MULTIPLE FLOODS DAMAGE RISK ASSESSMENT AND MANAGEMENT FOR ENGINEERING STRUCTURES IN FLOW

Boriss Gjunsburgs and Roberts Neilands

Water Engineering and Technology Department, Riga Technical University, Azenes Street 16 , LV-1048, Riga, Latvia,
phone: +371 67089253; fax: +371 67089084; e-mail: gjunsburgs@bf.rtu.lv; roberts.n@inbox.lv

INTRODUCTION

Water flow in rivers during multiple and flash floods strongly impacts transport system infrastructure – roads, bridges, dams, and etc. The danger of damage of piers, abutments, and guide banks of new, old, and critical bridges (with unknown foundations) located in the floodplain because of scouring during floods is very high. The reasons are multiple floods and also the fact that the erosion hole parameters near structures under clear-water conditions are summed up and increase from flood to flood. This occurs also in the case where the constructions are not damaged even after several floods, but the dimensions of scour hole increases from flood to flood, and each next flood with new scour can lead to failure of the structures and be the reason for damage of cultural heritage, as well as, environmental and economical losses. The flood damage critical areas and transport system infrastructure (main national roads that have economical importance, emergency evacuation roads, as well as, critical bridges and bridges with unknown foundations) should be included into flood risk maps.

The objective of this research is to study the scouring impact of flash and multiple floods on stability and safety of the bridge structure foundations. The research focuses on the development of scour processes at the abutments during the multiple floods and the equilibrium stage of scour process.

Existing methods and formulas do not take into account multiple floods impact on scour process near structures, probability, duration, frequency and sequence of the floods. To estimate current stage of the scour process after multiple floods and compare it with designed equilibrium stage is very important for prediction of stability and safety for abutment.

A method for predicting the flood damage risk of engineering structures from the viewpoint of scouring at foundations during multiple floods is presented. The method is based on two approaches to scour calculation: 1) determination of the scour development in time during multiple floods, and 2) determination of the designed equilibrium depth of scour. Using these two methods, we suggest estimating the factor of flood damage risk as a ratio between the scour depth calculated during/after multiple floods and the designed equilibrium scour depth.

SCOUR DEVELOPMENT DURING MULTIPLE FLOODS

In nature, the river engineering structures have to withstand the loads of multiple floods. We can calculate the scour depths developed at structure foundations in multiple floods of different probability, frequency, sequence, and duration by using the method that take into account the scour development in time (Gjunsburgs et al., 2001, 2004).

To determine the scour depth development during the flood, we divided the hydrograph into time steps with duration of 1 or 2 day, and each time step – into time intervals up to several hours (Fig. 1). At each time step the flow is steady, but is changing from step to step during the flood. In the laboratory tests, the time steps were divided into 20 time intervals. For each time step, the following parameters must be determined: h_f – water depth in the floodplain, Q/Q_b – flow contraction rate, Δh – maximum backwater, d – grain size, H – thickness of the bed layer with d, and γ – specific weight of the bed material. As a result, we have V_l, V_0, A_i, D_i, N_i, N_{i-1}, and h_s at the end of time intervals and finally at the end of the time step. For the next time step, the flow and bed parameters were changed because of the flood and the scour developed in the previous time step.

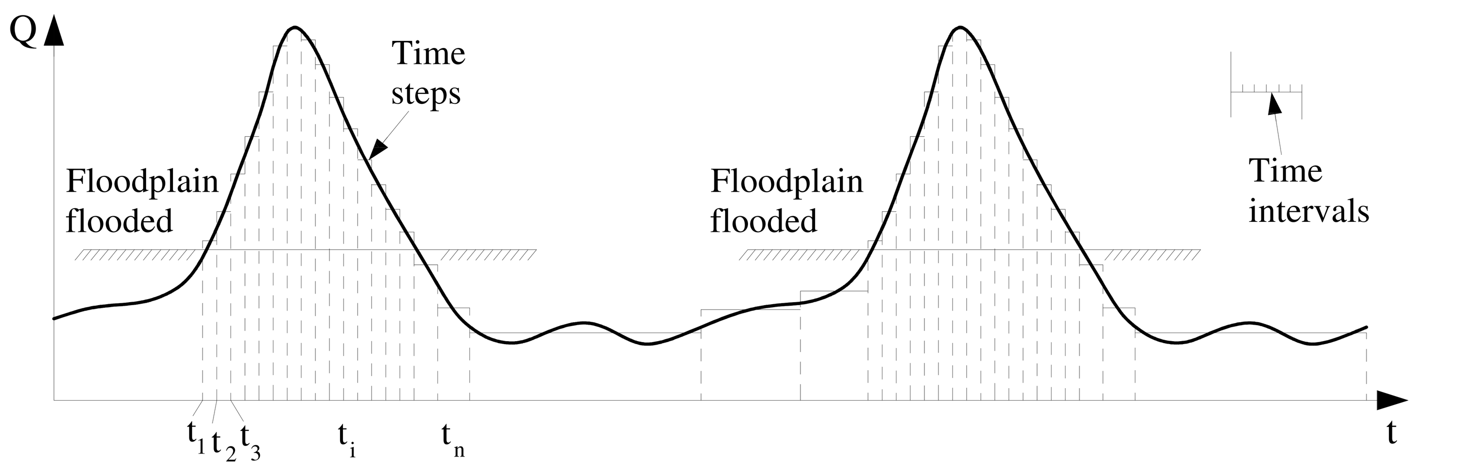

Figure 1. Hydrograph divided into time steps and time intervals

The scour depth depends on time and is calculated by the formula:

$$N_i = \frac{t_i}{4 D_i h_f^2} + N_{i-1} \quad (1)$$

where $N_i = 1/6x_i^6 - 1/5x_i^5$ (according to data by Gjunsburgs & Neilands, 2001); t_i is the time interval; D_i is a constant parameter in a steady-flow time step; and h_f is the flow depth in the floodplain.

Using the data for the calculated N_i, we find:

$$h_s = 2h_f(x-1) \cdot k_m \cdot k_s \cdot k_\alpha \quad (2)$$

here h_s is the scour depth at the end of time interval; k_m is a coefficient depending on the side-wall slope of the abutment (Yaroslavcev, 1956); k_s is a coefficient depending on the abutment shape (Richardson and Davis, 1995); and k_α is a coefficient depending on the angle of flow crossing (from Richardson et al., 1990, as presented in Richardson and Davis, 1995).

EQUILIBRIUM DEPTH OF SCOUR

The equilibrium depth of scour is an important parameter to be determined for the foundation of the structures at the design stage to ensure the lifetime guaranty of safe maintenance of the engineering structures in floods. This parameter is also important in determining the critical value of scour depth at which the emergency scour-protection measures should be taken.

In tests on the bridge abutment models, the streamline concentration, an additional flow action, flow separation, a sharp drop in water level, a local increase in velocities, the origin of eddy and vortex structures, and the development of a scour hole were observed at the corner of the abutment (Gjunsburgs et al. 2001, 2004).

The local velocity can be found in the form:

$$V_l = \varphi\sqrt{2g\Delta h} \quad (3)$$

where φ is the velocity coefficient for abutment which depends on the contraction rate of the flow; g is the gravitational acceleration; and Δh is the maximum backwater (Rotenburg, 1969).

During the scour process, the discharge across the width of a scour hole changes: $Q_f = kQ_{sc}$, where Q_f is the discharge across the width of a scour hole with a plain bed; k is a coefficient depending on the contraction of the flow; and Q_{sc} is the discharge across the width of a scour hole with a scour depth h_s.

This equation can be written as:

$$mh_s \cdot h_f V_l = k\left(mh_s h_f + \frac{mh_s}{2} \cdot h_s\right) \cdot V_{lt} \quad (4)$$

where h_s is the scour depth and m is the slope of a scour-hole wall.

The local flow velocity V_{lt} can be found at any depth of the scour hole:

$$V_{lt} = \frac{V_l}{k\left(1+\frac{h_s}{2h_f}\right)} = \frac{\varphi\sqrt{2g\Delta h}}{k\left(1+\frac{h_s}{2h_f}\right)} \quad (5)$$

The flow velocity at which the sediment movement starts is V_0, and it can be found at any depth of scour:

$$V_{0t} = \beta \cdot V_0\left(1+\frac{h_s}{2h_f}\right)^{0.25} = 3.6 \cdot \beta \cdot d^{0.25} h_f^{0.25}\left(1+\frac{h_s}{2h_f}\right)^{0.25} \quad (6)$$

where β is a coefficient of reduction in V_0 because of the flow vortex structures; d is the grain size of bed material.

The scour reaches its equilibrium stage and stops when the local flow velocity V_{lt} becomes equal to the velocity V_{0t}. Using the Eqs. (5) and (6), we find equilibrium scour depth:

$$h_{equil} = 2h_f\left[\left(\frac{V_l}{k\beta V_0}\right)^{0.8} - 1\right] \cdot k_m \cdot k_s \cdot k_\alpha \quad (7)$$

where k_m is a coefficient depending on the side-wall slope of the abutment (Yaroslavcev, 1956); k_s is a coefficient depending on the abutment shape (Richardson and Davis, 1995); and k_α is a coefficient depending on the angle of flow crossing (from Richardson et al., 1990, as presented in Richardson and Davis, 1995).

FLOOD DAMAGE RISK - ASSESSMENT OF STABILITY OF STRUCTURE

The stability of the engineering structures in floods from the aspect of scouring can be evaluated by combining two calculation methods, namely the method of computing the designed equilibrium depth of scour by Eq. (7) and the method of computing the scour development during multiple floods of different probability, frequency, sequence, and duration according to Eq. (2).

The scour-hole parameters calculated during or after multiple floods can be compared with the equilibrium parameters, and thus the stability of the engineering structure can be evaluated. The flood damage risk factor by abutment scour can be calculated as a ratio between h_s, the scour depth after the floods of certain probability, and h_{equil}, the equilibrium scour depth at the abutments in the flood of the same probability:

$$R = \frac{h_s}{h_{equil}} \quad (8)$$

The closer the current depth value of the scour hole to the equilibrium value of the latter, the greater the risk factor and the lower the stability of the construction. By using the risk factor, we can estimate the current stability of the structure or to predict/compute the time of safe maintenance at the stage of design. If the scour-hole depth developed is close to the equilibrium conditions, the critical conditions are reached and the emergency scour-protection measures (riprap, rock riprap, sand/cement-filled bags, etc.) for the structure should be taken. Thus, it is possible to be prepared in advance, because the hazardous river engineering structures are already recognized.

The results of calculation example of scour hole at the bridge abutments on a plain river after two floods of 1% probability – developed depth, width and volume of scour hole and equilibrium (critical) values are showed in Figs. 2, 3, and 4, respectively.

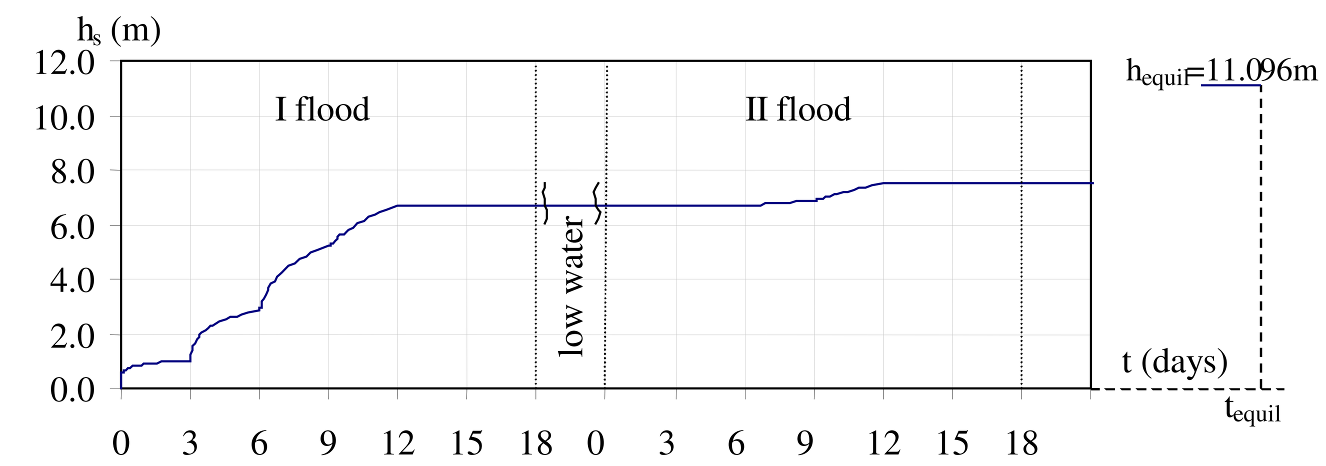

Figure 2. The equilibrium stage and development of scour hole depth during two floods

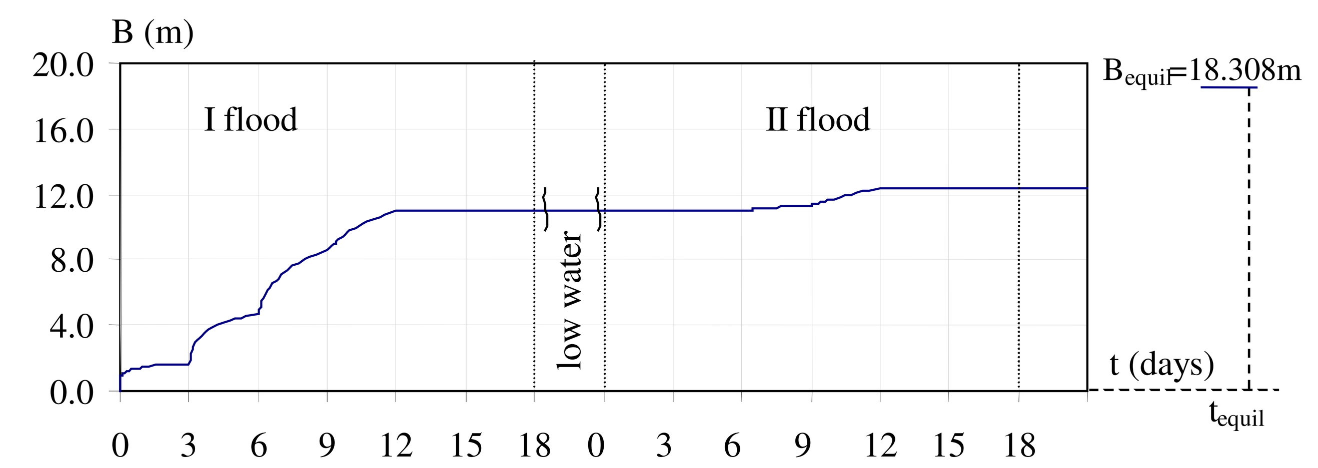

Figure 3. The equilibrium stage and development of scour hole width during two floods

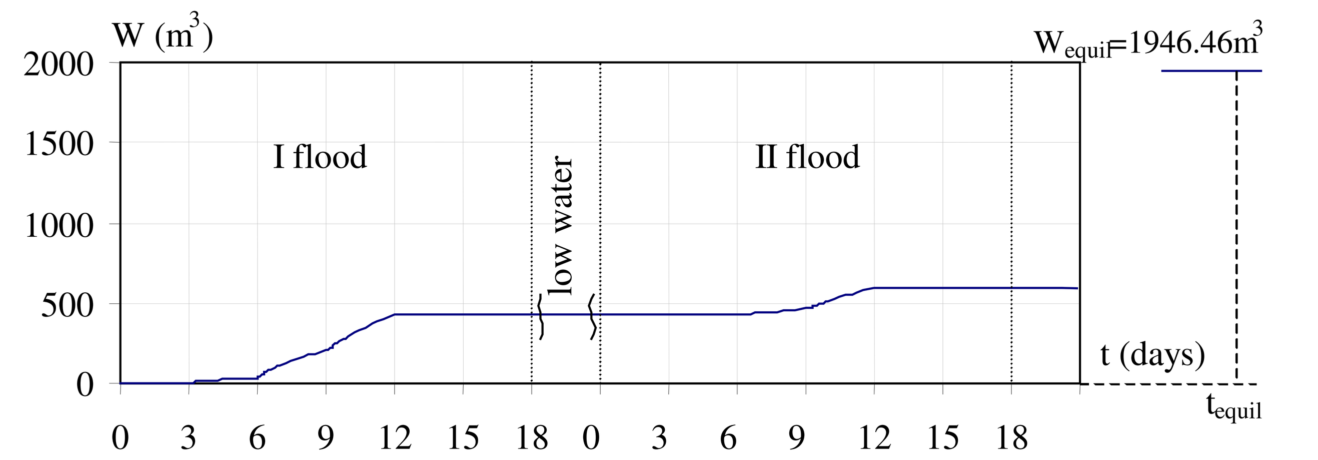

Figure 4. The equilibrium stage and development of scour hole volume during two floods

CONCLUSIONS

We suggest calculating the flood damage risk factor to estimate the stability of engineering structures in river flow. The flood damage risk factor can be computed by using two methods, which allows us to determine the scour-hole parameters during/after flash and multiple floods of different probability, frequency, sequence, and duration and the scour-hole parameters at the equilibrium stage.

The methods suggested can be used for:

1. Computing the development of scour depth during the expected usual or extreme flood events, varying with the flood probability, frequency, sequence, and duration, at the stage of designing a river engineering structure. In such a way, the most dangerous sequence of expected floods for engineering structures can be found;

2. Computing the currently developed scour depth; by comparing it with the designed equilibrium scour depth, we can determine the flood-damage risk factor and estimate the safety and stability of the engineering structure at the stage of maintenance;

3. Computing the flood damage risk factor. When the currently developed scour depth is close to the equilibrium scour depth and the flood damage risk factor has reached the critical value, the flood damage risk conditions for river engineering structures come into effect. Such critical river engineering structures should be marked as flood hazard zones and included into flood risk maps. By using the flood-damage risk factor, we can evaluate the necessity of the emergency scour protection measures for engineering structure.

4. Working out early-warning system based on the developed methods to take rapid measures to protect and prevent damage and failure of the bridge structures, as well as, developing information system to take emergency measures and actions to ensure safe humankind, and to reduce social, economic and environmental losses.

5. Developing of database and definition of high priority river structures in Europe in most critical areas by presented methodology: (A) In national level in roads, which have economic importance, regional emergency links (between airports, cities, railways, and etc.); (B) In community level in roads that provides critical access to local emergency services (roads to hospitals, evacuation roads, food and water delivery roads, and etc.). Thereafter including these structures into flood hazard and risk maps, according to European Directive 2007/60/EC .