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Experimental Investigation of Turbulent Flow Field at Downstream-Facing Round Nosed Pier

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Bridge pier in a flow induce turbulence and vortices that increase the risk of sediment bed scouring. The turbulent flow field around downstream-facing round nosed pier in a scoured bed was examined experimentally. The opposite bridge pier was embedded in a non-uniform soil with d_{50} = 1.45 mm and σ_g = 3.16. Experiments were carried out under live-bed condition. Flow velocities were measured with acoustic Doppler velocimeter. Measurement was conducted at the pier front. Result shows that the time-average velocity field, turbulent intensities and turbulent kinetic energy at different depths and distances from the original bed level differs. These results are benefiting for validation of three-dimensional flow model and turbulence close to the bridge pier.

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1. Introduction

The turbulent flow field around a pier is a complex three-dimensional unsteady flow including a flow separation, the formation of the horseshoe vortex, the wake vortex shedding and its interaction with the horseshoe vortex. The vortices around bridge elements are considered the main cause of local scour. Therefore, it has been investigated intensively in the last years both experimentally and numerically [1–3]. While most of the articles focused on scouring around circular pier, only very few studies are focused on scouring around non-circular piers [4–6].

The present study is perhaps the first experimental work to investigate the 3D turbulent flow field around downstream-facing round nosed pier (DS-FRNP) under live bed condition. In this study, experimental investigation of 3D turbulent flow field around downstream-facing round nosed pier in non-uniform scour hole under live-bed condition is presented.

2. Experiments

Experiments were conducted in hydraulic laboratory of civil engineering department of Gaziantep University. The flume is 12 m long, 0.8 m width and 0.9 m deep with glass sides and steel bottom. The test section was made with a ramp which is located at the beginning and the end of the section. The test section is 3 m long and 0.2 m deep. The test section was filled with sediment of median particle size d_{50} =1.45 mm and standard deviation $d_{50} = (d_{84}/d_{16})^{0.5} = 3.16$ with specific gravity of 2.65. Flume discharge was measured by magnetic flow meter installed in the pipe system before the inlet of the channel. The scour hole and the elevation of the bed were measured by laser meter. Experiments were performed under live bed water scour regime. The discharge was measured as 58 l/s for duration of 3 h. Two downstream-facing round nosed piers were used (4–10 cm and 8–10 cm) and is located in the test section as illustrated in Fig. 1. Stream velocity is measured upstream and downstream of the pier using acoustic Doppler velocimeter (ADV) in the centre of the flume. The ADV probe was then positioned above scour hole, and velocities were recorded for a period of 180 s. The sample period of 180 s was chosen to ensure that sufficient flow variations were captured.

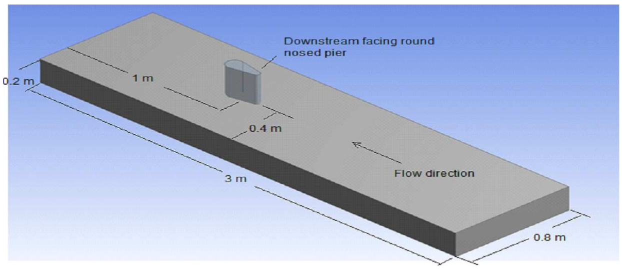

Fig. 1. Location of downstream-facing round nosed pier in test section.

2.1. Turbulent intensities

The patterns of turbulent intensities $\sqrt{u\prime u\prime}$ and $\sqrt{w\prime w\prime}$ at upstream plane for scoured bed for downstream-facing round nosed piers are shown in Figs. 2 and 3. The magnitudes at the pier front $\sqrt{u\prime u\prime}$ and $\sqrt{w\prime w\prime}$ increased toward the scoured bed, besides the turbulence intensities increased with decreasing distance to the pier ($x = 3$ cm) due to the down flow and flow separation. Figures 2 and 3 reveal that the distributions of $\sqrt{u\prime u\prime}$ and $\sqrt{w\prime w\prime}$ are almost similar. In general, there is a core of high turbulence intensity on the scoured bed as a result of flow separation.

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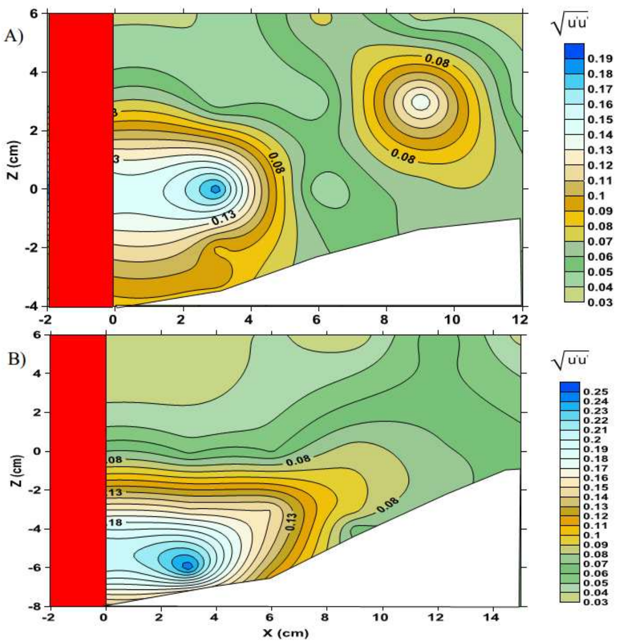

Fig. 2. Contour of longitudinal turbulent intensity $\sqrt{u'u'}$ in m/s at upstream plane: (A) DS-FRNP 4–10 cm, (B) DS-FRNP 8–10 cm.

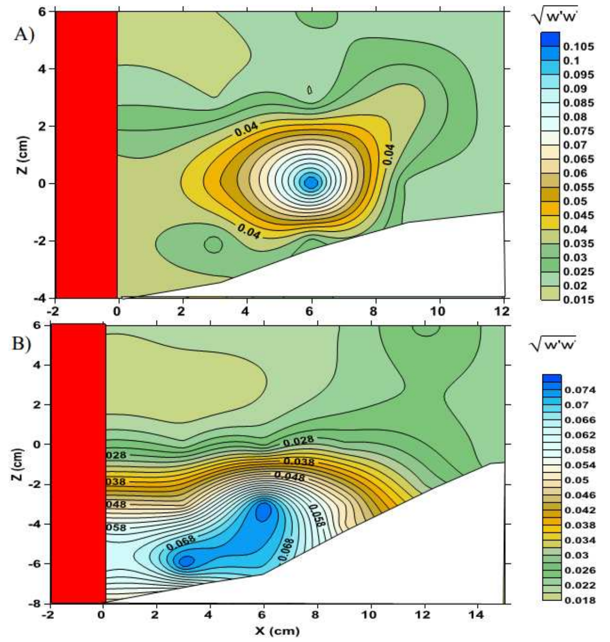

Fig. 3. Contour of vertical turbulent intensity $\sqrt{w'w'}$ in m/s at upstream plane: (A) DS-FRNP 4–10 cm, (B) DS-FRNP 6–10 cm.

2.2. *Turbulent kinetic energy (TKE)*

The TKE is the sum of the mean of the product and square of each of the fluctuating components of the velocity fluctuations as shown in Eq. (1).

$$\mathrm{TKE} = 0.5(u'u' + v'v' + w'w'), \tag{1}$$

where u', v', and w' are respectively the fluctuating components of velocity in the x, y, and z. The distributions of turbulent kinetic energy, whose contours are shown in Fig. 4, are similar to those of turbulence intensities. From Fig. 4, it is clear that the area of TKE were observed near and under the water surface for DS-FRNP.

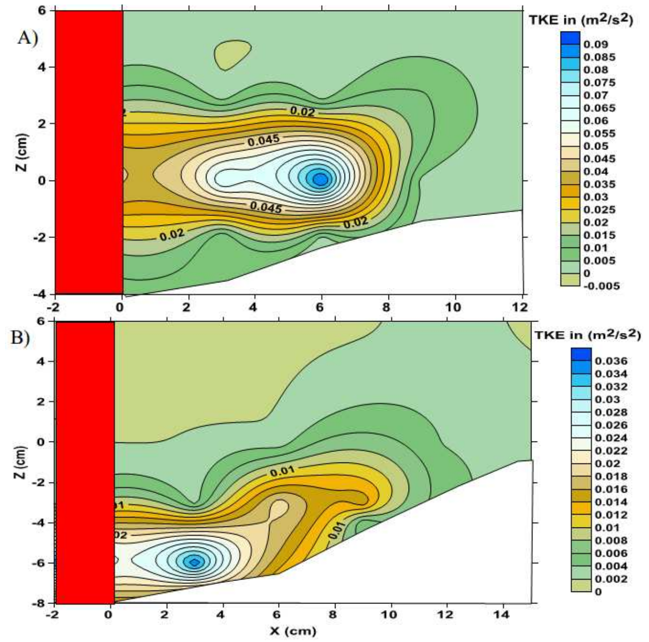

Fig. 4. Contour of TKE in m^2/s^2 at upstream plane: (A) DS-FRNP 4–10 cm, (B) DS-FRNP 8–10 cm.

3. Conclusion

An experimental investigation on the three-dimensional turbulent flow field around downstream-facing round nosed pier in non-uniform sand bed under live-bed condition was presented. The velocity measurement was done by using ADV. The measurement allowed the quantitative description of the main flow features around downstream-facing round nosed pier. The distribution of time-average velocity, flow vectors, turbulence intensities and turbulent kinetic energy has been presented. The results are useful for validation of computational fluid dynamics models that can be used to simulate scouring around bridge pier improving their design.

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