ABSTRACT

The three-dimensional turbulent flow fields and clear water scour in the vicinity of different types of short abutments (ratio of abutment length to approaching flow depth less than unity), namely vertical-wall, 45° wing-wall and semicircular were investigated experimentally. All the experiments were conducted in a 20 m long, 0.9 m wide and 0.7 m deep horizontal flume. In the experiments, altogether nine types of uniform sediments, five types of nonuniform sediments and five sizes for each type of abutment were used.

The time-averaged velocity components, turbulent intensity components, turbulent kinetic energy and Reynolds stresses on rigid flat bed and within stabilized scoured bed were taken by the Acoustic Doppler Velocimeter (ADV) at different vertical sections for vertical-wall abutment and azimuthal sections for wing-wall and semicircular abutments. The bed shear stresses in the vicinity of the abutments were estimated using the Reynolds stresses and velocity gradients. A Cartesian coordinate system is used to represent the flow field for vertical-wall abutment, whereas cylindrical polar coordinate system is used for 45° wing-wall and semicircular abutments.

A detailed parametric study was done using the laboratory experimental results on local scour at short abutments of all three aforementioned types in uniform and nonuniform sediments under a clear water scour condition. The equilibrium scour depth is related to the sediment size and approaching flow depth relative to the abutment length. The effect of sediment gradation on scour depth is pronounced for nonuniform sediments, which reduces scour depth significantly due to the formation of armor-layer in the scour hole. The time variation of scour depth for uniform sediments shows a family of parallel lines for different abutment lengths and sediment sizes. For nonuniform sediments, the time variation of scour depth reduces with increase in nonuniformity of the particle size distribution of sediments. The characteristic parameters affecting the maximum equilibrium normalized scour depth (scour depth - abutment length ratio), identified based on the physical reasoning and dimensional analysis, are excess abutment Froude number, flow depth - abutment length ratio, and abutment length - sediment diameter ratio. The experimental data in clear water scour condition under limiting stability of upstream bed sediments were used to determine the equations of maximum equilibrium scour depth.

An analytical model was developed to compute the time-variation of scour depth in an evolving scour hole at short abutments of different types, in uniform and nonuniform

sediments under a clear water scour condition. The model was derived from the concept of the conservation of mass of sediment, considering the primary vortex system being the main agent of scouring and assuming a layer-by-layer scouring process.

The effects of thin armor-layer on scouring process and on maximum equilibrium scour depth at abutments were also explored. Experiments on local scour at different types of short abutments embedded in a bed of relatively fine noncohesive sediment overlain by a thin armor-layer of coarser sediment, were conducted for different flow conditions, thickness of armor-layers, armor-layer and bed sediments. The armor-layer and the bed underneath it were composed of different combinations of uniform sediments. In the experiments, the approaching flow velocities were restricted to the clear water scour condition with respect to the armor-layer particles. Depending on the approaching flow conditions, three cases of scour at abutments in armored beds were identified. Also, effects of different parameters pertaining to scour at abutments have been examined. The characteristic parameters affecting the maximum equilibrium normalized scour depth (scour depth - abutment length ratio), identified based on the physical reasoning and dimensional analysis, are excess abutment Froude number, flow depth - abutment length ratio, armor-layer thickness - armor particle diameter ratio, and armor particle - bed sediment diameter ratio. Equations of maximum equilibrium scour depth in thin armor-layer for each type of abutments were given.

Keywords: Abutments; open channel flow; three-dimensional flow; turbulent flow; scour; sediment transport; hydraulics.