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NUMERICAL MODELLING OF AGGRADATION AND DEGRADATION IN ALLUVIAL CHANNEL

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Abstract: The unsteady open channel flow conditions are described using the Saint-Venant equations, which regulate the flow in an alluvial stream. A one-dimensional mathematical model for calculating channel bed aggradation and degradation has been developed. In this analysis, the Mac-Cormack explicit finite difference scheme was used. This scheme is second-order accurate, manages shocks and discontinuities in the solution without special treatment, and allows simultaneous solution of the water and sediment equations, which eliminates the need for iterations. The addition of clear water flow to a stream that was previously in equilibrium leads to degradation of the bed and banks. Similarly, withdrawing clear water flow from an equilibrium stream causes aggradation. These processes will proceed until a new equilibrium is reached. The present study investigated the problems of aggradation and degradation caused by the removal and addition of clear water from/to an alluvial stream of constant width and in equilibrium. In the case of aggradation and degradation channel bed consisting of uniform sediments, the transient bed and water profiles were predicted using the developed mathematical model. The data of Yadav (1992) were used for the verification of model. The model is able to predict transient bed and water surface profiles satisfactorily.

Keywords: Numerical modelling, Aggradation, Degradation, Mac-Cormack finite difference scheme, Alluvial channel

I. INTRODUCTION

The water and sediment discharges in natural streams which have evolved over geologic times are in equilibrium and produce no objectionable scour or deposition. However, various factors, both natural and man-made, can contribute to disturb the delicate balance among the many variables involved, which in turn lead to the aggradation or degradation along river reaches.

Bed aggradation and degradation occur in natural streams if the delicate balance among water discharge, sediment flow, and the channel shape is disturbed by natural or manmade factors, e.g., the construction of a dam, change in the sediment supply rate, base-level lowering.

Under natural conditions, evolution of an alluvial river is subject to the influences of many factors, including water and sediment discharges, channel geometry, water, and sediment properties. The addition of clear water flow to a stream that was previously in equilibrium leads to degradation of the bed and banks. Similarly, withdrawing clear water flow from an equilibrium stream causes aggradation. These processes will proceed until a new equilibrium is reached. The present study investigated the problems of aggradation and degradation caused by the removal and addition of clear water from/to an alluvial stream of constant width and in equilibrium.

Numerical models are mathematical models that use numerical time-stepping procedure to obtain the models behaviour over time so to understand process of aggradation and degradation in alluvial channels. The Saint-Venant equations describing unsteady flow in open channel and the continuity equation for the conservation of sediment mass are numerically solved to determine the aggradation and degradation of channel bottom. The complete Saint-Venant equations for water flow and the sediment continuity equation are solved simultaneously by the MacCormack second-order accurate explicit scheme suitable for hyperbolic equation.

II. DATA

The data of H. S. Yadav (1992) were used for the model.

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III. SAINT-VENANT EQUATION

There are three basic one-dimensional partial differential equations for unsteady flow in a wide rectangular channel with deformable bed. These equations are:

▪Continuity equation for water:

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=0 \quad \text{.......................................(1)}$$

▪Momentum equation for water:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q^2}{h}+\frac{gh^2}{2}\right)+gh\frac{\partial z}{\partial x}+ghS_f=0 \quad \text{..............(2)}$$

▪Continuity equation for sediment:

$$\frac{\partial}{\partial t}\left[(1-p)z+\frac{q_s h}{q}\right]+\frac{\partial q_s}{\partial x} \quad \text{.................................(3)}$$

▪ where q = water discharge per unit width; h = flow depth; z = bed elevation; q_s = unit sediment discharge; g = acceleration due to gravity; S_f = friction slope; x =the distance along the channel; t = time; and p=porosity of the bed layer.

▪ The friction slope S_f in (2) may be determined using the Manning's equation:

$$S_f=\frac{q^2n^2}{h^{3.333}} \quad \text{.. (4)}$$

▪ In which n = the Manning roughness coefficient and is taken equal to 0.4. The sediment discharge may be estimated by an empirical power function of the flow velocity.

$$q_s=a\left(\frac{q}{h}\right)^b \quad \text{.. (5)}$$

▪ In which a and b = empirical constants for which the values depend on the sediment properties.

IV. METHODOLOGY

Mac-Cormack scheme is a tool using which Saint-Venants equations are solved. For successful application of model appropriate initial and boundary condition are needed to close system of equation for obtaining the numerical solution.

The values of the dependent variables h, q, and z at the boundary nodes 1 and N + 1 can be determined by using the boundary conditions and initial condition (k=0). It can be shown that for sub critical flow conditions, two boundary conditions must be imposed at the upstream boundary, and one condition at the downstream boundary. The initial conditions can be specified for known values of flow depth (h), discharge (q) and bed level z at all the node points along the initial time line, i.e., t = 0. In present study, upstream boundary condition is defined with constant flow discharge as,

$$q_1^{k+1} = q(t) \text{ [known value] } t \geq 0$$

The second boundary condition at upstream end will be achieved by assuming a fictitious computational node upstream of the first computational node and specifying the sediment load at that node.

$$z_1^{k+1}=z_1^k+\frac{\Delta t}{\Delta x}\times\frac{1}{(1-p)}\left[(G_e+\Delta G_e)-G(1)\right] \text{............[For Aggradation]}$$

$$z_1^{k+1}=z_1^k-\frac{\Delta t}{\Delta x}\times\frac{1}{(1-p)}\left[(G_e+\Delta G_e)-G(1)\right] \text{............[For Degradation]}$$

Here, G_e is the equilibrium sediment transport rate and ΔG_e is the rate of excess sediment supply.

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The downstream boundary condition supplied was a constant flow depth observed at different time levels during the measurement of transient water profiles, which was specified as

$$H(N\Delta x, t) = H_d(t) \text{ [Known value]} t \geq 0$$

For the numerical stability of scheme, minimum Δt is dynamically computed after every time step to satisfy the Courant-Friedrichs-Lewy (CFL) condition, which can be expressed as

$$C_n = \frac{Actual\ wave\ velocity}{Numerical\ wave\ velocity} = \frac{|V| \pm c}{\frac{\Delta x}{\Delta t}} = \left(\frac{q}{h} + \sqrt{gh}\right)\frac{\Delta t}{\Delta x} \leq 1$$

V. Results

Figures 1 to 4 shows the comparison between the numerical and experimental results of the bed and water surface profiles for test Run No. A-13-(U3/U4) for aggradation and for test Run No.D-13-(U1/U3) for degradation at 1hr and 2.5hr.

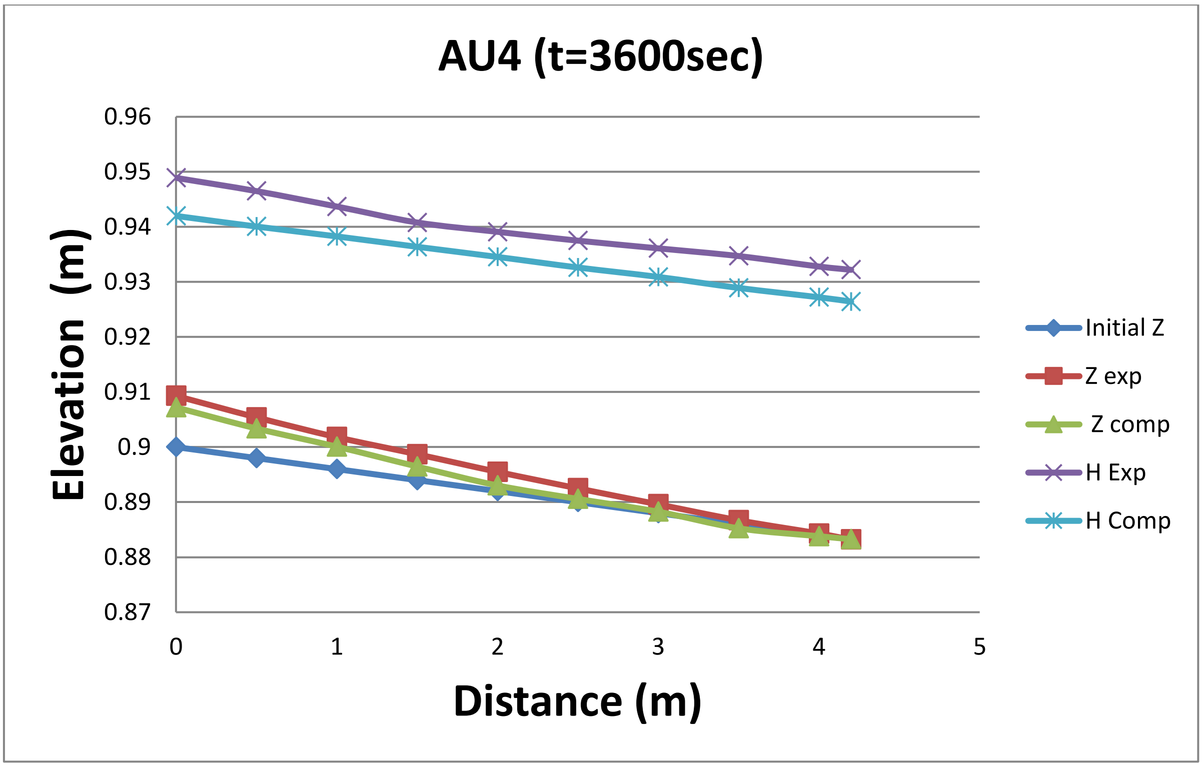

Figure 1: Transient bed and water profile for aggradation run no. A-13-(U3/U4) for U4 at t=3600sec

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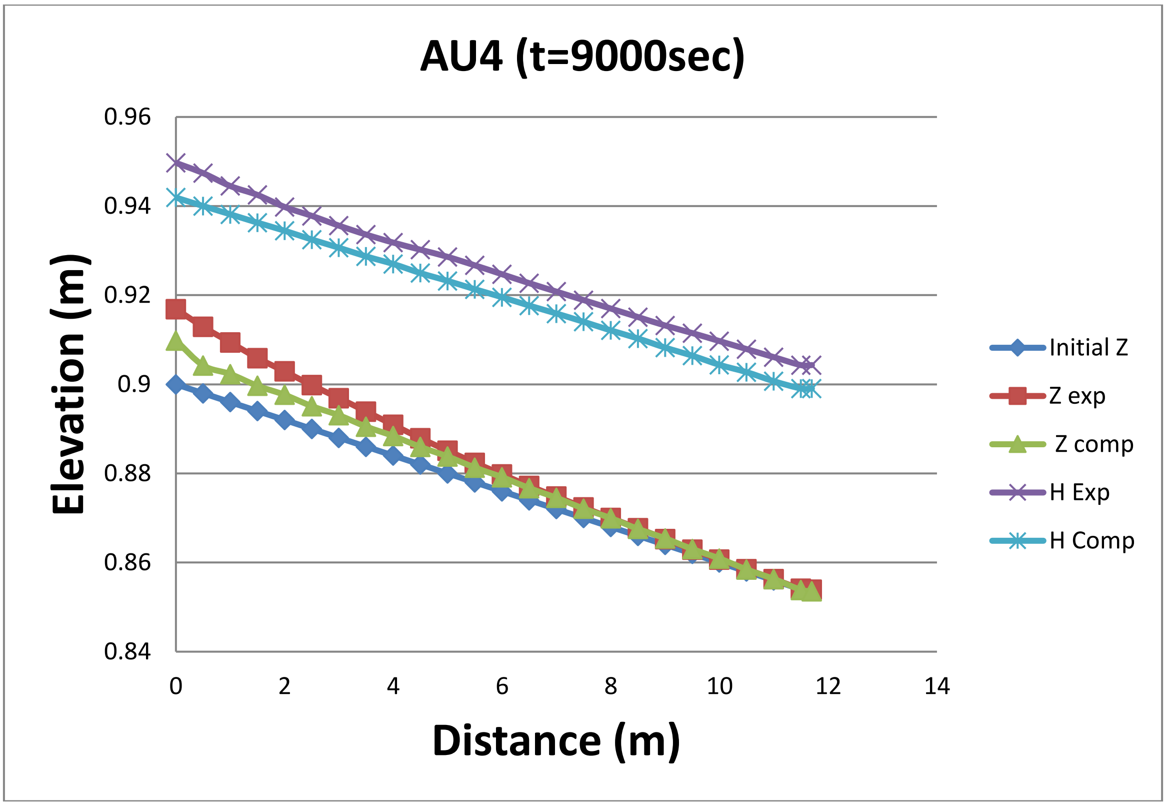

Figure 2: Transient bed and water profile for aggradation run no. A-13-(U3/U4) for U4 at t=9000sec

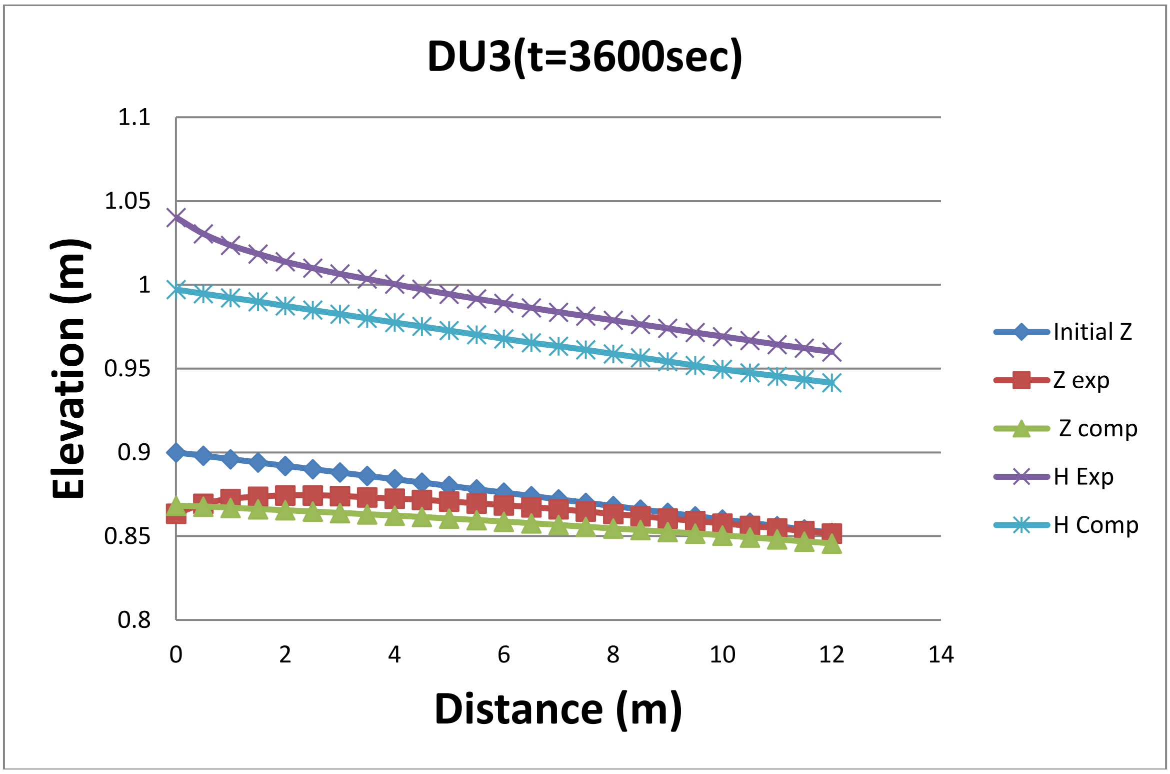

Figure 3: Transient bed and water profile for degradation run no. D-13-(U1/U3) for U3 at t=3600sec

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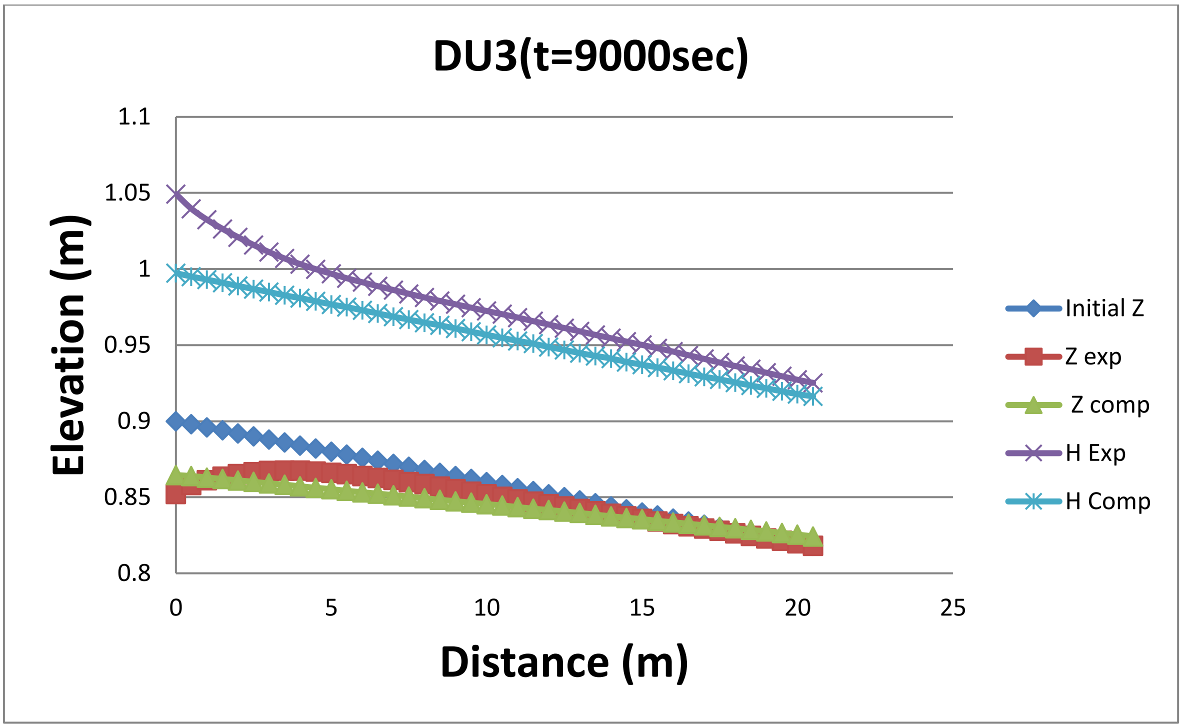

Figure 4: Transient bed and water profile for degradation run no. D-13-(U1/U3) for U3 at t=9000sec

VI. CONCLUSION

The Mac-Cormack explicit finite difference scheme, which is second-order precise, is considered to be effective in dealing with large and small-scale morphological phenomena. During every computational phase, all three governing equations are solved simultaneously, resulting in a coupling of the water-flow equations and the sediment continuity equation.

A numerical model is presented for the study of the aggradation and degradation process in alluvial channels. The MacCormack finite difference scheme solves both the Saint-Venant continuity equations and the momentum equations respectively. A mathematical model is developed using FORTRAN. The model is calibrated using Soni et al. (1980) data. The developed model is capable of predicting aggradation and degradation in an alluvial channel. The model has simulated the resulting aggradation and degradation caused by withdrawal and addition of clear water from/to an alluvial channel of constant width using Yadav (1992) data. The results show that the model is able to predict transient bed and water surface profiles satisfactorily. The close agreement between calculated and measured results demonstrates that the scheme can be extended to any alluvial river issues.

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