Pressure Coefficients of Curved Lip of Vertical Lift Gate in Dam Tunnels

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Abstract: The vertical lift gate shaft is installed across the dam tunnel to regulate the flow rate passing toward the downstream side to satisfy the water demand in addition to the power generation requirements. The flow through the shaft is mostly divided into two parts, over and below the gate, and as a result, two forces will be created, vertically ,downward and upward on both top and bottom gate surfaces. The difference between these forces produces so-called hydrodynamic force or hydraulic downpull force which has a vital effect on gate operation, so that in the case of negative values, this force will prevent the closure of the gate. The downpull force influences by many parameters, however, the geometry of gate is considered as one of the most common effective factor that influence the values and behavior of downpull force. In present study, physical hydraulic model is used to assess the effects of different rounded gate lip shapes on downpull force with respect to different gate opening ratios. The variation of bottom pressure coefficient along the gate surface has also been studied and the results are discussed.

Keywords: Downpull, Pressure Coefficient, Rounded Gate Lip

1. Introduction

The vertical lift gates subjected to many hydrodynamics forces due to the potential of pressurized water flow passing through the dam tunnel. The water flow just before the gate shaft takes two directions above and beneath the gate and in accordance with that, two vertical forces with opposite directions will created. The net force that has been obtained from the difference of these two forces, and called as downpull force, is considered an important reference for safe and economic design of the gates.

Many hydraulic and geometrical parameters affect the downpull force and have been studied by many researchers which their researches based upon one or both of experimental and mathematical approaches. The flow conditions, gate lip geometrics have been examined and a lot of results were analysed and suggestions being recommended. The effects of aeration, gate lip shape and the clearances sizes on forces issued by pressurized flow and hence on the gate stability was studied by Cox et al (1960).The study was used as guidance for next researches. The force exerted by air tunnel flow on vertical lift gate has received a great attention by Naudascher et al (1964).The effects of different flow conditions and gate lip shapes were considered and the main results were formulated by the following expressions:

$$F_d = (K_t - K_b).\gamma.B.d \qquad (1)$$

Where:

F_d = *downpull force, N,*

$K_t = 2g.(H_t - H_d)/V_j^2$,

$K_b = 2g.(H_i - H_d)/V_j^2$,

B = gate width, m,

d = gate thickness, m

γ = *water mass density,* N/m^3*, and*

V_j = *velocity of the contracted jet issuing from underneath the gate, m/sec.*

H_t= *Piezometric head on gate top surface,*

H_d=*Piezometric head just downstream the gate shaft m, and*

H_i=*Piezometric head at a point on the gate bottom, m.*

Two empirical methods were suggested by Sagar (1977) to evaluate the downpull forces, first one named as downpull coefficient which is based on Fort Randall Dam data, and the second is termed as pressure distribution method which is most common and based on estimating the forces acting on the top and bottom surfaces of the gate. These two methods are applicable for similar gate shapes.

The intensity of pressure and its distribution pattern were studied by Bhargava and Narasimhan (1989) for the gate under the specific frequencies and amplitude of vertical vibration was obtained by the integrating of the pressure fluctuations profiles over the gate thickness was used to obtain the total intensity of pressures on vibrating gates. The study specifies a pressure of common frequency which is considered as critical condition for gate design.

The effects of vibration created by the separation and reattachment of flow along the vertical lift gate bottom surface were examined by Thang (1990). The different lip geometries and flow conditions were considered and the study revealed that the fluctuation was caused by combined action of the vortices established just upstream the gate and unbalanced shear layer below the gate. The analysis leads to indicate the critical range of gate opening corresponding to potential gate vibrations.

The one dimensional finite element model based upon the velocity and mean pressure distribution along the bottom gate surface conducted by Al-Kadi (1997). The model was verified with the results of analytical prediction and gave a good agreement. The experimental work was conducted by Ahmed (1999) to study the effect of many gate geometries on downpull force. The study concludes that the downpull coefficient is influenced significantly by gate geometry and gate opening.

The experimental pressure distribution measurements along the bottom surface of different gate geometries were carried out by Aydin et al (2006). The results of measurements were used to evaluate the downpull forces for both cases of stationary and closing modes. The results of measurements were verified with the Predicted mathematical model order to confirm its validity.

The high head smooth upstream gate face of was exhibited by Markovic et al (2013) to study the effects vertical opening installed within the gate body on hydrodynamic forces. It is found from the various attempts of tests on different models that an expansion in vertical openings of the gate leaf will lead to produce significant reduction on hydrodynamic forces.

The ANSYS FLUENT programming was used by Uysal in 2014 to predict the downpull forces on intake gate of dam tunnel. The results obtained from the mathematical model were compared with experimental measurements and a very good agreement was observed.

The random hydraulic model was used by Taher et al (2016) to study the effects of different gate lips shapes on the values and distribution of downpull force. The study concluded that the gate openings ratios have inversely effects on values of bottom pressure coefficient (Kb) and hence on downpull force. In addition, the study indicated that the gate lip geometry influences the behavior of stream lines due to their attachment and reattachment and accordingly the values of (Kb) are affected.

In the current study, the pressure fluctuation on two different curved gate lip shapes of vertical lift gate is examined. The study investigated numerous hydraulic parameters that influence the values and distributions of pressure heads for various gate openings. The validity of the results is indicated by the comparison with corresponding cases of previous related works.

2. Experimental Set Up

The measurements were conducted in a rectangular glass recycling flume, 4m long, 0.2 m wide, and 0.3 m deep with horizontal steel bottom floor. The top of flume was covered by thick plate representing tunnel. The gate model made by thick plate (0.5 m x0.2 mx0.05 m) and supported by a steel frame slides in the vertical path of the steel gate shaft (1m x 0.3 m x 0.15 m). The gate can be adjusted by a screw placed on the top cover of the shaft to control the gate openings. The end of tunnel model was provided by control gate to satisfy the requirements of pressurized flow. The schematic layout of the tunnel is shown in Fig.(1-A).

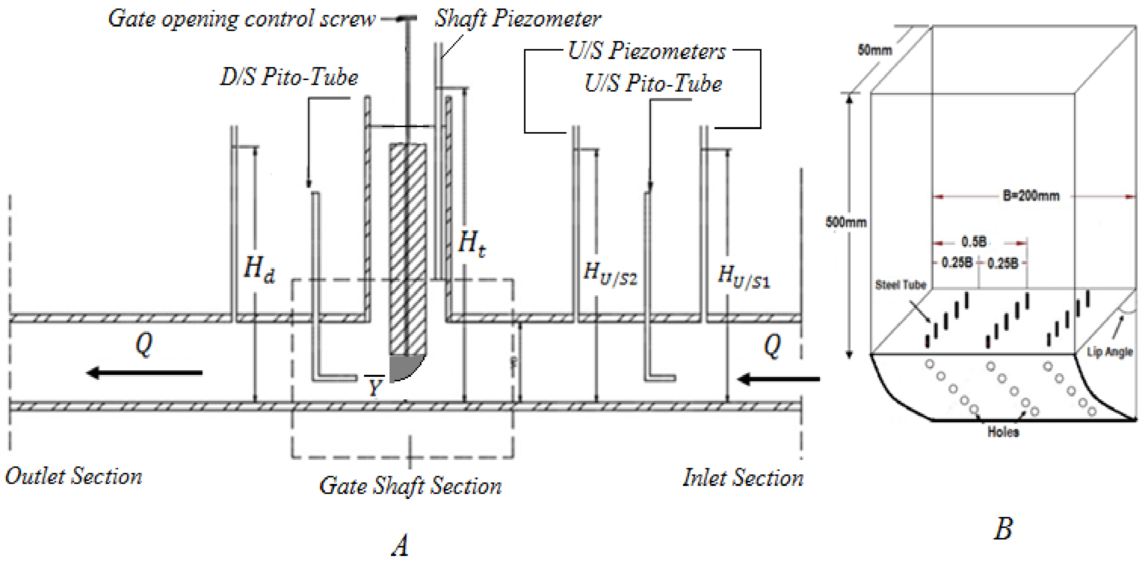

Figure 1: Schematic layout of the tunnel

Ten taps with 4 mm diameter for pressure head measurements were drilled on two parallel lines along the gate bottom surface .The first and second five taps were located at distances of 0.25 B and 0.5 B respectively from the gate edge. A small length of steel pipe of the same diameter inserted in each tap and then connected to piezometers board through plastic tubes. Two pito-tubes were installed upstream and downstream the gate shaft one to measure the mean velocity and the other for jet velocity just below the the gate. Fig. (1-B) shows the main details of gate model.

3. Results and Discussion

The experiments were conducted by the run of hydraulic model and the required measurements regarded to evaluating the downpull force were carried out.The top and bottom piezometric heads are necessary for determination of the top and bottom pressure coefficients (Kt and Kb) and consequently the downpull force coefficient. In current study, the attempts are made to investigate the influence of rounded edge of gate lip (r/d=1 and r/d=1.5) on the pressure coefficients as well as on the distribution of piezometric heads along the bottom gates surface and the values of all coefficients (Kt,Kb, and Kd) were obtained by using equation (1).

Figure 2 shows the variation of downpull coefficients with gate opening ratios for rounded gate lip shape with (r/d=1). It can be seen from the figure that top pressure coefficient (Kt) is uniformly varied with gate opening ratios and no significant change in values are observed. However, the intangible variance in values of bottom pressure coefficient (Kb) is appeared, which means that the downpull coefficient (Kd) is influenced mainly by (Kb) values. The (Kb) profile started from low values for gate opening ratio (Y/Yo=10%) and increased up to (Y/Yo=30%) beyond which the (Kb) profile moved with approximately constant values (Kb=0.6) and then increased obviously to attain the maximum values when (Y/Yo) becomes more than (70%).The sudden increase in (Kb) values caused the downpull coefficients to be negative for (Y/Yo ≥75%).The main conclusion states that the large gate openings lead to increase bottom pressure coefficient ((Kb) and reduce the values of downpull coefficient (Kd) Which indicates the probability of a problem on the prevention of occurrence of the closure of the gate.

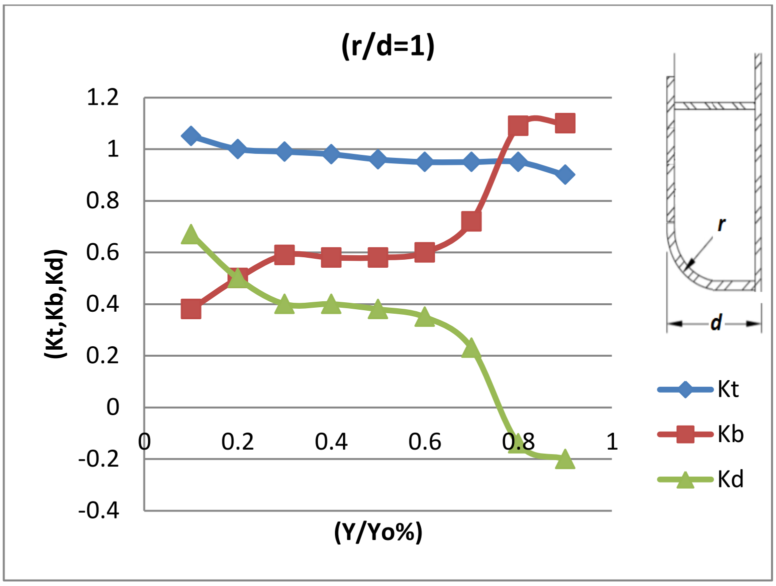

Figure 2: The variation of downpull coefficients with gate openings for r/d=1

Figure (3) with (r/d=l) and (Y/Yo =10%, 20%, 30% and 40%) reveal that (Kb) values are dropped uniformly with from its maximum values (Kb=0.8) at the leading edge up to (Kb=0) at trailing edge except (Y/Yo=10%) where the minimum (Kb) value ended at (0.4). However, the general view of (Kb) distribution indicated that the uniform decrease in values of (Kb) kept the flow stream lines with poor attachment to the bottom gate surface and no separation has been occurred.

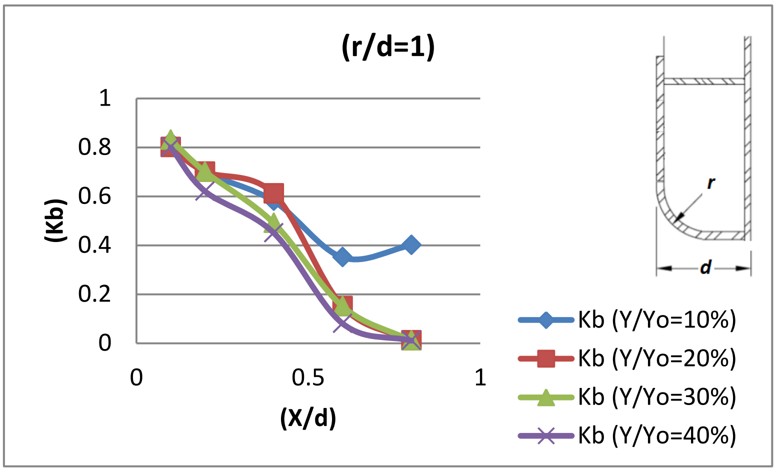

Figure 3: The variation of bottom pressure coefficient (Kb) along the bottom gate surface for each gate openings

Figure(4) shows the distribution of (Kb) values with (X/d) for (Y/Yo=50%, 60%, 70%, 80% and 90%).A general reduction in (Kb) values from leading edge toward trailing edge is observed especially for gate opening ratios of (Y/Yo=50%,60% and 70%) ,whereas, a relative higher values with same trend are indicated for (Y/Yo=80% and 90%) .As it can be noticed from the figure, that the (Kb) values are greater than those of low (Y/Yo) showed in figure (3), thus , a strong attachment of flow stream lines with the bottom gate surface is established and referred to better level of gate stability due to less probability of vibration occurrence.

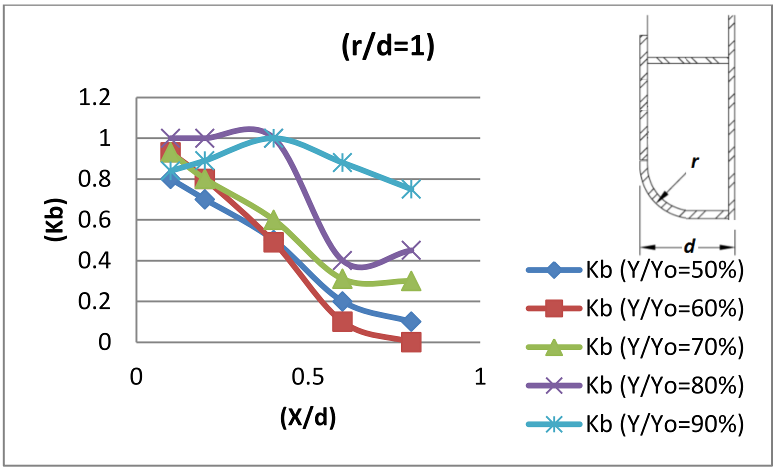

Figure 4: The variation of bottom pressure coefficient (Kb) along the bottom gate surface for each gate openings

The effects of rounded gate lip shape with (r/d=1.5) on downpull coefficients has also been studied .Figure (5) demonstrates that the (Kb) values profile decreased rapidly from high value at (Y/Yo=10%) toward low approximately uniform values along the gate opening ratios (Y/Yo= 20%, 30%, 40% and 50%).The increase in (Y/Yo) more than (50%) accompanied with sudden rising in (Kb) profile so that the maximum (Kb) values are attained and varied slightly for remaining large (Y/Yo) values. In view of slight change of (Kt) values profile, the downpull coefficient (Kd) values are influenced effectively by (Kb) values. Consequently, the high values of (Kb) lead to decrease (Kd) values to the extent that it generated negative values and could pose a challenge and a problem for the possibility of gate closing as indicated for gate opening ratio (Y/Yo=80%).

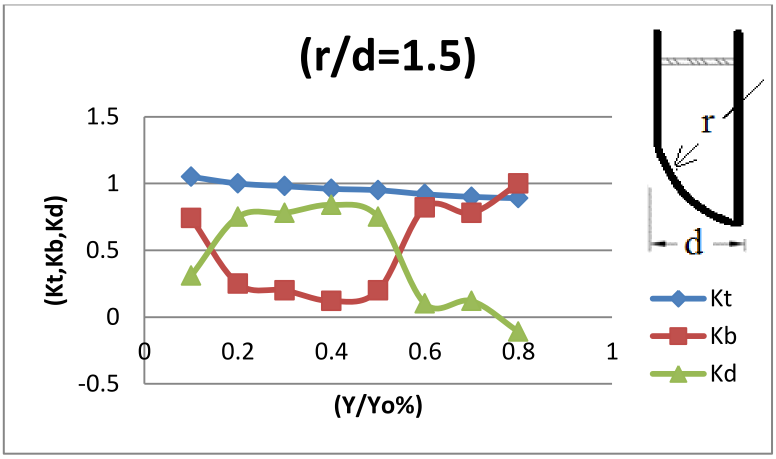

Figure 5: The variation of downpull coefficients with gate openings for r/d=1.5

Due to the determinants of rounded gate lip shape with (r/d=1.5) which did not accommodate all five taps , only the middle three taps were used rather than five to measure the bottom pressure. Figure (6) shows the variation of (Kb) values along the bottom gate surface for gate opening ratios (Y/Yo =10%, 20%,30% and 40%) .It is obvious from the figure that for distance between

(X/d=0.4) and (X/d=0.6), The (Kb) values are changed from high to low values and continue with invariant values toward the trailing edge. Also the figure indicates that at trailing edge, the (Kb) value for (Y/Yo=40%) is less than others considered ate opening ratios.

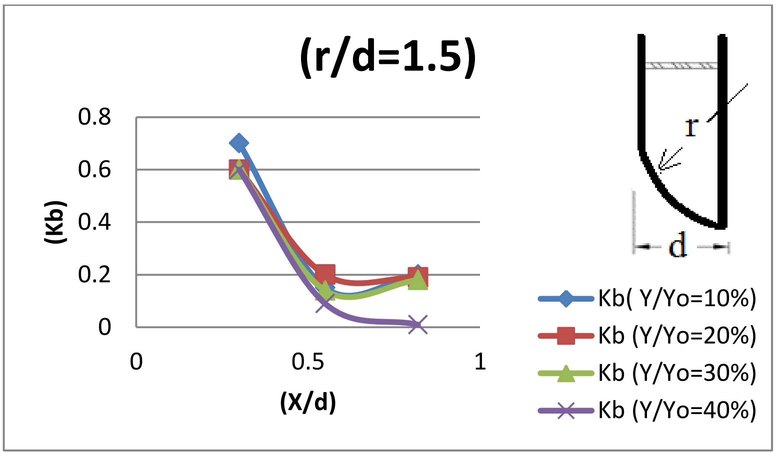

Figure 6: The variation of bottom pressure coefficient (Kb) along the bottom gate surface for each gate openings

Figure (7) indicates that the (Kb) values are decreases as (X/d) increases toward the trailing edge; furthermore, the general rate (Kb) values are increased as gate opening ratios increased. Hence a poor attachment of flow is observed for small gate opening ratios which accordingly may lead to some extent of gate instability.

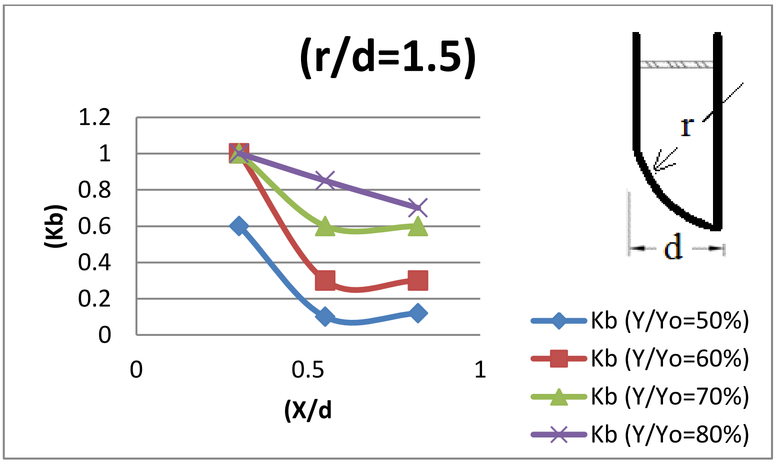

Figure 7: The variation of bottom pressure coefficient (Kb) along the bottom gate surface for each gate openings

3.1. Comparison with Previous Works

Naudascher, et al (1964) [12], were used the analytical method for determining downpull forces based on the effects of gate geometries and jet velocity through vena-contracta under the gate. The downpull force was estimated as the difference between the top and bottom pressure coefficients which applied for various gate lip shapes including the rounded lips with different ratios of (r/d). Figure (8) shows the comparison between the results of (Kb) obtained from the current study where gate lip shapes are with (θ=45^o and r/d= 1 and 1.5) and those obtained from [12] where (θ=45^o and r/d=0.4) .It can be seen from the figure that the (Kb) values for gate lip shapes with (θ=45^o and r/d= 0.4) are decreases from high values at small gate openings up to (Kb=0.6) which created for (Y/Yo=30% up to 90). A slight change in (Kb) values along all gate opening ratios is observed for gate lip shape with (θ=45^o and r/d=1) which has a greater values than other considered gate lip shapes. Accordingly, it is expected that in the case of invariant top pressure values, the downpull force will be greater with gate lip shape of (θ=45^o and r/d=0.4) which may lead to prefer the gate lip shape with (θ=45^o and r/d= 1) to be considered due to the limited impact of downpull force, in addition to ease of manufacturing this shape specifications when compared with other forms of gates. The figure also shows a clear non- uniformity of (Kb) values for gate lip shape with (θ=45^o and r/d=1.5), the values of (Kb) are decreased as the gate opening ratios increased up to ((Y/Yo= 40%) and then turn to increase with the increase in gate opening ratios and reached its maximum values beyond (Y/Yo=60%).

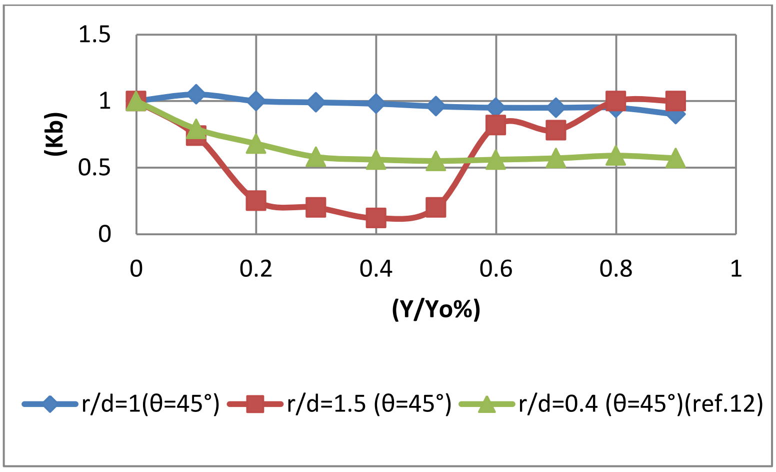

Figure 8: The variation of bottom pressure coefficient (Kb) along the bottom gate surface for each gate openings

4. Conclusions

Based on the current work, pressures coefficients for new cases of (r/d) of vertical lifts are presented, and the following conclusions can be drawn:

1-The top pressure coefficient values (Kt) are slightly changed with gate opening ratios and seem to be independent to gate geometries and hence have no significant effects on distribution of downpull coefficients.

2- It is found that for gate lip shape with (θ=45^o and r/d=1) , the (Kb) values increase as the (Y/Yo) increases whereas for (θ=45^o and r/d=1.5) are dropped rapidly from high value at (Y/Yo=10%) toward low values along the gate opening ratios (Y/Yo= 20%, 30%, 40% and 50%) and then suddenly turned up to attain maximum values for remaining (Y/Yo) values.

3- The (Kd) values for (θ=45^o and r/d=1) are decreased continuously and reached near negative values at large gate openings and such case is earlier occurred for (θ=45^o and r/d=1.5) where the gate opening ratio (Y/Yo ≥ 50%).

4-The (Kb) values for (θ=45^o, r/d=1and r/d=1.5) and all gate openings ratios are generally decreased along the bottom gate surface and hence a poor attachment has been indicated especially near the trailing edge of gate.

5-The large gate openings leads to increase (Kb) values.

6- The values of (Kb) for (θ=45^o and r/d=1) are higher than those obtained for (θ=45^o and r/d=0.4) [12], and accordingly, it can be stated based on this work that in the case of invariant top pressure values ,the downpull force will be greater with gate lip shape of (θ=45^o and r/d=0.4). In general, the magnitudes of downpull force obtained from the use of lip shape with (r/d = l) are less than those of (r/d=0.4 and r/d=l .5).

7-The (Kb) values of the (θ=45^o and r/d=1.5) are approximately close to those for (θ=45^o and r/d=1) just for (Y/Yo≥60%).

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