

# A Parametric Study on the Backwater Level Due to a Bridge Constriction

S. Atabay, T. A. Ali, Md. M. Mortula

**Abstract**—This paper presents the results and findings from a parametric study on the water surface elevation at upstream of bridge constriction for subcritical flow. In this study, the influence of Manning's Roughness Coefficient of main channel ( $n_{mc}$ ) and floodplain ( $n_{fp}$ ), and bridge opening (b) flow rate (Q), contraction ( $k_{con}$ ) and expansion coefficients ( $k_{exp}$ ) were investigated on backwater level. The DECK bridge models with different span widths and without any pier were investigated within the two stage channel having various roughness conditions. One of the most commonly used commercial one-dimensional HEC-RAS model was used in this parametric study. This study showed that the effects of main channel roughness ( $n_{mc}$ ) and flow rate (Q) on the backwater level are much higher than those of the floodplain roughness ( $n_{fp}$ ). Bridge opening (b) with contraction ( $k_{con}$ ) and expansion coefficients ( $k_{exp}$ ) have very little effect on the backwater level within this range of parameters.

**Keywords**—Bridge backwater, parametric study and waterways.

## I. INTRODUCTION

**H**YDRAULIC structures such as bridges and culverts affect the water level in waterways due to their constriction. Many factors (Manning's Roughness Coefficient of main channel ( $n_{mc}$ ) and floodplain ( $n_{fp}$ ), and bridge opening (b) flow rate (Q), the number and shape of openings in bridges, the presence or absence of piers, contraction and expansion coefficients etc.) affect the water level. Many research studies on the effects of bridges and culvert constriction on water level have been undertaken, however, the correct prediction of water levels upstream of these structures is still challenging task for engineers. There are many experimental investigations and analytical studies carried out to measure or predict the correct backwater levels [1]-[6]. However, the parametric studies related on these factors that influence the backwater level are very limited and there is a still need for robust computational models that takes into account of these parameters. This parametric study will therefore be of great interest to researchers to develop a model to predict the backwater level due to bridge and culvert constrictions.

## II. LITERATURE REVIEW

Many researchers have experimentally investigated the effect of bridge constriction on backwater level in the

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laboratory [1]-[6] and the field [7]. Experimental studies commonly were carried out in simple rectangular channels [1], [2], [3], [6]; however, comprehensive experiments with different bridge models were conducted in a compound channel of varied depth and roughness which is more common in the natural environment [5], [6].

Several analytical models have also been developed to predict the backwater profile at bridge constriction. Biery & Delleur [1] proposed a simple formula based on the Froude number and opening ratio for the initial assessment for the backwater. A regression base model, which takes into account of upstream Froud number, contraction ratio and piers positions, was developed to predict the backwater level [8].

HECRAS and ISIS are the two well-known commercial computer programs commonly used in the USA and the UK respectively to compute water surface profile. The US Army Corps of Engineers Hydrologic Engineering Center [9] developed HECRAS software with different bridge backwater subroutine methods. These bridge methods are Energy Method [10], Momentum Method [10], Yarnell Method [11] and WSPRO Method [12] for low flow computations. Sir William Halcrow Partners and HR Wallingford [13] developed the ISIS package program that uses two different bridge subroutine methods, HR ARCH Bridge Method and USBPR Method for computing backwater profile around bridge waterways.

Substantial analyses were carried out to investigate the accuracy of these bridge subroutine models in HECRAS and ISIS software packages [14]-[16]. These analyses were carried out using the experimental data that were conducted in a two-stage compound channel including various roughness conditions and different types of bridge models, including different span widths [5], [6]. The results showed that energy method in HECRAS package was able to simulate more accurately the measured backwater values than the other methods. Therefore, in this parametric study, energy method in HECRAS was applied to the identical experimental setup of [5], [6].

## III. BRIDGE MODEL SETUP

This current parametric study on bridge backwater effect was investigated for two stage channel with a 398 mm wide main channel and two 407.3mm wide floodplains (Fig. 1). Testing length that was implemented in HECRAS model was 15m and a deck bridge model was inserted at 7m downstream of the channel inlet. The channel longitudinal slope was set to be  $2.024 \times 10^{-3}$ . In natural rivers, the Manning's roughness values for the floodplains are higher than those for the main

channel. Therefore, the roughness value was assumed to be 0.03 and 0.06 for the main channel and floodplains respectively, and these settings are used for the base model throughout this parametric study.

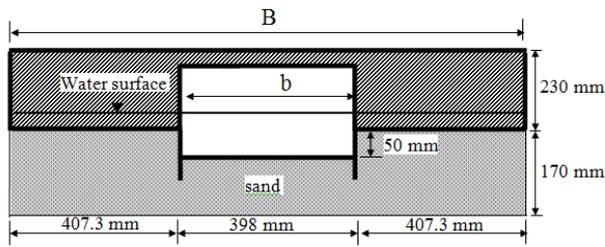


Fig. 1 Cross-section view with a deck bridge model

In order to carry out the parametric study, the HECRAS base model was firstly simulated for normal water-surface profile computations for each particular discharge without any bridge model. The base model was secondly simulated for the parametric study with the DECK bridge models with different span widths within the two stage channel having various roughness conditions. Fig. 2 clearly shows the effects of bridge structure on water surface profile. It should be noted that all flows tested in this parametric study are sub-soffit flows tested. This means that no orifice flow or weir flow tested since this was beyond the scope of this study.

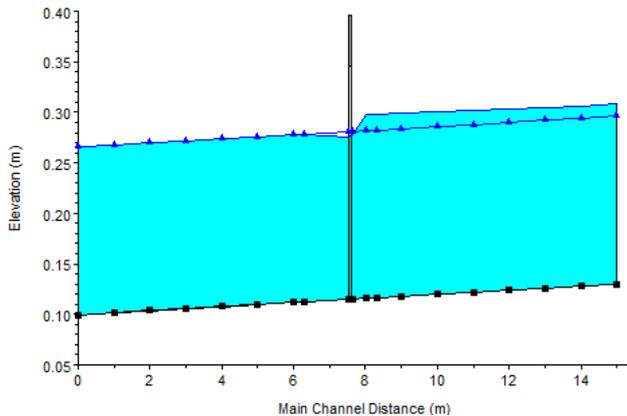


Fig. 2 Backwater profile with and without bridge model

Cross-section distances were generally set to 1m in HECRAS model, however where the bridge model inserted, a total of four more cross-sections were inserted to the model. Two out of four cross-sections were located immediately upstream and downstream from the bridge; representing the effective flow area just outside the bridge. One cross-section was located at upstream of bridge at a distance equal to one bridge opening width. The fourth cross-section was located at downstream of bridge at a distance equal to four times of bridge width. These two cross-sections are basically representing contraction and expansion length where the contraction and expansion coefficients were changed.

IV. PARAMETRIC STUDY

This parametric study investigates the factors that affect the water surface profile at upstream of bridge constriction. In this study the influence of Manning’s Roughness Coefficient of main channel ( $n_{mc}$ ) and floodplain ( $n_{fp}$ ), and bridge opening (b) flow rate (Q), contraction and expansion coefficients ( $k_{con}$  and  $k_{exp}$  respectively) were investigated.

The values that were used in the parametric study are given in

TABLE I. In the base model the roughness values for the main channel and floodplains were set to be 0.03 and 0.06 respectively. The values of  $k_{con}$ ,  $k_{exp}$  and b were chosen to be 0.3, 0.5 and 0.398m respectively for the base model that was simulated for each particular discharge given in Table I.

TABLE I  
VALUES FOR THE PARAMETRIC STUDY

Q (m <sup>3</sup> /s)	$n_{mc}$	$n_{fp}$	$k_{con}$	$k_{exp}$	b (m)
0.015	0.030	0.060	0.300	0.50	0.398
0.020	0.035	0.065	0.350	0.55	0.498
0.025	0.040	0.070	0.400	0.60	0.598
0.030	0.045	0.075	0.450	0.65	
0.035	0.050	0.080	0.500	0.70	
0.040					

In order to see the effect of roughness coefficients on backwater level for each particular discharge,  $n_{mc}$  was firstly kept constant (0.03) and  $n_{fp}$  were changed from 0.060-0.080. Then after  $n_{fp}$  was kept constant (0.06) and  $n_{mc}$  were changed from 0.030-0.05.

In order to investigate the effect of bridge openings, the different deck bridge spans; 0.398, 0.498m and 0.598m were used with corresponding roughness values stated above. In this case the values of  $k_{con}$ , and  $k_{exp}$  around bridge constriction were kept constant as 0.3 and 0.5 respectively.

V. RESULTS AND DISCUSSION

A. Effects of Discharge and Main Channel Roughness ( $n_{mc}$ )

In order to investigate the effects of  $n_{mc}$ , the value of  $n_{fp}$  was kept constant to 0.06 and the values of  $n_{mc}$  were increased by the increment of 0.05 in each time for particular discharge and ranged from 0.03 to 0.05. This process was also conducted for bridge width (b) of 0.398m, 0.498m and 0.598m respectively with  $k_{con}=0.3$  and  $k_{exp}=0.5$ .

Figs. 3 and 4 show the variation of backwater level at different values of  $n_{mc}$  with each corresponding discharge for b=0.398m and floodplain roughness of 0.06. It indicates that the backwater level increases with the increase in Q and  $n_{mc}$ . However, it is also clearly evident from Figs. 3 and 4 that the effects of Q on backwater level are more profound as  $n_{mc}$  increases.

B. Effects of Discharge and Floodplain Roughness ( $n_{fp}$ )

In order to investigate the effects of  $n_{fp}$ , the value of  $n_{mc}$  was kept constant to 0.03 and the values of  $n_{fp}$  were increased by 0.05 in each time for particular discharge and ranged from 0.06 to 0.08. This process was also conducted for bridge width

(b) of 0.398m, 0.498m and 0.598m respectively with  $k_{con}=0.3$  and  $k_{exp}=0.5$ .

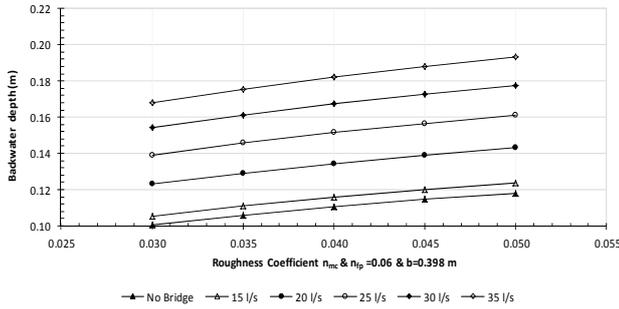


Fig. 3 Variation of backwater depth with  $n_{mc}$

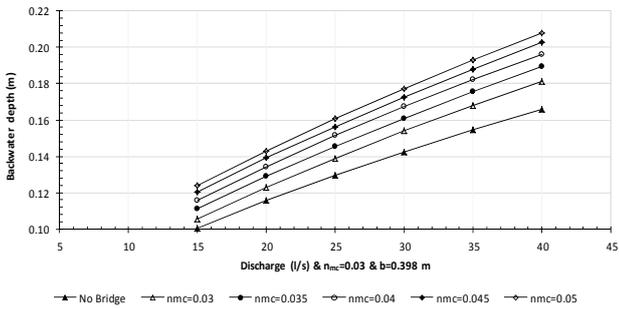


Fig. 4 Variation of backwater depth with Q and  $n_{mc}$

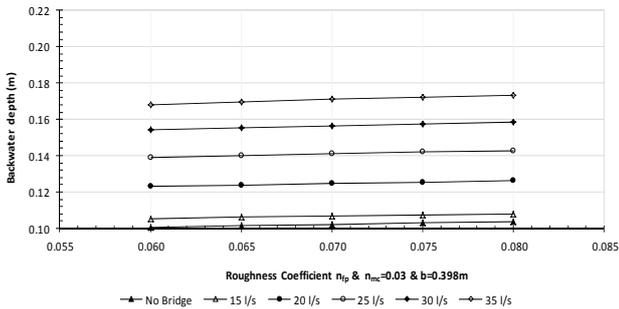


Fig. 5 Variation of backwater depth with  $n_{fp}$

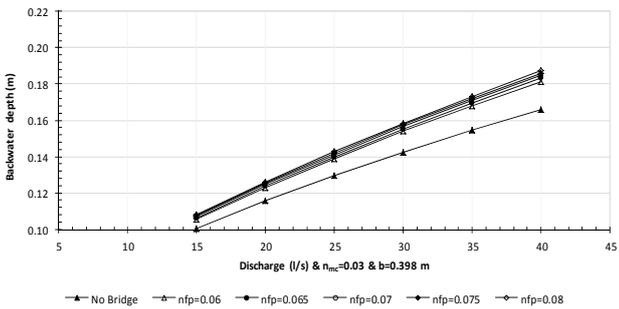


Fig. 6 Variation of backwater depth with Q and  $n_{fp}$

Figs. 5 and 6 show the variation of backwater level at different values of  $n_{fp}$  with each corresponding discharge for  $b=0.398m$  and floodplain roughness of 0.06. It is clear in Fig. 5 that the backwater level slightly increases with the increase

in Q and  $n_{fp}$ . However, as it can easily be seen in Figs. 3 and 5, that the effects of  $n_{mc}$  are much more significant than those of  $n_{fp}$ . It is also observed that the effects of  $n_{fp}$  are greater for the higher values of Q. This is due to the fact that the proportions of the floodplain flows are dramatically increase with Q and  $n_{fp}$ .

Fig. 6 clearly shows that the effects of  $n_{fp}$  on backwater level increases as Q increases but the overall effects of  $n_{fp}$  can be assumed to insignificant compared to those of  $n_{mc}$  (Fig. 4).

C. Effects of Bridge Width (b)

In this parametric study, the effects of the bridge opening width (b) were also investigated. In the base model the bridge opening was set to be 0.398m which was the same width of the main channel (see Fig. 1). Then, the openings were increased by 0.1m to 0.498m and 0.598m each time for corresponding  $n_{mc}$  and  $n_{fp}$ . Table II shows the backwater depth variation for the minimum and maximum flow rates only as b increases. As anticipated that as the bridge opening increases, the backwater effect due to bridge constriction reduces. As Q increases the backwater variation reduces more, and this also indicates that the effects of Q on backwater variation is more profound than the other parameters.

TABLE II  
VARIATION OF BACKWATER DEPTH WITH BRIDGE WIDTH

b	Q=15l/s			Q=40l/s		
	0.398m	0.498m	0.598m	0.398m	0.498m	0.598m
0.030	0.1054	0.1043	0.1035	0.1815	0.1776	0.1748
0.035	0.1111	0.1099	0.1090	0.1895	0.1853	0.1826
0.040	0.1159	0.1146	0.1137	0.1963	0.1922	0.1896
0.045	0.1201	0.1187	0.1177	0.2025	0.1983	0.1957
0.050	0.1237	0.1222	0.1212	0.2081	0.2037	0.2011

D. Effects of Contraction ( $k_{con}$ ) & Expansion Coefficients ( $k_{exp}$ )

The effects of  $k_{con}$  and  $k_{exp}$  on backwater level were also investigated in this parametric study. In base model with  $n_{mc}=0.03$ ,  $n_{fp}=0.06$  and  $b=0.398m$ , both the contraction and expansion coefficients increased by 0.05. Table III shows that for the minimum flow rate of 0.015l/s, the backwater level was estimated to be 0.1054m using  $k_{con}=0.3$  and  $k_{exp}=0.5$ , while it was estimated to be 0.1071m using  $k_{con}=0.5$  and  $k_{exp}=0.8$ . The similar trend was observed for the higher Q values but the variation still remained very small. This small variation proves that the effect of  $k_{con}$  and  $k_{exp}$  on backwater level was insignificant.

TABLE III  
VARIATION OF BACKWATER DEPTH WITH CONTRACTION & EXPANSION COEFFICIENTS

Q (l/s)	$k_{con}$ 0.3	$k_{con}$ 0.35	$k_{con}$ 0.4	$k_{con}$ 0.45	$k_{con}$ 0.5
	$k_{exp}$ 0.5	$k_{exp}$ 0.65	$k_{exp}$ 0.7	$k_{exp}$ 0.75	$k_{exp}$ 0.8
0.0150	0.1054	0.1058	0.1063	0.1067	0.1071
0.0200	0.1229	0.1234	0.1240	0.1246	0.1252
0.0250	0.1388	0.1396	0.1403	0.1410	0.1418
0.0300	0.1540	0.1546	0.1555	0.1564	0.1573
0.0350	0.1681	0.1688	0.1699	0.1709	0.1720
0.0400	0.1815	0.1828	0.1836	0.1848	0.1860

## VI. SUMMARY AND CONCLUSIONS

This study investigated a parametric study on the water surface elevation at upstream of bridge constriction. The influence of Manning's Roughness Coefficient of main channel ( $n_{mc}$ ) and of floodplain ( $n_{fp}$ ), and bridge opening ( $b$ ) flow rate ( $Q$ ), contraction ( $k_{con}$ ) and expansion coefficients ( $k_{exp}$ ) on backwater level were investigated. HECRAS software package with bridge subroutine Energy method was used. The following conclusions can be drawn from this parametric study

- The effects of main channel roughness ( $n_{mc}$ ) and flow rate ( $Q$ ) on the backwater level are much higher than those of the floodplain roughness ( $n_{fp}$ ).
- Bridge opening ( $b$ ) with contraction ( $k_{con}$ ) and expansion coefficients ( $k_{exp}$ ) have very little effect on the backwater levels.
- The parametric study carried out here will be of great interest to researchers to develop a model to predict the backwater level due to bridge constriction.

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