Effects of Tunnel Dam Gate Lip Geometries on Downpull Force Coefficients

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Abstract: Vertical lift tunnel type gates are subjected to hydrostatic and hydrodynamics forces created due to the operation conditions over a large variety of gate openings, flowrates and heads. The impact of the flow over and beneath the gate caused generation of two forces, downward force on the gate within the gate shaft and upward force on the gate bottom surface. The difference between these two forces is termed as downpull force by which the safe performance of gate can be evaluated. The downpull force is influenced mainly by the pressure heads on the top and bottom of the gate surface beside the jet velocity issued below the gate. The gate geometry has also been found as major factor may affect its response against pressures exerted by flow, especially near and around the gate lip.

In this research, a random hydraulic model was conducted to examine the effect of many gate lip shapes on the downpull force coefficients. More than 48 experimental runs are made. The result specifies that the behavior and magnitudes of top pressure coefficient is varied uniformly from high to low values as the gate openings increase, and seem to be not much more sensitive to changes in gate lip geometry. Some fluctuation is observed in the values and distribution of the bottom pressure coefficient due the changes in gate geometries and openings, so that the downpull coefficient is accordingly influenced effectively by this coefficient.

Keywords: Vertical Lift Gates, Bottom Pressure Coefficient, Top Pressure Coefficient, Downpull Pressure Coefficient

1. Introduction

The vertical lift gates are among the largest gates commonly used to control the flow under wide range of reservoir heads especially in the case of the emergency closure. It is mainly exposed to two forces, one resulting from the flow passing over the top gate through the upstream and downstream gate permits, while the other results from the pressure on the bottom surface of the gate due to the flow concern of the gate openings. The difference between these two forces causes an unbalanced force if it acts vertically downward, known as a hydraulic downpull force, whereas considered as negative when its effect is vertically upward.

In the case, that this force exceeds permissible values, it may pose a challenge to the safe operation of the gate and therefore its study under wide range of flow conditions and gate geometries is within the effective interest region of researchers and designers. Several studies were conducted to estimate the hydraulic downpull force under the effects of many relevant parameters.

The downpull force has received attention from several researches. Colgate (1959) has studied the parameters affected the downpull forces on high head gate, the pressure area computation method was employed, it was concluded that not all of the parameters controlling the hydraulic downpull forces on gates have been defined to a level that will permit an accurate mathematical analysis of each single problem. Furthermore, scale model investigations are of the main importance to the engineer in the solution of these problems.

A dimensionless relationship was developed by Cox et al. (1960) to estimate the hydrodynamic forces that reflect the effect of ventilation, gate bottom geometry, and gate shaft clearances on gate stability. The air tunnel experiments were conducted systematically by Naudascher et al. (1964) to assess the effects of flow parameters and gate geometry on the downpull forces applied on high leaf gates. The one-dimensional model can be used to estimate downpull force as follows:

$$Fd = (Kt - Kb)\,.B.d.\rho.\frac{v_j^2}{2} \qquad (1)$$

Where:

$Fd = Downpull\ Force,$
$B = Gate\ Width,$
$d = Gate\ Thickness,$
$\rho = Water\ Mass\ Density, and$
$Vj = Velocity\ of\ the\ contracted\ jet\ issuing\ from\ underneath\ the\ gate.$

$$Kt = (2g.(Ht - Ys))/Vj^2 \qquad (2)$$
$$Kb = \left(\frac{1}{B.d}\right)\iint\left[(Hi - Ys)/\left(\frac{Vj^2}{2g}\right)\right]dB\,.dx \qquad (3)$$

Where:

Kb: $Bottom\ pressure\ coefficient$
$H_t = pressure\ head\ on\ gate\ p\ surface$
$Y_s = Pressure\ head\ in\ the\ contractedjet. And$
$Hi = Pressure\ head\ at\ a\ point\ on\ the\ gate\ bottom$

Elder and Garrison (1964) presented a design of the 3-leaf intake gate as a result of experimental study simulating the TVAS Melton Hill Dam. The experiments contained tests on five proposed gate lip shapes and nine other basic shapes. The tests revealed some difficulties due to the large hydraulic forces induced by lip forms, oscillation and the failure of the gate to close.

The downpull force can also be expressed in terms of coefficients as stated below:

$$Fd = Ft - Fb \qquad (4)$$

Where:

$Fd: Downpull\ force, N$

$F_t =\ forces\ on\ the\ top.$

$F_b\ = bottom\ gate\ respectively, and$

Many experiments conducted by the US Bureau of Reclamation and Army Engineers (1966), it has been shown that the downpull force can be expressed in terms of operation head:

$$Kd = \frac{F_d}{\gamma.H.A} \qquad (5)$$

Where:
$\gamma: Specific\ weight\ of\ water.$
$H: Operating\ head\ , m$

Naudaseher (1986) demonstrated that the downpull may be significantly affected by the flow rate passing through gate. His study included a one-dimensional analysis based on data obtained from regular water tunnel experiments. The study included large gate openings and a disturbing effect of the gate movement to illustrate the negative downpull situations that may occur as a result of these conditions. The study concluded that the downward pressure can be reduced by controlling the flow passing through the gate.

Bhargava (1989) examined pressure fluctuations on different geometrical shapes from vertical lift gates. The study included measurements and analysis of several hydraulic parameters that affect the size and distribution of pressure through the various gate openings. In the deviation of the distribution pattern, the spatial relationships and the magnitude of the pressure changes were considered when the gate is forced to vibrate with one degree of freedom in the vertical direction at certain frequencies and amplitudes. The study reveals pressure for the dominant frequency, which is a critical condition for the design of hydraulic control gates.

Nguyen (1990) studied unstable load and vertical lifting gate activities with different geometrical gate shapes and discharge conditions in an open channel and at the entrance of a channel. Vibrations occurred in precise ranges of the velocity when the flow was changed between the total separation and re-attachment at the bottom of the gate. The excitation mechanism was due to the combined effect of the shear layer insufficiency and eddies induced in the front edge of the gate. It has been shown that the slope of the average lift curve works at the bottom of the gate, providing an effective means of predicting the critical diversity of gates development with reasonable accuracy with respect to potential gate vibrations.

The effect of many gate geometries with different clearances ratios of gate shaft on the downpull force was examined by Ahmed (1999). The study was based on the results analysis of the measurements obtained from the experimental operation carried out using the hydraulic laboratory. The main conclusion of the study indicates that the coefficient of downpull is affected by many parameters such as gate geometry and gate openings.

The hydraulic model of the tunnel-type vertical gate is used by Drobir et al. (2001) to investigate the effects of many water flow conditions downstream the gate shaft on downpull force. Standard measures of free and immersed flow were moved behind the gate shaft and the results were compared with those obtained from the calculations method proposed by Naudascher (1991).

Brankovic and Drobier (2013) found that using the new gate with the new smooth face would reduce hydrodynamic forces in the absence of negative downward forces. The study revealed that the new gateway with a new soft top head has made progress in the safety of water machinery equipment and reduced costs, and lowered the lifting force. In the current study, the water flow controlled by vertical lift gate in dams under high pressure had been modeled using arbitrary hydraulic lab. The model was examined several forms of gate lip with continuous discharge. In addition, the gap width of the gate has been maintained at specified values.

2. Experimental Works

The hydraulic model of dam tunnel was simulated by a rectangular glass walled recirculating flume, 4m long, 0.2 m wide, and 0.3m deep with horizontal glass floor supported by steel frame about 5mm thickness. The flume was covered along its upper part by a thick plate representing the tunnel roof, The general description of hydraulic model is shown in Figure (1). The gate model made by a thick plate with a thickness of 6 mm was supported by steel frame slides in vertical way of the gate shaft, (see Figure 2), and it can be adjustable by a screw placed on the top cover of the shaft to control the gate openings. Twelve piezometer taps, 4 mm in diameter, were drilled on upstream Gate face, the first six taps were located at a distance 0.25 B from right gate edge and dispersed along a line parallel to torrent side wall, with 5 cm interval distance, and hence the additional five taps located at 0.5 B with the same method. The small length steel tubes of the same diameter introduced in each tap, and then connected through plastic tubes to a manometer board.

The movable bottom plate of the gate was made by steel plate which can change the angles by the screw at the top of the gate shaft. The gate was provided with two sets of taps located along the lip parallel to the direction of flow. While the first was set with five taps fixed at a distance 0.25 B from right gate edge with equal interval distance from each to other, the second was located at 0.5 B with five taps of equal interval distance. These taps have also been inserted by 2cm length of steel tubes, which connected to the manometer board through plastic tubes. All experimental runs included all required measurements, upstream and downstream heads, top and bottom peizomteric heads in addition to the jet velocity.

3. Evaluation of Downpull Coefficient

As mentioned before, the K-values (K_t and K_b) and Vj are known from experiments and flow analysis respectively. The experiments included the investigation of (12) gate lip shapes, so the (K_t) and (K_b) values were determined at various gate openings for each gate lip shape. The downpull coefficient (K_d) can be estimated as follows:

$$Kd = Kt - Kb \tag{6}$$

However, to obtain an estimation of the total hydraulic down pull on gates, the mean value of bottom pressure coefficient (K_b) are determined by graphical integration of dimensionless profile plotted of each gate lip, and top pressure coefficient (K_t).

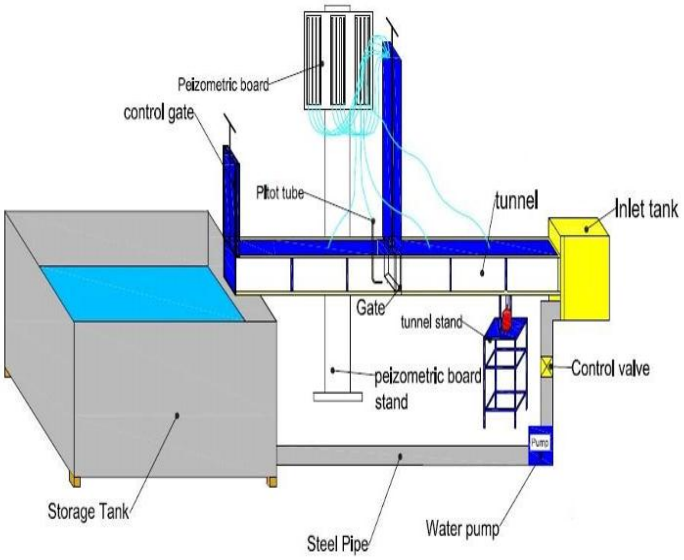

Figure 1: Schemaitic layout of hydraulic model

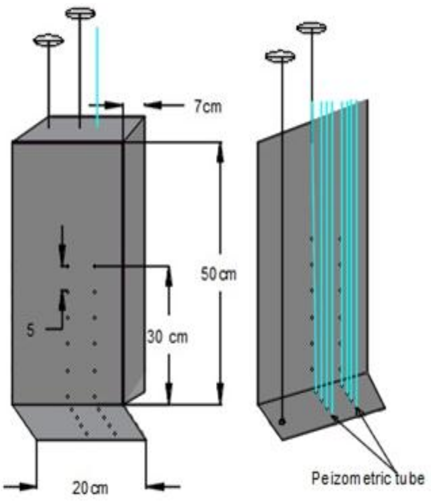

Figure 2: Gate model

Table (1) shows the relation between all downpull coefficients (K_t ,K_b,K_d) against gate opening ratio for gate lip shape with θ=45°. The table indicates that the values of (Kd) are increased from negative value at small gate opening upto maximum value for (Y/Y_o =30%) then decreased uniformly as gate openings increase.

Table 1: Downpull coefficient pressure with gate openings for gate lip shape θ=45°

Shape θ=45°			
Y/Y_o	K_t	K_b	K_d
0.1	0.25	0.30	-0.04
0.2	0.21	0.18	0.03
0.3	0.15	0.03	0.12
0.4	0.13	0.05	0.09
0.5	0.10	0.04	0.06
0.6	0.09	0.05	0.04
0.7	0.04	0.02	0.02
0.8	0.03	0.04	-0.01

Table (2) shows the relation between the downpull coefficient (K_d) for the different gate lip shapes with the different gate opening ratios (Y/Y_o). The results confirm that at gate opening (Y/Yo=30%) the downpull coefficient values (Kd) starts to decline as the gate opening ratios increases.

Table 2: Downpull pressure coefficient, with gate Openings for different gate lip shapes

Openings	shape=20°	shape=25°	shape=40°	shape=50°	shape=70°	shape=90°
Y/Y_o	K_d	K_d	K_d	K_d	K_d	K_d
0.1	0.15	0.13	-0.02	-0.09	-0.11	-0.10
0.2	0.17	0.12	0.10	0.00	-0.04	-0.22
0.3	0.23	0.20	0.15	0.28	0.06	0.00
0.4	0.14	0.13	0.09	0.12	0.04	0.05
0.5	0.10	0.10	0.07	0.11	0.02	0.03
0.6	0.07	0.06	0.05	0.09	0.01	-0.02
0.7	0.03	0.03	0.02	0.06	0.00	-0.01
0.8	0.02	0.00	0.01	-0.01	0.00	-0.01

As mentioned earlier, the results indicate that the (K_t) values distributions are approximately invariant and follow the same trend for all gate lip shapes investigated as long as the gap width ratio (b_2/b_1) remains constant (Ahmed, 2016); thus the (K_d) values are mainly influenced by the (K_b) values which are mostly varied and significantly affected by geometries of the gate lips. The results of the experiment included whether the hydraulic downpull increased or decreased as a result of the use of each gate geometry and how this caused the downpull to be positive or negative. In Figures (3) and (4), the downpull coefficient (K_d) is calculated by using equations (2,3 and 6) and the results represented with different values of gate openings and lip gate shapes. It can be seen from these figures that for all gate lip shapes, the Kd-gate opening relationship provides similar trends, that is, upto (Y/Yo=30%), the (K_d) values are seen low or even negative (θ=45°, θ=50°, θ=55°, θ=70° and θ=90°) and somehow fluctuating. At the (Y/Yo=30%), the (Kd) reached a noticed maximum values for most of the lip gate shapes considered in this work. However, for (Y/Yo > 30%), a descending part of (Kd) values appraoching to approximately zero at (Y/Yo=90%). These figures also show that for (Y/Yo=30%), the maximum (Kd) values increase as the inclination angle of gate lip shape decreases except (θ=50° and θ=55°). This may be attributed to effective respons of (Kb) to the effects of gate lip geometry as shown in figures (6) and (8), by which, the small values of angle may lead to reduce in the opportunity of flow lines attachment to bottom gate surface, which in turn cause a decrease in the values of the bottom pressure coeffiecient accompanied by an increase in the downpull pressure coeffiecient. This can indicate the importance of pressure coefficient values arising at the opening of 30% in the gate design and ensure the safe operation.

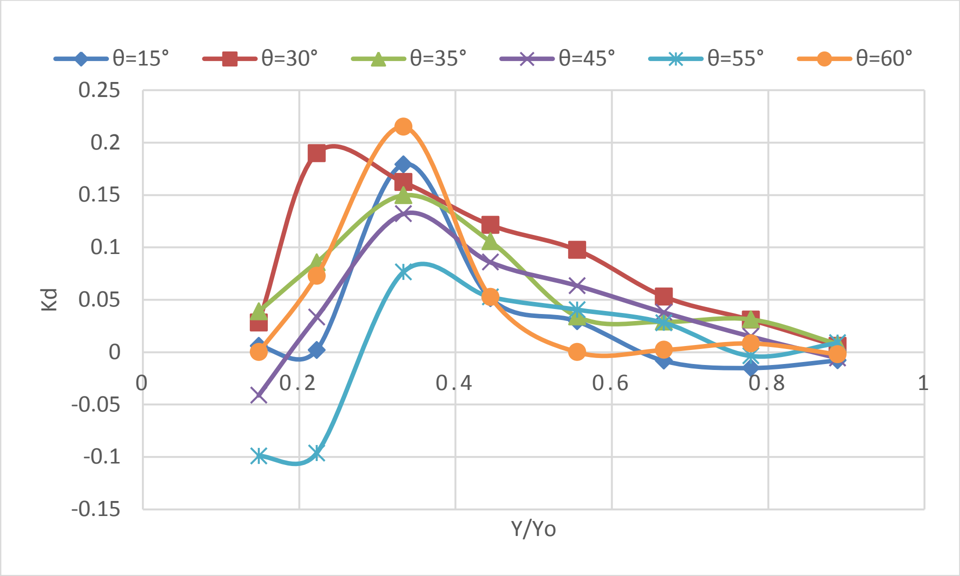

Figure 3: Variation of downpull pressure coefficient, with gate openings for different gate lip shapes

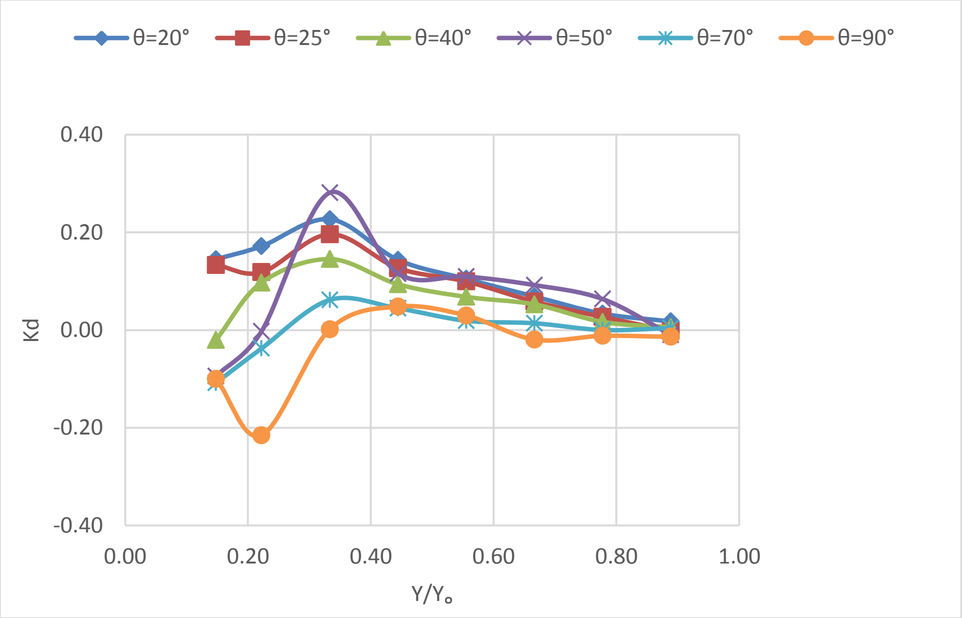

Figure 4: Variation of downpull pressure coefficient, withgate openings for different gate lip shapes

Figures (3) and (4) have also specified that in the case of taken gate opening (30%) as reference of significant change in values and behavior of (Kd) values, the magnitudes of (Kd) for (θ=50° and θ=60°) are comparatively highest than others. As it can be seen from figure (6) and (8), the reason behind this increase is (Kd) values may be attributed to complete separation of flow implemented from the bottom gate surface, in which, the values of (Kb) are reduced and consequently caused an increase in (Kd) values. In the same manner, the lowest values of (Kd) are indicated for (θ=55° and θ=90°) which reveal that the (Kb) values seem high as a result of the impact of flow lines attachment at Y/Yo=30 %.

The estimation of negative downpull coefficient is important to ensure that the gate will be safe due to the closure prevention. As mentioned earlier, that for gate openings (Y/Yo) up to 30%, the negative (Kd) values were observed for gate lip shapes (θ=45°, θ=50° ,θ=55°, θ=70° and θ=90°). However, since the dowpull coefficient is based mainly on the bottom pressure coefficient (K_b), the selection of a lip shape should be treated as the major factor to dominate the downpull force and keep it at minimum positive value. However, in the current study, the experiments and hence the analysis specify that the general minimum positive downpull may be obtained by inclined gate lip shape with (θ=35°) where the value ranged from 0.09 to 0.15.

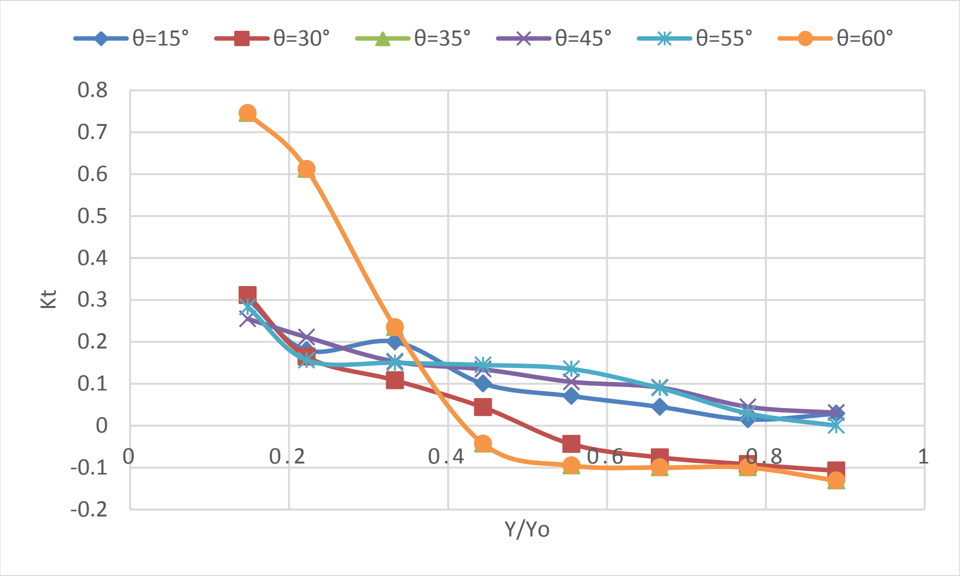

Figure 5: Variation of top pressure coefficients with gate openings for different gate lip shapes (Ahmed 2016).

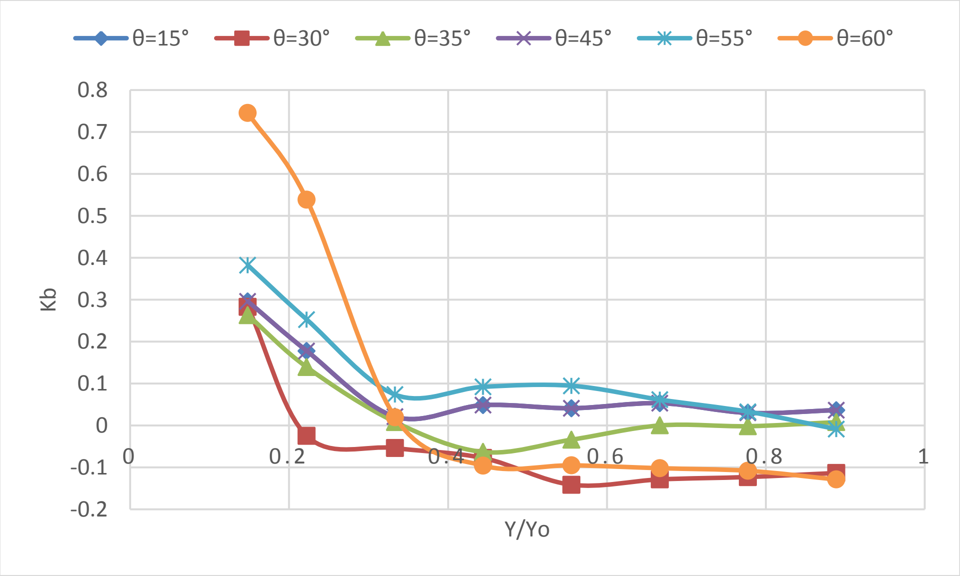

Figure 6: Variation of pressure coefficients with gate openings for for different gate lip shapes

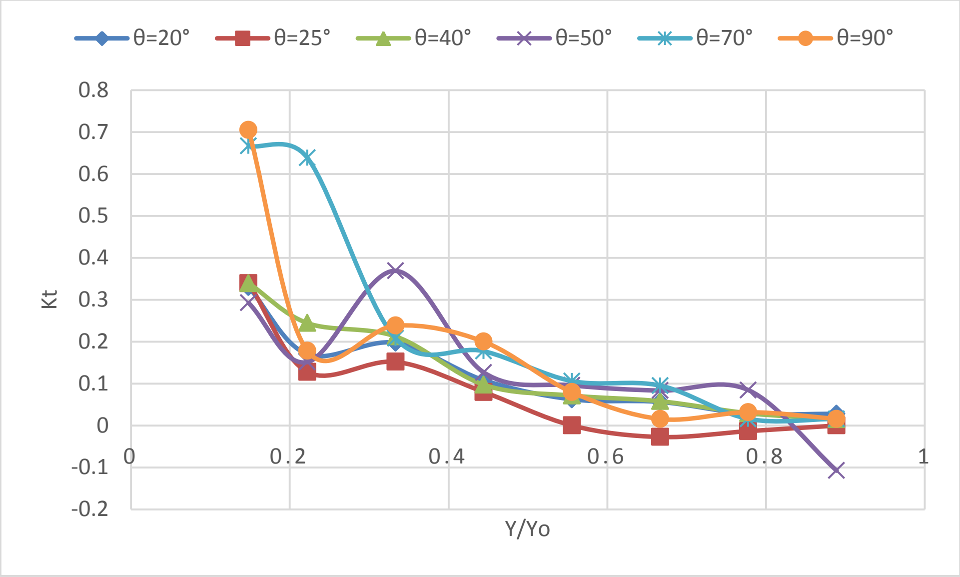

Figure 7: Variation of pressure coefficients with gate openings for for different gate lip shapes (Ahmed 2016).

It is approporaite to note the work of Nudascher (1965) for (θ=20° , θ=30° and θ=45°). Although the (Kb) trends of this work and those of Nudascher (1965) are similar at gate openings from (20%) upto (70%) as shown in Figure (9), some discrepancy in Kb values are observed especially for (θ=45°). This may be due to the flow conditions which have been applied for exprimental work hence, additional research work may required to obtain more data that may help the explaination of such differences in the behavior of pressure coefficients.

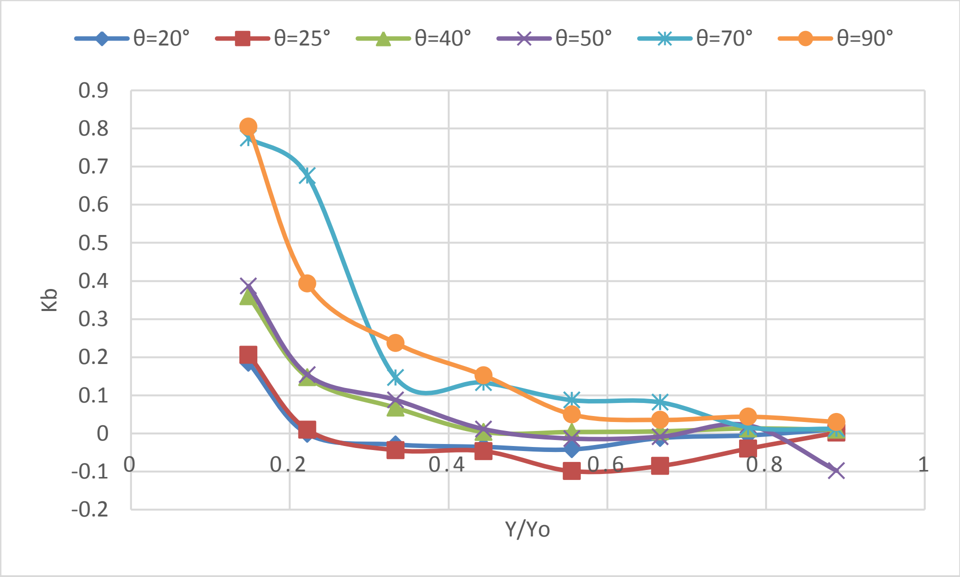

Figure 8: Variation of bottom pressure coefficients with gate openings for for different gate lip shapes

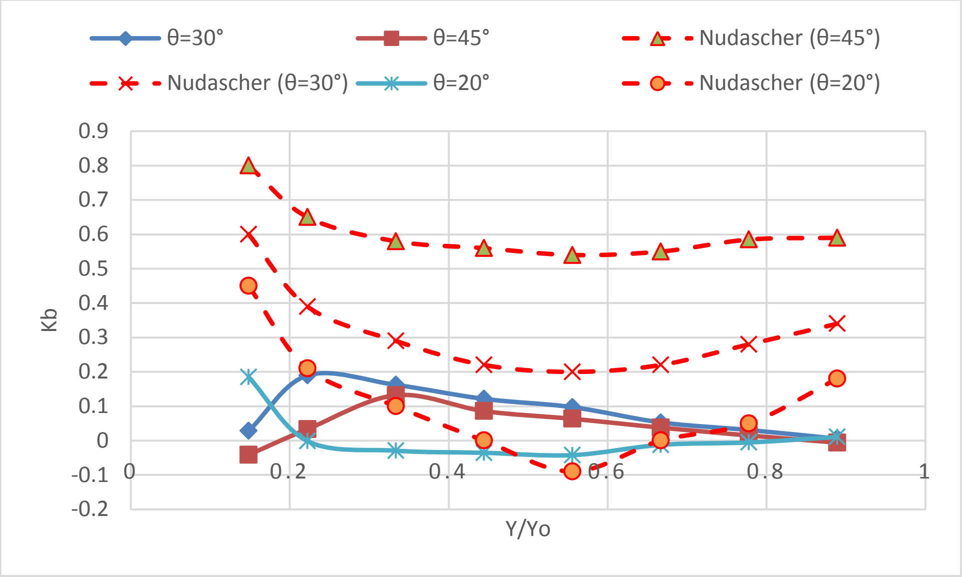

Figure 9: Comparison of variation of bottom pressure coefficients with previous work of Naudascher (1965).

4. Conclusion

Physical model was created at the Hydraulic laboratory of Ishik University in Erbil to study the effect of twelve gate lip shapes on the downpull force coefficient in the case of constant values of flow rate and gate shaft clearences. The jet velocity and pressure head measurements at several locations along the tunnel model were carried out. The estimation of the downpull coefficient was based upon the determination of the top pressure coefficient (K_t) and the bottom pressure coefficient (K_b). The following conclusions can be drawn from the study:

1. The comparison between the gate lip shapes specified that the use of inclined gate lip shape with(θ=35°) kept the (K_d) values at minimum and it may reduce the effects of negative down pull.
2. The study specified that the downpull force is controlled by the bottom pressure coefficients (K_b) which was influenced mainly by the flow pattern beneath the gate and therefore by the gate geometry.
3. The study shows that at gate opening (Y/Yo=30%), the change in trend and values of (Kd) are clearly observed, morover, it is seen that the maximum (Kd) values increase as the inclination angle of gate lip shape decreases except for (θ=50° and θ=55°).
4. The Kd-gate opening relationship provides similar trends, that is, upto (Y/Yo=30%), the (Kd) values are seen low or even negative (θ=45°, θ=50° ,θ=55°, θ=70° and θ=90°) and somehow fluctuating. At the (Y/Yo=30%), the (Kd) reached a noticed maximum values for most of the lip gate shapes.
5. The magnitudes of (Kd) for (θ=50° and θ=60°) are comparatively higher than others and the lowest values of (Kd) are indicated for (θ=55° and θ=90°).

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