National Conference with International Participation
ENGINEERING MECHANICS 2001
Svratka, Czech Republic, May 14 - 17, 2001

INFLUENCE OF BRIDGE STRUCTURE ON RIVER FLOW

Zdeněk CHÁRA, Pavel VLASÁK •

Summary: *The paper deals with an open channel flow over model of a bridge when whole discharge is going through the model opening and the upstream water level is at the same level as upper deck of the model. The downstream levels were controlled by means of a tailgate in such a way that the flows in the channel were non-uniform even downstream the model. For such conditions discharge coefficients were determined and for particular model opening also the velocity profiles were acquired. For the case of non-uniform flow it was obtained relationship between discharge coefficient and flow depths.*

1. INTRODUCTION

The most frequent structures occurred in river systems are bridge structures, which could considerably influence the waterways mainly during flood events. To describe and analyse the interaction of bridge structures with river flow it is a very complex task, which has to take into account many different aspects like geometry of the bridge, types of embankments and abutments, hydraulic characteristics of the river channel, flow rates and others. Since the hydraulic design of the bridges is very important a lot of research efforts have been devoted to this topic. But there are still parts where some improvements could be achieved.

Depending upon the upstream and downstream stage there are several types of the stream flowing through the bridge. The main types can be described as:

- The bridge opening is submerged at both the upstream and downstream face. Water is flowing through full opening.
- The upstream face of the bridge is submerged but the downstream face is above the water level.
- The water level is below the top of the opening at both the upstream and downstream face of the bridge.
- The capacity of the bridge opening is exceeded and water is going partly over the bridge deck.

In our paper we have focused on the first case, when the upstream water level is approaching the top of the bridge deck and water is just going to spill over the bridge and the flow downstream the bridge is non-uniform. We have used a sectional model of rectangular bridge, inserted into a hydraulic flume. The influence of abutments has not been considered that means that the bridge-opening ratio $\boldsymbol{M = b/B = 1}$, ($\boldsymbol{b}$ is width of the bridge opening and $\boldsymbol{B}$ is width of the channel).

2. BASIC THEORETICAL DESCRIPTION

The pressured flow through rectangular bridge opening that we are dealing with is schematically shown in Fig. 1, where $\boldsymbol{H_1}$ is upstream depth, $\boldsymbol{\Delta H_1}$ is upstream velocity height, $\boldsymbol{H}$ is height of bridge opening, $\boldsymbol{H_2}$ is downstream depth and $\boldsymbol{T}$ is distance between water level and the lowest part of bridge deck (in our case $\boldsymbol{T}$ is height of the bridge construction).

• Ing. Zdeněk Chára, CSc., Ing. Pavel Vlasák, CSc., Institute of Hydrodynamics, ASCR, Pod Paťankou 5, 166 12 Praha 6, e-mail: chara@ih.cas.cz, vlasak@ih.cas.cz

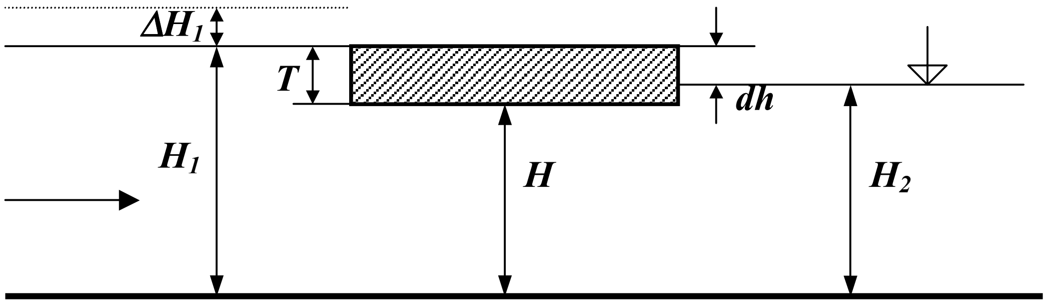

Fig. 1 Schema of the flow through bridge

One of the most comprehensive analysis of bridge hydraulic is known as US Geological Survey (USGS) method [1]. This method assumes that the contracted section formed by the bridge and channel bed is effectively a discharge meter that can be utilised to calculate flood flows. This is achieved by substituting into the discharge equation the values of a series of experimental coefficients that relate to standard types of bridge opening and the measured difference in water levels upstream and downstream. The discharge equation is derived from the continuity and energy equations and for the flow situation shown in Fig.1 can be written as (neglecting friction losses)

$$Q = C_{USGS}\, A_2 \sqrt{2g\left(dh + \frac{\alpha_1 U_1^{\;2}}{2g}\right)} \qquad (1)$$

where $\boldsymbol{A_2}$ is downstream cross sectional area of flow, $\boldsymbol{\alpha_1}$ is velocity head coefficient in section ***1*** (upstream), $\boldsymbol{U_1}$ is mean velocity in section ***1***. C is dimensionless coefficient of discharge and is obtained by means of a 'standard' base coefficient, ***C'***, and a series of numerical adjustment factors, $\boldsymbol{k_i}$. Base coefficient, ***C'***, is depending on different types of embankments and abutments. For bridge-opening ratio, ***M=1***, the value of base coefficient, ***C'***, equals ***1***. Assuming that the flow through bridge opening is pressured the coefficient of discharge depends only on submergence adjustment factor $\boldsymbol{k_T}$, so that

$$C_{USGS} = k_T \qquad (2)$$

In [1] the values of factor $\boldsymbol{k_T}$ could be obtained from a linear relationship between $\boldsymbol{k_T}$ and a bridge submergence ratio, BSR, which is defined as

$$BSR = \frac{T}{h_2 + \Delta h} \qquad (3)$$

where $\boldsymbol{h_2}$ is average depth in section ***2*** and ***dh*** is difference between upstream and downstream water levels. In the case of smooth rectangular channel the bridge submergence ratio could be rewritten as

$$BSR = \frac{T}{H_1} = 1 - \frac{H}{H_1} \qquad (4)$$

This equation indicates that the discharge coefficient for the pressured flow is a function only of the upstream conditions.

Another approach how to solve the pressured flow is to consider such flow as drowned orifice type, for which the discharge can be determined by an equation of the form

$$Q = C_D\ A\sqrt{2g\left(dh + \frac{\alpha_1 U_1^2}{2g}\right)} \tag{5}$$

where C_D is discharge coefficient and A is cross sectional area of bridge opening. The ratio of USGS discharge coefficient, C_{USGS}, and discharge coefficient of drowned orifice flow, C_D, is just ratio of cross sectional areas

$$\frac{C_{USGS}}{C_D} = \frac{A}{A_2} \tag{6}$$

In the next section the experimental data of discharge coefficients for non-uniform flow conditions will be presented and compared with the recommended values of USGS methodology.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experiments were performed in a horizontal hydraulic flume of the cross section ***0.4x0.4 m*** and of the length ***24 m***. Side walls of the flume are made of glass tables, the bottom of the flume is made of steel plates. In the distance ***16 m*** from flume inlet was located a model of rectangular bridge structure. Three heights of bridge opening were used – ***H = 10; 15 and 20 cm***. The height of the bridge model was ***T=5*** cm and width in flow direction was ***20 cm***. The upstream water level was kept just on the upper edge of the model. A needle gauge was used to determine the water levels. Flow rates varied between ***15-50 l/s***. In all runs the downstream water level was always above lower edge of the model.

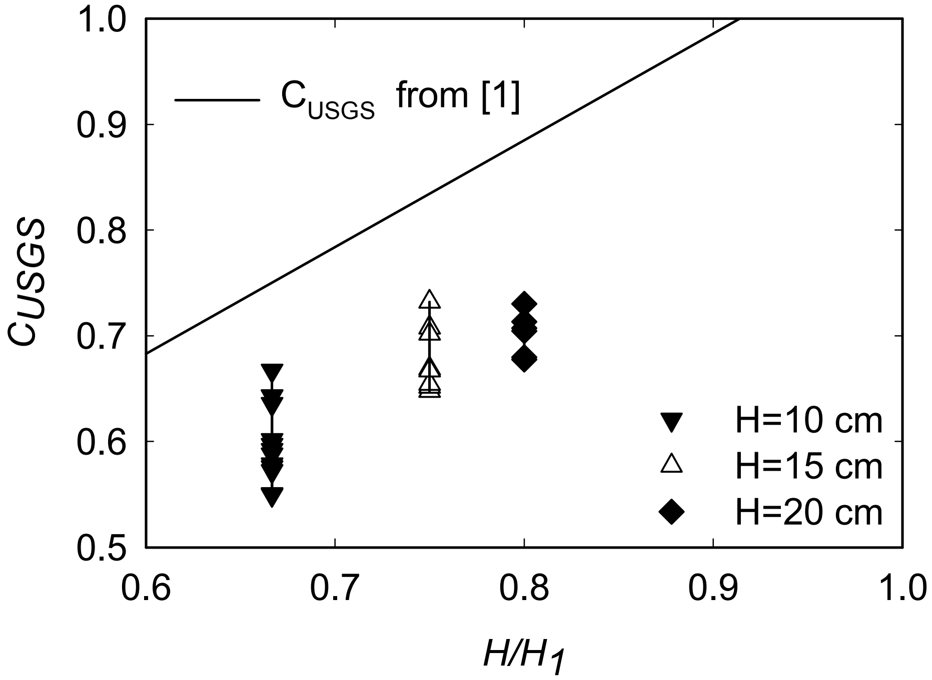

Fig. 2 Discharge coefficient determined by the USGS methodology

The values of USGS discharge coefficient, C_{USGS}, determined by Eq.(1) together with recommended data of the C_{USGS} given by the USGS methodology [1] are shown in Fig.2. As was shown previously the USGS submergence adjustment factor, k_T, (in our case is equal to the discharge coefficient) depends only on the upstream flow conditions. Since we kept the upstream water level constant (on the upper edge of the model), so the upstream conditions were identical for each tested height of the model opening. We changed only the downstream water levels by a manipulation of both the flow rate and the flume tailgate and therefore the experimental data of USGS discharge coefficient are scattered in vertical direction for given value of model opening. Also the values of experimental data are lower than the recommended data of the USGS methodology for the case of submergence. From Fig. 2 it is clear that the discharge coefficient expressed only by the upstream flow conditions ***(H/H_1)*** does not give satisfactory results for the case of non-uniform flow. To improve that we used Eq. (5) to determine the discharge coefficient, $\boldsymbol{C_D}$, and we expressed it by means of ***($(T+\Delta H_1)/H_2$)*** which takes into account also downstream conditions. The results are shown in Fig.3 and it seems that this relationship is more reliable than the previous case (Fig.2). Thus to calculate the discharge for submerged structure and for non-uniform flows it is more convenient to use the Eq.(5) with discharge coefficient taken from graph on Fig.3.

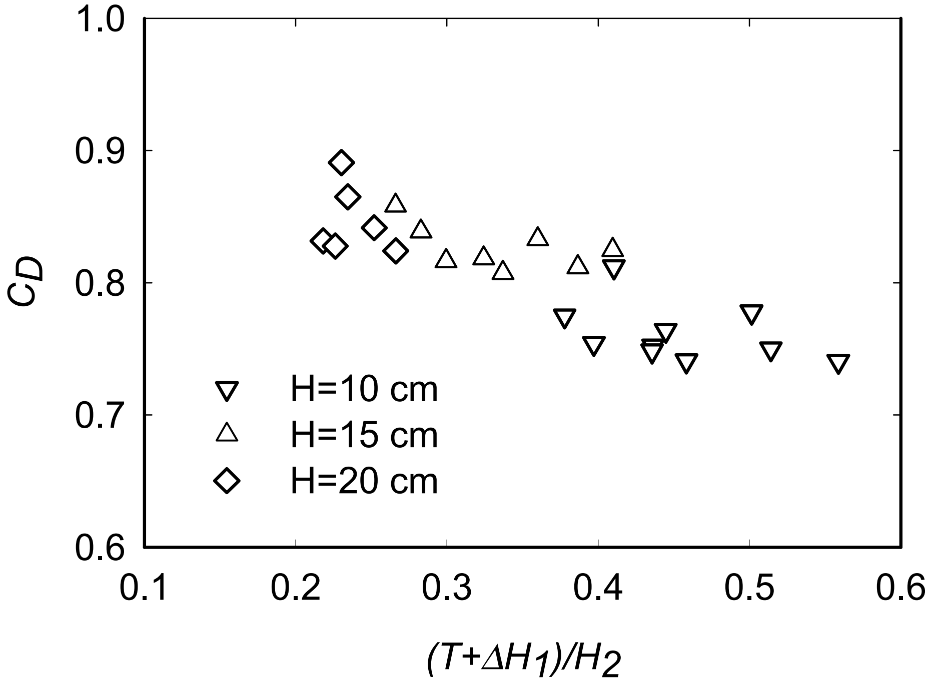

Fig.3 Discharge coefficient determined from drowed orifice flow

Along with the measurements of water levels we also performed measurements of velocity field under the model bridge. To perform that we used the Ultra Sound Velocity Profilometer UVP-Monitor (model UVP-XW-PSi made by Met-Flow, SA) which allows to measure the instantaneous velocity profiles in 128 points projected onto the ultrasound beam direction. The principle of the measurement is based on the Doppler effect. The ultrasonic probe after transmitting a short emission of ultrasound of given frequency starts to receive echoes generated by small particles scattered in the fluid. If the particles are moving along the acoustic axis the echoed frequencies are shifted and from measured frequency differences between transmitted and echoed frequencies and time delays it is possible to determine the local velocity. To cover relatively high velocity range we used the 2 MHz transducer working with an initial ultrasound beam diameter of ***8 mm***.

The ultrasonic transducer was fixed on a traversing device located downstream the model, the transducer face was oriented against the flow direction and the ultrasound beam axis was parallel with channel bed. This arrangement enabled to measure the longitudinal velocity profiles in the whole region under the model. The measured data were approximated by a spline function except near wall region where a power law approximation was used. The results are shown in Fig. 4 in the form of velocity iso-contours (only contours higher than ***450 mm/s*** are plotted). The data were obtained in the middle of the flume, for model opening ***H* = *10 cm*** and for flow rate ***26 l/s***. Fig. 4 indicates, that the most dangerous parts of the bottom with relation to scour is located in the distance about ***80 mm*** from upstream entrance. Individual velocity profiles in the three longitudinal positions (***x = 0, 90 and 180 mm***) are plotted in Fig. 5.

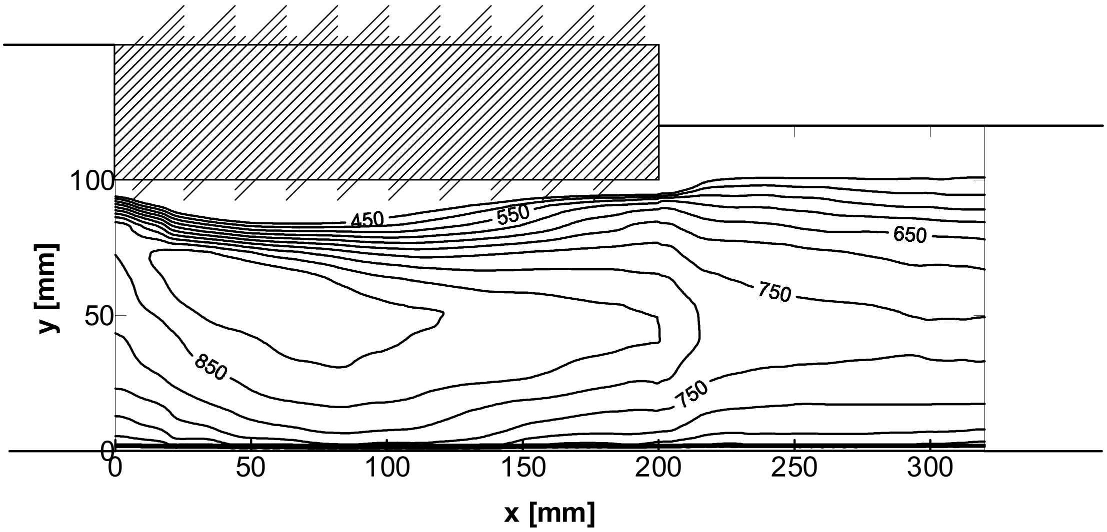

Fig. 4 Longitudinal velocity contours for ***H = 10 cm***

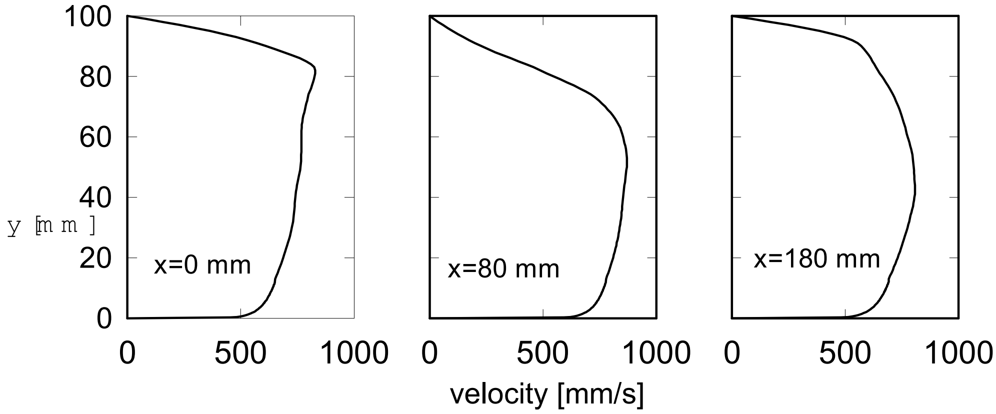

Fig.5 Velocity profiles under model bridge for ***H = 10 cm***

Acknowledgement

This research was supported in part under Grant No. 103/00/1620 of the Grant Agency of the Czech Republic.

4. REFERENCES

[1] Matthai H.F.: Measurement of peak discharge at width contractions by indirect methods. Techniques of Water-Resources Investigations of the US Geological Survey. Book 3, Chapter A4, 1967