Numerical Simulation of the effect of simple and T-shaped dikes on turbulent flow field and sediment scour/deposition around diversion intakes

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Abstract

The interaction of flow patterns with the movements of live bed of natural channels is a complex 3D process which requires precise investigation in different scenarios to be fully understood. This study effort to investigate the flow patterns and its effect on the formation of scour holes and deposition stacks in the vicinity of a diversion channel entrance considering the presence of a single dike with various lengths normal to flow and different simple and T-shaped models. Results indicated that Dike shape and its length normal to flow significantly affects the ratio of diverted discharge, volume of sediment transport into the diversion channel, and volume and depth of the scour holes as well as the shape, height and location of the formation of the deposition stack. Increasing the length of wing for the T-shaped dikes could decrease the depth and span of the scour holes efficiently as well reducing the dimensions of deposition stack to form out of the diversion channel.

Keywords: T-shaped dikes, turbulent flow field, sediment scour, diversion intakes

I. Introduction

Understanding the Complex processes of Sediment Scour and deposition in channel diversions and intakes requires comprehensive information of the 3d flow behavior and its interaction with the sediment particles. Such information include the ratio of diverted discharge, velocity distribution, intensity and the area of recirculation zones, induced shear stress on the living bed and the position and magnitude of scouring and sedimentation points. So far, various researchers have studied different features of side intakes and many changes have been applied to various parameters, including channel dimensions, intake angle, and divergence ratios. Also, many studies such as Kasthuri and Pundarikanthan (1987) [IV], Neary and Odgaard (1993) [IX], Barkdoll et al. (1999) [I], and Neary et al (1999) [IX] have
considered the effect of side structures including dikes and submerged vanes on reducing the ratio of sediment transport into side basins and intakes as well as their effect on the flow behavior along the channel. Hassanpour et al (2007) investigated the effect of flow incidence angle with submerged vanes on the ratio of flow diversion as well as the flow surface profile in the vicinity of a 90 lateral diversion and concluded that the best placement angle for vanes in both sub-critical and super-critical flows is equal to 20°[III]. A series of laboratory experiments on hydraulics of flow in a vertical lateral diversion are performed by Neary and Odgaard (1993), Their results indicated that changing the bed roughness and the ratio of flow velocity in the diversion to the velocity in the main channel affects the power of secondary flow and the width of flow separation zone in the main channel. They stated that a wide knowledge of the 3D flow behavior at the entrance of a lateral diversion is necessary to explain the sediment behavior at such occasions. Finally, they concluded that the high resemblance between the flow at a diversion and in a channel bend makes it logical to use the bend flow models to estimate the 3D flow behavior at a diversion entrance [IX]. Barkdoll et al. (1999) studied the limitations of the use of submerged vanes by means of reducing the sediment input and deposition in the diversion basins. They stated that in cases with discharge diversion ratio less than 0.2, sediment transport into the basin reduces dramatically by installing the submerged vanes at the entrance. They also suggested that for diversion ratios>0.2 increasing the diversion width and application of skimming walls connected to the submerged vanes improves the performance of vanes while other enhancements like modifying the vanes shape and increasing the flow transport into the diversion have no significant effect [I]. Kasthuri and Pundarikanthan (1987) performed some laboratory experiments on the effect of diversion ratio on the dimensions of vortex areas and flow separation zone at a 90° diversion channel. They inferred that the length, width and power of vortex areas diminish by increasing the ratio of discharge diversion up to 0.7. For higher diversion ratios, the vortex area remains constant [IV]. Masjedi and Foroushani (2012) experimentally studied the effect of flow depth on the ratio of diverted discharge in to lateral intakes in an 180° river bend. They concluded that for every main channel discharge, increasing the upstream level results in the increase of diverted discharge ratio[VI].

Spur dikes/groynes as a widely used structure in hydraulic engineering, which is considered and extensively studied by various researchers as a scour protection structure to bridge spans [VII], a talweg control structure, a protective structure to river inner banks and reducing the sediment entry into the side channels and intakes. Uijttewaal (2005) investigated the effect of different shapes of spur dikes on the flow field in a 1:40 physical model of a river reach. The results indicate that changing the permeability and slope of the upstream end of a spur dike could minimize the dimensions of the scour hole as well as the turbulence properties near and downstream of the spur dike. Also he states that the flow around spur dikes is completely 3D which make it illogical to use a 2D model or 3D models with large gridding size specifically in the vertical direction[X]. Xuelin et al. (2006) utilized the LES turbulence model to simulate the three-dimensional flow around a non-submerged spur dike and studied the recirculation are downstream of a spur dike[XIII]. Also, Xuelin (2007) studied the flow patterns around a non-submerged...
spur dike in a physical model for a navigation channel of the Three Gorges Project in China [XIV]. Kuhnle et al (1999) investigated the geometry of scour holes formed around spur dikes with various lengths normal to the stream in clear water condition. Studying different flow depth, dike length, and shear velocity ratio they concluded that these parameters significantly affect the volume of the scour hole [V]. Duan (2009) experimentally studied the mean flow and turbulence around a spur dike in a plane fixed bed flume. The results indicated that two counter rotating recirculation areas formed at the upstream and downstream faces of the dike. Also, calculated bed-shear stresses utilizing the Reynolds stresses showed that the maximum bed-shear stress were about two times larger than the mean bed-shear stress of the approaching flow [II]. Nazari Giglou et al. (2017) numerically studied the effect of various angles and distances of consecutive spur dikes on the hydraulic conditions and the pattern of sedimentation areas in a straight rectangular channel using FLOW-3D software by utilizing the RNG turbulence model. They concluded that the length and width of sedimentation area increases by increasing the angle of spur dike relative to the flow direction; so that increasing the angle of dike from 90 to 120 results in 71% and 92% increase in the length and width of the sedimentation area as well as the length and width of induced vortex behind the dike. Also, the stated that increasing the distance of consecutive dikes, results in the increase of flow return zone which finally may increase the sedimentation ratio behind the dike [XII]. Vaghefi et al (2012) performed some laboratory experiments to study the scouring around a T-shaped dike in a channel bend. They concluded that two scour holes at the nose and at the downstream side of a T-shaped dike form. Also, changing the position of the dike towards the downstream oart of the bend may result in the maximum scour depth [XI]. Vaghefi et al. (2015) utilized the SSIIM model to investigate the effect of distance between the T-shaped dikes on flow behavior and scour pattern in a 90 channel bend. They studied both submerged and non-submerged spur dikes at different locations and concluded that for all models, the maximum intensity of secondary flow power occurs at the upstream face of first dike, maximum sedimentation at the end of inner bank and the maximum depth of scouring at the nose of first dike. They also suggested that the maximum distance between consecutive dikes should not exceed 5 times of the dike length otherwise the extent of sedimentation between dikes reduces significantly. Reviewing Literature reveals that so far no study has considered the effect of Dike shape on bed pattern and sediments transport as well as the flow pattern around the dike structure in the vicinity of a lateral diversion. Hence, this study benefits from 3D simulation to study the full flow field and its effect on the sediment behavior around simple and T-shaped dikes normal to the stream adjacent to a channel diversion [XII].

II. Theory and Simulation

Governing equations

In this study, a commercial 3D CFD code was utilized in order to solve the equations of 3D flow movement. Governing equations including continuity and momentum equations are as follows:
Equation (1) presents the incompressible form of the continuity equation where $(u,v,w)$ are the velocity components in $(x,y,z)$ directions, $(A_x, A_y, A_z)$ are the fractional area of flow in $(x,y,z)$ directions, $V_f$ is the fractional volume of flow, $\rho$ is density of fluid and $R_{SOR}$ is the mass source. Equation (2) shows the momentum equations:

$$\frac{\partial u}{\partial t} + \frac{1}{V_f} \left( uA_x \frac{\partial u}{\partial x} + vA_y \frac{\partial u}{\partial y} + wA_z \frac{\partial u}{\partial z} \right) = - \frac{1}{\rho} \frac{\partial \rho}{\partial x} + G_x + f_x$$

$$\frac{\partial v}{\partial t} + \frac{1}{V_f} \left( uA_x \frac{\partial v}{\partial x} + vA_y \frac{\partial v}{\partial y} + wA_z \frac{\partial v}{\partial z} \right) = - \frac{1}{\rho} \frac{\partial \rho}{\partial y} + G_y + f_y$$

$$\frac{\partial w}{\partial t} + \frac{1}{V_f} \left( uA_x \frac{\partial w}{\partial x} + vA_y \frac{\partial w}{\partial y} + wA_z \frac{\partial w}{\partial z} \right) = - \frac{1}{\rho} \frac{\partial \rho}{\partial z} + G_z + f_z$$

Where, $(G_x, G_y, G_z)$ are body accelerations and $(f_x, f_y, f_z)$ are accelerations due to viscosity in different directions. (Flow Science Inc 2015)

### 2-1 Turbulence Simulations:

In this study, three turbulence models were utilized in order to estimate the flow field around the dike and diversion intake including K-ε standard, RNG, K-ω and LES. K-ε turbulence model is a sophisticated and widely range used model consists of two transport equations, one for turbulence kinematic energy $(k)$ and one for diffusion term $(\varepsilon)$, hence its called K-ε model. The 3D governing equations of this model is as follows:

$$\frac{\partial}{\partial t} \left( \rho k \right) + \frac{\partial}{\partial x} \left( \rho u k \right) = \frac{\partial}{\partial x} \left[ \mu + \frac{H_k}{\sigma_k} \right] \frac{\partial k}{\partial x} + G_k + G_b - \rho \varepsilon Y_M$$

$$\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho \varepsilon u)}{\partial x} = \frac{\partial}{\partial x} \left[ \mu + \frac{\mu_1}{\sigma_1} \right] \frac{\partial \varepsilon}{\partial x} + C_{1\varepsilon} \frac{\varepsilon}{k} \left( G_k + C_{3\varepsilon} G_b \right) - C_{2\varepsilon} \frac{\rho \varepsilon^2}{k}$$

Where $G_b$ and $G_k$ are turbulent kinematic energy terms related to buoyancy and average velocity gradients, $(C_{1\varepsilon}, C_{2\varepsilon}, C_{3\varepsilon})$ are constant coefficients equal to 1.44, 1.92 and 0.09 respectively, $\sigma_k$ and $\sigma_\varepsilon$ are prandtl turbulence numbers for $k$ and $\varepsilon$ and are equal to 1 and 1.3 respectively. RNG turbulence model is a statistical variant of K-ε model which applies the Renormalization-Group method to elicitation of the averaged equations for quantities of turbulence such as turbulent kinetic energy and its dissipation rate. Governing equations of this method is similar to standard K-ε, however, constants that are calculated experimentally in the standard K-ε, are found explicitly in the RNG model.

### Boundary conditions and gridding

A structured non-uniform mesh domain was utilized in order to calculate the flow field in the main channel and the diversion. Size of meshes in both x and y directions

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are reduced as they get closer to the diversion intake. Thus, the maximum intensity of meshes in plan (x-y plane) is defined at a distance of 0.8 m prior to the intake and 0.8 m after the intakes outer wall (in x direction) in order to increase the accuracy of simulation of surface profile and velocity distribution in the vicinity of the diversion intake. Also a high density mesh profile in y direction is defined at the nose of dike and at the main channel junction with the diversion. Figure (1) shows the plan and 3D view of mesh domain used in this study. The number of cells is equal to 346, 40 and 25 in x, y and z directions respectively for the main channel and 24, 30 and 20 for the diversion channel.

![Fig1. view of produced mesh (a) far view plan, b) close view of dike and diversion channel and c) 3d view](image)

**Boundary layer mesh:**
Determining a suitable size for boundary layer cell, requires a precise estimation of the boundary layer thickness normal to the solid surfaces and walls. An appropriate method through this, is to utilize the \((Y^+)\) index which is called viscous length and is calculated as follows:

\[
Y^+ = \frac{u_T y \rho_f}{\mu_f}
\]

Where \(u_T\) is the shear velocity, \(y\) is the normal distance from solid, \(\rho_f\) is the fluid density and \(\mu_f\) is the dynamic viscosity of fluid. Based on some recommendations, \(Y^+\) must have a value in the range of 11.225 for lower limit to 30 as an upper limit [XII]. The optimum size for boundary layer mesh normal to the channel walls was chosen equal to 10 mm in order to keep the \(y^+\) index lower than the recommended values as well as satisfying the recommended amount for the mesh faces ratio to average diameter of sediment particles.

**Model verification**
Verification of the model was performed using experimental data from Omidbeigi et al., (2012). The design of the laboratory flume is presented in Fig. 2.
Three-dimensional components of the velocity were predicted by three turbulence models, including the $k$-$e$, $k$-$w$, and RNG models in different sections of the main channel and diversion channel with diversion ratios of 11% and 16%, respectively. Comparison of the velocity profiles provided by numerical modeling and laboratory experiments are given in Fig. 3. The results of error analysis are shown in Table 1. Laboratory measurements of velocity at $x=4.73$ m are compared to the results of numerical models in cases of 11% and 16% diversion ratios (Fig 4). According to the results, the RNG turbulence model presents the most accurate results for the velocity field.

Table 1. Comparison of turbulence models with error assessment criteria for diversion ratios of 11% and 16%.

| Turbulence model | Diversion ratio of 11% | Diversion ratio of 16% |
|------------------|------------------------|------------------------|
|                  | $R^2$ | $RMSE$ | $MAE$ | $R^2$ | $RMSE$ | $MAE$ |
| $k$-$e$          | 0.6465 | 0.4605 | 0.4083 | 0.7642 | 0.3855 | 0.3291 |
| RNG              | 0.9362 | 0.2619 | 0.1275 | 0.8602 | 0.2325 | 0.1786 |
| $k$-$w$          | 0.7349 | 0.3059 | 0.2584 | 0.7235 | 0.3085 | 0.2450 |

Note: $R^2$ is the coefficient of determination, $RMSE$ is the root mean square error, and $MAE$ is the mean absolute error.
Fig 3. Comparison of velocity profiles provided by numerical modeling and laboratory experiments at $z = 0.09$ m at $x = 4.73$ m.

Fig 4. Comparison of experimental results of flow velocity with RNG model at $z = 0.09$ m.
Simulation scenarios

The solution field consisted of two straight flumes normally connected to each other with rectangular sections with side walls made of Plexi-glass is shown in figure (2). The length, width ($W_{mc}$) and longitudinal slope of the main channel were equal to 12m, 1 m and 0.002 respectively. A uniform sandy sediment bed with $d_{50}$ equal to 1mm, density of 2650 Kg/m$^3$ and sediment layer height of 0.2 is adjusted at the bottom of the flume from 2 m upstream of diversion channel to 1.6 m downstream of it. The rest of the channel length is covered with rigid bed with the same level as the sediment layer. The diversion channel with a length ($L_{dc}$) equal to 2m and width ($W_{dc}$) of 0.4 m was connected to the main channel at a distance of 8.7 m to 9.1 from the upstream inlet of main channel in order to provide enough travel distance for flow to become fully developed. The bed of main channel was at the level of sediment surface.

Dikes with 4 different length normal to flow ($L_D$) including 0.15m, 0.2m, 0.25m and 0.3 m in different shapes of simple and T-shaped were modeled. Three T-shaped dikes with different wing lengths ($L_W$) were modeled per normal dike length ($L_D$) (table2). All dikes were located at a distance of 0.6 m upstream of the diversion channel intake and their effect on the 3D turbulent flow field and bed scour and sediment transport was investigated. Input discharge had a constant value of 58 L/s with a constant height of 0.15m at the channel entrance for all simulations.

Table 2. Different investigated dike parameters

| Test no. | Length of Dike normal to flow (m) $L_D/W_C=R_t$ | Length of wing ($L_W$) | $(L_W)/(L_D)$ |
|----------|-----------------------------------------------|------------------------|---------------|
| 1        | 0.15                                          | 0                      | 0             |
| 2        | 0.15                                          | 0.05                   | 0.33          |
| 3        | 0.15                                          | 0.1                    | 0.66          |
| 4        | 0.15                                          | 0.15                   | 1             |
| 5        | 0.2                                           | 0                      | 0             |
| 6        | 0.2                                           | 0.05                   | 0.25          |
| 7        | 0.2                                           | 0.1                    | 0.5           |
| 8        | 0.2                                           | 0.2                    | 1             |
| 9        | 0.25                                          | 0                      | 0             |
| 10       | 0.25                                          | 0.1                    | 0.4           |
| 11       | 0.25                                          | 0.15                   | 0.6           |
| 12       | 0.25                                          | 0.25                   | 1             |
| 13       | 0.3                                           | 0                      | 0             |
| 14       | 0.3                                           | 0.1                    | 0.33          |
| 15       | 0.3                                           | 0.15                   | 0.5           |
| 16       | 0.3                                           | 0.3                    | 1             |

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III. Results and Analysis

Flow and Sediment discharge diversion Ratio:

Table 3 presents the results of diverted discharge and sediment input into the diversion channel, as well as the maximum depth of scour hole and the maximum height of sedimentation stack simulations in various shapes of dike. Generally, it is indicated that in case of simple dikes (Lw=0) the ratio of diverted discharge (Qd/Qt) into the diversion channel decreases by increasing the length of dike normal to flow (LD). Also, for T-shaped dikes, the ratio of diverted discharge increases by increasing the ratio of wing length to the length of dike normal to flow (Lw/LD).

Considering the effect of dike length on maximum scour depth and sedimentation height at the diversion intake, it could be concluded that increasing the length of simple dikes normal to flow, may result in the increase of the maximum scouring depth of the scour hole which forms at the nose of the dike. On the other hand, increasing the ratio of Lw/LD in T-shaped dikes results in the reduction of scouring depth.

Investigating the effect of dike length on the deposited sediment height, it could be inferred that an increased length of dike which increases the depth and volume of scour holes, could result in a larger and higher deposition stack. This is true for Ld/Lmc =0.15 to 0.25. Longer dikes (Ld =0.3) provide deeper scour holes and at the same time a smaller sedimentation stack at the diversion intake. This is the direct consequence of increased flow velocity at the dike section for longer dikes (λ=0.3) which has transported the scoured sediment into the diversion channel and the downstream of main channel and increased the volume of sediment entrainment into the basin significantly. However, installation of a wing at the nose of a simple dike, has reduced the height of sedimentation stack and depth of scour hole, increasing the ratio of Lw/Ld for T-shaped dikes with LD=0. 15 and 0.3, may result in an increase in the height of the stack. For LW/LD =0.2-0.25, increasing the length of dike wing has reduced the height of the deposition stack by reducing the depth and size of sedimentation holes.

Obtained results show that there are optimal scenarios of dike shape and length in which the desired ratio of flow is diverted and the volume of sediment entrance into the diversion channel is minimized. Also by choosing a correct ratio of LW/LD, the maximum scour depth and deposition stack height could be controlled.
Table 3. Values of diverted discharge, sediment transport volume into the diversion channel for various dike shapes as well as Maximum scour depth and maximum deposition height

| Model no. | Ld/Lc = Rf | LW/LD | Diverted discharge ratio = Qd/Qt | Integrated diverted sediment Volume | Maximum Scour depth (m) | Maximum deposition height (m) |
|-----------|------------|-------|---------------------------------|-----------------------------------|-------------------------|-------------------------------|
| 1         | 0.15       | 0.00  | 0.22                            | 0.88                              | -0.021                  | 0.030                         |
| 2         | 0.15       | 0.33  | 0.21                            | 0.30                              | -0.019                  | 0.021                         |
| 3         | 0.15       | 0.67  | 0.20                            | 0.32                              | -0.014                  | 0.025                         |
| 4         | 0.15       | 1.00  | 0.21                            | 1.28                              | -0.016                  | 0.030                         |
| 5         | 0.2        | 0.00  | 0.20                            | 1.01                              | -0.037                  | 0.030                         |
| 6         | 0.2        | 0.25  | 0.16                            | 0.51                              | -0.031                  | 0.021                         |
| 7         | 0.2        | 0.50  | 0.17                            | 0.60                              | -0.021                  | 0.021                         |
| 8         | 0.2        | 1.00  | 0.17                            | 0.36                              | -0.015                  | 0.020                         |
| 9         | 0.25       | 0.00  | 0.18                            | 3.81                              | -0.052                  | 0.047                         |
| 10        | 0.25       | 0.40  | 0.15                            | 2.10                              | -0.048                  | 0.041                         |
| 11        | 0.25       | 0.60  | 0.15                            | 0.80                              | -0.041                  | 0.030                         |
| 12        | 0.25       | 1.00  | 0.15                            | 0.82                              | -0.035                  | 0.020                         |
| 13        | 0.3        | 0.00  | 0.11                            | 2.29                              | -0.065                  | 0.028                         |
| 14        | 0.3        | 0.33  | 0.12                            | 1.48                              | -0.066                  | 0.025                         |
| 15        | 0.3        | 0.50  | 0.14                            | 1.58                              | -0.062                  | 0.025                         |
| 16        | 0.3        | 1.00  | 0.16                            | 2.16                              | -0.054                  | 0.030                         |

**Bed profile**

Figure (5) presents the effect of various dike shapes on the live bed topography in the vicinity of the diversion channel and the dike. Bed topography for various ratios of LW/LD in LD=0.2 are presented and it could be concluded that two scour holes form at the front face of dike as well as the junction of the upstream wall of the diversion channel with the main channel; which the latter is smaller and more shallow (figure 5).

Considering the effect of dike shape on the bed topography it could be stated that in case of simple dikes, the scour hole is more deep and wide spread (see table 3). Also, the deposition stack at the entrance of diversion channel is higher and is more likely to form inside the diversion channel. The use of T-shaped dikes has decreased the area of deposition stack as well as reducing its height and has caused the deposition stack to be more likely to form out of the diversion channel (inside the main channel). Also, It has reduced the depth and the expanse of the scour holes specially on the dike nose (Fig. 6). It is also showed that increasing the ratio of tightening (Ld/Wc) may result in the increase of depth and area of the scour hole.

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Fig 5. Bed topography in $R_T=0.2$ for various ratios of $L_w/L_D$.
Fig 6. Comparison of bed topography between Simple and T-shaped dikes with $L_W/L_D=1$ in different $R_T$

**Vortex system**

Figure 7 presents the 3D view of the stream lines colored with the Turbulent Intensity, Froude number ($F_r$) and the streamwise velocity component ($U$) at the presence of a simple dike with $L_D=0.25$. Generally three vortexes form within the system of the main channel-dike- diversion channel; including a horse-shoe vortex at the front face of the dike and two recirculation areas behind the dike and at the intake of diversion channel tangent to the inner wall.

Generally, two scour holes are recognizable in the main channel. The first scour hole is the direct result of the formation of a horse-shoe vortex at the front face of the dike. The horse shoe vortex is the result of flow collision with the dike wall which forms a downward flow that can lift the bed particles up dramatically and form a deep scour hole. Such scour holes threatens the structural sustainability of the dike and requires...
precise estimation to avoid failures. Rotational and downward movement of the flow at the upstream dike face is clearly visible in figure 7(b-c).

The second scour hole which is formed at the junction of diversion with the main channel is the result of high flow velocity at the junction of the inner wall of diversion intake with the main channel. Presentation of the Froude number in figure 7 (c-d) clarifies the point that a high Froude flow zone forms at the junction of the inner wall of the diversion channel with the main channel.

The recirculation area inside the diversion channel provides space for the deposition of scored particles from the zone of dike installation. Considering the turbulence intensity of vortex areas indicate that the recirculation area within the diversion channel has higher turbulence intensity compared to that behind the dike.

The formation mechanism of horseshoe-vortex behind simple and T-shaped dikes is presented in fig (8). It could be observed that a simple variation between this mechanism behind simple and T-shaped dikes, may result in the reduction of scour-
hole in cases with T-shaped dikes compare to simple ones. Generally, by colliding the normal body of dike, the flow moves downward and forms a spiral where the flow passes adjacent to the bed. This high-speed spiral-movement of the flow tangent to the bed is the main reason for the intense scour at the dike nose. By adding a wing to the main dike, the flow which collides the dike, moves downward and returns upstream tangent to the bed for a short distance. Then it returns and rounds the wing. This backward movement and then getting away from the bed in an upward-spirally-returning movement, causes the elimination of the high velocity at the dike nose adjacent to the bed.

![Fig 8. horse-shoe vortex behind T-shaped (a) and simple dikes (b)](image)

**Turbulent structure of the flow**

A comprehensive understanding of the turbulent flow structure is required so that the processes and trends in discharge diversion ratio and bed scour could be justified. The effect of dikes main body and wing on the stream-wise and transverse velocity distribution of flow around the diversion entrance is presented in figures 9 to 11. It is obvious that increasing the dike length increases the flow velocity in main channel at the dike placement section and consequently reduces the flow discharge into the diversion channel. Also, it could be indicated that the diverted discharge reduction ratio increases by increasing the $L_d/W_c$ due to the increased velocity of flow in the main channel as well as the reduced width of flow separation plate width. Also, width of vortex area in the diversion intake is increased with increasing the narrowing ratio in main channel. Figure 10&11 present the effect of wing length on stream-wise (U-component) and transverse (V-component) the velocity distribution around diversion intake in case of dike with narrowing ratio of 0.2. It could be concluded that increasing the wing length reduces the maximum value of U component in the vicinity of the diversion entrance. Also, Plotted stream lines indicate that increasing the wing length, reduces the width of the recirculation area in the main channel (fig 10). Added wings have significant effect on the flow behavior in the diversion channel so that increasing the wing length may result the length and width of the induced vortex in the lateral channel. Also, increasing the $L_w/L_d$ ratio up to 0.5, increases the V-velocity component in the diversion, while higher ratios may decrease it.
Considering the values of flow diversion ratio, it could be concluded that installation of wing, has reduced the diverted discharge into the lateral channel especially in narrowing ratio of 0.15 to 0.25. For narrowing ratios higher that 0.25, addition of a wing with every desired length, increases the discharge diversion ratio. Also, for all narrowing ratios, addition of wings with a length equal to the main body of dike (Lw/Ld=1), increases the discharge diversion ratio.

Fig 9. Stream-wise velocity distribution around dikes with different length

Fig10. Stream-wise velocity distribution around T-shaped dikes with different wing length
The distribution of the turbulent kinetic energy at the presence of simple and T-shaped dikes with different narrowing and Lw/Ld ratios are presented in figure 12 to 13. TKE is generally a measure of the intensity of the turbulent intensity. Also it could be as a function of the eddy size. In Reynolds averaged Navier stokes equations, the turbulence kinetic energy (TKE) could be determined as the mean of the turbulence normal stresses as follows:

\[ k = \frac{1}{2} ((u')^2 + (v')^2 + (w')^2) \]

It is indicated that increasing the narrowing ratio increases the TKE in both main channel and the diversion channel. Hence, it could be concluded that the eddy size and the turbulence intensity increases as the narrowing ratio increases (see fig.12). Figure (13) investigates the effect of wing length on the TKE distribution. It is indicated that increasing the ratio of Lw/Ld, decreases the intensity and spread of the TKE in the main channel and diversion channel so that reduces the size and power of induced eddies.
Fig 12. Turbulent Kinetic Energy distribution around dikes with different length

Fig 13. Turbulent Kinetic Energy distribution around dikes with different Lw/Ld
IV. Conclusion

This study investigates the effect of simple and T-shaped dikes with different length and different ratio of wing length to the dike length normal to flow on the flow field and bed scour and sediment deposition at the diversion channel entrances. Ratio of diverted discharge to total channel discharge, volume of sediment entrainment into the diversion channel, Maximum scour depth and scour patterns, and the shape and height of deposition stacks were studied indifferent shapes of dikes. Results indicated that the maximum scour depth and its span in case of simple dikes are higher compared to T-shaped dikes. Deposition stacks are higher and more likely to be formed inside the diversion channel at the presence of simple dikes. Increasing the dike length normal to flow (LD) may result in deeper and wider scour holes while increasing the length of dike wings (Lw), decreases the depth, span and intensity of sediment scour and entrainment except for high Narrowing ratios (LD/Wmc=0.3).

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