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NUMERICAL SIMULATION OF FLOW PATTERN IN SERIES OF IMPERMEABLE GROYNES IN FIXED BED

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Abstract

This paper presents a numerical simulation of recirculating flow patterns in groyne fields. Moreover, it entails the concept determination of proper spacing of vertical unsubmerged and impermeable groynesin seriesto control the bank erosion. Flow pattern between the groynes varies along their space. The flow in groyne field may significantly affect the flow change, bed change, bank erosion and condition of habitat. In this regard, an assessment of flow along the space of groynes will yield important data needed to diversify the object of groyne installation. So, knowledge about determination of the proper spacing of groynes in groyne field is important. Space of vertical groynes was set from 1.5 to 10 times the length of groynes. The velocity field between groynes was simulated by using Computational Fluid Dynamics (CFD) model Nays 2D. Simulated velocity field was compared with existing experimentaldata for the same parameter, which agreed satisfactorily. Based on simulated results,the optimal spacing of vertical groynes to control the bank erosion was recommended.

Keywords: *groynes, groynefield, aspect ratio, bank erosion, bed change, habitat, CFD, simulation*

1. Introduction

Spur dikes or groynes are used to protect river banks from erosion and also keep the channel navigable.Depending upon the flow characteristics, spur-dikes may be classified as submerged and un-submerged. Also, based on the permeability, spur dikes are further classified as permeable and impermeable. Herein, un-submerged –impermeable spur dikes are dealt. These structures are built from the river bank into the stream flow and usually built in group. Construction of groyne against the flow causes significant changes in flow pattern in channel. Those changes may result in scour phenomenon around groynes which may lead structure instability and changes in river morphology. Moreover, in series of groynes, spacing of groynes leads different types of recirculating flow patterns.Therefore, investigating the characteristics of flow pattern around groynes have been a great interest in river engineering. Numerous researchers like Sukhodolov et al. (2002), Hao Zhang et al.(2009), Beheshti (2010), Duan (2009), Naji(2010), Karami(2011) made a variety of experiments in order to determine the flow pattern around groynes. Most of these researchers studied effect of single groyne, while using series of groynes is more effective in protection of rivers. Besides experimental studies, variety of CFD models have been developed for computing flow pattern around hydraulic structures; like Fluent, Flow 3D, Nays 2D, Nays CUBE and SSIIM. In this study, Nays 2D numerical modelling has been used to investigate flow and recirculating pattern around a series of groynes and streamlines including components of velocities.

2. Flow pattern in groyne fields

Under conditions where the groynes are not submerged, the groyne fields are not really part of the wetted cross section of a river. Because of that, the flow pattern in the groyne-field is not directly the result of the discharge in the main channel. Reducing the main stream velocity has no effect on the flow pattern itself, whereas lowering the water level does (Uijttewaal et al.2001). Moreover, the flow pattern inside a groyne field may change with the change of its geometry, location along the river (inner curve, outer curve, or straight part), and/ or the groynes orientation(Przedwojski et al.1995).

However, there is an indirect effect of the discharge on the flow pattern in the groyne field. Because of the flow that is diverted from the main channel into the groyne fields, water flows into the groyne field with low velocity through the downstream half of the interfacial section between the groyne field and the main channel. This water flows back to the main channel through a small width of, just downstream the upstream groyne of the groyne field (Termes et al.1991).

Flow separates on a groyne head and forms a secondary flow represented by a large scale vortex with a vertical axis of rotation called primary gyre. Deflection of the flow inside the groyne field by banks and upstream groynes leads to the development of a secondary gyre with an opposite direction of rotation to the primary gyre. Location, mutual interactions, and energy exchange between gyres are the factors that create a specific recirculation pattern, and, consequently assuming correspondence with sedimentation processes, they define deposition patterns.

3. Model Formulation

The CFD model selected for this study is the publically available software NAYS 2D (iRIC 2.0), which is an analytical solver for calculation of unsteady two-dimensional plane flow and riverbed deformation using boundary-fitted coordinates within general curvilinear coordinates. A numerical channel of length 8.0m and width 0.9m was created with grid size of 0.01m im stream wise and 0.03m in cross stream directions. Groynes or spur dikes of length 0.15 and width 0.01m were chosen in series. Groyne field with various aspect ratio (b/x) 0.7, 0.25, 0.17, 0.125 and 0.10, where b=length of spur dike, x=spacing of two dikes. Discharge of 0.0175 m^3/s was applied. For boundary conditions, water surface at downstream and velocity at upstream were considered as uniform flow. Relaxation coefficient for water surface calculation was considered as 0.8.

For the finite-difference method, the CIP method was applied to the advection terms in equations of motion. For the turbulent field calculation, Constant eddy viscosity, Zero-equation model and k-ε models were applied and compared. The model's accuracy in predicting the velocity magnitudes is evaluated using statistical parameters- mean absolute error (MAE), mean square error(MSE), and root mean square error (RMSE). The comparison of results shows the importance of selecting an appropriate turbulence model in simulating flow field around a spur dike. From the comparison, k-ϵ model is found superior over zero energy model and eddy viscosity model. So, k-ϵ model is chosen as appropriate turbulence closure model.

4. Model's Validation

The capability of CFD model Nays 2D to simulate the velocity field and recirculation pattern in groyne field was compared with experimental data of laboratory experiments by Sukhodolov et al. (2002). The numerical simulation was validated for aspect ratio (R=b/x=0.7) and R=0.25. For aspect ratio R=0.7, one gyre system occupies the whole area of the groyne field. The areas with lower-than-average velocity values are clearly seen in the central part of the gyre and near its corners. Velocities increase towards the margins of the gyre. For aspect ratio R=0.25, two gyre velocity fields were observed in the groyne field. In the downstream part of the groyne field a large gyre, covering two-thirds of the area is clearly visible. The left part(upstream) contains second gyre rotating much more slowly and in the direction opposed to the primary gyre. The simulated and observed velocity field pattern and gyre found satisfactorily agreed.

Now, after validation, the model was used for further analysis of velocity field for various aspect ratios.

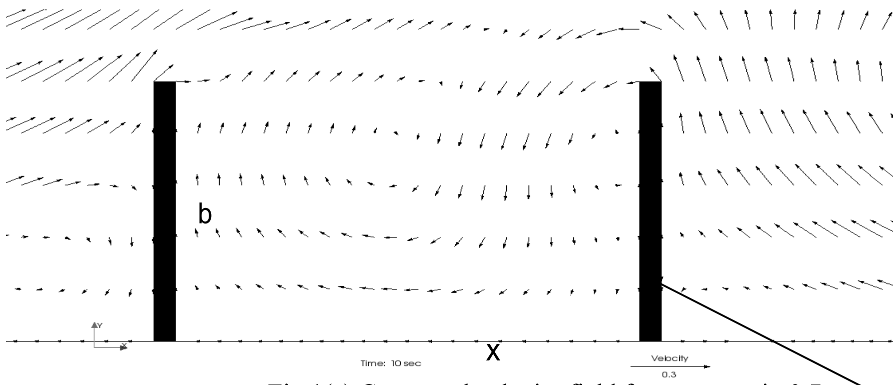


Fig 1(a) Computed velocity field for aspect ratio 0.7

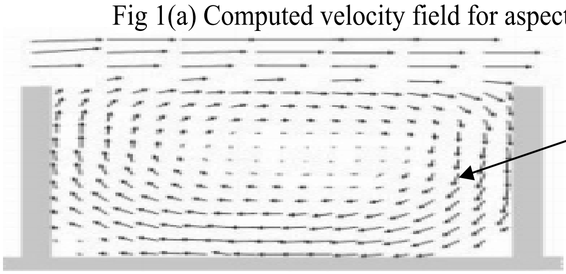


Fig 1(b) Observed velocity field for aspect ratio

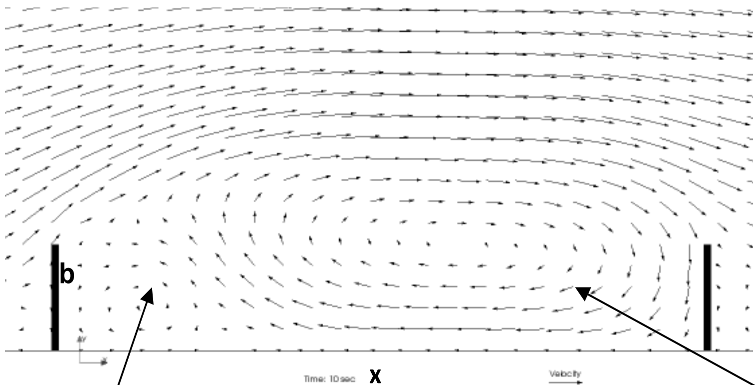


Fig 2(a) Computed velocity field for aspect ratio 0.25

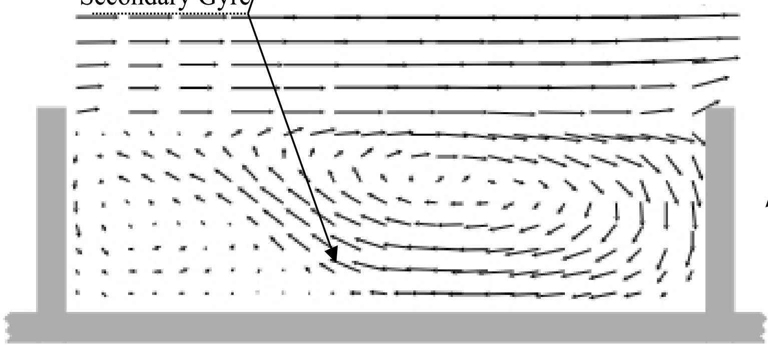


Fig 2(b) Observed velocity field for aspect ratio 0.25(Sukhodolov 2002)

5. Results and Discussions

The calibrated model was applied to five different cases of un-submerged and impermeable groyne fields with aspect ratios R=0.70,0.25,0.17,0.125 & 0.10 and flow pattern was numerically simulated. For aspect ratio R=0.7 i.e x/b=1.5, Fig 1(a) only one lateral primary gyre was formed inside the groyne field. The circulation pattern in this case is distinguished by the main flow that is deflected outside the groyne field. The developed primary gyre prevents the main flow from penetrating the groyne field.

Therefore, this pattern is desirable for navigation purposes as a continuous deep channel is maintained along the face of the groyne field. Simulated velocity pattern satisfactorily agrees with the observed velocity field Fig 1(b) for the same aspect ratio by Sukhodolov (2002).

The spacing of the groyne was further increased maintaining aspect ratio R= 0.25 i. e x/b=4 Fig 2(a) and flow pattern inside the groyne field was simulated. In this case, in the downstream part of the groyne field, a primary gyre occupying almost two-third area was formed. In addition, deflection of the flow inside the groyne field by banks and upstream groynes leads to the development of a secondary gyre with an opposite direction of rotation to the primary gyre covering almost one-third part of the groyne field. Likewise in the first case, the main current is maintained deflected outside the groyne field. Simulated velocity pattern satisfactorily agrees with the observed velocity field Fig 2(b) for the same aspect ratio by Sukhodolov (2002).

The spacing of the groyne was further increased maintaining aspect ratio R=0.17 i.e x/b=6. In this case the flow pattern was similar to the aspect ratio R=0.25.

The spacing of the groynes was further increased maintaining aspect ratio R=0.125 i. e x/b=8. In this case, similar to the previous scenarios two longitudinal gyres but with different positions are formed. The main current is directed in to the groyne field (Fig 3) creating a much more stronger eddy near the upstream groyne and greater turbulence along the upstream face and at the groyne lower head.

As the spacing between groynes increased maintaining aspect ratio R=0.10 i. e x/b=10 (Fig 4), still primary and secondary gyres are generated. The formed gyres deflect the main flow thus preventing to enter in to the groyne field in upstream part. However, in the downstream of the primary gyre and just upstream of the second groyne, the flow attacks the bank directly.

The resultant velocity profiles at the deflected region y/b=3 were plotted and how the spacing of second groyne affect the result was analyzed. Spacing of groynes makes little change in upstream resultant velocity. However, in the deflected region, its effect is significant. Higher value of spacing of groyne leads higher average deviation in resultant velocity. For aspect ratio R=0.7, the average deviation estimated as 0.02%. In the case of aspect ratio R=0.25, this value was reached to 1.57%. Further increment of spacing i. e decreasing the aspect ratio R=0.17, average deviation was found 3.82%. For the aspect ratio R=0.125, that value was estimated as 4.16%.

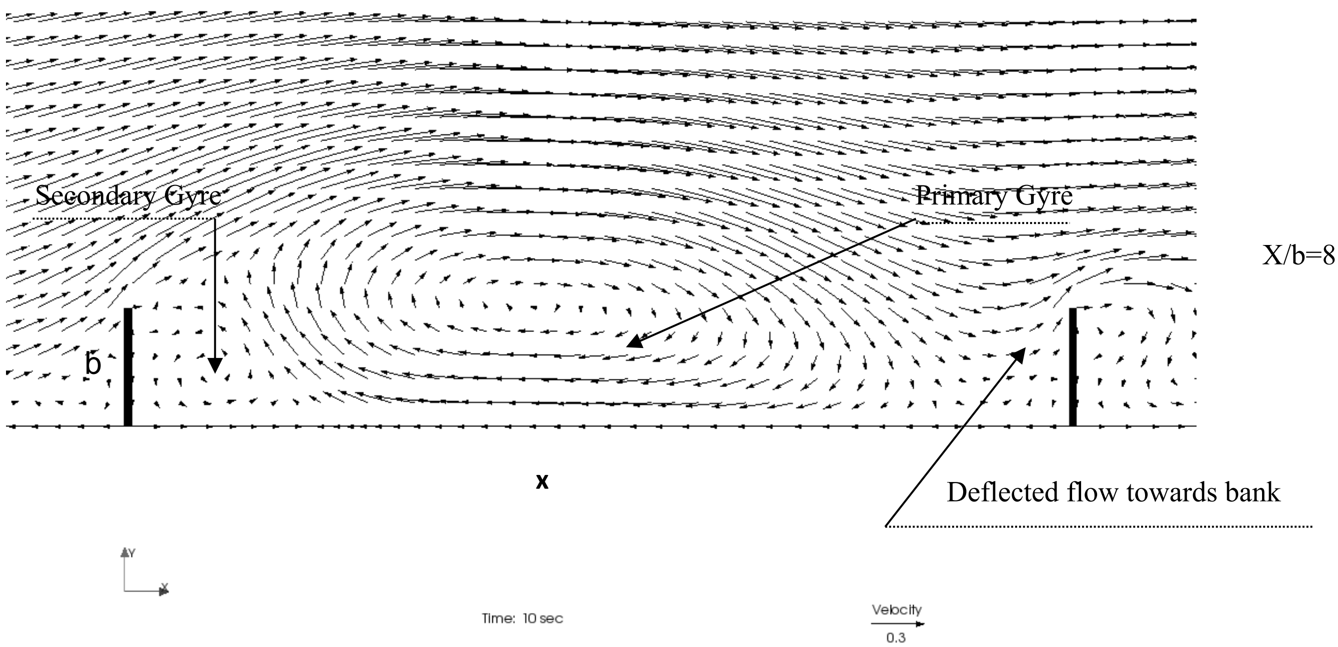


Fig 3 Computed velocity field for aspect ratio 0.125

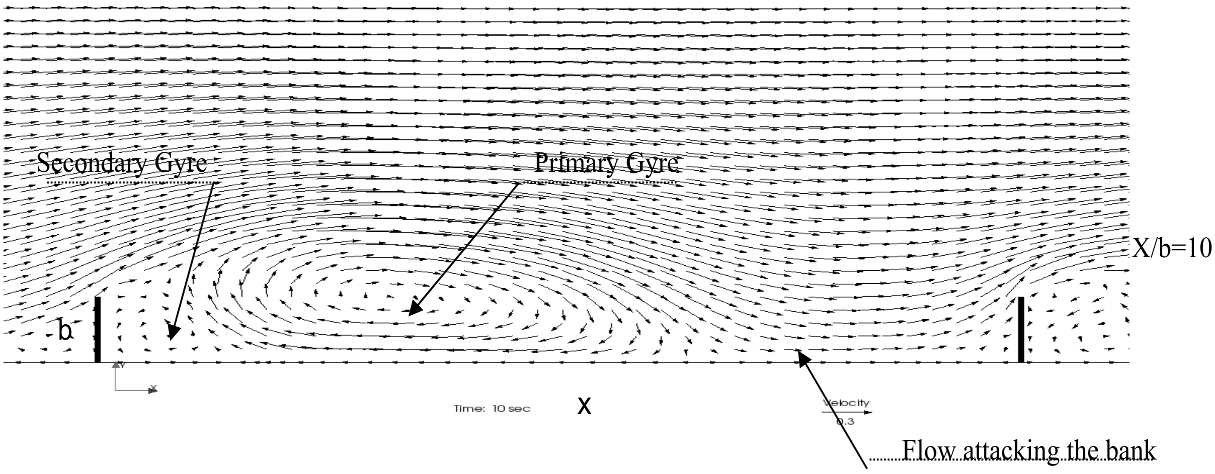
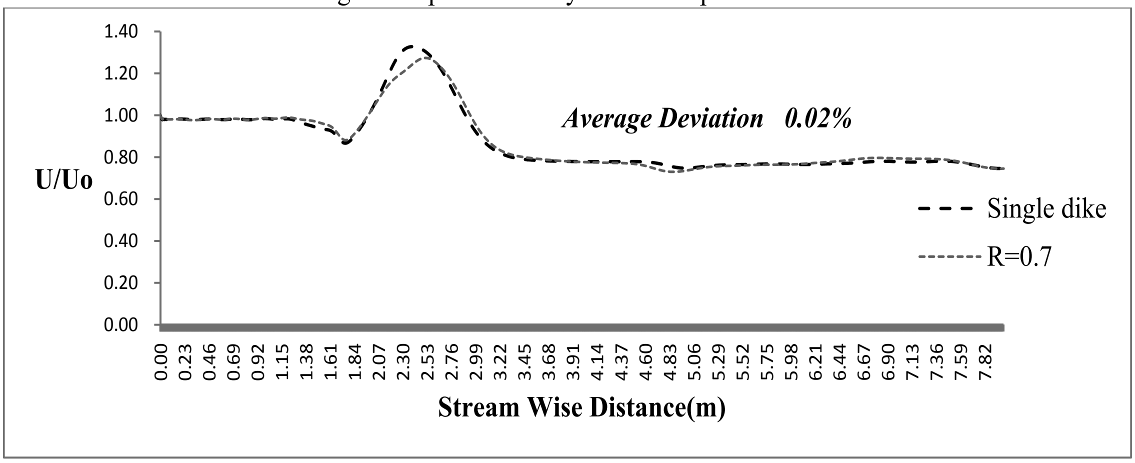
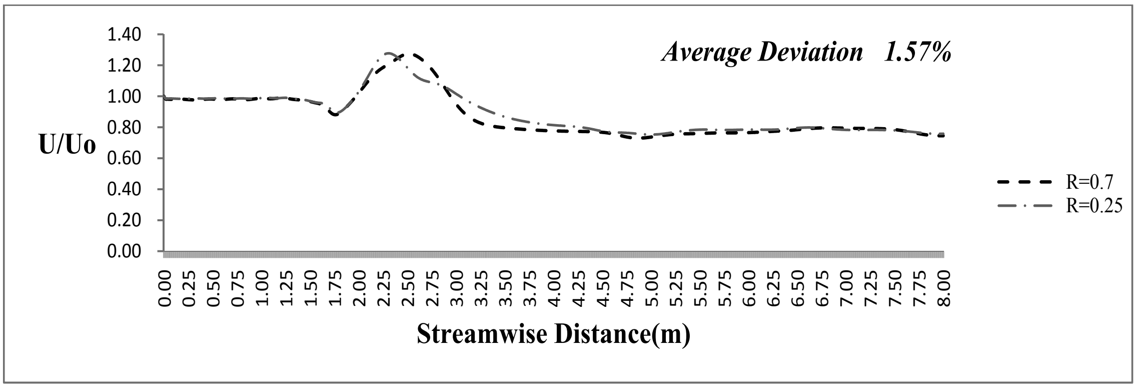
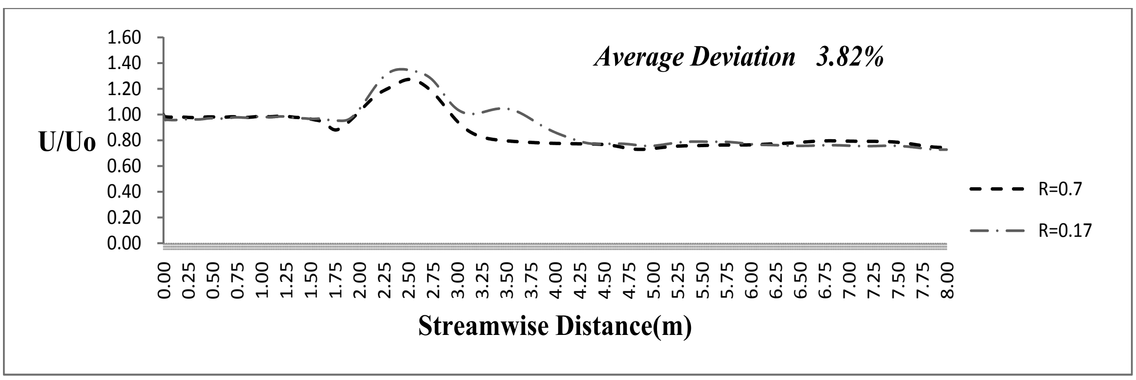


Fig 4 Computed velocity field for aspect ratio 0.10







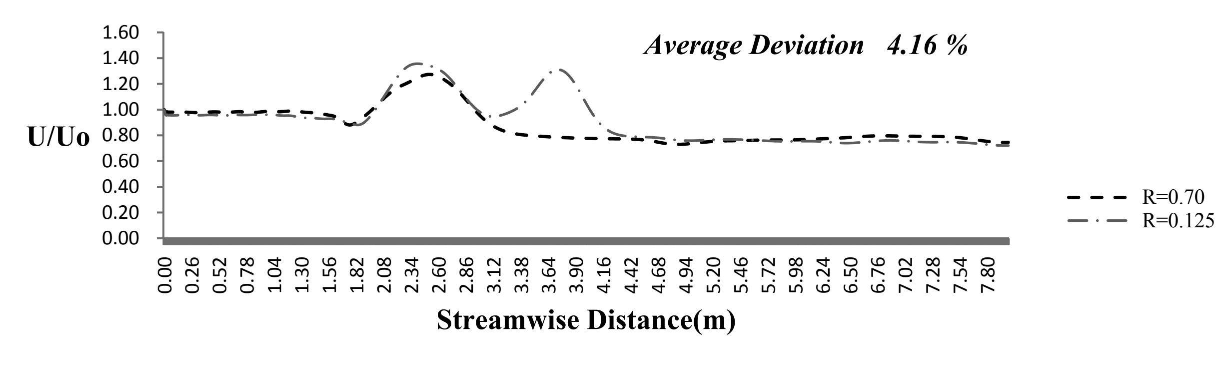


Fig 5 Resultant velocity profiles at y/b=3

6. Conclusions

Geometry of the groyne fields; width and length of the groyne field mainly cause the specific flow patterns including number and shape of eddies or gyres. Eddies developed inside the groyne field deflects the main flow preventing it entering into the dead zone. An aspect ratio close to unity gives rise to a single eddy. A smaller aspect ratio (higher spacing between groynes) gives room to two stationary eddies, a large one called primary eddy, in the downstream part of the groyne field, and a smaller secondary eddy emerges near the upstream groyne. The extreme long groyne field -case of length to width ratio of larger thaneight shows penetration of main flow into the groyne field. The two eddies remain in a relatively stable position, while the main flow zone starts to penetrate into groyne field further downstream. In all cases, there is an eddy detaches from the upstream groyne tip that travels along the main channel groyne field interface and eventually merges with the primary eddy. The simulated results indicate that the spacing of groynes or spur dikes from the controlling of bank erosion point of view should be limited within six times the length of groyne.

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