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Performances of Straight Head and T-head Groynes as River Training Structures

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Abstract. Any structure which is constructed within a river, for managing the flow of the river to make it beneficial for mankind is termed as river training structure. Groyne is one such type of hydraulic structures, which is generally constructed for various purposes including bank erosion prevention, facilitating smooth navigation, etc. These structures are generally constructed from the river bank and extend towards the main channel flow. Depending upon the head shape, groynes may be further classified into straight and T-head types. Literature survey has revealed that comparative analysis of performances of straight head and T-head groynes is still not sufficient enough. Therefore, in the present work numerical models have been developed for both the types of groynes specifically in channel bend and their performances are compared. In order to numerically simulate the flow processes, MIKE21C modeling tool is used here. From the comparison it appears that in case of T-head groyne, the shifting of the thalweg line from the outer is more. Moreover, higher value of sediment deposition is also observed in the T-head groyne field. All these results finally establish that T-head groynes are better than straight head groyne in river bend.

1. Introduction

Any kind of structures those are constructed in a river for guiding/managing the river water for beneficial purpose of mankind are termed as river training structures. Groyne or spur dike is one of the most commonly used river training structures generally constructed from the river bank and extend towards the main channel flow. Depending upon the head shape, they may be classified into straight head and T-head groynes. They are constructed for various purposes including, deflecting/repelling the flow away from bank for safety, increasing flow depth for smooth navigation, etc. Construction of these structures leads to blockage in the flow and always leads to changes in the local hydrodynamics as well as the morphology of the river. At the same time, the flowing water also imparts some effects on the groyne. These effects may be in the form of increment in the flow speed near the tip of the structure, development of local scouring around the structure due to pressure difference between the top and bottom water pressures near the structure. These local scouring many a time even may leads to failure of the structure itself. Moreover, the opposite river bank also faces high speed and shear stress upon construction of these structures. Therefore, before implementing a project deals with construction of groyne, it is always essential to conduct a model study to evaluate the probable effect of the groyne on the river as well as the reverse effect of the river on the structure itself. These model studies however, may be based on either experimental approaches or numerical approaches. However, experimental approaches are not generally preferred due to their large investment cost, repetitive approach etc. Numerical modeling however has become very popular techniques in this regard.

Ahmad [1] conducted one of the first experimental studies for simulating scouring process around straight head groynes. After that several numerical and experimental studies [2, 3, 4] are reported in the literatures for flow simulation around straight head groynes. Application of T-head groynes in rivers is comparatively a recent topic in computational hydraulics. A few literatures are also available [5, 6] for flow simulation around T-head groyne. Mansoori et al. [7] first compared the performances of straight head and T-head groynes in straight channels. Results have shown that the magnitudes of velocity vectors inside the T-head groyne's fields are much smaller than the similar areas in straight groynes, leading to more safety of the near bank, using T-head groynes. So far the authors' knowledge, no study has been taken up yet for comparing the performance of straight head and T-head groynes in channel bend. Therefore, the present work tries to simulate series of straight head and T-head groynes in channel bend to appraise their performances for bank stability.

2. Numerical model for morphological flow simulation

2.1. MIKE21 governing equations and solution techniques

MIKE 21C is an integrated river morphology modelling tool based on a curvilinear version of the 2D surface water model MIKE 21. MIKE 21C simulates the changes in the river bed and plan form, including bank erosion, scouring associated with construction work and changes in the hydraulic regime. The hydrodynamic equations solved in MIKE21C are;

$$\frac{\partial H}{\partial t} + \frac{\partial p}{\partial s} + \frac{\partial q}{\partial n} - \frac{q}{R_s} + \frac{p}{R_n} = 0 \tag{1}$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial s}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial n}\left(\frac{pq}{h}\right) + 2\frac{pq}{hR_n} + \frac{p^2-q^2}{hR_s} + gh\frac{\partial H}{\partial s} + \frac{g}{C^2}\frac{p\sqrt{p^2+q^2}}{h^2} = RHS \tag{2}$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial s}\left(\frac{pq}{h}\right) + \frac{\partial}{\partial n}\left(\frac{q^2}{h}\right) + 2\frac{pq}{hR_s} + \frac{p^2-q^2}{hR_n} + gh\frac{\partial H}{\partial n} + \frac{g}{C^2}\frac{q\sqrt{p^2+q^2}}{h^2} = RHS \tag{3}$$

where, s, n are co-ordinates in the curvilinear co-ordinate system, p, q are mass fluxes in the s-and n-direction, respectively, H is water level, h is water depth, g is gravitational acceleration, C is Chezy roughness coefficient, Rs, Rn are radius of curvature of s and n line, respectively and RHS is the right hand side in the force balance contains Reynolds stresses, Coriolis force and atmospheric pressure. The governing hydrodynamic equations are solved here using Alternate Direction Implicit (ADI) scheme.

The sediment continuity equation solved in MIKE21C is;

$$(1-n)\frac{\partial z}{\partial t} + \frac{\partial S_x}{\partial x} + \frac{\partial S_y}{\partial y} = \Delta Se \tag{4}$$

where, Sx is total sediment transport in x-direction, Sy is total sediment transport in y-direction, n is bed porosity, z is bed level, t is time, (x, y) are Cartesian co-ordinate system and ΔSe is the lateral sediment supply from bank erosion.

From equation (4) the calculation of sediment transport of bed material (bed load and suspend load), the bed level change can be computed. The total sediment transport is the sum of the bed load and suspended load. A space centred-time forwarded difference scheme is applied here for solving the equation. The time step is limited by the Courant criterion i.e. that the Courant number should be less than 1.

2.2. Validation of the Numerical Model

A numerical model has been developed to validate the model with available analytical data presented by Mohapatra and Bhallamudi [8]. Figure 1 show the channel which is gradually expanding in nature.

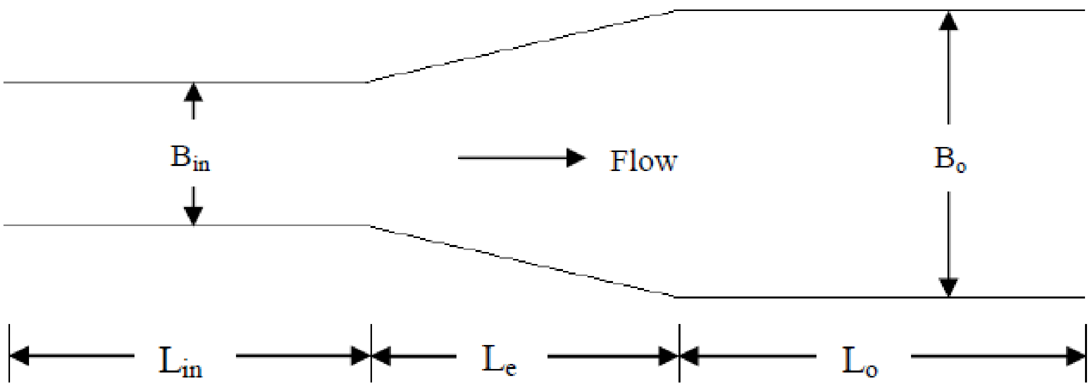

Figure 1. Definition Sketch (Plan) (Mohapatra et al.1994) ; Lin = 5.6 m, Le = 4.0 m, Lo = 6.4 m, Bo= 0.9 m and Bin = 0.3 m.

Grids for the considered channel have been developed in MIKE21C Grid Generator. Along the channel no of grid points are 161 and across the channel no of grid points are 61. Initial surface elevation has been considered as 0.107 meter throughout the channel. For upstream boundary, a discharge of value 0.019 m3/s and for downstream boundary water depth of 0.107 meter has been considered. Time step interval has been considered as 0.06 sec, with this maximum Courant no has been found out as 9. As mentioned in literature by Mohapatra and Bhallamudi [8], sediment is considered as Non cohesive in nature, with a porosity of 0.4. The mean diameter of grains is reported as 0.28 mm. Englund-Hansen sediment transport formula is chosen to find morphological changes in channel. The model ran for total 6hr 40min. Figure 2 shows the comparison of steady state bed level for analytical and numerical cases. This comparison shows the capability of the present numerical model for morphological flow simulation.

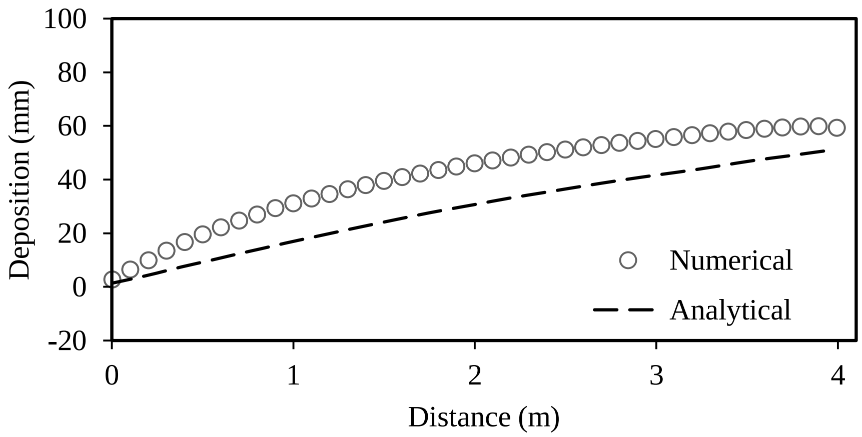

Figure 2. Comparison between simulated and analytical bed level along the centre line.

3. Results and discussion

A hypothetical channel bend is considered as shown in figure 3. It consists of two straight reaches of length 1000 m each, joined by a 600 bend. Width of the channel is considered as 200 m, with a bed slop of 0.0002.

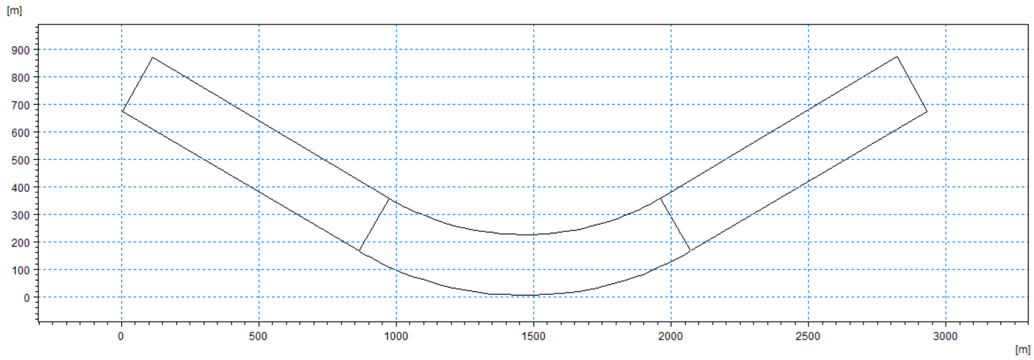

Figure 3. Hypothetical channel bend

An upstream discharge of 2000 cumec is considered for simulation; along with a downstream flow depth of 7.05 m. Amount of sediment transport is calculated using Englund-Hansen formula. Uniform sediment of D50=1.5 mm is considered in the channel. The specific gravity (s) and the porosity (λ) of the considered sediment particles are, 2.65 and 0.4, respectively. For numerical simulation, the whole domain is discretized into 6480 grid. First of all, the model is run without any groynes. Figure 4 shows the bed level variation specifically on the bend. The bed level is found to be scoured near the outer bank and the sediments are deposited near the inner bank, as intuitively expected.

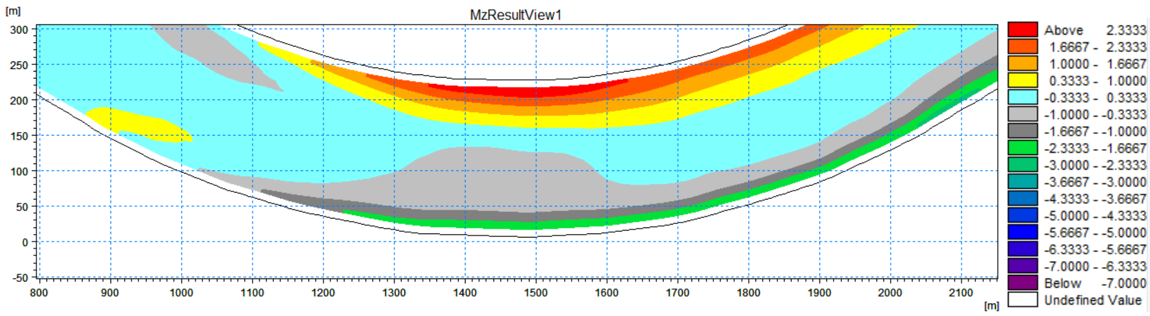

Figure 4. Bed level variation in the hypothetical bend withpout any groyne

The developed model is again run with 7 straight head groynes and the steady state result is shown in figure 5. Figure 6 shows the result with 7 T head groynes. In both the cases, the thalweg line is found to be shifted from the vulnerable outer bank.

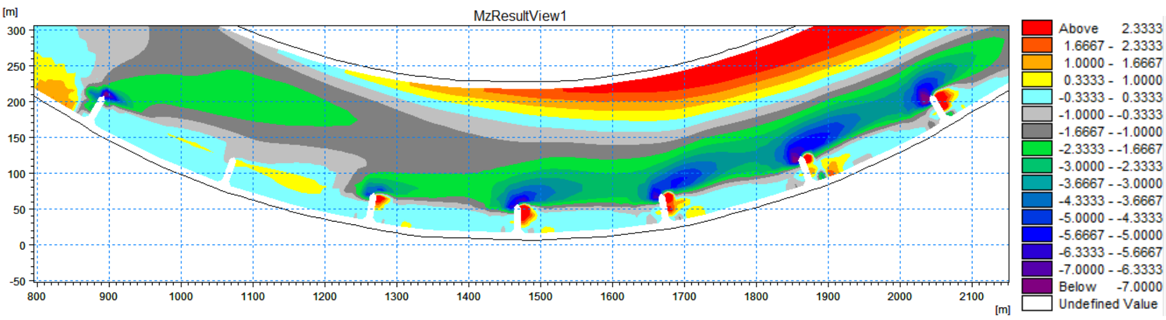

Figure 5. Bed level variations in the hypothetical bend with 7 straight head groynes

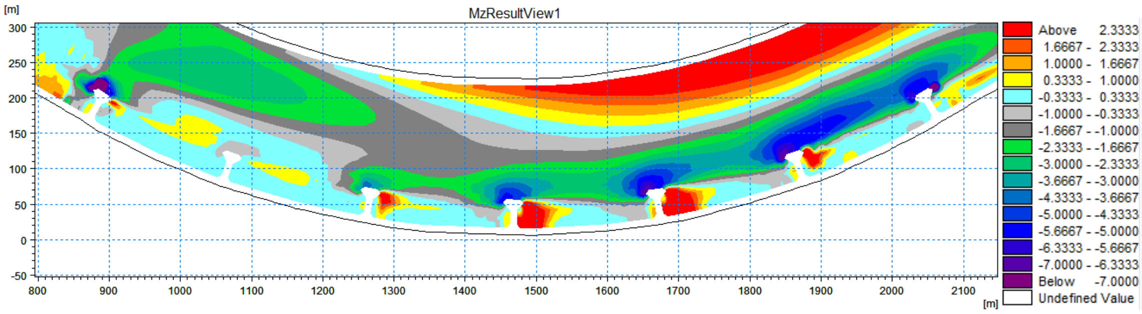

Figure 6. Bed level variation in the hypothetical bend with 7 T-head groynes

In order to compare the performances, three parameters such as, average distance of thalweg line from the groynes, maximum scour depth near the groyne tip and maximum deposition depth in the groyne field, are chosen. Table 1 shows the corresponding values for both the cases.

Table 1. Performance parameters for straight and T head groynes

Groyne system	Average distance of thalweg line from the groynes (m)	Maximum scour depth near the groyne tip (m)	Maximum deposition depth in the groyne field (m)
Straight head	21.43	5.88	0.46
T-head	25.71	6.25	0.87

It may be observed from the table 1 that T-head groynes shift the thalweg line more, leading to more safety of the outer bank. Deposition in the groyne field is also more for T-head groynes. The scour depth near the T-head groyne tips is found to be slightly more. However, it is believed that this scouring will not affect the stability of the groynes, as the flange portion will impart additional stability. From these results it may be conclude that T-head groynes are better for stability of the outer bank, in channel bend.

4. Conclusion

In this study, the performances of straight head and T-head groynes are compared for vulnerable channel bend. For this purpose, numerical models have been developed using the user friendly MIKE21C modeling tool. A hypothetical channel bend is considered first and the morphological modeling has been done. As intuitively expected, the thalweg line is found to be near the outer bank leading to vulnerability for the bank. After that, series of straight head and T-head groynes are installed on the outer banks and the numerical models are run separately. In both of the case, the thalweg lines are found to be shifted from the outer bank. In order to compare the performances, three parameters are considered, such as, average distance of thalweg line from the groynes, maximum scour depth near the groyne tip and maximum deposition depth in the groyne field. Comparing these parameters for both the groyne cases, it is found that T-head groynes are better for stability of the outer bank.

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