Investigation of Scouring at Rectangular Abutments in a Compound Channel under Unsteady Flow (Experimental Study)

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ABSTRACT

One of the most important parameters in the design of bridge abutments and piers is to calculate the depth of scouring. The previous relationships for measuring the scour depth were based on steady flow, and it is not expected that the amount of scour depth computed from these relations is accommodated to the actual value during a flood wave. Inasmuch as in this condition, the flood hydrograph occurs in an unsteady state, the discharge is variable between base and peak values. In this study, experiments were conducted to measure the clear-water scour depth of a rectangular abutment under steady and unsteady flow conditions by approaching flood waves with triangular hydrographs and equivalent stepped hydrographs in a compound channel. Then, by using the measured scour depths values in steady flows, a relationship is calculated to estimate the maximum scour depth in terms of dimensionless time parameter and flow intensity. By changing the peak discharge time parameter, the effect of slope at ascending and descending part of the triangular hydrograph on the scouring was investigated. A comparison of the scouring of two stepped hydrographs with the same time duration showed that the difference between the scouring values was 1.5%. Moreover, the results of the scour depth measurements of triangular and stepped hydrographs were compared.

KEYWORDS

Bridge Abutment, Scour Depth, Stepped Hydrograph, Time Step, Unsteady Flow

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1. Introduction

The costly construction and repair of the bridge, as well as its role in communicating between the two sides of the river, have a significant economic and social significance. The main reason for the failure of the bridge is scouring at the abutment or pier due to flood wave. Therefore, the local scouring of abutment or pier, which play an important role in the destruction of bridge, attracted engineers and led to a lot of research in order to find a formula for estimating the depth of scouring at bridge abutment.

Formulas for scour depth estimation provided for steady flow so far, and it is not expected that the scour value calculated from these formulas will be consistent with the actual value that occurs at the time of the flood event. Because at the time of the flood, flow in the river occurs in an unsteady state where the flow rate varies between a base and peak value.

2. Methodology

To carry out the present research, a flume with a length of 12 m and a width of 1 m and a height of 0.8 m with glass walls is used. For control of depth, a gate at the end of the flume that moves with the cable is used. The pump used in the flume has a nominal flow rate of 120 liters per second and the discharge is measured by an ultrasonic flowmeter mounted on the pump suction pipe. To create a flood hydrograph, a driver was used to perform the pump connection to the computer. Through this driver, the command is sent from the computer to the pump and can be controlled at any time.

The sediments used in the channel bed are sand with uniform size σ_g =1.36 and d_{50} =1mm. The erodible area is 6 m from the beginning of the flume and has a length of 3.5 m and a depth of 42 cm. The purpose of this study is to investigate the depth of scouring at the abutment of the bridge in the floodplain and the cross section defined in a way that the main channel wall (the opposite wall) has a slight effect on localized scouring in the nose of the abutment.

Using dimensional analysis, an equation defined to calculate the time variation of scour depth d_s/d_{se} with respect to u_*/u_{*c} and t/t_e parameters. The constant coefficients were calculated using steady flow experiments.

$$\frac{d_s}{d_{se}} = 1.035\left(\frac{t}{t_e}\right)^{0.223}\left(\frac{u_*}{u_{*c}}\right)^{-0.287} \tag{1}$$

3. Discussion and Results

In order to investigate the effect of the time to peak parameter on the scour depth of the abutment, simple symmetrical and non-symmetrical triangular hydrographs as shown in figure 1 were used to examine the effect of ascending and descending limbs on the scour depth and It was concluded that the upward and downward slope of the limbs does not affect the amount of scour depth, and only a higher slope in the upward limbs reduces the time of maximum scouring (figure 2).

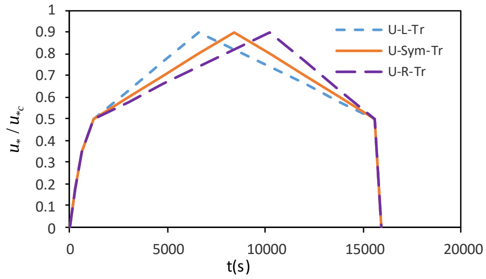

Figure 1. Symmetrical and non-symmetrical triangular hydrographs

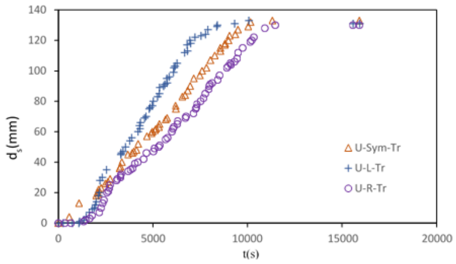

Figure 2. Time variation of scour depth in tested hydrographs

In order to investigate the effect of time step on the stepped hydrograph, as shown in figure 3 and in figure 4, two time steps $\Delta t = 42\text{min}$ and $\Delta t = 30\text{min}$ were used for stepping the triangular hydrograph. The results showed that the change in time step, in other words, change in the number of the steps has little impact on the amount of scour depth of the abutment.

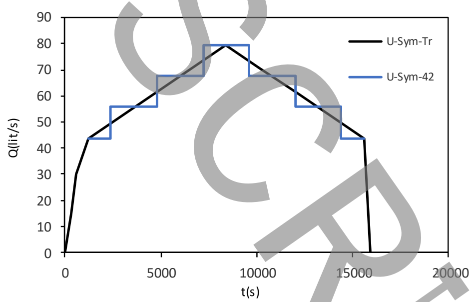

Figure 3. Symmetric triangular and stepped hydrographs with $\Delta t = 42\text{min}$

It was found that the difference in the amount of scour depth in two hydrographs is less than 2% and actually indicates that the time step is not effective in stepping the hydrograph.

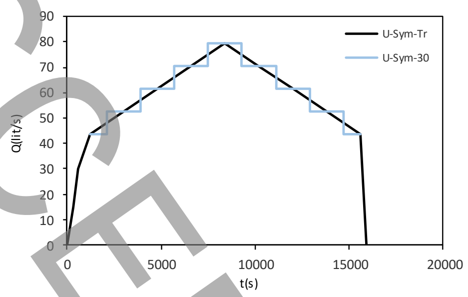

Figure 4. Symmetric triangular and stepped hydrographs with Δt = 30min

By comparing triangular and stepped symmetric hydrographs, it was found that the difference between the values of scour depth was less than 4%, which it can be due to the operation of the pump and its adaptation to the required flow rates at different times. Table 1 summarizes the results of Final scour depth in stepped hydrographs.

Table 1. Comparing Final scour depth in triangular hydrograph and Stepped hydrographs

Triangular hydrograph	Stepped hydrograph		
U-Sym-Tr	U-Sym-30	U-Sym-42	
133	136	138	Final scour depth

4. Conclusions

In this study, local scouring of the floodplain bed in a compound channel at the nose of a rectangular abutment under flood wave was investigated. Tests performed under clear water conditions in the uniform sediments with a constant depth. By identifying the parameters affecting scouring and performing dimensional analysis, a relation was defined to calculate the scour temporal changes in terms of dimensionless parameters in the problem. Then, using the results of steady state flow tests, the root mean square error of 0.059 and R^2 = 0.943 were calculated. The hydrographs studied in this study have the same duration time. By changing the time of peak discharge, it was observed that the amount of final scour depth does not change, but the temporal development of scour is different. By comparing the final values of scour in stepwise and non-stepped hydrographs, it was found that there is a slight difference between the values obtained. Using the proposed equation of Oliveto and Hager, the time evolution of the scour calculated and the final value difference with respect to the laboratory tests is 5.2%.

5. References

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