EFFECT OF CROSS SECTIONAL SHAPE ON GRAVITY CURRENTS IN VEGETATED VALLEYS

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Abstract- In this study experiments in laboratory tanks with vegetation bed are performedfor the investigation of the effect of cross sectional shape on the movement of gravity currents. For this reason a series of experiments for rectangular and composite (upper rectangular and lower trapezoidal) cross-section are carried out. The results show that the different cross-section influences significantly the motion and the front velocity of gravity currents.

Keywords- Gravity Currents, Lock-Exchange Experimental, Vegetated Bed, Front Velocity.

I. INTRODUCTION

Gravity currents play an important role in geophysical and engineering applications. The lock-exchange experiments have used to study the behaviour of gravity currents.
Initially,exchange flows through sand are studied [1] which are drag dominated and the interface is inclined to the horizontal plane, rotating about its midpoint.

In the research of [2] experiments on a boundary gravity current are conducted, which show thatthere is a relative forward velocity behind the steadily advancing front, which suppliesthe volume flux necessary to balance the losses from the current due to mixing. Theyfound, based on mean volume flux measurements, that there is an internal flow withinthe current characterized by a mean `overtaking speed' of about 15% greater than the front speed.
Measurements of the density field in gravity currentsshow that the fluidwithin the head of a gravity current produced by a fixed-volume release does notchange significantly during the constant speed phase [3].

In the research of [4] new theory and experiments on gravity currents produced by lock-exchange are described, which suggest the dissipation due to turbulence and mixing between the current and the surrounding ambient fluid is unimportant when the Reynolds number is sufficiently high. They provided an alternative theory that predicts the current speed and depth based on energy-conserving flow.

[5] performed a lock-exchange experiment to investigate the propagation of gravity currents through a random array of rigid, emergent cylinders which represents a canopy of aquatic plants. As canopy drag increases, the propagating front varies from the classic profile of an unobstructed gravity current to a triangular profile. Unlike the unobstructed lock-exchange, the gravity current in the canopy decelerates with time as the front lengthens. Two drag-dominated regimes associated with the linear and nonlinear drag laws are identified. The theoretical expression for toe velocity was supported by observed values. Empirical criteria were developed to predict the current regime from the cylinder Reynolds number and the array density. The paper provided a template for understanding flow regimes that arise from the presence of vegetation and insight into ways in which hydrodynamic effects of rigid vegetation may be incorporated into numerical models of convective circulation.

Newtonian viscous gravity currents propagating along horizontal and inclined channels with semicircular and V-shaped boundaries are examined in [6]. The mathematical equations are compared with data from laboratory experiments. Geological applications of the results are discussed.

In the study of [7], lock-exchange experiments are performed in which the bed is covered by grass-type of vegetation of different submergence ratio h_v/H (h_v=height of vegetation, H=water depth). The effects of density ratio ($\gamma=\rho_1/\rho_2$), submergence ratio (h_v/H) and channel slope (S_0) on the motion of gravity current are investigated.

The motion of saline gravity currents propagating horizontally in a tank of rectangular upper cross section and lower V-shaped valley by lock-exchange experiments and a box model was investigated in [8]. The presence of the valley results in three major differences in the gravity current compared to that flowing along a flat bottom. These are : i) the front of the current is approximately parabolic ii) for sufficiently large time t the velocity of the current in the V-shaped valley varies in the flat bottom case and iii) the width of the current in V-shaped valley decreases with time t. They have used the box model to predict the effect of changing the slope of the valley after obtaining good agreement between experiments and box model results. The result is that

for equal volume currents, the steeper the valley the faster the flow.

The motion of saline gravity currents in lock-exchange experiments which are carried out in a tank of rectangular upper cross section and a lower valley of trapezoidal shape is investigated experimentally in [9]. The movement of the gravity current is monitored with a digital video of high definition, the front velocity is measured and the height of the front is captured. The main conclusions of this work are: a) the gravity current propagates with a parabolic head and b) the effect of density difference is more pronounced in the case of the composite section thanthat of the trapezoidal section.

In the research of [10] the evolution of bottom propagating gravity currents from full- and partial-depth locks as they encounter a rising uniform slope, ranging from moderately shallow to steep, was examined. Besides the fundamental interest in exploring how fast and how far the current moves upslope, this research more broadly constitutes the start of a theoretical and laboratory experimental program investigating the advance of sea breezes over complex coastal terrain in order to provide a better understanding of their impact upon vegetation, industry, and communities.

Finally lock-exchange experiments in a tank of rectangular upper cross section and a lower vegetated valley of trapezoidal shape to study the effect of drag resistance, due to vegetation, on gravity currents are performed [11]. For the simulation of the vegetation the bed is covered by flexible grass Results show that the effect of the valley geometry and the steepness of the side walls on the motion are significant.

In this study experiments are performed in laboratory tanks with vegetated bed to investigate the effect of cross-section on the movement of gravity currents. For this reason experiments for rectangular and composite (upper rectangular and lower trapezoidal) cross-section are carried out. Results show that the geometry of the tank influences the front velocity and the motion of gravity currents. Also theexperimental results of this study are compared with experimental data of other researchers ([4], [5] and [8]).

II. EXPERIMENTAL PROCEDURE

Initially experiments in a 4.0m length and 0.25m width rectangular tank are conducted (**Fig.1**). Also, a tank of a composite cross section, which consists of a rectangular upper cross section and a lower trapezoidal shape,is used.The dimensions of the composite tank are: width W=23cm, height H=25cm and total length L=5m. The trapezoidal section of the valley has the following dimensions: bottom width B=5cm, height H_{tr}=10cm and side slope 1:1 (**Fig.2**).

The tanks were separated into two reservoirs by a removable thick vertical partition, which was removed at the start of the experiments. One reservoir was filled with 20cm or 25cm of well-mixed saltwater of density ρ_{sw} and the other with freshwater of density ρ_w ($\rho_w<\rho_{sw}$) until the free surface in both reservoirs was aligned. The distance from the lock gate to the front edge of the current head is denoted as x.

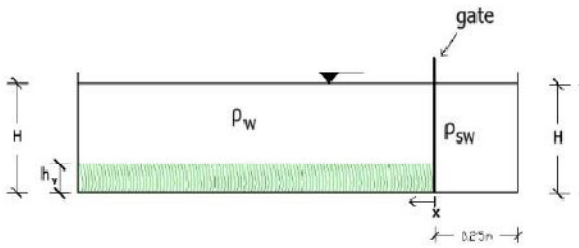


Fig.1. Rectangular tank with vegetation bed

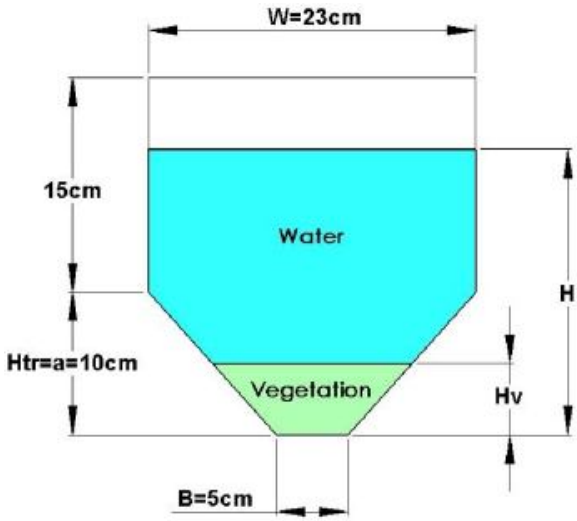


Fig.2.Composite tank with vegetation bed

The slope of the channel was horizontal. Experimental runs began with the removal of the vertical partition. For flow visualization the saltwater was dyed with red or green food dye in all runs. The density of the saltwater in all experiments ranging from 1.047 gcm^{-3} to 1.112 gcm^{-3} while the density of freshwater was around ρ_1=1.000 gcm^{-3} giving $\gamma=\rho_w/\rho_{sw}$ ranging from 0.899 to 0.955. For the simulation of vegetated bed a grass vegetation with height of h_v= 2.0cm. was used (**Fig.3**).

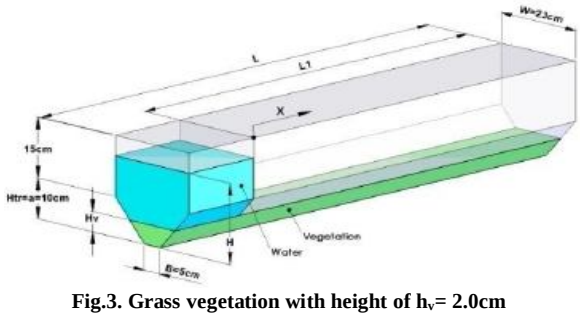


Fig.3. Grass vegetation with height of h_v= 2.0cm

When the lock is removed, because of difference in hydrostatic pressure, the denser fluid flows in one direction along the bed of the tank, while the lighter fluid flows in opposite direction along the top of the tank. As the two currents move a series of images were captured using a camera mounted on a stationary tripod in front of the tank. These recordings were subsequently analyzed to determine the temporal evolution of the front position and velocity, by measuring the time required for the front to travel fixed-length intervals marked on the tank. A digital camera was used for viewing the current and measuring the height and the position of the current front (**Fig.4, Fig.5**).

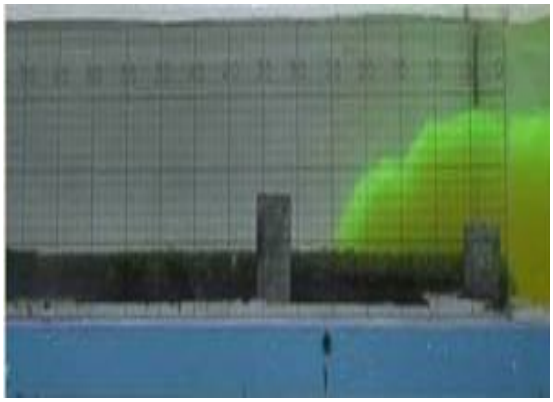


Fig.4. Gravity current for rectangular tank

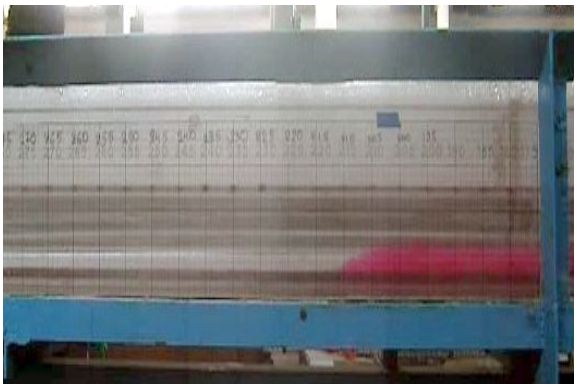


Fig.5. Gravity current for composite tank

III. ANALYSIS OF RESULTS

From **Fig.4**and **Fig.5** it is clear that for the same time and the same distance from the tank the gravity current of the rectangular tank has greater height in comparison with this in composite tank. This is due to the fact that the presence of composite cross-section limits the development of the gravity current and reduces its height. For this reason the front velocity in the case of rectangular tank is lower than that in the composite tank.

Fig.6 shows the development of the phenomenon in relation with the relative depth h_v/H. The current with the lower h_v/H travels faster in both cases (rectangular and composite cross-section). Generally, the time development of the front current increases with decreasing h_v/H. Also from this figure it is clear that the gravity current in the case of composite tank travels faster than that within the rectangular tank.

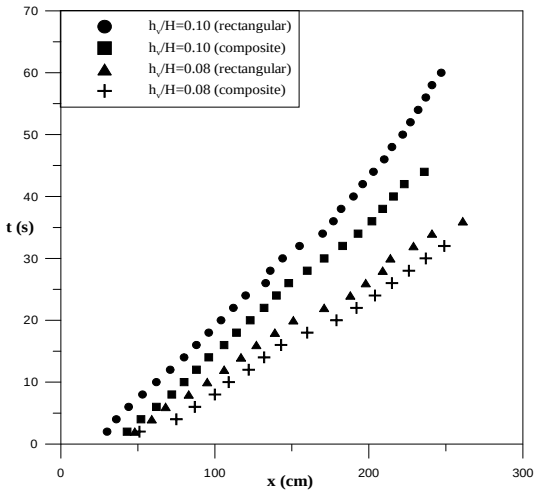


Fig.6. Influence of the h_v/H in the motion of the current

In **Fig.7** the dimensionless distance x* is plotted against the dimensionless time t* from the opening of the gate for currents for a) rectangular and b) compositecross-section. The distance x is made dimensionless with the water depth H (x* =x/H) and the time t from the lock exchange with the parameter $\sqrt{g(1-\gamma)/H}$ ($t^* = t\sqrt{g(1-\gamma)/H}$, $\gamma = \frac{\rho_w}{\rho_{sw}}$).

It is shown that the motion of the current depends on the shape of the cross-section. The current moves faster, within the composite cross-section, than that within the rectangular tank. This means, as it mentioned before, that the front velocity in the composite tank is greater than that in the rectangular tank.

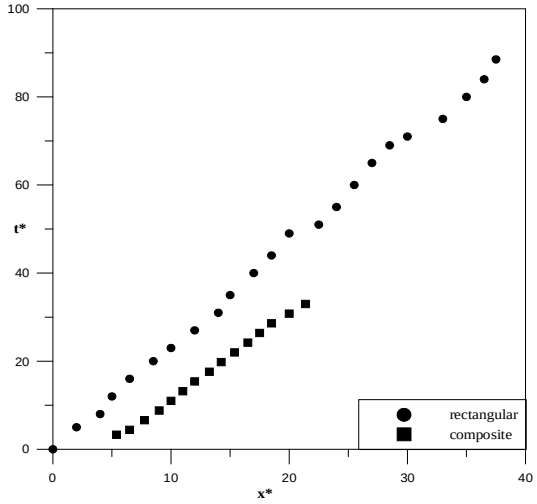


Fig.7.Time development of gravity front for rectangular and composite cross-sections (dimensionless)

In **Fig.8** the results of this study are compared with experiments for gravity currents which are performed by [4], [5]. The dimensionless distance x^* is plotted against the dimensionless time t^*. The distance x is made dimensionless with the water depth H (x/H) and the time t with the parameter $(g'/H)^{1/2}$, where $g' = g(\rho_2 - \rho_1)/\rho_2$, with $\rho_2=\rho_{sw}$, $\rho_1=\rho_w$.

The comparison of those experiments with the experiments from [4] shows that the front velocity for the vegetated cases is lower than that of gravity currents without vegetation. Also the front velocity, in the case of rectangular cross-section, is lower than that of the composite cross-section. This is due to the greater resistance to the motion of gravity current which is observed in the case of the rectangular cross-section.

In [5] the velocity of current is approximately the same with the corresponding ofthe composite cross-section. Small differences with the rectangular cross section are observed but a satisfactory agreement exists between these studies.

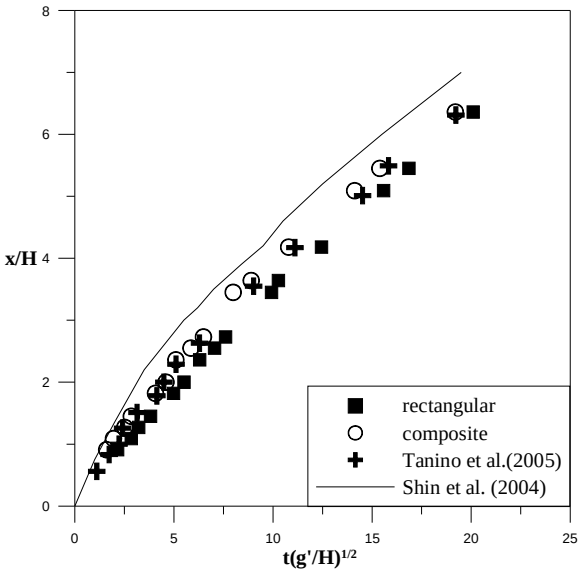


Fig.8. Time development of front velocity (dimensionless)

In **Fig.9** the results of this study are compared with similar experiments performed by [8]. As it is shown in **Fig.9** the dimensionless distance y (distance from the lock gate) is plotted against the dimensionless time τ. The distance y is made dimensionless with the parameter l and the time t with the parameter σ. The former parameter l is defined as: $l = \left(\frac{2V}{aW}\right)$, V= volume of the current $(V = L_1 W(H_0 + \frac{1}{2}a)$, L_1=distance between the lock gate and the rest of the tank, W=current width, H_0 =height of the water over the valley, a= depth of the valley), and $\sigma = \frac{1}{Fr}\sqrt{2/g'a}$ where Fr=Froude number, $Fr = U/\sqrt{g'h}$ (U=current speed, h= height of the current and $g' = g(\rho_{sw} - \rho_w)/\rho_{sw}$ with g=9.81 m/s^2). As it is observed (**Fig.9**) a satisfactory agreement exists between the measurements of these studies.

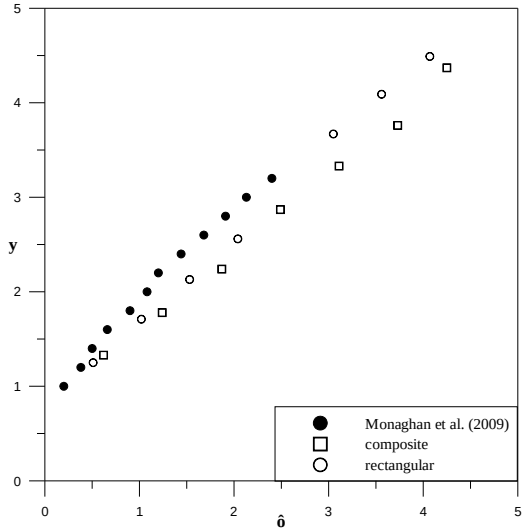


Fig.9. Time development of gravity front (dimensionless)

CONCLUSIONS

In this study lock-exchange experiments are performed in laboratory tanks with different cross-sections: a) rectangular and b) composite (upper rectangular and lower trapezoidal) with a vegetated bed to investigate the effect of cross-section on the movement of gravity currents. The major conclusions are as follows:

1. For the same time and the same distance from the tank the gravity current from rectangular tank has greater height in comparison with this in composite tank. This is due to the fact that the presence of composite cross-section limits the development of the gravity current and reduces the height.
2. Also for the same reason the front velocity in the case of rectangular tank is lower in comparison with this in composite tank.
3. The current with the lower h_v/H travels faster in both cases (rectangular and composite cross-section). The time development of the front current increases with the reduction of the h_v/H.
4. From the above it is clear that the motion of the current depends on the shape of the cross-section.

5. There is a satisfactory agreement between the results of this study with similar experiments from other researchers ([4], [5] and [8]).

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