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Study of Wide Compound Channel Flow

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Abstract: This research paper is based mainly on the findings of application of a two dimensional depth averaged modeling package CCHE2D developed by NCCHE, University of Missisipi to a variety of experimental test cases consisting of benchmark large scale flume data from EPSRC FCF series A and some fresh experiments conducted in Hydraulics lab of NIT, Rourkela, INDIA for wide straight two stage compound channels. The results from simulation match very well with the experimental values and capture the two main flow outputs of interest to field engineers e.g. depth averaged velocity and boundary shear distribution across the compound channels with sufficient accuracy. Results from simultaneous application of a quasi one dimensional modeling software Conveyance Estimation System(CES)to these experimental runs are also reported and used to cross check the accuracy for both FCF & new experimental data .Finally the outputs from CCHE2D and CES are compared and discussed regarding their suitability both as an open access and computationally inexpensive modeling tools in the field of river hydraulics. It is shown that both are not alternative to each other, but can constitute as a pair of complementary tools in predicting flow in complex physical domains and can be of immense potential in handling hydrodynamics in a riverine medium.

Keywords: Compound channel, 1D-modeling, 2D-modeling, Depth averaged velocity, Boundary shear

I. INTRODUCTION

Rivers being the lifeblood of any civilization have also been the cause of destruction of the very life they seem to sustain during flood times. Many rivers have wreaked havoc and have simply wiped vast tracts of habitation, flora & fauna resulting in loss of life and property due to some massive floods in past. Although floods are usually associated with high stages in rivers, some proper planning and design of floodplains can to a large extent mitigate the potential of destruction by allowing smooth passage of high discharge without allowing high stage to build up in the flow section. So often rivers are naturally or artificially made to inundate their adjacent floodplains thereby lessening the load in main river and minimizing the effects of devastation. Such river sections which are flanked by one or two adjacent floodplains are commonly addressed as two stage compound channels in river hydraulics vocabulary. These compound channels are extremely complex from analysis point of view due to presence of a number of geometrical and physical parameters and hence have attracted the attention of researchers in last half century. Geometrically the main river section is often narrow and deep where as floodplains are wide and shallow. Hence the main channel flow are usually much faster as compared to the floodplain flow and due to physical connection between two adjacent flow sections considerable exchange of momentum takes place which was first demonstrated by [1]. Also the cross sections usually vary from prismatic sections such as rectangular, trapezoidal, parabolic as in artificial channels to naturally occurring irregular channel sections. In their plan form the rivers are sometimes straight having no directional change in their path whereas at times they are sinuous or meandering with varying degree of sinuosity. The primary velocity occurring in stream wise direction is often associated with some amount of secondary currents which are perpendicular to main velocity vector both in straight and in meandering channels and thus velocity is often three dimensional in such channels, albeit with varying degree. Even the flow in a straight channel is associated with spiral motion [2] thereby increasing complexity in flow analysis. From practical point of view engineers are often entrusted not only with task of accurate prediction of stage discharge curve but also finding distribution of velocity and boundary shear across the whole compound section for a host of floodplain design measures. Many researchers have contributed significantly in the field of flow modeling in both straight and meandering compound channels. Notable among them are due to the works of [3-13]. On the basis of modeling dimensions there are 1D,Quasi 1D,2D,Quasi2D and 3D analysis methods are often applied to the compound channel research. An 1D method only solves for primary velocity component i.e. the major velocity direction in the flow in stream wise direction by solving the St. Venant equations. The prismatic trapezoidal channels flanked by symmetric floodplains are one of the most preferred laboratory flumes on account of its similarity with artificially constructed or manmade channels used in field widely for irrigation and other purposes as evident from past research conducted on them[1 & 14].Compound channels used for investigating flow characteristics often varied with respect to different geometric and hydraulic parameters. Aspect ratio(δ, where δ=ratio of bottom width and depth of main channel) and width ratio (α, where α=ratio of width of floodplain to width of main channel) are the main geometric factors while relative depth or depth ratio(β) is the main hydraulic parameter defining the flow condition where β is the ratio of depth of flow over floodplain to the overall depth of flow. As a method of analysis numerical models often act as handy complementary tools vis a vis analytical and experimental investigations in this complex area of research in both straight and meandering compound channels due to presence of a number of complex flow mechanisms [15-17]. The 1D numerical models using solutions of St. Venant equations have been used in popular hydrodynamic packages such as HEC-RAS, MIKE11, ISIS etc. and are used for predicting stage discharge curve or conveyance in a riverine medium. These are quite user friendly and have been used with much confidence by field engineers all over the world. However to further analyse the flow mechanism one has to take recourse to a higher dimensional model such as 2D and 3D numerical tools where velocity in two orthogonal direction in a horizontal plane and velocity along all three spatial axes can be predicted respectively. But since the 3D models are based on complete solution of all nodal values of three dimensional flow quantities by solving full Navier-Stokes equation with help of some calibration coefficients and turbulence closure schemes ,it is usually computationally prohibitive and has been limited to small domains on account of such limits on computational power and resources. Against this backdrop the 2D models come as a good compromise between the two extremes i.e. 1D &3D with the first being criticized for being over simplistic and raw for ignoring the mechanisms whereas the latter being too complex and costly for routine use in field. The 2D models are usually based on shallow water equations(SWE) where the vertical component of velocity can often be neglected or assumed invariant and the flow is assumed to take place in mainly horizontal plane.The flow domain is also mostly spread in a horizontal plane and vertical dimension is assumed insignificant thereof. Thus depth integration of Navier-Stokes equation are used in the model for analysis of flow. Many popular tools using this approach are Telemac2d,River2d,Delft2d,CCHE2D and other similar free or commercial packages. The CCHE2D is a state of the art analysis system for two-dimensional, unsteady, turbulent river flow, sediment transport, and water quality evaluation and is developed by the National Centre for Computational Hydro science and Engineering (NCCHE), Missisipi State University. Although many researchers have used CCHE2D and other ancillary tools for a variety of problems in large scale models for river and sediment studies as well as some validation studies in laboratory scale models in past [18-21] but compound channels have been seldom analysed using this model to the best knowledge of authors except one reported case of validating the compound channel case of experiments of [22]as mentioned in literature [18].Since the availability of large scale FCF data (SeriesA) has made possible verification and validation of many analytical &numerical models developed by researchers worldwide [23-25]particularly for straight smooth and rough compound channels, the option of applying the CCHE2D to some experimental test cases from Series A was found quite tempting and hence numerical analysis was conducted for a few runs. The second part of analysis pertains to application of the model to the test results for a new set of flume experiments conducted in wide smooth straight trapezoidal compound channel in Hydraulics and Fluid Mechanics laboratory of NIT, Rourkela, India where the said experiments were done for compound channel of high width ratio($\alpha \approx 12$ as against the value of 6.67 for FCF channels) to study different flow aspects. Thirdly another widely recommended [26,13] quasi-1D package ,the Conveyance Estimation System(CES) developed by joint Agency/DEFRA research programme on flood defense, with contributions from the Scottish Executive and the Northern Ireland Rivers Agency, HR Wallingford and the Environment Agency, UK, for reducing uncertainties in the estimation of river flood levels, discharge capacities, velocities and extent of inundation has also been tested for above flow cases. Out of so many simple 1D or quasi-1D models CES has been chosen to compete with this CCHE2D model for tesing the latter against the former as CES has been now recommended and accepted as conveyance estimation tool for majority of Europe and also world due to its sound physical basis on account of solution of Reynolds averaging of Navier-Stokes equations forming the core analysis and due to its wide application and subsequent validation against ,field data, large scale river data, large scale experimental data(e.g.FCF series A,B &C) as well as small scale laboratory data. Also both models provide outputs in form of spanwise distribution of depth averaged velocity and boundary shear, which are very important from analysis& design point of view to the researchers and engineers. So both of them have been selected as tools for comparing their efficacy and validity in the context of flow in wide trapezoidal compound channels .The results from CCHE2D and CES analysis are compared and contrasted against the experimental values and commented upon in the sections relating to results & discussion as well as conclusion.

A. Cche2d Model

The shallow water equations are usually derived from depth-integrating the Navier–Stokes equations, in the case where the horizontal length scale is much greater than the vertical length scale. Under this condition, conservation of mass implies that the vertical velocity of the fluid is small. It can be shown [27] from the momentum equation that vertical pressure gradients are nearly hydrostatic, and that horizontal pressure gradients are due to the displacement of the pressure surface, implying that the horizontal velocity field is constant throughout the depth of the fluid. Vertically integrating allows the vertical velocity to be removed from the equations. The momentum equations for depth-integrated two-dimensional turbulent flows in a Cartesian coordinate system are:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial \eta}{\partial x}+\frac{1}{h}\left[\frac{\partial h\tau_{xx}}{\partial x}+\frac{\partial h\tau_{xy}}{\partial y}\right]-\frac{\tau_{bx}}{\rho h}+f_{Cor}v \qquad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial \eta}{\partial y}+\frac{1}{h}\left[\frac{\partial h\tau_{yx}}{\partial x}+\frac{\partial h\tau_{yy}}{\partial y}\right]-\frac{\tau_{by}}{\rho h}-f_{Cor}u \qquad (2)$$

where u and v are depth-integrated velocity components in x and y directions, respectively; t is the time ; g is the gravitational acceleration; η is the water surface elevation; ρ is the density of water; h is the local water depth; $f_{Cor}$is the Coriol is parameter and τ_{xx}, τ_{xy} ,τ_{yy}, and $\tau_{yx}$are depth integrated Reynolds stresses and τ_{bx} and τ_{by} are shear stresses on the bed and flow interface. However the shear stress terms at the water surface are dropped since wind shear driven effect is not considered in the present version of CCHE2D model. Free surface elevation for the flow is calculated by the depth-integrated continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \qquad (3)$$

Assuming the bed elevation ,ζwould not change in the flow simulation process and

so $\frac{\partial \zeta}{\partial t}=0$; (4a)

also $h=\eta-\zeta$ (4b),

Henceone gets simplified continuity equation as $\frac{\partial \eta}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0$ (5)

Where η is the free surface elevation, h is the water depth. For hydrodynamic process in absence of bed morphological changes (as in rigid smooth channels applicable in present case)equation (5) is usually applicable .However in case of fast erosion and deposition as in case of loose or mobile bed equation(3) instead of equation(5) is to be solved in conjunction with equations (1&2) for flow simulation. The turbulent Reynolds stresses in equations(1 &2) are approximated according to Boussinesq's assumption that they are related to the main rate of the strains of depth averaged flow field with coefficients of eddy viscosity and can be chosen from two models available in the CCHE2D viz.depth integrated parabolic eddy viscosity model and depth integrated mixing length model. In addition to these two further models are available ;one is a k-ε model and another Smagorinski model as the accuracy of turbulence closure is critical [28]. The finite element method used in CCHE2D is called Efficient Element Method which was initiated by [29]. Collocation approach of the finite element method is adopted to discretize the mathematical equation system. Further details regarding the Interpolation functions, finite element transformations ,mesh and solution methods are available in technical manual of CCHE2D [27]. The structured mesh generator (CCHE2D Mesh Generator) is used to prepare the mesh for the flow domain to be simulated and can then be imported to the main engine of CCHE2D for hydrodynamic simulation.

B. Conveyance Estimation System

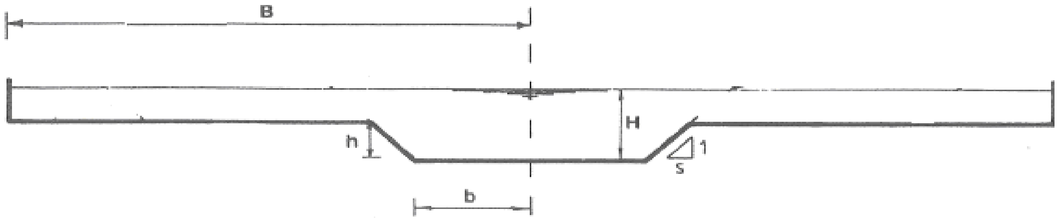
The Environment Agency for England and Wales identified the need to reduce the uncertainty associated with flood level prediction through incorporating the recent research advances in estimating river and floodplain conveyance in response to the cry for a simpler ,user friendly yet physics based approach instead of prevalent empirical based approaches as used to be done by applying Manning's or Chezy's formula. The new conveyance system has been developed taking into account the advances made in research in channel conveyance, the vast diversity in roughness of river and associated floodplains and finally understanding and quantifying the uncertainty due to methodology adopted and model inputs [30],(www.river-conveyance.net/ces)

Conveyance Estimation System was conceived and developed after certain shortcomings were pointed out in the existing ID models such as ISIS,HECRAS,MIKE11 in their methodology of estimating conveyance. The major drawbacks were demonstrated in expert paper of Knight [31] and could be mentioned here briefly for some critical review. ISIS adopted mainly a divided channel method(DCM) approach which suffers from unphysical basis and poor quality output in case of overbank flow(ISIS

V2.0[32].Almost a similar approach was adopted by HECRAS [33] where flow domain is subdivided on basis of uniform velocity coefficient and is usually done on basis of input cross-section Manning's n value breakpoint as the basis of subdivision. Mainly both of above models are usually based on improper physics, overestimating floodplain and underestimating main channel conveyance. Mike11 [34] adopted a modified form of DCM in its conveyance estimation approach in which bed resistance can be chosen on basis of Manning's M or Chezy's C where M is the Manning number (=1/ n) which is equivalent to the Strickler coefficient.. The Chezy coefficient C is related to Manning's n [35]. Hence to overcome these lacunae in the approach in the existing 1D models, after a very rigorous brainstorming among the scientists, engineers, researchers and after quite a good amount of testing in laboratory scale models and field model as well as after interaction with potential users it was decided to adopt Reynolds-averaged Navier-Stokes (RANS) approach as the solution basis for a new Conveyance Estimation System which significantly improved the conveyance estimation in all types of channels such as straight, meandering (simple & compound) and with very little uncertainty. Also compared to previous 1D models, its outputs are much diverse as CES can generate a host of parameters such as lateral distribution of depth averaged velocity, boundary shear, friction velocity across the flow cross section in addition to normal outputs such as flow, conveyance, Boussinesq and Coriolis coefficient etc.In light of foregoing discussion it was only thought appropriate to pit the CCHE2D model against CES package and compare their outputs visa vis experimental values obtained from FCF data and NIT,Rkl experimental data and finally draw some conclusions for general applicability of the models either separately or in conjunction to wide compound channels.

II. FCF DATA AND NEW EXPERIMENTS AT NIT:

The present work is mainly based on numerical simulation of some past experiments conducted at EPSRC-Flood Channel Facility-Series A [For details please see,36] as well as some new experiments carried out in Hydraulics and Fluid Mechanics laboratory of NIT, Rourkela, India in a straight wide compound channel of trapezoidal cross sections. The former data series (FCF) needs no introduction as many researchers in past have used these data for validating their models and to this date also the FCF data acts as a guidepost to all emerging new concepts in compound channel investigations. The data base at FCF has been created after a number of series of well planned experimental runs carried out on a variety of large scale models of compound channels of numerous shapes and dimensions under a variety of geometrical and hydraulic conditions [37-38].For the present research all runs from SeriesA-01 are chosen with varying relative depth (β) where a wide trapezoidal compound channel section($\alpha \approx 6.67$) consists of a smooth trapezoidal main channel flanked by adjacent rectangular smooth flood plains. A schematic cross sectional diagram of channel sections used in present research is given in Fig.1



. Fig.1

Schematic cross section for FCFA1 &NIT, Rourkela Channels.

For the FCFA-01 channel ,length of the flume is 56 m long and width(2B) is 10m with maximum discharge of 1.01m3/s. The main channel is trapezoidal in section with a depth(h) equal to 150mm and bottom width(2b) of 1500 mm and a 45° bank slope(s=1) (Fig.1). The valley slope of the floodplain is equal to the mean longitudinal bed slope at 1.027×10^{-3}. The overbank depth for this series was varied from 0.15899m to 0.25012 m i.e.($0.059<\beta>0.67$).All the cases are for smooth bed and wall on main channel and floodplains with Manning's 'n' value taken as 0.01.The flow data for these runs are collected from the web site of University of Birmingham(http://www.birmingham.ac.uk). Some excerpts from hydraulic conditions regarding the FCFA-Series1 experiments are reproduced in Table.1.Smooth cases were chosen for simulation as the fresh experiments at NIT, Rourkela also are for smooth compound trapezoidal channels but with a comparatively higher width ratio (α) value. In order to extend the research on flow characteristics in a trapezoidal compound channels for higher width ratio ,some experiments were carried out on a trapezoidal compound section where a trapezoidal main channel is flanked by two adjacent symmetric rectangular floodplains. The whole compound channel was made up of smooth Perspex sheet of 10mm thickness and was cast inside a rectangular steel tilting flume of about 15m length. The total width of the section including floodplains(2B) was kept at 3.95m and the bottom width of main channel(2b) is 0.33m and side slope 1:1 with aspect ratio(δ) kept at value of 5 where δ is the ratio of bottom width of main channel to depth of main channel section The slope was kept fixed for this particular set of experiments as 1.1×10^{-3}. Further details regarding conduct of experiments are given in a separate paper (Mohanty et al,2012).

Table.1: Hydraulic parameters for FCF A-Series1 channel

RUN No.	Q in 10^3 lit/sec	Overall depth (H)in cm	Relative depth(β)
1	0.2082	15.899	0.056544
2	0.2337	16.519	0.091955
3	0.2852	17.563	0.145932
4	0.3535	18.656	0.195969
5	0.4511	19.881	0.245511
6	0.6046	21.443	0.300471
7	0.6001	21.411	0.299426
8	1.0145	25.012	0.400288

Table.2:Hydraulic parameters for the experiments at NIT,Rourkela

Run No.	Q in lit/sec	Overall depth (H)in cm	Relative depth(β)	Froude no.	Reynolds no
1	13.543	7.3	0.109589041	0.50697216	39476.24919
2	17.482	7.5	0.133333333	0.55535058	45032.55712
3	36.396	8.8	0.261363636	0.50807784	52362.66527
4	53.546	10.1	0.356435644	0.3724667	47199.45618
5	60.282	10.5	0.380952381	0.36404032	48899.10562
6	106.181	11.5	0.434782609	0.5048913	77734.19975

The velocity and boundary shear was recorded by pitot static tube (4.77mm OD) and preston tube method respectively using a preston tube of similar dimension at predefined grid points comprising the entire flow section @ 4cm in main channel 8cm in floodplain respectively in a horizontal plain and at 0.2H interval in vertical direction starting with bed. At the top of water surface care was taken to see that pitot tubes did not come out of water. Due to symmetry only half of entire cross section was used for measurement. The details of experimental flow conditions are given in Table.2 and some photographic images of test are given in Fig.2.

Fig.2(a-d:Starting with clockwise from top left): (a)&(b)Side & top view of Series of pitot static tubes fitted to stand with transparent pipes & pointer gauge, (c)D/S tail gate and volumetric tank . (d) Set of Piezometers fitted to wooden board to record pressure with spirit level, digital clock etc.

III. NUMERICAL ANALYSIS

A. Mesh,Initial & Boundary Conditions,time step

The mesh is created for both the flow domains for FCF channel and NIT channel with the help of mesh generator module provided separately with the CCHE2Dpackage.Considering the nature of domain for both types of channel a multiblock boundary approach is adopted as the method is considered more suited to present cases than a single block approach.For the FCF channel a 5block domain is chosen whereas for NIT channel a 3 block domain is selected . The total width of crosssection is divided into 5 blocks and 3 blocksconsidering the resolution of data to be extracted in FCF and NIT channel respectively selecting the width of each block so that a smooth transition in mesh resolution is obatined from centre of main channel to the floodplain ends resulting in gradual reduction in mesh density in outward direction for both cases(Fig.3a &b).The mesh for FCF channel consists of 256×150 nodes having 256grid lines in spanwise direction and 150 lines in stream wise direction. The mesh quality is tested by evaluating the several parameters available in the mesh GUI. Some useful indicators are Average deviation from orthogonality (ADO)=0.8568,Average aspect ratio(AAR)=9.800,Minimum cell length in I(spanwise)direction=0.0297936m and Min cell length in J(streamwise)direction=0.364176m. For the NIT channel the mesh consists of 206×60 nodes with 206 grid lines in span wise direction and 60 lines in streamwisedirection.ADO= 0.62548,AAR= 11.51798, Minimum cell length in I(spanwise)direction=0.01227 m and Min cell length in J(streamwise)direction=0.18407m.

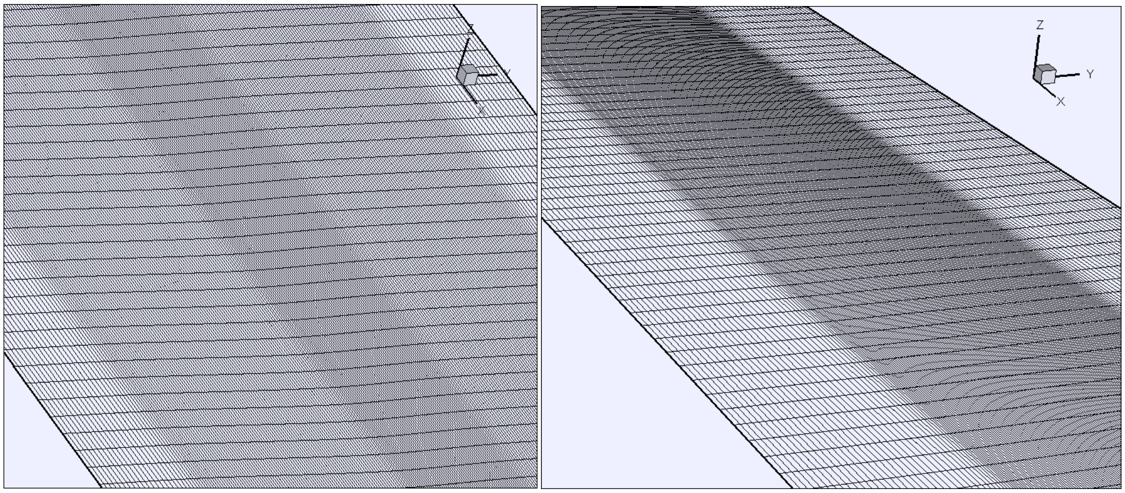


Fig.3(a-b)Left: (a)Mesh for FCF cases and Right: (b) Mesh for NIT channel

The bathymetry data for both the cases were prepared by analysing the cross sectional details,length of channels and bed slope and used for interpolation so as to generate the test domains ready for numerical analysis. Since CCHE2D can run a simulation as a initial and boundary value problem so some parameters need to be prescribed to the model before running the simulation. For the both cases i.e. FCF channel and NIT channel the water level at both inlet and outlet of the flow domain are computed from experimental data and put as initial conditions for different runs.Similarly the measured discharge for each case are taken as boundary condition at inlet and the water level as boundary condition at outlet.Also the time steps for both the cases were taken as 0.01s and total simulation time were taken as 100s in order to have a onverged solution keeping the Courant's no. less than 10(as advised in personal communication with Dr.Y.Zhang, of NCCHE).Although there are provisions of four turbulence closure schemes in CCHE2D, but after repeated testing it was observed very little sensitivity of the results to chosen turbulence closure scheme.So finally k-ε scheme was chosen as the turbulence model.

IV. RESULTS AND DISCUSSION

The first aim of any modelling system is to predict a stage –discharge relation with a great degree of accuracy. As CCHE2D is a modelling tool based on solving Navier-Stokes equation is an initial and boundary value problem(Zhang[39]) only CES is used to predict the stage-discharge relation for both FCFA1 cases as well as NIT ,RKL experiments. Fig.4(a&b) shows the stage-discharge curves for these cases in overbank conditions respectively.

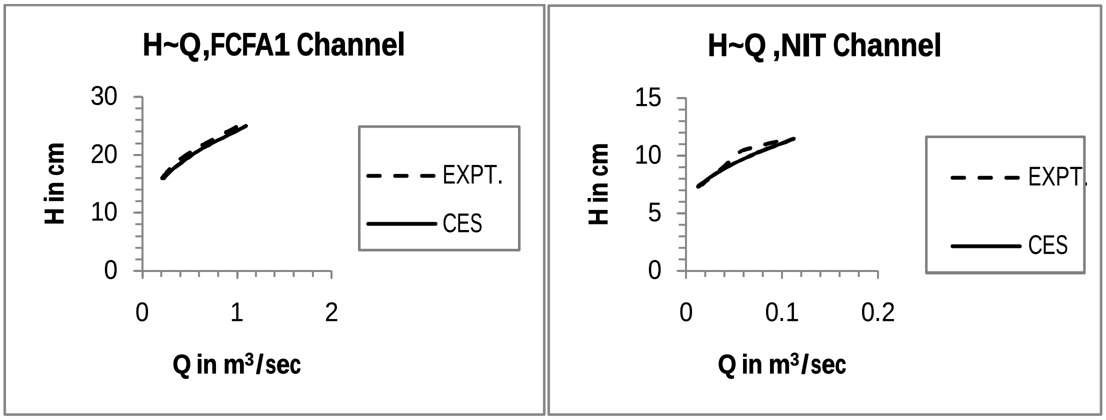


Fig.4 (a&b): a)Left-H~Q Curve for FCF test case,(b)Right-H~Q Curve for NIT,RKL experiments.

It is seen that in both the cases CES can predict with sufficient accuracy a stage-discharge curve for wide compound channels under overbank flow conditions although the prediction is more consistent in case of FCF channels than that in case of NIT channel as can be seen in the small kink in the curve at around the depth(H) value of 10.1 cm. This may be due to minor experimental error. Once the discharge is predicted with sufficient accuracy the next goal is to estimate the depth averaged velocity and boundary shear stress across the lateral section of flow domain. As stated earlier the main aim of this research presentation is to test or validate the CCHE2D hydrodynamic package for wide compound channels by performing simulations for benchmark large scale experiments done on FCF channels(SeriesA-1, wide channel with α=6.67) and then comparing the results against the data set reported in website(http://www.birmingham.ac.uk) as well as against the CES results. We present the comparative result in form of graphs showing the lateral variation of depth averaged velocities(U_d) for all runs(total 8nos.) for FCF channel considering the simulated result from CCHE2D,CES and the original data from experiments as reported(Pl.seeFig.5).Similarly the spanwise distribution of boundary shear stress(τ) for all runs are shown in Fig.6. Both velocity and boundary shear values have been normalized by maximum value of velocity (U_{max}) and maximum value of shear(τ_{max}) respectively by considering the absolute maximum value occurring among all three types i.e. CCHE2D,CES & experimental data.

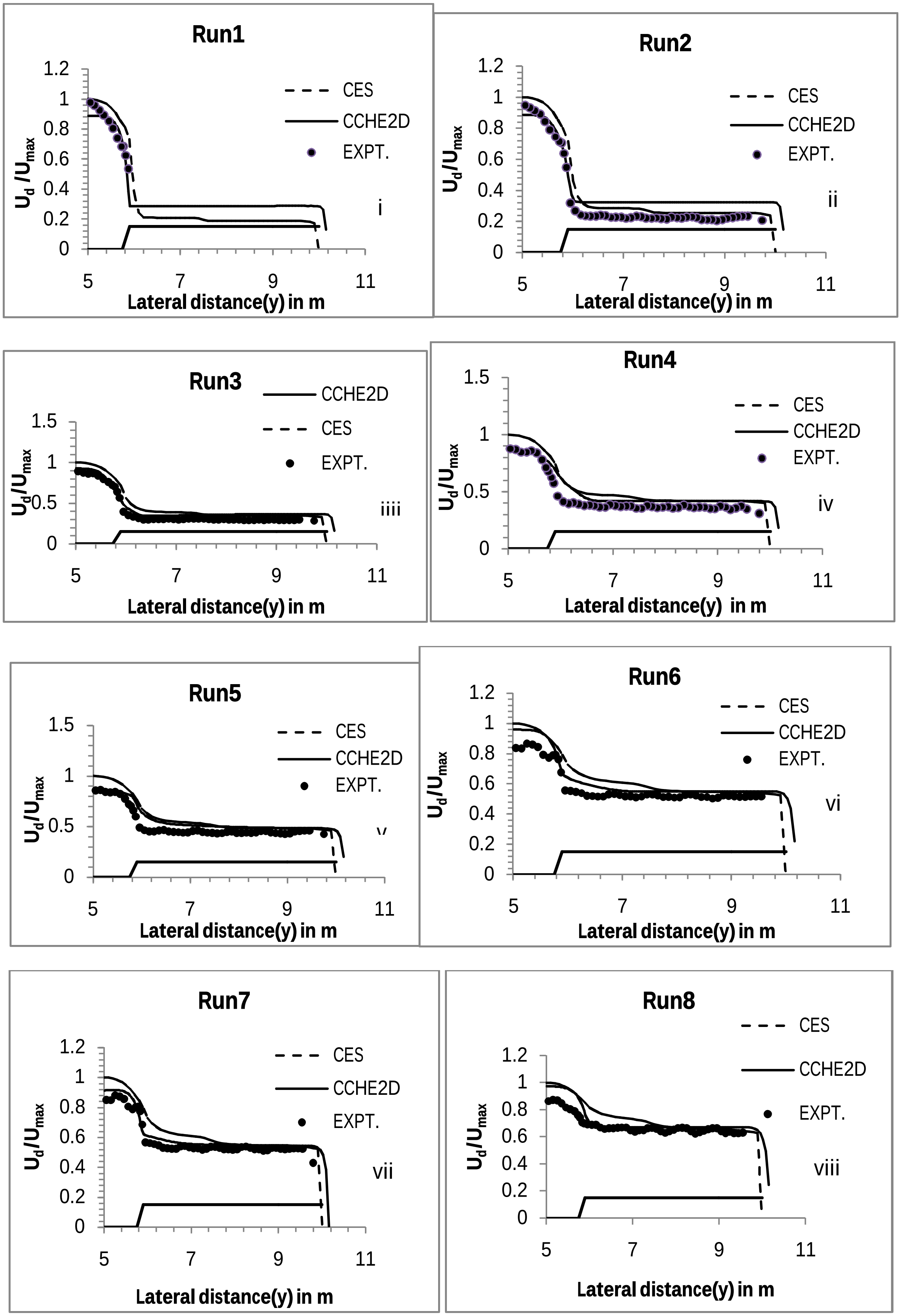
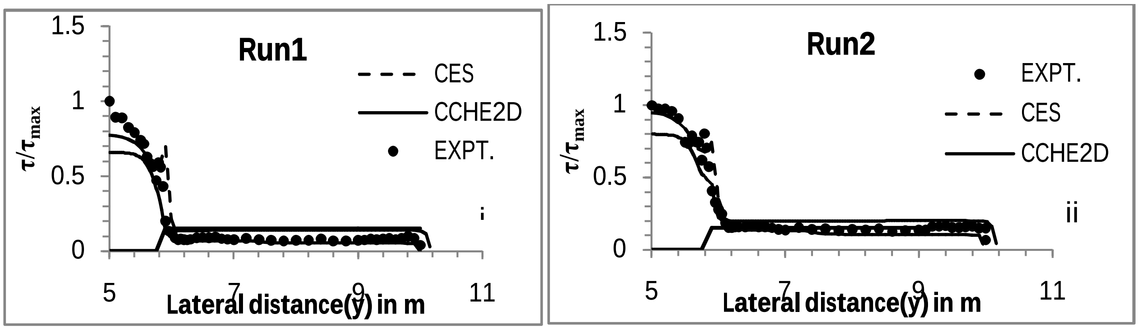


Fig5(i-viii): Variation of depth averaged velocity across the section for FCFA-1 Channel for 8nos. runs.

Only half (here right one)of the channel is shown as is customary due to symmetrical compound section. It is seen from fig.5 that both CES and CCHE2D are well competent to capture the lateral variation of depth averaged velocity for all most all the runs .Small variations could though be observed in their performance as evident on close scrutiny of the runs. Only at very low overbank conditions i.e. for Runs 1&2 it is observed that CES predicts the flow better in floodplain than CCHE2D whereas the latter gives better prediction than former in main channel region. For the rest of runs the CCHE2D even performs better as compared to CES result when seen against experimental result. The distribution of boundary shear stress for all the runs are shown in fig.6 and overall agreement of CCHE2D outputs with CES as well as experimental values are quite satisfactory as is evident from the figure. However under close scrutiny it is seen that in Run1,2 CES better performs than CCHE2D .While in main channel for Run1 both deviate a little from experimental value in floodplain the CES values are in higher agreement than those of CCHE2D .Similarly for Run2 CES performance is slightly improved than CCHE2D all through the compound section. In Run4 both CES and CCHE2D prediction of shear stress is somewhat lower than actual experimental values. In rest 5 no. of cases CCHE2D predictions very nearly match experimental values and are more satisfactory than CES outputs.



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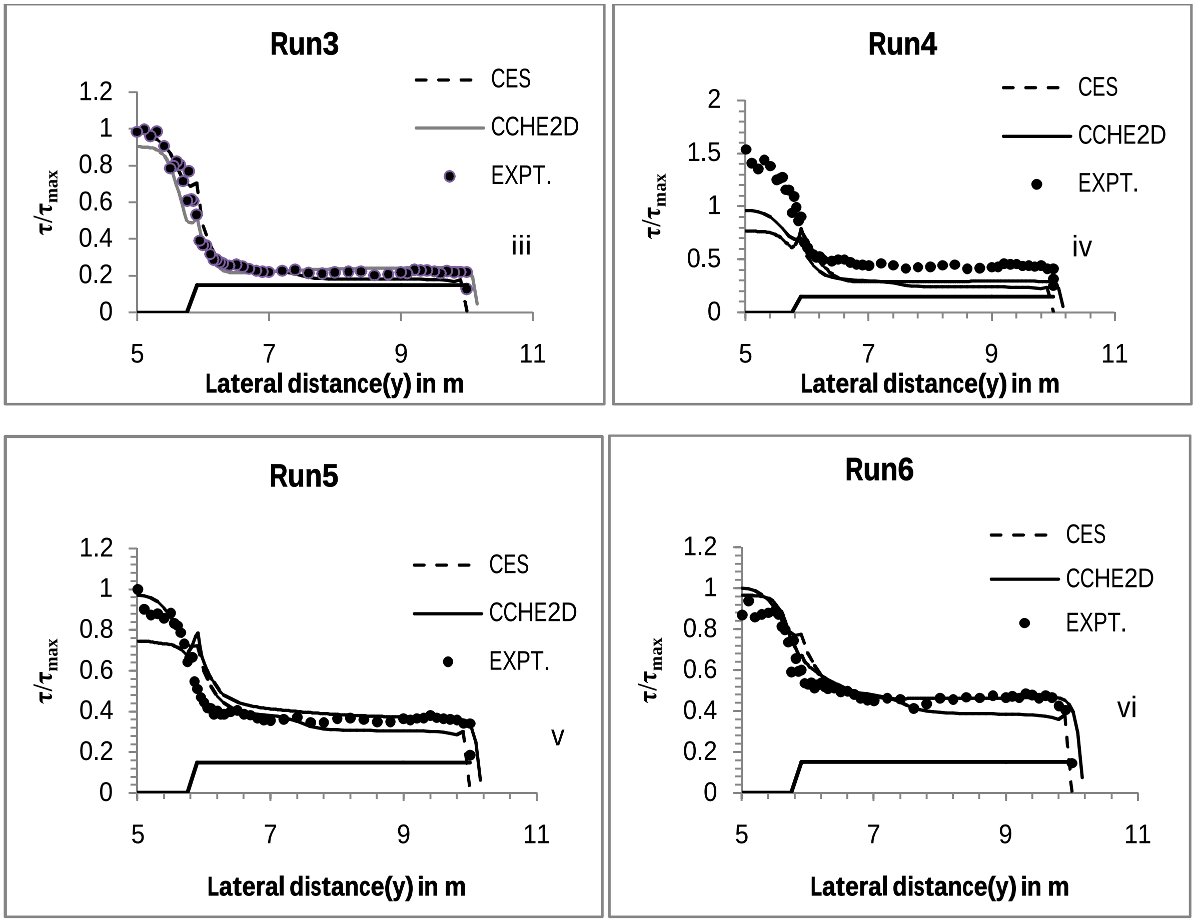

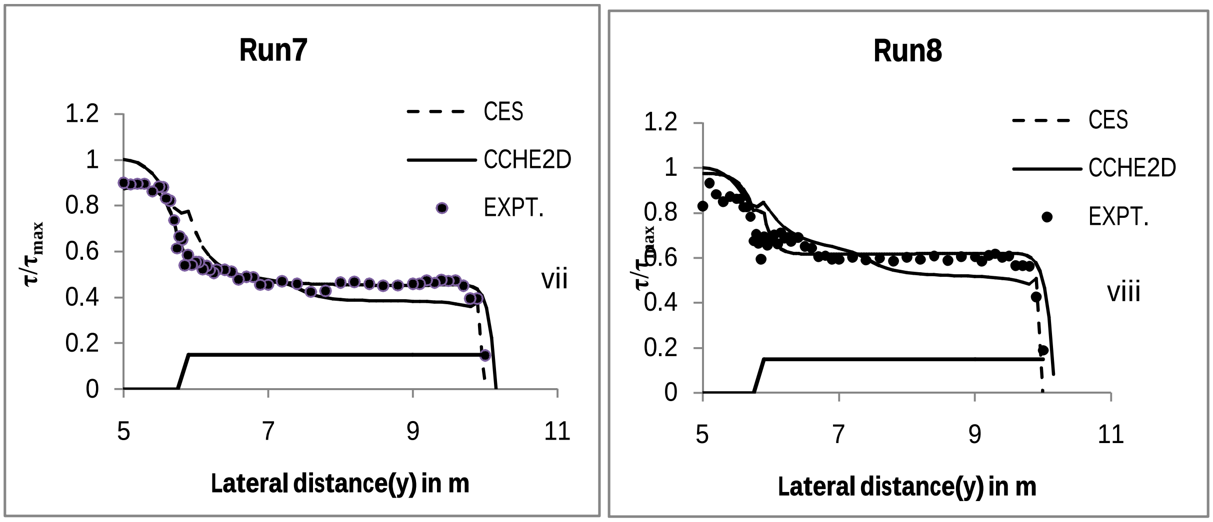

Fig6(i-viii): Variation of boundary shear stress across the section for FCFA-1 Channel for 8nos. runs.

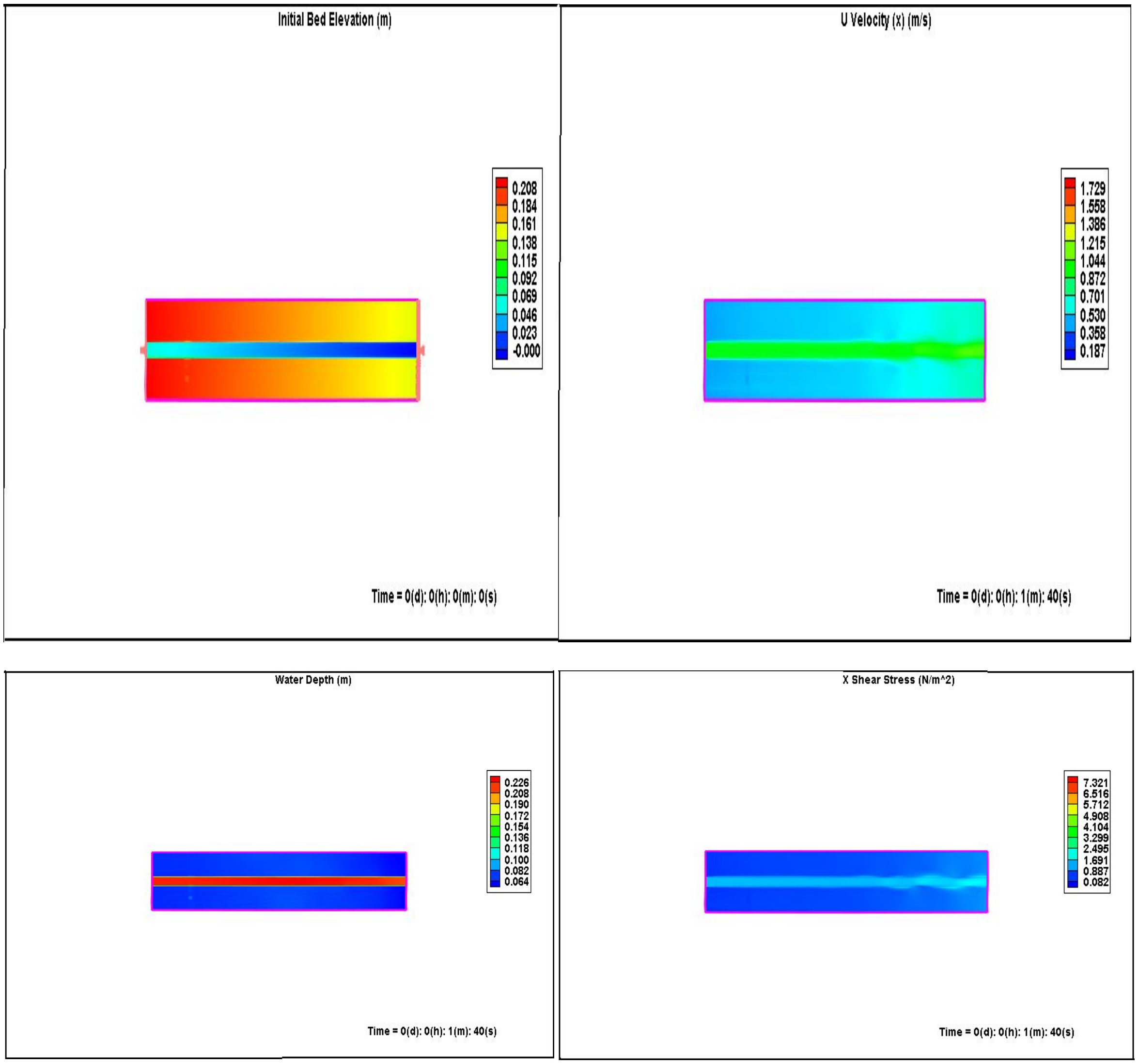

Fig.7(a-d)An indicative diagram showing the results from simulation (Run6 for FCFA-01 channel)Starting clockwise from top: (a) Initial bed elevation at time(t)=0s.(b)U velocity at t=100s (c)X shear stress at t=100s & (d) final water depth in the channel

Figure 7(a through d) also shows some indicative pictures of simulation. As there are other parameters also like y direction velocity and shear stress but being quite insignificant in magnitude they are ignored in present analysis. The figure 7 relates to simulation of run6 from FCFA-01 channel. After the FCFA-1 channel runs are simulated through CCHE2D and CES the results of simulation of experimental runs for the case of NIT ,RKL channel is now considered. Figures 8 & 9 show depth averaged velocity and boundary shear stress across the half of the trapezoidal compound section respectively. These figures pertain to all total six sets of experimental runs as mentioned in Table.2.

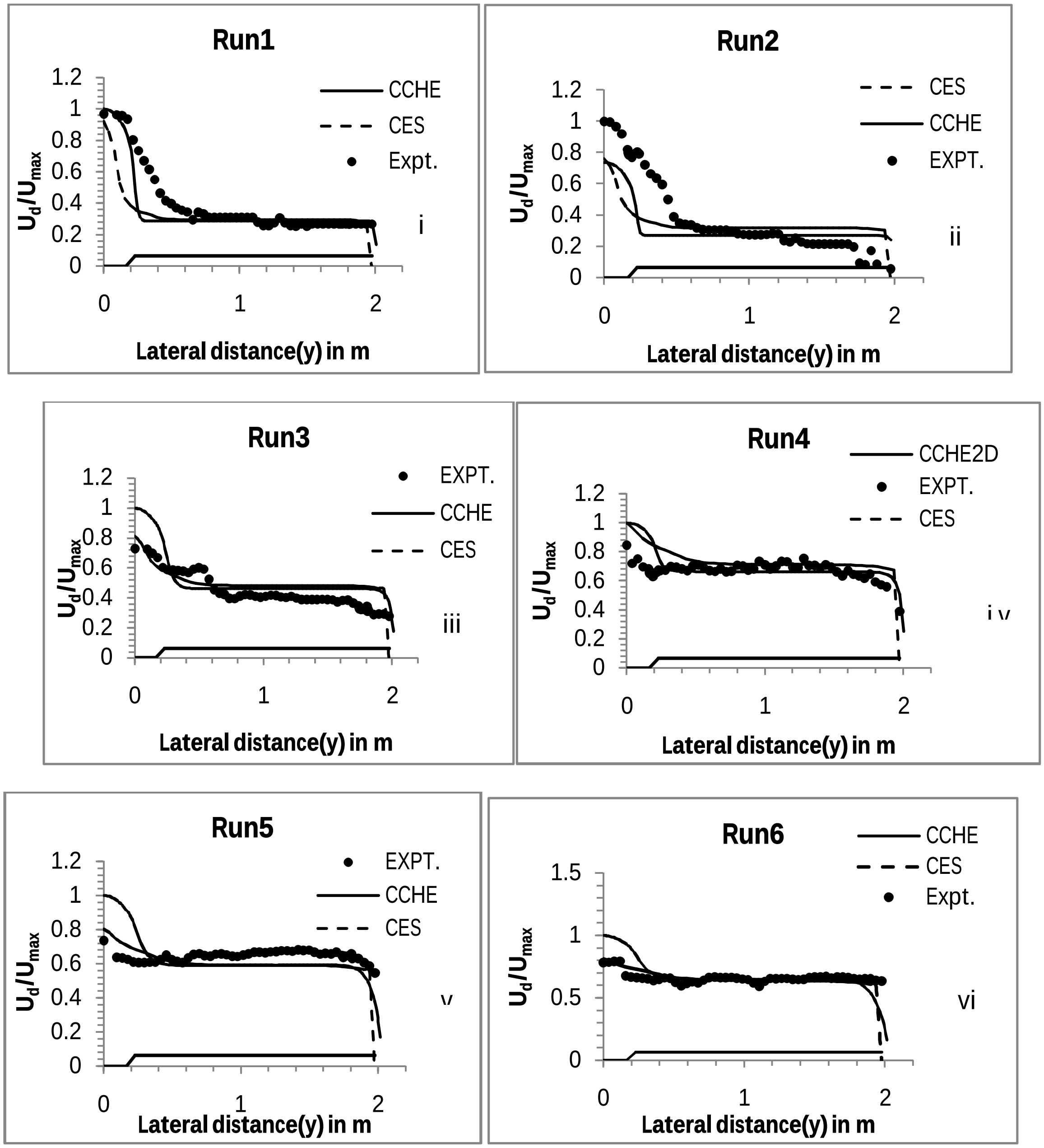

Fig8(i-vi): Variation of depth averaged velocity across the section for NIT channel for six runs.

Once again it is observed that although the channel considered in this case has a significantly higher width ratio(α≈12) still CCHE2D predictions for distribution of depth averaged velocity and boundary shear are quite satisfactory in comparison with CES results. However experimental results are not in as close agreement with both CES and CCHE2D results as in case of FCFA-1 channel. This may be due to some errors in experimental values reported. Nevertheless CCHE2D is sufficiently capable on basis of both FCFA-1 and NIT,RKL channel simulations outputs to predict the depth averaged velocity and boundary shear stress in the wide trapezoidal compound channels.

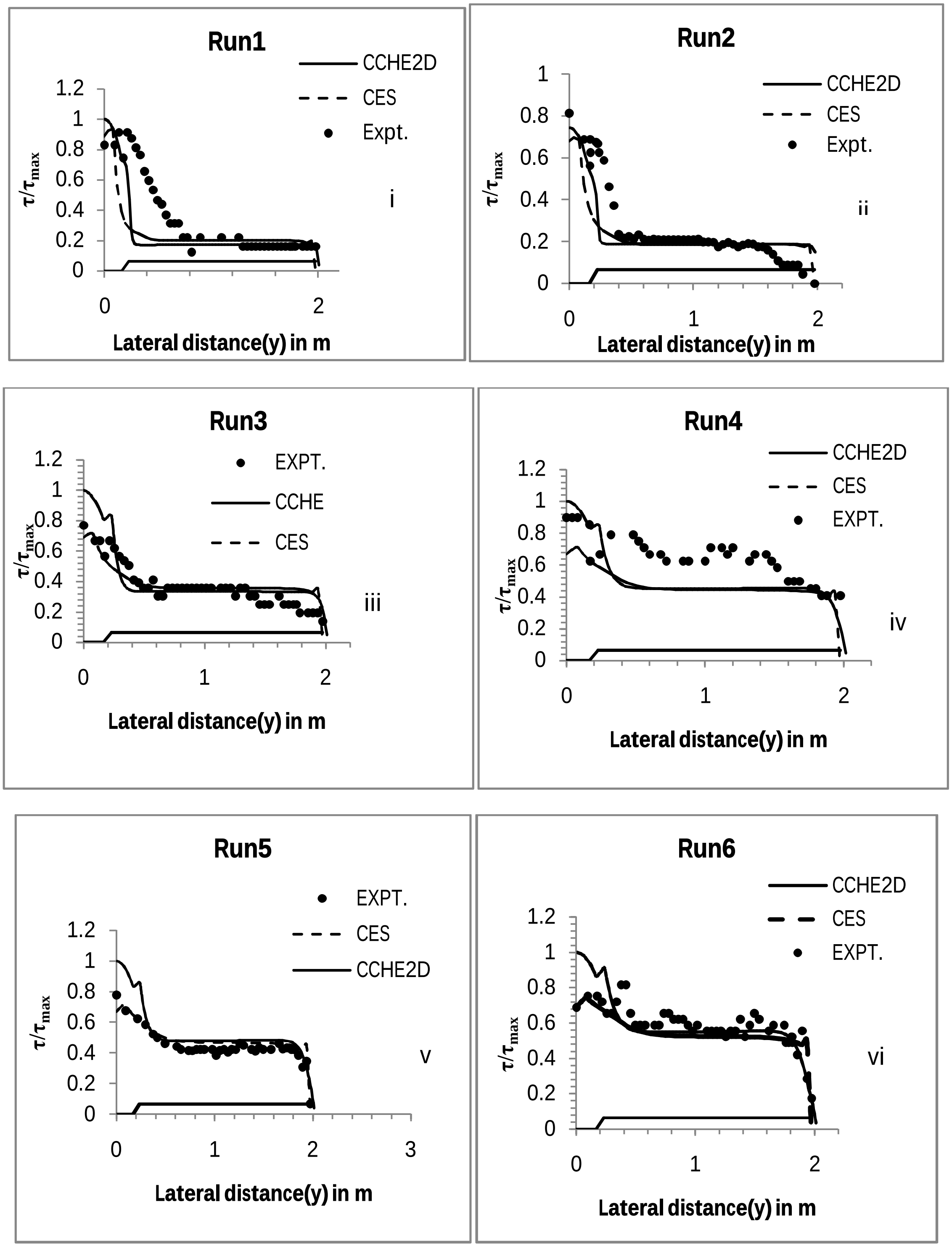

Fig9(i-vi): Variation of boundary shear stress across the section for NIT,RKL channel for six runs.

For want of space ,velocity and boundary shear distribution at various points are not shown here along the streamwise direction nor any other flow parameters such as distribution of specific discharge, eddy viscosity etc is also presented here. Only the distributions are shown at a length far away from u/s & d/s sections as advised in the manual [39] for satisfactory simulation. Interested user in fact can obtain the velocity and boundary shear data anywhere in the flow domain in addition to a host of other flow parameters such as Froude's no, eddy viscosity, specific discharge, water surface elevation etc. after a successful simulation which render CCHE2D extremely useful for hydrodynamic analysis in a riverine domain.

V. CONCLUSIONS

A 2-dimensional depth averaged model CCHE2D has been applied to a variety of subcritical flow conditions in wide smooth compound channels consisting of EPSRC-FCF channel and newly constructed channel at NIT, Rourkela, India.

A. The experimental data pertaining to FCF-A channels for Series 1 are used for validating numerical results of CCHE2D and good agreement between the two is observed.
B. To evaluate the CCHE2D results regarding the quality of outputs, results obtained from a similar analysis from a quasi 1-D package Conveyance Estimation System(CES) are also compared and contrasted with the former.
C. is seen that both are good enough to predict the distribution of boundary shear and depth averaged velocity in wide trapezoidal compound channels having width ratio(α) as 6.67
D. extend the application of the models to still wider compound channels, fresh experiments were conducted on a wide(α≈12) compound trapezoidal channel at NIT, Rourkela and velocity and boundary shear data obtained and used for validating the CCHE2D predictions.
E. CCHE2D predictions satisfactorily matched the experimental values and very well matched with CES results.
F. Both CCHE2D and CES can be used to predict the velocity and boundary shear satisfactorily for wide trapezoidal compound channels for large scale and small scale flume experiments and can be applied to riverine medium having similar properties.
G. CES can be used to estimate stage-discharge relationship whereas CCHE2D can predict the spanwise velocity and boundary shear as well as other flow parameters such as eddy viscosity, specific discharge etc which lend a distinct edge to the software.
H. In view of both the models being highly capable, inexpensive and computationally efficient to handle complex compound channel flow, it is suggested that both can be used in conjunction as a pair of complementary tools to help scientists and engineers in the field of river engineering to solve a majority of hydrodynamic problems.
I. However it is also suggested to apply and validate the CCHE2D model with straight and meandering compound channels with varying roughness criteria for further application of the model.

VI. ACKNOWLEDGEMENT

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A. Notations

The following symbols have been used in this paper.
α =Width ratio
β = Relative depth
τ=boundary shear stress at a point
τ_{max}=absolute maximum shear stress
$\tau_{xx}, \tau_{xy}, \tau_{yy}$ and τ_{yx}=Reynolds stresses
η= water surface elevation
δ= aspect ratio
ρ=density of water
ζ=bed elevation
g= acceleration due to gravity
h= depth of main channel
H=Overbank or overall depth
f_{Cor} =Coriolis parameter
Q =Discharge
U_d=depth averaged velocity in stream wise direction

U_{max} =maximum depth averaged velocity

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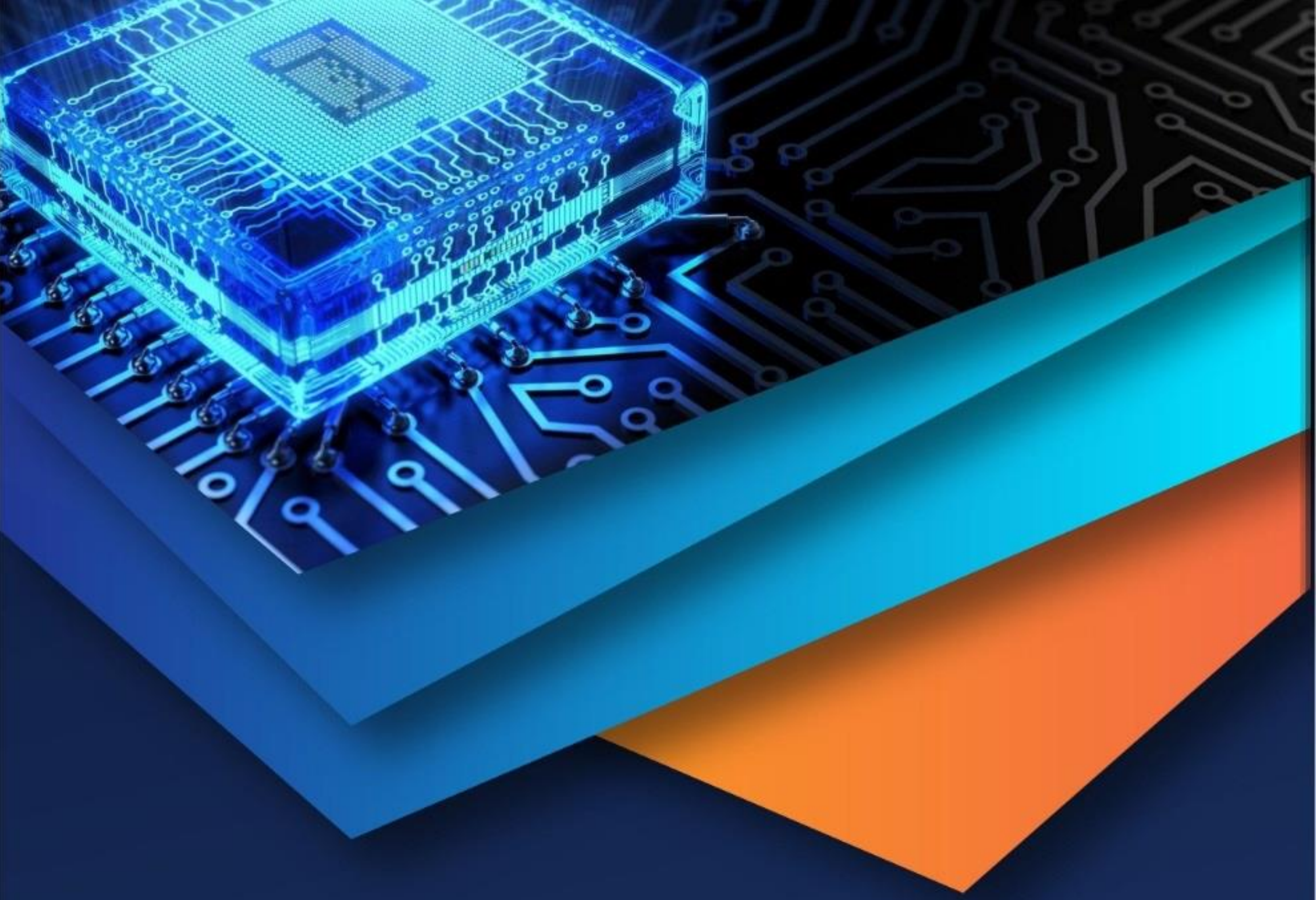

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