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APPLICATION OF THE U.S.G.S. DIFFUSION HYDRODYNAMIC MODEL FOR RIVER OVERFLOW FLOODPLAIN ANALYSIS

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ABSTRACT

The two-dimensional Diffusion Hydrodynamic Model, DHM, is applied to the evaluation of floodplain depths resulting from an overflow of a leveed river. The environmental concerns of flood protection and high flow velocities can be studied with the help of the two-dimensional DHM flow model than by use of the one-dimensional modeling techniques. In the considered test case, some of the predicted flood depth differences between the DHM and the one-dimensional approach (i.e., HEC-2) are found to be significant. Although the DHM generates considerable information, it is easy to use and does not require expertise beyond that required for use of the one-dimensioanl approaches.

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INTRODUCTION

The main objective of this paper is to review the findings of a detailed study of the Santa Ana River 100-year event floodplain in the City of Garden Grove, California, using the two-dimensional Diffusion Hydrodynamic Model (DHM) (Hromadka, 1985, Hromadka et al, 1985, Guymon and Hromadka, 1986, Hromadka and Durbin, 1986, Hromadka and Nestlinger, 1985, Hromadka and Yen, 1986, Hromadka and Yen, 1987).

The local terrain slopes southwesterly at a mild gradient (i.e., 0.4%) and is fully developed with mixed residential and commercial developments. Freeway form barriers through the study site so that all flows are laterally constrained with outlets at railroads and major streets crossing under the freeways. Because of the flood flow conveyed through the floodplain and the mild cross sectional terrain, the floodplain analysis needs to include two-dimensional unsteady flow effects.

DESCRIPTION OF THE DHM

The DHM provides the capability to model two-dimensional unsteady flow where storage effects and diverging flow paths are important, and hence, the steady state one-dimensional flow approach may be inappropriate.

The two-dimensional unsteady flow equations consist of the equation of continuity;

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial z}{\partial t} = 0 \qquad (1)$$

and two equations of motion;

$$\frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q_x^2}{Ax}\right) + \frac{\partial}{\partial y}\left(\frac{Q_x Q_y}{Ax}\right) + gAx\left[S_{fx} + \frac{\partial h}{\partial x}\right] = 0 \qquad (2a)$$

$$\frac{\partial Q_y}{\partial t} + \frac{\partial}{\partial y}\left(\frac{Q_y^2}{Ay}\right) + \frac{\partial}{\partial x}\left(\frac{Q_x Q_y}{Ay}\right) + gAy\left[S_{fy} + \frac{\partial h}{\partial y}\right] = 0 \qquad (2b)$$

in which t is time, x and y (and the subscripts) are the orthogonal directions in the horizontal plane; q_x and q_y are the flowrates per unit width in the x and y directions; z is the depth of water; Q_x an Q_y are the flowrates in the x and y directions, respectively; h is the water surface elevation measured vertically from a horizontal datum; g is the acceleration of gravity, Ax and Ay are the cross sectional areas; and S_{fx} and S_{fy} are the friction slopes in the x, y directions. The DHM utilizes the uniform grid element to model the two-dimensional unsteady flow, therefore, Ax and Ay ar defined as the length of uniform grid element times the depth of water.

The friction slopes S_{fx} and S_{fy} can be estimated by using Manning's formula;

and $$S_{fx} = \frac{n^2 Q_x^2}{C^2 Ax^2 R_x^{4/3}} \qquad (3a)$$

$$S_{fy} = \frac{n^2 Q_y^2}{C^2 Ay^2 R_y^{4/3}} \tag{3b}$$

in which n is the Manning's roughness factor; R_x R_y are the hydraulic radiuses in x, y directions; and the constant C = 1 for SI units and 1.486 for U.S. Customary units.

In the DHM, the local and convective acceleration terms in the momentum equation (i.e., the first three terms of Equation 2) are neglected (Akan and Yen, 1981). Thus Equation (2) is simplified as;

$$S_{fx} = -\frac{\partial h}{\partial x} \tag{4a}$$

and

$$S_{fy} = -\frac{\partial h}{\partial y} \tag{4b}$$

Combining Equations (3) and (4) yields;

$$Q_x = \frac{C}{n} Ax\, R_x^{2/3} \frac{\left(-\frac{\partial h}{\partial x}\right)}{\left|\frac{\partial h}{\partial x}\right|^{1/2}} \tag{5a}$$

$$Q_y = \frac{C}{n} Ay\, R_y^{2/3} \frac{\left(-\frac{\partial h}{\partial y}\right)}{\left|\frac{\partial h}{\partial y}\right|^{1/2}} \tag{5b}$$

which may account for flows in both positive and negative x and y directions. The flowrates per unit width in the x and y directions can be obtained from Equation 5 as;

$$q_x = \frac{C}{n} Z\, R_x^{2/3} \frac{\left(-\frac{\partial h}{\partial x}\right)}{\left|\frac{\partial h}{\partial x}\right|^{1/2}} \tag{6a}$$

$$q_y = \frac{C}{n} Z\, R_y^{2/3} \frac{\left(-\frac{\partial h}{\partial x}\right)}{\left|\frac{\partial h}{\partial x}\right|^{1/2}} \tag{6b}$$

Substituting Equation (6) into Equation (1) gives;

$$\frac{\partial}{\partial x}\left[\frac{C}{n} Z R_x^{2/3} \frac{\left(-\frac{\partial h}{\partial x}\right)}{\left|\frac{\partial h}{\partial x}\right|^{1/2}}\right] + \frac{\partial}{\partial y}\left[\frac{C}{n} Z R_x^{2/3} \frac{\left(-\frac{\partial h}{\partial y}\right)}{\left|\frac{\partial h}{\partial y}\right|^{1/2}}\right] + \frac{\partial h}{\partial t} = 0$$

or

$$\frac{\partial}{\partial x}\left[K_x \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y \frac{\partial h}{\partial y}\right] = \frac{\partial h}{\partial t} \tag{7}$$

where

$$K_x = \frac{C}{n} Z R_x^{2/3} \Big/ \left|\frac{\partial h}{\partial x}\right|^{1/2}$$

In general, the DHM is used for floodplain analysis because this approach is capable of handling unsteady backwater effects in overland flow, unsteady overland flow due to constrictions, such as culverts, bridges, freeway underpasses, and so forth, unsteady flow overland flow across watershed boundaries due to backwater and ponding flow effects. In general, several important types of information can be generated from the DHM analysis. These include: (1) the time versus flood depth relationship; (2) the flood wave arrival time; (3) the maximum flood depth arrival time; (4) the direction and magnitude of the flood wave; (5) the stage versus discharge relationship; and (6) the outflow hydrograph at any specified grid element within the study area.

CONCLUSIONS

The DHM (1987), which provides another tool for floodplain management, was published by the U.S. Geological Survey as a Water Resources Investigation Report (87-4137). The flow path reduction factor and the effective grid area were added to the DHM (1987) for a more realistic representation of the field conditions.

Because the DHM provides a two-dimensional hydrodynamic response, use of the model eliminates the uncertainty in predicted flood depths due to the variability in the choice of cross sections used in the one-dimensional models. That is, model users might select a cross section perpendicular to the direction of flow, but on urban areas the selection becomes somewhat arbitrary. Additionally, the DHM accommodates both backwater effects and unsteady flow, which are typically neglected in HEC-2 (1973) floodplain analysis.

NOTICE

The computational results shown in the paper are to be used for research purposes only. No governmental approval of the results shown are to be construed nor implied.

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