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Flow Mechanism around Bridge Abutment Models

Upain Kumar Bhatia* and Baldev Setia**
*(Civil Engineering Department, M.M. Engineering College Mullana, Haryana.
Email: bhatia_u@rediffmail.com.)
** (Civil Engineering Department, N.I.T. Kurukshetra, Haryana,
Email: setia_b@rediffmail.com)

ABSTRACT
The paper presents the results and analysis of laboratory studies on understanding the mechanism of flow modification and scouring around an abutment with the help of flow visualization techniques. These techniques have been selectively used for comprehensive study of the entire flow region around an abutment. These techniques have been categorized to understand the flow modification in three different domains that include *Surface flow region*, the *intermediate layers* and the area near the *sediment-structure interaction junction*. The techniques include Wet Paint Technique, Reflective Powder Technique and Dye Injection Technique. Different flow fields have been observed and photographed and a comprehensive flow modification around abutment models has been presented.
***Keywords* -** Abutment, Flow Visualization, Flow Fields, Mechanism

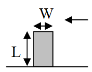
I. INTRODUCTION

Flow pattern and mechanism of scouring around an abutment is a complex phenomenon resulting from the strong interaction of the three-dimensional turbulent flow field around the bridge foundations and the erodible sediment bed. Adverse pressure gradient along the upstream face of the abutment creates a down-flow which after impinging the bed returns and creates the primary vortex. The obstruction due to the abutment deflects and accelerates the flow towards the constriction zone causing separation of flow from the upstream corner of the abutment and generation of turbulent wake vortices. Secondary vortices are generated because of the shearing effect of the wrapping primary vortex. These vortices are generated in the outer portion of the developing scour hole. Principal vortex, which is analogous to the horseshoe vortex around bridge piers, is primarily responsible for scour-hole development around bridge abutments. Many researchers including Barbhuiya and Dey[1], Dey and Barbhuiya [2], Gangadharaiah et al. [3], Kothyari and Ranga Raju [4] and Kwan [5] have attempted to visualize and analyze the flow fields around abutments.

This paper is the result of an experimental investigation in two water flumes 1 and 2 that deals with the studies on understanding the physics of flow modification and mechanism of scour around a vertical wall abutment with the help of flow visualization tools and techniques.

The models used in the study have been presented in table 1, where L = Abutment length, W = abutment width, B = flume width, y = flow depth and T = water temperature.

Table 1: Models of abutments used for the visualization study

Model No.	Configuration (Plan)	L (cm)	W (cm)	B (cm)	y (cm)	T (°C)	Reynolds No.	Material
1		3.3	3.3	15	6	8	860	Acrylic
2		6.6	3.3	15	6	8	860	Acrylic
3		10	3.3	15	6	8	860	Acrylic
4		3.3	6.6	15	6	8	860	Acrylic
5		3.3	10	15	6	8	860	Acrylic
6		3.0	1.5	25	7.5	28	10000	Wood
7		2.6	6.0	25	7.5	28	10000	Wood

II. TECHNIQUES ADOPTED

Flow visualization techniques have been selectively used for comprehensive study of the entire flow region around an abutment. These techniques have been categorized to understand the flow modification in three different domains. These domains include Domain A: Surface flow modification, Domain B: Flow modification in intermediate layers and Domain C: Area near the sediment-structure interaction junction (near the bed). Reflective Powder Technique, Dye Injection Technique and Wet Paint Technique have been used for Domains A, B and C respectively.

2.1 Domain A: Surface Flow Modifications

The essential requirements for visualization in this domain include a tracer material which can float on the water surface without affecting the flow characteristics; tracer dispenser; lighting arrangement and photography arrangement. The *reflective powder technique* was found suitable. Commercially available powdered metallic silver paint (without binder) was sprinkled on the water surface through a specially fabricated dispenser. The flow patterns were captured as the flow passed around the abutment. The results have been presented in the form of long exposure photographs. The exposure time of these photographs varies from 4 to 8 seconds. Thus, these images show the flow lines by tracing the paths of fine particles of reflective powder for 4 to 8 seconds.

Fig. 1 shows flow modification due to a vertical wall abutment (model 1) wherein the protruding length of abutment was kept 3.3cm. In these photographs, the abutment is found to deflect the oncoming flow towards the zone of constriction. Also, the point of flow separation can be clearly observed in the photographs. The water in the wake zone has come in circulating motion (*Wake eddies)* under the shearing effect of the flow through constriction zone. The wake eddies are always associated with small water mass just behind the abutment, in the form of counter-rotating eddies. Intermittently, the grains of reflective powder escape from these eddies and move towards the point of flow separation. This movement takes place in the constriction zone and is opposite to the main flow. This is henceforth being referred to as *Wake Reverse Flow* for the convenience of discussion in the present study. Fig. 2 presents a series showing the effect of width of abutment model on the flow modification. Three vertical wall shaped abutment models of widths 3.3cm, 6.6cm and 10cm were tested with their length kept same at 3.3cm. It may be noted that the flow lines for W = 3.3cm (Model 1) are converging in the constriction zone and then diverge to the full width after crossing the abutment. For the next abutment model, i.e. Model 4, the flow lines are made to pass parallel to each other in the constriction zone, preventing them to diverge to the full width of flume. The widest abutment model, Model 5, shows the reattachment of flow to the abutment surface and hence effectively guided the flow lines to be parallel not only in the constriction zone but also beyond it.

A dead water zone in the form of a small water mass just upstream of the abutments and near the flume wall was found to be almost stagnant with little circulatory motion due to the shearing effect of the oncoming flow. This dead water zone is almost triangular in plan and it guides and deflects the oncoming flow to the constriction zone. The circulatory motion in this zone has been referred as *weak eddies* by Kwan [5].

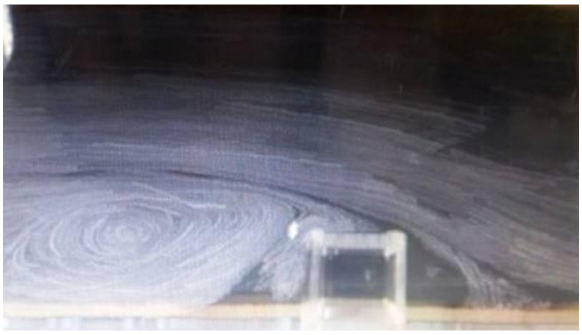
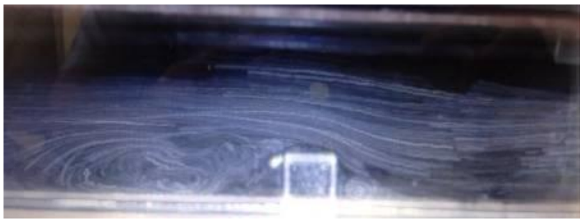


Figure 1: Flow Modification by Vertical wall Abutment (Flow is from Right to Left)



(a) Vertical Wall Abutment (Model No. 1)

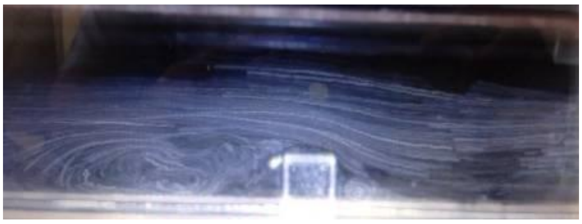
(b) Vertical Wall Abutment (Model No. 4)

(c) Vertical Wall Abutment (Model No. 5)

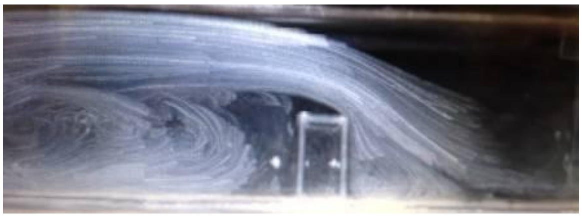
Figure 2: Flow Modifications by Vertical Wall Abutments of Different Width

The centre of wake eddies has shown a downstream shift with increase in abutment width. Another important observation that can be made from this figure series is that the *wake reverse flow* is feebly present for Model 4, where as it is totally absent in case of the widest abutment, Model 5.

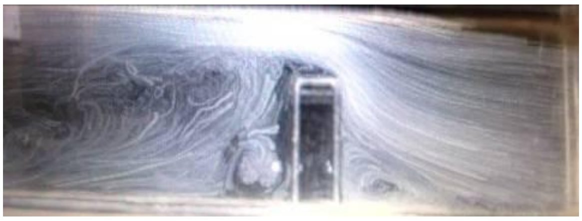
The effect of abutment length was also investigated on similar lines and the results are presented in Fig. 3. This was attempted with three abutment models of length 3.3cm, 6.6cm and 10cm. The width of all models was kept 3.3cm. The deflection of oncoming flow has been found to be increasing with increase in abutment length. The centre of wake eddies shows a shift near to the abutment. Size of the dead water zone and its circulation activity has been observed to increase with increase in abutment length.



(a) Vertical Wall Abutment (Model No. 1)



(b) Vertical Wall Abutment (Model No. 2)



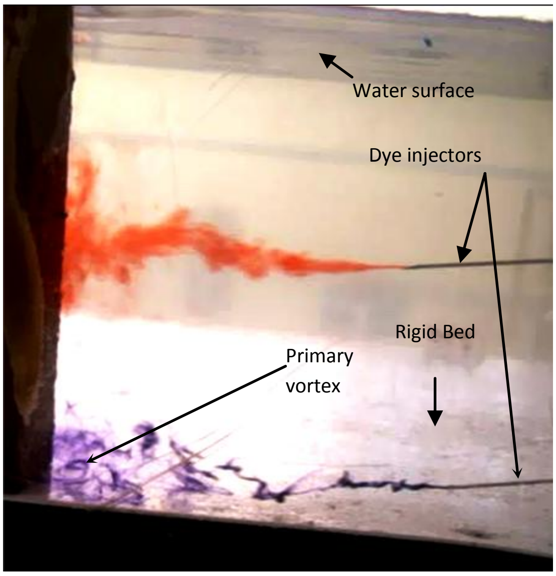
(c) Vertical Wall Abutment (Model No. 3)

Figure 3: Flow Modification by Vertical Wall Abutments of Different Lengths

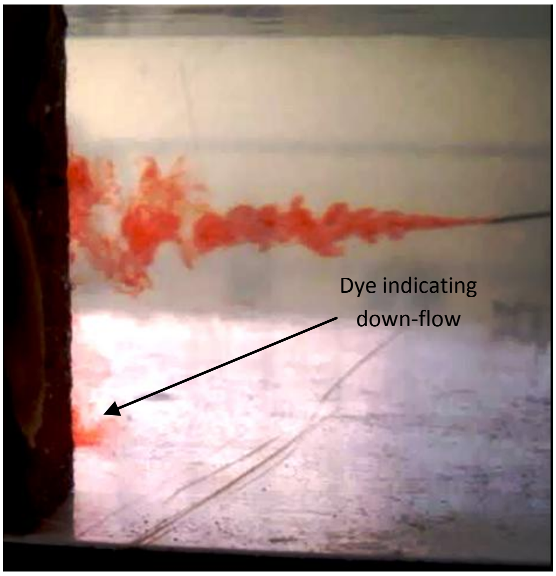
2.2 Domain B: Flow Modification in Intermediate Layers

The visualization of intermediate layers requires the introduction of easily detectable tracer free from the effects of gravity. *Dye injection technique* is an acceptable technique for this domain. The dye used in this study was commonly available writing ink of different colors. Dye was injected into the flow using a low pressure dual dye dispenser. The abutment (model 6) was installed in flume. The model measured L= 3cm and W= 1.5cm. The flow corresponding to a Reynolds number of 10,000 was maintained in the flume.

Fig. 4(a) presents the snapshot where in the formation of primary vortex (in blue dye) near the abutment-bed interaction junction is clearly visible. Fig. 4(b) presents a snapshot where in only red dye is being dispensed at about mid depth of flow. The downward movement of flow after it encounters the obstruction in the form of abutment is clearly indicated by the presence of red dye near the bottom layers. The line sketch inference of Fig. 4 (a & b) is presented in Fig. 5.



(a)



(b)

Figure 4: Flow Modification Visualized through the Glass Panel of Flume

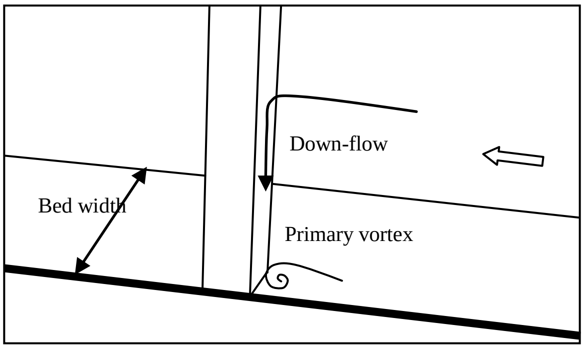
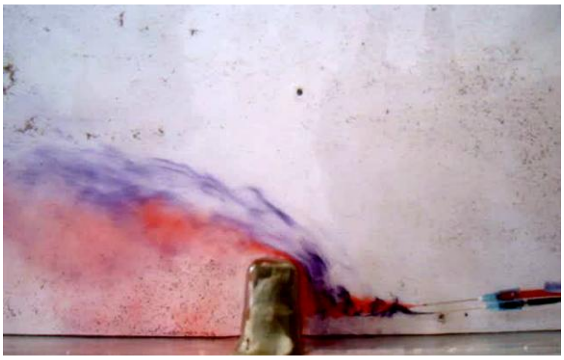
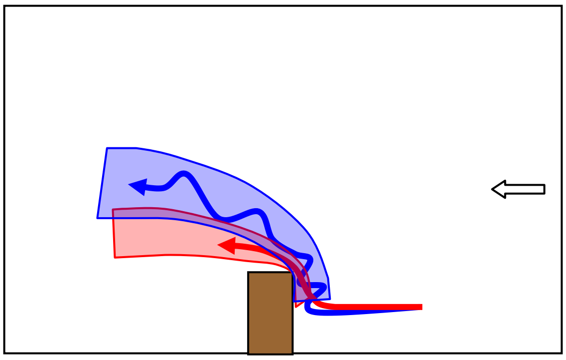


Figure 5: Line Sketch Inference of Fig. 4 (a & b)

The flow modification as visualized from the top is presented in Fig. 6 (a). The flow in the bottom layers (blue dye) has shown to cover more lateral extent as compared to the flow in intermediate layers (red dye), after being deflected by the abutment. The possible reason for this could be the wrapping of primary vortex around the abutment along with the flow separation at the upstream corner. Contrary to this, the flow in the intermediate layers is only deflected by the abutment, and its separation takes place at the nose of abutment. The line sketch inference of this has been presented in Fig. 6(b), where in flow in bottom layers has been shown by blue coloured spiraling arrow within its lateral extent and the flow in intermediate layers is presented by red arrow.



(a)



(b)

Figure 6: Lateral Spread of Flow in Bottom and Middle Layers

2.3 Domain C: Area near the Sediment-Structure Interaction Junction

The flow modification in this domain finds its importance on account of its direct interaction with the sediment around the abutment. The pre-requisite to the flow visualization in this domain is the selection of a technique that is capable of highlighting the flow modification only in the bottom layers of the flow. Wet paint technique has been found capable for the same and hence adopted for visualization studies for Domain C.

Wet paint technique (Setia, [6]) achieves the objective of obtaining a flow pattern of long duration flow-structure interaction. Steel sheet of size 24.5cm wide and 80cm long was used for wet paint visualization. Sheet was painted with white base paint and allowed to dry. With abutment model suitably fixed over the plate, blue paint was spread over the plate in wet condition and the assembly was gently place in the Flume.

Fig. 7 shows the wet paint impression for a rectangular abutment (model 7) measuring 26mm normal to flow and 60mm along the flow at Reynolds number of 10000. The dark blue color indicates the zones of deposition and white color indicates the scour affected area or zone of influence of abutment. As evident from this figure, the zone of influence is extended in the downstream direction at an angle of 45 degrees (approx). Thus it indicates that upstream face of the abutment is likely to experience more scouring as compared to the downstream face.

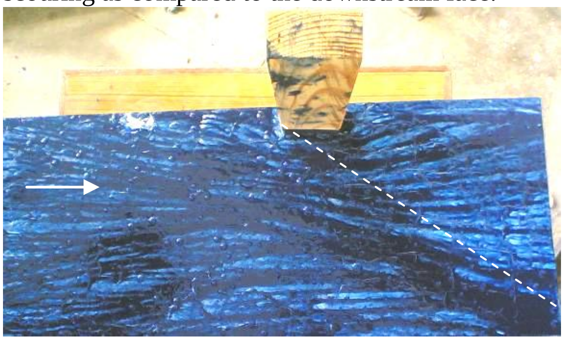


Figure 7: Wet Paint Impressions around Vertical Wall Abutment (L = 26mm and W = 60mm, Re = 10000)

III. CLOSURE TO MECHANISM

The description of flow and its modification presented in this section has been obtained through experimentation on short, solid unprotected abutments resting on a rigid bed, a condition that is analogous to scour initiation on a mobile bed. The abutment offers an obstruction to the oncoming flow and constricts its passage. Different localized flow structures have been observed depending upon the obstruction offered by it. On the basis of likely potential to cause scouring around abutments, the flow structures can be categorized into five components, namely down-flow, primary or principal vortex, wake vortices, bed-swirls and secondary vortices. Other flow structures include surface rollers, reverse eddies and wake-reverse-flow. The flow structures as visualized and inferred through the various aids and techniques are being comprehensively presented in Fig. 8.

The velocity gradient along a vertical section in an open channel is steeper near the bed and gradually becomes gentle in the top layers. As the oncoming water meets the upstream face of abutment, it is retarded and a stagnation pressure is developed. This pressure depends on the velocity of oncoming flow. Steeper velocity gradient in bottom layers causes greater stagnation pressure difference, thereby inducing a strong down-flow component. This down-flow impinges the bed like a vertically downward water jet and dislodges the material from in front of the abutment.

The down-flow takes the form of a vortex whirling in front of the abutment in a vertical plane, with its axis of rotation held horizontal and parallel to the abutment length. This vortex wraps around the abutment and has been termed as primary vortex or principal vortex.

The protruding length of abutment causes slow whirling reverse eddies on its upstream and thus creates a dead water zone. This dead water zone tends to suppress the down-flow along the length of the abutment. Hence, the down-flow and primary vortex are found more prominent near the end of abutment.

The water in the mainstream is guided and deflected by the dead water zone and is made to accelerate towards the zone of constriction. Highly turbulent wake vortices are generated at the point where flow is separated from the abutment. These wake vortices act like intermittently but frequently shooting whirlings like tornados that trap the sediment dislodged by the down-flow and the principal vortex. The interaction of wake vortices and the wrapping principal vortex near the bed is highly complex. This complex flow structure has been termed as bed-swirls.

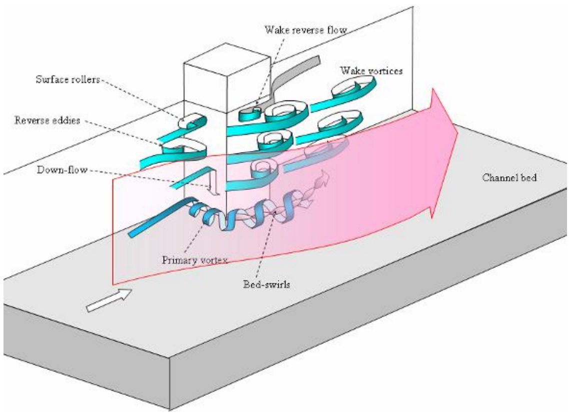


Figure 8: Flow Structures around an Abutment

REFERENCES

[1] Barbhuiya A. K. and Dey S (2003), "Vortex Flow Field in a Scour Hole around Abutments", *International Journal of Sediment Research, Vol. 18, No. 4, 2003,* pp. 310-326.

[2] Dey S. and Barbhuiya A.K. (2005), "Flow Field at a Vertical-Wall Abutment", Journal of Hydraulic Engineering, ASCE, Vol. 131, No. 12, December 1, 2005, pp 1126-1135.

[3] Gangadharaiah T, Setia B. and Muzzammil M. (2000), "Flow Visualization in Hydraulic Engineering", Proceedings of the International Symposium on Recen Advances in Experimental Fluid Mechanics, December 18-20, 2000, Indian Institute of Technology, Kanpur, India, pp 341-359.

[4] Kothyari U.C. and Ranga Raju K.G. (2001), "Scour around Spur Dikes and Bridge Abutments", Journal of Hydraulic Research, Vol. 39, No. 4, pp 367-374.

[5] Kwan T.F. (1984), "Study of Abutment Scour", Report no. 328, School of Engineering, University of Auckland, New Zealand.

[6] Setia B. (1997), "Scour around Bridge Piers: Mechanism and Protection", PhD. Thesis, Department of Civil Engineering, Indian Institute of Technology, Kanpur, India.