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Gravity currents with large salinity in a gravel bed valley: an experimental study

E. Keramaris*, C. Vasileiou and K. Sagiannis

Department of Civil Engineering, University of Thessaly, Pedion Areos, 38334, Volos, Greece
*Corresponding author. E-mail: ekeramaris@civ.uth.gr

ABSTRACT

In the current study experiments in a valley (a composite cross-sectional tank consisting of a rectangular upper cross section and a lower trapezoidal) were performed. The purpose of this research is to study the gravel bed in gravity currents with large salinity. The tank is separated in two parts by a vertical gate, which separates the fresh water with the gravel bed from the salt water with the impermeable bed. When the gate opens, a flow is created due to density difference. The salinity densities are large (from 1,050 to 1,090 kg/m^3). These specific densities have been chosen to simulate liquid wastes that affect the environment. Compared to experiments in the same tank without a gravel bed, it is observed that the gravel bed reduces the propagation of currents and mainly reduces the current with the smallest density difference at the lowest height. The main conclusion of this study is that the kind of channel bed plays a key role in the propagation of gravity currents. The gravel bed affects significantly the velocity and the distance traveled by the currents in comparison with impermeable bed.

Key words: front velocity, gravel bed, gravity currents, large salinity, lock-exchange experiments

HIGHLIGHTS

- Lock-exchange experiments were performed in a tank of composite cross section.
- The tank had a trapezoidal cross-section at its lower part and rectangular in its upper part.
- It was discovered that the kind of channel plays a key role in the propagation of gravity currents.
- The motion of gravity current in the case of an impermeable bed differs significantly from the case of a permeable (gravel) bed.

1. INTRODUCTION

Gravity currents are produced by the density difference between two liquids and occur in both natural and industrial flows. Density differences may be due to changes in salinity, temperature or concentration of suspended particles (Benjamin 1968; Simpson 1997). The currents may be along horizontal or sloping surfaces. Mainly the currents spread due to the horizontal density difference and this dispersion is important for many geophysical and industrial applications. Typical examples of gravity currents in the natural environment are: the release of pollutants into rivers, avalanches, sea breeze and oil spills.

Gravity currents are also formed in estuaries where freshwater volumes with less density than salt water flow to the surface. The currents of turbidity are formed when the water slides into the ocean. In geophysical environments in nature, gravity currents propagate in stratified environments. If inside the gravity current there is a density gradient, multiple intrusions can form in the stratified water body (Baines 2001; Wells & Nadarajah 2009; Cortés *et al.* 2014; Snow & Sutherland 2014). Except for natural gravity currents, there are now an increase in anthropogenic gravity currents in the coastal environment, such as the discharge of brine effluents from seawater desalination facilities. The release of pollutants into rivers, the leakage of oil into the ocean, the outflows from both desalination and power plants are some examples of gravity currents caused by human activities and are largely leading to negative effects on the environment. In all these cases, the density between the freshwater and all these activities differs significantly.

The first theoretical attempt to describe the rate of spread of a gravity current using flow theory was made by Von Kármán (1940). This research evolved a few years later with Benjamin (1968) with the same result, with a more accurate analysis using the theory of hydraulic jumps.

After experimental research, Huppert & Simpson (1980) described the dispersion of a gravity current in three phases: an initial descending phase where the current moves with almost constant velocity, followed by an inertial phase in which the

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current moves under the balance of buoyancy and inertial forces, and finally a viscous phase dominated by the viscous effects and the buoyancy balance. They concluded that the inertial phase is absent if viscous effects become important before the slumping phase has been completed. Peters & Venart (2000) reported that viscous effects dominate earlier on the flow when the bed is rough, compared to smooth bed experiments. They observed that roughness decreases the front velocity and induces higher dilution in the head region.

O'Donnell (1993) studied gravity currents at the mouth of rivers where salt water and fresh water meet. The estuarine fronts (small-scale regions of significant changes in hydrographic variables) are divided into three categories, which are tidal penetration fronts, tidal mixing fronts and shear fronts. But he made it clear that real fronts often have characteristics of two or all three categories together.

Oldham & Sturman (2001) have demonstrated that steady, buoyancy-driven, down-slope flow decreases with decreasing permeability within a vegetated region. The main conclusion of this study is that the arrival of bottom convective currents in the center of the wetland strengthens the temperature stratification. In the study of Shin *et al.* (2004) lock-exchange experiments are performed to analyzed the mixing relation of gravity currents with an ambient fluid. The main conclusion of this research was that when the Reynolds number is high, the influence of dissipation is negligible. They proposed a new theory for the calculation of front velocity and fluid height based on energy-conserving flow. Tanino *et al.* (2005) studied the behavior of gravity currents through a permeable bed. The simulation of the permeable bed was achieved with the use of submerged rigid cylinders. In this way, they simulated a typical example of natural environment (canopy of aquatic plants). They observed that with the increase of canopy drag, the parabolic shape of front current was changed approximately in triangular shape.

A very small number of experimental studies have been performed for gravity currents in a valley. Monaghan *et al.* (2009a, 2009b) performed experiments (lock-exchange experiments) and numerical simulation (box model) to investigate the motion of gravity currents (with salinity) in a tank. The shape of the tank was rectangular in upper cross section and a V-shaped valley in lower cross section. They observed that the front side of the current has a parabolic shape. Also, in valley the width of the gravity current is reduced with the time t. In the study of Monaghan *et al.* (2009a, 2009b) an extended research of saline gravity currents was presented in V-shaped valley when the Reynolds number is high (in the case of fully turbulent flow). Also in this study, the front side of the current has a parabolic shape, according to previous studies. The presence of the valley results in three major differences in the gravity current compared to that flowing along a flat boundary. First, the front of the current is straight in the flat bottom. Second, for large time t, the velocity of the current in the V-shaped valley varies as compared to t in the flat bottom case. Third, the width of the current is constant in the flat bottom case whereas, in the V-shaped case, it decreases with time.

Keramaris & Prinos (2010) investigated the movement of salt water gravity currents in a complex cross section, which more realistically approaches the basins that occur in nature. A gate separates fresh and salt water in two reservoirs. The water depth was equal for both sides. After the removal of partition the gravity current was generated due to different densities between fresh and salt water. The density of salt water was from 1,010 to 1,040 kg/m^3, when the density of fresh water was 1,000 kg/m^3. The fluid with greatest difference in density different (1,040 kg/m^3) travels faster than the others in all water heights. Also they concluded that the shape of the section plays a critical role in the propagation of gravity currents and significantly influences the front velocity of the current.

Nogueira *et al.* (2013) studied the gravity currents produced by releasing salt water after removing a vertical partition in a freshwater tank. The purpose of the experiment was to investigate the effect of the initial density of the salt water in the movement of the gravity current. The temporal evolution of the position and front velocity in various phases of the current and the evolution of the current height were evaluated. The bed roughness significantly reduced the front velocity due to the friction that developed. The dynamics of the current at each stage of its development and important variables were determined by the analysis of the Froude numbers. They observed that the current develops in two distinct phases, the bed roughness plays an important role in the current development and the head region is where higher density is observed within the gravity current.

Longo & Di Federico (2014) analyzed the propagation of single-phase gravity currents caused by the release of a volume of fluid into a porous field. They compared their theoretical results with results from two experimental data, one of which was with fresh water and the other containing air as ambient fluid. They concluded that the numerical results coincided with the experimental results.

Keramaris & Prinos (2016) conducted experiments in a laboratory tank with vegetation to study the effect of cross-sectional and vegetation resistance on the movement of gravity currents. The experiments were performed in a composite cross section, which is rectangular at the top and trapezoidal at the bottom. To simulate vegetation, the bed was covered with flexible vegetation. The results showed that the different shape of cross section significantly affects the movement as well as the front velocity of gravity currents. The presence of trapezoidal cross section increases the velocity of gravity currents compared to triangular or rectangular cross-section.

Keramaris (2017) studied the effect of a permeable material, whether flexible or rigid, on the bed of a laboratory tank on the motion of gravity currents. The permeable material on the bed was simulated with grass in the case of flexible material and in the case of inflexible material with a bundle of rods. Lombardi *et al.* (2018) performed lock-exchange experiments that showed that the size of the lock width plays an important role on the shape, the front velocity and the propagation of the gravity current. For relatively large lock gates the current is similar to a flat current and develops a characteristic fall with a constant front velocity, while for lock gate widths under a definite threshold the current acquires a cylindrical symmetry and the propagation is always decreasing. Upon removal of the gate, an initial transient develops in which the flow rate increases up to an asymptotic value. They observed that three distinct spreading regimes are found: slumping, inertial and viscous. These are quite similar in nature to those in the case of constant-volume axisymmetric gravity current.

In the study of Vardakostas *et al.* (2020) experiments were performed in a tank with impermeable bed of composite cross section (trapezoidal cross section at its lower part and rectangular in its upper part). The tank is separated by a vertical gate in two sections containing liquids of different density, water and salt water. Due to different density, the heavier fluid moves to the bottom of the tank while lighter flows on the free surface. Most of these experiments are for fluids with small density differences (Boussinesq currents) that represent most geophysical flows. A small amount of work has been done on fluids with large density differences (non-Boussinesq currents). The density differences range between 5 and 9%, to simulate liquid waste whose spreading is an environmental problem such as pollutants into rivers (gases) and oil spills. The results are compared with those of similar experiments with a lower ratio of densities. The main conclusion of this study is that the shape of the tank has an important role in the propagation of gravity currents. The presence of the trapezoidal cross-section increases the velocity of gravity currents compared to corresponding triangular or rectangular cross-sections.

Lock-exchange experiments and numerical simulations have been used to investigate gravity currents propagating over close-packed, fixed porous beds of monodisperse spherical particles (Köllner *et al.* 2020). They concluded that the dense current front moves rapidly away from the resident fluid in the exposed pore spaces between the top layer of spheres. This depends on the bed permeability, which is a function of the particle diameter. The bed roughness reduce the motion of the flow.

Finally, in the study of Nasrollahpour *et al.* (2021) the velocity profile of density currents over rough beds is investigated. Laboratory experiments were performed for density currents flowing over a smooth and rough bed for comparison. They concluded that the bed roughness reduces the velocity of the currents and also modified the shape of velocity profiles, especially in the region near to the bed.

In this study lock-exchange experiments were performed in a tank of composite cross section (trapezoidal cross-section at its lower part and rectangular in its upper part). The tank is separated in two parts by a vertical gate, which separates the fresh water with the gravel bed from the salt water with the impermeable bed. The density of salt water varies from 1,050 to 1,090 kg/m^3. These specific densities have been chosen to simulate liquid wastes that affect the environment. The results are compared with similar experiments in tanks with impermeable bed and: (a) orthogonal cross-section (Shin *et al.* 2004) (b) triangular cross-section (Monaghan *et al.* 2009a, 2009b) (c) composite cross section (trapezoidal lower part and rectangular up-per part), tank with the same shape and dimensions and with different density difference between salt water and fresh water (Keramaris & Prinos 2010) and (d) composite cross section (trapezoidal lower part and rectangular upper part), tank with the same shape, dimensions and density difference between salt water and clear water (Vardakostas *et al.* 2020). The comparisons showed that the shape of the tank plays a key role in the propagation of gravity currents and the gravel bed affects significantly the velocity and the distance traveled by the currents. The aim of the present study is to investigate the formation of lock-exchange flows evolving in gravity currents with large salinity (cases for example: the release of pollutants into rivers or the leakage of oil into the ocean) in a composite bed (which is the most common bed in nature) when salt water penetrates into rivers. In the world literature, only a very small number of experimental studies have been performed on gravity currents in a valley and probably none on gravity currents with large salinity, which proves the novelty of this study.

2. METHODOLOGY AND LABORATORY EXPERIMENTS

The experimental study was conducted in a tank of composite cross section (rectangular upper cross section and a lower valley of trapezoidal shape). The tank has 25 cm width, 25 cm height and 205 cm length (W = 25 cm, H = 25 cm,

$L = 205$ cm). The lower valley of trapezoidal shape has 5 cm bed width, 10 cm height and side slope 1:1 ($B = 5$ cm, $H_{tr} = 10$ cm, $S = 1{:}1$). The tank is horizontal (slope = 0.00).

The rectangular upper cross section has 25 cm width and 15 cm height ($W = 25$ cm, $H_r = 15$ cm). The horizontal distance from the wall to the lock gate is 25 cm. The distance from the lock gate to the front edge of the current head is denoted as x (Figure 1(a) and 1(b)). The width of the channel is 25 cm but does not influence the front velocity and also the sidewall effects are negligible. Keramaris *et al.* (2013) carried out experiments to investigate the impact of lateral walls on the velocity profile in an open channel with the width of 7.5 cm. Results from these experiments showed that the lateral walls influence the velocities only in a distance of 0.4 cm from the walls. This result indicates that the wall doesn't influence the velocities in the central area of the channel in which the velocity measurements are usually conducted. The impact of the lateral walls on the flow dynamics in the rest of the channel is negligible.

The tank is separated in two parts by a vertical gate, which was removed at the start of the experiments and separates the fresh water with the gravel bed from the salt water with the impermeable bed. The median size of bed materials is approximately $D_{50} = 0.30$ mm and the thickness of the gravel bed is 2 cm. These two sections containing liquids of different density, salted water (sw) in the part of impermeable bed and fresh water (w) in the part of permeable (gravel) bed. This is very common in cases when pollutants penetrate into rivers (Abeshu *et al.* 2022). At the end of the tank there is a single-flow spherical spigot designed to help run off the water and facilitate cleaning of the tank. The spigot is connected to a plastic tube, which ends up in the laboratory's drainage system. The tank is mounted and secured on a horizontal table.

One reservoir was filled with $H = 5$, 10, 17.5 or 25 cm of well-mixed salt water (part with impermeable bed) of density ρ_{sw} and the other with fresh water (part with permeable gravel bed) of density ρ_w ($\rho_w < \rho_{sw}$) until the free surface in both reservoirs was aligned. The procedure was performed for four different heights: (a) in the middle of the trapezoidal cross section (5 cm), (b) at the top of the trapezoidal cross section (10 cm, c) in the middle of the composite cross section (17.5 cm) and (d) at the top of the composite cross section (25 cm). A series of 20 experiments were performed, 10 inside the trapezoidal section (5 or 10 cm) and 10 over the trapezoidal section and inside the rectangular upper cross section (17.5 or 25 cm). The density for fresh water was $\rho_w = 1{,}000\ \mathrm{kg/m^3}$, while the density of salt water with large salinity ranges from 1,050 to 1,090 $\mathrm{kg/m^3}$ ($\rho_{sw} = 1{,}050$ or 1,060 or 1,070 or 1,080 or 1,090 $\mathrm{kg/m^3}$).

Initially, the vertical gate was removed and the generation of gravity currents began due to the different densities between the two fluids (water and salt water). The lighter fluid (clear water) propagates along the free surface while the heavier fluid (salt water) propagates along the bed of the tank. The salt water (part with impermeable bed) was dyed with rhodamin (red color) for flow visualization. During the experimental procedure there was a camera mounted on a stationary tripod in front

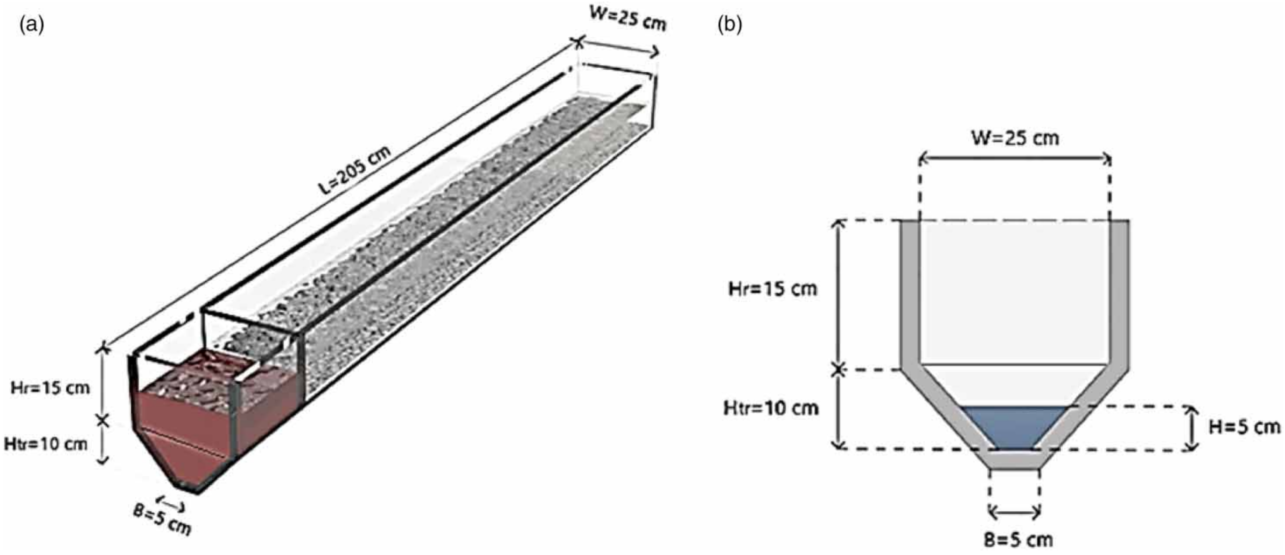

Figure 1 | (a) The tank of composite cross section (rectangular upper cross section and a lower valley of trapezoidal shape), (b) Composite cross-section. The lower valley of trapezoidal shape has 5 cm bed width, 10 cm height ($B = 5$ cm, $H_{tr} = 10$ cm). The rectangular upper cross section has 25 cm width and 15 cm height ($W = 25$ cm, $Hr = 15$ cm).

of the tank to capture a series of images after the initiation of the current. This camera was placed in front of the vertical gate, which separated the two fluids. From these images, the initial motion of the gravity current was observed. It was easy to observe that the different water heights influenced the motion of the current. With the increase of water height, the flow became more vigorous. Also there was a second camera, which followed the motion of the current up to the end of the tank (Figure 2).

3. ANALYSIS OF RESULTS

The trapezoidal cross section includes heights of H = 5 cm and H = 10 cm. The composite cross section includes heights of H = 17.5 cm and H = 25 cm. Five separate experiments were carried out at each height for the five different densities. In Figure 3 the time evolution of current in trapezoidal cross section at height H = 5 and 10 cm for the same density ($\rho_{sw} =$ 1,050 kg/m^3) is examined. The difference of front velocity in these two cases is very clear. The same result is observed in Figure 4 for the composite section, but the difference of front velocity is lower in comparison with Figure 3. This is due to the fact that the water height effects the motion of the current. Figure 5 includes all the cases together.

In the study of Vardakostas *et al.* (2020) the motion of saline gravity currents in the same tank of rectangular upper cross section and a lower valley of trapezoidal shape with impermeable bed is investigated. Lock-exchange experiments with the same characteristics as this study were performed. They concluded that the presence of the trapezoidal shape at the bottom of the composite cross section results in a significant increase in the velocity of the gravity currents in comparison with the rectangular cross section and the effect of density difference is more pronounced in the case of composite section than in the case of trapezoidal section.

In comparison with the same experiments without a permeable (gravel) bed (Vardakostas *et al.* 2020) a reduction of front velocity of gravity currents is observed in all cases (Figures 6–9). The results of the present study are presented with curves with small symbols and the results achieved by Vardakostas *et al.* with lines curves (Vardakostas *et al.* 2020). The five curves of each case are from 1,050 (the first in the figures) to 1,090 kg/m^3 (the last in the figures). For example in Figure 6 the first figure for present study is colored red and for Vardakostas *et al.* (2020) is colored blue. The presence of a permeable bed significantly influences the motion of gravity currents. In the results of Vardakostas *et al.* (2020), as observed in Figures 6 and 7, there are linearity and uniformity in the motion of gravity currents in all different densities. The gravity current with an impermeable bed travels faster in all cases in comparison with the cases with a permeable (gravel) bed.

These linearity and uniformity do not exist in the diagrams with the presence of permeable (gravel) bed when the water height is small. This is due to the fact that the gravel bed with the trapezoidal cross section significantly influences the motion of gravity currents and also influences the linearity of the motion when the water height is small. When the water height increases and the cross section changes from trapezoidal to composite with a rectangular upper cross section (Figures 8 and 9), the influence of the presence of gravel bed gravity currents is reduced significantly. The reduction in front velocity is smaller than in the other two cases (5 and 10 cm) and in these two cases (17.5 25 cm) the linearity and uniformity are approximately the same with the experiments without permeable bed.

The main observation of the Figures 6–9 is that the gravel bed influences with critical role the motion of gravity currents. The presence of permeable bed reduces the front velocity of gravity current because there is a penetration of the mass of salt water inside the gravel bed. The effect of this penetration is very clear in the first two cases of trapezoidal cross section (Figures 6 and 7) while is reduced in the cases of rectangular cross section (Figures 8 and 9).

Moreover, the effect of bed roughness (effect of gravel bed) is very significant regarding the front velocity of the gravity current. In the region below the free surface region, the flow is strongly influenced by the gravel bed. However, moving toward the bed, the flow is affected by a combined effect of gravel bed, firstly, and bed roughness, secondly. In particular, the increase of bed roughness reduces the front velocity of the current. This is due to the fact that the bed roughness influences the motion of the water over the bed. The bottom friction leading to a more rapid deceleration of the flow. Both of them (penetration of the mass of salt water inside the gravel bed and bed roughness) reduce the velocity, but the bed roughness has the main role in this context, because it creates turbulence and small vortices in the interface between bed and water and that reduces the motion of gravity current and the front velocity.

In Figures 10–13 the distance from the lock gate to the front edge of the current head (x) is made dimensionless with the water height H $x^* = x/H$ and the time t of the motion of gravity current with the parameter $\sqrt{g(1-\gamma)/H}$ ($t^* = t\sqrt{g(1-\gamma)/H},\ \ \gamma = \rho_w/\rho_{sw}$). The dimensionless distance x^* is plotted against the dimensionless time t^* for all cases.

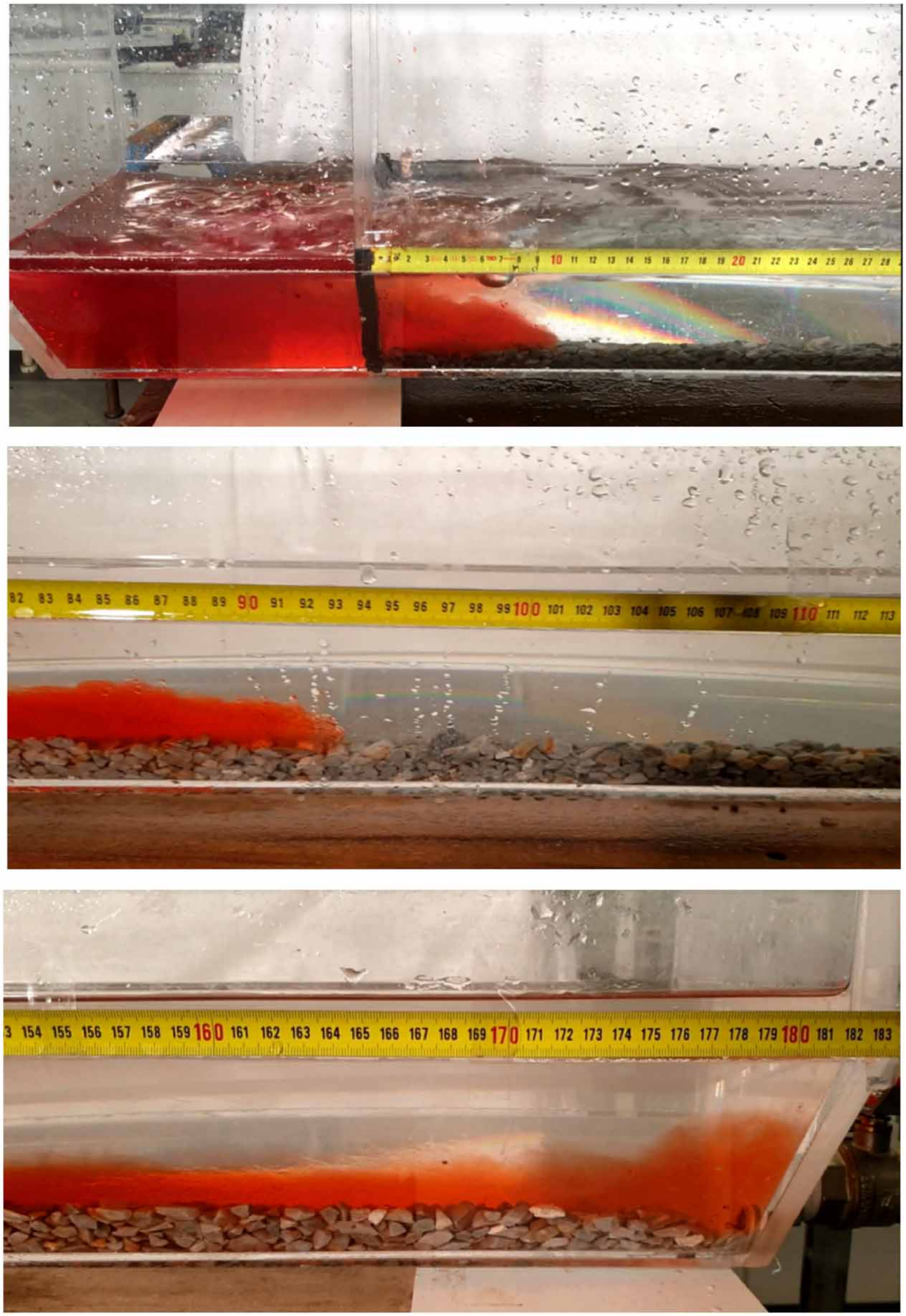

Figure 2 | Experimental procedure (H = 25 cm, $\rho_{sw} = 1{,}070$ kg/m^3) at three different phases.

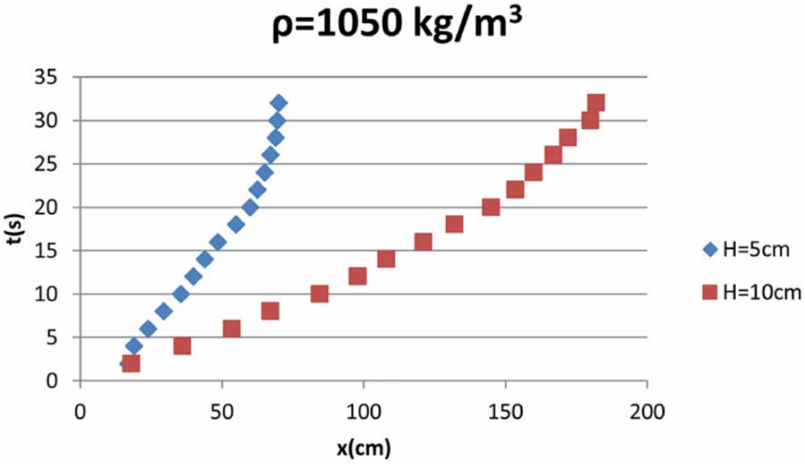

Figure 3 | Time development of current in trapezoidal cross section at height H = 5 and 10 cm for the same density.

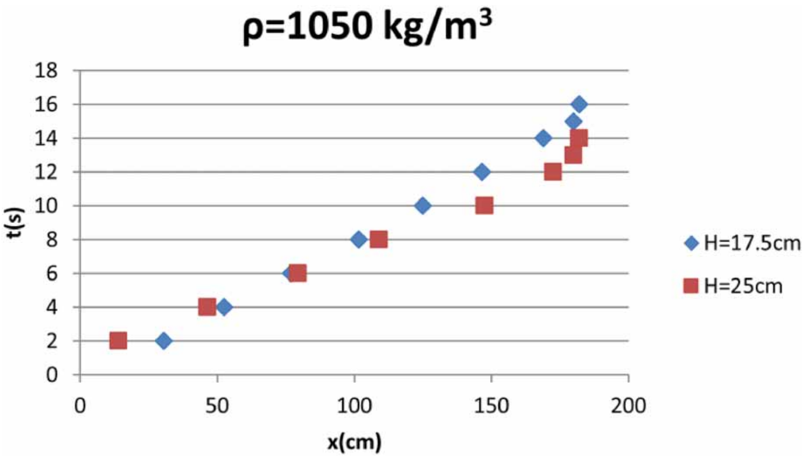

Figure 4 | Time development of current in composite cross section at height H = 17.5 and 25 cm for the same density.

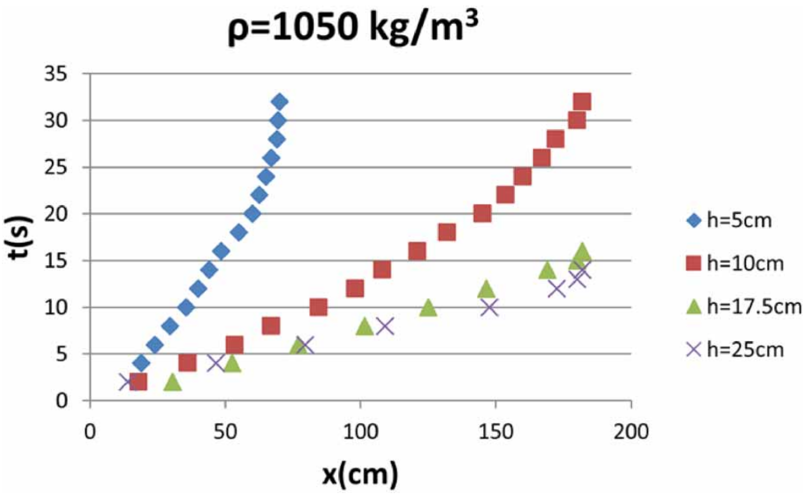

Figure 5 | Time development of current in both trapezoidal and composite cross section for the same density.

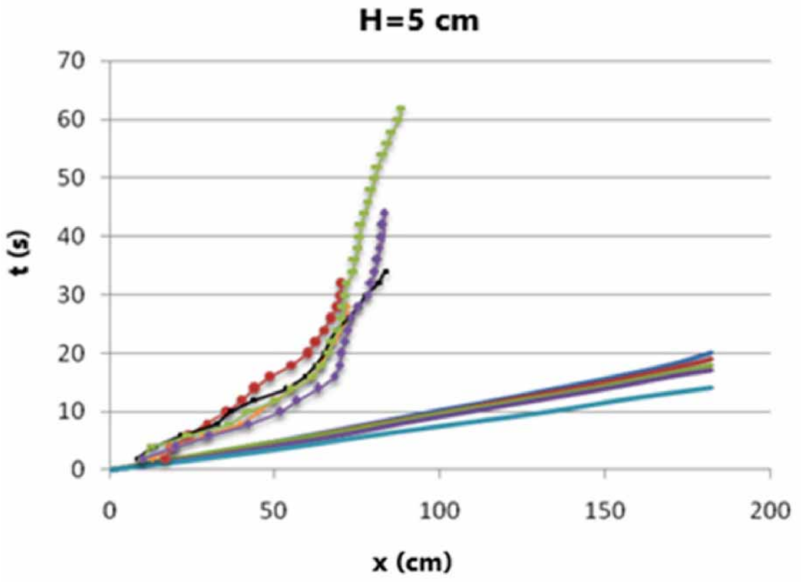

Figure 6 | Time development of current in trapezoidal cross section for height H = 5 cm for all densities (present study with lines with bullets and Vardakostas *et al.* (2020) with lines).

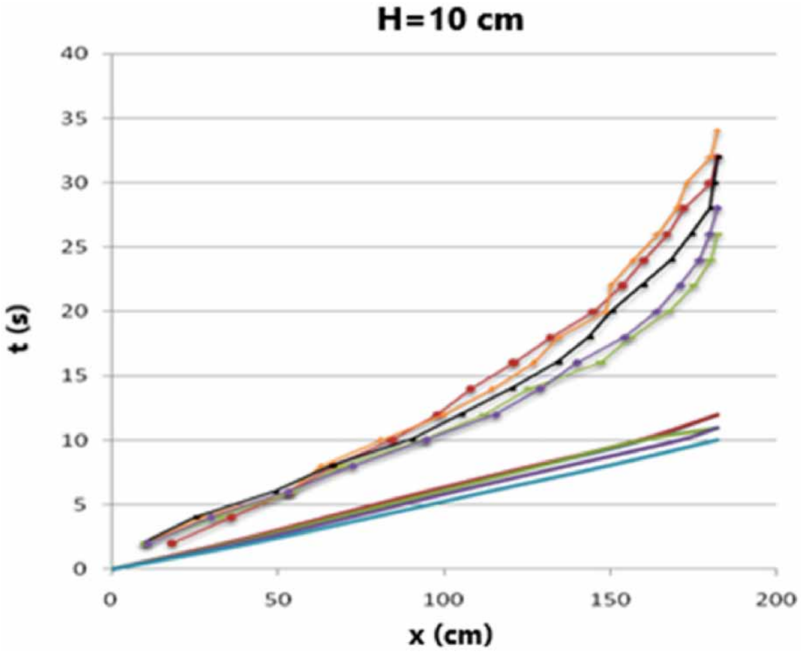

Figure 7 | Time development of current in trapezoidal cross section for height H = 10 cm for all densities (present study with lines with bullets and Vardakostas *et al*. (2020) with lines).

These dimensionless variables were adopted to demonstrate the general trends in the numerical results. They allow easy comparison between experimental cases at different scales. As it observed from these figures that the total water depth H influences significantly the front velocity of the current. This is due to the fact that the increase of the amount of the total water depth H increases the drift capacity of the current resulting the acceleration of the gravity current. This means that the front velocity of the current increases with the increase of the total water depth. Also, it is obvious that the density difference doesn't play a crucial role in the time development of gravity front, especially with the increase of depth H. Figure 14 includes all the cases together.

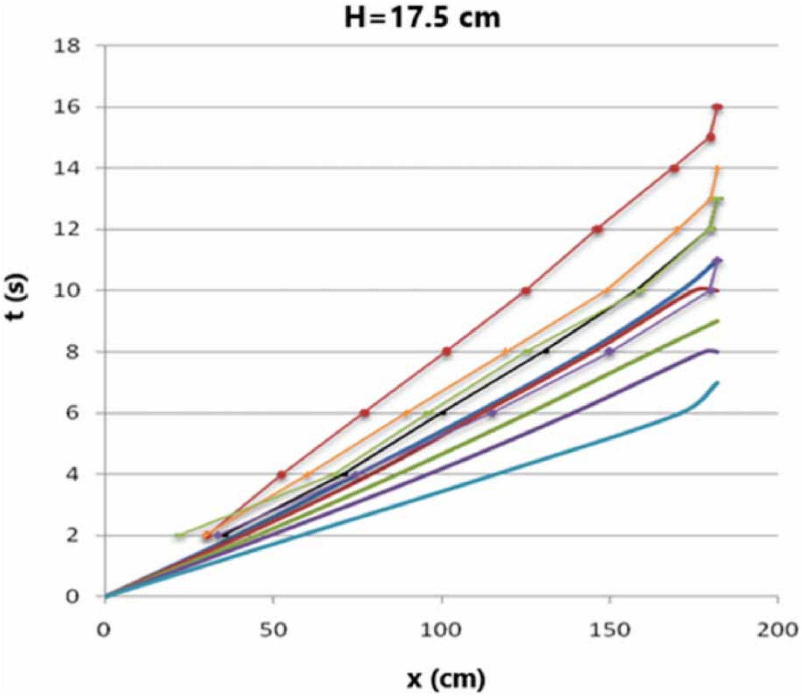

Figure 8 | Time development of current in composite cross section for height H = 17.5 cm for all densities (present study with lines with bullets and Vardakostas *et al.* (2020) with lines).

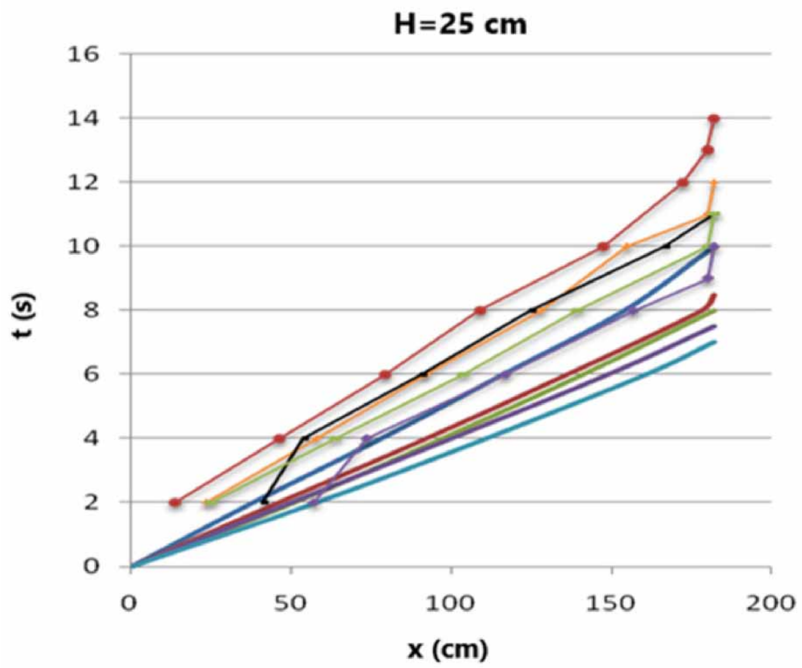

Figure 9 | Time evolution of current in composite cross section for H = 17.5 cm and for all densities.

In Figure 15 a dimensionless comparison between triangular, orthogonal and composite shape is presented. This comparison includes results from: (a) rectangular cross-section (Shin *et al.* 2004), (b) triangular cross-section (slope of the valley is 12°, 23° and 41° to the horizontal with respective depths of the valley a = 0.03 m, a = 0.06 m and a = 0.12 m) (Monaghan *et al.* 2009a), (c) composite cross section (trapezoidal lower part and rectangular upper part), tank with the same shape and

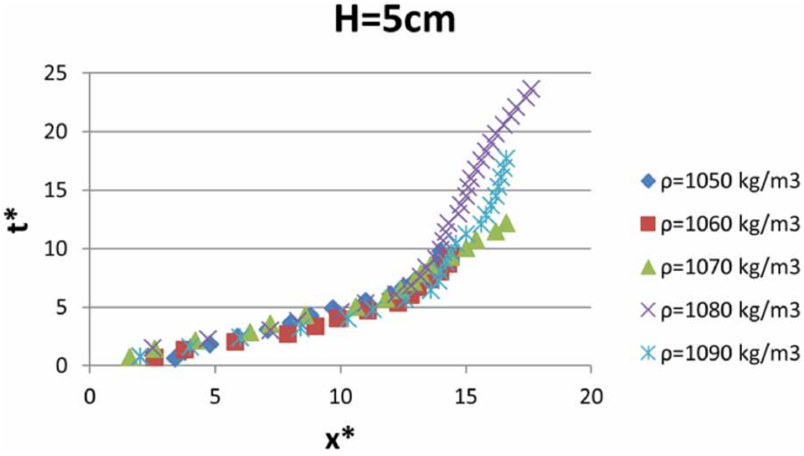

Figure 10 | Time development of gravity front for H = 5 cm (dimensionless) for all densities.

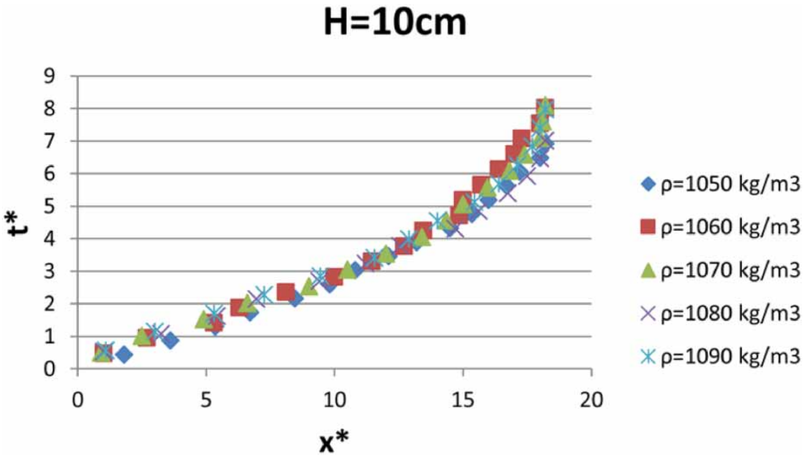

Figure 11 | Time development of gravity front for H = 10 cm (dimensionless), for all densities.

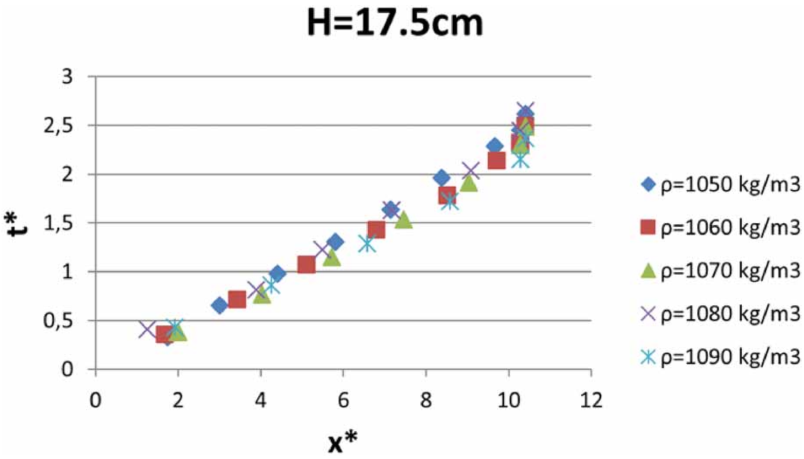

Figure 12 | Time development of gravity front for H = 17.5 cm (dimensionless), for all densities.

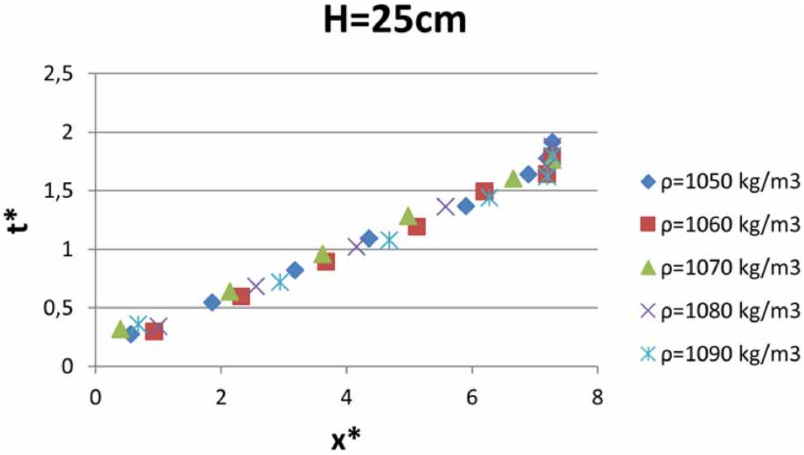

Figure 13 | Time development of gravity front for H = 25 cm (dimensionless), for all densities.

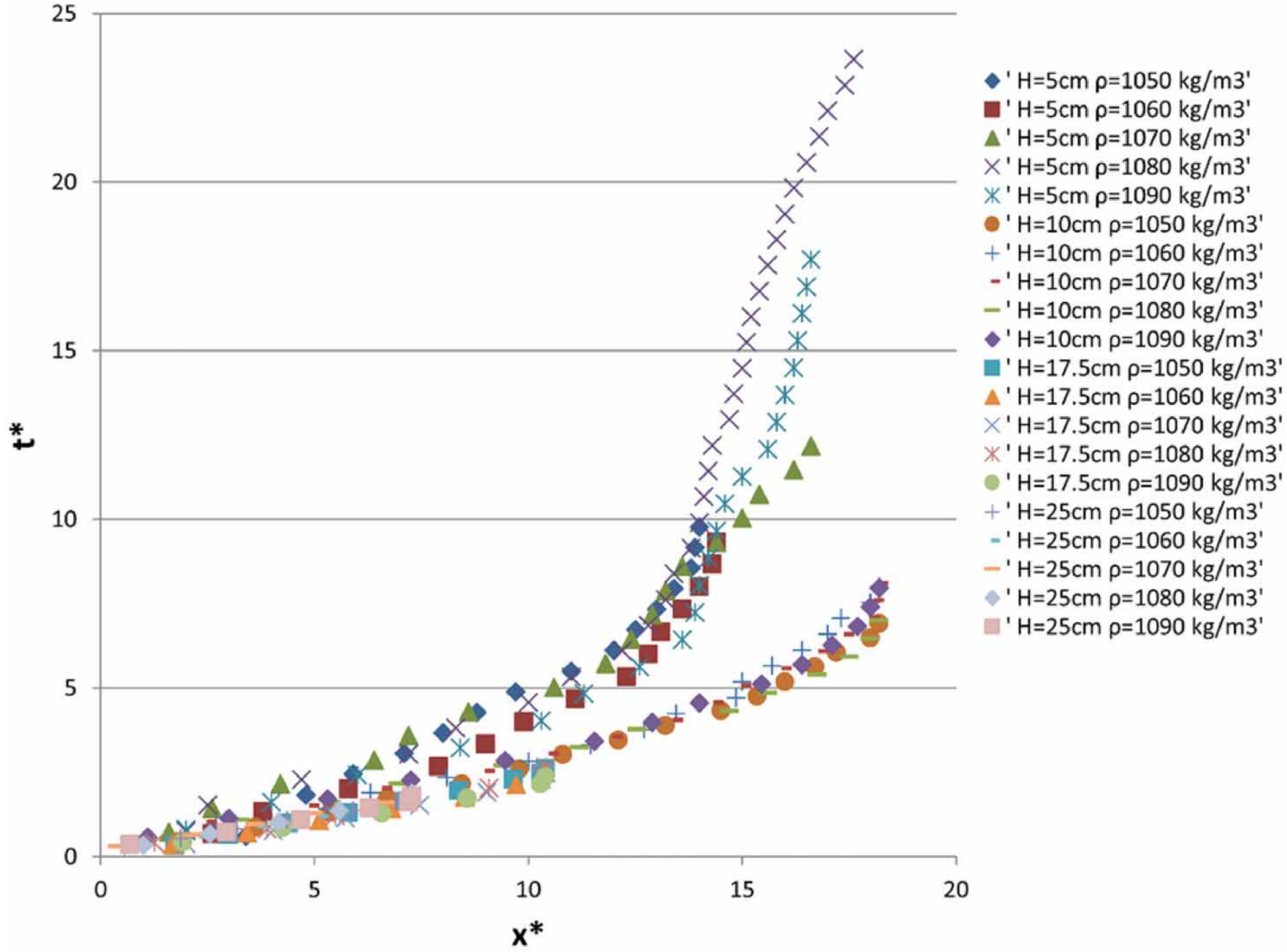

Figure 14 | Dimensionless diagram for all cases together.

dimensions and with different density between salt water and fresh water (Keramaros & Prinos 2010) and (d) composite cross section (trapezoidal lower part and rectangular upper part), tank with the same shape, dimensions and density difference between salt water and clear water (Vardakostas *et al.* 2020) and results from present study.

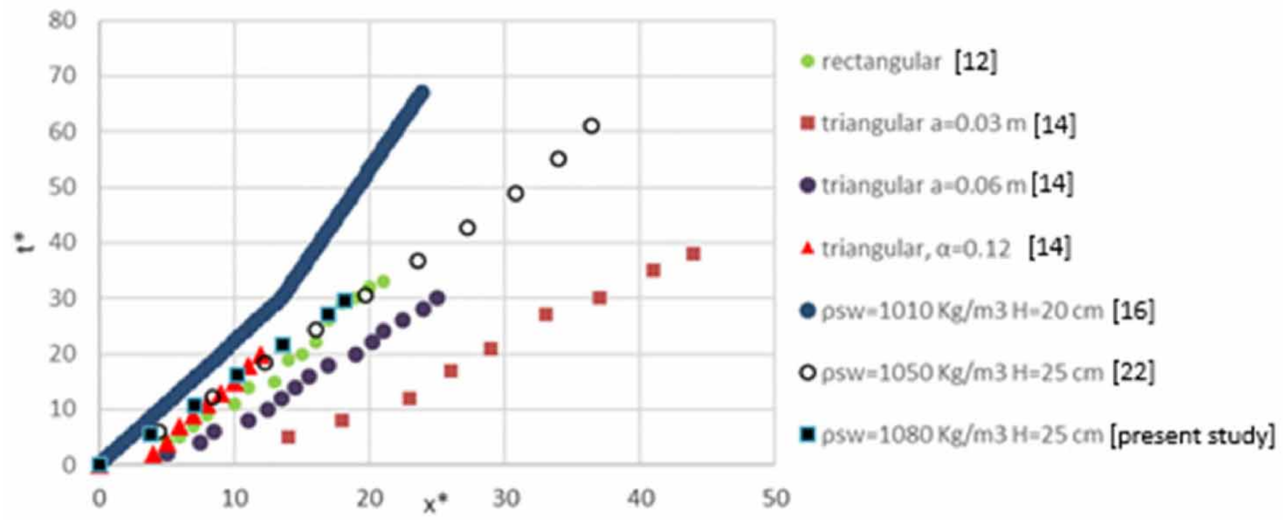

Figure 15 | Dimensionless comparison between triangular, rectangular and composite shape.

The presence of permeable bed reduces the motion of the gravity currents especially inside the trapezoidal cross section at lower part of the tank. As it shown in Figure 15 all the researches have approximately the same gradient, but there is a significant difference between the present and the other studies. The presence of permeable bed (flexible vegetation) reduces significantly the front velocity with resulting the declaration of the gravity current in comparison with experiments with: (a) rectangular cross section (Shin *et al.* 2004), (b) triangular cross section with small valley depth (Monaghan *et al.* 2009a) and (c) the same cross section with impermeable bed (Vardakostas *et al.* 2020).

4. CONCLUSIONS

In the present study lock-exchange experiments in a tank of composite cross section were performed. The motion of gravity currents with large salinity in this valley is investigated. The tank was separated in two parts by a vertical gate, which separates the fresh water with the permeable (gravel) bed from the salt water with the impermeable bed. The density of salt water varied from 1,050 to 1,090 kg/m^3. These specific densities have been chosen to simulate liquid wastes that affect the environment.

The motion of gravity current in the case of impermeable bed differs when it compared with this with permeable (gravel) bed. The presence of permeable bed reduces the front velocity of the current and delay the motion. The section of the tank influences the motion of the current. In the case of an impermeable bed, there is linearity and uniformity in the motion of gravity currents in all different densities. These linearity and uniformity do not exist in the diagrams with the presence of a permeable (gravel) bed when the water height is small. When the water height increases and the cross section changes from trapezoidal to composite with a rectangular upper cross section this influence is reduced significantly.

From the dimensionless comparison for orthogonal, triangular and trapezoidal cross sections, it is clear that the different shape of the cross section influences the motion of gravity currents in different ways. In addition, the presence of a permeable bed reduces the motion of the gravity currents, especially inside the trapezoidal cross section at the lower part of the tank.

All these collected data and findings of this study can be used in real geophysical environments in cases when solute with large salinity (for example, release of toxic chemicals due to industrial accidents) may be inadvertently released. At the field scale, large density difference between water and solute may even lead to unstable flow, resulting in formation of solute vortices that penetrate the bed at a fast pace.

CONFLICTS OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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