Flow Imaging around Bridge Abutments

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Abstract: *Visualization of flow modification around a hydraulic structure can make scour studies effective, efficient and economical. It had been a long-established tool for supporting fluid mechanics research. Different techniques used for flow visualization include dye injection, mud flow visualization, thymol blue visualization, hydrogen bubble technique, wet paint technique etc, but no single technique gives the complete understanding of the flow modification around a structure. A laboratory investigation had been carried out to visualize the flow modification around model bridge abutments in three different zones. Wet paint technique had been utilized to study the flow modification near the channel bed, Reflective powder technique had been used for visualizing modification on the surface of water flowing past a model abutment and hydrogen bubble technique is employed for investigating flow fields in between the above two extremities. Experiments were conducted in a recirculating flume and a wind tunnel under laboratory controlled flow conditions. The visualizations had been made using laboratory generated facilities and captured with the help of a digital camera. A qualitative comparison of the techniques is also presented in this paper.*

Key words: *flow imaging, flow visualization, abutment.*

1. INTRODUCTION

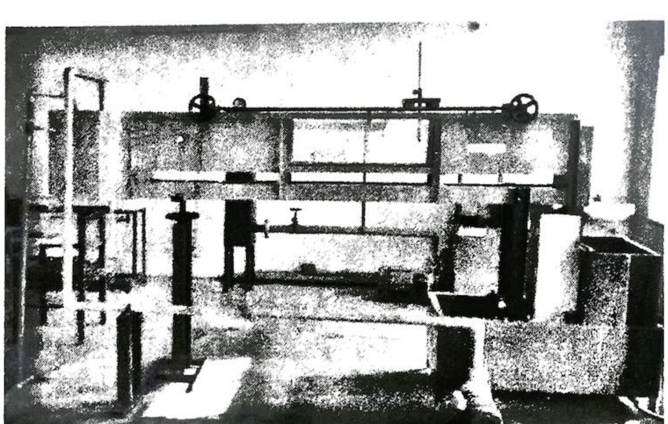
Bridges across rivers have always been a focus of research for the hydraulics engineers as bridges are the lifeline of the national economy. Failure of an important bridge can cause a huge catastrophe. A bridge can fail either structurally or due to hydraulic reasons. Besides other reasons, hydraulic failure of a bridge involves the undermining of the sediment bed by the process of scouring which is initiated due to three dimensional separation of flow around the bridge elements in the form of vortices [22], [20]. Piers and abutments constitute the essential but vulnerable parts of a bridge and though abutment failures have commonly occurred, yet as evident from open literature, research on bridge piers has received greater attention relative to that on bridge abutments. Most of the researchers who have carried out studies on abutments, have concentrated on the prediction of scour around the bridge abutments. Experimental studies towards the understanding of the mechanism of the flow modification around abutments have been relatively lesser. During the last five decades many researchers have studied various aspects of scour around abutments with the help of laboratory experiments, field studies or simulation modeling. Earlier studies in this direction were carried out by Ahmad [1], Liu et al. [18], Laursen [15], Wong, [25], Rajaratnam et al. [21], Tey [24], Kwan [13], Kandasamy [9], Breusers et al. [5], Melville [19], Lim [16], Kandasamy and Melville [10], Lim et al. [17], Ballegooy [3], Singh Kulbir [23]. All these studies were mainly experimental and were carried out with the objective of prediction of scour depth around abutments.

A few more studies, relatively recent, were aimed at getting an insight into the flow modification in the presence of abutments. Kwan and Melville [14] used hydrogen bubble technique to detect the flow field around the wing wall abutment while scour hole developed. Ahmed and Rajarathnam [2] experimentally investigated the flow around a 45° wing wall abutment model under rigid bed flow condition and found 3.63 times amplification of bed shear near the upstream nose of the abutment. The authors also made a comparison of the velocity distributions around a pier and an abutment and observed greater skewness of velocities near an abutment, especially downstream, thus illustrating the limitations of treating the abutment as a half pier. Barbhuiya and Dey [4] have called attention to the need of investigating the flow field in the vicinity of a wing wall abutment placed on a rough rigid bed. Dey and Barbhuiya [7] experimentally measured the three dimensional turbulent flow fields using acoustic Doppler velocimeter at a short vertical wall abutment and reported the existence of a primary vortex associated with the down flow in the upstream and a chaotic flow field comprising of irregularities owing to the vortex shedding in the downstream. Bhatia and Setia [6] have presented results of an experimental work on initiation and propagation of a vortex in wake zone of a wing wall type abutment model using hydrogen bubble technique.

In order to get a complete insight to what is happening in the vicinity of an abutment that may cause scour around it and ultimately endangers its stability, different techniques are applied in the present experimental investigation for highlighting the flow in three different zones. Wet paint technique had been utilized to study the flow modification near the channel bed, Reflective powder technique had been used for visualizing modification on the surface of water flowing past a model abutment and hydrogen bubble technique is employed for investigating flow fields in between the above two extremities. All these experiments have been performed under rigid bed condition.

2. EXPERIMENTS

Experiments were conducted in the Fluid Mechanics Laboratory of M.M. Engineering College, Mullana. A re-circulating flume measuring 3m long, 0.25m wide, 0.35m deep (Figure 1a) and a wind tunnel measuring 9.0m long with a square cross section of size 0.30m (Figure 1b). The flume had some portion of glass on the sides to facilitate visualization of flow modification inside the channel. The discharge in the flume was maintained with the help of a centrifugal pump. The discharge was controlled by a valve on the delivery pipe. The flow depth was controlled with the help of an under-sluice type tail gate. For measurement of discharge, the flume was linked with a collecting tank at the end. The waves generated at the inlet were suitably dampened by placing some floating wooden planks. Short Abutment models with L/y ratio d" 1, (where L is protrusion length of abutment and y is the flow depth) were tested on a rigid bed and the flow conditions were maintained steady and uniform throughout the experimental run. Model abutments were used and flow modification was studied using wet paint technique, hydrogen bubble technique and reflective powder technique. The schematic of the setup is shown in Figure 2. The wind tunnel had a test section measuring 0.3m wide and 0.3m deep, made of transparent Perspex glass. The flow was maintained at laminar conditions conducive for visualizing the smoke streaks. A rectangular obstruction representing an abutment was placed in the test section and smoke streaks were fed into the wind tunnel with the help of a single nozzle smoke dispenser.



(a) Recirculating Flume (3m long, 0.25m wide, 0.35m deep)

(b) Wind Tunnel (9m long, 0.3m wide, 0.3m deep)

Fig. 1: Test Facilities

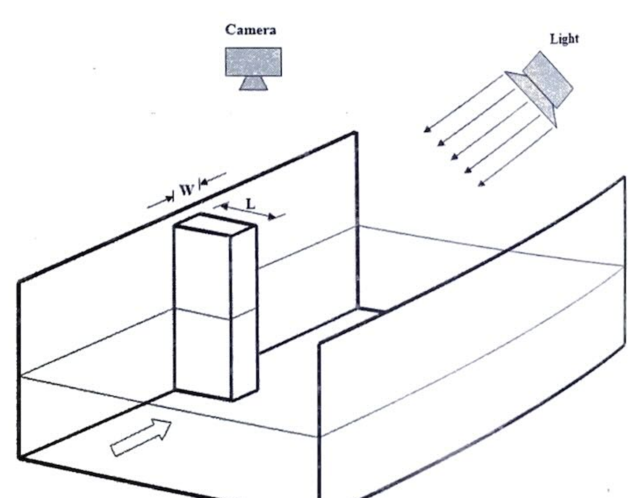


Fig. 2: Schematic of the Setup

3. FLOW VISUALIZATION STUDIES

Different techniques for flow visualization have been successfully applied to visualize the modification of flow due to an obstruction in the form of an abutment model. The visualization of flow has been categorized as shown in Figure 3:

3.1 Visualization of Flow Modification in a Water Flume:

Experiments were conducted in the recirculating flume mentioned above (Figure 1a). Short abutment models (protruding length to flow depth ratio d" 1) were placed in the flume under preset flow conditions. Flow visualization techniques were applied as per the categorization shown in Figure 3 and the flow modification was captured with the help of a camera. The observations have been presented in the form of photographs.

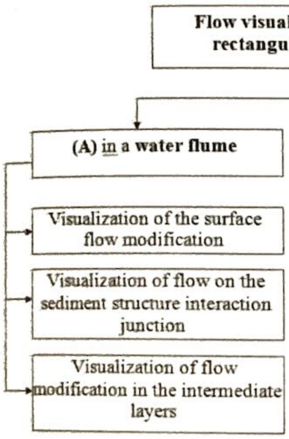
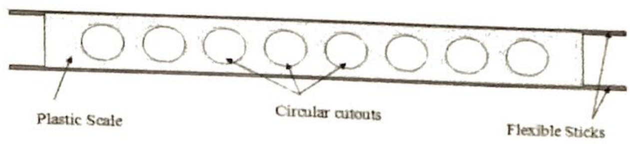


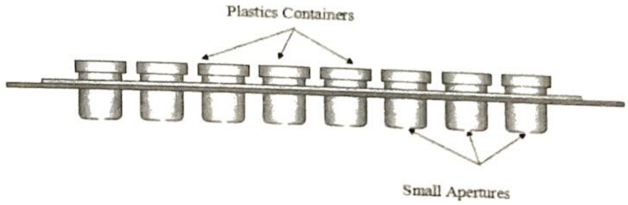
Fig. 3: Categorization of Flow Visualization

(a) Visualization of Surface Flow Modification around an Abutment using Reflective Powder

Reflective powder technique is a simple and effective tool for visualizing flow modification of the surface of flow around abutments. This technique involves sprinkling of a reflective powder on the water surface in the upstream of the model through a dispenser (Figure 4) and capturing the flow modification with a camera. Reflective powder used for this technique was in the form of two commonly available metallic paints (powdered) used without binder. Copper and Silver coloured metallic powders were sprinkled through alternate plastic containers of the dispenser so as to differentiate between the adjacent layers of surface flow and facilitate their visualization. Two abutment models (a square model L=W=30mm and a rectangular model L=30mm, W=15mm) were tested under rigid bed with a flow Reynolds number of 10,000. The flow



(a): Reflective Powder Dispenser (PLAN)



(b): Reflective Powder Dispenser (ELEVATION)

Fig. 4: Reflective Powder Dispenser

modifications in both the cases are shown in Figures 5 and 6. It may be clearly observed in Figure 5 and 6 that

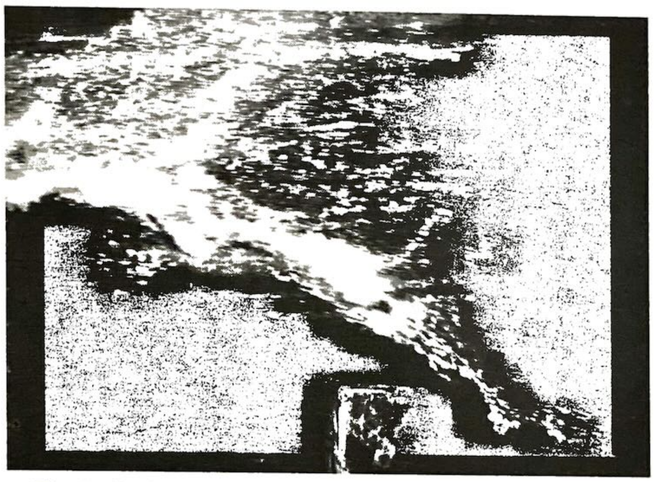


Fig. 5: Surface Visualization around a Square Abutment using Reflective Powder (L = W = 3cm, Re = 10,000, Flow is from Right to Left)

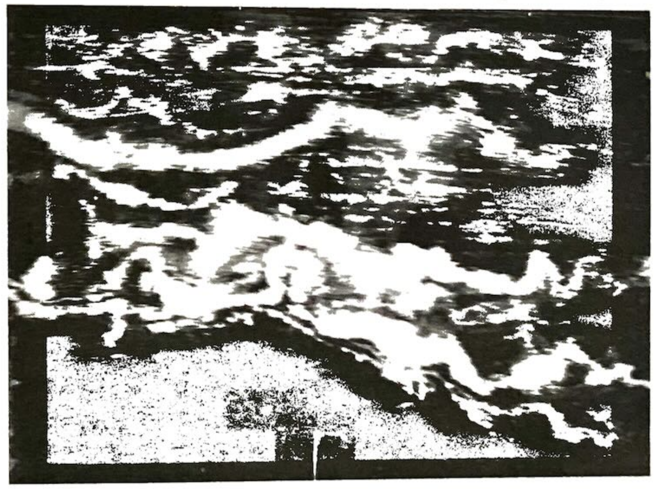
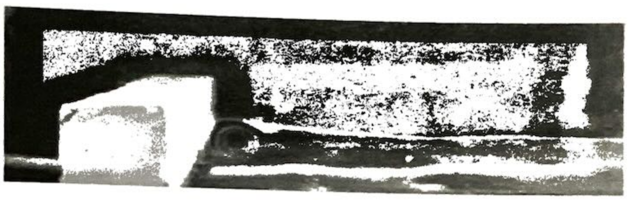
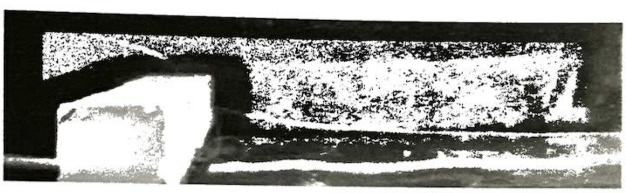


Fig. 6: Surface Visualization around a Rectangular Abutment using Reflective Powder (L = 3cm, W = 1.5cm, Re = 10,000, Flow is from Right to Left)

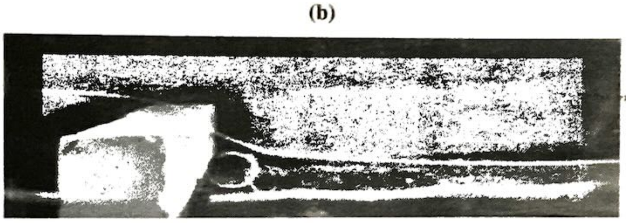
0.3m x 0.3m in cross section. In this experiment, smoke streaks were used to visualize the flow. A smoke dispenser was fabricated by the authors in the laboratory itself. The smoke streaks were illuminated by a light sheet in a vertical plane. The photographs were captured with the help of a camera and are presented in Figures 13(a, b and c) below. The vortices formed in the upstream of rectangular obstruction are very clearly seen in Figure 13(a). Intermittent breaking and spiting of this vortex is clearly visible in Figures 13(b) and 13(c) respectively, thereby proving the usefulness of smoke streaks in studying the flow modifications around an obstruction in the wind tunnel.



(a)



(b)



(c)

Fig. 13 (a, b and c): Visualization of Smoke Streaks around a Rectangular Obstruction in a Wind Tunnel (Flow is from Right to Left)

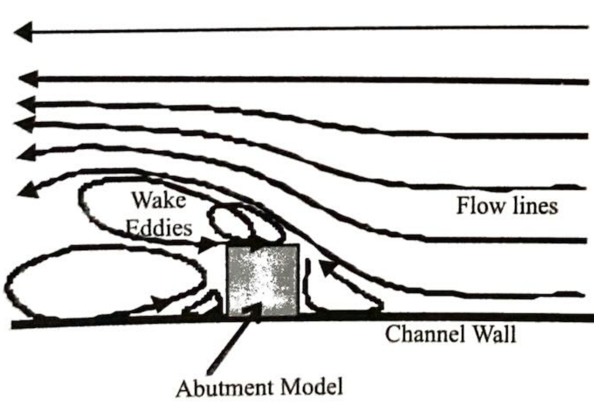


Fig. 14: Line diagram of modified flow lines

On the basis of the visualizations made above, the line diagram of modified flow is shown in Figure 14 and following can be inferred.

1. flow lines get deflected away from the abutment model.
2. deflected flow lines get constricted, causing increase in velocity in the zone of constriction.
3. this deflection causes the formation of strong wake eddies/vortices in the wake zone of the obstruction.
4. these wake vortices act as whirling cyclones, causing a lifting effect on the sediment particles, thereby initiating the scouring around the abutment.

4. CONCLUSIONS

Visualization of flow modification and its imaging are necessary for studying the behaviour of an abutment. No single technique of flow visualization can give appropriate visualization for imaging the flow modification around an abutment. Different techniques may be employed to get the overall behaviour of an abutment towards flow modification. Reflective powder technique is very useful in visualizing the surface flow patterns around an abutment model. Wet paint technique is a very effective tool for getting the impressions of long term interaction of flow and the sediment bed. Hydrogen bubble technique of flow visualization is a simple yet very effective and economical method. It has an advantage over other techniques that the hydrogen is not a pollutant or contaminant. Also, being insoluble in water it leaves the water at some stage of time, when drag on the bubbles becomes less and buoyant force starts prevailing. The oxygen generated at the anode is soluble in water and helps in oxidizing many impurities present in the water.

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