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Bifurcation Simulation Modeling Review

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Abstract

This paper reviews the advances made on studies related to bifurcation. Bifurcation has been an area of interest by researchers in hydraulics, hydrology and river engineering disciplines. This paper reviews the findings of nearly 10 years of researches into modeling bifurcation system with numerous simulation techniques. Efforts have been made to simulate behavior of bifurcation through the uses of numerical and physical models. The numerical approach under the pretext of computational fluid dynamic is an approach that uses the fundamental theory of fluid mechanics and hydraulics that simulates flow behavior.

Keywords: bifurcation; modeling simulation; numerical model; physical model.

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1. Introduction

The use of computational models to simulate and predict bifurcation has gained popularity among researchers as compared to physical models. This is due to some consideration that namely the nature of the problem that needs to be solved, the availability resource, overall cost and issues relating the temporal and spatial scales. The combination of physical and computational models may give a better understanding of the process under investigation for specific problem. Few advantages of modeling are that it can adapt to the different physical domains more easily than physical model, constructed to represent site specification condition. Besides it was not subject to distortion effects of physical models when a solution can be obtained for the same flow conditions. The objective of this paper is focused on multidimensional computational model (1D, 2D and 3D models) software that had been used by many researches in their study that simulates the flow and sediment transport.

1.1. Governing equations

This section provides description of model formulation, spatial and temporal characteristics. It may also provide the useful information about the model capabilities to handle unsteady flow, bed load, suspended load and multifractional sediment transport. The 1D Model are formulated in a rectilinear coordinate system and solve the differential conservation equations of mass and momentum of flow (St. Venant flow equations) along with the sediment mass continuity equation (the Exner equation) by using finite-difference schemes. Most of the 2D models are currently available to the hydraulic engineering community as interface-based software to allow easy data input and visualization of results. This extra capability has made these models user-friendly and popular. 2D models are depth-averaged models that can provide spatially varied information about water depth and bed elevation within rivers, lakes, and estuaries, as well as magnitude of depth averaged streamwise and transverse velocity components. Most 2D models solve the depth-averaged continuity and Navier-Stokes equations along with the sediment mass balance equation with the methods of finite difference, finite element, or finite volume. In many hydraulic engineering applications, one has to resort to 3D models when 2D models are not suitable for describing certain hydrodynamic or sediment transport processes. Most 3D models solve the continuity and the Navier-Stokes equations, along with the sediment mass balance equation through the methods of finite difference, finite elements or finite volume [1].

1.2. CCHE2D Model

The CCHE2D is a two-dimensional depth-averaged, unsteady, turbulent flow model with nonuniform sediment and conservative pollutant transport capabilities. An efficient element scheme of it is an integrated package for simulation and analysis of free surface flows, sediment transport and morphological processes. There were two types of analysis pattern that is a mesh generator (CCHE2D Mesh Generator) [2] that can generate the mesh of the studied area while the second one is a Graphical Users Interface (CCHE2D Generator-GUI) [2] that is a visual interface.

The authors in [3] investigate the sediment pattern using mathematical and physical model and the finding of this study can be applied to design the workable structures which can minimized the sedimentation problem at Ijok intake. Using CCHE2D to simulate the flow behaviour (specific discharge, shear stress, velocity magnitude and distribution) and sediment transport (sediment transport rate, grain size distribution, bed and bank changes). The result shows that Froude number (Fr) that approaching 1 gave the similarity values between physical and mathematical model. Both model indicate that the sediment start to accumulate at location in front of the intake structure. Simulation of sediment pattern showed accumulation at locations after the weir without intake structure and before the weir with intake structure. CCHE2D simulation predicts more bed changes for physical model with structure compare to without structure.

Simulation of flow field was done by [4] for the Tarbela Reservoir on the Indus River, Pakistan. Initial Water Surface Level is important as model will not do any execution if the initial water level is too low as it will leave too many dry nodes. Other parameters such as Input and Output Hydrographs, Bed Load Adaptation Length, porosity, Suspended Sediment Concentration, Bed Load Transport rate, Sediment Size Classes and Manning's coefficient was identified in the model calibration using measured field data. The findings indicate that all variables and constants that were used to calibrate the model gave reasonably good simulated results. Results of simulation may not be favorable at low flows.

Flow and sediment pattern in rivers had been simulate by [5] with the assumption that the flow is unsteady for 25 and 50 years flood event. They study on the effects of parameters like velocity, shear tension, water surface profile on the bridge range and river arch. Velocity, Froude number and shear stress for 50-year flood are more than 25-year flood. It concluded that suspended sediment, bed load discharge, sediment deposit and erosion volume for the 50-year flood are more than that of the 25-year flood.

The authors in [6] studied the capability of CCHE2D Model in simulating the flow field in Nile River. The main parameter involved in the model and affecting the flow field is the bed roughness parameter. Analysis was done by CCHE2D on bed level and velocity. It had proven that Van Rijn numerical formulae showed better efficiency in determining the bed roughness and to predict the depth averaged flow velocity compared to Wu and Wang formulae. It was found that the outputs of CCHE2D model using roughness height (Ks) is well verified and an accurate tool to predict the averaged flow velocity along Nile River and its branches in comparison with that use Manning's (n) parameter.

The authors in [2] simulated the flow movement using the example of Yudu reach in Yangtze River as to study the characteristics of flow movement in the bending and bifurcated river including the cross sectional velocity distribution and the water surface longitudinal slope along and with flows. It studies the distinction of location of the dynamic axis of flow and the top spot of river bank with discharge variation. The flow movement under different intro-annual discharge is simulated using the landform of April 2005. 5 groups of inlet flow data are selected, and the outlet water level was extract by relationship between the water level of Baiyang gauge station and the discharge of Yichang hydrologic station. Findings stated that the main characteristics of the variation of the maximum velocity along the flow is that the velocity at section 2 in the bifurcation region in the inlet of the bending reach upstream is lower than the other reaches downstream. According to the distribution of velocity along the flow, the transverse distribution of velocity differs with reaches, on one hand; on the other, the variation of distribution of velocity differs with the increase in discharge. According to the variation of water surface longitudinal slope, the variation law of water surface slope varies in different reaches and changes with the variation in discharge.

The authors in [7] carried out a study on the hydraulics and sediment transport of Ijok intake to simulating the turbulent, free surface flow in open channels, sediment transport, channel morphological changes, bank erosion water quality evaluation, total load, bed load and suspended load. Data required is geometry data obtained by surveying of cross section, flow discharge to calculate the Manning's number and to establish stage–discharge rating curve and sediment data that include bed material, bed load and suspended load. Bed load transport was used to determine the suitable equation used in the model. Bed load occurs at non equilibrium stage. They use the Engelund and Hansen equation due to discrepancy ratio (DR) within range 0.5 to 2.0. Sediment properties: sediment grain size, specific gravity 2.65, grain shape factor 0.7, bed material porosity. They found that the velocity is higher at the meandering area near the left bank compared to right bank due to the presence of the weir at the left bank. Shear stress concentrates at the left bank and at the upstream portion and decrease gradually to the downstream portion. Sediment pattern accumulate in front of Ijok intake that has low velocity. Erosion occurs at inner side of river bank where the higher velocity and shear stress were identified. Higher erosion rate occur immediately after the weir due to turbulent water flow. Results have shown good agreement between the measured and computed values.

1.3. CAESAR Model

The two dimensional flow and sediment transport model that can simulate morphological changes in river catchments or reaches, on a flood by flood basis over periods up to several thousands of years. There were few models develop by modification of CAESAR model by enhancing the flow routing, sediment transport, sediment suspension and lateral erosion. These new routines allow simulation of point bar formation, floodplain deposition (splays and levees), river bank erosion, channel migration, and terrace formation. CAESAR can be run in two modes: a catchment mode, with no external influxes other than rainfall and a reach mode, with one or more points where sediment and water enter the system. In both modes the model requires the specification of various spatially distributed landscape parameters.

The authors in [8] produced first imitation of the model that showed extension of all the meander bends, with tighter bends exhibiting more erosion due to the lateral erosion patterns that comes from eroded material swept away from the system, and deposited material 'appears' on the inner bend. Some of the difficulties encountered is to illustrate the inside bend deposition. Erosion at the outer bank can be used to determine a cross-stream gradient of curvature that is used to calculate lateral sediment flux. The cross-stream movement of sediment creates a narrower, better-defined channel, and also forms point bars on the inside edge of meander bends and a meandering thalweg within the channel. Both methods are successful in demonstrating how lateral erosion can be simulated in a CA framework. It consisted of two different algorithms to simulate deposition and the redistribution of sediment within the channel, both of which have flaws. The first approach fails to maintain the sediment mass balance and has little or no basis in the depositional processes that operate within river channels, yet produces visually appropriate results. The second, more successful method has a better grounding and implements a simple algorithm for lateral or cross-stream circulation patterns, which are thought to govern the deposition of material on point bars. Indeed, this method leads to the development of such features, which in itself is a significant step in the enhancement of cellular river models.

The authors in [9] modified CAESAR to improve the representation of hydraulic and geomorphic processes in an alluvial environment. The modification to the present CAESAR model were made in terms of model structure that use variable length time steps depending on the erosion and deposition and generate the output data such as elevations, sediment distributions through space with time, discharge and sediment fluxes at outlet. Flow routing that have high resolution grids allow the channel exceeds the grid cell size. Sediment layer that is bedrock layer is fixed and cannot be eroded. Introduced lateral erosion that shows the erosion and deposition of sediment due to hydraulic condition. The findings indicated that incorporates a lateral erosion scheme that allows the new CAESAR to simulate transition of braided to meandering and determine control factors of this phenomenon. However, this new model pose some limitations Introduction of new parameter and data requirement that warrants further investigation. The lateral erosion algorithm simulating the symptoms rather than the cause. Unrealistic for natural rivers consist multiple layers of river bed with equal thickness. This model is too simple for detailed predictions whereas too complex for exploratory research.

The authors in [10] had conducted a study on the predictions of hydraulics model that solves the shallow water form of the Navier Stokes equations. Design model that minimizes the problem by CA and generate more realistic predictions of flow redistribution in multi channel environment. CRS predict the distributions of flow over regular topographic grid. In this study the simulation was done for the braided river of Avoca River. It concluded that Cellular Routing Scheme (CRS) simplify the CA model by routing the discharge into boundary cell so that it distributes to five immediate downstream cells that allow lateral transfer of water at 60° angle. The routing potential determined by calculation of depth of flow at the cell from which water is being routed with parameter f (routing constant proportional to the ratio of slope roughness) and m (slope exponent = 0 and 0.5) provided. If higher values of f and m, promote stronger routing of discharge to low points on the bed. CRS able to replicate the flow patterns observed in the field at low discharge.

1.4. DELFT3D and RIVER2D Modeling

The Delft3D-FLOW model computes flow characteristics (flow velocity, turbulence) dynamically in time over a three-dimensional spatial grid. The model is based on a finite-difference solution of the three-dimensional shallow-water equations with a kappa (k–e) turbulence closure model. River2D is a two-dimensional (2D) depth-averaged hydrodynamic model developed by the University of Alberta. River2D applies the Finite Element Method to solve the 2D depth averaged St. Venant Equations. The computational mesh is unstructured (irregular) and composed of triangular elements that can easily accommodate complex planform geometries of almost any type. For every node (vertex of a triangular element) in the computational domain, River2D computes the values of water depth h and depth-averaged velocity components (u,v) in the two respective coordinate directions (x,y).

The authors in [11] used River2D to computes the values of water depth h and depth-averaged velocity components (u,v) in the two respective coordinate directions (x,y) The unstructured Finite Element mesh was used to simulate flow through diversions for two challenging test cases: An acute 30°diversion with sharp corners and a 90° diversion with a very small width-depth ratio. It is found that River2D is not recommended for deep and narrow rivers as frictions of the bed cannot be considered. Changes in the default values of River2D may result in a different turbulence generating mechanism in the diversion. River2D allows automatic mesh refining based on the computed flow field after a hydrodynamics solution has been achieved. The bifurcation occurred when the deposition due to disproportionate amount of bed load sediment.

The authors in [12] identified spatial sedimentation and erosion patterns developing within patches of epibenthic structures (i.e. physical structures that protrude from the sediments, originating either from animals or plants) as a consequence of biophysical interactions. The finding of Delft3D-Flow that use to simulate the turbulence and flow velocity over a three dimensional spatial grid above the bamboo patches indicate that erosion and sedimentation patterns can be illustrated through simulation of spatial patterns of bed shear stress within and around the bamboo patches.

2. Conclusion

In conclusion this review facilitates the identification of suitable simulation technique which can be used in the future study. This review can be useful as it provides some insight of the available models to simulate bifurcation of which further improvement are very much required. Examination on the features of the different models of the different models has indicated that CAESAR is the most acceptable and appropriate to be used for the intended study. Not with standing some limitation the model posed in the modeling works, some enhancement on the algorithm are encouraged.

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