A statistical Model to simulate the Geometry of the Tunnel Gates Lips

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Abstract. The determination of the down pull force for the tunnel gates requires the estimation of the water pressure coefficient (KB), which is affected by the geometry of the gate lip and the water flow beneath the gate. The prediction of (KB) is depended upon the mean head pressure and the distribution of velocity along the bottom gate surface for each lip geometry. A statistical model is predicted to estimate the bottom water pressure coefficient (KB) of the down pull force for a tunnel gate lip.

This model is developed from relevant experimental data obtained from hydraulic model tests conducted in laboratory for nine gate lip geometries with nine gate openings for each gate lip geometry to ensure the correctness of the model results by comparing them these data. The statistical model is verified with (SPSS) software for a good correlation coefficient equal to (0.95). The statistical model is applied to reveal the distribution of the (KB) values on the gate bottom surface along the gate lips with different openings ratios between (0.1-0.9) and is indicated the extensions with round edge of the inclined gates lips. From the distribution of the (KB) values indicate that these values are high and vary smoothly along the gate lip for openings ratio between (0.1-0.5), with complete attachment from the leading edge to the trailing edge of the gate bottom surface. For other gate openings (0.6-0.9), the flow is attached at the leading edge of gate bottom and then decreased toward the trailing edge of gate with smooth variation. While the inclined gate lips with extensions reveal that the values of (KB) are approximately constant and uniform which representing stability of gate along the bottom gate surface for openings ratio between (0.1-0.5), and for other gate openings ratio these values vary smoothly from the leading edge to the trailing edge of the bottom surface of gate. Also, the influence of rounded edge of gate lip with (r/d=1) on the distribution of pressure head along the bottom surface of gate is investigated, where the values of the (KB) values are dropped and decreased toward the trailing edge of gate.

Key words. Bottom water pressure, Geometry of Tunnel Gates lips, Statistical Model.

1. General
In the absence of any fluid flow under the gate, that is completely submerged is subjected to hydrostatic pressure that produces a buoyant force. When water is passed beneath a gate lip, it creates a reduced pressure due to a change in energy from pressure head to velocity head. The downward hydraulic force on the gate is equal to the difference in pressure above and below the gate multiplied by the affected crosssectional area of the gate and is defined as down pull. By changing the shape of gate lip, or by
altering the flow passage, a pressure variation might be achieved which would reduce the hydraulic down pull, [3].

This force is influenced by various parameters which may be classified into three groups [5]. The first is the flow state which includes the type of flow whether free or submerged flow condition, operating head on the gate, aeration downstream the gate and turbulence characteristics of the flow. The second group includes the fluid properties such as specific weight of water, dynamic viscosity and vapor pressure. The third group is the geometry of gate installation which includes gate thickness, height of gate opening, conduit dimensions, angle of inclination of the sloping gate bottom with the horizontal, geometry of the lip and location, gate shaft dimension and thickness of skin plate. All these factors can be summarized by a dimensional analysis expression in non-dimensional form, as follows:

\[ KB = f(Re, IF, y/d, \theta) \]

Where, \( Re \): Reynolds number, \( IF \): Froude number, \( b \): tunnel width , \( B \): gate width, \( KB \): bottom pressure coefficient, \( \theta \): Angle between horizontal and slopping bottom of the gate, \( Q \): Total rate of flow, \( Q_1 \): Rate of flow released under the gate , \( X \): Distance measured horizontally from the leading edge of gate lip toward the trailing edge of gate , \( d \): Gate thickness , \( e \): Lip extension of the gate , \( y \): Height of gate opening , \( y_0 \): Tunnel height.

A large number of model studies and publications were predominately preoccupied with down pull force on high-head gates. These previous studies included an experimental models and analytical methods but modern studies present numerical models to estimate the down pull force on gates [2], developed a dimensional relationship for estimating the hydrodynamic forces depended on the effect of ventilation, geometry of gate bottom and clearance of gate shaft with its effect on the stability of gate [4], presented a one-dimensional form that can be used for estimating down pull force acting on high head leaf gate taking into account the effect of flow parameters and boundary geometry on it, as follows:

\[ Fd = (KT - KB) B d \rho (v^2/2) \]  
\[ KT = (HT - Ys)/(v^2/2g) \]  
\[ KB = \int [(Hi - Ys)/(v^2/2g)] db dx \]  
\[ K = KT - KB \]

Where, \( Fd \): down pull force, \( K \): down pull coefficient, \( KT \): Top pressure coefficient, \( HT \): piezometric head on gate top surface, \( Ys \): piezometric head in contracted jet, \( Hi \): piezometric head at a point on the gate bottom.

Sagar [6], published two empirical methods for predicted of down pull on vertical lift gate. These methods are down pull coefficient method which based on the data of Frot Randall dam outlet tunnel gate and pressure distribution method based on estimating the total force acting on the top and bottom surfaces of the gate. It was conducted that these methods are directly applied at the gate with shapes similar to those used in developing the formula. This formula was examined the geometrical factors influencing on the down pull force as follows:

\[ Fd = (y/y_0, He, e/d, b1/b2, dl/y_0, r/d, \theta) \]

Where, \((y/y_0)\): opening ratio, \((e/d, \theta)\): gate bottom geometry, \((b1/b2)\): gap width ratio, \((d1/y_0)\): thickness of gate, \((r/d)\): radius of curvature on the upstream bottom portion of the gate. \( He \): overall entrance loss that occurs between reservoir and gate section.
2. Aims of the study:
The main objectives of this study are:
1- Reformulating experimental hydraulic data for deferent tunnel gates lips with non-dimensional expression.
2- Predicting a statistical model to estimate the bottom water pressure coefficient and its variation with tunnel gate openings.

3. Experimental Investigation:
The case study used in this work is the experimental hydraulic model which presented by Ahmed [1]. The model was conducted in rectangular recirculation flume, (4m long, 0.2m wide, and 0.3m deep) with horizontal steel floor. The flume was covered along its upper part by a thick plate representing the tunnel roof as shown in figure 1. The gate shaft (0.3×0.15×0.9) m, was installed at mid way along the flume, it was made by steel and covered by the plate. The model gate made by a thick plate with thickness of (50mm) was supported by steel frame slide in vertical way of the gate shaft and it can be adjusted by a screw placed on the top cover of the shaft to control the gate openings. The exchangeable bottom plates of the gate made by steel blocks formed with (9) different shapes of gate lips as shown in figure 2, each of them was provided for two sets of tap located along the lip parallel to the direction of flow.

![Figure 1. Tunnel Model under operation [After Ahmed (1)].](image-url)
The experimental data of the hydraulic model can be summarized in table (1).

Table 1. Experimental Data of the case study. [After Ahmed (1)]

| $\theta$     | $\gamma/\gamma_0$ (%) | $H_u$(cm) (1) | $H_d$(cm) (2) | $H_i$(cm) | $H_T$(cm) | $V$(cm/sec) | Shape No. |
|--------------|------------------------|---------------|---------------|-----------|-----------|-------------|-----------|
| 35°          | 10-90                  | 73.5-71.5     | 30-69.7       | 69.7-71.3 | 72.7-71   | 43.5-1.2    | 1         |
| 42°          | 10-90                  | 73.5-70.25    | 39.5-68.9     | 27.5-69.1 | 73-69.9   | 37-1.3      | 2         |
| 45°          | 10-90                  | 73.5-70.5     | 40-68.5       | 53.7-70.4 | 75-70.1   | 35.5-1.6    | 3         |
| 55°          | 10-90                  | 72.9-70.0     | 38-69.2       | 59.5-69.5 | 72-69.9   | 34.5-1.3    | 4         |
| 45°, $e/d=0.42$ | 10-90                  | 75.5-70.5     | 30-68.7       | 69-70.6   | 70.5-70.4 | 42.5-2.3    | 5         |
| 45°, $e/d=0.64$ | 10-90                  | 73.5-75.0     | 30-74         | 69.6-74.8 | 71.7-74.6 | 43.5-1      | 6         |
| 42°, $e/d=0.6$  | 10-90                  | 70.5-69.8     | 30-67         | 51.2-67.9 | 69.3-69.1 | 40.5-2.8    | 7         |
| 55°, $e/d=0.2$  | 10-90                  | 73-72.5       | 30-72         | 62.7-72.5 | 70.7-72.3 | 43-0.5      | 8         |
| $r/d=1$      | 10-90                  | 73.5-71.6     | 52.5-70       | 67.8-71.5 | 73.3-71.4 | 21-1.6      | 9         |

(1): Piezometric head U/S of the gate.
(2): Piezometric head D/S of the gate after the hydraulic jump.
4. **Analysis of the case study:**

From the experimental data as shown in table 1 of this case study, a dimensional analysis expression in non-dimensional form can be used as follows:

\[
KB = f\left(\frac{x}{d}, \frac{e}{d}, \frac{ys}{yo}, \frac{V}{2g}, \frac{Hi}{2g^2} \right) \quad (5)
\]

Therefore, an analysis is investigated to statistical package of the social science (SPSS) software for the correlation to find a relationship between the dependent and the independent variables. A statistical model is built to establish an equation used to predict the \( KB \) for any lip geometry depending on the available data, which can present as:

\[
KB = \left[ -0.002\left(\frac{Hi}{ys}\right)^{-0.079} - 0.201\left(\frac{V^2}{ys^2}\right)^{0.139} + 3.853(\frac{\theta}{yo})^{0.633} - 0.202\left(\frac{\theta}{d}\right)^{1.908} - 0.753\left(\frac{V}{yo}\right)^{0.097} \right] \quad (6)
\]

Where, \( \theta \) is in radian.

This prediction is acceptable with good correlation coefficient of multiple determination \( R^2 \), equal to \( 0.95 \).

The statistical model with eq. (6), can be applied to illustrate the variation of the \( KB \) with different values of \( x/d \) for each opening ratio \( Y/Yo \) value and different gates shapes, as shown in figures (3-11).

![Figure 3. Variation of the bottom pressure coefficient for different gate openings. (shape No.1)](image-url)
Figure 4. Variation of the bottom pressure coefficient for different gate openings. (shape No.2)

Figure 5. Variation of the bottom pressure coefficient for different gate openings. (shape No.3)

Figure 6. Variation of the bottom pressure coefficient for different gate openings. (shape No.4)
Figure 7. Variation of the bottom pressure coefficient for different gate openings. (shape No.5)

Figure 8. Variation of the bottom pressure coefficient for different gate openings. (shape No.6)
Figure 9. Variation of the bottom pressure coefficient for different gate openings. (shape No.7)

Figure 10. Variation of the bottom pressure coefficient for different gate openings. (shape No.8)

Figure 11. Variation of the bottom pressure coefficient for different gate openings. (shape No.9)
Figures 3-6 indicate the distribution of (KB) values on gate bottom surface along inclined gate lips where, these values are high and vary smoothly along the gate lip for openings ratio between (0.1-0.5). For other gate openings (0.6-0.9), the flow is attached at the leading edge of gate bottom and then decreased toward the trailing edge of gate with smooth variation. While figs. (7-10), present the inclined gate lips with extensions at the trailing edge of gate, these lip extensions provide a stabilizing influence on the distribution of (KB) along the bottom surface of gate. And fig. (11), investigate the influence of round edge of gate lip (r/d=1) on the distribution of pressure head along the bottom surface of the gate, where the values of the (KB) values are dropped and decreased toward the trailing edge of gate.

5. Conclusions:
A statistical model is predicted from the dimensional analysis of the relevant experimental data obtained from hydraulic model tests conducted in laboratory for nine gate lip geometries with nine gate openings. This model is used to estimate the bottom pressure coefficient (KB) which can be applied to calculate the down pull force for a tunnel gate lip.

This model also may be utilized for any lip geometry and the bottom pressure coefficient have a main effect on the down pull force, which is influenced by the flow beneath the gate and the gate lip geometry. The statistical model is revealed the distribution of (KB) values on the gate bottom surface along the inclined gate lips which are varied smoothly along the leading edge of the gate lip for openings ratio between (0.1-0.5) and these values are decreased at the trailing edge of this gate for openings ratio (0.6-0.9).

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