1992

Verification Techniques Used in Modeling Charleston Harbor, South Carolina

Samuel B. Heltzel
US Army Engineer Waterways Experiment station

Published in Hydraulic Engineering: Saving a Threatened Resource—In Search of Solutions: Proceedings of the Hydraulic Engineering sessions at Water Forum '92.
Baltimore, Maryland, August 2–6, 1992. Published by American Society of Civil Engineers.

VERIFICATION TECHNIQUES USED IN MODELING CHARLESTON HARBOR, SOUTH CAROLINA

By Samuel B. Heltzel,[1] M. ASCE

Abstract

Verification to field data provides a means to assess a model's ability to reproduce behavior of the natural system being modeled. Often neither time nor funds are available to collect extensive sets of field data, and alternate techniques are required. This study used the results of a laterally averaged model to provide limited verification for a two-dimensional depth-averaged hydrodynamic and sediment model.

This numerical model investigation used the US Army Corps of Engineers TABS-MD numerical modeling system for open channel flow and sedimentation. Boundary conditions and a verification data set were obtained from the laterally averaged numerical model FIne-Grained Bed Sediment (FIBS).

The numerical model mesh used in this study is a comprehensive mesh of the Charleston Harbor system. Verification was very carefully conducted, and a sensitivity analysis was also performed on model parameters. This paper presents the results of this unique verification process.

Background

The South Carolina State Ports Authority (SCSPA) is evaluating development plans for additional port facilities in the Charleston Harbor/Cooper River for container vessels to dock and load and unload their cargo. The vessels will dock parallel to the berthing

[1]Research Oceanographer, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

facilities and be turned prior to exiting the Cooper River. The two facilities are referred to as Daniel Island and Clouter Creek. The proposed Daniel Island facility is to be located on the east side of Cooper River along Daniel Island. The proposed Clouter Creek facility is located on the east side of the Cooper River across from the North Charleston Terminal facility. Each facility will extend into and beyond the natural shoreline. Clouter Creek is a split facility; the I-526 bridge will separate the two portions of the terminal. Daniel Island is a continuous facility.

Objective

The primary objective of this study was to provide a preliminary evaluation of potential impacts to channel and facility shoaling and maintenance dredging requirements associated with the development of each site. These results were used for preliminary project planning.

Approach

This study was less detailed than a complete design analysis, which requires extensive field data collection and model verification. The basic approach was to modify available numerical models developed for other studies of Charleston Harbor area as a starting point to develop a model to specifically address the sedimentation objectives of this study.

The models included the US Army Engineers TABS-MD numerical modeling system for open-channel flow and sedimentation (Thomas and McAnally 1985). RMA-2 was used to develop depth-averaged hydrodynamic conditions for transport. STUDH was used to assess sedimentation resulting from the interaction of the bed and the depth-averaged hydrodynamics. Boundary conditions (water level elevations, discharge, and suspended sediment concentration) were obtained from the laterally averaged numerical model, (FIBS) (Teeter and Pankow 1989).

The individual tasks associated with the modeling effort included the following:

1. Modify the initial mesh to include a sufficient downstream ocean boundary and an adequate Cooper River upstream boundary condition for sedimentation modeling.

2. Make a run with FIBS to develop upstream discharge and downstream water-surface boundary conditions.

3. Run the numerical hydrodynamic model, RMA-2, and check results.

4. Run the numerical sedimentation model, STUDH, and check results.

5. Run two plan conditions with RMA-2 and STUDH.

6. Analyze model predictions.

Description of the Models

Sedimentation in the Cooper River was predicted using three mathematical models. A two-dimensional laterally averaged model, FIBS (Teeter and Pankow 1989), provided the boundary conditions for the two-dimensional vertically averaged hydrodynamic model, RMA-2. The hydrodynamic model, RMA-2, generated time-varying currents and water-surface elevations at computational nodes in a finite element numerical mesh representing Charleston Harbor. These hydrodynamics were used in a sediment transport model to solve the convection-diffusion and bed exchange equations. RMA-2 (A Two-Dimensional Model for Free Surface Flows) and STUDH (Sediment Transport in Unsteady 2-Dimensional Flows, Horizontal Plane) are included in the TABS-MD modeling system, which is supported by the US Army Corps of Engineers (Thomas and McAnally 1985).

Numerical Mesh

The initial computational mesh used was a modified version of a mesh previously developed for use in evaluating contraction dikes in Charleston Harbor. The mesh was modified to include a better resolution of the navigation channel and the proposed alternative terminal designs for development of the hydrodynamic data bases for the ship simulation study. This mesh was further modified for the sedimentation study by extending the lower portion of the mesh to the Atlantic Ocean and extending the upper portion of the mesh to mile 32 in the Cooper River. This mesh extension was undertaken to move the model boundaries further from the primary areas of interest, since sediment model predictions are generally more subject to error near the boundaries.

The revised mesh included definition for the two plan terminal configurations to eliminate mesh refinement between testing conditions. The two terminal designs and existing Federal channel were overlain on a computer-aided design drawing of these features to insure their accurate representation in the mesh. The mesh consisted of 2,522 elements with 8,206 nodes. The

outer portion of the training dike adjacent to the southern end of the Daniel Island facility was removed during the plan testing of this facility condition (i.e., it did not extend into the river from the edge of the facility).

Hydrodynamic Model Verification

Limited verification of the RMA-2 model consisted of comparing its surface elevations with those predicted by the FIBS model. This was done to assure proper tidal propagation. Discharge was also compared since the FIBS model predicted only laterally averaged velocity at different levels in the vertical, and direct comparison with the RMA-2 model could not be made.

The FIBS model tidal propagation was verified for the 15,600- and 4,500-ft^3/s base conditions using physical model results. The sediment transport model was verified to observed field shoaling rates under the conditions of 15,600-cfs inflow and a -35-ft mean low water project channel. The average annual maintenance dredging records from 1965-1984 were used for the shoaling verification.

During model verification the model coefficients subject to adjustment were bottom roughness, as represented by Manning's n value, and eddy viscosity coefficients. Normally, the Manning's value is assigned based on water depth and bottom conditions. However, for this study a single value of 0.020 was selected for use in the new part of the mesh. Coefficients in the old portion of the mesh were unchanged in this application (i.e., Manning's values varied from 0.025 in the shallow areas to 0.020 in the channel areas). To determine the best value for the eddy viscosity, sensitivity tests were started with a value of 25 lbf-s/ft^2 and increased by 5 until the model produced stable and reasonable results. A value of 50 lbf-s/ft^2 was selected as the final testing value.

Sediment Model Verification

Several model coefficients and parameters required adjustment during the verification process. The values were selected to allow the best practical limited verification process. The diffusion coefficients were specified at 10 m^2/sec for the x- and y-directions. The Crank-Nicholson time-stepping implicitness coefficient , theta, was set at 0.66, which is the recommended value for operation of STUDH. The time-step of 30 min used in RMA-2 was sufficient to maintain stability in STUDH. The hydrodynamics required by STUDH at each time-step were created through postprocessing of RMA-2 results. Boundary concentrations were the same boundary conditions used in FIBS. The process of model verification gave satisfactory results with a particle settling velocity of 0.1 mm/sec.

Numerical Hydrodynamic Modeling Results

Comparison of the two potential plan terminal sites showed substantial velocity differences when compared to the pre-expansion base conditions. Plan velocities in the Clouter Creek facility were generally low. Plan velocities in the main channel were generally lower than base velocities. Maximum velocities in the Daniel Island facility were greater than in the Clouter Creek facility. As with the Clouter Creek facility, the Daniel Island expansion generally reduced the main channel velocities.

Numerical Sediment Transport Modeling Results

Sedimentation rates are generally sensitive to small variations in hydrodynamics. Reduced velocities associated with increased cross-sectional area tend to increase shoaling rates in areas of sediment transport as a result of reduced energy and transport capability. The sediment transport model, STUDH, demonstrated the probable sedimentation change to be expected for each of the two terminal designs. Table 1 provides the predicted shoaling index summary values for the designated Federal channel and facility area illustrated in Figure 1. As indicated, each of the plan conditions resulted in increasing the shoaling volume and rate. Therefore, the required maintenance dredging requirement will be greater in the designated part of the Federal Channel. Shoaling in the Federal Channel in the Daniel Island area with the developed Daniel Island facility was predicted to increase by about 48 percent, and shoaling in the Federal Channel in the Clouter Creek area with both Clouter Creek terminals developed was predicted to increase by about 68 percent.

Acknowledgments

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research sponsored by the South Carolina States Ports Authority and conducted by the US Army Engineer Waterways Experiment Station, Vicksburg, MS. Permission was granted by the Chief of Engineers to publish this information.

TABLE 1. Shoaling Index

Facility (1)	Base (2)	Plan (3)	Percent Increase (4)
Daniel Island			
Channel	1.0	1.48	48
Channel and Terminal	1.0	3.28	238
Clouter Creek			
Channel	1.0	1.68	68
Channel and Terminal	1.0	4.27	327

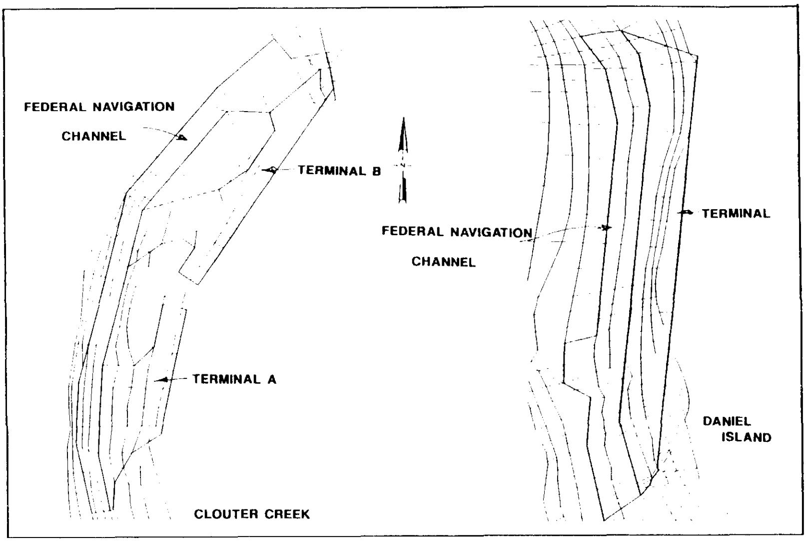

Figure 1. Sedimentation Comparison Location Map

APPENDIX I. REFERENCES

Teeter, A. M., and Pankow, W. (1989). "Schematic numerical modeling of harbor deepening effects on sedimentation, Charleston, South Carolina." Miscellaneous Paper HL-89-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thomas. W. A., and McAnally, W. H. 1985. "A system for numerical modeling of open-channel flow and sedimentation, TABS-2 User's Manual." Instruction Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.