EFFECT OF FLOOD WAVES ON BRIDGE PIER SCOUR

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Bridge pier scour was mainly investigated for steady approach flow conditions. This research considers the effect of a single-peaked flood wave on pier scour using both a computational and an experimental approach. Clear-water scour of incohesive sediment by an approach flow of well-defined flow depth and velocity, a circular-shaped cylindrical bridge pier and a flood hydrograph is investigated. The results relate to scour advance with time, generalized temporal scour development and the end scour depth in terms of the densimetric particle Froude number involving the maximum approach velocity and median sediment size. The effect of the remaining parameters on the end scour depth is discussed; predictions are essentially in agreement with model observations if the limitations for the present computational procedure are respected.

Scour is experimentally modeled using the Froude similitude (Hoffmans and Verheij 1997). Bridge scour is a two-phase flow involving water and sediment at a relatively small Froude number (Melville and Coleman 2000); accordingly this process may be characterized with the densimetric (subscript d) particle Froude number $\mathsf{F}_d=V_o/(g'd_{50})^{1/2}$, with V_o as the approach flow velocity, the reduced gravitational acceleration $g'=[(\rho_s-\rho)/\rho]g$ with ρ_s and ρ as densities of sediment and fluid, and g as the gravitational acceleration. The sediment is characterized by the mean grain size d_{50} and the sediment non-uniformity parameter $\sigma=(d_{84}/d_{16})^{1/2}$. The scour geometry depends essentially on F_d provided a number of limitations as expressed by Oliveto and Hager (2005) are satisfied. These involve minimum pier diameter and approach flow velocity to ensure that the flow is in the turbulent rough regime, the clear-water regime and a minimum grain size of the order of 1 mm. Further, the flow depth should have a minimum of some 50 mm and the original bed in a rectangular channel should be plane.

The temporal scour advance for steady approach flow may be described for the single cylindrical circular-shaped pier as (Oliveto and Hager 2005)

$$Z = 0.068\sigma^{-0.5}\mathsf{F}_d^{1.5}\log T \tag{1}$$

The computational procedure for unsteady flow conditions was presented by Hager and Unger (2005). The approach flow depth h_o in a wide rectangular river was approximated with the Manning-Strickler equation.

A typical flood wave is single peaked, starting at time t=0 to reach maximum (subscript M) flood discharge q_M at time to peak $t=t_M$. Single-peaked flood waves may be approximated as

$$q/q_M = Q_M = [T_M \exp(1-T_M)]^n \tag{2}$$

with the hydrograph shape parameter n typically larger than n=1.

From the computational procedure the relative end scour depth may be approximated as (Hager and Unger 2005)

$$\frac{z_e}{(h_M^4 D^5)^{1/9}} = 0.068\sigma^{-1/2}\mathrm{F}_{dM}^{3/2}\left(\frac{\sigma^{1/3}(g'd_{50})^{1/2}t_M}{h_M n}\right)^{1/6} \tag{3}$$

where $\mathrm{F}_{dM}=V_M/(g'd_{50})^{1/2}$ is the densimetric particle Froude number relative to the maximum velocity V_M. The end scour depth z_e relative to the square root of the approximate product of maximum approach flow depth h_M times pier diameter D varies essentially with the densimetric approach Froude number F_{dM} and only slightly with additional effects composed of sediment non-uniformity σ, density ratio of sediment and fluid involved, grain size d_{50}, time to peak t_M, approach flow depth h_M and hydrograph shape parameter n.

The expression in brackets of the right hand side of (3) $P=[(g'd_{50})^{1/2}t_M/h_M]^{1/6}$ represents an almost constant value because sediment size d_{50} is small and flow depth h_M is large for a large time to peak t_M, whereas the sediment size is normally large and flow depth is small for short flood waves, resulting in

$$z_{e,appr}\Big/\left(h_M^4 D^5\right)^{1/9} = 0.25N\mathrm{F}_{dM}^{3/2} \tag{4}$$

Equation (9) demonstrates the significance of F_{dM} on the scour end depth, an appreciable effect of scour element (N=1.00 for piers and N=1.25 for the abutment), and a relatively small effect of the approach flow depth and the pier diameter. This equation allows preliminary estimations, whereas (3) should be used otherwise.

The end scour depth is a function of the densimetric particle Froude number at peak discharge F_{dM} and normalized time to peak T_e. The time to sediment entrainment and the scour time are specified, and the relation between discharge and flow depth was experimentally investigated. These results are governed by a large number of parameters. However, the final outcome is simple allowing for a straightforward design. The present approach was verified experimentally for circular bridge piers and may be expanded for other scour elements relevant in river engineering.

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