Effects of Gate Lip Shapes on Hydrodynamic Forces on Gate Dam Tunnels

Thamir M.Ahmed[1]

[1] Civil Engineering Department, Ishik University, Erbil, Iraq
Correspondence: Thamir M. Ahmed, Ishik University, Erbil, Iraq.
Email: thamir.ahmed@ishik.edu.iq

Received: October 23, 2017 Accepted: November 27, 2017 Online Published: December 1, 2017

doi: 10.23918/eajse.v3i2p47

Abstract: The lift gate is one of the major types of dam tunnel gates which is used to regulate the water flow transmitted from the reservoir to downstream side in order to satisfy several demand requirements. Due to pressurized flow, the upstream face, top and bottom surfaces of gate are subjected to hydrodynamics forces. As a result of gate openings, the downpull force is created from the difference between the downward force exerted by water passing over the top surface of gate and that established by the water jet beneath the gate. The estimation of downpull force is so important due to its significant effects on the movement and closure of the gate which in case of its negative value the gate may prevent to close and lead to some failures and damages.

In the present study, the estimation of downpull force is made based upon the results of measurements which have been achieved by using hydraulic model of tunnel with different shapes of inclined gate lips with and without extensions. The pressure heads along the bottom and upper surfaces of gate, the upstream and downstream heads are measured in addition to the jet velocity for different gate openings. One of the main conclusions drawn from the measurements and analysis is that the effects of the gate lip shapes on the values of downpull force is significant, and the lip extensions with different ratios which were provided at trailing edge of gate have effectively contributed to reducing the downpull forces

Keywords: Lift Gate, Downpull Forces, Pressure Coefficients

1. Introduction

The vertical lift gate is one type of gates which are commonly used to control the quantity and heads of water in dam structures. These types of gates are located at suitable section of the dam tunnel and allowed to lift and lowered vertically through a guided rail of a gate shaft. According to the effects of wide range of high head water in the reservoir of dam, such gates are subjected to many hydraulic forces. These forces could be classified into three categories, force develops on upstream face due to the influence of operating head, downward force established by flow passing over the top surface of the gate, and uplift force generated by flow issued beneath the bottom surface of gate. The last two types of forces play a vital role in operation of gate, where the difference between them produces a new term of force called as hydraulic downpull which may be act vertically either with upward or downward direction. The negative downpull force may cause operational problems, especially those related to preventing the emergency closure of the gate. Hence, the estimation of such force is still necessary and all elements and parameters which could affect its values and behavior have received a big attention from hydraulic researchers and designers.

Aydin (2002) indicates that the vertical lift gate may be subjected to large downpull forces and severe vibration as a result of high speed fluid around the gate lip and low pressure due to suction induced by high momentum fluid downstream of the control section. Cox et al. (1960) has developed a study for estimating the stability of gate based upon a dimensionless relationship among many hydraulic variables such as geometry of gate bottom and clearance of gate shaft with the effect of ventilation. Naudascher et al. (1964) has conducted many tests of hydraulic air model to formulate the effects of many parameters on the values of hydraulic forces acting on high head leaf gates. It is found that the force depend mainly upon the geometric parameters of the gate and on the jet velocity in the contracted jet under the gate formulations can be expressed as follows:

$$F_d = \gamma . K_d . B . d . \frac{V_j^2}{2g} \quad (1)$$

$$K_d = K_t - K_b \quad (2)$$

$$K_t = \frac{2g(H_t - H_d)}{V_j^2} \quad (3)$$

$$K_b = \frac{2g(H_i - H_d)}{V_j^2} \quad (4)$$

Where

B: Gate width (m),

d: Gate thickness (m),

H_d: Downstream pressure head (m),

H_i: *Pressure* head at a point on the gate bottom (m),

H_t: Total head at the gate shaft (m),

K_t: Top pressure coefficient (dimensionless),

K_b: Bottom pressure coefficient (dimensionless), and

V_j: Velocity in the contracted jet flowing beneath the gate, Jet velocity, (m/sec).

The jet velocity created below the gate can be represented by the following equation (Naudascher et al., 1964):

$$V_j = \sqrt{2g(H - H_e - h)} \quad (5)$$

Where

H: total head in the reservoir

He: embodies the entrance head-loss

h: piezometric head at the top of the vena contracta.

The jet velocity it will starts from maximum when the gate opening is considered as approximately closed, (y≈0). However, the jet velocity it may adopted as function of the head and gate openings:

$$V_j = \sqrt{2g(H - H_e - C_c y - H_d)} \quad (6)$$

Cc: contraction coefficient of vena contracta

y : clear gate opening

Hd : depression downstream of the gate.

By assuming that the flow exists only underneath the gate, the maximum flow Q can have expressed as:

$$Q = C_c . A_j . V_j = C_c . Y . B . V_j \quad (7)$$

Where Aj is the cross-sectional area of the vena contracta.

The effect of operating head of water on the downpull force has also been studied and according to its values the downpull force can be expressed as shown below (Naudascher et al., 1964):

$$F_d = \gamma . K_d . B . d . H \quad (8)$$

Where

γ=specific weight of water, in KN/m^3

K_d=downpull coefficient,

B =gate width, in m,

d=gate thickness, m,

H =operating head on the gate bottom, in meters.

Sagar et al. (1979) has reported that numerous geometrical features of the gate influencing the downpull force can be formulated as follows:

$$F_d = f(H, Y/Y_o, e/d, \theta, b_1/b_2, d'/d, d/Y_o, r/d) \qquad (9)$$

Y: Gate opening (m),

Ys: Pressure head in the contracted jet, (m),

Yo: Tunnel height, (m),

Y/Yo: Gate opening ratio,

θ :Lip orientation (degrees),

e:Length of lip extension ,(m),

d:Gate thickness ,(m),

r:Radidus of curved gate lip,(m),and

b1&b2: Upstream and downstream clearances of gate shaft, (m).

In this research the downpull force has been evaluated by using the data obtained from experiments conducted on systematic hydraulic model with many types of gate lip shapes, and compared the results with those obtained from previous works.

The effects of gate lip shapes, gate shaft geometry and discharge rating on hydraulic downpull force exerted on high-head leaf gate for power house have been studied by Smith **(**1964**)** in the cases of fixing gate and moving gate with different speed of closure. It is found that the maximum downpull produced during the moving gate was about 74% of that in the case of fixing gate.

Murray and Simmons (1966) studied the effects of gate leaf, gate geometry and the size of air vent on the design values of hydraulic downpull on downstream seal. In their study, roller-mounted gates located in entrance transition of large conduits were used and the results of analysis were presented in both dimensional and non-dimensional forms. They found that maximum downpull force was about (3160 KN) during emergency closure of outlet works emergency gates in San Luis dam, if free discharge conditions occur at the downstream gate frame.

Narasimhan and Bhargava (1975) had evaluated the effects of many parameters such as Froud No., gate opening and the gate lip shapes with skin plate extension on the hydrodynamic forces exerted by water flow on gate.

Many approach flow conditions and separation phenomenon at the leading edge of intake gate were studied by Thang et al. (1983) to measure their effects on the downpull forces. It is found that the downpull force values were influenced by separation of stream lines from the bottom surface of gate.

Naudascher et al. (1986) also found that the downpull force is significantly affected by flow passing over the top of the gate through the gate shaft. The finite element technique was used by (Alkadi, 1997) to estimate the downpull force depending on the values of top and bottom pressure coefficients with constant and variable eddy viscosity. The results were compared with observed measurements and negative downpull forces cases of large gate openings were also studied.

An arbitrary hydraulic model was constructed by Ahmed (1999) to study the effect of many gate lip shapes and gap width ratio on the value of downpull force. The study revealed that the downpull force is significantly affected by gate geometry and the change of gap width between the gate and the shaft wall.

The various flow conditions, free and submerged flow in downstream zone of gate tunnel, were investigated by Drobir et al. (2001**)** using hydraulic model. The downpull forces on tunnel type high head gate were estimated under the effects of these flow conditions and compared with the results obtained from calculations based on the method of Naudascher (1986).

2. Aim of the Study

The stability and safety of mechanical gate system subjected to seriousness challenges due to the effects of hydrodynamic forces that arise from a pressurized flow in dam tunnel. The main aim of the current study is to asset the impact of gate geometries on the values and distribution of hydrodynamic forces, beside the identification of the best gate lip shapes which may dominate the downpull forces to be within an acceptable value which not to reflect negatively on the performance of gate operation. The inclined gate lip is the most common shape which has been adopted for vertical lift gates. Hence, various angles of inclined gate lip shapes with and without extension were need to be examined.

3. Methodology

The study implemented the experimental work to carry out all the required measurements relevant to the estimation of the hydraulic forces. All measurements regarding the downpull force such as upstream head, downstream head, top piezometric head, and pressure head distribution on the bottom of the lift gate and jet velocity beneath the gate have been achieved through the hydraulic model for each gate lip shape and different gate openings. Figure (1) shows the scheme of hydraulic model that used to conduct the required measurements. The model consists of glass rectangular recirculation flume, 4m long, of a 0.2 m wide, and 0.3mhigh covered by steel plate to complete the simulation of dam tunnel. Constant head tank of water is connected to pipe-pump-valve system to allow a specific flow rate passing to the tunnel through the inlet tank (400 mm long, 250 mm wide and 600 mm high).A (500 mm high,200 mm wide and 50 mm thickness) thick plate gate with changeable lip parts was used. In order to prevent any deviation or torsion, the gate was supported by steel frame and designed to be moved vertically through the gate shaft of (300 mm wide, 100 mm and 1000 mm high). The gate shaft was located in midway of tunnel and its top surface was provided by adjustable screw to regulate the gate openings. Many inclined changeable gate lips have been made by steel blocks with and without lip extensions. Each gate lip was provided with two sets of holes positioned along two lines (0.25 B and 0.5 B from edge of gate) parallel to the flow direction. Each line includes five holes with same interval distances and provided by short steel tubes to facilitate their connections to the Piezometers board. Figure (2) shows the main body of the gate and all seven gate lip models which were considered in present study. The gate lip shapes are classified into two groups, first four have inclined bottom surface with angles of (θ=42°, θ=45°, and θ=55°) and the second four with the same angles and different lip extension ratios as it can be seen in the figure.

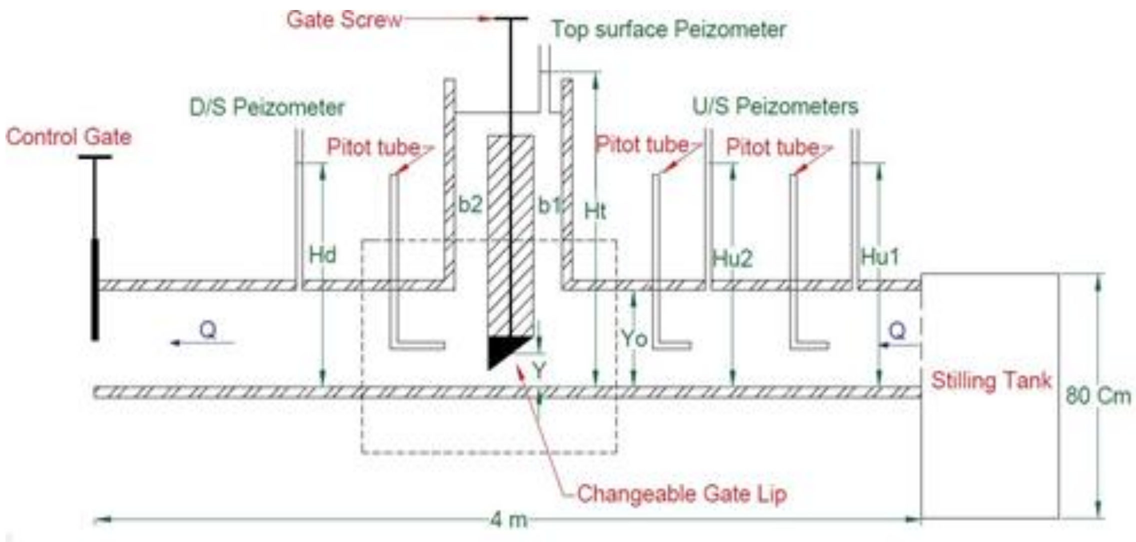

Figure (1): Scheme of hydraulic model

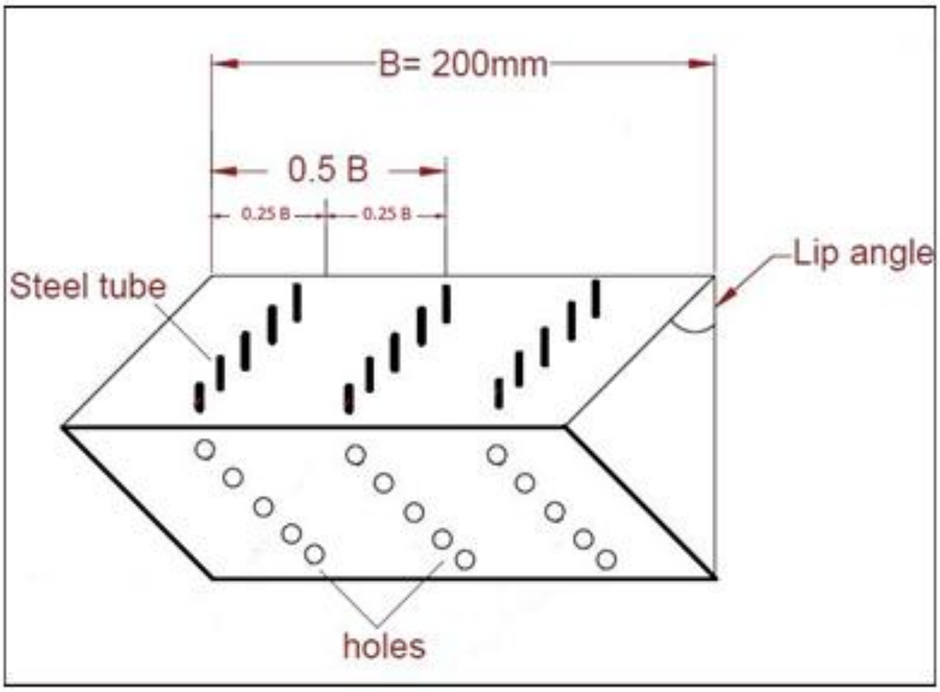

Figure (2): Gate lip shape

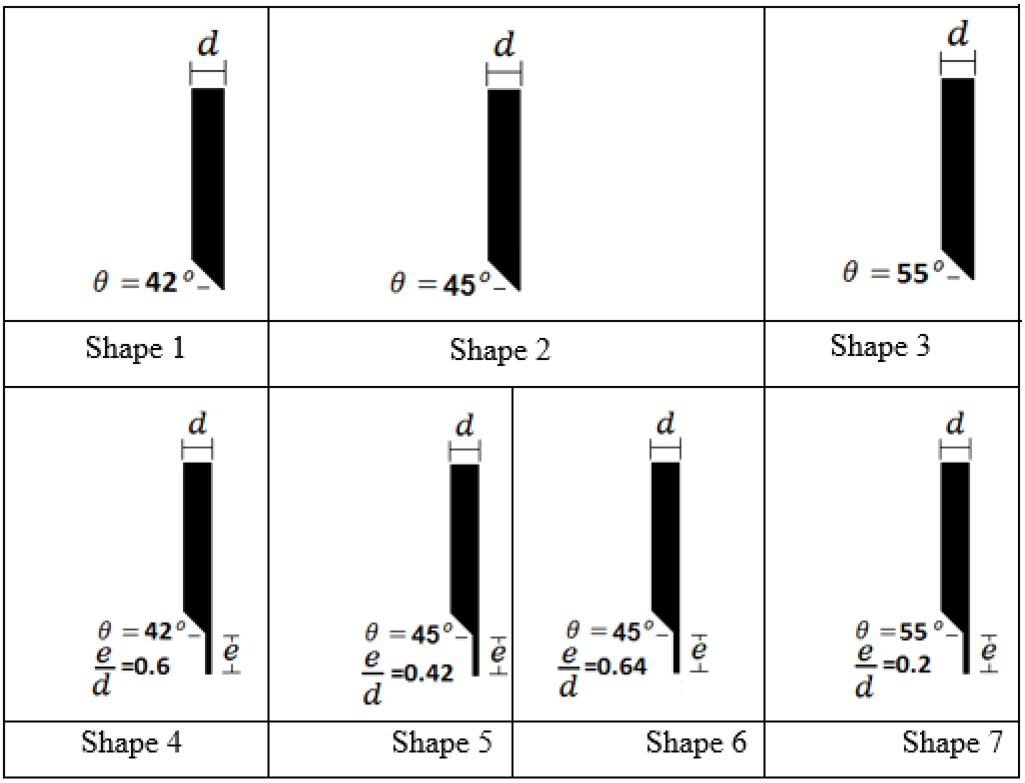

Figure (3): Gate lip shapes considered in study

4. Results and Discussion

In present study, different inclined lip shapes with and without extensions were examined. The measurement results of hydraulic model runs were introduced in Eq.(1) and the values of hydrodynamic force (*Fd*) for all considered gate lip shapes are found. The variations of (*Fd*) for each gate lip shape and gate opening ratios are demonstrated through figures (4) to (8).

4.1 Effects of Gate Lip without Extensions

It can be seen from these figures that for all different gate shapes adopted in this study, the distribution of the downpull forces with the different gate openings does not undergo the same behavior or reflect a regular variation. Obviously, each gate shape reflects its effect on hydrodynamic forces differently. However, for gate lip shapes with (θ=42° and θ=45°), the force values for small gate openings (Y/Yo) up to approximately 50% appear to be higher than that achieved in the large openings during which the values of downpull force are dropped rapidly and reach negative values for the lip gate shape of (θ=45°).Accordingly, these negative values may threaten the safe movement and closure of the gate. The state of gate lip shape with (θ=55°) seemed to be different as the downpull force values are positive and varied slightly as gate opening increase which confirms the difficulty in finding a common denominator in the performance and the influences of these types of gates.

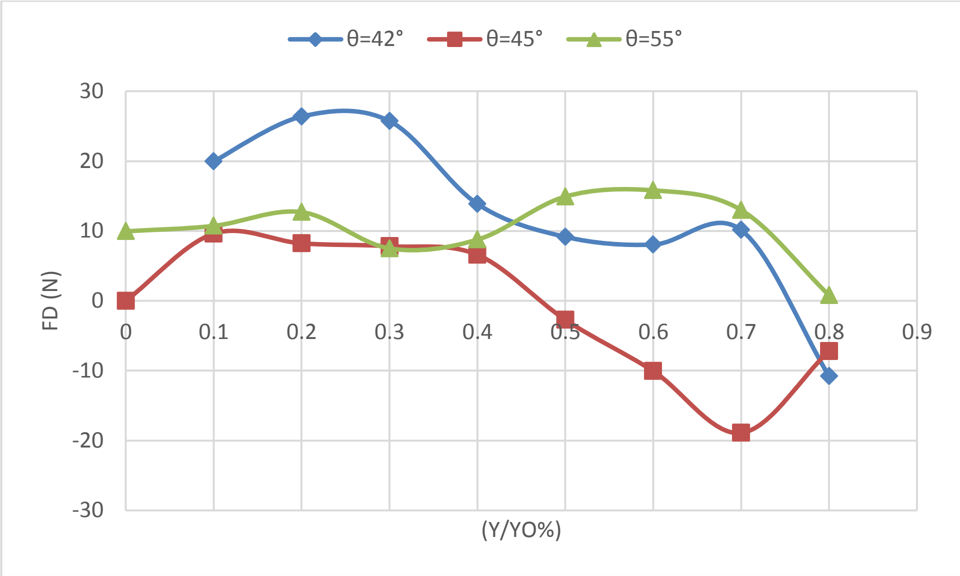

Figure (4): Variation of downpull force with gate opening ratios for shapes No. (1, 2, and 3)

4.2 Effects of Gate Lip with Extensions

The gates with lip extension are also being examined in the present study. The extensions were added to the trailing edge of gate lips with different arbitrary (e/d) ratios as shown in figure (3). The adding of lip extension to the gate lip was intended to produce a new pattern of flow beneath the gate which mostly caused an increase in values of the bottom pressure and tended accordingly to decrease the values of downpull force (Fd). It is found that for considered gate shapes with extensions, the reduction in (Fd) values are indicated as about 50%, especially for gate openings ratio up to 45 % as shown in figure (5). It can also be noted that the forces are positive with a slight change in their values and the turning toward negative have been occurred for all gate opening ratios more than 45%. However, for gate openings up to 45%, the (Fd) values for gate lip shapes of (θ=45°, e/d=0.64 and θ=45°,e/d=0.64) are higher than other corresponding considered gate lip shapes while for (θ=42°,e/d=0.6) the values appear to be lower than others with less rate of change.

Figures (6), (7) and (8) show the comparison of downpull force (Fd) values for the gate lip shapes with and without lip extensions. As mentioned before, the values of downpull force in the case of gate with lip extension are less than those obtained for gates without lip extension. As it can be observed from figure (6), the addition of lip extension with (e/d=0.6) to the gate of ($\theta = 42^o$) lead to reduce the values of (Fd) by 57% for small gate openings up to (Y/Yo=40%), beyond which the reduction percentage decreases to be around 10%. Figure (7) shows the variation of (Fd) for ($\theta = 45^o$) gate lip shapes with different values of lip extension ratios, (e/d=0.42 and e/d=0.64) .The figure clarify that for gate openings up to (Y/Yo =50 %), the reduction percentage of downpull force due the effects of lip extension is around 47%. The reduction percentage of (Fd) values due to the effects of addition the extension with (e/d=0.2) to the gate lip of ($\theta = 55^o$) are also investigated, however, figure (8) indicates that the values of (Fd) has reduced by 71% for values of (Y/Yo) up to 30% and more than 90% for (Y/Yo) between 50% and 85% .

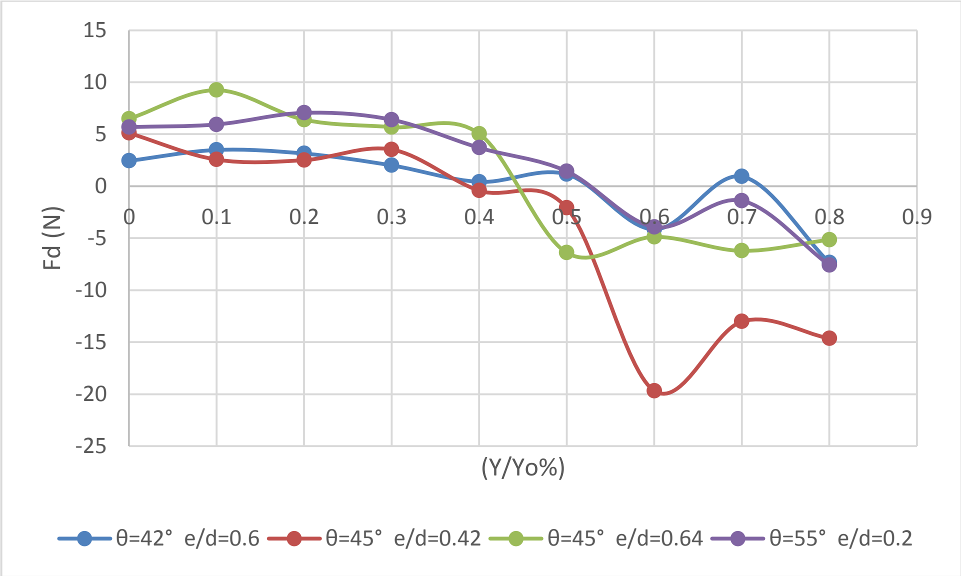

Figure (5): Variation of downpull force with gate opening ratios for shape No.(5,6,7 and 8)

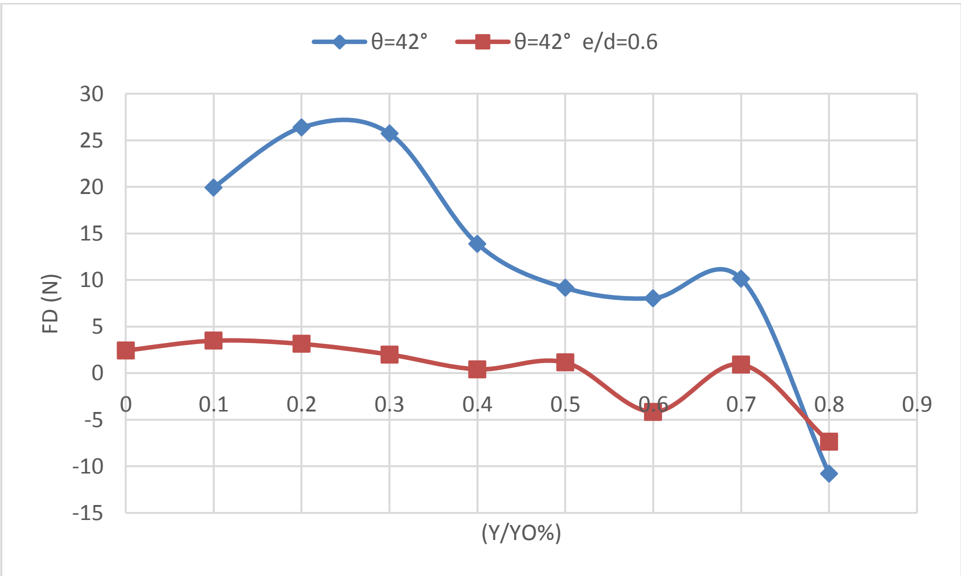

Figure (6): Variation of downpull force with gate opening ratios for shapes No.(2 and 4)

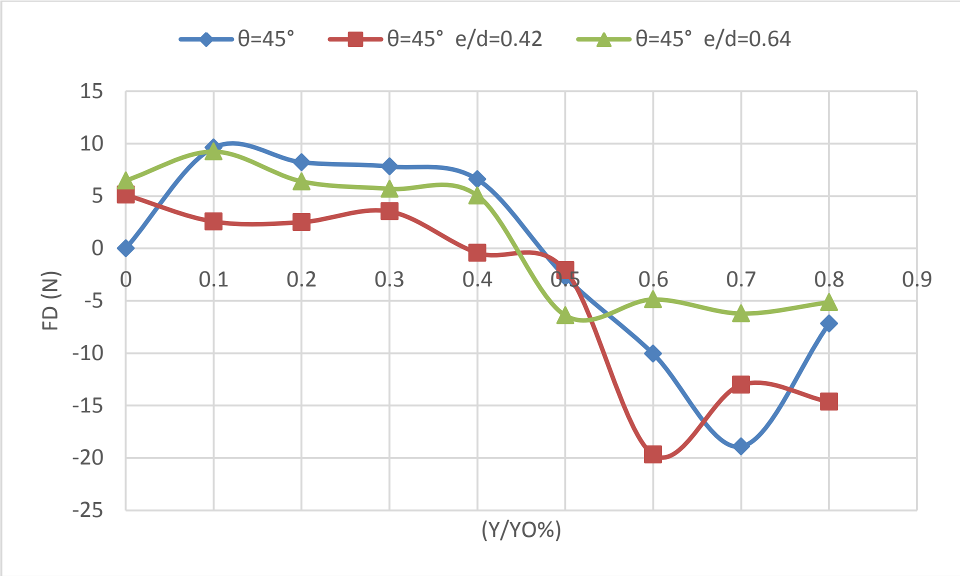

Figure (7): Variation of downpull force with gate opening ratios for shapes No.(2,5 and 6)

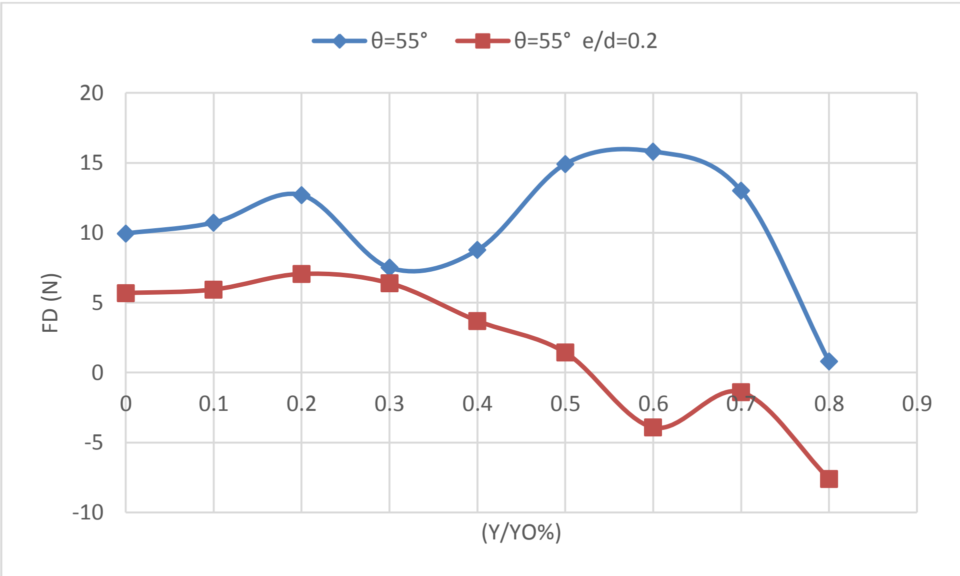

Figure (8): Variation of downpull force with gate opening ratios for shapes No.(3 and 7)

5. Conclusion

In the current study, the effects of inclined lip gate shapes with and without extension on dimensional downpull force values were studied for different gate opening ratios. The following are the main conclusions of the results analysis.

1-The study showed that the considered inclined gate shapes varied in their effect on the downpull forces and were not organized in one context, which confirms the difficulty in finding specific relationship for all the variables that are related to the effect of the gate shapes on the values and distribution of hydrodynamic forces.

2-For the small openings of the gate up to (50%), positive and relatively higher values of forces have been observed for the inclined gate shapes. The increase of gate openings is accompanied by a decrease in force values which dropped for (θ =45^o) to be negative.

3-The addition of extensions with different length ratios to the trailing edge of the gate have less contributed to reducing the values of forces and led to less discrepancy in their distribution along the small gate openings ratios up to (50%) .

4-The negative values of the downpull forces which are observed generally for gate openings more than 45% mean that the adding of the extension, which was intended to increase the bottom pressure and reduce the downpull force, did not match the desired result in the case of large gate openings. For such case, the need is necessary to reconsider the dimensions of the extensions and find the best under different flow conditions.

5-The reduction ratios for the values of downpull forces due to the significant influence of lip extensions are indicated as, 57% for small gate openings up to (Y/Yo=40%) for gate lip shape of (θ =42^o ,e/d=0.6) and 10 % for the remaining .For gate lip shape of (θ =45^o e/d=0.42 and e/d=0.64) is around 47% for the gate openings up to (Y/Yo =50 %) .The reduction percentage of (θ =55^o, e/d=0.2) is indicated as 71% for values of (Y/Yo) up to 30% and more than 90% for (Y/Yo) between 50% and 85% .

References

Ahmed, T. M. (1999). *Effect of Gate Lip Shapes on the Downpull Force in Tunnel Gates*. Doctoral dissertation submitted to the College of Engineering, University of Baghdad.

Al-Kadi, B. T. (1997). *Numerical Evaluation of Downpull Force in Tunnel Gates*. Doctoral dissertation submitted to the College of Engineering, University of Baghdad.

Aydin, I. (2002). Air demand behind high head gates during emergency closure. *Journal of Hydraulic Research*, *40*(1), 83-93.

Cox, R., G., Ellis, B. P., & Simmons, W. P. (1960). Hydraulic Downpull on High head Gates. *ASCE Discussion Hy*, *5*.

Drobir, H., Kienberger, V., & Seyerl, J. (2001). Downpull on tunnel-type high-head leaf gates. In *Proceedings of the Congress-International Association for Hydraulic Research* (pp. 473-478).

Murray, R. I., & Simmons, W.P. (1966). Hydraulic downpull forces on large gates. U.S. Government Printing Office.

Narasimhan, S., & Bhargava, V. (1975). Flow-Induced Forces on Protruding Walls. *Proc. ASCEJ. ofHydr. Div*, *101*.

Naudascher, E., Kobus, H., & Rao, R. P. R. (1964). Hydrodynamic analysis for high-head leaf gates.

Naudascher, E., Rao, P. V., Richter, A., Vargas, P., & Wonik, G. (1986). Prediction and control of downpull on tunnel gates. *Journal of Hydraulic Engineering*, *112*(5), 392-416.

Sagar, B. T. A., & Tullis, J. P. (1979). Downpull on vertical lift gates. *Water Power & Dam Construction*.

Sagar, B. T. A. (1978). Prediction of Gate Shaft Pressure in Tunnel Gate. Water Power and Dam Construction.

Smith, P. M. (1964). Hydraulic downpull on ICE harbor power gate. *ASCE*, 90, 193-213.

Thang, N. D., & Naudascher, E. (1983). Approach Flow Effect on Downpull of Gates. *ASCE*, 109, 11.