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The effect of lateral intake slope on sedimentation transport

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Abstract

Generally, The problem of sediments at the entrances to subsidiary channels is considered one of the most common problems for which water resources engineers seek to find appropriate solutions, as it causes significant damage to hydraulic installations, as the accumulation of these sediments in the canal rollers over time leads to the collapse of those channels, which results in many losses.

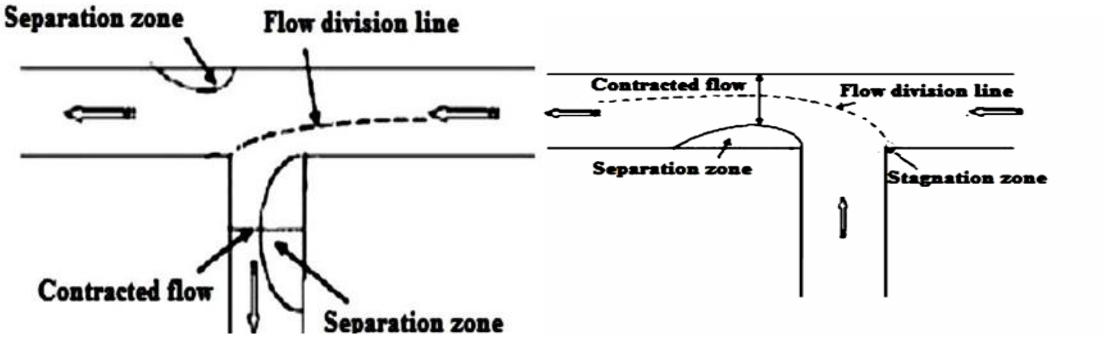
In this study, a three-dimensional mathematical model was developed using the Ansys Fluent CFD program, and this model was matched with previous laboratory experiments, as this mathematical model showed clear accuracy and consistency. Work was done on changing the geometry of the sub-channel and studying the effect of changing the inclination of the sub-channel on reducing the amount of sediment entering the channel or not, since the channel used in this study is 2 m. Adjustments were made to the inclination of the canal in two different forms: The first is to make the first half (1 m) of the canal horizontal, and the inclination begins in the second half, at three different angles, namely 15, 30, and 45 degrees. The other form is to change the inclination along the total length of the sub-channel (2 m) with the same effect. Angles 15, 30 and 45. The results showed the ineffectiveness of changing the inclination of the sub-channel from the middle of the distance, while the results of changing the total inclination were different. It is possible that the slope angle of 45 is considered the best in terms of increasing the speed and clearly reducing the area of the separation zone and the erosion zone.

Keywords: Separation zone, Lateral intake, Sediment.

الخلاصة: تعتبر مشكلة الرواسب عند مداخل القنوات الفرعية من اكثر المشاكل شيوعا والتي يسعى مهندسي لموارد المائية لايجاد الحلل المناسبة لها لم لها من اضـــرار كبيرة على المنشـــات الهيدروليكية حيث يؤدي تجمفي هذ ع الرواســب في مداخل القنوات وبمرور الوقت الى اندثار تلك القنوات والذي يترتب عليه الكثير من الخسائر. في هذه الدراسة تم تطوير نموذج رياضي ثلاثي الابعاد ببرنامج انسيز وتمت مطابقة هذا الموديل مع تجارب مختبرية سابقة حيث اظهر هذا الموديل الرياضـي دقة وتطابق واضـحين. تم العمل على تغيير في هندسة القناة الفرعية ودراسة تاثير تغيير الميل الخاص بالقناة الفرعية في تقليل كمية الرواسب الداخلة الى القناة من عدمه بمانه القناة المســتخدمة في هذه الدراســة هي 2م . تم اجراء تعديلات على ميل القناة بشــكلين مختلفين: الأول هوان يكون النصــف الأول(1م) من القناة بصــورته الافقية ويبدا الميلان في النصــف الثاني وبثلاث زوايا مختلفة وهي 15 و30 و45 درجة.اما الشــكل الاخر هو تغيير الميل على طول القناة الفرعية الكلي (2م) وبنفس الزوايا 15و30و45 فقد أظهرت النتائج عدم فعالية تغيير ميل القناة الفرعية من منتصــف المسافة بينما كانت نتائج تغيير الميل الكلي مغايرة . من الممكن اعتبار زاوية الانحدار 45 هي الأفضل من حيث زيادة السرع وتقليل مساحة منطقة الفصل ومنطقة التعرية بصورة واضحة.

1. INTRODUCTION

Any lateral water diversion from open channels or rivers is represented by a branching channel (Fig1) [1]. Numerous practical applications, including drainage systems, irrigation networks, and other water resource projects, benefit greatly from these branching channels [2, 3]. These natural or man-made river diversionary features exist [1].



(a) (b)

Fig1: Types of open channel intersection (a) Confluence , (b) lateral intake [1].

Confluence and lateral intake are the two types of open channel junctions that are most frequently found. (Fig1) [1]. Sediment is strongly inclined to be directed towards the lateral channel by the intake flow (Fig. 2) [4]. The movement and deposition of sediment are two of the most essential and challenging problems that need to be resolved in the open channel [5]. Because this intake involves the entry and deposition of sediment, the installed facilities are vulnerable to damage, which drives up maintenance costs. Thus, when examining the effects of flow intrusion and hydraulic structures, attention must be paid to the flow and stream conditions as well as the system's characteristics [6].

This is important because the centrifugal forces are the same as those found in the bent channel flow. Therefore, the main feature near the intake's entry is the enormous zone of separation visible along the upstream portion of the diversion bank[7]. There are noticeable eddies, low velocity, and recirculation flow in this region of the flow. This area of separation is detected because of the high momentum entry of the flow into the lateral channel in the direction of the flow in the main channel. Strong sedimentation potential is revealed by this separation zone and the low-pressure circulating flow that is created (Fig. 3). Furthermore, compared to the bottom, the separation zone's size is substantially greater at the free surface [7].

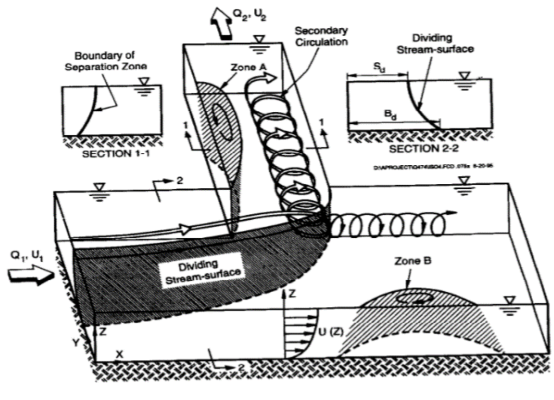


Fig. 2: Vortices formed at the lateral channel junction [7].

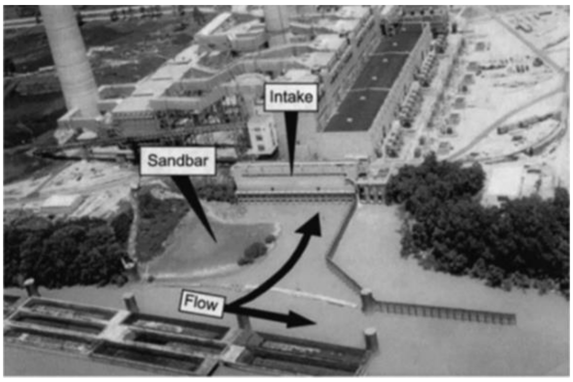


Fig. 3: Sediment deposition at the Ohio River intake [7].

Sediment entering and accumulating in the lateral channel is decreased by any preventive action used to lessen secondary flows and eddies downstream of the intake entrance and separation zone at the upstream intake bank [5].

Numerous methods have been developed and implemented in recent years to reduce the amount of sediment entering the intake channel. Modifying the intake channel geometry, such as applying the proper diversion angle and adjusting the intake inlet's dimensions, is one practical way to solve this problem [8]. Submerged vane techniques, which are relatively new, have effectively reduced sediment-related problems in rivers, particularly in the diversion and curved channels [9].

2. NUMERICAL SIMULATION

The commercial CFD program ANSYS is utilized in this work to solve the governing equations [10]. In this work, the ANSYS FLUENT, version 19.2 commercial software was used to analyze the 3D turbulent flows of the lateral channel parameters for individual examples. Currently, CFD is widely applied in many complex applications. Because the computer expedites the operations, this method lowers physical experiments' costs. transport and fluid flow are being modeled more and more with computational fluid dynamics (CFD). When used to recreate what happened in a variety of engineering applications, the commercial codes exhibit greater efficacy and attractiveness. CFD makes it easier to predict results even before testing is done and even assists in more efficiently organizing the research. Physical problems are theoretically formulated as a set of partial differential equations (PDE) that must be numerically resolved through the Finite Volume Method (FVM).

2.1. Governing equations

The governing equations for the flux in open channels include the Reynolds Averaged Navier– Stokes (RANS) and incompressible equations. In the ANSYS FLUENT simulation algorithms, continuity and momentum equations were applied for incompressible flows [5].

The above equations were applied for a given control volume in the fluid flow with a volumetric mass of Newtonian. The following is the expression for the continuity and momentum equations in the Cartesian x, y, and z coordinates:

“Continuity equation”:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0 \tag{1}$$

“Momentum equations”:

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u V) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \tag{2}$$

$$\partial (\rho v) \qquad + \nabla \cdot (\rho v V) = -\frac{\partial p}{} + \frac{\partial \tau_{xy}}{} + \frac{\partial \tau_{yy}}{} + \frac{\partial \tau_{zy}}{} + \rho f_y \tag{3}$$

$$\overline{\partial t} \qquad \partial y \quad \partial x \quad \partial y \quad \partial z$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla \cdot (\rho w V) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \quad (4)$$

Where f represents the body forces,t indicates time, ρ: density of the fluid element, τ is the stress tensor (viscous stresses), and p denotes pressure. The vector operator for the Cartesian coordinates (Δ) and the velocity component (V) are calculated as follows:

$$V = ui + vj + wk \quad (5)$$

$$\nabla \equiv i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z} \quad (6)$$

where the unit vectors of the x, y, and z axes are, respectively, i, j, and k.

2.2. Verification

The lab experimental was approved [11] The channel, which is supported at a height of 0.8 meters allowing the researcher to easily monitor the flow of water and sand, was constructed out of galvanized metal. The dimensions are 10 meters by 0.3 meters by 0.45 meters above the ground. 8.73 meters divided the starting point of the main channel from the lateral channel. Its dimensions are 2 meters long, 0.2 meters wide, and 0.45 meters high. It must also be a comparable height above the natural ground fig. (4). In this work, simulations were carried out to investigate the flow patterns at the lateral intake using the ANSYS Fluent tool. Following the model validation procedure, the impacts of modifying the lateral channel's flow and physical characteristics are investigated. The simulations that look at the properties of the intake intersection flow and various approaches to make it better and less problematic are included in the following sections. The simulation is based on the same basic model geometry, mesh creation, boundary condition, setup, and solution methods as the validation technique, with only minor changes to the geometry or discharge ratio fig (5).

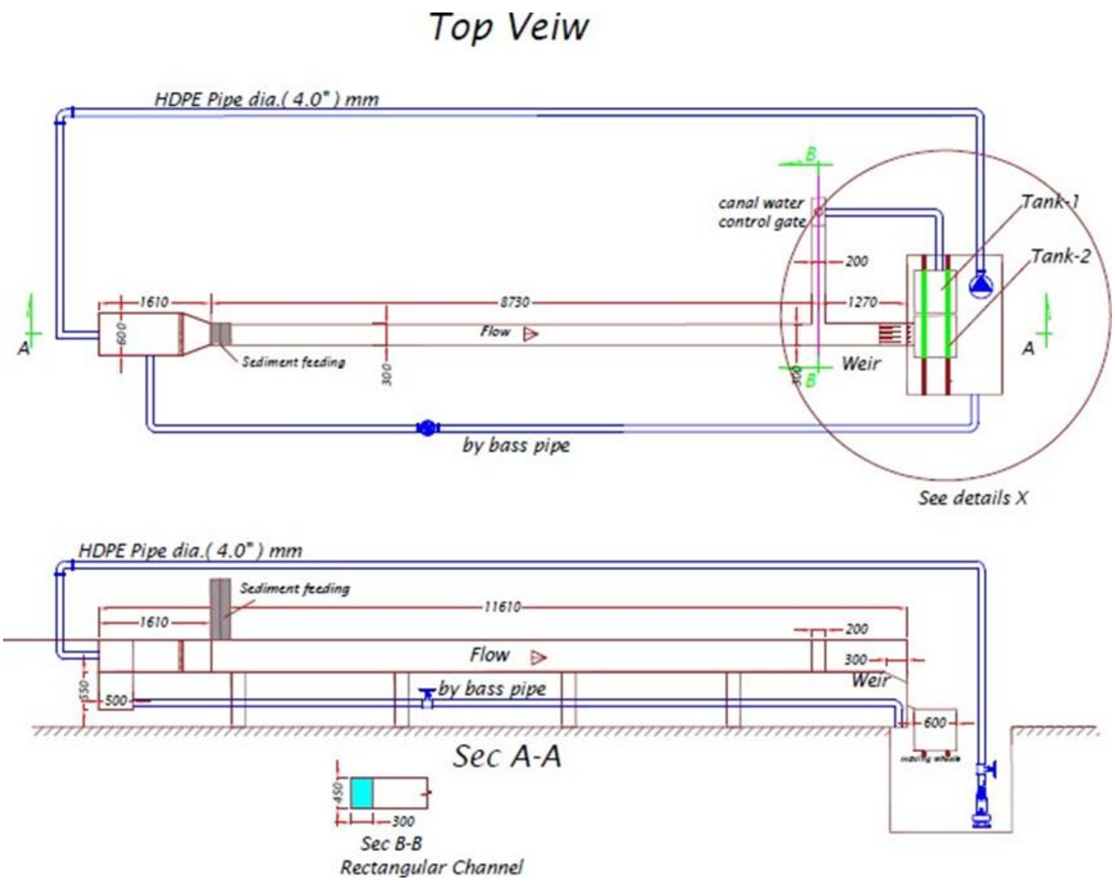


Fig.4(A)

Fig.4(B)

Fig.4: laboratory work (A) Illustration of the Manufactured Channel (B) Image of the manufactured hydraulic channel

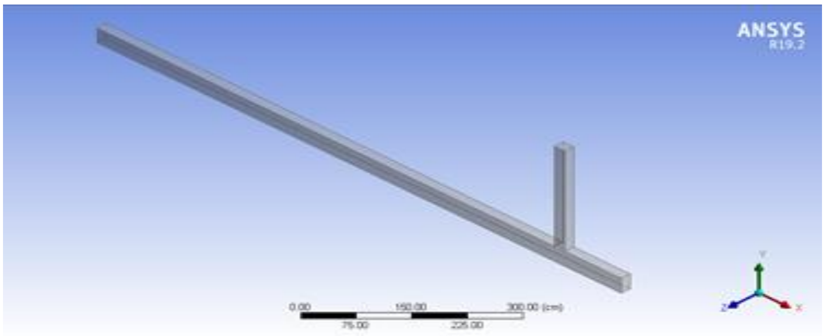


Fig.5: numerical simulation

The parameters of flow at a lateral diversion were simulated in this section. Impact of the Qr discharge ratio, In this Section. Three models were simulated with different discharge ratios (19.1%, 27 %, and 30.5%). The hydraulic parameters and zoomed intake connection shape used in this situation are shown in Table1,2 and Fig.6, and 7, respectively

Table 1: Comparison between Qi experimental and numerical

Inlet discharge (Q) (l/s)	Depth of water ($\boldsymbol{d}°$) (m)	Average inlet velocity ($\boldsymbol{U}°$) (m/s	Fr	Discharge ratio (Qr)=($\boldsymbol{Qi}/\boldsymbol{Q}$)	$\boldsymbol{Qi}$ (l/s)	ANCY
27	0.17	0.53	0.31	19.1%	5.16	5.15
				27%	7.3	7.28
				30.5%	8.23	8.22

Table2: Comparison between Qm experimental and numerical

Inlet discharge (Q) (l/s)	Depth of water ($\boldsymbol{d}°$) (m)	Average inlet velocity ($\boldsymbol{U}°$) (m/s	Fr	Discharge ratio (Qr)=($\boldsymbol{Qi}/\boldsymbol{Q}$)	$\boldsymbol{Qm}$ (l/s)	ancys
27	0.17	0.53	0.31	19.1%	21.84	21.827
				27%	19.7	19.696
				30.5%	18.76	18.752

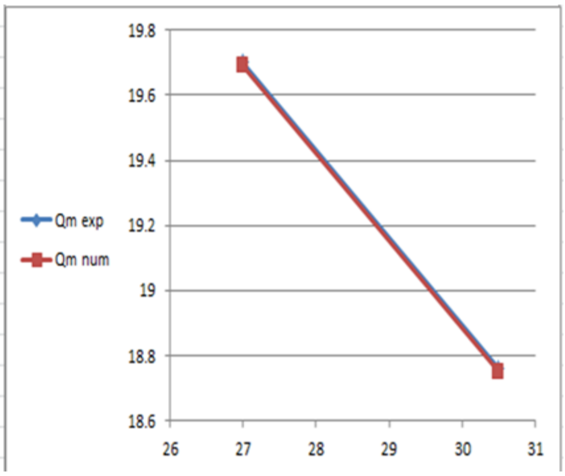


Fig 6: Comparison between Qm num and exp

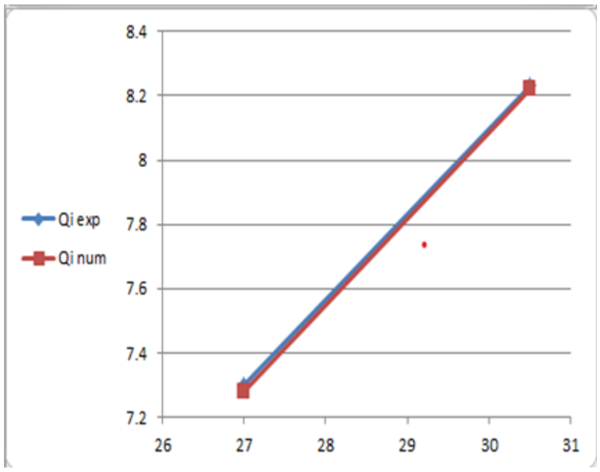
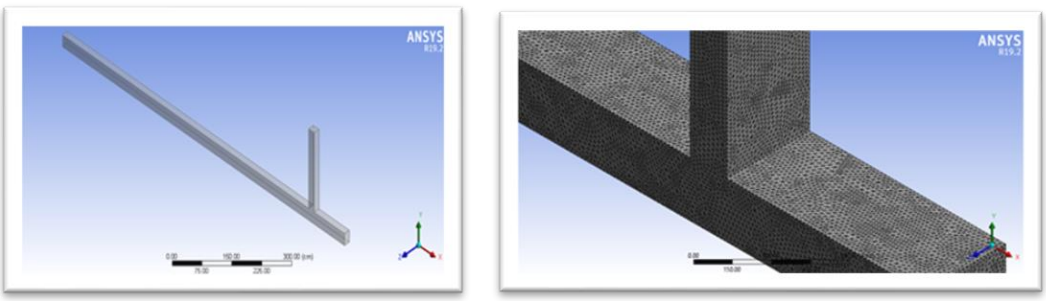


Fig 7: Comparison between Qi num and exp

2.2.1. Geometry , meshing

The problem's three-dimensional geometry and mesh generation are made possible by the pre-processor programs ANSYS Design Modeler and ANSYS Meshing (Figure 8). In the simulation, tetrahedral items are used for the domain as a whole. So as to generate accurate numerical simulations, the grid has a high concentration at edges and curves. In addition, by using the meshing solver's capture curvature and proximity options, the grid size and time required for computation can be reduced.

For verification of the mesh quality, the mesh metric values evaluated with the ANSYS meshing solver have been utilized [12–13]. In order to maintain the mesh metric factors within the permitted bounds, which would indicate the network quality, the element size had to be decreased and the mesh had to be enhanced; alternatively, the solution might involve inaccurate.



(a) **(b)**

Figure :A 3-D view of; **(a)** geometry, and **(b)** zoomed mesh elements.

Tetrahedral elements are employed to achieve a mesh size of 20 mm. As a result, the quality of the mesh was rated between Very good and Excellent. The conditions of the boundary surfaces are given names once the mesh has been generated, and then their purpose, hydraulic properties, and operational parameters are added to the steps of the setup procedure.

3. MODELS DESCRIPTION :

The flow characteristics at a lateral diversion were simulated in this study in two scenarios:

Firstly, is to change half the inclination of the channel at a distance of (1 m) from the beginning of the side channel **Model A** Figure (9). The channel inclination was tested at three angles: 15, 30, and 45 degrees

Secondly, testing the effectiveness of changing the geometric features of the lateral channel by modifying the total side channel slope (2 m) **Model B** Figure(10).

All these cases were compared with the original case. For all cases,27% was the discharge ratio chosen for setting up a clearer separation zone area.

Note that the term "Original Case" indicates a state used in the validation and had identical geometry, boundary conditions, and flow characteristics as the test of the experimental setup.

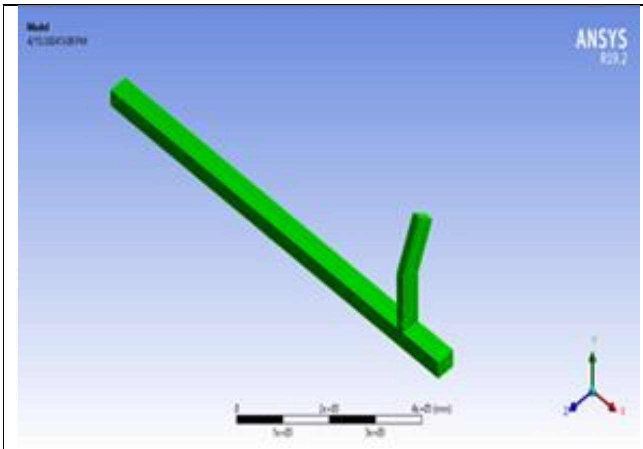


Fig. 9: Model A changes the geometric model at half bed slope

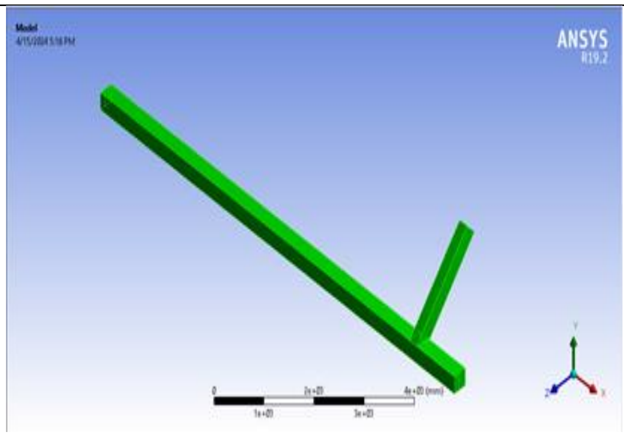


Fig.10: Model B changes the geometric model with total bed slope

4. Result and discussion

The results showed:

- **Model A:** The ineffectiveness of changing the inclination from the middle in increasing the speed or reducing the area of the separation zone, and it occurs in the inclination angles 15, 30, and 45 in the first and second sections (0.5 and 1 m).
- slight change occurring and an increase in speed in the third section at a distance of 1.5 m at The inclination angle is 45 and 30 in the third section.
- **Model B:** While changing the overall slope of the channel at the same angles had a clear effect in that the

speeds decreased, but vortices did not form clearly, which indicates that the separation zone was not formed and thus a decrease in the amount of sediment entering the side channel.

- When comparing the speeds in the three sections (0.5, 1, and 1.5), the slope of the side channel at angle 45 showed a clear superiority over the other two angles, especially in the third section.

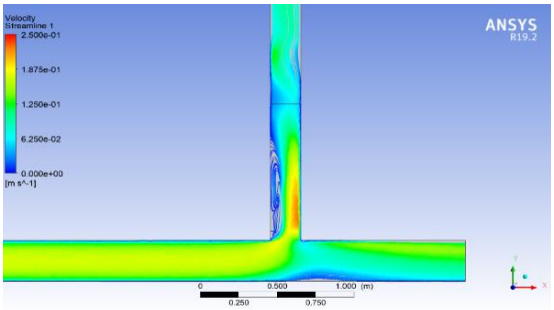


Figure 10: Model A, half slope15 deg.

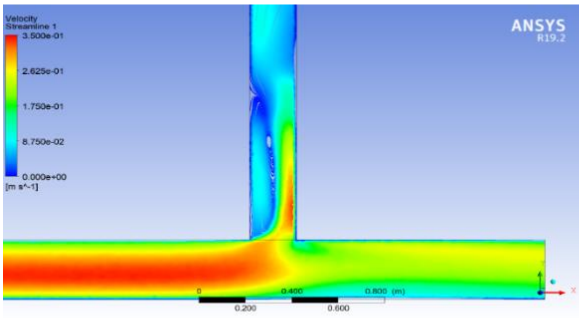
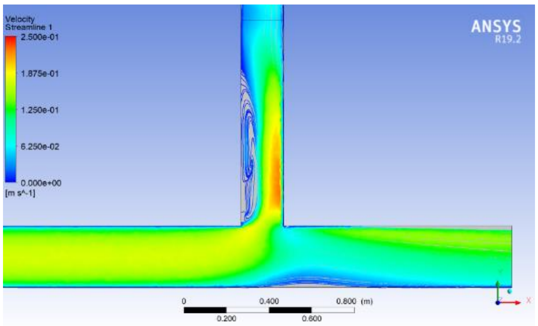


Figure 11: Model B, intake slope15 deg.



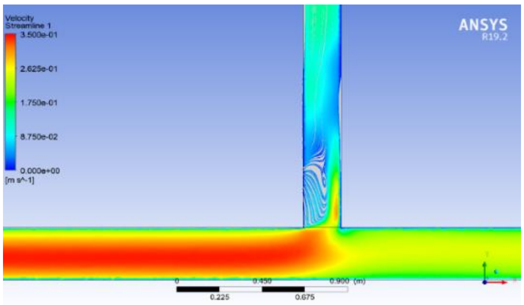


Figure 12: Model A, half slope30 deg**.**

Figure 13: Model B, intake slope30 deg.

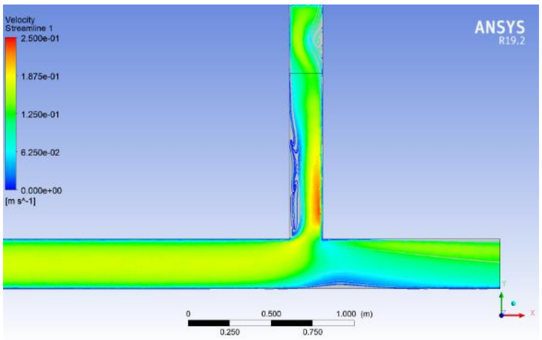


Figure 14 Model A, half slope45 deg.

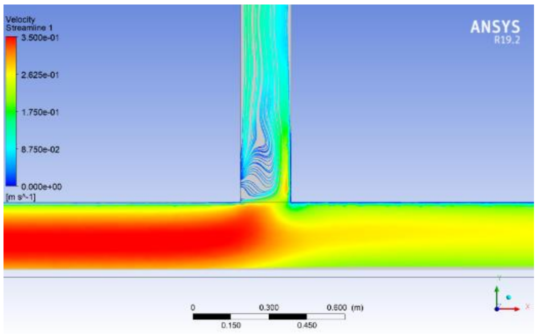


Figure 15 Model B, intake slope45 deg.

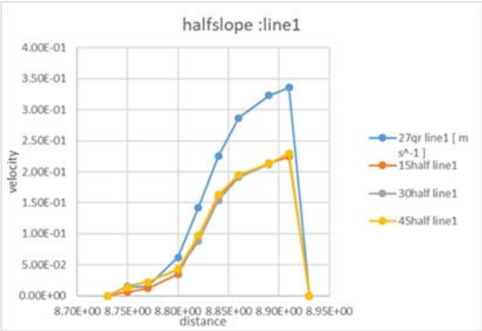


Figure 16: ModelA, comparison velocity sec.1.

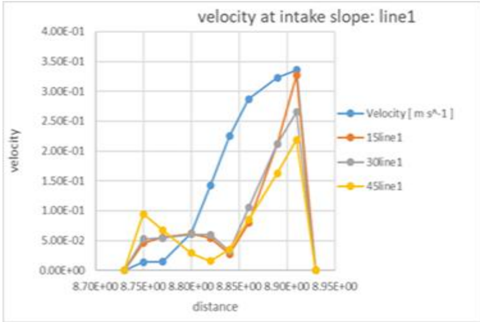


Figure 17: Model B,. comparison velocity sec.1

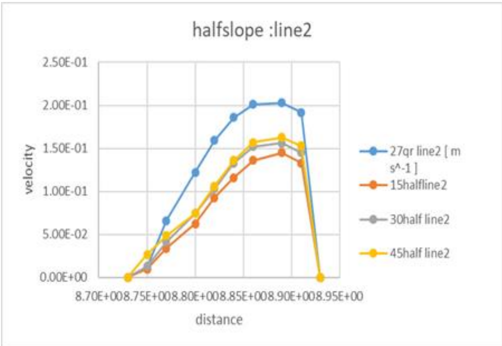


Figure 18: Model A, comparison velocity sec.2.

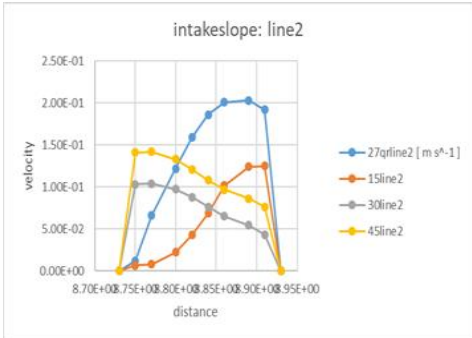


Figure19: Model B comparison velocity sec.2.

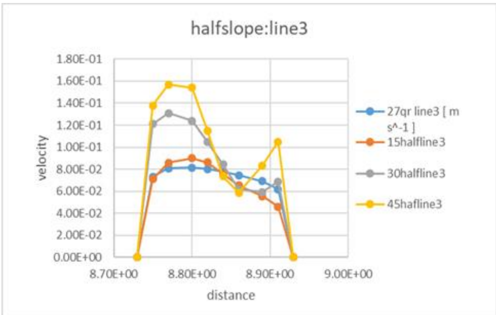


Figure 20: Model A, comparison velocity sec.3

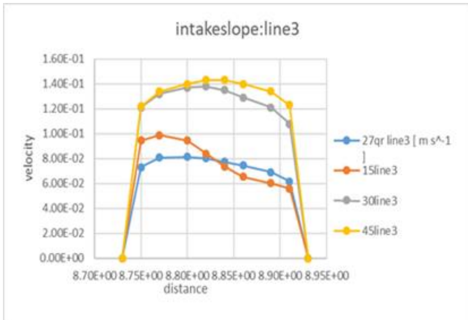


Figure 21: Model B, comparison velocity sec.3.

5. CONCLUSIONS

In this research paper, the simulation process was carried out using the Ansys Fluent program to study the effects of changing the geometric characteristics of the intake channel on the flow characteristics in terms of comparing speeds and area of the separation zone and the extent of their effect on the sedimentation process at the side intake. Two adjustments to the slope of the intake channel were studied numerically in two ways: the first is that the slope is partial, and the second is that the slope is complete at three different angles (15, 30, 45) degrees, respectively.

Comparing the velocity results from three sections calculated from the beginning of the side channel with the original condition and discharge rate of 27%.

1. The results showed a negative effect of the first change, Model A, as the shape of the separation zone area in angles 15 and 30 did not change, and the speeds in the first and second sections were less than the original case, as shown in the figures 16,18 respectively.
2. As for the third section, a clear turbulent flow occurred at angles 30 and 40 degrees, and the negative effect was more evident at angle 45, where a new separation zone was formed, as in the figure (14)
3. As for Model B, the results were more acceptable in terms of increased velocity and a clear change in the separation zone, where a low-velocity zone was observed, but the vortices in the lobe zone were not completely formed, and as a result, there was less sediment entering the lateral intake.
4. The total slope at an angle of 45 is considered the best in terms of increasing the apparent velocities in the three sections in the area where the separation zone is formed and reducing the velocities in the erosion zone, as shown in the figures (15). Ultimately, based on the study presented in this work, altering the geometry of the inclination junction calls for prudence and precision.

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