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SPAIN WATER 2018
ting River Management in an Era of Change (Madrid, Spain)
15th November 2018

EXPERIMENTAL STUDY OF CLOGGING IN BOTTOM RACKS. CASE OF CIRCULAR BARS WITH HIGH VOID RATIOS

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ABSTRACT

Bottom intake systems have been used in mountain regions countries to produce renewable energy and reduce maintenance costs. Sediment laden flows may reduce the efficiency of bottom intake racks due to the obstruction of the spacing between the bars. This leads to serious operational problems and important increases in maintenance costs. Most of the recommendations are based on the experience obtained during the operation phase and sometimes after a stop in the production of energy. The Hidr@m Group of the Universidad Politécnica de Cartagena with financial support from the Seneca Foundation of the Region of Murcia has been working in the study of bottom intake systems and presented experimental results with gravel-sized sediments in bottom racks made with T-shaped flat bars. A main objective is to characterize the most efficient design parameters, such as: bar profile, spacing between bars, and longitudinal slope. The current work includes a campaign of racks with circular bars and void ratio of 0.60. Flow rates vary between 0.155 to 0.250 m^3/s/m. 100 kg of gravels with $d_{50} \approx 58$ mm are tested in each case. Longitudinal slopes are also variable in the range of 10 to 35% and tests are developed in an existing device. Main results include the analysis of derivation capacity of the bottom rack with circular bars and a high void ratio. Comparison with the previous works as well as the approach of new tests are presented.

Keywords: Bottom Racks, Clogging effect, High Void Ratio, Circular bars

1. INTRODUCTION

One of the constant concerns of governments nowadays is the need to provide quality basic services to the population they serve, and the projects developed to achieve this goal must produce the least impacts in the environment. More concretely, in Ecuador, during the last decade the government has been promoting the country's energy development, displacing obsolete energy generation systems -floating power plants that used fossil fuel and contaminated the environment- and developing renewable energy generation projects, taking advantage of the important source of hydric resources of the country.

One of the advantages mentioned in technical literature about bottom rack intakes is related to the scarce operation and maintenance tasks (Krochin, 1978); however, there is still uncertainty in the effect of the rack occlusion and in the flow derivation capacity when sediment transport is present. The present work is focused on defining the efficiency percentage (flow derivation capacity) of the bottom rack with circular bar and a void ratio, m = 0.60 when sediment transport is present, and comparing the results with those previously obtained by Castillo et al. (2016) with T-shape flat bars.

The Hidr@m Group of the Universidad Politécnica de Cartagena has been working on bottom intake systems since 2008 in collaboration with the Fundación Euromediterránea del Agua and Universidad de Murcia. In 2014 began the work on the Seneca Foundation project: “Optimización de los sistemas de captación de fondo para zonas semiáridas y caudales con alto contenido de sedimentos. Definición de los parámetros de diseño”. Currently, as part the project, a PhD student from the Escuela Politécnica Nacional of Ecuador has been linked to the present work, in such a way that the additional knowledge that is being acquired can be disseminated and applied through collaboration agreements with other universities and companies regionally and internationally.

2. PHYSICAL DEVICE

The Hydraulic Laboratory of the Universidad Politécnica de Cartagena has a bottom intake system that was built in 2011 and was designed based on the experiences of Noseda (1956). The physical model has an approximation channel of 5.00

m long and 0.50 m wide with methacrylate walls. The bottom rack is located below the channel and it could tilt to adopt different slopes from horizontal to 35%. The racks were built with aluminum bars with circular profiles. The diameter of the bars is 0.030 m, length is 0.90 m in the flow direction and the space between bars is 0.045 m. Bars are longitudinally oriented with the flow direction. Figure 1 shows the physical model and Figure 2 shows the configuration of the bottom rack. Further details of the model could be obtained in Castillo et al., 2016 and García, 2016.

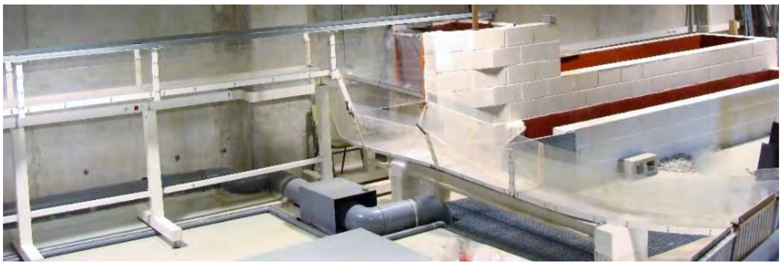
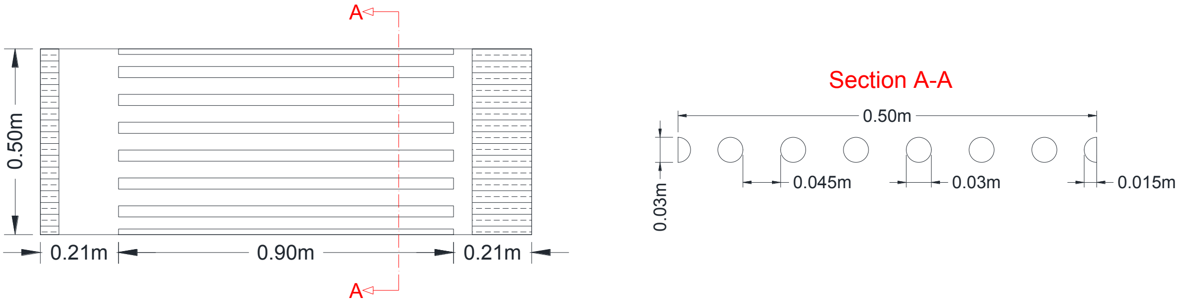


Figure 1. Physical model of the bottom rack intake built in the Hydraulic Laboratory of the Universidad Politécnica de Cartagena.



(a) (b)

Figure 2. Configuration of the bottom rack: (a) Dimensions of the rack, and (b) Detail of the bars.

3. SEDIMENT EXPERIMENTAL TEST

The gravel that have been used in the tests presented rounded faces and its median grain size is d_{50} = 58.0 mm. The gravel classification using the Zingg's methodology (Zingg, 1935) is shown in Table 1.

Table 1. Zingg's shape classification

d_{50} (mm)	BLADE	DISC	ROD	SPHERE
58.0	2%	6%	15%	77%

Three inlet specific flows (q_1 = 155.5, 198.0 and 250.0 l/s/m) and five rack slopes (tanθ = 10%, 20%, 30%, 33% and 35%) and different rack lengths that varies from 0.25 m to 0.45 m were tested. The rack lengths, *L*, used in each test ensure that the flow could be totally derived in case of clear water and avoid that the deposition of gravel over the total length of the rack (0.90 m) would produce a retention effect that can lead to a complete occlusion if the gravel is not swept as shown in Figure 3. This effect would not allow the tests to be properly developed and would affect the results.

(a) (b)

Figure 3. Retention effect over the total rack length: (a) with running flow; and (b) gravel deposited over the rack.

To reduce the length of the original rack (Figure 2), a thin metallic sheet of 0.50x0.90 m was used as shown in Figure 4. The metallic sheet slid over the rack to obtain the length *L* and was fastened to the ends of the rack with plastic ties in such a way that the length *L* was kept constant during each test.

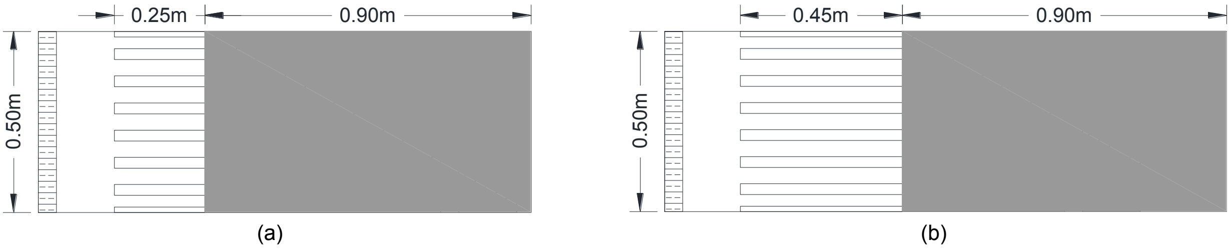


Figure 4. Use of the metallic sheet to reduce the length of the original rack: (a) Minimum length used, and (b) Maximum length used. Flow direction goes from left to the right.

The inlet specific flow, q_1, was measured with an electromagnetic flowmeter Endress Häuser Promag 53W of 125 mm with an accuracy of 0.5%. In addition, the rejected flow, q_2, was measured by a 90-degree V-notch weir. 15 tests were made; each condition was repeated three times.

One-hundred-kilogram gravel bed was placed along the approximation channel. The flow dragged the solids towards the bottom rack in such a way that one part was derived, another was retained between the slits of the bars and the rest continued downstream. At the end of each test the solid weight of each part was quantified.

The flow derived at the end of each test is calculated as the difference between the approximation flow and rejected flow (q_2 - q_1). The efficiency of the rack related to derived flow calculated as (q_2 - q_1)/q_1.

4. RESULTS AND DISCUSSION

4.1 Derivation Capacity

In technical literature there are recommendations to consider an increase in the bottom rack area to compensate the percentage that could be occluded (Drobir, 1981; García, 2016; Krochin, 1978). A first step to determine this increase is to have knowledge of the derivation capacity of the rack when it is occluded.

Figure 5 shows the inlet flow (q_1 = 155.5 l/s/m) passing over the rack with different slopes (10, 20, 30, 33, 35%) when the total amount of gravel was dragged. It could be observed the deposition of the gravel in the slits between bars without the expected flow derivation.

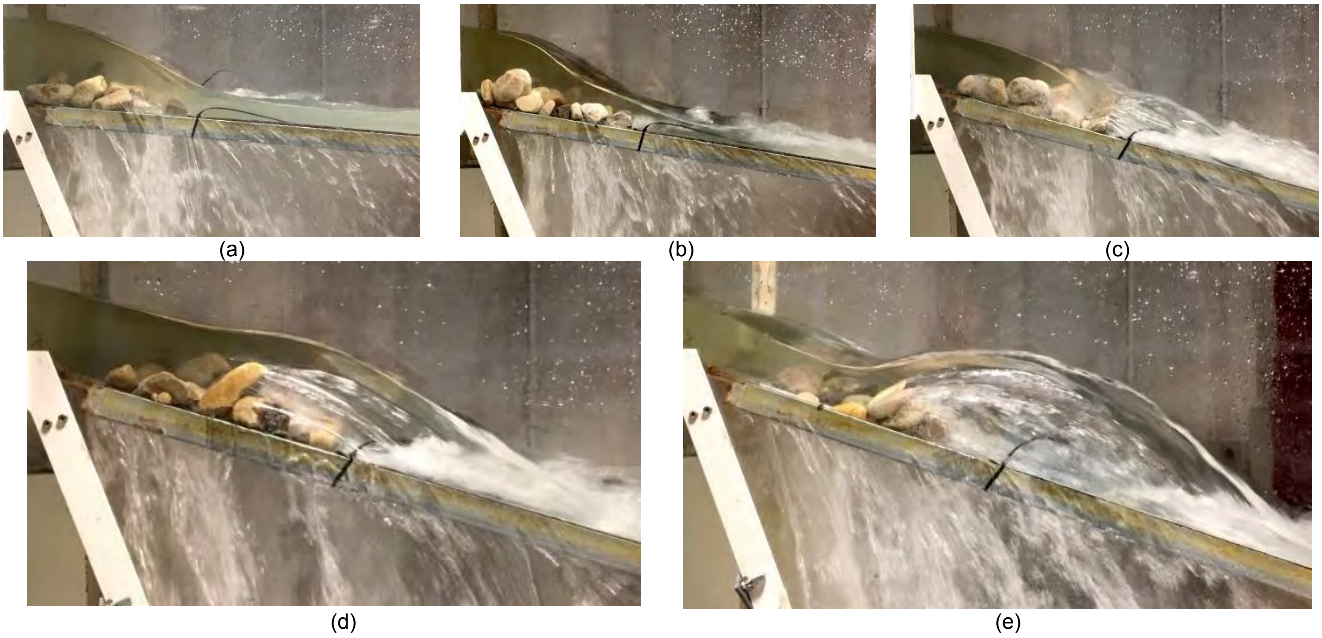
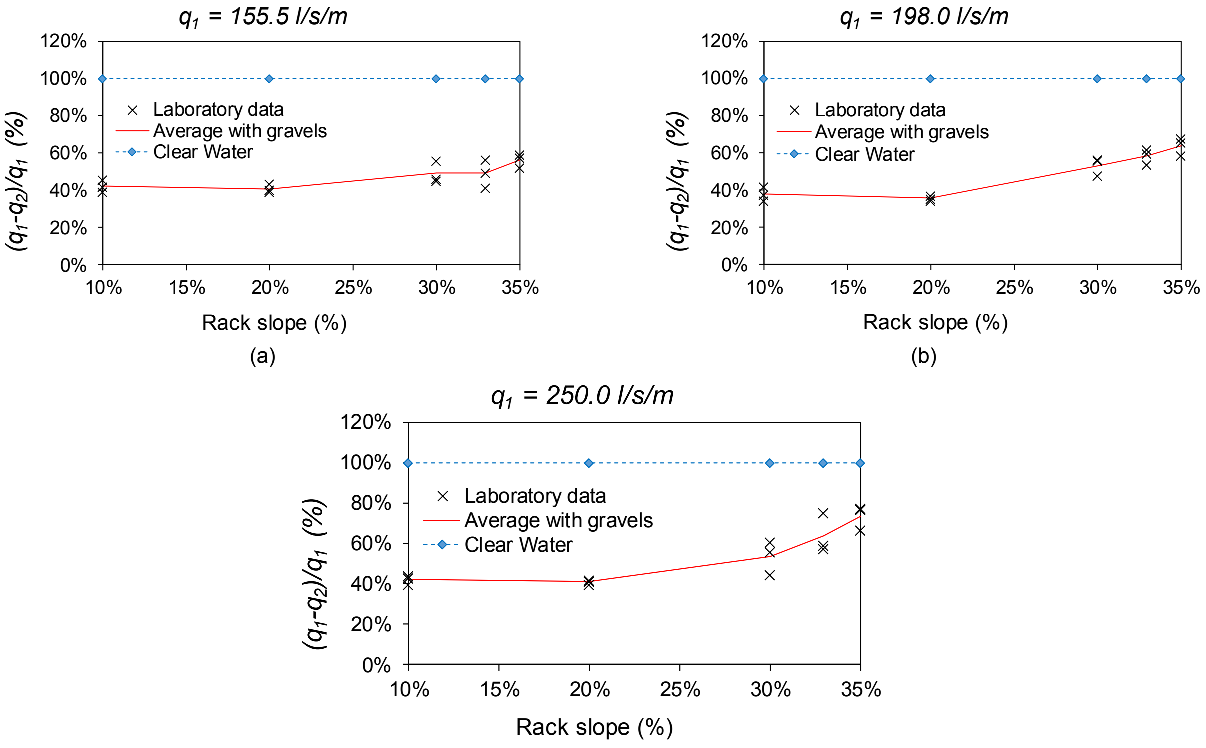


Figure 5. Flow passing over the rack for q_1 = 155.5 l/s/m and different longitudinal slopes: (a) 10%; (b) 20%; (c) 30%; (d) 33%, and (e) 35%.

Figure 6**¡Error! No se encuentra el origen de la referencia.** shows the derivation capacity of the rack, (q_2 - q_1)/q_1, in function of the longitudinal rack slope. The values for clear water are also presented. It could be observed that the percentage of derived flow presented an almost constant value for longitudinal slopes of 10 and 20% (approximately 40%) and a growing trend for longitudinal slopes of 30 to 35% por every inlet flow (56, 64 and 73% respectively).



(a)

(b)

(c)

Figure 6. Percentage of derived flow for specific inlet flow: (a) 155.5 l/s/m, (b) 198.0 l/s/m and (c) 250.0 l/s/m.

It could be seen that exist influence of the longitudinal slope in the flow derivation capacity. The shape and configuration of the gravels affects the way they are deposited on the bars when the slope varies, as is shown in Figure 7 and Figure 8.

(a)

(b)

(c)

Figure 7. Top view of occluded bottom racks with circular bars with *m* = 0.60, q_1 = 250.0 l/s/m and (a) tgθ =10%, *L* = 0.35 m; (b) tgθ =30%, *L* = 0.40 m; and (c) tgθ =35%, *L* = 0.45 m.

(a)

(b)

(c)

Figure 8. Top view of occluded bottom racks with circular bars with *m* = 0.60, q_1 = 155.5 l/s/m and (a) tgθ =10%, *L* = 0.25 m; (b) tgθ =30%, *L* = 0.30 m; and (c) tgθ =35%, *L* = 0.35 m.

Comparing the quantity of gravel retained on the rack for the case of the highest (Figure 7) and the lowest (Figure 8) flow tested, it could be seen that in the case of the lower longitudinal slopes, there is a considerable amount of gravel retained between the bars and deposited on the rack, while for the higher slopes, this amount visibly decreases.

4.2 Comparison of derived flow capacity

Castillo et al. (2016) developed laboratory tests on T-shaped flat bars and void ratio, *m* = 0.28, using two different gravel types whose characteristic diameters were: 14.8 mm and 22.0 mm. The tests were developed with three types of flows: 77.0; 114.6 and 155.5 l/s/m in five different slopes (0%, 10%, 20%, 30% and 33%). Among the conclusions of this study, it can be mentioned that: the deposition of the sediment in the rack produces an increase in the water depth over the rack that increases the rejected flow, and that the derivation capacity has a growing trend with the longitudinal slope longitudinal up to 30%.

Comparing the results obtained in this experimental campaign with those obtained in previous works developed by Castillo et al. (2016), for the inlet flow q_1 = 155.5 l/s/m, it could be observed that the rack with circular bars and a high void ratio (m = 0.60) presents the lowest flow derivation capacity in relation to the bars with T-shape flat bars and void ratio m = 0.28 tested with the two types of gravel, as is shown in Figure 9. The difference in the values for the two types of bars tested is that gravels were trapped between the slits of the bars due to the configuration of the circular profile in such a way that the flow can no longer remove them.

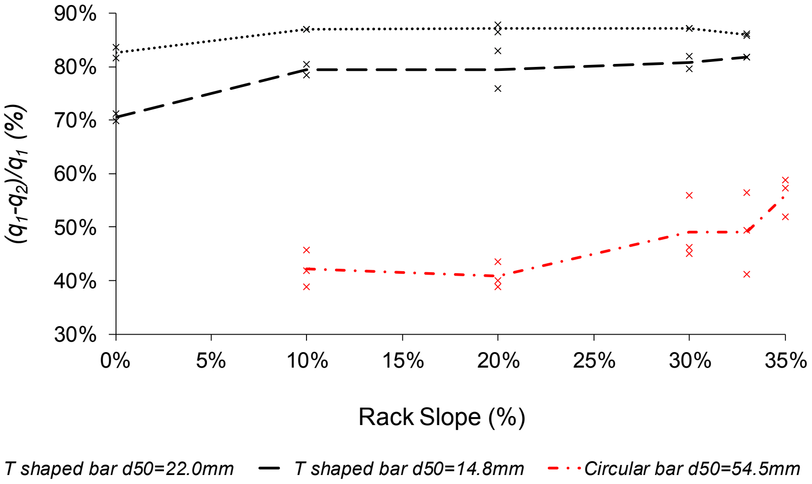


Figure 9. Comparison between percentage of derived flow for bottom racks with T-shaped bars and circular bars for $q1$ = 155.5 l/s/m

This results are in agreement with the design recommendation made by authors like Krochin (1978), who does not recommend using circular bars because they are more easily clogged.

5. CONCLUSIONS

Despite the number of investigations that have been developed using bottom racks intake systems, there is still uncertainty in the effect produced by sediments passing over the rack and the gravel deposition between the slits of the rack in the design of this type of intakes.

Sediment transport is a principal issue in water intake projects for electricity generation, either because there is scarce information about solid flow or because of the problems associated with the occlusion of the racks and the decrease in the derivation capacity.

Bottom racks with circular bars and void ratio, m = 0.60 present lower derivation capacity in comparison with the T-shaped flat bars rack (m = 0.28), although the increase in the slope improves the capacity of flow derivation in the case of circular bars, the trend continues to remain below the results obtained for the T-shaped bars ones, as is shown in Figure 9, the difference for 35% slope is approximately 20%.

ACKNOWLEDGMENTS

The authors are grateful for the financial support received from the Seneca Foundation of Murcia Region (Spain) through the project “Optimización de los sistemas de captación de fondo para zonas semiáridas y caudales con alto contenido de sedimentos. Definición de los parámetros de diseño”. Reference: 19490/PI/14.

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