On Reducing Scouring by Controlling Junction Flow

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INTRODUCTION

The number one cause of failure for bridge piers is scouring [1]. As flow encounters a bridge pier, vortices are produced that remove the river bed material, resulting in the appearance of scour holes around bridge piers. The scouring problem has been investigated extensively [2]. There has also been a significant effort aimed at finding ways to reduce scouring and scour depth. However, most of the existing scour-control measures are too expensive for practical application [3]. A new insight is needed for its prevention.

The Occurrence and Control of Junction Flow

"The basic mechanism causing local scour at piers or abutments is the formation of vortices (known as horseshoe vortices) at its base" [4]. Junction flow occurs when a boundary layer encounters a surface-mounted obstacle, protruding horseshoe vortices that wrap around the obstacle. Such vortices are unsteady and produce high turbulence intensities, undesirable high surface pressure fluctuations, and enhanced nearby mass transfer rates resulting in scouring.

With the objective of seeking junction flow control, the hydrogen bubble flow visualization technique was used, and pressure measurements were carried out in a water channel. It was found that a small control rod, such as an airfoil placed upstream of the obstacle, could attract and capture the neck of the horseshoe vortices, thus causing the original horseshoe vortices to circulate around the control rod [Fig. 1]. Such capture can be explained by vortex fusion [6]. The junction flow immediately upstream of the obstacle was noticeably steady and free of disturbance [Fig. 1]. Surface pressure measurements also showed a significant reduction in fluctuation. Experimental results with an obliquely-mounted square cylinder demonstrate that the captures and controls were effective for all angles of attack [Fig. 2]. The control technique appears versatile, and could be useful for the prevention or reduction of scouring.

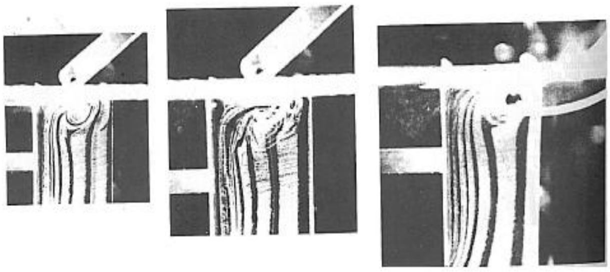

Figure 1: Flow visualizations. a) positive angle of attack of the control foil resulting in a tighter capture; b) Negative angle of attack of the control foil resulting in a loose capture; c) capture of horseshoe vortex by a small circular rod.

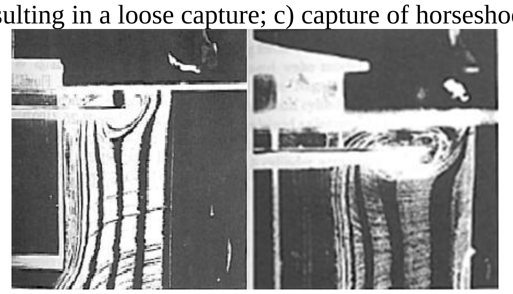

Figure 2: Capture and control of horseshoe vortex for a) a normal mounted and, b) an oblique mounted square cylinder.

RESULTS AND DISCUSSION

The Validation of the Control Technique

The initial stage of testing was carried out in a scouring-research flume at Dalian University of Technology. It is 48 meters in length, 1 meter wide and 1.5 meters deep. The flume features a piston-type wave generator that can generate a wave period of 0.4 – 5.0 seconds, wave height of 0.0 –0.35 meters, and water depth of 0.2 – 1.2 meters. There's a sand pit at the middle of the flume which is 2 meters long, 1 meter wide, and 0.5 meters deep. By testing the design (Figure 3) in the flume under various flow conditions, and examine the resulting scouring pattern on the flume bed, the effectiveness of the scour control in terms of the reduction of the bed material removal of 50% or more in critical areas around the pier was demonstrated (Figure 4, a, b).

Figure 3: Circular Cylinder Pier Model with Control Ring Attached.

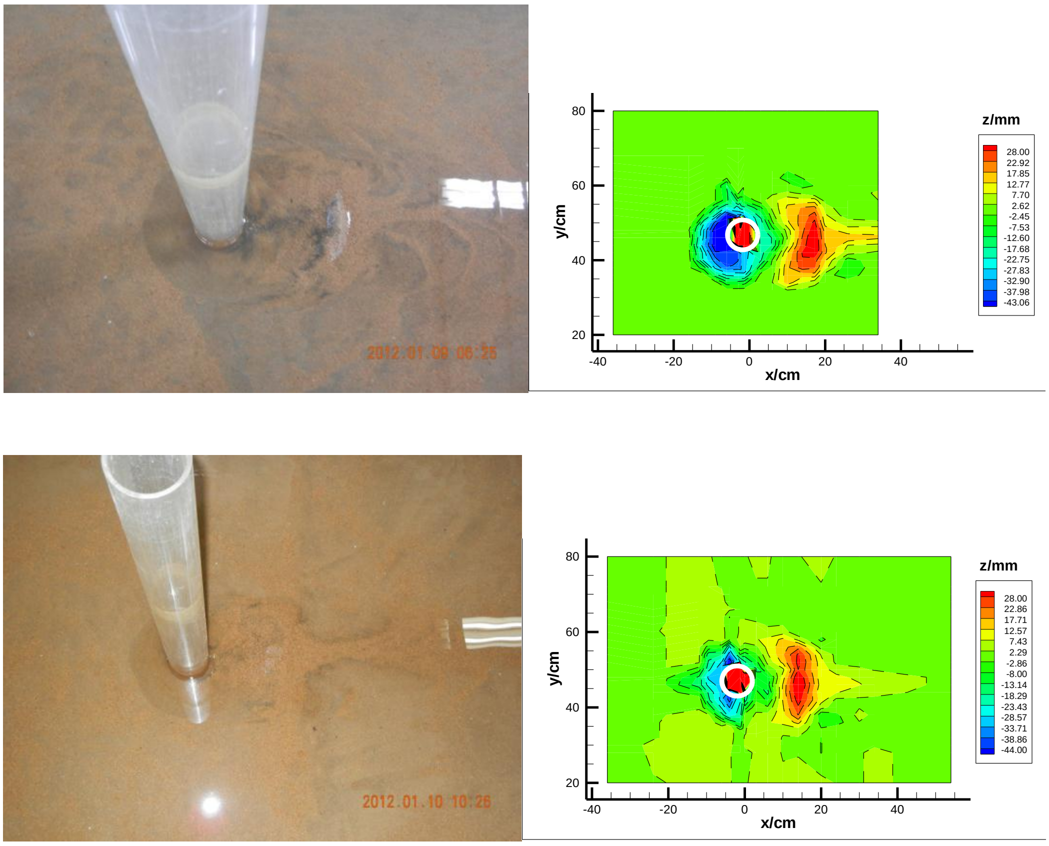

Figure 4: The scouring pattern with (bottom) and without (top) control ring attached. The right figures show the contour of scouring based on the vertical profile measured acoustically after test

CONCLUSIONS

A scouring control device is being developed based on the new insight of capturing of horseshoe vortex by a control ring. Initial experiments validate the concept by showing a significant reduction in scouring extent. Based on a 75% reduction of pressure fluctuation previously measured, additional testing may reveal further reduction in scouring.

References

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