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Numerical Analysis of Velocity Distribution in A Meandering Compound Channel

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Abstract : *Rivers are one of the most important sources of water which are continuously changing. It is very important to identify and recognize factors which affect the behavior and morphology of the river or channel such as the form of Meander River, waterway geometry, the shape of the channel bed and the profile of the channel. In particular, these factors are valuable for meandering compound channel which have unsteady flow patterns. In this study, the present research work utilizes the flume facility available in the Fluid Mechanics and Hydraulic Engineering Laboratory of the Civil Engineering Department at the National Institute of Technology, Rourkela, which has a sinusoidal-like turn is analyzed using CCHE2D. Commonly, for being done a numerical modeling of any natural phenomenon, like as water flow pattern, need to an exquisite and modify calculated mesh. Thus, the optimum calculated mesh could be selected. For simulating of flow pattern, the boundary conditions must be entered on a perfect calculated mesh. Finally the mesh has been generated as of the domain provided using CCHE-MESH generator. Moreover experimentation value was compared with the concerned numerical model for longitudinal velocity distribution and depth average velocity.*
Keywords : *CCHE2D, CCHE-MESH, Compound Channel, Depth Average Velocity, longitudinal Velocity*

I. INTRODUCTION

River has always been main source of water for agriculture, domestic needs, industries etc. Also river provide as with energy, recreation and transportation routes. Eventually, it becomes hard to believe that during flood a gentle river inundate its flood plain thereby causing serious damage to the lives and shelter of the people residing in downstream areas. Generally river engineer's use hydraulic model to make flood prediction. The broadly streams are classified as straight, braided and meandering. Almost all natural rivers meander. The flow path in a meandering channel continuously changes along its course. Due to this the energy dissipation is not uniform over the meander length. The motion in meandering channels comprised of two components, the longitudinal component in stream wise direction which is nearly uniform and gradually varied and transverse component varies significantly over a meander wavelength. Distribution of flow velocity in longitudinal and lateral direction is one of the important aspects in open channel flows. It directly relates to no of flow features like estimation of water profile, shear stress distribution, secondary flow, channel conveyance and host to other flow entities [1]. Various factors that affect the velocity distribution such as geometry of channel , types and patterns of channel, channel roughness and sediment concentration in flow has been critically studied by many eminent researchers in the past. Patra and Kar (2004) reported the test results concerning the flow and velocity distribution in meandering compound river sections [2]. Using power law they presented equations concerning the three-dimensional variation of longitudinal velocity, transverse, and vertical velocity in the main channel and floodplain of meandering compound sections in terms of channel parameters. The results of formulations compared well with their respective experimental channel data obtained from a series of symmetrical and unsymmetrical test channels with smooth and rough surfaces. They also verified the formulations against the natural river and other meandering compound channel data. This project is basically centered upon meandering compound channel to calculate longitudinal velocity distribution and depth average velocity in a particular water depth which subsequently will get validated with the two dimensional numerical model i.e. Centre of Calculation and Hydraulic Engineering (CCHE 2D). The CCHE2D model is a two-dimensional depth-averaged, unsteady, flow and sediment transport model [3]. The flow model is based on depth-averaged Navier-Stokes equations. The turbulent shear stresses are modeled using Boussineq's approximation, and three different turbulence closure schemes are available for the calculation of the turbulent eddy viscosity. Commonly, for being done a numerical modeling of any natural phenomenon, like as water flow pattern, need to an exquisite and modify calculated mesh. For gaining this standard mesh calculated, different calculated meshes must be analyzed sensitively [4]. Thus, the optimum calculated mesh could be selected. For clarifier simulating of flow pattern, the boundary conditions must be entered on a perfect calculated mesh.

Finally, the results showed that, the best and closest predicted results pertaining to the made calculated mesh by 48*200 dimensions and fined width by canceling of flood plain. In this study, the study domain is about 967cm (longitude direction) x 167cm (latitude direction), and multiple-scaled objects are required to be represented in detail, which makes it more difficult for quality structured mesh generation [5]. Thus assembled final mesh with 2103 x 1088 (= 2.288 M nodes) in this large complex domain was successfully generated using CCHE-MESH, a 2D mesh generator for both quality structured and unstructured meshes [6]. Besides, variation of parameters like channel bed elevation, water surface, velocity, specific discharge, Froude number, shear stress, and eddy viscosity of the river are calculated and discussed.

II. EXPERIMENTAL SET UP

Evaluation of discharge capacity in a compound meandering channel is a complicated process due to various factors such as geometry of channel, types of channel and patterns of channel, channel roughness and sediment concentration. It is directly dependent on accurate prediction of velocity distribution in the compound meandering channel. Velocity distribution is never uniform across a cross-section of compound channel. It is higher in deeper main channel than the shallower floodplain, as in compound channels the shallow floodplains offer more resistance to flow than the deep main channel. The present research work utilizes the flume facility available in the Fluid Mechanics and Hydraulic Engineering Laboratory of the Civil Engineering Department at the National Institute of Technology, Rourkela, India. The objective behind the experiment is to get better understanding on the variation of velocity distribution. The following section provides a brief overview of details of hydraulic and geometric parameters of the present meandering channel, experimental arrangements, measuring equipment's and procedure used in the experimentation process. Water is supplied through a Centrifugal pumps (15 hp) discharging into a RCC overhead tank. There will be a measuring tank present in downstream end followed by a sump which will feed to overhead tank through pumping thus completing recirculation path. The Fig.1 represent the schematic diagram of experimental setup of Meandering Compound Channel. Water was supplied to the flume from an underground sump via an overhead tank by centrifugal pump (15 hp) and recirculation to the sump after flowing through the compound channel and a downstream volumetric tank fitted with closure valves for calibration purpose [7]. Water entered the channel bell mouth section via an upstream rectangular notch specifically built to measure discharge in the experimental channel. An adjustable vertical gate along with flow strengtheners was provided in upstream section sufficiently ahead of rectangular notch to reduce turbulence and velocity of approach in the flow near the notch section. At the downstream end another and maintain a uniform flow in the channel. The movable bridge was provided across the flume for both span wise and stream wise movements over the channel area so that each location on the plan of compound meandering channel could be accessed for taking measurements [8].

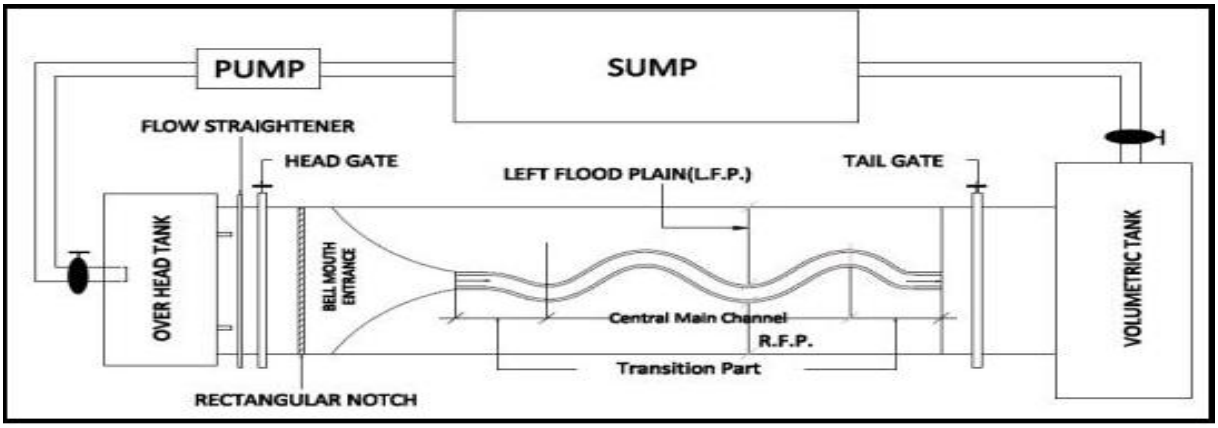


Fig. 1 Experimental Setup of Meandering Compound Channel

2.1 Channel Description-

Table 1.Description of compound meandering channel

Sl.no	*Description*	*Types*
1.	*Type of Channel*	*Meandering channel*
2.	*Flume Size*	*(14*2*1.5)*
3.	*Meandering Channel Geometry*	*Rectangular*
4.	*Type of Bed Surface*	*Smooth*
5.	*Section of Channel*	*0.25m*
6.	*Bank Full Depth*	*0.12m*
7.	*Meandering Angle*	*60°*
8.	*Width of the main channel section*	*0.28m*
9.	*Top width of compound channel*	*1.67m*
10.	*Bed slope of main channel*	*0.0006*

III. NUMERICAL MODEL

CCHE2D is an aggregated software package created in 2005 by Wang, Jia and San in the National Centre of Calculation and Hydraulic Engineering (NCCHE) under the supervision of University of Mississippi, USA. This model is a two dimensional hydraulic model that is created for analyzing and simulation of flow hydraulic, sediment transport and morphology processes in open flows. The model uses average equations of Reynolds for solving flow area in depth. Two zero models of parabolic distributed equations and the panels mix length model and also the model of two equations *k-ε* are used for modeling of distributed flow. The network used in this model is curved and not orthogonal. This model is applicable for unsteady flow. The CCHE2D has two important categories: CCHE2D Mesh generator and CCHE2D GUI (Graphical User Interface).

3.1 Governing Equations For Modeling

Equations which are used in CCHE2D software are the equations for flow and sediment in open channels and rivers as the followings. Equations for wave dynamic model in an open channel are Saint Venant equations

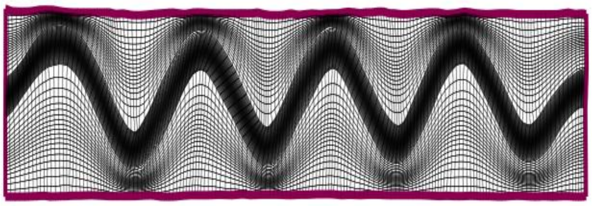
$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (1)$$

$$\frac{\partial}{\partial t}\left(\frac{Q}{A}\right) + \frac{\partial}{\partial x}\left(\frac{\beta Q^2}{2A^2}\right) + g\frac{\partial h}{\partial x} + g\,(S_f - S_o) = 0 \qquad (2)$$

Equation 1 is the Continuity equation and Equation 2 is the Momentum equation. In these equations, x and t represents time and place axles. *A* is flow space, *Q* is flow discharge, h is flow depth, *S0* is steep of the river bed, *b* is correction factor of momentum factor, *g* is gravity speed, *q* is discharge to width unit and *Sf* represents frictional steep.

3.2 Numerical Simulation

This stage is the first step in flow simulation and it is important because creating an appropriate network increases the accuracy of final results. In desirable mesh making, the areas locations are specified thoroughly in networks and the relation between them will be preserved [9]. Created cells are almost uniform with equal aggregation. Input and output ridges of flow must be far enough from the center spots so that the flow becomes normal (balanced). The mesh lines should also go the same as the flow direction as illustrated in Figure (2) and (3). The mesh generation takes place in CCHE-MESH in two major steps. An algebraic mesh is generated first where a quick but crude initial mesh is created. For further refinement and generation of a numerical Mesh Smoothness and orthogonality; the major two qualities are intermittently checked to evaluate the quality of mesh.CCHE2D-GUI, is a graphical user's environment for the CCHE2D model with four main functions: They are preparation of initial conditions and boundary conditions, preparation of model parameters, run numerical simulations and visualization of modelling results. The CCHE2D-GUI provides a graphical interface to handle the data input and visualization for CCHE2D numerical model [10].CCHE-GUI: it provides file management, simulation management, results visualization, and data reporting etc. For flow, the initial conditions include the initial mesh, the initial bed elevation, the initial water surface and the bed roughness; and, for sediment, they include the initial bed erodibility, the initial bed layers, and the initial bed samples. We need to define inlets and outlets, hydraulic structures, and set the boundary conditions associated with them. For flow simulation, only the flow parameters needs to be set, while for sediment transport simulation, we need to set both flow parameters and sediment parameters. For other simulations, such as water quality, chemical spill, cohesive sediment transport, and coastal processes, we need to set the corresponding parameters, respectively. After specifying all initial conditions and boundary conditions, setting the flow parameters the Model Simulation can be started. Also multiple runs may be necessary with some changes in flow parameters to get the desired results as numerical simulation is often a trial and error process.



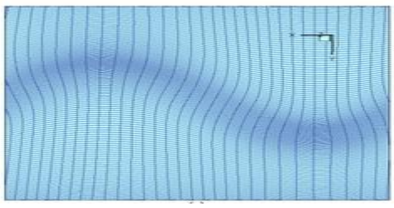


Fig.2 Top view meshing of channel Fig.3 zoom part meshing of channel

IV. VALIDATION RESULTS

4.1 LONGITUDINAL VELOCITY DISTRIBUTION IN CHANNEL DEPTH

For a given discharge the velocity profile data are taken throughout the meander path across the channel. The variations of velocities from point to point along the meander path of the meandering compound channel are plotted. Longitudinal velocity profiles for each section at 5cm interval on either side of the centre-line are analysed. The sections indicated are the bend apex sections as shown in fig.4. By analysing the profiles, it is clearly observed that the velocity remains higher on the inner wall than at the outer wall while moving over a curve.The fig 5 represent velocity distribution in left flood plain. Here velocity profile gradually increases upto middile section then slightly decreases.The fig.6 shows main channel which indicates velocity profile increases towards inner bend and decreases towards outer bend.The fig.7 shows right flood plain where velocity distribution gradually decrease towards boundary of channel.Accurate prediction of velocity distribution in channels is very important for flood studies and estimation of stage discharge curve in natural channels. The present research attempts to analyse the flow profile characteristics of water on a meander path, where the path continues as a meandering channel on both the ends.By analysing the experimental value with numerical model (CCHE2D) , it is clearly observed that the velocity remains higher on the inner wall than at the outer wall while moving over a curve.

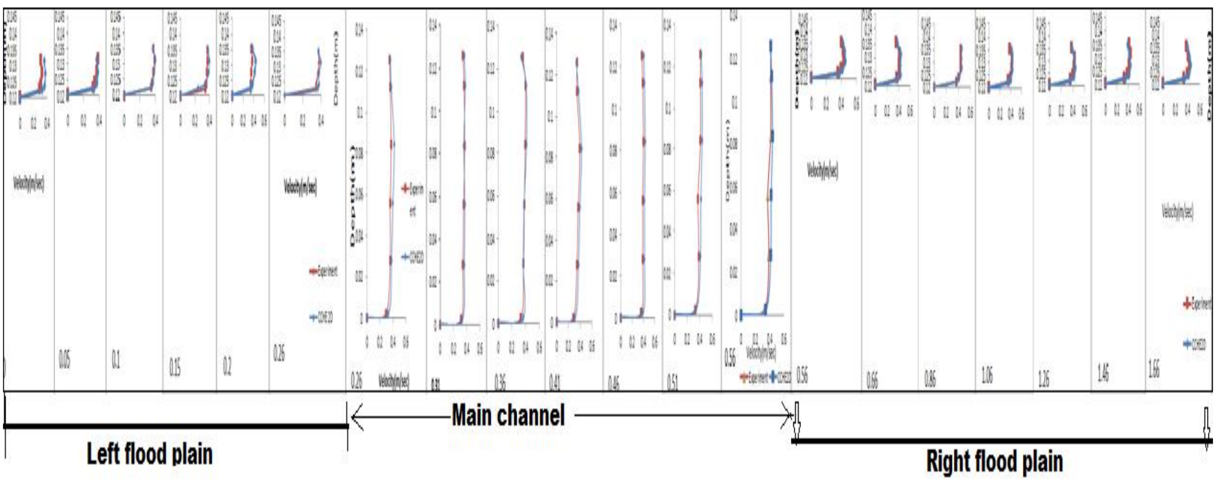


Fig.4. longitudinal velocity distribution in channel

4.2 Left Flood Plain

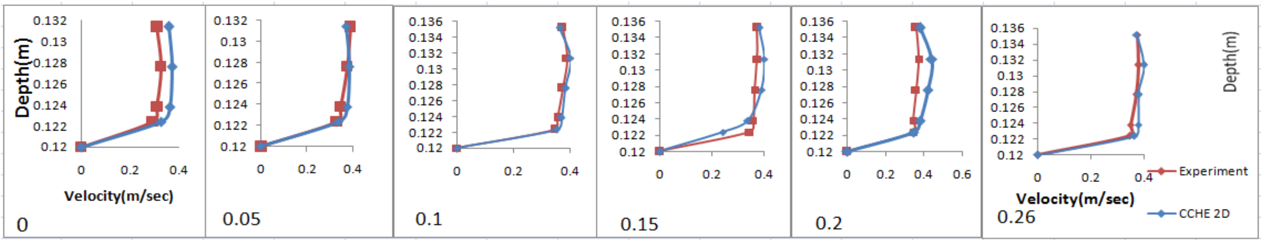


Fig.5. Longitudinal Velocity Distribution In Left Flood Plain

4.3 Main Channel

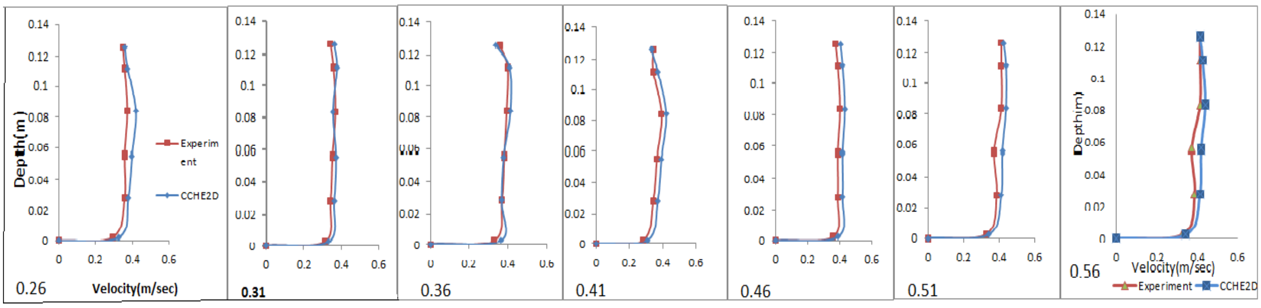


Fig.6. longitudinal velocity distribution in main channel

4.4 Right Flood Plain

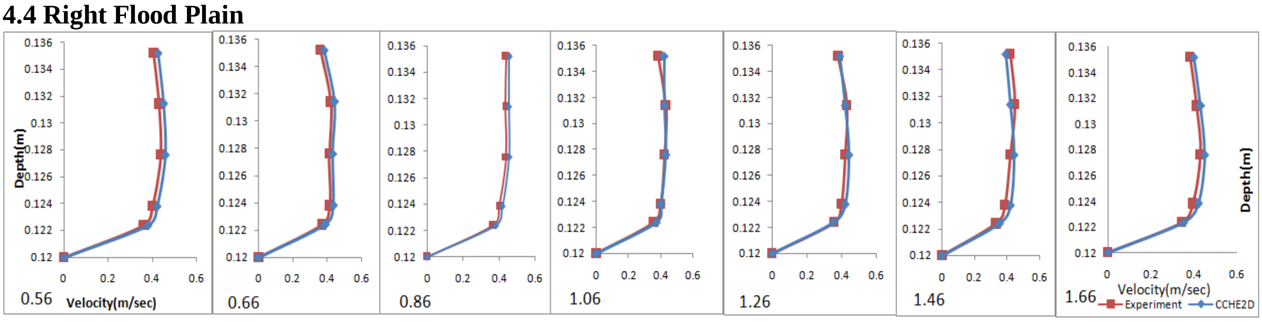


Fig.7. longitudinal velocity distribution in right flood plain

4.5 Validation Of Experimental Data With Cche 2d:

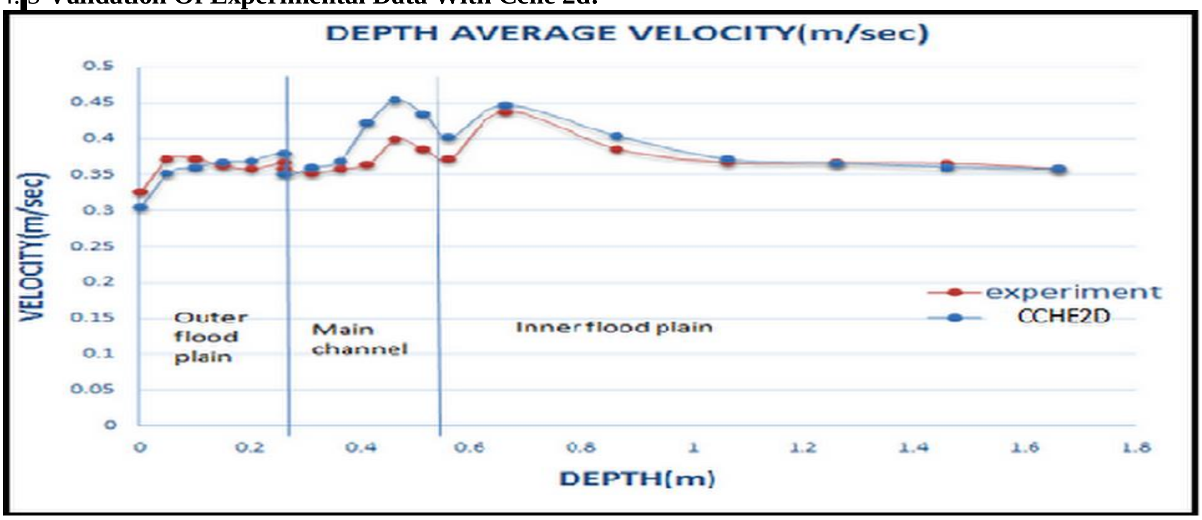


Fig.8. VALIDATION OF EXPERIMENTAL DATA WITH CCHE 2D

The depth-averaged velocity distribution in a cross section was measured at experimental section along the flume. Point depth-averaged velocity measurements were made laterally each 5cm at a depth of 0.4*H* from the bed in the main channel and $0.4(H-h)$ on the floodplains. It obvious that the depth-averaged velocity distributions show good symmetrical patterns in different measurement sections. The Fig.8 show the following effects of the contractions on the velocity distributions, (a) the numerical simulation gives good agreement with the experimentation, (b) the depth average velocity increases along the main channel of the flume.

V. CONCLUSION

- From the velocity profile study, it is observed that the velocity remains higher towards the inner wall as compared to the outer wall while moving in the curved path of the meandering channel.
- This observation can be applied to study the variations of flow velocity in meandering channels unlike straight channels where velocity profiles are somewhat uniform through the width of section.
- In compound meander channel, the higher values of depth averaged velocity are found at the inner flood plain region and attain a maximum value at the junction between the main channel bank and the flood plain. It can also be seen that the minimum depth average velocity values occurred at the junctions between the bed and the outer bank of main channel.
- From depth-average velocity profile, it clearly conclude that the numerical analysis gives good results and it is slightly overestimating the data when it is compared with the experimental result with an positive error of more or less than 5% but when the numerical analysis results are compared with the rest of the section, then it is underestimating the data.
- CCHE2D predictions are in very good agreement with their experimental values.

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