Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 8 (14): 2631-2635, 2008
ISSN 1812-5654

Effects of Slope and Area Opening on the Discharge Ratio in Bottom Intake Structures

[1]Amir Abbas Kamanbedast and [2]Mahmood Shafai Bejestan
[1]Science and Research Center of Ahwaz, Islamic Azad University, Ahwaz, Iran
[2]Shahid Chamran University, Ahwaz, Iran

Abstract: The main purpose of this study is to conduct experimental tests on a physical model of bottom intake structures to investigate the effects of slope and area opening of the screen on the amount of diverted discharge. To reach such goals, a bottom intake model was constructed in a flume of 60 cm wide, 8 m long and 60 cm high. The model was tested under different flow discharges, screen slopes and screen open area. Tests were conducted with and without sediment to see the rate of clogging of the screen due to presence of sediment. The results have shown that for small slope the sediment trap between the screen bars which reduce the area opening. Increasing the slope is reducing the sediment to trap but the flow depth over the screen reduces and thus the flow discharge reduces. It was found that at slope of 30%, diverted flow discharge is maximum and at the same time the diverted sediment is minimum. The presence of sediment can reduce 10% the discharge intake.

Key words: Bottom intake, river intakes, bottom rack, screen, hydraulic performance

INTRODUCTION

Now a days the needs for construction of small hydropower in the mountain area of Iran is increasing. The water for generating electricity is supply from the high elevating area. Because of lack of sufficient roads in this area, the intake must be simple from the construction point of view and requires less maintenance work during and after the construction. The structure also must be able to divert the desired flow discharge at all time even during the dry season. Bottom rack or bottom intake is the most suitable intake structure which can satisfy all the above mentioned criteria.

Bottom intake is a simple structure which is consist of a channel on the river bottom vertical to the river flow and a screen on top of the channel of it is shown in Fig. 1.

River water enters to the channel after passing the screen. The flow then will move to one side of river where there is a tunnel or open channel to transport the water to the penstock of hydropower. The screen should be sized so the riverbed sediment not to enter the channel and at the same time to be large enough to let enough water to be diverted. Although this structure has been on use for the past five decades, some of its design criteria for optimum design of this structure need to be studied.

The review of present knowledge is restricted to rectangular channels with an opening in the bottom made up of racks to divert sediment and to produce an intake structure for which sediment sizes larger than the bar spacing are excluded. Escande (1955) considered a bottom

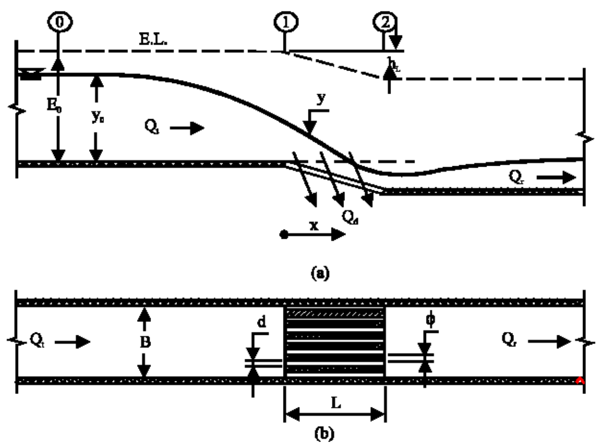

Fig. 1: Sketch of bottom rack structure

rack downstream of a rounded spillway crest having a bottom slope of 25% for three rack spacing. The discharge was expressed as a function of head on the spillway. However, No definite results were available for the present study. Ract-Madoux *et al.* (1955) presented general experiences on bottom intakes obtained by various projects in the Savoy region of the French alps their general conclusions may be summarized as follows: (1) a knowledge of the water and sediment discharges is important for design; (2) the rack should consist of rounded profiles in the stream wise direction; (3) to obtain a minimum risk of sediment clogging, the bottom slope of the rack should be more than 20% and (4) a rack spacing of less than 0.10 m should be acceptable for mountainous

Corresponding Author: Amir Abbas Kamanbedast, Science and Research Center of Ahwaz, Islamic Azad University, Ahwaz, Iran

regions. Bianco and Ripellino (1994) verified Noseda's (1955) observations with a larger model and found no essential scale effects. Their bar profile was semicircular at the top with a rectangular bottom reinforcement. They considered ratios of intake to rack cross- sectional areas of 1/3 and 1/4.

Shafai-Bejestan and Shakouhirad (1997) conducted experimental tests. They developed the following equation for discharge coefficient.

$$C_d = 0.223E^{-0.79}Fr^{-0.286}(\frac{a}{L})^{0.054} \tag{1}$$

In which, C_d, E, Fr, a, y_1, L are: coefficient discharge, area opening, Froude number, bar diameter, flow depth and length of rack, respectively. For best hydraulic performance of the bottom intake, they found that the rack slope must be further investigated and based on few tests they found that the slope should be more than 20%. Wahl (2001) performed experimental tests and developed a computer program to predict the discharge through the screen and the overflow off the screen in high velocity flow. Brunella *et al.* (2003) conducted experimental tests in a rectangular channel 0.5 m wide and 7 m long. Based on extended laboratory observation, the effect of various parameters was explored, such as the bottom slope, the rack geometry and the rack porosity. In addition a novel approach to determine the discharge coefficient of a rack structure was developed. Finally the intake channel below the bottom rack was investigated and several interesting features were found, including a significant flow instability that may have a strongly adverse effect on the rack performance. Lee *et al.* (2005) studied bottom rack intake structure to divert supercritical storm water flows in steep rivers. They found that the intake discharge depends on the approaching flow conditions, length of bottom rack, the characteristics of channel bed and bottom rack chambers. The hydraulic performance of bottom racks with longitudinal bars have been studied by Riggetti and Lanzoni (2008). They measured the water surface profile, the velocity field over the rack and in the slit between two adjacent bars. Based on these data, they developed a relationship for computation of diverted discharge as follow:

$$Qi = C_o EBL\sqrt{2gE_o}(-0.0528\frac{L}{E_0}F + 1)\tanh\left[1.5(\sqrt{2} - F)^{0.6093}\right] \tag{2}$$

In which, C_0 is the discharge coefficient under static conditions, F is the modified Froude number equal to $V/\sqrt{gE_0}$, V is the flow velocity and E_0 is the approaching specific energy. The effect of rack slope have not been studied and tests were conducted without sediments.

Although it seems that bottom intake been studied in the past, still there of many questions regarding the optimum design of the structure. Therefore it is the purpose of this study to investigate the effects of bottom rack area opening and slope on the intake flow discharge and to have contributed new idea for better design of this structure.

Governing equations: The governing equations for the flow in a river with a lateral outflow through a bottom screen are as follow:
Continuity equation:

$$-\frac{dQ}{dx} = Qi = EC_d b\sqrt{2gE_n} \tag{3}$$

Energy equation:

$$\frac{dy}{dx} = \frac{S - S_f - (Q/gA^2)(dQ/dx)}{1 - F_r^2} \tag{4}$$

In these equation:

- Q = Discharge in the main channel
- Q_i = Diverted flow discharge (passing through bottom rack)
- E = Ratio of the screen opening in percent
- C_d = Discharge coefficient
- E_n = Specific energy of the flow over the screen and is the sum of the flow depth (y) and velocity head ($v^2/2g$)
- y = Flow depth on the screen
- b = Channel width
- S = Screen slope
- S_f = Slope of energy grade line
- A = Flow area cross section in the main channel
- F_r = Froude number.

To determine the water surface profile over the screen, both equations must be solved. The analytical solution for these equations is possible through use of a few assumptions. The first assumption is that since the length of bottom rack generally is short, consequently the effect of channel and friction slopes on the flow profile can be assumed to be negligible. This assumption reveals that the value of specific energy is constant. The second assumption is that the channel shape is wide and the discharge coefficient is constant. Applying these assumptions and substituting Eq. 3 into Eq. 4 and calculating Q from specific energy definition which is $Q = by\sqrt{2g(E_n - y)}$ and rearranging the terms in the resulting equation, one obtains:

$$\frac{dy}{dx} = \frac{2EC_d\sqrt{E_n(E_n - y)}}{3y - 2E_n} \quad (5)$$

Integration of Eq. 4 yields:

$$x = -\frac{y}{\varepsilon C_d}\sqrt{1 - \frac{y}{E_n}} + \text{const.} \quad (6)$$

The constant of integration can be determined from the flow conditions at the upstream of the bottom rack which yields:

$$x = \frac{E_n}{\varepsilon c_d}\left(\frac{y}{\varepsilon}\sqrt{1 - \frac{y_1}{E_n}} - \frac{y}{E_n}\sqrt{1 - \frac{y}{E_n}}\right) \quad (7)$$

From this equation it can he seen the discharge coefficient is an important factor in determining the intake flow discharge.

Dimensional analysis: Before conducting experimental tests, a general relationship has to be developed. This can be done by using the dimensional analysis. It can be shown that the intake discharge (Qi) depends on the following variables:

$$Q_i = f(Q, E, S, D_S, a, L) \quad (8)$$

In which, Q is the river discharge, is the percent of screen area opening, S is the rack slope, a is the space between screen bars and L is the screen length. By applying the Π- theorem, the non dimensional equation for discharge coefficient (Cd) and discharge ratio (Qr)can be developed as follow:

$$Q_r = f\left(\frac{a}{D_s}, \frac{a}{l}, E, S\right) \quad (9)$$

During the experimental tests, the flow conditions were in fully turbulent flow therefore the effect of Reynolds number can be neglected. For a constant bar dimensions the effect of a/l can be neglected so the final equation is in the following form:

$$Q_r = f(E, S) \quad (10)$$

MATERIALS AND METHODS

Experimental setup: The experimental set- up consists of a 60 cm wide flume. The bottom screen installed at the center of flume. A pipe was connected to the bottom of flume to transport the diverted water into the sump A v-notch weir at the downstream end of the channel was installed to measure the discharge and the discharge passing through the screen was measured volumetric. Figure 2 is the sketch of the experimental setup. The

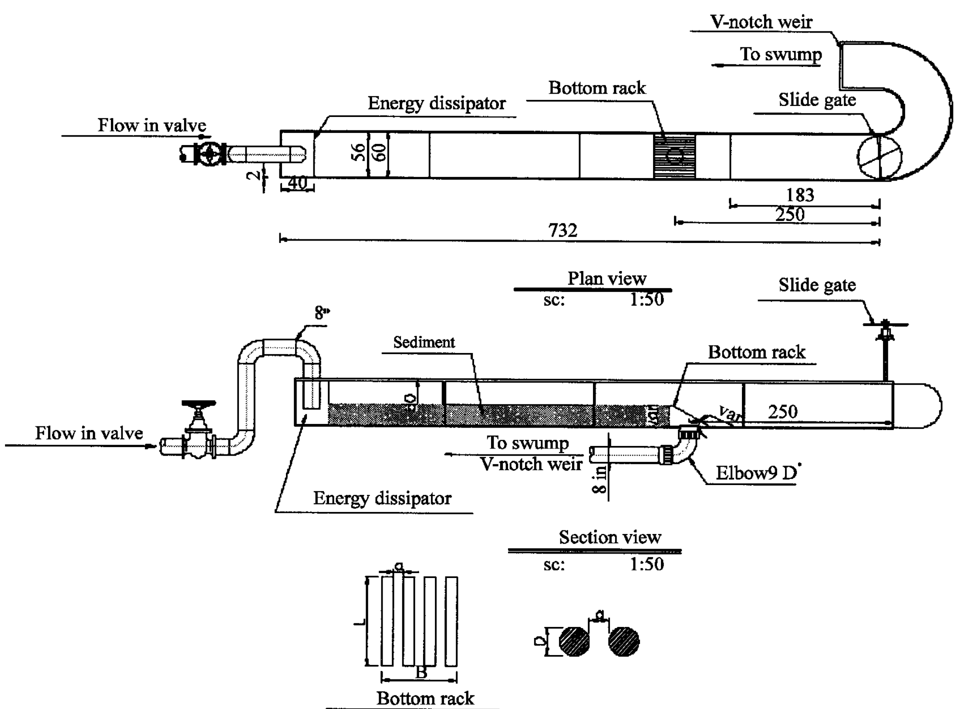

Fig. 2: Sketch of the experimental set-up

Table 1: Range of variables conducted in this study

Name of variable	Notation	Range conducted
Discharge	Q (1/sec)	5-30
Diameter of rack's bars	D (mm)	6,8
Area opening of rack	E (%)	30,35,40
Slope of rack	S (%)	10,20,30,40
Sediment size	D_S (mm)	2,5,7

experimental program was conducted at the hydraulic laboratory of Shahid Chamran University, Ahwaz, Iran.

Experimental procedure

Series A-Hydraulic tests: After installing one of the model of the bottom racks at the desired slope, the flow was allowed to enter the flume by gradual opening of the entrance valve until the flow discharge reaches to the desired discharge. This situation was kept constant for one hour during this time water surface elevation especially above the bottom rack was measured. The diverted flow discharge also measured. Then flow discharge in the flume was increased and the same variables were measured. The same procedure was followed for three more discharge. Then a new model of bottom rack was installed at a new slope and the above mentioned procedures were repeated. Therefore Six model of bottom rack with three different percent of area opening equal to 30, 35 and 40% using two different sizes of bars equal to 6 and 8 mm were tested. Each model was tested under three different slope and five different flow discharge.

Series B-Sediment tests: To investigate the performance of bottom racks when the sediment is passing over the rack, tests of series B were conducted. In these series sediment was placed on the bed of flume upstream of the bottom rack (Fig. 2). In this series, tests were conducted under the same conditions as series A. However in these tests, only those flow discharges were conducted that can transport the bed sediment. Table 1 slows the range of variables conducted in this study.

RESULTS AND DISCUSSION

The value of discharge coefficient were calculated using the measured data from the following equation.

$$c_d = \frac{Q_i}{E\sqrt{2gE_0}} \qquad (11)$$

In which, E_0 is the approaching specific energy of the flow and was computed from flow conditions just upstream of the bottom rack. Table 2 shows the results.

The main purpose of this study was to design an optimum bottom rack. This can be achieved by designing smaller size rack in such that the ratio of discharge which is passing through the rack is maximized. From dimensional analysis it was found that intake discharge depends on area opening and slope of rack as well as the Froude number. Therefore to see how these parameters can effect the intake discharge. The discharge ratio (Qr = Qi/Q) was plotted versus rack opening (E) and rack slope (S) (Fig. 4).

As it can be seen from this Fig. 4, as the slope of rack increases, the discharge ratio increases too. However the

Table 2: Summary of the experimental results

		Bottom rack					
Test series	Test No.	Dmm	E (%)	S (%)	Q (L/s)	Qi (L/s)	Qr
A	1	8	30	10	24.5	11.0	0.45
	2	8	35		24.5	12.8	0.52
	3	8	40		24.5	13.6	0.56
	1	8	30	20	24.5	14.0	0.57
	2	8	35		24.5	15.2	0.62
	3	8	40		24.5	16.0	0.65
	1	8	30	30	24.5	14.8	0.61
	2	8	35		24.5	17.8	0.73
	3	8	40		24.5	19.0	0.78
	1	8	30	40	24.5	10.2	0.42
	2	8	35		24.5	11.0	0.45
	3	8	40		24.5	12.0	0.49
B	1	8	30	10	24.5	8.1	0.33
	2	8	35		24.5	9.3	0.38
	3	8	40		24.5	10.8	0.44
	1	8	30	20	24.5	9.8	0.40
	2	8	35		24.5	11.3	0.46
	3	8	40		24.5	12.7	0.52
	1	8	30	30	24.5	12.5	0.51
	2	8	35		24.5	15.2	0.62
	3	8	40		24.5	17.2	0.70
	1	8	30	40	24.5	10.0	0.41
	2	8	35		24.5	11.0	0.45
	3	8	40		24.5	12.0	0.49

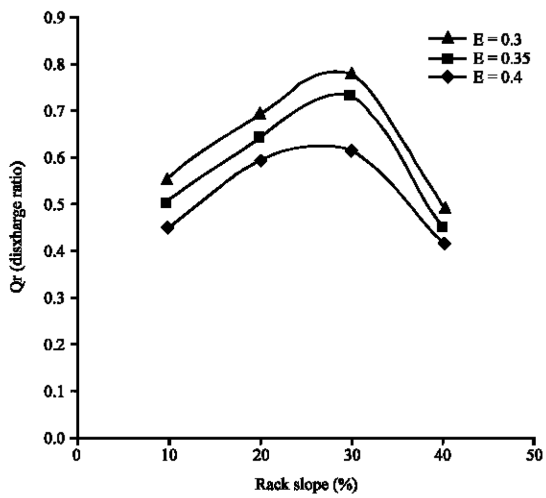

Fig. 4: Values of discharge ratio against slope for three different rack opening (Test Series A, No sediment in the flume)

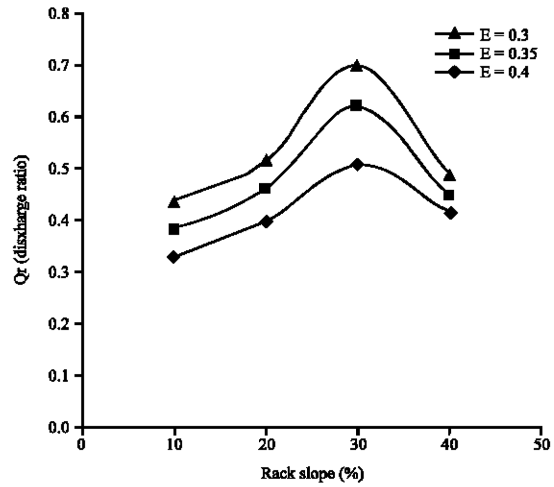

Fig. 5: Values of discharge ratio against slope for three different rack opening (Test series B, Sediment moving in the flume)

the discharge ratio reaches to a maximum at slope of about 30% and then the discharge ratio decreases. The same trend is observed for three different rack opening. This means that the maximum intake discharge can be achieved when the slope of rack is 30%. From Fig. 4 it can be seen that when the rack opening is increases, the discharge ratio, as it was expected, also increases. The maximum discharge ratio which is equal to 0.8, was achieved when the rack area opening was 40% and the slope was 30%.

To see if the present of sand can influence the discharge ratio, the values of discharge ratio for data of test series B was plotted versus the bottom rack slope for different values of rack area opening. Figure 5 shows the same trend happens here too. The discharge ratio is reached to a maximum when the bottom rack slope is 30% and the rack area opening is 40%. However as it was expected the maximum values are smaller when the sediment is moving through rack. This is because the sediment particles trap between the rack bars and therefore the rack opening decreases.

The finding of this study is agreement with the studies of Ract-Madoux *et al*. (1955) and Shafai-Bejestan and Shakourirad (1997) in which they found that for best hydraulic performance the bottom rack slope should be more than 20%.

CONCLUSION

Although the bottom rack structure has been in used for decades, the effects of many variables on the hydraulic performance of this structure is steel unknown. Among these variables are the bottom rack slope and area opening. In the present study the effects of these variables were investigated. Tests were conducted with and without sediment in the flume. By analysis of the data it was found the best hydraulic performance can be achieved when the rack slope is 30% and the rack opening is 40%. The discharge ratio is about 10% less when the sediment is presented because of clogging the opening area. Comparison with the results of other investigated reveals that the new results are in agreement with their design advice.

ACKNOWLEDGMENTS

This study is a part of research which was supported financially by the research office of dam and hydropower of Khuzestan Water and Power Authority under contract No. 85-02-02-36.

REFERENCES

Bianco, G. and P.G. Ripellino, 1994. Attualita delle opere di presa a traversa derivante e studio con modello idraulico di un tipo di griglia suborizzontale (On the hydraulic model study of bottom rack structures). Idrotecnica, 21: 3-12.

Brunella, S., W.H. Hager and H.E. Minor, 2003. Hydraulic of bottom rack intake. J. Hydraul. Eng., ASCE., 129: 2-10.

Escande, L., 1955. Prise d' eau a travers une grille Nouveau complements (Taking water through a rock bottom structures) d'hydraulique. Publications scientifiques et tech niques du ministere de l air (Science and Techniques of the Minist 302: 59-63.

Lee, J.H. W., D. Yu, H.C. Chen, L. Gore and J. Ackers, 2005. Bottom rack intake for supercritical storms flow diversion on steep urban catchments. 31st IAHR, Congress, Seoul, Korea, 11-16 Sep., IAHR., pp: 2746-2756.

Noseda, G., 1955. Operation and design of bottom intake racks. Proc. VI IAHR, La Haye, 3: C17-1-C17-11.

Ract-Madoux, M.B., J. Molbert and J. Zumstein, 1955. Ouelques realizations recentes de prises en- dessous a haute altitudeen savoie (General experiences on bottom intakes obtained by various projects in the Savoy region). La Houille Blanche, 10: 852-878.

Riggetti, M. and S. Lanzoni, 2008. Experimental study of the flow field over bottom intake racks. J. Hydraul. Eng. ASCE., 134: 15-22.

Shafai-Bejestan, M. and Gh. Shokouhirad, 1997. Experimental investigation of hydraulic and sediment criteria at bottom intakes. J. Int. Sci. Eng. Univ. Sci. Technol. Tehran, Iran, 8: 41-53.

Wahl, T.L., 2001. Hydraulic performance of coanda-effect screens. J. Hydraul. Eng. ASCE., 127: 480-488.