Effects of Dam Tunnel Longitudinal Slope, Flow Rates and Gate Lip Geometry on Top Pressure Coefficient

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Abstract: Hydrostatics and Hydrodynamics forces are generated and applied on the vertical lift tunnel gates due to the influence of wide range of heads and operation conditions. Many hydraulic and geometrical parameters control the initiation of these forces, especially, when the flow passing over and below the gate and consequently two forces are created along the top and bottom surfaces of the gate. The difference between these two forces generates the downpull force which in turn determines the stability of the gate and its sound performance and operation. In current study the focusing is applied on the top pressure coefficient and regarding factors those affect its values and distribution. A hydraulic model was build up and the effect of three flow rates, seven lip gate geometries and four tunnel longitudinal slopes on the behavior of top pressure coefficient are examined. The results show that the top pressure coefficient is effectively affected by change of discharge, gate lip angles, and slopes of tunnel and less effect are observed with change of gate openings ratios.

Key Words: Hydraulic Downward Force, Top Pressure Coefficient， Vertical Lift Gate

1. Introduction

The vertical lifting gate mostly constructed across the dam tunnel to satisfy requirements of power generation and to control the demand of water downstream the dam. Due to this task, the gate is affected by a wide range of the high heads that occupy the dam reservoir. Many hydrostatic and Hydrodynamic forces are applied to the vertical lift gate under the impact of pressurized flow passing the tunnel. Downpull is the most effective force generates as a result of two opposite forces**,** one caused by the flow passing over the gate (downward force) and the other results from the jet flow issued below the gate (upward force). The downward force is important in prediction of downpull force and often is studied in terms of top pressure coefficient which based mainly on top pressure head and pressure head just downstream the gate shaft.

The top pressure coefficient has been studied by many researchers. Naudascher (1964) specified the between downpull force and both of top and bottom coefficients by using the following expression:

$$F_d = (K_t - K_b).B.d.\rho \quad (1)$$

Where:

F_d = *downpull force,*

B = gate width,

d = gate thickness,

ρ = water mass density, and

V_j = velocity of the contracted jet issuing from underneath the gate.

In which the (Kt) coefficient can be represented by following form: The top pressure coefficient (Kt) can be found by using the following formula, Naudascher (1964):

$$Kt = 1/Bd\int_0^d \int_0^B (H_t - H_d)\ /(Vj^2/2g)\ dB.\ dx \quad (2)$$

Where:

d =the gate thickness, and
Vj = the jet velocity beneath the gate.

According to the invariant distribution of top pressure head along top surface of gate the above equation can be reduced to be:

$$Kt = (Ht- Hd) / (Vj^2 /2g) \quad (3)$$

Where:
H_t= Piezometric head on gate top surface

H_d=Piezometric head in the contracted section below the gate.

The various forces acting on gate during opening and closing were discussed by Sagar (1977). It is concluded that the following form of downpull force on gate can also be used:

$$F_d = F_t - F_b \quad (4)$$

$$F_t = \gamma . A_t . (H - \frac{V_o^2}{2g}) \quad (5)$$

$$F_b = \gamma . B . d\ [H_z - (\frac{\frac{q^2}{2g}}{y.(y+d\tan\theta)})] \quad (6)$$

Where:

Ft, Fb : Forces on the top and base of gate respectively.
At: top area of gate exposed to water pressure,
D: thickness of the gate downstream skin plate and seal get together,
B: width of skin plate and seal get together,
d : thickness of downstream skin plate and seal assembly,

$Hz = (H - \frac{V_o^2}{2g})$.

$\frac{V_o^2}{2g}$ *: Velocity head upstream the gate,*

q: discharge of water per unit width of the gate,

y: height of the gate opening and

θ: angle among flat and inclining base of the gate.

The evaluation of pressures caused by the passage of water through the gate shaft was studied by Sagar (1979) for the case of free flow conditions. The method is based on the principle that the entire velocity head of the jet flow issuing through the upstream gap is lost because of sudden expansion within the gate shaft as it moves toward downstream gap. Although the method is restricted with some limitations due to the error that could occur as a result of entrance losses and its comparison with San Luis type gate only revealed good agreement between predicted and actual values.

Ahmed (1999) investigated the effect of many gate geometries with various gate width ratios on downpull coefficients. The study was based on the analysis results of the measurements gained by the experimental runs conducted by using hydraulic lab model. This study concludes that the downpull coefficient is influenced by various parameters such as; gate geometry and gate opening but less effect of these parameters were observed on top pressure coefficient.

A two-dimensional CFD model was applied by Almani et al. (2010) to predict a downpull coefficient (KT and KB) which is named as FLUENT program. The finite volume method is employed on a Reynolds averaged Navier-Stokes equations. The turbulence effects are simulated using the standard (k-ε) model. The simulation model is used for relevant experimental data obtained from hydraulic model tests conducted by (Ahmed, 1999) in laboratory for nine gate lip shapes with different gate openings for each gate lip geometry. It is found that the minimum positive downpull force can be reached for lip geometry with ($\boldsymbol{\theta}$=35°).

A random hydraulic model was created by Ahmed (2016) to specify the effect of twelve gate lip shapes on the behavior of flow and consequently on the top pressure coefficients. The results reveal that no significant effect was found of gate geometry on the top pressure coefficient. In the current study, the top pressure coefficient on the gates is evaluated for different flow rates, different gate lip geometries and different longitudinal slopes. The validity of the results is indicated by the comparison with corresponding cases of previous related works.

2. Experimental Set –Up

The experiments were conducted by using rectangular recirculation flume Sheeraz (2016), 4m long, 0.2 m wide and 0.3m deep. The bed and both sides of channel were made by glass and covered along its upper part by a thick plate representing the tunnel roof. The steel gate shaft (0.3 x 0.15 x 0.6) m was installed mid-way above the flume roof.

The head of tunnel was fed by stilling tank to confine the flow within the acceptable limits due to the turbulence effects. The flow is returned to the storage tank through the control sluice gate which was installed at the end tunnel. The control gate is essential to create a pressurized flow

and hence satisfy the flow conditions required for study. AC motor was used to derive a 4 kW pump, thereby providing the discharge which adjusting by a valve. The main components of hydraulic model are shown in Figure (1).

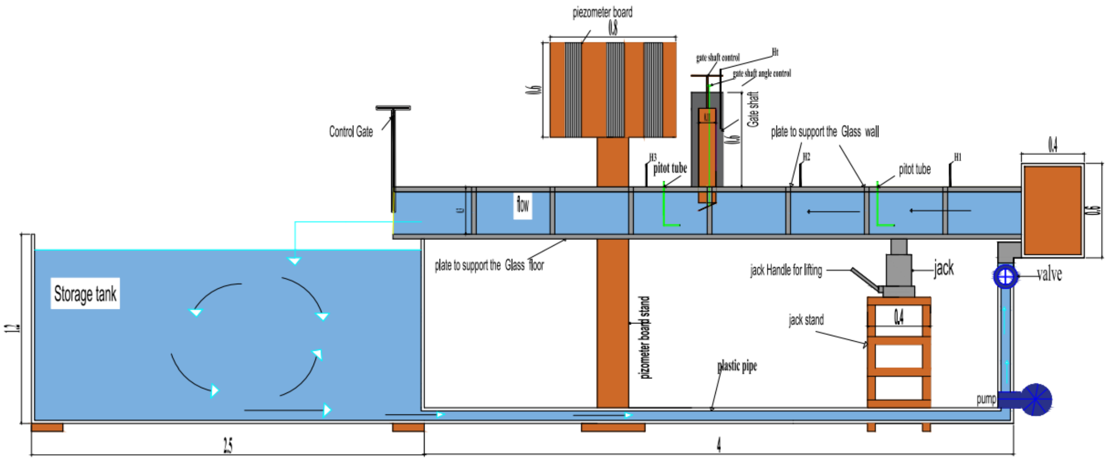


Figure 1: Main components of hydraulic model

The model of gate was made by a thick plate with a thickness (d) of 70 mm, 200 mm wide and 50 mm height was supported by steel frame slides in vertical way of the gate shaft, for mechanical function, the gate is provided by two screw shafts had been located on the top cover of gate shaft, one to control the gate openings and the other to adjust the angle of lip gate. Figure (2) shows the main details of gate model.

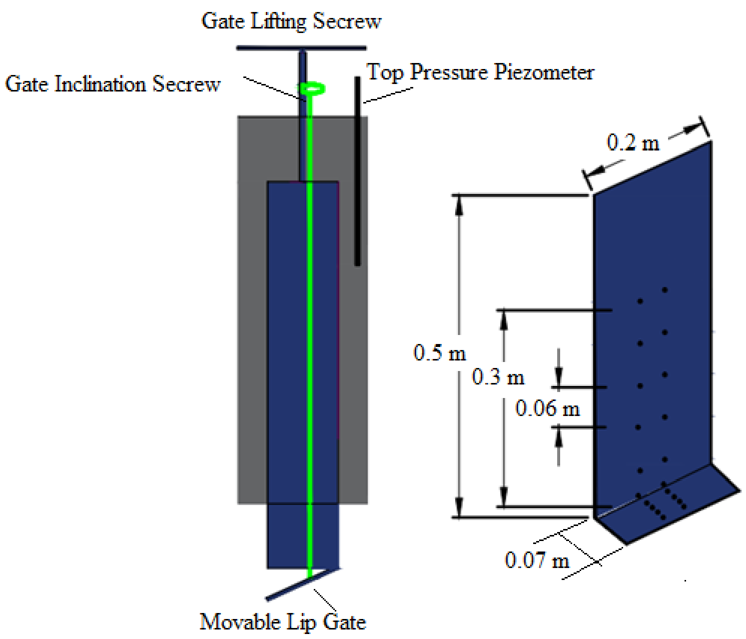


Figure 2: Main Details of gate model

The estimation of flow rates ($Q_{max.}$, $Q_{med.}$ and Q_{low}) and the velocity distribution have been carried out by using two pito-tubes. One of them was located at a distance 1 m upstream the gate shaft while the other locates just downstream the gate shaft. Two Piezometers were installed upstream the gate shaft with consecutive distances (0.25 m and 0.5 m) to represent the operation heads. Furthermore, another one was needed to be 20 cm downstream the gate shaft which is necessary for determining the pressure coefficients. The longitudinal slope of tunnel was adjusted by using a hydraulic jack.

2.1 Procedure of Measurements

The current study includes more than (84) runs. Each run was conducted for specific values of gate lip angle, longitudinal slope and flow rate. Herein, seven gate lip angles were used, each one was examined for three different values of flow rates and four longitudinal slopes.

Each run starts by letting the constant flow rate enters the stilling tank and moves along the tunnel and then returns back again to the main tank through the control gate. Figure (1) shows the sections of the tunnel, its apparatus and the main points of measurements.

The following measurements have been achieved for each run with different gate openings (*Y/Yo*):

1. Two upstream pressure heads (H_1 & H_2) and one downstream head (H_3) were measured. The determination of (H_3) is important to predict the pressure coefficients as mentioned previously.

2. The top pressure head (H_t), which reflects the effects of that part of the flow rate passing through the clearances of gate shaft, was measured by using a single piezometer installed on the top surface of gate.

3. The measurements of velocity profiles were made in two stations, first one is located at 1.0 m upstream the gate shaft to measure mainly the total flow rate, and the second is just 0.1m downstream the gate shaft to measure the jet velocity head beneath the gate. The discharge at each run was estimated by using the integrating area method of the velocity.

4. For each run, the slope of gate lip was adjusted by using the related screw in the top of gate shaft whereas the longitudinal slope was fixed by using hydraulic jack located below the tunnel bed.

3. Results and Discussion on Top Pressure Coefficient (Kt)

The top pressure coefficient (K_t) is considered as a function of several factors related to gate geometry and flow conditions which can be expressed in the following form (Ahmed 2016):

$$K_t = f(H_t, \frac{V_j^2}{2g}, H_d) \quad (7)$$

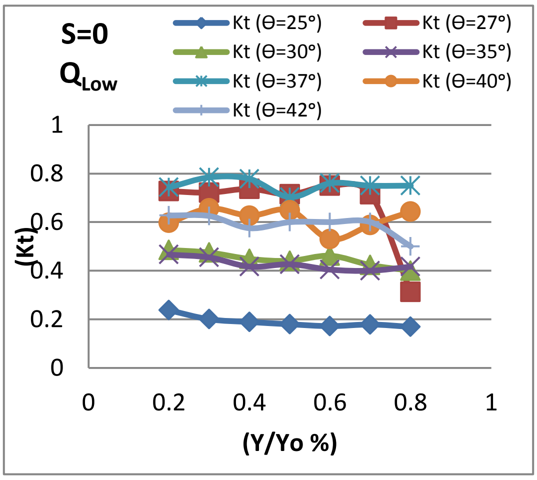
Where

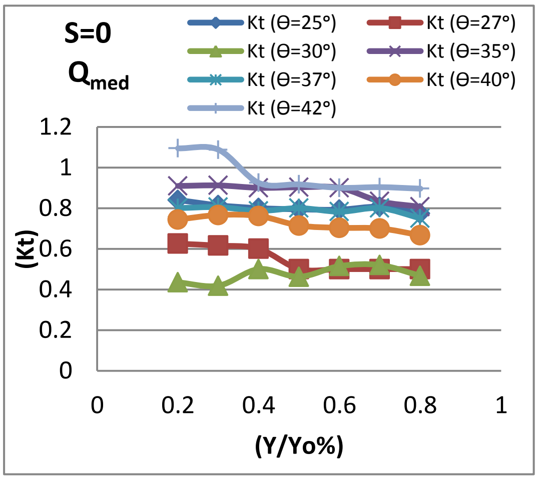
K_t: Top pressure coefficient,
H_t: Piezometric head on top gate surface,
$\frac{V_j^2}{2g}$: Jet velocity head, and
H_d: Downstream Piezometric head.

In the current study the top pressure coefficient was examined for various angles of inclined lip gate, different values of flow rate and longitudinal slope of simulated tunnel. Equation (3) indicates that the calculation of (*Kt*) depends upon the measurements of the piezometric head on the top surface of the gate (*Ht*), piezometric head at downstream of the gate (*Hd*), and the average jet velocity beneath the gate (*Vj*). The measurements of (*Ht*) were made by installing the scaled glass tube on the top surface of the gate. Many readings were taken and the average value was considered and the upstream and downstream gap widths are assumed to be constants.

Figures (3) to (6) showed the relation between the gate opening ratios (Y/Yo) and top pressure coefficients for different flow rates, longitudinal slopes and gate lip angles. It can be seen from these figures that for each gate lip geometry, mostly, a slight change in distribution profile of Kt occurs with the increase of gate opening ratios. The general scheme of *(Kt)* profile curves emphasizes that only the (Kt) values have been effectively influenced by gate geometries and consequently it will create an effect on values of downpull force. Figure (3), indicates that for (S=0), the increase in flow rate has caused increase in (*Kt*) values for all gate lip angles except (***θ***=25°,35° and 42°) which are mostly have lower values. Figure (4) demonstrates that for (S=0.25%), with the gate lip of (***θ***=37°), peak values and independent effect due the change in flow rates were observed. In general, some changes have been observed for the (*Kt*) values not for behavior of the whole gate lip shapes with the increasing of flow rates.

It can be seen from figure (5), that the increase in longitudinal slope and flow rates had not accompanied by a clear change in values and distributions of (*Kt*) for all gate lips except for (***θ***=27°) where the values of (Kt) are dropped as a result to the increase in flow rates. Figure (6) indicates that for (S=0.75%) and (Qlow, Qmed. and Qmax.), the values of (*Kt*) seem to be concentrated around (0.5) for all gate lip shapes except (***θ***=27°and 35°) where the values are often greater than others.





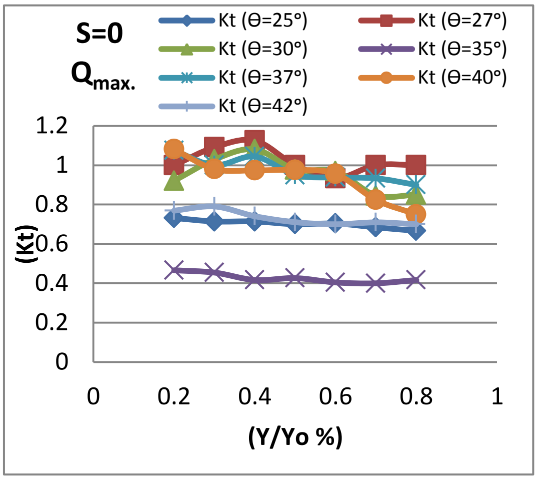


Figure 3: Variation of top coefficient pressure with gate openings for slope= 0 and different lip gate shapes and discharges

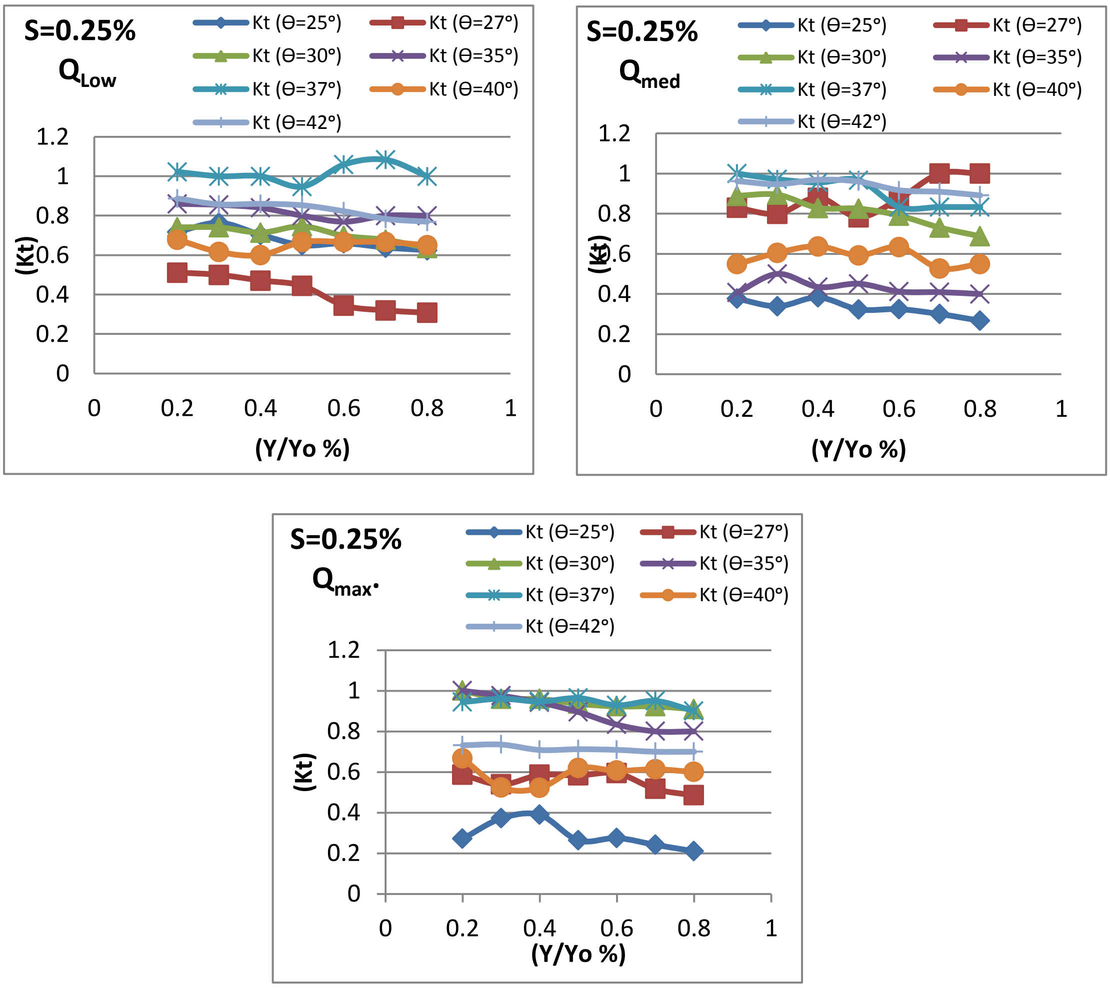


Figure 4: Variation of top coefficient pressure with gate openings for slope= 0.25% and different lip gate shapes and discharges

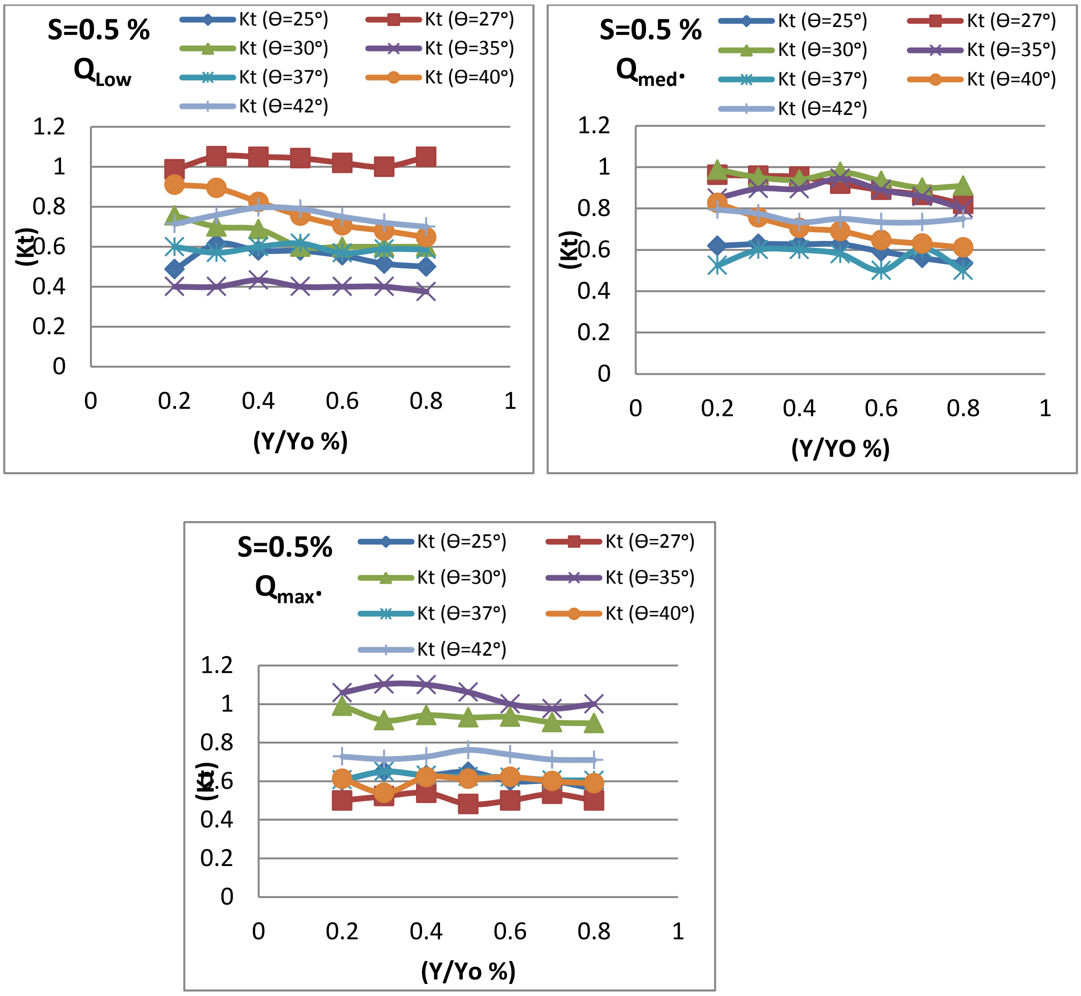
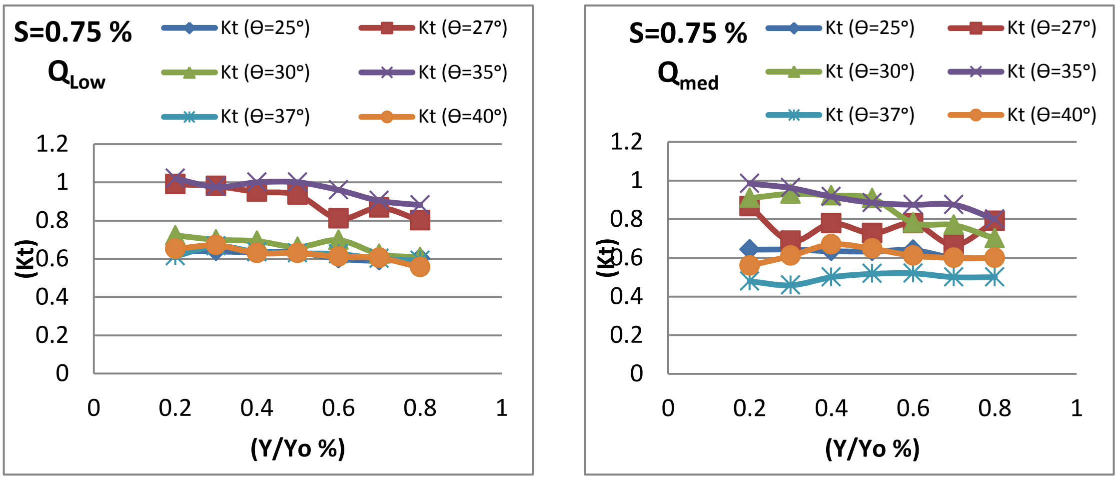


Figure 5: Variation of top coefficient pressure with gate openings for slope= 0. 5% and different lip gate shapes and discharges



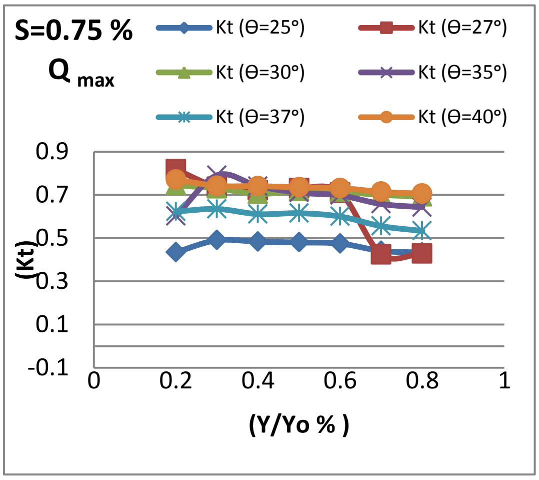
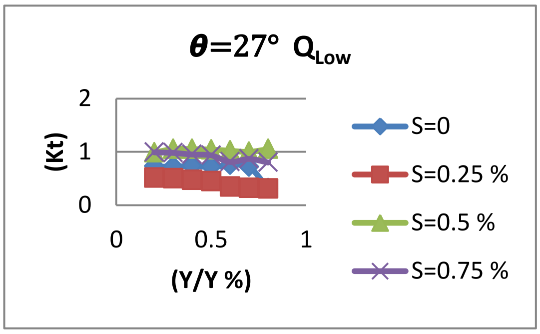


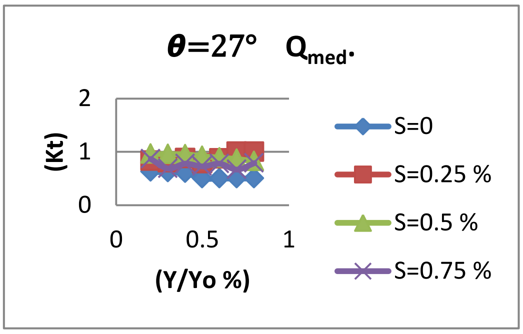
Figure 6: Variation of top coefficient pressure with gate openings for slope= 0.75% and different lip gate shapes and discharges

The effects of four considered values of slopes with different geometry shapes of gate lip on (Kt) values have also been studied for specific values of flow rates as shown in Figures from (7) to (9). These figures show that there is no single slope has a definite clear effect on (Kt) for all cases, and then, each case may have subjected to the influences of its limits. However, the values of slopes (S=0.25%) and to some extent (S=0%) have a greater impact in increasing top pressure coefficient values especially for low and maximum flow rates of angles ($\theta = 27^{\circ}$ and $\theta = 37^{\circ}$) up to (Y/Yo = 50%).

Figure 7 indicates that for ($\theta = 27^{\circ}$) and low discharge, the increase in longitudinal slope produces higher values of (Kt). The results has also showed that the increase in discharge leads to increase the (Kt) values for S=0 and caused reduction in values as the slope increase.

Figure 8 shows that in the case of ($\theta = 37^{\circ}$), the values of (Kt) are kept high for longitudinal slopes (S= 0.25%) and somehow for (S=0). Figure 9 shows that in the case of ($\theta = 42^{\circ}$), (Kt) values are high for low discharge and (S=0.25%), and then changed to be low as discharge increases.





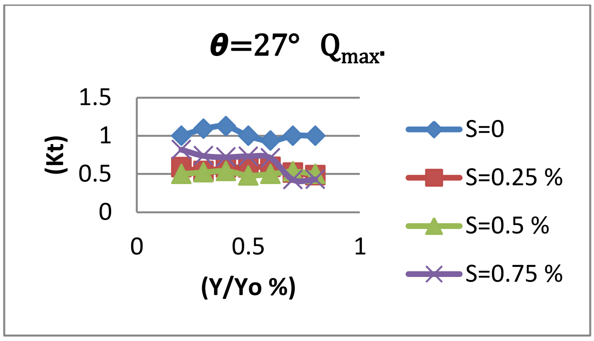


Figure 7: Variation of top pressure coefficients with gate openings of shape lip 27° for different slopes

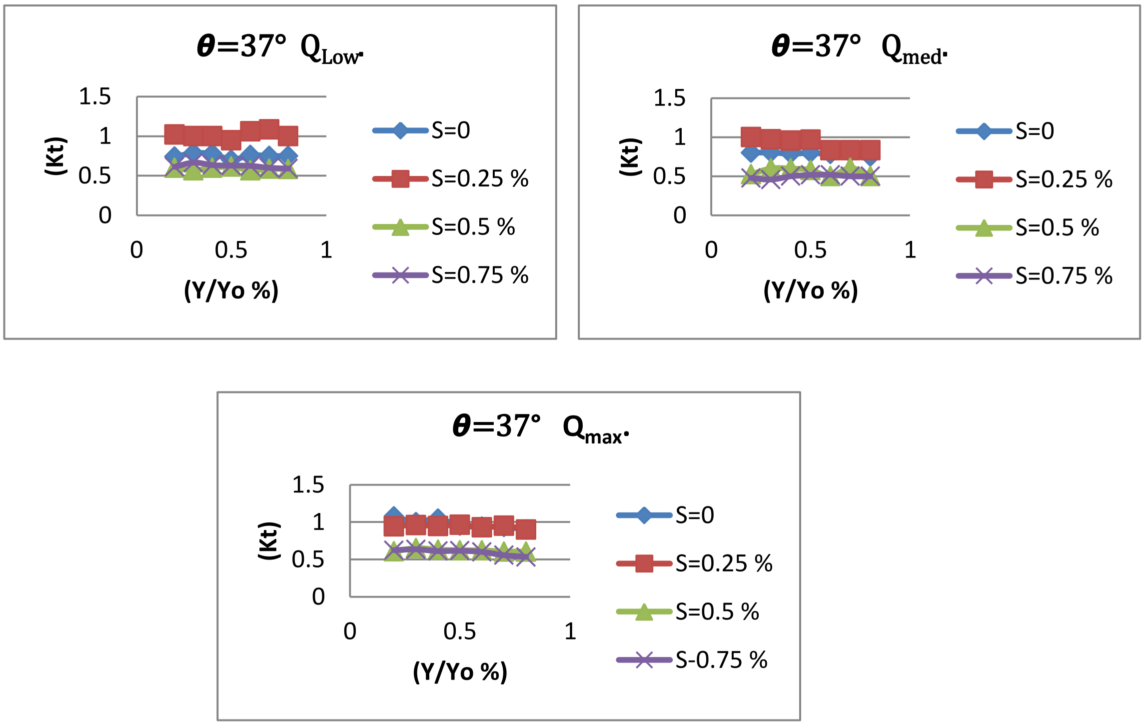
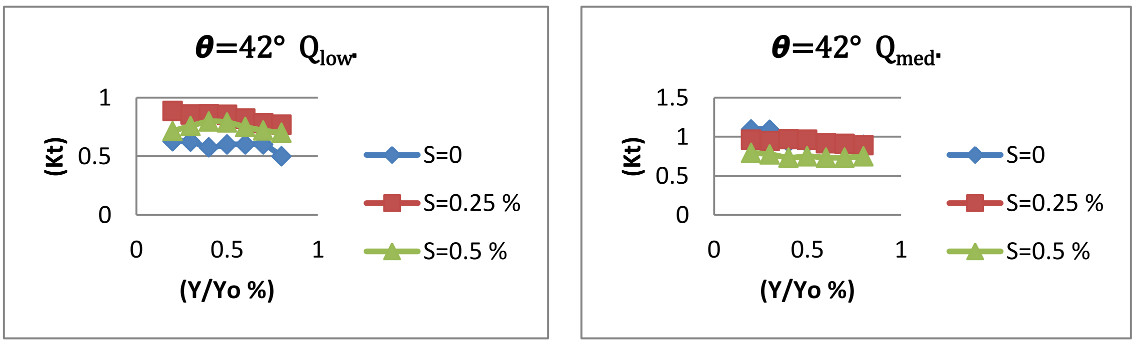


Figure 8 Variation of top pressure coefficients with gate openings of shape lip 37°for different slopes



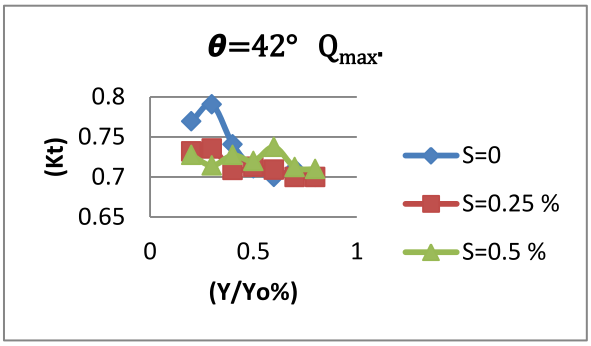


Figure 9: Variation of top pressure coefficients with gate openings of shape lip 42°for different slopes

4. Conclusion

1- For each gate lip geometry, a slight change in distribution profile of Kt occurs with the increase of gate opening ratios.
2- For (S=0.25%), and all discharges with the gate lips of (***θ***=37°, ***θ***=42°), peak values of (Kt) and independent effect due the change in flow rates were observed. For (***θ***=27°), only at Qmed., peak values of (Kt) were obtained.
3- The increase in longitudinal slope and flow rates had not accompanied in general by a clear change in values and distributions of (*Kt*) for all gate lips.
4- For (S=0.75%) and for all considered discharges, the values of (*Kt*) seem to be concentrated around (0.5) for all gate lip shapes except (***θ***=27°and 35°)
5- There is no single slope has a definite clear effect on (Kt) for all cases.
6- For low discharge, the increase in longitudinal slope produces higher values of (Kt).
7- Gate lip geometry affects the (Kt) values rather than its distribution.

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