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Controlling Salt Wedge propagation by using roughness elements

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Abstract— The research aims to study the effect of using roughness elements in controlling the propagation of salt wedge upstream river mouth. The computational fluid dynamics, CFD, was used to simulate the propagation of salt wedge in a flume system with roughness elements, a cube shape of 1.5cm, arranged at its bed with different configurations. The roughness elements work to increase the flow turbulence that dispersion the salt wedge that moves beneath the fresh water and reduce its propagation. The results of the eight model runs showed that roughness elements can reduces the propagation up to 66.7% when the roughness elements are places close to the end of the flume, at the highest an applied discharge of fresh water, and at the minimum bed slope of the flume. Roughness elements provide obstruction to the movement of the salt wedge and mixing of salt water with the fresh water that helps to reduce the propagation of the salt wedge.

Keywords- CFD, salt wedge, roughness elements.

1. Introduction

The propagation of salt is a natural phenomenon that occurs in all in rivers estuaries all over the world. It may have a negative impact on the environment and the different uses of water. As an example, the salt wedge in Shatt Al-Arab River, Iraq, propagate up to 130 km upstream the river mouth that deteriorates the quality of the river, which is the source of fresh water to cities and villages along this river. Salt wedge propagation is effected by many factors such as the fresh water discharge, slope of the bed, salt water concentration, and roughness of the river .

Previous studies proposed a number of solutions to control the propagation of salt wedge. These solutions include, increasing the discharge of fresh water (Tuin, 1991 [3]), changing the geometry of the river mouth (US Army Corps of Engineers 1993 [10]), constructing the sill on the riverbed (Fagerburg and Alexander, 1994 [9]), constructing inflatable dams or gates (Liu et al, 2016 [2]), using air or water curtains (Haralambidou, et al [5], Nakia and Arita[7], Al-Fuady and Azzubaidi [6], Naderi and Zolfaghari [8]), and increasing the roughness of the riverbed (Ibrahim et al, 2008 [11]).

Recently, Alwan and Azzubaidi, 2021 [4] carried out a mathematical investigation study on the use of large-scale geometric roughness elements to change the hydraulic characteristics of open channel flow. Their finding can be useful in controlling the propagation of the salt wedge .

This study amid at mathematically investigating the use of large-scale geometric roughness elements to control the salt wedge propagation. A mathematical model is prepared by using ANSYS FLUENT 19, CFD Software. Computational Fluid Dynamic for comprehensive details of the propagation of the salt wedge.

2. Description of the Case under Study

The laboratory flume system model by (Al-Fuady and Azzubaidi, 2021) [6] which was used to investigate the factors affecting the behavior of salt wedge intrusion under different flow conditions, was used to prepare the numerical simulation model to control salt wedge propagation by using the roughness elements. The flume system model, **Figure 1** consist a flume of 6 m supplied by fresh water at its upstream. A weir is installed at the downstream end of the flume that is used to discharge water out of the flume and to supply salt water through a hole at its center that is connected to salt water reservoir having a constant head. The weir retains salt water to a level that simulates the level of the sea. Potassium permanganate was added in a small amount to the salt water that clearly dyes it with a purple color.

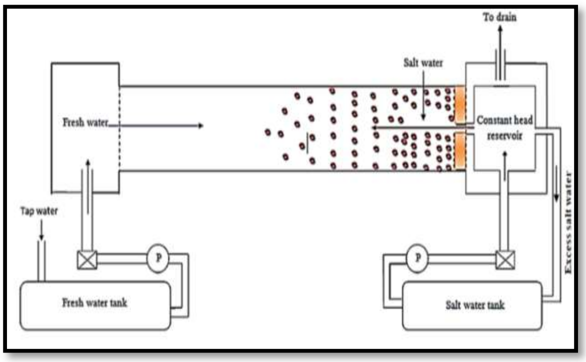


Figure 1: A top view schematic diagram showing the flume system.

A detailed geometry of the flume system was prepared by using SOLIDWORKS 2018 software. Cubic roughness elements of 1.5cm arranged in ten rows, each row contains 3 cubic elements, **Figure 2.**

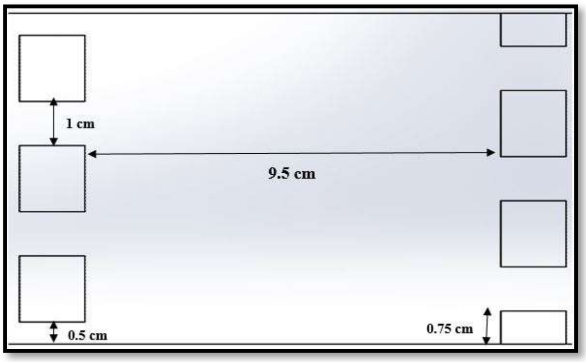


Figure 2: Spacing between rows and columns of thee cubic roughness elements.

These elements are fixed within 1m longitudinal section of the channel bottom to control the propagation of salt wedge. This section is located in turn at four different locations. **Figure 3.**

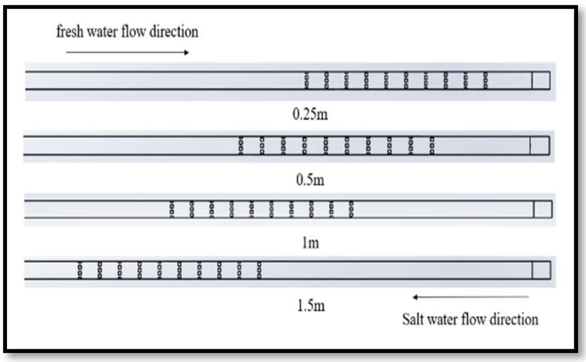


Figure 3: A top view showing the configurations and locations of roughness elements.

The detailed geometry model of the flume system was imported by ANSYS Fluent 19. **Figure 4**.

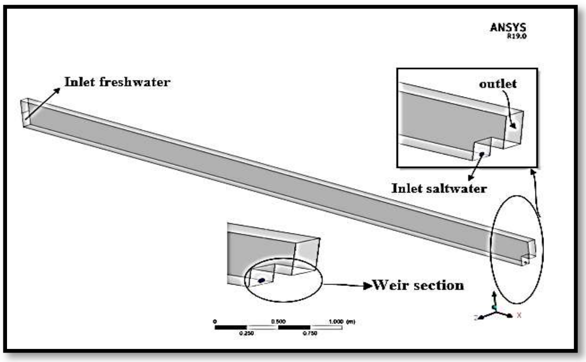


Figure 4: The geometry model of the flume system.

3. Description of CFD Model

The commercial ANSYS FLUENT, CFD was an effective method used to simulate the hydrodynamic study of fluids flow under different conditions. This method helps to avoid possible errors in laboratory experiments or field. The ANSYS Fluent Software was used the Navier-Stokes equations to numerically solve the continuity and momentum equations derived from Newton's second law of fluid motion. The governing equations in the software are solved numerically by the finite volume**.** Flow in open channels is incompressible and turbulent. In this study, to simulate the flow turbulence away from the wall, used the turbulence model k-ε. Where, K is the kinetic energy and ε is the dissipation rate (Versteeg and Malalasekera, 2007) [1]. It is gives a good

comparison between computational power needed and accuracy**.** Boundary condition is used to determine the quantities of inputs and outputs in an open channel. The inlet and outlet were define as a velocity inlet and a pressure outlet and the surface of a flume was free surface.

Generally, stages of creating a CFD model includes create geometry and meshing domain, defining the problem, determining the limits of the input, and properties of the fluid used in the setup. Finally, post-processing includes presentation the results to get a clear picture and analyzing them such as contour plots, streamline or vector etc. **Figure 5** show a model divided into small irregular tetrahedral cells. The mesh quality is subject to several criteria represented by skewness that were acceptable to good quality.

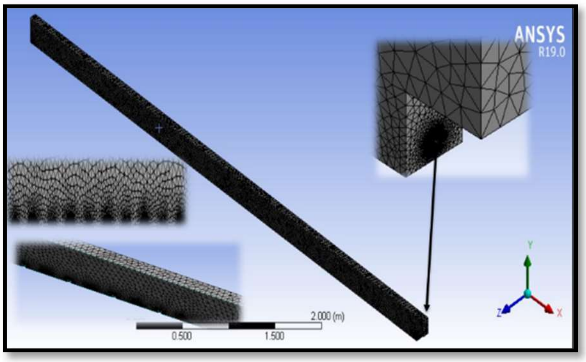


Figure 5: The meshing of geometry.

The flow conditions and results of two elected laboratory experiments conducted by (Al-Fuady and Azzubaidi, 2021) [6], were selected. That is a slope of the flume of 0% and 1%, the freshwater discharge of 55.6 L/min and 45.1 L/min, and the density of fresh water of 998.2 kg/m^3 and that for the salt water of 1022.68 kg/m^3.
Eight CFD mathematical model runs were carried out to simulate salt wedge preparation and control under different distances. **Figure 6** shows the details of these model runs. For each slope and discharge four location of the roughness section were tested, that is 0.25-0.5-1-1.5 m measured from the end side of the flume.

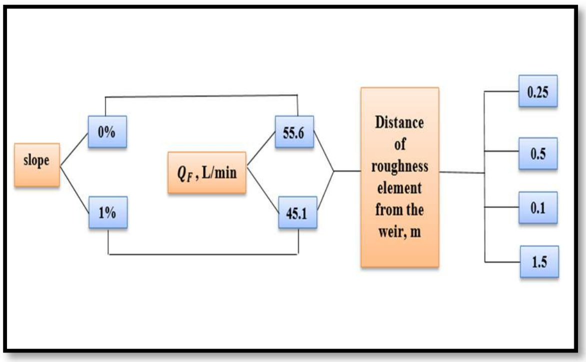


Figure 6: Design of CFD model runs.

4. Results and Analyzes

Simulations to study the effect of roughness elements on the propagation of salt wedge were conducted by using the CFD model. The model results are presentation using post-processing on the basis of velocity vectors and contour of finite volume profiles of saltwater.

The roughness elements provide obstruction to movement of the salt wedge. **Figure 7** shows a side view of the vector velocity distribution around the roughness elements. Clear eddies are form around roughness elements obstruct the flow and may help to dissipate the salt wedge by mixing salt water with the fresh water. This process contributes to reducing wedge propagation due to the washing of saltwater with freshwater.

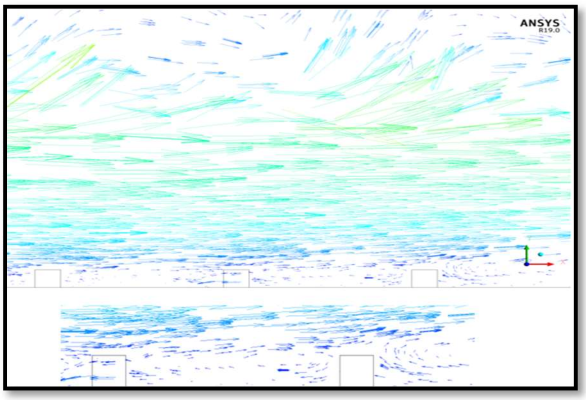
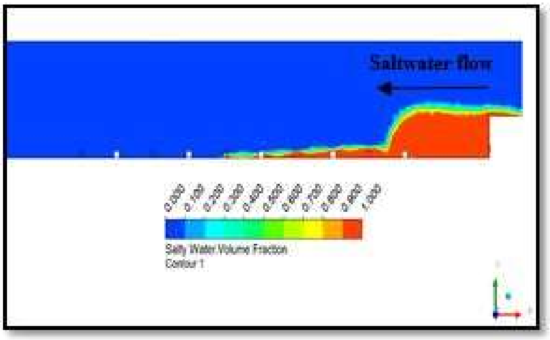
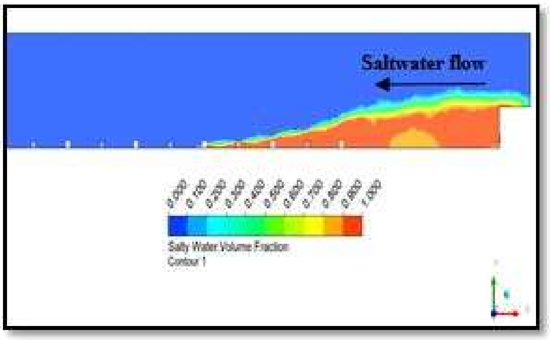


Figure 7: A side view showing the vector velocity distribution.

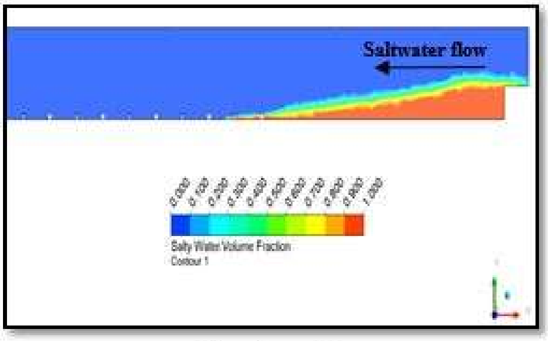
Figure 8 and 9 show the stationary propagation of salt wedge when the roughness elements are placed at different locations. **Table 1** presents the values of salt wedge propagation without and with roughness elements. The model results without using roughness element have an excellent agreement with that of the laboratory experiments. the salt wedge propagated up to 2.4 m and 1.47 m, upstream the end of the flume, at fresh water discharge 55.6 l/min and 45.1 l/min and at flume slope of 0 and 0.1%, respectively. Propagation of salt wedge is reduced as the location of the roughness elements section approaches the end side of the flume. The maximum reduction in the propagation of salt wedge is 66.7% when the roughness elements section is places at a distance of 0.25 m from the end of the flume and applied discharge 55.6 l/min for 0% the flume bed slope. While, at a discharge 45.1 l/min, a slope 1%, and the same location of the elements, the propagation is reduced by 45.5%. Minimum reduction is achieved as the maximum distance of 1.5 m where the roughness section is placed.



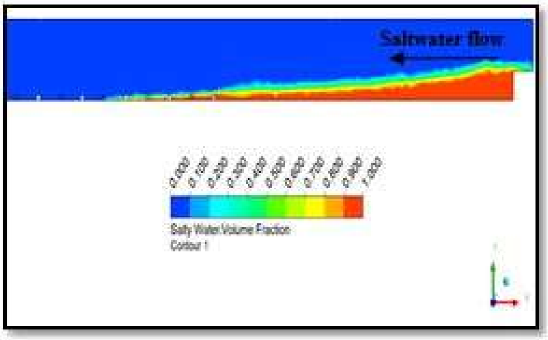
a- Location at 0.25 m



b- Location at 0.5m

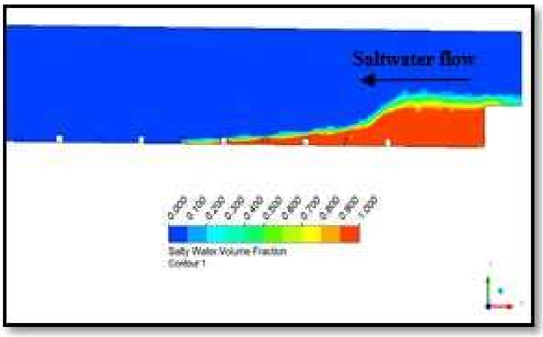


c- Location at 1m

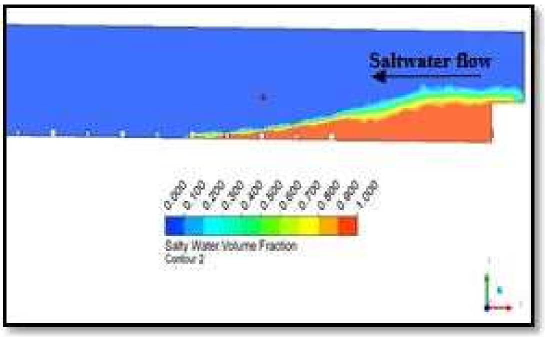


d- Location at 1.5m

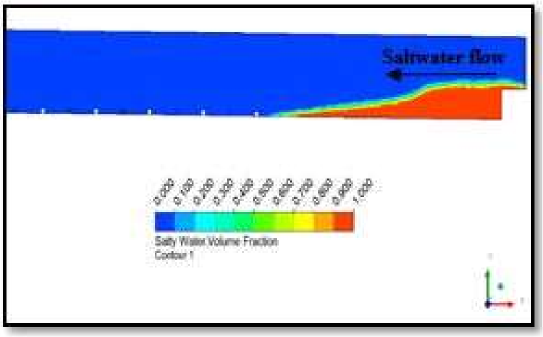
Figure 8: Propagation of salt wedge with roughness elements for a discharge of 55.6 l/min, a slope of 0%, and different roughness section location measured from the flume end



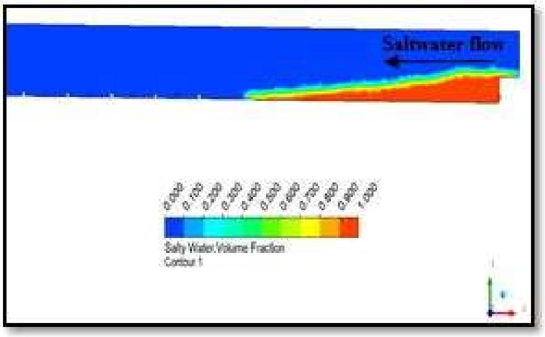
a- Location at 0.25m



b- Location at 0.5m



c- Location at 1m



d- Location at 1.5m

Figure 9: Propagation of salt wedge with roughness elements for a discharge of 45.1 l/min, a slope of 1%, and different roughness section location measured from the flume end.

Table 1: Propagating of the salt water under different conditions

Slope %	**Discharge** l/min	**Propagation of the salt without roughness element**, m		**Location of roughness element from the flume end**, m	**Propagation of the salt water with roughness elements**, m	**Percentage of reduction in propagation of salt wedge %**
		Laboratory experiment*	**CFD model**			
0%	55.6	2.6	2.4	0.25	0.8	66.7
		2.6	2.4	0.5	0.97	59.6
		2.6	2.4	1	1.15	51.7
		2.6	2.4	1.5	2	16.7
1%	45.1	1.48	1.47	0.25	0.8	45.5
		1.48	1.47	0.5	0.95	35
		1.48	1.47	1	0.95	35
		1.48	1.47	1.5	1.25	15

* Laboratory experiments conducted by (Al-Fuady and Azzubaidi, 2021) [6].

5. Conclusion

Vector velocity distribution shows eddies formed around the roughness element that obstruct the flow and may help to mix the salt water with the fresh water. The results showed a reduction in the propagation of salt wedge when using the roughness element varies between 66.7% and 15% depending on the flow conditions. Moreover, results indicated that as the roughness element section is placed close to the end of the flume, the higher reduction in the propagation of slate wedge is obtained.

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السيطرة على امتداد الموجة الملحية باستخدام عناصرالخشونة

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الخلاصة – يهدف البحث لدراسة تاثير استخدام عناصر الخشونة في السيطرة على امتداد الموجة الملحية في اعلى مجرى النهر.تم استخدام ديناميكية الموائع الحسابية (CFD) لمحاكاة امتداد الموجة الملحية مع عناصر الخشونة على شكل مكعب ذو ابعاد 1.5م ومرتبة في قعر القناة بتوزيعات مختلفة. تعمل عناصر الخشونة على زيادة اضطراب الجريان وتشتت الموجة الملحية المتحركة تحت المياه العذبة وتقلل من امتدادها. اظهرت نتائج ثمانية تجارب ان عناصر الخشونة يمكنها تقليل الامتداد الملحي حتى 66.7% عند وضع هذه العناصر في مواقع قريبة من نهاية القناة خلال اعلى تصريف للمياه العذبة واقل ميل طولي. كما تبين عند استخدام عناصر الخشونة ينتج عنه دوامات واضحة حول هذه العناصر وكما تعمل هذه العناصرعلى اعاقة حركة الموجة الملحية وخلط المياه المالحة مع المياه العذبة والتي تساعد على تقليل امتداد الموجة الملحية.

الكلمات الرئيسية – الموجة الملحية، عناصر الخشونة، حسابات الموائع المتحركة .