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HYDRAULIC MODELING FOR BRIDGE SCOUR ANALYSES IN TIDAL WATERWAYS

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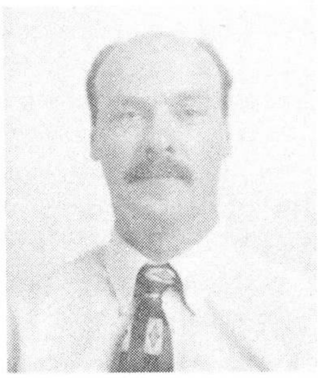

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SUMMARY
Tidal waters are subjected to dynamic flow conditions caused by daily (astronomical) tides, ocean currents, storm surges, and upland runoff. Accurate hydraulic information is necessary for calculating scour at bridge crossings, assessing channel stability, and designing bridge foundations and countermeasures. This paper presents guidance on simulating bridge hydraulics in tidal waterways. Selection criteria for 1- and 2-dimensional hydraulic models for tidal waterways are presented, and guidance is provided for developing appropriate boundary conditions.

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1. INTRODUCTION

Tidal waters are subjected to dynamic flow conditions caused by daily (astronomical) tides, ocean currents, storm surges, and upland runoff. Highway encroachments are subjected to stream instability and foundation scour resulting from these dynamic flow conditions. Although simplified methods for determining tidal hydraulic conditions often provide useful and reasonable results, complex hydraulic conditions may require unsteady flow computer modeling. Computer modeling is the most accurate method for determining the hydraulic conditions for extreme hurricanes that cause scour at many tidally affected bridge crossings.

In 1993, 12 east coast State Highway Agencies in the United States initiated a study to develop computer models to analyze coastal waterway hydraulic conditions at highway structures [1]. Phase I focused on three tasks: (1) compile a database of literature on tidal processes and computer models, (2) evaluate sources and methodologies for determining ocean tide and storm surge hydrographs, and (3) evaluate which computer models are best suited for use by bridge engineers for tidal hydrodynamic and scour investigations. Task 2 included determining the storm tide hydrograph, which consists of the storm surge height, the duration of the rise and fall, and superimposing the storm surge hydrograph on daily tides. Task 3 included accurate representation of bridge, culvert, and embankment overtopping hydraulics.

Phase II of this study [2] focused on three tasks: (1) developing storm surge hydrographs for the east and gulf coasts of the U.S., (2) developing case studies and testing selected models, and (3) developing a users manual and providing training. This paper summarizes model selection criteria and boundary condition generation methodologies developed during this study, and provides references to resources available for bridge scour analyses in tidal waterways.

2. MODEL SELECTION

The modeling approach should be selected based on the geomorphic and hydraulic characteristics of the tidal waterway [3]. Depending on the application, a simple tidal prism or orifice approach could be used. These approaches are presented in HEC-18 [4]. At times, a steady-state hydraulic model, based on the worst-case conditions determined from a simplified procedure, can be used to obtain conservative hydraulic parameters for scour analysis.

When the use of more sophisticated approaches is necessary, the model and approach will also vary depending on the site geomorphic conditions and hydraulic complexity. In Phase I of this study, 21 models were reviewed to determine their applicability to tidal bridge hydraulic and scour studies. It was anticipated that several models would be needed to efficiently model the range of conditions which are encountered in tidal waterways. One-, two- and three-dimensional models were evaluated.

Of the 21 original models, four were subjected to detailed evaluation. These included two 1-dimensional and two 2-dimensional models. The 1-dimensional models were DYNLET1 [5] and UNET [6]. The 2-dimensional models were FESWMS [7] and RMA-2V [8]. Each of the four models performed well for tidal hydraulic modeling. The models replicated observed tide gage readings well, generally within 0.12 m. The 1-dimensional models were easier to set up and ran much faster than the 2-dimensional models. Calibrated Manning n values for the inlet and bay areas were similar for all the tested models. The 1-dimensional models produced similar results to the 2-dimensional models, although it was anticipated that many complex hydraulic situations would require 2-dimensional modeling.

Because analyzing the hydraulics and scour potential at highway structures was the focus of the study, tests were performed of flow through culverts and bridges and over embankments. RMA-2V contained limited structure hydraulic analysis capabilities which consist of specifying various types of rating curves at structure locations. Since the specific geometric characteristics of a structure are not included directly as input, RMA-2V was not included in the structure hydraulic tests. The other models use various methods for computing structure hydraulics, and their performance varied significantly. UNET provided the best structure hydraulic computations. FESWMS performed well for embankment overtopping flows and some culvert conditions, but did not give reasonable results for bridge pressure flow. Of the three models tested for structure hydraulics, DYNLET1 gave the least acceptable structure hydraulic analysis.

Based on the results of the hydraulic tests, UNET (1-D) and FESWMS (2-D) were recommended for use in tidal hydraulic modeling of bridges. UNET was selected because it accurately simulates tidal and structure hydraulics. In comparison to the other models, UNET is most capable of modeling very long river reaches, including branched and looped channel networks. DYNLET1 performed well on tidal hydraulics, but was not as powerful as UNET, did not simulate structure hydraulics as well, and ran much slower than UNET. FESWMS was selected because it accurately simulates tidal hydraulics, adequately simulates many structure hydraulic conditions, and is well suited for simulating complex flow conditions. FESWMS has enhanced pre- and post-processing software [9]. RMA-2V is also well suited for tidal hydraulic modeling, and also has advanced pre- and post-processing systems. RMA-2V is currently being enhanced to include structure hydraulics. Once these enhancements are complete, FESWMS and RMA-2V will have comparable capabilities, and model selection will depend on site specific conditions of the waterway to be analyzed.

For tidal hydraulic modeling, the selection of the model and approach should be directed toward obtaining accurate results for the specific site conditions. Simplified methods have provided reasonable results for many locations with relatively little effort. More complex methods should be used when the limitations of the simplified approaches produce overly conservative, and often costly, results. UNET, DYNLET, FESWMS and RMA-2V have all been successfully applied to many complex tidal applications.

3. BOUNDARY CONDITION DEVELOPMENT

Tidal hydraulic studies require estimates of tide and storm surge stage hydrographs as boundary conditions. Upstream flood hydrographs may also need to be included, as well as wind stresses for some applications.

The Federal Emergency Management Agency (FEMA) and National Oceanographic and Atmospheric Administration (NOAA) publish peak storm surge elevations related to the frequency of occurrence or hurricane severity. Because FEMA's focus is on flooding potential, maximum surge elevations are reported, but the storm tide hydrographs are not available. NOAA reports peak surge elevations for each class of hurricane for use by emergency managers. Although the NOAA data provide an alternative to the elevations reported by FEMA, storm tide hydrographs are also not available from NOAA.

To address the fact that NOAA and FEMA provide peak surge height only and not the full hydrograph, Cialone et al. [10] reported a procedure for developing surge hydrographs from available information. The storm tide (storm surge combined with the daily tide) is computed as

$$S_{tot}(t) = S_p\left(1 - e^{-\left|\frac{D}{T-t}\right|}\right) + H_t(t) \tag{1}$$

where S_p is the peak surge height, D is the storm duration (defined as the radius of maximum winds divided by the storm forward speed), T is the time of the peak surge, t is time, and $H_t(t)$ is the daily tide component. Excluding daily tides results in a storm surge hydrograph symmetrical about time T. Depending on when the surge is assumed to occur during the daily tide, Sp is adjusted to produce a selected extreme condition, $S_{tot}(t)$, from NOAA or FEMA data.

Equation 1 was tested to see if it adequately predicted the shape of storm surge hydrographs. The ADCIRC [11] 3-dimensional model has been used to simulate numerous hurricanes along the east and gulf coasts. In the ADCIRC model, the surge is a result, not an input, so comparing the ADCIRC results with equation 1 is a reasonable test of the equation. Figure 1 shows the twelve largest storm surges predicted by ADCIRC for a 104 year historic record at Sapelo Sound on the Georgia Coast. Also shown is the 100-year surge predicted using equation 1. The daily tide is excluded from all of the hydrographs. The equation appears adequate for use in developing surge boundary conditions. The primary drawback of equation 1 is that negative surge elevations, due to offshore wind, are not predicted.

Judgment and experience are needed to determine whether extreme upland runoff should be included in a storm surge simulation. Where the timing of upland flooding is independent of the timing of the hurricane storm surge, average daily flow should be used as an upstream inflow condition. Where extreme upland runoff is generated by the hurricane conditions <u>and</u> the runoff can reach the tidal waterway during the surge, a more extreme upland flow could be included.

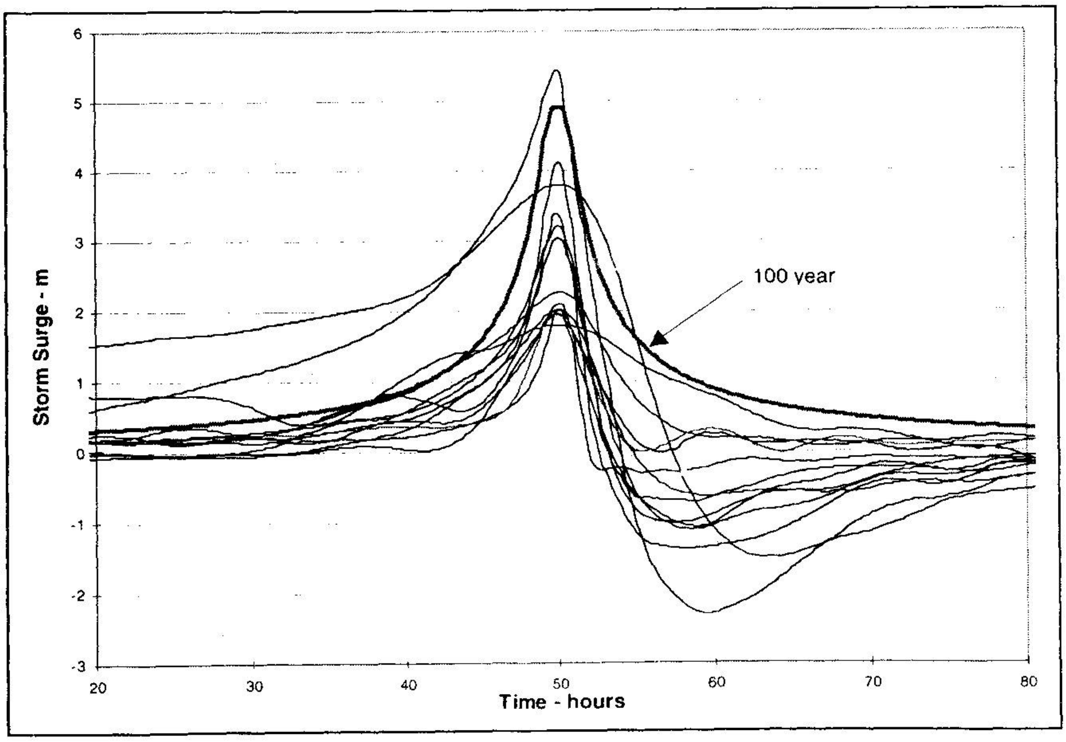

Figure 1. Comparison of design hydrograph with computed historic hydrographs.

4. RESOURCES AVAILABLE IN THE UNITED STATES

The primary product of the east and gulf coast study was a Users Manual for tidal hydraulic modeling of bridges [12]. The manual includes guidance on model selection, model development, data on hurricane characteristics, and case studies illustrating boundary condition development and the use of UNET and FESWMS. Also developed as part of this study is a CD-ROM which contains the selected models, electronic versions of the manuals, the case study input files, data and utility programs for model development and scour calculations.

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