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Influence of bridge pier position according to flow direction on scour reduction

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***Abstract*--An experimental study was conducted to examine the effect of change the position of bridge pier to reduce the scour. The experiments were carried out with Q=0.058 m^3/s he piers were tested under clear-water conditions for duration of 3 hours. The velocity field measurements were obtained using an Acoustic Doppler Velocimeter. The depth of scour in front of the pier was found to have decreased very effective in controlling the down flow at the upstream face of the pier and hence reducing the horseshoe vortex strength. Scour depths were measured along the center axis of the channel.**

Results show that the change of position of bridge pier, the maximum scour depth of opposite pier reduced 40% as compared with normal pier and it reduced to 54% as compared to a circular. Change the position of bridge pier is an effective countermeasure in the reduction of local scour depth.

***Keywords*—bridge pier scour, bridge pier position, scour reduction, scour.**

I. Introduction

The local scour along a river is defined as the removal of bed material around an obstacle immersed in a flow field. This phenomenon can generate many problems, because it modifies locally the river's equilibrium. If the obstacle is a bridge pier, the biggest danger is represented by the possible undermine of piers foundations, that can take to bridge's collapse. When this type of accidents happens, the prices, in terms of human life and economic resources to restore interrupted connections, are often very high. During the past decades, several investigations were conducted to assess the adequacy of countermeasures against local scour at bridge piers. The shape of the bridge piers has important effect on the local scour.

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No experimental studies on the change position of piers on scour reduction are available. Breusers, and J.A. Raudkivi [1] showed that scour depth increases for an upwardly widening pier and decreases for an upwardly narrowing pier.
Therefore different shapes of bridge piers should be investigated experimentally and numerically to find a reliable efficiency before field application, especially under live-bed scour condition.

It has been long established that the basic mechanism causing local scour at bridge piers is the down flow at the upstream face of the pier and subsequent formation of vortices at the base [2].

There are many parameters that affect the flow pattern and the process of scour around bridge piers. These include the size, cohesion, and grading of the bed material, depth of flow, size and shape of the bridge pier, flow constriction, flow velocity, and geometry of the bed. Other factors that influence scour that are the result of significant flood events include floating debris and accumulation and buildup of debris.

Drysdale [3] applied dimensional analysis to examine the effectiveness of an aero foil shaped bridge pier by comparing a scaled circular pier with a scaled aero foil shaped pier of the same diameter. Drysdale found that for the same flow condition, the vortex shedding from the aero foil shaped pier was significantly less than the circular pier. He further concluded that the aero foil shaped pier had a 26% reduction in drag force compared to that of the circular pier.

Christensen [4] examined the effectiveness of a slotted aero foil shaped bridge pier in reducing local scour, as compared to an aero foil and circular pier. Christensen concluded that the aero foil shaped pier reduced local scour by a volume of 27% when compared to the circular shaped pier. The slotted aero foil shaped pier had a reduction in the scour hole volume of 85% when compared to the circular shaped pier.

Gibson [5] examined the effectiveness of skirted, straight aero foil shaped bridge pier in reducing local scour. Results demonstrate that symmetrical aero foil shaped piers are an effective countermeasure in the reduction of local scour hole volume. The skirt on the aero foil shaped pier is an effective countermeasure in the reduction of local scour depth.

Khwairakpam et al. [6] investigate experimentally the scour hole characteristics around a single vertical pier in clear water. They were observed that the entire scour geometry (scour depth, length, width, area and volume) depended on densimetric Froude number (F_{D50}) and inflow depth (h). Empirical relationships were developed on the basis of obtained results.

Chen et al. [7] examine the use of a hooked collar for reducing local scour around a bridge pier. The efficiency of collars was studied through experiments and compared with an unprotected pier. The velocity field measurements were obtained using an acoustic Doppler Velocimeter. Results show that a hooked-collar diameter of 1.25 b has an effectiveness similar to a collar diameter of 4.0 b used by [8], where b is the pier width. With hooked collar installed at the bed level, there was no sign of scouring and horseshoe vortex at the upstream face of the pier. In contrast with unprotected pier, the down flow and turbulent kinetic energy were reduced under the effects of the hooked collar.

This study concentrated on the change the position of the bridge pier with respect to direction of flow. So, the main objective of this paper is to determine the effect of change the position of the bridge piers on the reduction of scour hole depth as shown in "Fig. 1."

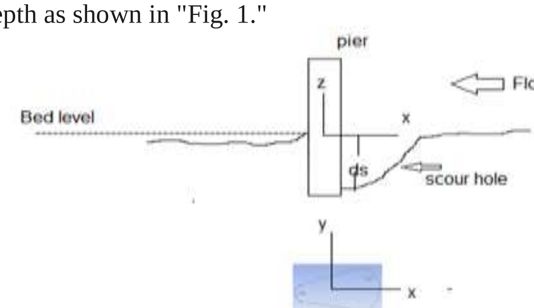

Figure 1. Longitudinal scour hole

II. Experimental work

The experiments were carried out in the laboratory of civil engineering of Gaziantep University. The flume had a length of 12m, width of 0.8m, and depth of 0.9m, with glass sides and steel bottom, the glass sides to allow the direct observation of the hydrodynamic and scour phenomena. "Fig. 2", shows details for the flume.

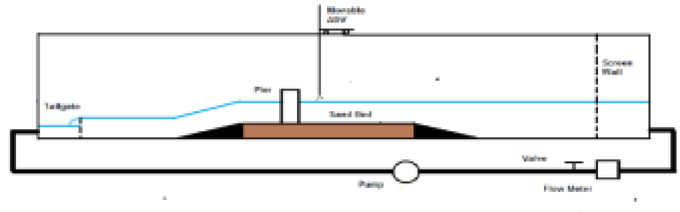

Figure 2. Schematic layout of the flume

The test section at the flume bed is 3m long, 0.8m wide and 0.2m depth was prepared at a distance 3m downstream of the flume beginning, and was filled with sediment of median particle size, d_{50}=1.45mm as in "Fig 3." The standard deviation, σg=3.16; specific gravity = 2.65. Flume discharge was measured by Magnetic Flow Meter installed in the pipe system before the inlet of channel. The scour hole and the elevation of the bed was measured by Laser Range finder, the instrument mounted on a lifting carriage a manually moving carriage sliding on rails on the top of the flume wall.

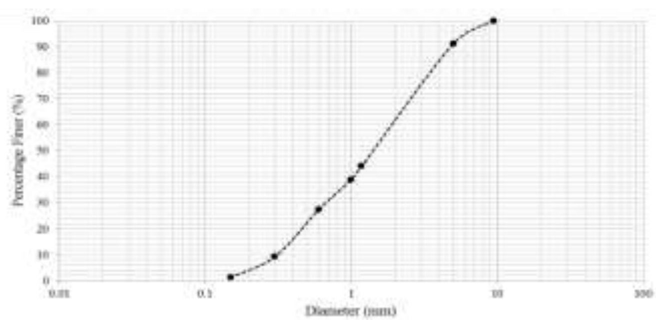

Figure 3. Grain size distribution of bed material

It is known that when, σg > 1.3 the sediment is considered non-uniform and armoring occurs on the channel bed and in the scour hole [9] as shown in "Fig. 4."

Figure 4. Armoring the channel bed and in the scour hole

The pier was first installed in the flume at the desired location. The different pier shapes as in "Fig. 5" were tested in sequence.

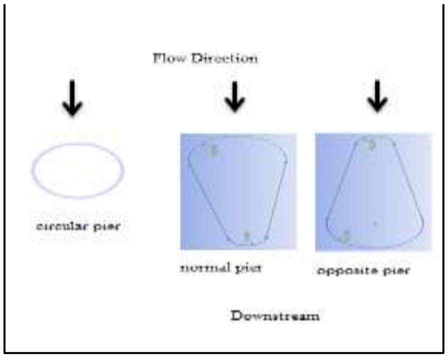

Figure 5. Top view of tested bridge pier

Experiments were performed under a clear water scour regime with 0.058 m^3/s discharge and a 0.125 m flow depth. By employing laser range finder, initial bed elevations were taken randomly to check the leveling of the test section to avoid undesirable scour of bed sediment under inadequate flow depth. The flume was first filled with water desirable flow depth was reached. The discharge in the flume was then gradually increased to the desired value, and the temporal variation of scour was monitored. The scour depths were measured using an intense light enabled one to read the scour depth from the graduation on the transparent body of the pier with an accuracy of 1 mm. The pump was shut down to allow the flume to slowly drain without disturbing the scour topography. The flume bed was then allowed to dry.

III. Acoustic Doppler Velocimeter (ADV)

The ADV measures flow velocity using the Doppler shift principle. The ADV assumes a user defined 3-15 mm deep sampling volume which is approximately 50 mm (1.97 in) away from the transducer. The ADV sends out a beam of acoustic waves at a fixed frequency from the center transducer to the sampling volume. The reflection from moving suspended particles within the sampling volume causes a Doppler shift which is received by the 4 receivers. The ADV measures the Doppler shift of the moving particles to determine the speed of the suspended particles within the sampling volume. The ADV assumes the speed of the suspended particle equal to the flow velocity.

IV. Acoustic Doppler Velocimeter Testing

During each experiment, the velocity is periodically monitored using an Acoustic Doppler Velocimeter (ADV). Stream velocity is measured upstream of the pier using the ADV in the center of the flume. The ADV probe was then positioned above the scour hole and velocities were recorded for a period of 180 seconds. The sample period of 180 seconds was chosen to ensure that sufficient flow variations were captured.

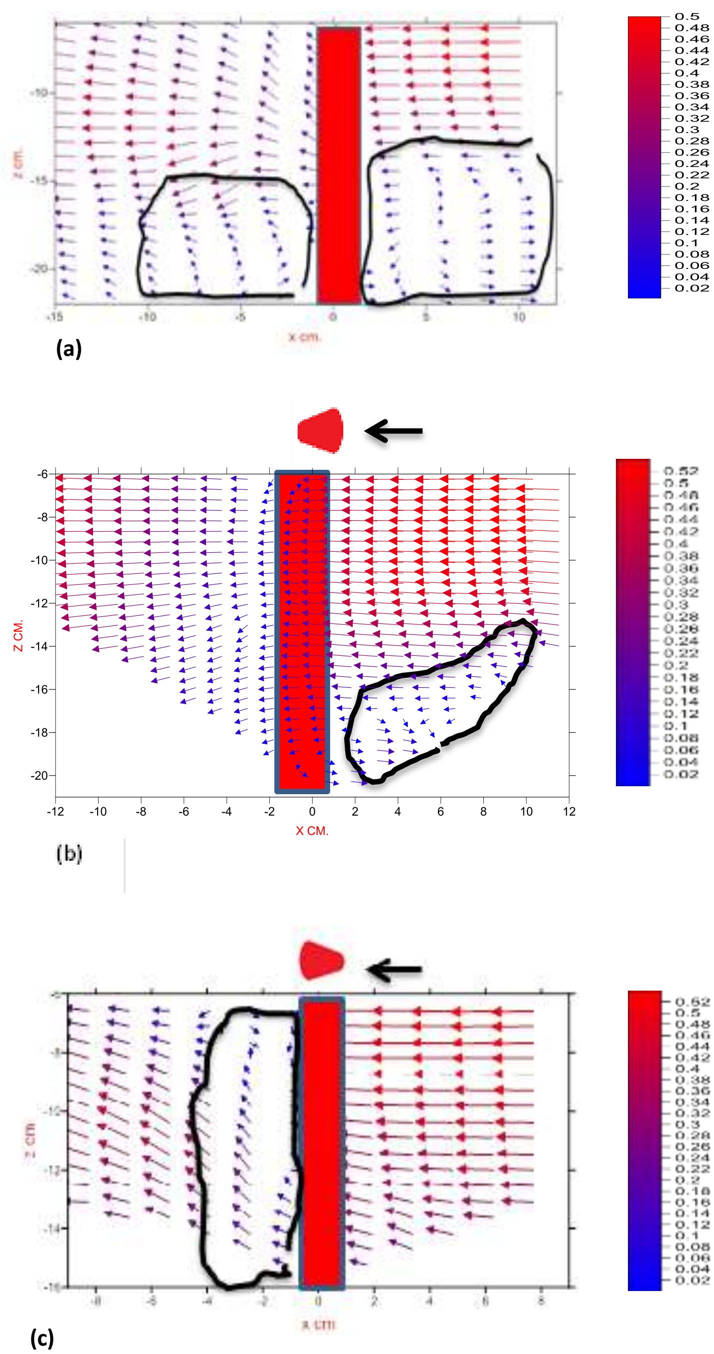

Figure 6. Time-averaged velocity vectors along the vertical plane of symmetry of the pier (a) circular pier ; (b) normal pier; and (c) opposite pier

V. Results and Discussion

Experimental results of the model piers within cohesionless bedding material will be compared and discussed in this section. The results are a comparison of scour and sediment transport parameters and have been made between the circular (10 cm diameter), normal (10-4 cm) and opposite shaped model piers (4-10cm) as shown in "Fig. 5".

The elapsed time taken from the start of each experiment for the scour hole to develop for each pier is shown below.

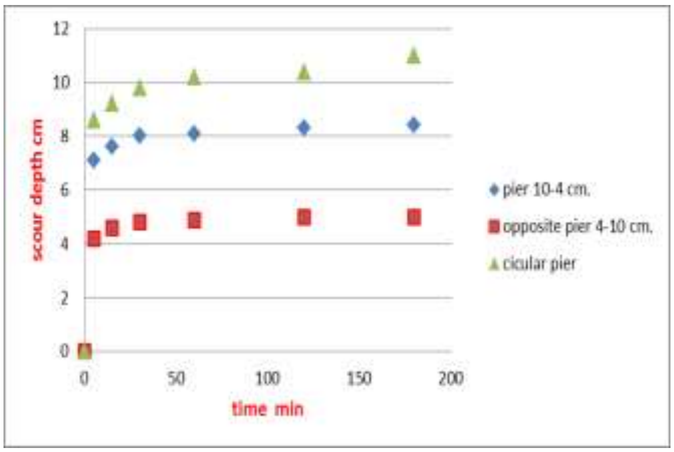

Figure. 7 Scour Hole Development measured at the Upstream Face of each tested pier

From the "Fig. 7" the evolution of scour hole for the circular and normal are quite similar due to the shape and geometry of the these two piers on the upstream side.

"Fig.6 (a-c)" shows that, in the upstream reach of circular and normal piers a strong horseshoe vortex was detected, positioned at the base of piers, but for the opposite pier the effect of horseshoe vortex reduced (not so visible) due to the down flow being deflected away from the base of opposite pier. In the downstream reach of circular a strong wake vortex was visible and leading into scour hole, and for opposite and normal piers there exist a flow reversal towards the water surface and the bed.

A. Scour Hole Dimensions

Dimensions of the scour holes for each of three piers were measured. The top width of scour in the transverse direction, distance from upstream face to front outer edge of hole, and depth at upstream face were compared for each of the three bridge piers as in "Table 1."

Table (1) Scour Hole Dimensions from Physical Modeling

Normal bridge pier Diameter = 10-4 cm.	**Opposite bridge pier Diameter = 4-10 cm.**	**Circular bridge pier Diameter =10 cm.**
Top Scour Hole Width =0.36 m	Top Scour Hole Width =0.30 m	Top Scour Hole Width = 0.50 m
Distance from Upstream face to front outer edge of hole = 0.16 m	Distance from Upstream face to front outer edge of hole = 0.07 m	Distance from Upstream face to front outer edge of hole = 0.18 m
Depth at Upstream face = 0.084 m	Depth at Upstream face = 0.05 m	Depth at Upstream face = 0.109

Scour hole depths for the circular and normal bridge piers were quite similar which was expected due to the identical shape on the upstream side of the pier as illustrated in "Fig.7". A 54 % reduction in scour hole depth of the opposite bridge pier was observed as compared to the circular pier and 40% reduction as compared to the normal bridge pier. The effect of the horseshoe vortex was reduced due to the down flow being deflected away from the base of opposite bridge pier. The development of the scour hole around the pier perimeter is therefore strongly influenced by this down flow.

The percentage reduction in distance from the upstream face of the pier to the upstream front outer edge of the hole as compared to the circular pier was 11% for the normal bridge pier and 61% for the opposite bridge pier, it is clear that the scour area at the downstream for opposite and normal bridge piers is significantly less than for the circular piers. The horseshoe vortex intensity is being diminished at the downstream area for normal and opposite bridge piers as shown in " Fig. 8."

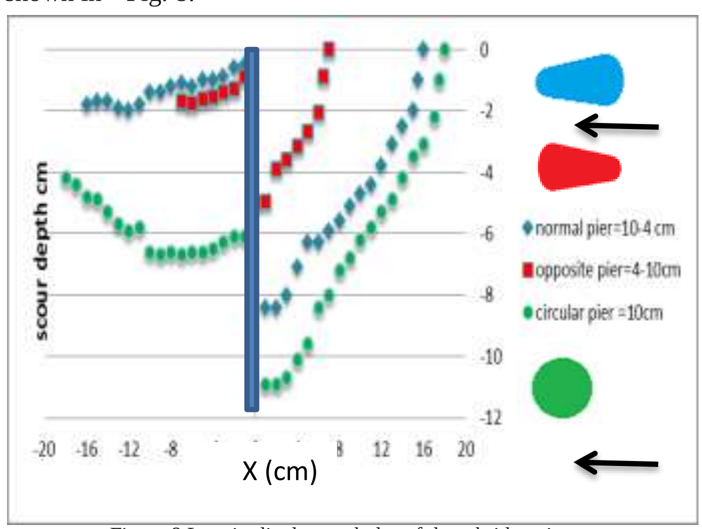

Figure.8 Longitudinal scour holes of three bridge piers

"Fig. 9" demonstrates the top scour holes of three bridge piers. The top scour hole width of opposite bridge shaped pier was

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0.20 m or 40% less than the circular pier and 0. 06 m or 17 % less than the normal bridge pier.

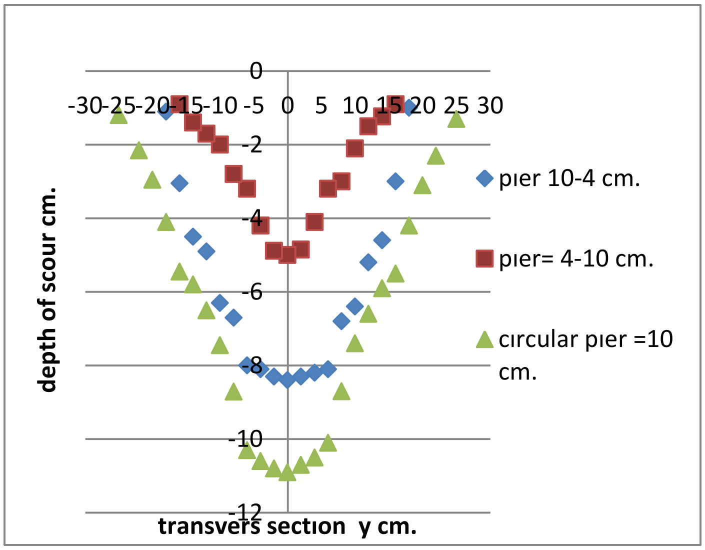

Figure 9 transverse scour holes of three bridge piers.

VI. Conclusion

Opposite bridge pier is an effective countermeasure in the reduction of local scour depth. The percentage reduction in scour hole depth for the normal and opposite piers as compared to the circular pier was 40% and 54.5% respectively. The effect of the horseshoe vortex was reduced due to the down flow being deflected away from the base of the opposite bridge pier. The development of the scour hole around the pier perimeter is therefore strongly influenced by this down flow.
The opposite pier is an effective countermeasure in the reduction of distance from upstream face to front outer edge of hole.

The percentage reduction in distance from the upstream face of the pier to the upstream front outer edge of the hole as compared to the circular pier was 11% for the normal bridge pier and 61% for the opposite bridge pier.

The top scour hole width of opposite bridge pier was 40% less than the circular pier, and 17% for normal pier.

Through the use of the ADV testing, in terms of the normal bridge pier and after change the position of bridge pier (opposite pier), it was revealed that;

•It minimizes the length of the horseshoe vortex;

• It significantly reduced the intensity of the wake vortices and;
• It removed the interaction of the horseshoe vortex and wake vortices.

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