ABSTRACT

Upstream and downstream piers are often found in different arrangements in neighboring bridge crossings on a river. In this study, interference of an upstream pier on clear water scour at the downstream piers was experimentally investigated and the results were discussed. Following three types of pier arrangements were tested: (i) two identical piers in a tandem arrangement, (ii) two identical piers in a staggered arrangement, and (iii) three identical piers in a symmetrically staggered arrangement. Two different pier diameters (60 and 82 mm) were studied in the tandem arrangement. The equilibrium scour depth at the downstream pier varies approximately from 0.8 to 0.87 times the scour depth that occurs at a single pier. The minimum value of the equilibrium scour depth at the downstream pier in the tandem arrangement occurred at a spacing of $8b$, which was considered as the best configuration for the design, where $b$ was the pier diameter. For the two piers in a staggered arrangement, the equilibrium scour depth at the downstream pier was the lowest for the streamwise spacing of $6b$, and the offset distance of $4b$. It was observed that for a streamwise spacing $> 8b$ and the offset distance of $4b$ the equilibrium scour depth at the downstream pier was more than that at the upstream pier. In the case of three piers in a staggered arrangement, as the radial distance between the upstream and downstream piers increases, the scour depths at the downstream piers decrease.

A semi-empirical model was presented to estimate the time variation of scour depth at the downstream pier when two piers are arranged in tandem arrangement under the clear water scour condition with uniform sediments. The methodology developed for computing the time variation of scour depth was based on the concept of the mass conservation of sediment, considering the primary horseshoe vortex system as the main agent of scouring and assuming a layer-by-layer scouring process. The final analytical equation was a first-order differential equation, which has been solved numerically by the fourth-order Runge-Kutta method. The proposed model satisfactorily agreed with the present experimental data of time varying scour depth at the downstream pier in a tandem arrangement.

The efficiency of a splitter plate as a countermeasure in terms of reduction of the equilibrium scour depth at a circular pier in a uniform sediment bed under the clear water condition was investigated. In this regard, experiments were conducted with a splitter plate attached to a pier at the upstream vertical plane of symmetry. In this study, two uniform sediment beds of median sediments ($d_{50}$) 0.96 and 1.8 mm were considered. Different combinations of lengths and thicknesses of splitter plates were tested. The experimental results demonstrated that the scour depth consistently decreases with an increase in the splitter plate length, while the scour depth remains independent of the splitter plate thickness. The best combination of splitter plate dimensions was found to be $b/5$ and $2b$ for splitter plate thickness and length respectively, which results in the minimum scour depth at a pier. In addition, the temporal evolution of scour depth at a pier with and without a splitter plate was investigated. Finally, an empirical formula to estimate the equilibrium scour depth at a pier with splitter plate was obtained using the multiple linear regression analysis of the experimental data.

The flow fields at a circular pier with and without a splitter plate, including plain bed and equilibrium scour hole conditions were measured by using an Acoustic Doppler Velocimeter (ADV). The turbulent flow fields of the above mentioned configurations were investigated by plotting the velocity vectors and the turbulent kinetic energy contours on vertical and horizontal
planes. The splitter plate attached to a pier deflected the approach flow and thus weakened the strengths of the downflow and the horseshoe vortex, therefore instrumental in reducing the equilibrium scour depth at the pier. The proposed method of pier scour countermeasure was found to be easy to install and cost effective as well.

**Key words:** Scour, erosion, pier interference, bridge piers, sediment transport, analytical model, time variation, scour countermeasure, pier protection, splitter plate.