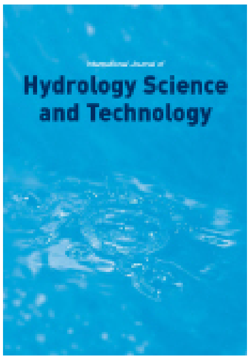

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Azza N. Altalib

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Effect of debris on the upstream hydraulic head of sluice gate

Azza N. Altalib

Dams and Water Resources Engineering Department,
College of Engineering,
University of Mosul, Iraq
Email: a.altalib@uomosul.edu.iq

Abstract: Debris caused during flood events and transports by the river maybe lead to many hydraulic troubles due to accumulated debris upstream hydraulic structures. Debris caused during flood events and transported by rivers leads to many hydraulic troubles due to accumulated debris upstream of the hydraulic structure. Therefore, many authors were preoccupied with stopping or reducing this debris from accumulating. Many studies dealt with the debris' effect on hydraulic structures, especially on scour at the weir and pier. However, studies on hydraulic flow characteristics under the sluice gate are few and limited. In this study, the effect of accumulated debris upstream sluice gate on the approached water depth was highlighted. The study found that the approached water level increased by 14% when accumulated debris increases, while a 40% decreased upstream water level led to debris passage beneath the gate. The gate opening and debris volume were more sensitive to the water depth upstream the sluice gate.

Keywords: debris; flood; hydraulic; open channel; sluice gate.

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Biographical notes: Azza N. Altalib is currently an Assistant Professor in the Department of Dams and Water Resources Engineering, University of Mosul, Mosul, Iraq. She has authored more than ten international refereed journal articles. Her research interests include investigation of hydraulic behaviour of hydraulic structures and experiments in hydraulic energy dissipation

1 Introduction

Debris is one of the hydraulic problems when accumulated upstream hydraulic structures are transported during a flood by a river course. Accumulated debris upstream hydraulic structures may be affected on the hydraulic performance of structures, one of the unfavourable effects is rising water level upstream hydraulic structure, and in the sluice gate, this head rising can influence gate performance and increased pressure on gate upstream. The size and intensity of debris depending on the catchment area to determine debris volume this is important to know the effect on the hydraulic structure. When increased debris is trapped upstream this may reduce clear waterway and increased upstream water depth.

Several studies dealt with hydraulic characteristics of flow under sluice gate such as Shayan et al. (2014a, 2014b), Menon and Mudgal (2018), Binnie (1952), Habibzadeh et al. (2019), Yen et al. (2001), Khaleel and Mohammed (2017), Mohammed and Khaleel (2012, 2013) and Hayawi and Mohammed (2011) other studies dealt with theoretical flow under sluice gate such as Kim and Kim (2007), Wu and Rajaratnam (2015), Huang et al. (2008) and Cassan and Belaud (2012), the studies dealt with the effect of debris on scouring studied by Chen et al. (2016), Rezaie-balf and Rashedi (2016), Pagliara and Carnacina (2011), Park et al. (2016), Zevenbergen et al. (2006) and Melville and Dongol (1993).

Schalke et al. (2016, 2018) studied backwater rise caused due to debris Accumulations and found that backwater rise mainly depends on the Froude number, wood accumulations, and percentage of organic fine material.

In Pfister et al. (2013), the effect of debris accumulated on the water level upstream of the piano weir and affected discharge efficiency. They found that discharge decreases when debris accumulated at the upstream weir.

In Furlan et al. (2019), in this study submitted the debris blockage with reservoir flow using a model of ogee spillway with piers. The results show that increasing blocked volume caused effects on the water level increase in the reservoir.

Few studies dealt with the debris effect on the sluice gate, especially upstream water depth. The present study dealt with the debris effect on water depth upstream sluice gate and its effect on gate performance and hydraulic characteristics taking into account the effect of wooden trunks provided upstream sluice gate and tested for different gate opening and upstream water levels.

2 Experimental works

2.1 Hydraulic model

The experiments were taking place in the laboratory channel 10 m long 30 cm width and 45 cm height, in hydraulic laboratory of dams and water resources engineering, college of engineering, university of Mosul (Figure 1). The sluice gate was made of plastic (30*45*2) cm length, height, and thickness respectively, made according to the British Standard Index (BSI).

Five water head values (5.4, 5.8, 9.1, 9.8, 10.1) cm and four gate openings (2, 3, 4, 5) cm are used in experiments.

The seventh different debris sizes and dimensions are shown in Table 1 and Figure 2, were tested and examined in different types of water head and gate openings.

2.2 Debris

The seventh different debris sizes and dimensions are shown in Table 1 and Figure 2, were tested and examined in different types of water head and gate openings.

Figure 1 The laboratory channel sketch

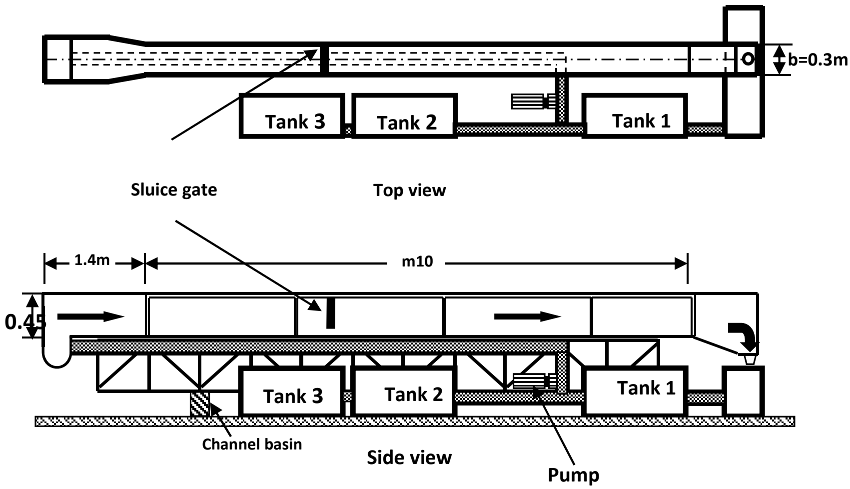


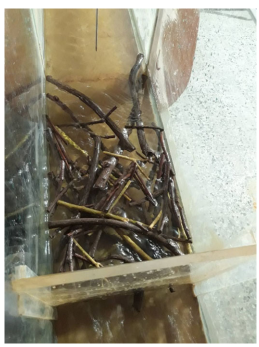
Figure 2 The seventh different debris shapes (see online version for colours)

Table 1 Amounts and dimensions of wood debris

No.	*Case*	*Diameter (D)cm*	*Length (T) cm*	*No. amount*	*Volume (V*10⁻³) m³*
1	A	2	40	4	18.616
2	B	1.5	32	5	10.471
3	C	1	22	13	8.319
4	D	0.8	16	8	2.382
5	E	0.6	15	12	1.884
6	F	0.5	10	37	2.691
7	G	0.2	3	50	0.174

The tests were done in two ways (individual) and accumulated. All these debris were added sequentially randomly at 3.5 m upstream of the sluice gate (Figure 3).

Figure 3 Debris added upstream sluice gate in an open channel, (a) debris started to pass beneath sluice gate and (b) debris accumulated upstream sluice gate (see online version for colours)



(a)

(b)

3 Dimensional analysis

Head of water upstream sluice gate after debris added (*H*) depend on several hydraulic parameters on sluice gate such as; gate opening (*a*), debris diameters (*D*), debris length (*T*), debris volume (*V*), discharge of channel (*Q*), a width of the channel (*b*), water head before adding debris (H_r), acceleration due to gravity (*g*), water density (ρ) and dynamic viscosity (μ) the following equation can be written as shown:

$$H = f\left(a, D, T, V, Q, b, H_r, g, \rho, \mu\right) \quad (1)$$

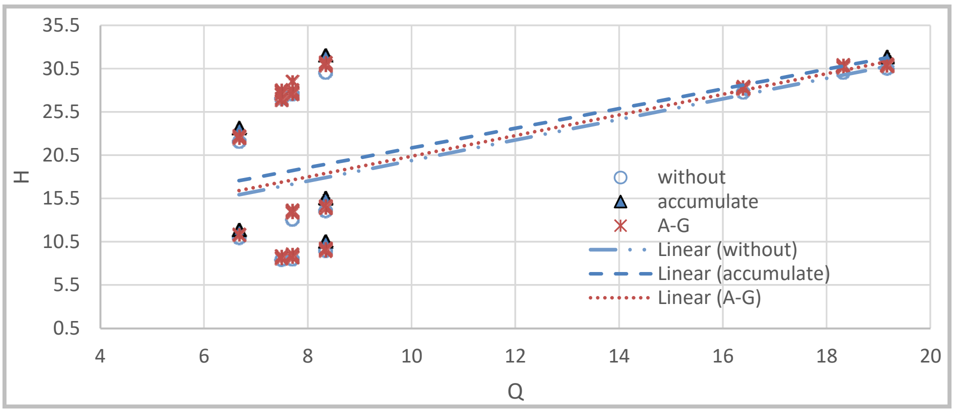
According to (Pi) theory theorem applied on equation (1), with multiplying and dividing on dimensionless parameters and cancelling the effect of Reynold's number on an open channel, then the following equation resulted:

$$\frac{H}{H_r} = f\left(\frac{V}{bH^2}, \frac{H}{a}, \frac{D}{T}, F_r\right) \quad (2)$$

4 Results and discussion

The head discharge curve is shown in Figure 4. It can be seen the effecting of debris accumulated upstream sluice gate on the water level, the best fit is shown increases in water level upstream sluice gate in case of debris added (cases A–G) corresponding of a case without adding, this water level increasing the reach to a maximum at debris accumulates (all cases added), thus increasing in upstream water level reached to 14%.

Figure 4 Head discharge relationship (see online version for colours)



When debris added increases (increasing supply) the debris trapped increases this also depends on gate opening size. Increasing opening size lead to increased debris passed beneath the sluice gate and then decrease debris trapped.

Head of water upstream sluice gate also effects of debris trapped. High levels of water upstream decrease the percentage of debris passage corresponding to low water level. Experiments show decreases upstream water level to 40% lead to debris passage beneath the gate (at the same gate opening) because vortex appears on the two sides of the sluice gate at that percentage of water level, these vortexes dragged debris down.

Figure 5 shows the relative head upstream sluice gate after and before debris supply (H / H_r) to debris volume to water volume (V / bH^2) for all cases of debris added (A–G) with different discharge and gate opening.

The water volume represents gate width, upstream water depth and the distance of debris reach to accumulate upstream sluice gate represents also as upstream water depth, so the water volume represents as (bH^2).

For different upstream water head (H) and gate opening (a) tested, it can be seen an increasing head of water upstream the sluice gate when increasing the volume of debris supply. Overall, when upstream water head increasing and gate opening decreases, the driftwood trap increased, this case leads to an increasing ratio of upstream water depth after and before driftwood added

From the figure it also can be seen maximum (H / H_r) values happened when $H = 5.5$ m and $a = 3$ cm this means occurred in (40%–50%) of maximum head and gate opening, this case happened because pulled driftwood beneath the sluice gate and trapped under gate this lead to decreasing the sluice gate waterway then increasing in upstream water head rather than the general case. When gate opening increased and water level decrease, the effect of accumulated debris decreased this can be seen when v / bH^2 greater than 0.05.

Figure 5 The relationship between V / bH^2 and H / H_r for all cases (see online version for colours)

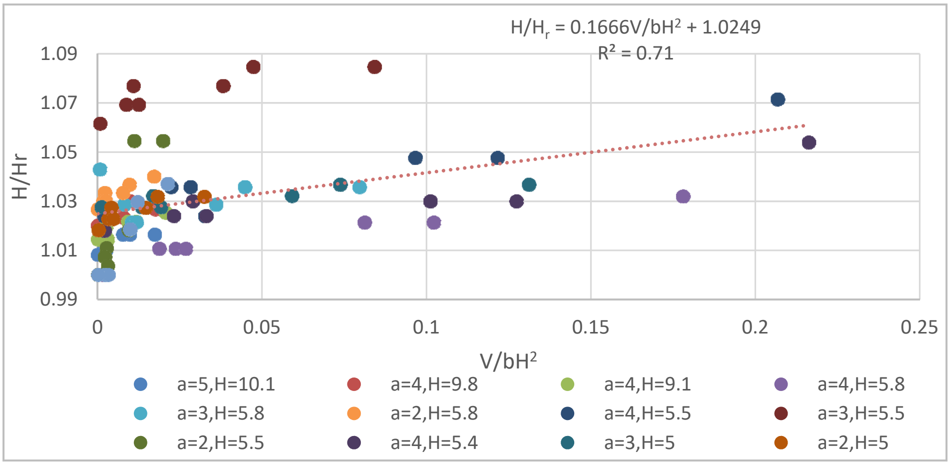
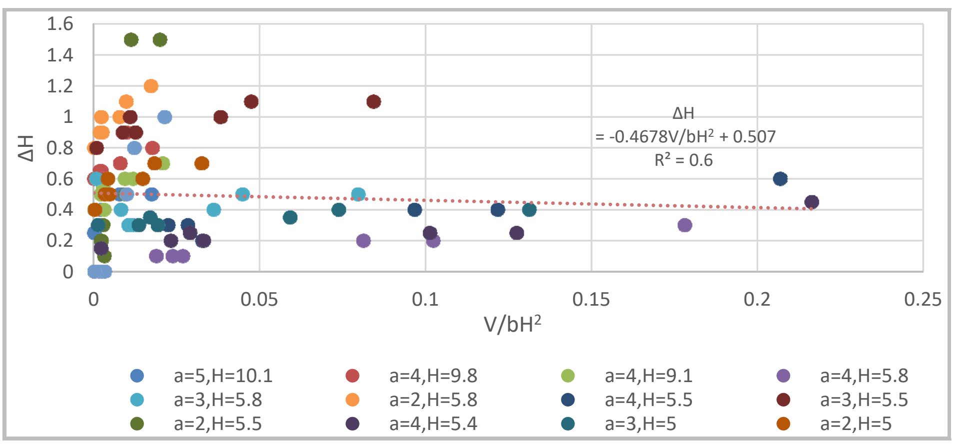


Figure 6 Relationship of ΔH and V / bH^2 (see online version for colours)



This lead to gate opening as well as debris volume more sensitive to the water head upstream sluice gate, the increase in upstream head reached 4%. This can be expressed as equation (3).

$$H / H_r = 0.1666V / bH^2 + 1.0249 \quad (3)$$

$$R^2 = 0.94$$

According to equations (1) and (2) and by applying statistics programming (SPSS), the following equation can be derived to find the relation between upstream head after and before debris added in the laboratory conditions. By divided data into three groups first, one to generate equation and the second group to validate it then the third group used to find the last equation.

$$H / H_r = \left(V / bH^2\right)^{2.019} + (H / a)^{0.003} + (D / T)^{1.331} + \left(F_r\right)^{-6.484} \quad (4)$$

$$R^2 = 0.725$$

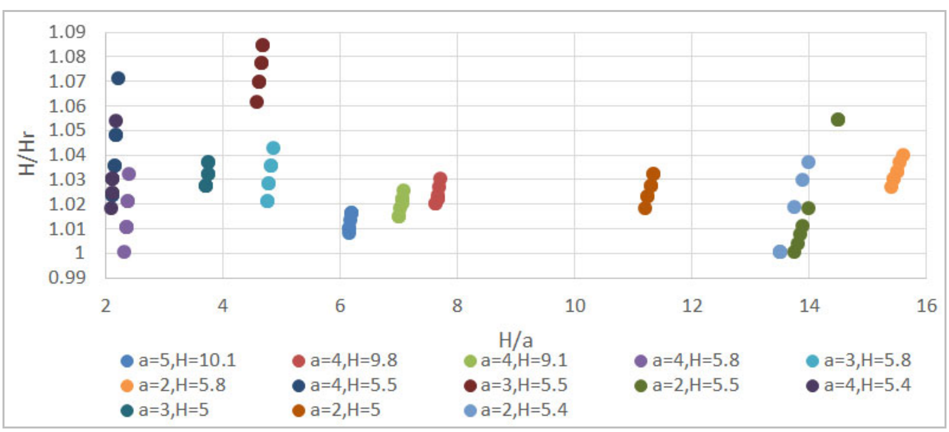
Figure 6 refers to absolute head increase $\Delta H = H - H_r$ is given as a function of debris volume, according to different values of gate openings and discharges. It can be seen the values of (ΔH) increased when gate opening decreasing and water head increased because accumulated debris in these cases more than others, from the figure, can also be seen water head more affected than debris volume so when (V / bH^2) values increasing (ΔH) values decreasing this can be expressed by the equation:

$$\Delta H = -0.4678 \frac{V}{bH^2} + 0.507 \quad (5)$$

$$R^2 = 0.6$$

Figure 7 shows the relative head upstream sluice gate before and after debris supply to head upstream concerning gate opening for all cases of debris added (A–G).

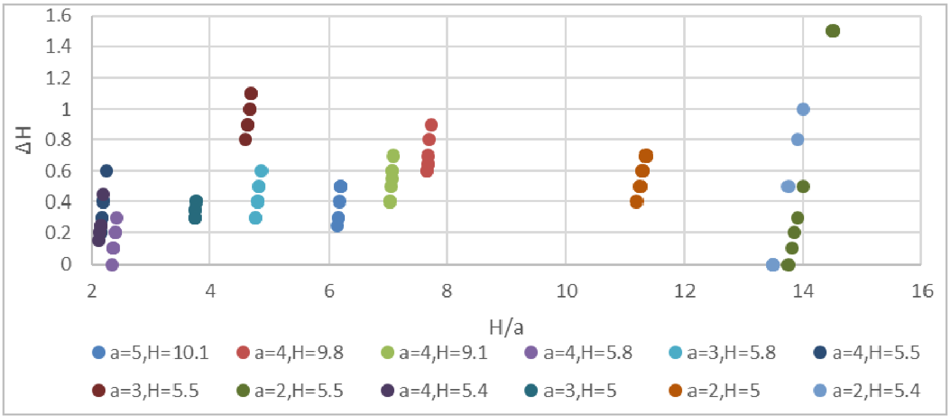
Figure 7 The relationship between H / a and H / H_r for all cases (see online version for colours)



It can be seen decreasing relative head (H / H_r) when increasing the head of water upstream to gate opening (H / a). Gate opening (a = 3 cm) and percentage head of water (40%–50%) of the maximum head (H = 5.5 cm) given a large relative head of water. This leads to gate opening as well as debris volume more sensitive to the water head upstream sluice gate.

Figure 8 refers to absolute head increase $\Delta H = H - H_r$ is given as a function of upstream water head to different values of gate openings and discharges. it can be seen at gate opening a = 3 cm and percentage water head (40-50) % from maximum head (H = 5.5 cm) given large values of relative increasing head ΔH

Figure 8 Relationship of ΔH and H / a (see online version for colours)



5 Conclusions

The debris present in the hydraulic structures caused many hydraulic problems, so the studied of debris affecting these structures important to decreases these effects, so, this research focusing on this problem. It was found that increases in the size and the number of debris added upstream sluice gate lead to the increasing upstream water level reached 14%, increasing gate opening as well as decreasing upstream water levels reduced probability of debris passage beneath sluice gate. Decreasing upstream water level to 40% lead to debris passage beneath the gate because vortex appears on the two sides of the sluice gate, and the percentage water head (40%–50%) from maximum head given large values of the relative increasing head. So recommended in flood cases which expected debris with flood water, the sluice gate opened at maximum capacity and control the water level upstream with above percentage to control debris at sluice gate.

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Notations

F_r	Froud number
ΔH	Absolute head
A	Gate opening
B	Width of channel
D	Debris diameter
G	Acceleration due to gravity
H	Head of water upstream sluice gate after adding debris
H_r	Water head before adding debris
Q	Discharge of channel
T	Debris length
V	Debris volume
P	Water density
μ	Dynamic viscosity