

**Advanced Flow Visualization Techniques for the Federal Highway Administration
Hydraulics Research Laboratory**

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Abstract

The Federal Highway Administration's Hydraulics Research Laboratory has facilities to physically and numerically model hydraulic and sediment transport phenomena to support State highway administration initiatives. Recent advances in physical modeling instrumentation have facilitated flow visualization to support research. Flow visualization is now performed using the hydrogen bubble technique whereby a platinum wire is mounted vertically upstream of a bridge structure (pier, abutment, etc.) in the test flume. A graphite rod is used as an anode. The hydrogen bubbles produced are small enough ($\text{\O} < 0.025$ mm) that their buoyancy may be ignored within the visualized area. By employing pulsed time line markers with a specially built hydrogen bubble generator, it is possible to visualize the phase speed of the diving current formed at the face of the structure. This diving current is usually responsible for bridge scour.

Introduction

Flow visualization is a long-established tool for supporting fluid mechanics research. The following references present examples of such research.

(Deniz & Staubli, 1997) Mechanisms leading to transverse oscillations of rectangular profiles were visualized with the hydrogen bubble technique. In this case the hydrogen bubble system was mounted on a forced oscillator.

(Nakamura & Nakashima, 1986) Visualization of low turbulence flow past an H-section ($Re = 1200$) and stationary prisms with and without splitter plate were reported.

(Naudascher & Wang, 1993) Consecutive photos of hydrogen-bubble flow patterns were obtained with one-sided illumination during a cycle of plunging vibration of a rectangular prism with rounded edges in a free stream.

(Kerenyi, 1998) This study examines the flow around an isolated rectangular prism as well as around and through an array of equidistant bars. The hydrogen bubble technique was employed for visualization and an interpretation of flow images is given.

(Kobayashi, 1997) Laboratory experiments to analyze horseshoe vortices around a vertical cylinder on a scoured bed by using an image processing technique were described. Vorticity concentration of the horseshoe vortex counter-rotating were observed in a deep part of the scour hole.

Experimental Set-Up

Test Facilities. The physical configuration of the experimental setup is as follows:

- 20 m long flume (2 m across and 0.5 m high)
- test section for models located 12 m from upstream end of flume
- $0.3 \text{ m}^3/\text{s}$ variable speed pump
- 0.04 percent slope
- Velocities were measured with the Acoustic Doppler Velocimeter (ADV) probe using PXI hardware and LabVIEW software. For the experiments, the program was set to read the velocity probe for 60 seconds at a scan rate of 25 Hz. The flow discharge, Q , was also measured at the same settings (60 s, 25 Hz). This was measured with a flow meter placed in the pipe 30 feet after the pump and before the entrance to the flume
- Velocities ranged from 10 – 30 cm/s in the approach section.
- Depths were held at 30 cm in the approach section.
- The Reynolds Number ranged from 20 000 to 60 000 in the approach section.

The upstream flow conditioning (uniform velocity distribution) was achieved using filter mats, a honeycomb flow straightener, and a carefully designed trumpet-shaped inlet.

Geometry of the Piles. A number of pier configurations were tested as shown in Figure 1 (10 cm square piers were used):

- Figure 1a shows a vertical pier;
- Figure 1b shows a vertical pier with roughness elements along the front face
- Figure 1c shows a pier tilted 40

- Figure 1d shows a tilted pier with roughness elements along the front face
- Figures 1e and 1f show shields installed at the front face

The roughness elements were tested to determine their effectiveness in breaking up the diving currents responsible for pier scour. The tilted piers were tested to determine whether or not tilting affects the diving currents. The shields were tested to determine if an under-pressure zone could be created in front of a pier reversing the direction of the diving current.

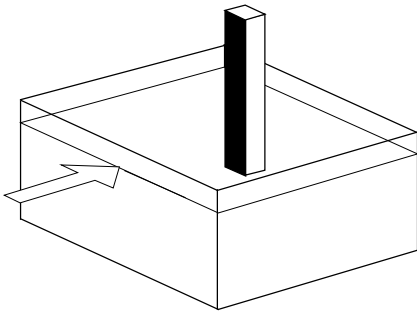


Figure 1a: Vertical Pier

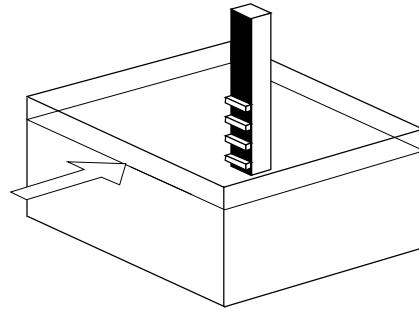


Figure 1b: Vertical Pier with Roughness Elements

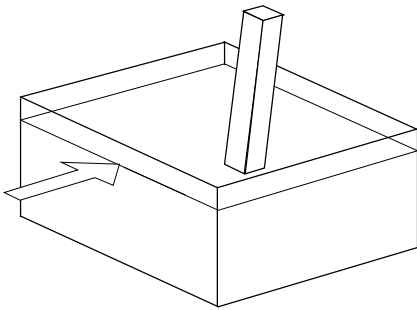


Figure 1c: Tilted Pier

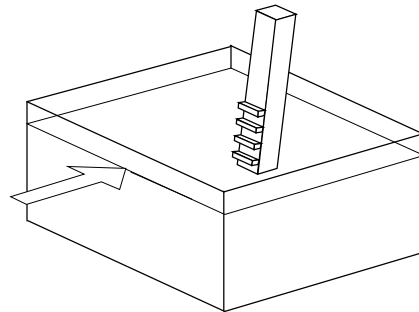


Figure 1d: Tilted Pier with Roughness Elements

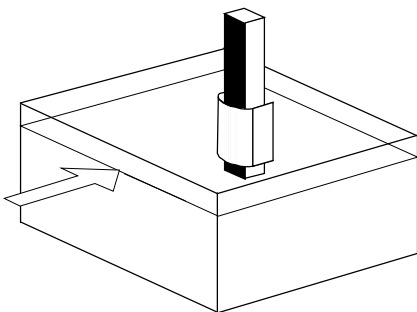


Figure 1e: Pier with Rounded Shield

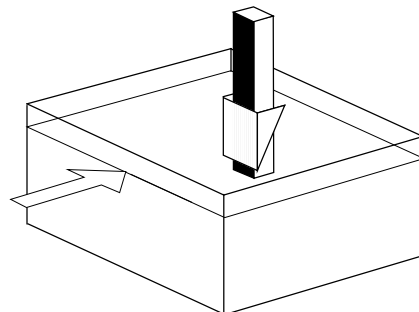


Figure 1f: Pier with Square Shield

Hydrogen Bubble Technique. Flow visualization was performed using the hydrogen bubble technique, whereby a platinum wire 0.025mm in diameter was mounted vertically at a distance of 70 mm upstream of the pier. The hydrogen bubbles produced are small enough ($\text{Ø} < 0.025 \text{ mm}$) that their buoyancy may be ignored within the visualized area. By

employing pulsed time line markers with a bubble generator it was possible to visualize the phase speed of the diving current and the rate of development of the coherent vortex structures forming at the face of the structure. The bubble generator was controlled with a digital I/O using LabVIEW software. The time period of the pulse generation was varied between 0.1 and 1 sec and the pulse duration was between 10 and 60% of the time period. Illumination was done with light projectors. An optimum angle for illumination of the hydrogen bubble sheet had to be found by trial and error and had the most important impact on image quality. One of the major advantages of using a Plexiglas shield was that, with the transparent shield, the space between could also be lighted. A video camera was mounted on the side of flume, which was linked to a TV screen (Figure 2).

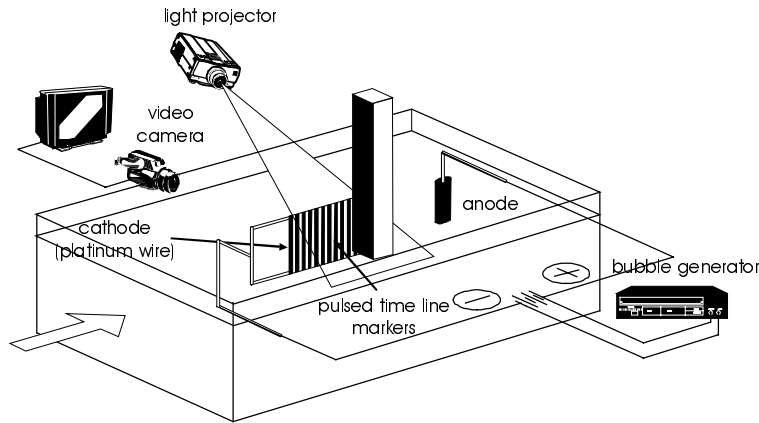


Figure 2: Hydrogen Bubble Setup

Flow Structures

Figures 3 – 8 show time-phased photos of the vortex structure illuminated by the hydrogen bubbles. The Figure 3 series shows the vertical pier. The horseshoe vortex at the base of the pier is apparent. The Figure 4 series shows the vertical pier with roughness elements. The elements reduce the vortex strength at the base of the pier. The Figure 5 series shows the tilted pier. The tilted pier did not show a well-developed vortex at the base. The Figure 6 series shows the tilted pier with roughness elements. This configuration disturbed the diving currents. The Figure 7 series shows the rounded shield. This configuration did in fact reverse the diving currents. The Figure 8 series shows the square shield with live bed conditions. This configuration also reversed the diving currents, but accelerated flow under the shield could cause scour problems.

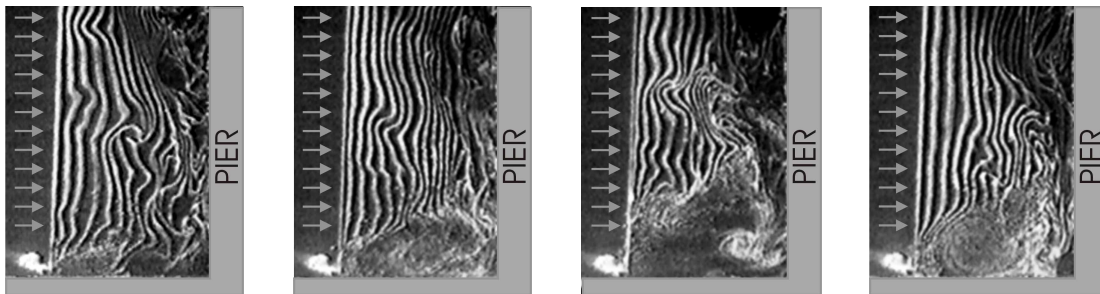


Figure 3: Time Sequence of Flow Structure for Vertical Pier

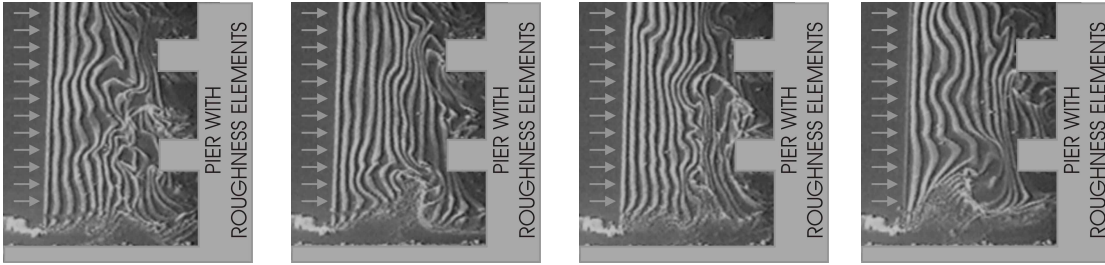


Figure 4: Time Sequence of Flow Structure for Vertical Pier with Roughness Elements

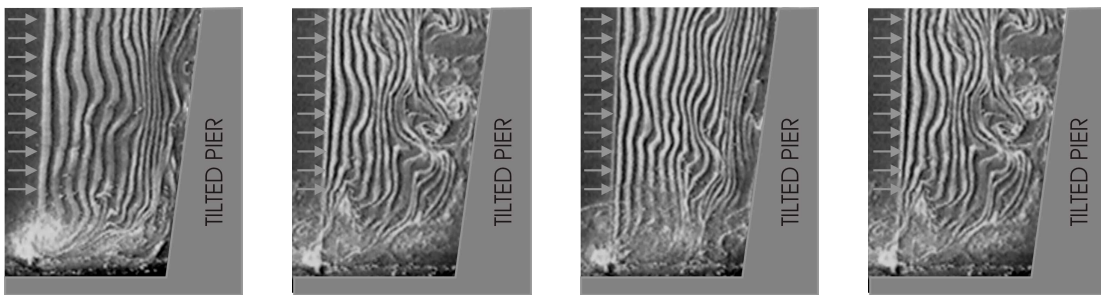


Figure 5: Time Sequence of Flow Structure for Tilted Pier

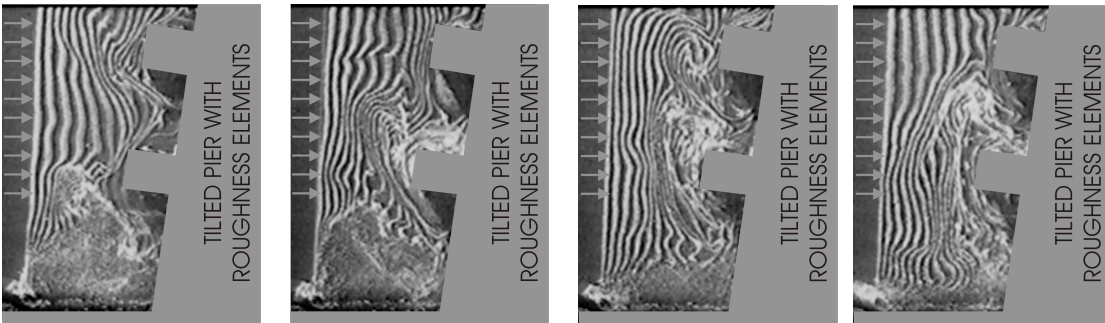


Figure 6: Time Sequence of Flow Structure for Tilted Pier with Roughness Elements

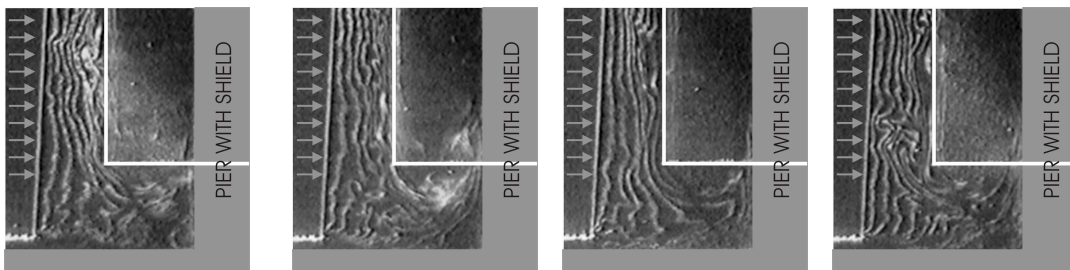


Figure 7: Time Sequence of Flow Structure for Pier with Rounded Shield

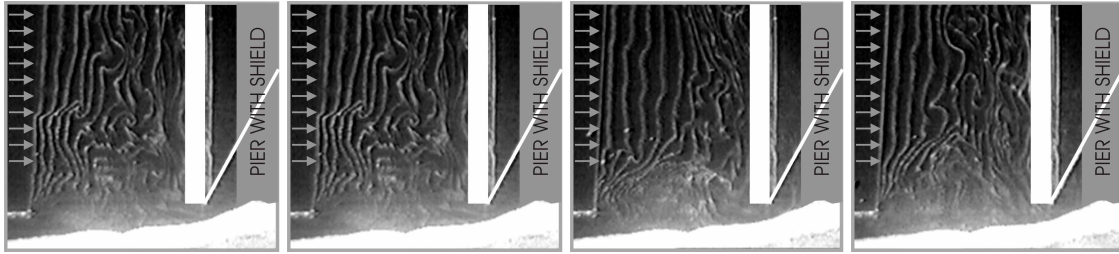


Figure 8: Time Sequence of Flow Structure for Pier with Square Shield

Conclusion

Flow visualization provides many advantages for physical modeling:

- It gives better insight into flow patterns caused by obstructions. These insights can form the basis for numerical models and can be used to validate current numerical models.
- It can give quick feedback for flow alteration ideas.
- It can reduce experiment time because fixed bed experiments can be performed to evaluate flow patterns. Scour magnitude can then be inferred from the flow patterns. Currently, most hydraulics laboratories perform movable bed experiments and measure scour holes after long run times (up to 48 hours or longer per experiment).
- The hydrogen bubble technique can eventually be used in conjunction with Particle Image Velocimetry (PIV) to measure velocity structures.

References

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