Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 24 No. 3-2019
ISSN:1813-1786 (Print) 2313-7770 (Online)

Flow Hydrodynamics In A Multistage Compound Channel With Riparian Vegetation

M.J Naseer[1], G. A Pasha[2], Z. Ali[3], A. Raza[4], H.M Aamir[5]

[1,2,3,4,5]Civil Engineering Department, University of Engineering and Technology Taxila, Pakistan

[1]junaid.naseer@uettaxila.edu.pk

Abstract- The concept of hydro-engineering employing the lateral velocity is valuable approach to protect the floodplains from excessive flooding. Reynold Stress Model (RSM) is labored with FLUENT, a 3-D numerical code. In non-symmetric compound channel, lateral velocity distribution is premeditated in efficient two stage floodplain. Using the RSM, it is pertinently observed that the forecast of the lateral depth average velocity distribution of numerical model coincides with the observed experimental calculations used for validation. The effects of the emergent vegetation of the floodplain were identified by using an asymmetric compound channel:150 cm length,100cm wide flume. Vegetation model used consisted of 0.5cm diameter and 15cm height cylinder, placed along the junction edges. A deceleration in the flow velocity gradient in the first and second terrace of vegetated floodplain show a dominant role in momentum exchange and increase Reynold stresses near vegetation area.

Keywords-Numerical model, Emergent vegetation, floodplain, Velocity distribution, Reynold stresses.

I. INTRODUCTION

Nowadays flood has become a common natural disaster outside our control and occur in many parts of the world. This phenomenon seems to be becoming more frequent and worse. This has led to increasing human and economic losses. Hydraulic resistance to the water flow increases by growing vegetation. The increased flow resistance results decrease in flow velocity and a rise in water depth. Hence, the vegetation in a riverbank is useful to overcome flood intensity.

In case of rivers, vegetation nurtures on floodplains, commencing multifaceted velocity field across compound channel. The momentum exchange along with velocity variance, between the tree and non-tree area, creates vortices as well as strong shear layer [1]. The lateral velocity distribution may be utilized to find flow parameter in both simple and compound channel, which imparts the key role inside a natural stream [2]. For high flood level, in natural river to gain reliable velocity distribution across the river is complex and often dangerous [3]. The interaction of the main channel and the floodplain imparts major role to create change in velocity due to exchange of momentum across the main channel and floodplain while accelerating the floodplain flow; causing decelerating of main channel flow [4-6]. Accounting aesthetic reasons, pasture, crops, bushes and trees are the key vegetations across floodplains i.e. natural condition which imparts their role in erosion rheostat. As the growth of vegetation over the floodplain alters the flow structure in compound channels [7]. Mathematical integration was used to establish turbulent transfer, a significant phenomenon in compound channels, as accomplished by Castanedo et al. [8] who recognized three different procedures for the term turbulent diffusion as that of depth-averaged Navier–Stokes expression. The experimental study [9-11] for overbank flow in a compound channel, having immobile bed and meandering geometry, has revealed that secondary current cells across the main channel section are of high potential as compared to the floodplain. The study of turbulent flow using compound channels, having vegetated floodplains, carried by Pasche & Rouve [12]; Yang et al. [13] among others, Västilä et al. [14] carried out this study on numerical modelling. Kang and Choi [15], Rameshwaran and Shiono [16] as well as Jahra et al. [17]. All the earlier studies have acknowledged and determined the important flow patterns across such type of channels. Li and Zeng [18] considered the flow at channel junctions for both: with vegetation and without vegetation by using 3-D RANS model. They investigated their complete study on the basis of Reynolds stress model (RSM): utilizing FLUENT code i.e. Computational Fluid Dynamics (CFD) as applied by Anjum et al. [19] to determine the flow pattern across discontinuous and layered vegetation patches inside an open channel. Jahra et al. [17] carried the study by using a nonlinear k - ε turbulence model along with a vegetation model to divulge mean velocity distribution and other turbulent features. Reynolds stress model was also incorporated by Kang and Choi [15] deprived of accounting the vegetation impact in

the transport equations.
In the current study, three-dimensional computations of the Reynolds Stress (RS) model, were conducted for asymmetrical compound channel and floodplain: incorporated with staggered vegetation. This setup was similar to the experimental set-up used by Nur.sh ha. [20].

II. Numerical Model Validation

The validation of numerical model was carried out using experimental data of Nur.sh ha. [20]. They carried experimental study in a channel of width 1.0 m at the University Technology: hydraulic laboratory. The arrangement of vegetation was linear in experimental study having main channel breadth (B_m) is 0.5m, floodplain width (B_F) is 0.5m and 0.15m height of vegetation as given in Fig. 1. The simulated outcomes are found to be in excellent agreement with the outcomes of the experiment given in Fig.2 (a, b and c).

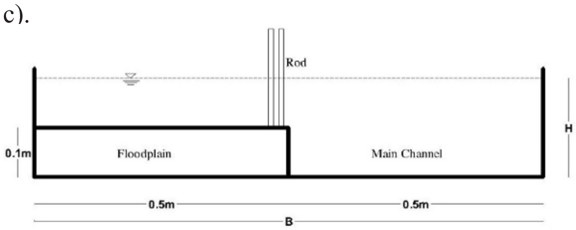
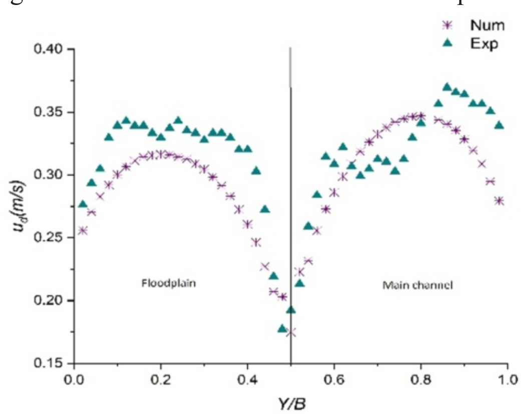
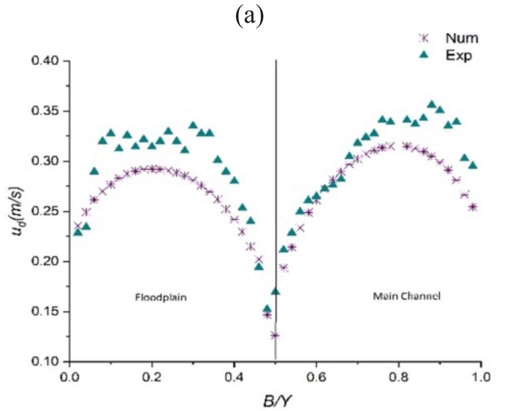


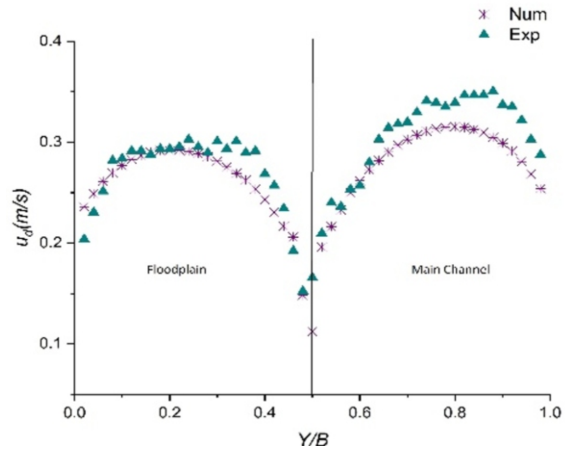
Fig. 1 The Section of the flume where trees planted



(a)



(b)



(c)

Fig. 2 Comparison of computational and experimental velocity profile [20].
(a) x=0.375L, (b) x = 0.5L, (c) P = 0.625L

III. Methodology

In this study, using length 1.5 m and 1.0m wide domain having a slope of 0.003 containing continuous and two stage double-line staggered vegetation was adopted. The graphic sketch of the domain is presented in Fig. 3 tri-pave mesh having tetrahedral elements for simulation. A mesh consisting 285×60×15 nodes in the directions of transverse and vertical and longitudinal, respectively. All the boundary domain was remained similar. The following boundary conditions were integrated into the model: (i) inlet/outlet (periodic condition), (ii) free surface (symmetry) and (iii) domain (non-slip wall) i.e. side wall, channel bed, and vegetation walls. After all the residual time is set as $1x10^{-6}$, the calculation was believed to have converged. A mesh independence trial was directed by increasing the nodes. However, no noteworthy dissimilarity was noticed in the outcomes due to refinement of the mesh. The alteration in primary velocity values due to the mesh refinement was less than 1%, which indicated that the results are mesh independent. Two stage channels were followed in order to compare the present study flow characteristic with the single stage compound channel. The geometric and hydraulic terms for the both cases are given in Table I.

Table I Model details

Group No.	Discharge Q (m^3/s)	Velocity u (m/s)	Re L(cm)	Re (cm)
S1	0.040	0.243	1215	51030
S2	0.040	0.225	1125	47250

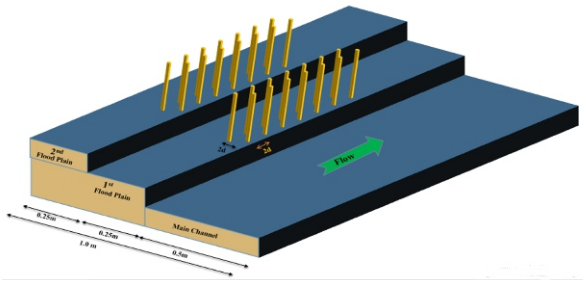


Fig. 3. Schematic diagram of the computational model

IV. GOVERNING EQUATIONS

The Reynolds-averaged Navier–Stokes and continuity equations for open channel flow. For steady incompressible flow, these equations can be written as:
Continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x_i}(\rho u_i) = 0 \qquad \text{(i)}$$

Momentum equation

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}$$

$$\text{x}(\mu(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k})) + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \qquad (2)$$

where u_i is the velocity component in i direction, u_j is the velocity component in j direction, ρ is the water density, P is the pressure, μ is the dynamic viscosity, δ_{ij} is the Kronecker delta, and $\rho u_i u_j$ are the Reynolds stresses. Equation (3) is the general form for the transport of Reynolds stresses including various terms. Each term represents the partial differential equation used for the transport of independent Reynolds stresses. The equation for the Reynolds stresses transport can be written as:

$$\frac{\partial R_{ij}}{\partial t} + C_{ij} = P_{ij} + D_{ij} - \varepsilon_{ij} + \prod_{ij} + \Omega_{ij} \qquad (3)$$

where $\partial R_{ij}/\partial t$ is the rate of change of Reynolds stresses, C_{ij} is the transport of convection, P_{ij} is the rate of production of Reynolds stresses, D_{ij} is the transport of stresses by diffusion, ε_{ij} is dissipation rate of stresses, ij is stresses transport due to turbulent pressure–strain interactions, and Ω_{ij} is the transport of stresses due to rotation. g = gravitational acceleration

V. RESULTS AND DISCUSSION

A. Depth average velocity

The comparison of depth average velocity profile between single and two staged channels taken by numerical models given in fig.4.

Initial velocity 'U' was used to normalize the velocities. Keeping in view the both cases of vegetation, it is obvious that the value of the maximum velocity-when flood plain with double staged vegetation was used-rises on ordinate as compared to first staged vegetation. The numerical modelling showed that velocity of the flow diminishes at the sides of floodplain. The existence of vegetation across two staged floodplains showed the contrast-velocity diminishes to the greater extent at the second stage-in velocities as compared to the vegetation in single floodplain.

In lateral distribution of cross wise velocity (v) and depth wise velocity (w) profile- as shown in fig.-If we consider stream-wise direction, then it is evident that the transverse and vertical velocity distributions are same for both the cases. In main channel, the distribution of velocities is almost approaching to zero and abrupt change occurred as vegetation hampered the stream flow.

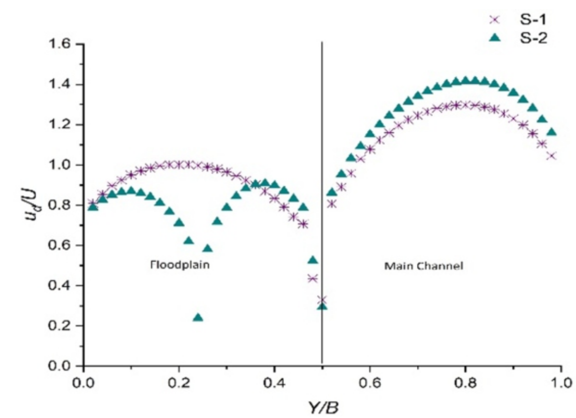
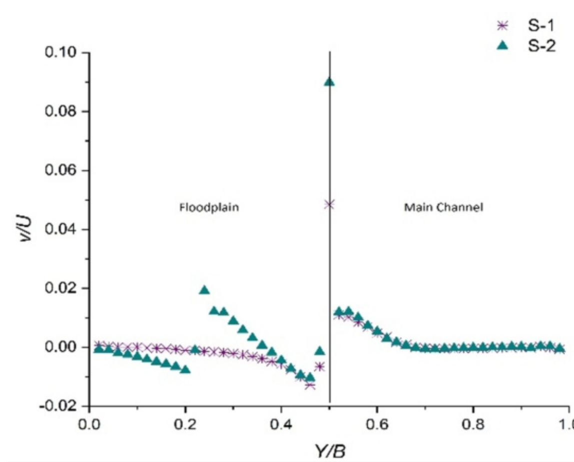
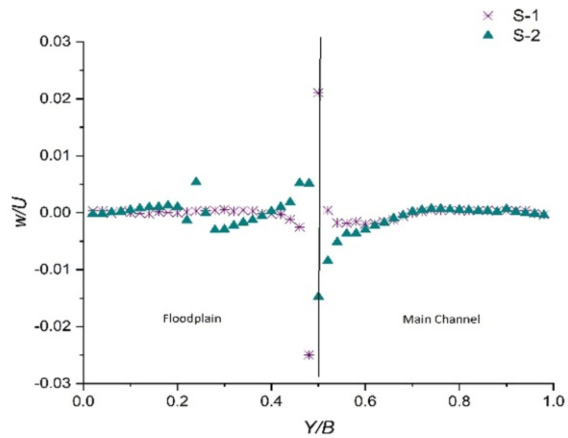


Fig. 4 Depth averaged velocity (u_d) profile for S-1 andS-2



(a)

Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 24 No. 3-2019
ISSN:1813-1786 (Print) 2313-7770 (Online)

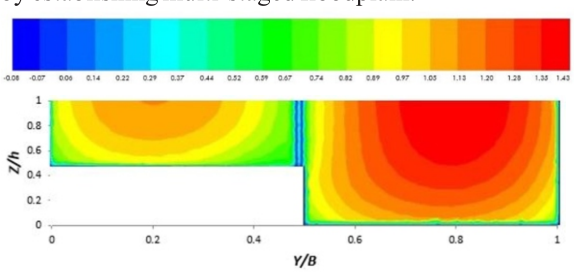


(b)

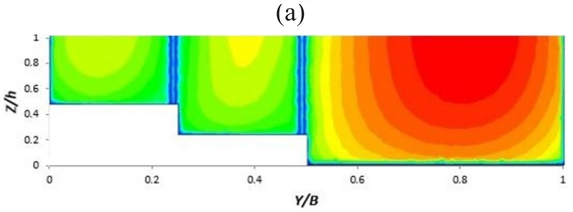
Fig. 5. profile of velocity distribution in transverse (v) and vertical (w) direction for S-1 and S-2

B. Velocity distribution contours

The Fig. 6. represents the velocity distribution (streamwise) contours along the cross section for both the first staged and second staged vegetated floodplain. The bulges of contours of main channel and the floodplain similar to Sun and Shiono [10] as they explained that this was due to the high momentum and secondary current producing in main channel towards floodplain. It is evident that presence of vegetation yielded the decrease in velocity adjoining to the bank of floodplain. If we further study the graph it can be deduced that there is increase in velocity inside main channel yielding result similar to the Sun and Shiono as they explained that existence of rigid cylinder staggered array resulted in velocity increase due to large transverse shear stress and secondary current. This increase in velocity inside main channel would cause adverse effects i.e. erosion of the bank. The stability of bank of channel can be augmented by growing vegetation along with the bank of channel and by establishing multi-staged floodplain.



(a)



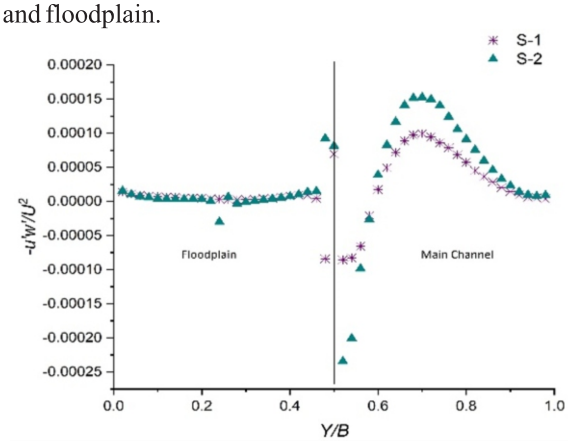
(b)

Fig. 6. Contour plots of velocity along the lateral section of S-1 and S-2

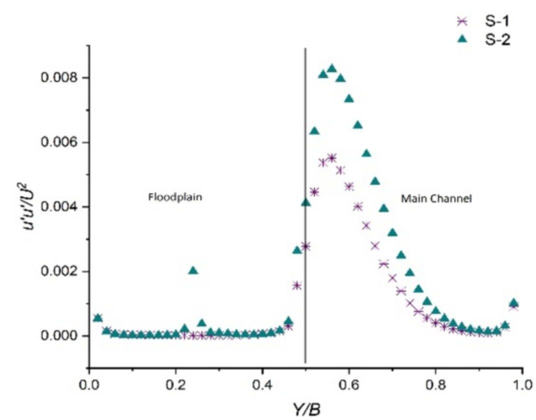
C. Reynold Stress

Reynold stresses (used to present the turbulence characteristic), including shear (-$u'w'$) and normal stresses, to investigate along the lateral direction. Theses stresses were composed of non-dimensional as per U^2 and width of the domain was normalized with channel breadth B. figure 7.a shows the profiles of stresses for both cases. In this Fig. 7 (a) "u" represents the streamwise variation and "w" represent the variation in vertical component of the velocity. The Reynold shear stresses are nearly constant in the middle of the floodplains area of the both cases. The variation in the shear stresses can be found in the main channel and higher value of shear stresses observe at the $B_m/3$ (were B_m is the main channel width) of the main channel form floodplain edge. The negative Reynold shear stresses are visible at the edge of the floodplain where vegetation grow. From this it can be concluded that the edge of the floodplain acquires lesser Reynold shear stresses which results higher stabilization of the floodplain i.e. lesser erosion of floodplain edge.

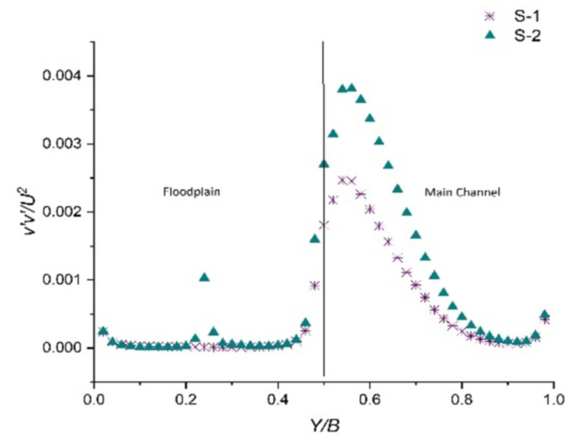
The profile of the normal stresses is constant almost zero value in the floodplain area. In case of two stage compound channel, there is lower fluctuation and turbulence at the edge of the second stage as compared to the first stage; because of higher stresses in the zone of main channel: at the interface of the main channel and floodplain.



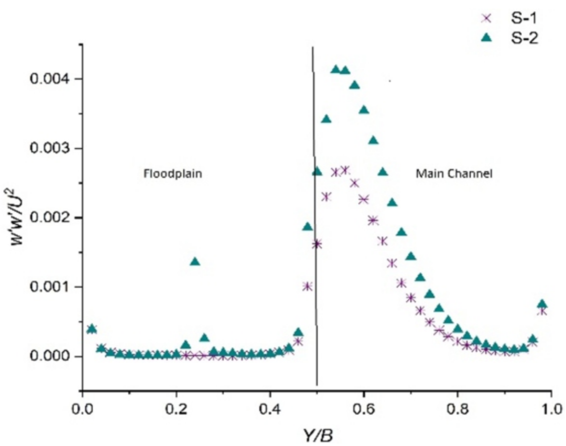
(a)



(b)



(c)



(d)

Fig. 7. Simulated profile of Reynold shear stresses and normal stress of S-1 and S-2

C. Turbulence Intensity (%)

The Fig. 8. clearly shows the profiles for the turbulent intensity: by evaluating both cases S_1 and S_2. The study further revealed that there is a turbulence of greater extent as compared to single staged floodplain: lower value of turbulence intensity was pertinently observed at second stage floodplain in case of S_2. The difference in value of turbulent intensity is 24 percent higher in S_2 as compared to S_1. The difference in values of turbulent intensity was caused due to the high value of flow velocity inside main cannel which ultimately causes fluctuations in turbulent intensity. The study further disclosed that turbulence intensity faces resistance at the two-stage floodplain.

D. Contour of turbulent intensity distribution:

The formation of contours-as shown below in fig. 9. of cases S_1 and S_2 provided a pertinent observation of fluctuations of turbulent intensity in main channel due to eminent flow velocity. The Fig. 9 Shows that there is low turbulent intensity in main channel which is less as compared to the formation of contours of two stage compound channel. This large difference is appositely justified by the occurrence of vegetation at the edge of main channel and floodplain.

For installation in river training works it will be better to install two stage floodplains as compared single stage floodplains in order to augment the bank stability of open channels. This will not only salvage the deterioration of banks but will also allow the flood of mediocre intensity to pass through without severe effects.

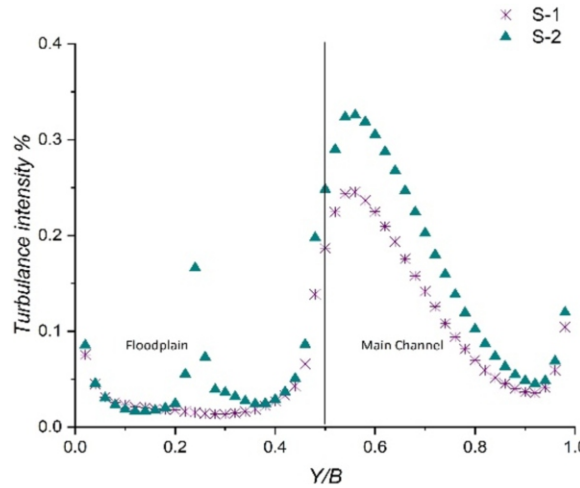
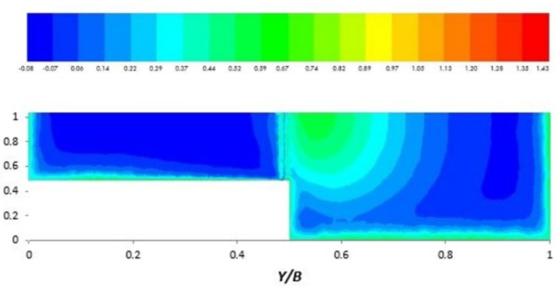
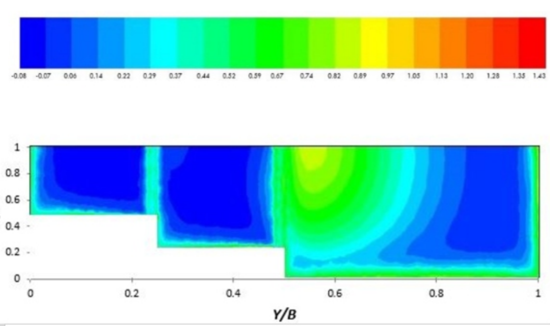


Fig.8 Simulated profile of turbulent intensity of S-1 and S-2



(a)



(b)

Fig. 9. turbulent intensity (%) contour along the lateral section of S-1 and S-2

VI. Conclusion

This paper is thoroughly composed of computational method to study the flow characteristics by incorporating two cases of floodplains with staggered vegetation: of finite diameter in lateral direction. The Reynold Stress Model (RSM) was applied with the purpose of investigate flow properties in this study. The studied cases can be applied for efficient use of Reynold Stress Model in predicting flow behavior. The crux of this paper is delineated by following key points;

1. The maximum depth average velocity was observed in the main channel and by incorporating two-stage floodplain: the value of velocity increased by 16 percent as compared to single stage floodplain.
2. The velocity diminishes 0.095 m/s in two stage floodplain area of value 0.907m/s as compared to single stage floodplain value of 1.002m/s.
3. There was prominent difference in flow behavior: passing through two different floodplains with staggered vegetation as result by limited first floodplain reducing momentum exchange.
4. In two stage floodplains, there is a higher turbulence of 8 percent relative to single floodplain.

Acknowledgments

The authors are grateful to Higher Education commission, Pakistan, for rendering their services of CFD software at University of Engineering & Technology Taxila, Pakistan, this software was utilized to conduct the research work.

References

[1] CH Liu, X Luo, X Liu, K Yang. Modeling depth- averaged velocity and bed shear stress in compound channels with emergent and submerged vegetation. Adv Water Resour 2013. 60:148–159.

[2] D.W Knight, Practical channel hydraulics. London, UK: Taylor & Francis 2010.

[3] A. Zahiri. X. Tang, 2017. Optimal prediction of lateral velocity distribution in compound channels

[4] Yang Z., Li D., Huai W., Liu J., A new method to estimate flow conveyance in a compound channel with vegetated floodplains based on energy balance, Journal of Hydrology, (2019) 575, 921-929.

[5] F. Huthoff, P.C. Roos, D.C.M. Augustijn, S. Hulscher, Interacting divided channel method for compound channel flow, J. Hydraul. Eng. 134 (2008) 1158–1165.

[6] K. Yang, S. Cao, D.W. Knight, Flow patterns in compound channels with vegetated floodplains, J. Hydraul. Eng. 133 (2007) 148–159

[7] K. Yang, S. Cao, X. Liu, Research on system dynamics model of conveyance capacity in symmetric compound channels, J. Hydrodyn. Ser. B 17 (2005) 295–300

[8] S. Dey, M. Lambert, Discharge prediction in compound channels by end depth method, J. Hydraulic. Res. 44 (6) (2006) 767–776.

[9] S Castanedo, M Medina, FJ Mendez. Models for the turbulent diffusion terms of shallow water equations. J Hydraul Eng. 2005;131(3):217–23. http://dx.doi.org/10.1061/(ASCE)0733-9429(2005) 131:3(217).

[9] P Rameshwaran , J Spooner, K Shiono, JH Chandler. Flow mechanisms in two stage meandering channels with mobile bed. In: Process 28th congress of IAHR, vol. 256, Graz, Austria; 1999. p. 259–266.

[10] K Shiono, Y Muto. Complex flow mechanisms in compound meandering channel for overbank flow. J Fluid Mech 1998; 376:221–61. http://dx.doi.org/10.1017/S0022112098002869.

[11] K Shiono, Y Muto, DW Knight, AFL Hyde. Energy losses due to secondary flow and turbulence in meandering channel for overbank flows. J Hydraulic Res 1999;37(5):641–64.

[12] E Pasche, G Rouve. 1985. Overbank flow with vegetative roughened floodplains. J Hydraulic Eng.-ASCE. 111:1262–1278.

[13] KJ Yang, SY Cao, DW Knight. 2007. Flow patterns in compound channels with vegetated floodplains. J Hydraulic Eng.-ASCE. 133:148–159.

[14] K Västilä, J Järvelä, H Koivusalo. 2015. Flow-vegetationsediment interaction in a cohesive two-stage channel. J Hydraul Eng-ASCE. doi:10.1061/(ASCE)HY.1943-7900.00 01058.

[15] H Kang, SK Choi. 2006. Turbulence modeling of compound open-channel flows with and without vegetation on the floodplain using the Reynolds stress model. Adv Water Resource. 29:1650–1664.

[16] P Rameshwaran, K Shiono. 2007. Quasi two-dimensional model for straight overbank flows through emergent vegetation on floodplains. J Hydraulic Res. 45:302–315.

[17] F Jahra, Y Kawahara, F Hasegawa, H Yamamoto. 2011. Flow– vegetation interaction in a compound open channel with emergent vegetation. Int J River Basin Manage. 9:247–256.

[18] CW Li, C Zeng (2009) 3D Numerical

modeling of flow divisions at open channel junctions with or without vegetation. Adv Water Resource 32:49–60

.[19] N Anjum, U Ghani, GA Pasha, A Latif, T Sultan, S Ali (2018) To Investigate the flow structure of discontinuous vegetation patches of two vertically different layers in an open channel. Water 10:75

[20] SH Nur, B.I Zulhilmi, "Bed Formation in Compound Straight Channel"

[21] N Anjum, U Ghani, GA Pasha. (2018) Reynolds stress modeling of flow characteristics in a vegetated rectangular open channel. Arab J Sci Eng. https://doi.org/10.1007/s13369-018-3229-8

[22] SU Choi, HS Kang (2004) Reynolds stress modeling of vegetated open channel flows. J Hydraul Res 42(1):3-11

[23] X Su, CW Li (2002) Large eddy simulation of free surface turbulent flow in partly vegetated open channels. Int J Numer Meth Fluids 39(10):919–937

[24] GA Pasha, N Tanaka (2017) Undular hydraulic jump formation and energy loss in a flow through emergent vegetation of varying thickness and density. Ocean Eng. 141:308–325 [xxv] F. M. Henderson, "1966, Open channel flow, Macmillan, New York."

[25] C Zeng, C.W Li (2014) Measurements and modeling of open-channel flows with finite semi-rigid vegetation patches. Environ Fluid Mech 14:113–134

[26] C Yan, HM Nepf, WX Huang, GX Cui (2017) Large eddy simulation of flow and scalar transport in a vegetated channel. Environ Fluid Mech 17(3):497–519