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Determination of Shape Co-efficient and Drag Co-efficient of Triangular Piers under Sub-Critical Flow Conditions

Nikhil Agarwal, S. Sree Ram and C.R. Suribabu

Centre for Advanced Research in Environment, School of Civil Engineering, SASTRA University, Thanjavur, India

Corresponding Author: C.R. Suribabu, Centre for Advanced Research in Environment, School of Civil Engineering, SASTRA University, 613401, Thanjavur, India Tel: 0091-4362-264101 Fax: 0091-4362-264120

ABSTRACT

The piers to the bridge are very important component for the stability of bridge structure. These piers need to be placed within the channel width in addition to the abutment wall on either side of water ways. This arrange in the bridge structure obstruct the flow and may cause an increase in water level on upstream side of the bridge. This increase in water level is termed as afflux and this afflux may create adverse impact on the stability of bridge and responsible for scouring action around the bridge pier especially during flood flow. In the present work, the drag characteristic of bridge piers with respect to its shape is studied. Rectangular model with triangular nose and tail shaped pier models are made for various aspect ratios with constant contraction ratio of 0.4. The experiment is conducted for sub-critical flow conditions in a flume having rectangular flow section. The afflux, drag force and coefficient of drag are calculated for different discharge values and their variations with respect to Froude number are studied. On comparing the experimental results with the Yarnell's formula, the most widely used empirical equation for calculation of backwater rise; it was found that the Yarnell's equation gives over estimated results. In the present study, a different shape co-efficient value (K) with respect nose dimension is determined and suggested. This new K value can be used for triangular shaped bridge piers having a various aspect ratio. It was found that the rise in water level due to bridge pier is a function of aspect ratio, pier shape and Froude number.

Key words: Shape coefficient, bridge piers, yarnell's equation, afflux

INTRODUCTION

The bridge superstructure rest on piers which act as main support for the bridge. No matter what be the shape of pier, the obstruction of flow within the channel is inevitable. The obstruction results in an increase in the water level on the upstream side of the piers, thus causes an adverse impact on the stability of bridge. It also results in scouring action in the bridge piers. The amount of obstruction depends mainly upon the geometric shape, the position in the stream of the bridge pier, thickness of piers and flow rate. Charbeneau and Holley (2001) explained the importance pier shape and its influence on channel obstruction and its hydraulic efficiency. The rise in the water level due to bridge piers and abutments, for sub critical flow, is assumed to occur where the flow contraction begins upstream of the bridge. Energy loss in the flow is caused by drag forces on the bridge piers and results in consequent increase in water level on the upstream of the piers under subcritical flow conditions. The drag force on the water is equal and opposite of the force on the pier

and is combination of friction drag and pressure drag. When the wake resistance becomes significant, one is usually interested in the total drag only which is the case with bridge piers. The total drag can be calculated using momentum equation. Uplift of the deck slab is also possible when the level rise in the upstream equals the pier height. Velocity on the upstream and downstream of the piers also influences the drag force. Lot of research has been carried out on backwater effects from channel obstructions and a few studies related specifically to bridge piers (Charbeneau and Holley, 2001). Sreelash and Mudgal (2010) conducted an experimental work to establish the drag characteristics of cylindrical piers with different slot-collar combinations. The current work attempts to evaluate the water level change due to bridge piers and to study the nature of the variation of water surface upstream of the piers. Also, the drag characteristic of bridge piers of triangular shape is evaluated. In the present study, variation of experimental values of $\Delta y/y$ with empirical relation given by Yarnell (1934) for higher values of contraction ratio is studied and a new shape co-efficient to suit higher values of contraction ratio 0.4, of triangular shaped piers is proposed.

Calculation of drag coefficient and froude number: The drag experience by the pier model is obtained by applying the linear momentum equation. Neglecting boundary friction, the linear momentum equation may be written as:

$$P_1 - P_2 - F_d = \rho Q (V_2 - V_1) \quad (1)$$

where, P_1 and P_2 are the hydrostatic pressure forces on the upstream and downstream respectively, F_d is the drag force on the model, ρ is the mass density, Q is the discharge, V_1 and V_2 are average velocities on the upstream and downstream.

The drag force F_d is given by:

$$F_d = \frac{1}{2} C_d \rho V_1^2 A \quad (2)$$

where, C_d is the coefficient of drag and A is the projected area (i.e. $d \cdot y_1$) of the model obstructing the flow, d is the width of the pier and y_1 is the upstream flow depth.

The Froude number is calculated using:

$$F_r = \frac{V}{\sqrt{gy}} \quad (3)$$

where, F_r is the Froude number, V is the average velocity, y is the height of water level and g is the acceleration due to gravity.

Yarnell's equation for backwater rise: The most widely used empirical equation for calculating the increase in the water level due to bridge piers is the Yarnell (1934). Yarnell conducted 2600 laboratory experiments by changing the shape of the piers, the width, the length, the angle and discharge to develop empirical equation. The equation estimates the height of water surface just at the upstream of the bridge for given height of water surface just at the downstream of the bridge with respect to the shape of the piers. The equation accounts for the velocity of flow, area obstructed

by the piers and the pier shape. But, it is not sensitive towards the shape of the abutment, wing walls and shape of bridge opening. Hence, it is suitable at which energy losses are mainly due to the piers.

The ratio of backwater rise to the undisturbed water level under sub-critical flow condition is given by:

$$\left[\frac{\Delta y}{y} \right]_{\text{empirical}} = K(K + 5F_r^2 - 0.6)(\alpha + 15\alpha^4)F_r^2 \quad (4)$$

Where:

Δy = Backwater generated by the bridge pier

y = Original (i.e., undisturbed) local flow depth

F_r = Corresponding Froude number downstream of piers

α = Ratio of the flow area obstructed by the piers to the total flow area downstream of the piers

K = A coefficient reflecting the pier shape

According to Yarnell, the shape coefficient of pier with triangular nose and tail is 1.05.

Experimental setup: Rectangular shape pier with triangular nose and tail of constant contraction ratio of 0.4 are made for 4, 6, 12 and 16 cm length (parallel to flow) with height 15 cm using wood. Experiments are conducted in hydraulic tilting flume of 4 m length, 0.15 m wide. The flume consists of a rectangular channel with transparent side walls. Water from the supply pump is supplied to the flume inlet section through a gate valve and a flexible hose. This water after passing through the stabilization zone, flows in the transparent test section and returns to the sump tank. Discharge was measured using orifice meter provided at the inlet pipe. The height of the water level both in upstream and downstream of the channel after the placement of the pier is measured using pointer gauge. Flow rate is controlled by a valve available next to the pump. Schematic profile of the river in the vicinity of the pier is shown in Fig. 1. Sub-critical flow condition was created for all the experiments. The depth of flow at the upstream and downstream is measured at the control points as shown in the Fig. 2.

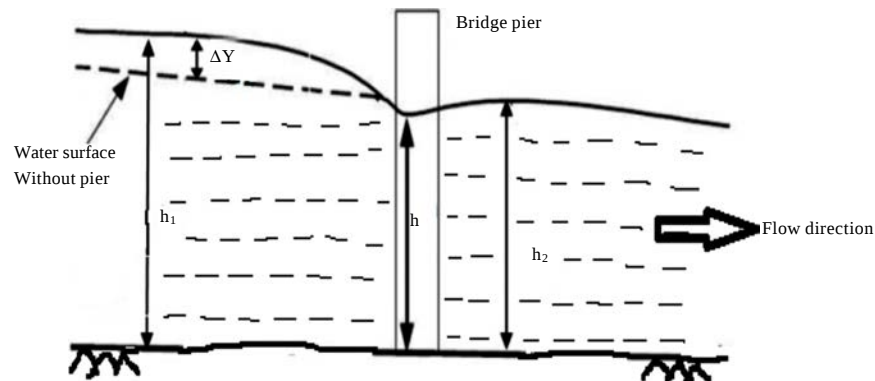


Fig. 1: Schematic profile of the river in the vicinity of the pier

RESULTS AND DISCUSSION

The experiment results (Fig. 3) shows that the drag force increases with increases in discharge irrespective length of pier. The drag co-efficient for each model is evaluated using 1 and 2. By varying the flow rate in the channel, drag force and corresponding drag co-efficient is evaluated. Table 1 shows the average drag co-efficient for various aspect ratio. The aspect ratio is calculated by taking the ratio of thickness of the pier and length of the pier model. The thickness of all the pier model is kept as 6 cm in order to have a constant contraction ratio of 0.4. It is evident from the Table 1 that the value of C_d is less for lower aspect ratio. When length of the pier increases, boundary layer growth will more and therein the area for free stream velocity is considerable getting reduced when the length of the pier increases. This could be main reason in which the increased value of drag is anticipated. It is obvious that increase in the discharge results in the higher value of Froude Number for all the aspect ratio as shown in Fig 4. Figure 5 show the various shape co-efficient with respect to discharge. There is a decreasing trend of shape co-efficient value while increase in the discharge. From the Fig. 6, it is found that the suggested K value is inversely proportional to the discharge. Thus, the value of Δy which is directly proportional to K, will also decrease as Q increases. The value of K has also been found to decrease as the Froude number



Fig. 2: Position of measurement at upstream and downstream depths

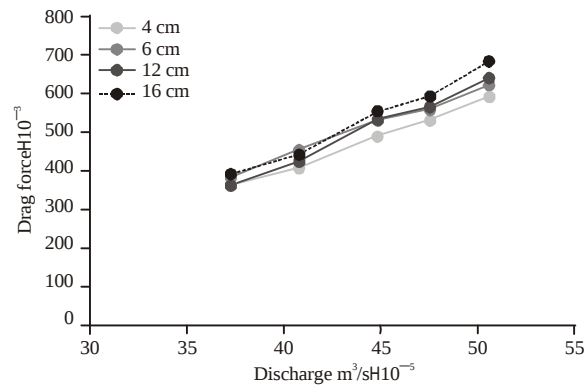


Fig. 3: Discharge vs. drag force

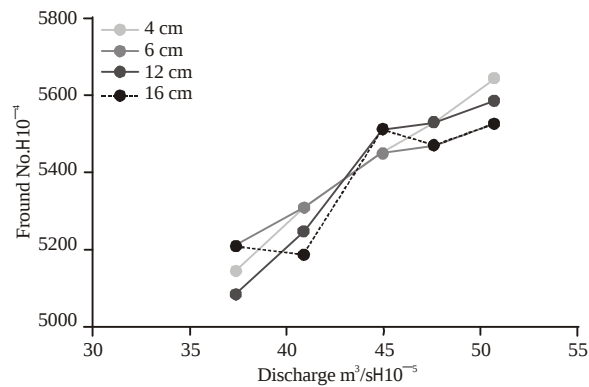


Fig. 4: Discharge vs. Froude No.

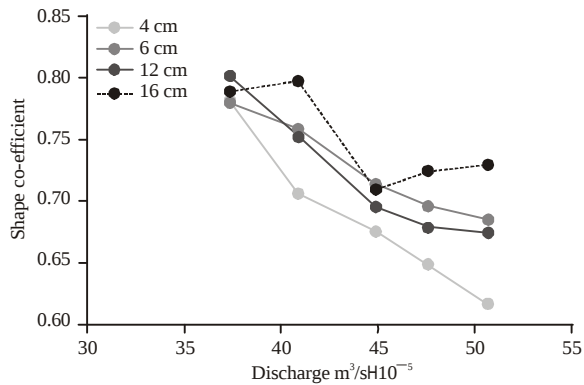


Fig. 5: Discharge vs. shape co-efficient (K)

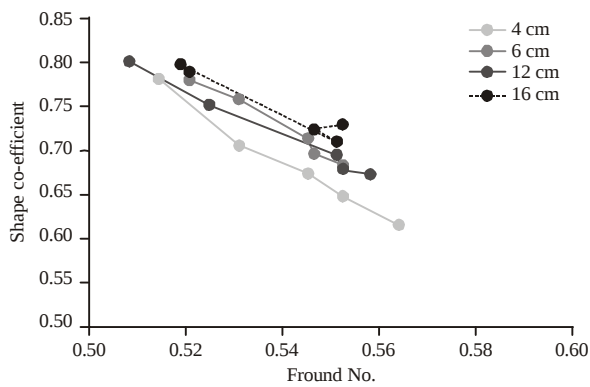


Fig. 6: Froude No. vs. shape co-efficient (K)

Table 1: Co-efficient of drag	
Aspect ratio (Thickness/Length of rectangular portion)	C _d
6 : 4 (3:2)	1.77
6 : 6 (1:1)	2.11
6 : 12 (1:2)	2.04
6 : 16 (3:8)	2.34

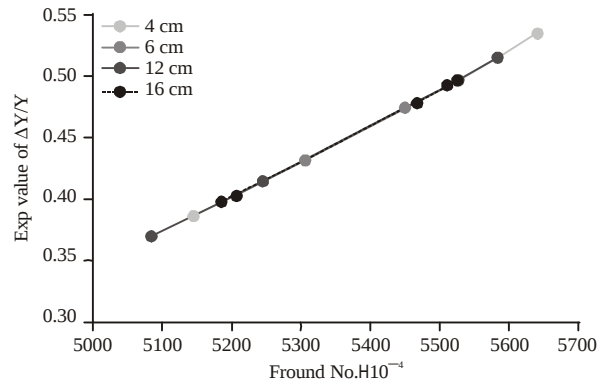


Fig. 7: Froude No. vs. experimental values of $\Delta y/y$

increases as shown in Fig. 6. The variation of $\Delta y/y$ with Froude number calculated based on the downstream side depth of flow. The value of Froude number is found to vary between 0.50-0.57. Due to larger wake formation at the downstream side of the pier, the effective flow area decreases on the downstream side which increases velocity of flow and therein Froude number. This depicts that the backwater rise on the upstream bridges for subcritical flow is directly proportional to the downstream Froude number as shown in Fig. 7. The experimental values of $\Delta y/y$ are found to be much lesser than the $\Delta y/y$ values calculated using Yarnell's equation. Similar observation was made by Martin-Vide and Prio (2005). It is to be noted that all the experiments are conducted rigid side flume.

CONCLUSIONS

The following observations are made from the experimental results:

- The experiments conducted on drag characteristics show that the value of C_d depends upon the aspect ratios of the pier
- The backwater rise on the upstream side of bridge for subcritical flow between piers is directly proportional to the value of the downstream Froude number (Fr) irrespective of contraction ratio and slope
- The shape coefficient is found to be inversely proportional to discharge, irrespective of the contraction ratio and slope
- The backwater rise on the upstream side decreases with increase in discharge for each aspect ratio
- The suggested value of K increases with increase in backwater rise in the upstream side
- The suggested value of K is inversely proportional to the downstream Froude number (Fr), irrespective of the aspect ratio
- The water level changes ($\Delta y/y$) measured in this study are generally smaller than those calculated using Yarnell's equation for backwater caused by bridge piers
- The experimental value of ($\Delta y/y$) is found to be same for particular value of Froude number irrespective of the aspect ratio

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