in the Dock such that the sedimentation would be reduced or eliminated.

The dike is placed near the upstream end of the Dock. Its length, angle, height and location are the major parameters that should be identified using three-dimensional simulation.

The tests start by using one steady, ebb tide flow discharge.

The physical constraint of the dike is that the top height of the dike should not exceed 3.1m (10ft) below water surface.

The dike itself should not result in additional eddy or recirculation.

The dike should not have a negative effect in the flood tide periods.

More than thirty dikes with different combinations of parameters have been tested. It is apparent from these flow patterns that the dike design presented in Figure 4 produces the most desirable flow field. This flow pattern is the best because it could reduce the deposition near the dock. However, the flow velocity reduction behind the dike posts a slight problem because it may cause deposition.

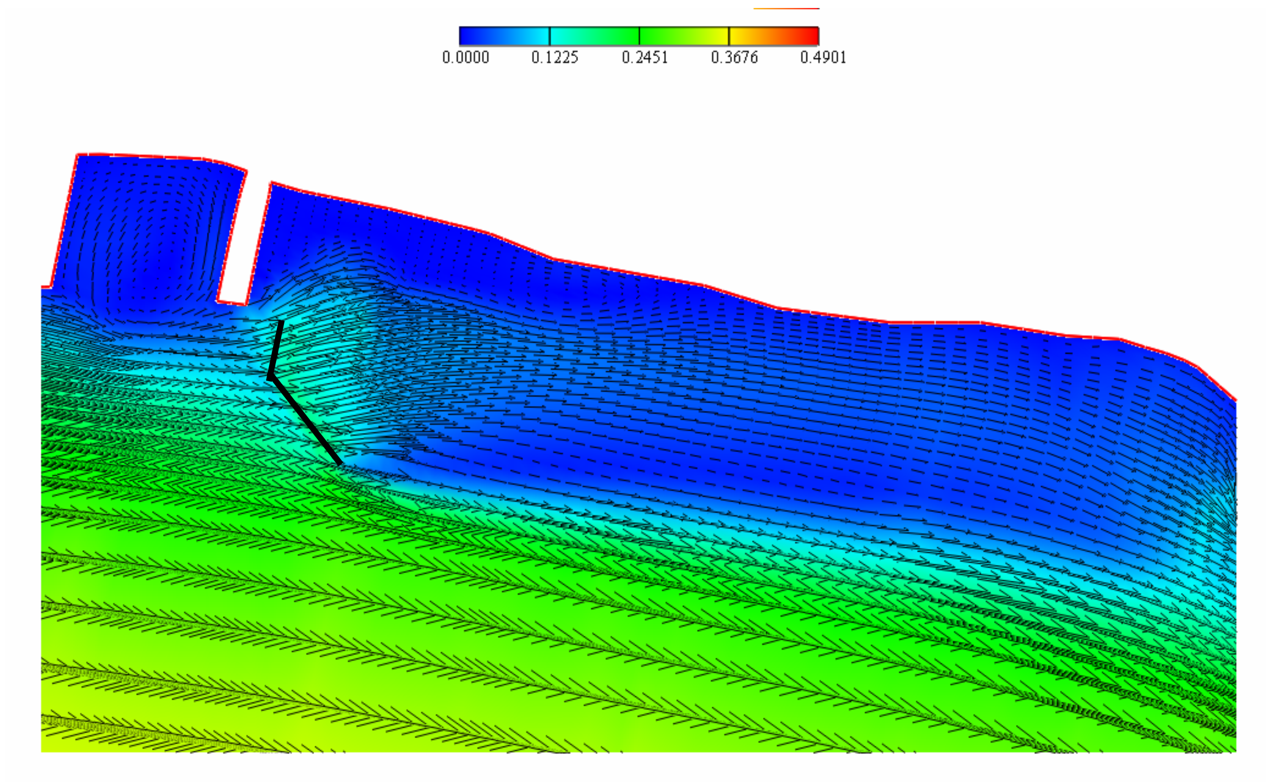

Figure 4 Velocity distribution for optimum dike design.

SUMMARY AND CONCLUSIONS

The study of the sedimentation problems on the Hudson River with the use of the 3-D hydrodynamic model demonstrates the effective use such a numerical tool to solve complex problems. Similar studies on other major rivers have also successfully applied multi-dimensional models to complex hydraulic problems.

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