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ORIGINAL

Investigation of Flow Hydraulic Gradient Through Self-Spillway Dams

Investigación del gradiente hidráulico del flujo a través de presas de autovertedero

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ABSTRACT

Dams are hydraulic structures constructed across rivers in order to store or rise water level for multi-purposes such as irrigation and power generation. The upstream face of the dam is subjected to water drag force which makes possible of flow seepage through the dam body. In the present study, the difference in water level between upstream and downstream sides of a rock-fill dam is investigated under different flow conditions demonstrating the flow behavior through the dam body. Two well graded samples of river aggregates with d50 of 56 mm and 40 mm are used to build the dam model. One sample of poor graded crushed rocks of d50 33 mm is included as well. The obtained results show that due to the porosity of the gabion containing the aggregates, the hydraulic gradient line dropped down significantly where it is inversely proportional to the porosity non-linear relationships for all. In addition, a linear relationship has dominated on the relation between upstream water depth and discharge through the self-spillway dam with and without impermeable core.

Keywords: Hydraulic Gradient; Rock-Fill Dam; Self-Spillway Dam; River Aggregates; Difference in Water Level.

RESUMEN

Las presas son estructuras hidráulicas construidas a lo largo de los ríos para almacenar o elevar el nivel del agua con fines múltiples, como el riego y la generación de energía. La cara aguas arriba de la presa está sometida a la fuerza de arrastre del agua que hace posible la filtración del flujo a través del cuerpo de la presa. En el presente estudio, se investiga la diferencia de nivel de agua entre las caras aguas arriba y aguas abajo de una presa de escollera bajo diferentes condiciones de flujo demostrando el comportamiento del flujo a través del cuerpo de la presa. Para construir el modelo de presa se utilizan dos muestras bien graduadas de áridos de río con d50 de 56 mm y 40 mm. También se incluye una muestra de roca triturada pobremente graduada de d50 33 mm. Los resultados obtenidos muestran que debido a la porosidad del gavión que contiene los áridos, la línea de gradiente hidráulico descendió significativamente donde es inversamente proporcional a la porosidad relaciones no lineales para todos. Además, una relación lineal ha dominado en la relación entre la profundidad del agua aguas arriba y la descarga a través de la presa de auto aliviadero con y sin núcleo impermeable.

Palabras clave: Gradiente Hidráulico; Presa de Escollera; Presa de Autovertedero; Áridos Fluviales; Diferencia de Nivel de Agua.

INTRODUCTION

During the last decades, Self-spillway dams or weirs that are made from natural aggregates have significantly taken place in hydraulic engineering as it satisfies the ecological conditions Michioku et al.[1] and can meet economical requirements due to low construction costs. Self-spillway dams can preserve natural aquatic habitat as well as the transportation of chemical and physical substances and the longitudinal movement of natural water habitat are prevented due to conventional weirs structures that are made from impermeable materials[2] and it can contribute in restoration-management by increasing the bio diversional of invertebrates[3] in contrast to porous retention structures which survive aquatic life. However, flow through porous media self-spillway dams requires more understanding in terms of critical equations that describe the flow regime. Therefore, this study aims to state the relationship between upstream water depth and discharge through the permeable weirs that are made from river aggregates and crushed stone with different graded-aggregates using 3 samples of materials.

Previous Studies

Many laboratory experiments have been conducted to examine the flow through the self-spillway dams and to find associated relationship that can describe main variables of flow regime.

An experiment studied effects of mean particle sizes of gabion materials on two flow regimes, transient and through flow.[2] The study used single-size aggregate of three different samples (10 to 14) mm, (14 to 20) mm and (20 to 25) mm. Researchers proved that the water head at upstream side (hu) of rockfill dam increases by decreasing the materials mean size. While for the same gravel size, the water depth is increased by lengthening the weir dimension along the water stream. The study stated a linear relationship between hu and discharge per unit width (q) for all samples.[2]

Another study tested four samples of d50 from river aggregates with impermeable layers located at the center of the self-spillway dam.[4] The particle size are 16,3, 24,8, 39,3 and 62,2 mm. The experiments stated non-linear relationship for the main variables of flow regime through self-spillway dams. The study obtained the below equation:

$$\frac{q}{g^{1/2}\,d_{50}^{3/2}} = \phi\left(\frac{h_c}{d_{50}}, \frac{\mu}{\rho g^{1/2}\,d_{50}^{3/2}}, \frac{\sigma}{\rho g\, d_{50}^{2}}, \mathrm{e}, \mathrm{c}, \mathrm{r}\right) \quad (1)$$

Where q = discharge per unit width, g= gravitational acceleration, d50= particle size distribution of gravel, ρ = mass water, hc = water depth above impermeable wall, μ = dynamic water viscosity, σ= surface tension, C = shape factor r = surface roughness of gravel. The findings showed dimensionless relations is good and it can be employed for studying and analyzing problems related to flow through self-spillway rockfill dams. The findings emphasized the linear relationship between the discharge and the flow depth of water above the cut-off wall, and it was stated a refraction in the line in case of fixing a cut-off wall at the front surface of the dam.

Further study conducted to evaluate possible effects of different particle size and longitudinal slope of the gabion on the flow velocity at downstream side.[5] Researchers used three different longitudinal slopes, 0,028, 0,014 and zero with using three single-sized rockfill (64 to 76) mm, (37,5 to 50) and (50 to 64)mm for each proposed slope. The findings have shown a linear relation between downstream flow velocity and discharge through the rockfill dam for all particle sizes. The study has also proved that the effectiveness of discharge on the downstream flow velocity by increasing the gabion slope.

A. Shiko[6] used five samples of river aggregates single-size aggregates to study flow over self-spillway, trapezoidal shaped dams with inner, impermeable dyke. The research emphasized the liner relation between discharge and the depth of flow above the dyke at upstream and center of the dam for the flow through rockfill dams, while the flow over the same dam adapts a non-liner relationship between same parameters. In addition, Shiko proved the non-liner relationship between the dimensionless relationship for the main variables and represented by one equation for all samples. In contrast to the flow over the dam for the same dimensionless relation were following different straight lines for each sample. Another experiment showed a liner relation between Reynold number and diameter of particles.[7] The same study stated a power type relation between discharge coefficient (Cd) and particle diameters D, where Cd decreases against larger D. This paper examines the relationship between discharge per unit width and water depth upstream and downstream of the rockfill dam.

Velázquez-Luna et al.[8] the flow through a gabion has been evaluated with different slopes using 100-300 mm diameter aggregates. Findings demonstrated the effect of particle size and shape of rock-fill dams on water discharge and sediments trapping efficiency. In addition, shape of rocks larger percentage sediment retaining angled" with notable effect of channel on flow regime.

Gabion weirs were compared to solid types in another experiment. Results stated inapplicability of using solid weir flow equations on due to larger divisions.[9]

Similar to the rock-fill dams natural conservation, lab tests determined slit-check dams' effects on woody debris. Results has shown linear relationship between sediments trapping efficiency and relative opening width.[10]

Experimental Setup

The experiments are conducted using a hydraulic channel with 12 m long and 0,3 m width and 0,5 m height, figure 1 the canal's bed and walls are made from 8 mm timber glass. Three samples of aggregates were used, two of them are river aggregates, one is 56 mm of d50 of well-graded aggregate and the other one is 40 mm of d50. While the third sample was made from 33 mm, d50 poor-graded crushed stone. All samples were having a rectangular shape (Length 52 cm, Width 30 cm and 33 cm height), figure 2. For measurement purposes, a water height measurement gauge trolly were fixed above the canal with sliding measurement ruler.

Figure 1. Experimental channel and model position

Figure 2. Self-Spillway dam model

The water flowrate was measured by installing a V notch weir having the equation 2, located after the rockfill dam model:[11]

$$Q = Kh^{5/2} \qquad (2)$$

Where:
Q = flowrate (m3/min)
h = water head above the weir (m)
K = head correction factor, and it is calculated according to equation 2

$$K=81.2+\frac{0.24}{h}+\left[8.4+\frac{12}{D}\right]\left[\frac{h}{B}-0.09\right]^2 \qquad (3)$$

Where
B = channel bed width (m)
D =Height of the weir crest from canal bed = 0,3 m

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The aggregate samples were installed 3 m away from canal upstream, inside a steel wire-mesh basket. Once the water entered into the channel, water retention occurred at upstream of each sample in addition for the flow through the samples. Once the water reaches a steady-state flow, Water height at upstream of the dam (hu) against discharge (Q) through the dam have been measured for a number of times for each sample as shown in the tables 1,2 and 3.

RESULTS AND DISCUSSION

The upstream water depth and discharge through self-spillway dam were obtained through in-lab readings as shown in the table 1,2 and 3 for each aggregate sample where the water level upstream and through and downstream the dam model was significantly been noticed especially at large flowrate values figures 1-3.

Table 1. Flow regime through self-spillway dam for well-graded river aggregates d_{50}=56 mm

Upstream water depth (h_s) cm	Discharge (Q) L/sec	Discharge per unit width (q) L/sec	h_u / d_{50}	q/ ($g^{0,5}$ $(d_{50})^{3/2}$)	Log (h_u/d_{50})	Log [q/ ($g^{0,5}$ $(d_{50})^{3/2}$)]
27,21	6,926	13,85	4,86	0,333	0,68	-0,47
24,13	5,582	11,16	4,31	0.269	0,63	-0,57
20,91	4,663	9,33	3,73	0,224	0,57	-0,65
15,93	2,95	5,9	2,84	0,142	0,45	-0,85
14,33	2,54	5,08	2,56	0,122	0,4	-0,91
11,99	1,959	3,92	2,14	0,094	0,33	-1,02
9,83	1,446	2,89	1,75	0,069	0,24	-1,16
5,36	0,529	1,05	0,96	0,025	0,01	-1,6

Table 2. Flow regime through self-spillway dam for well-graded river aggregates d_{50}=40 mm

Upstream water depth (h_s) cm	Discharge (Q) L/sec	Discharge per unit width (q) L/sec	h_u / d_{50}	q/ ($g^{0,5}$ $(d_{50})^{3/2}$)	Log (h_u/d_{50})	Log [q/ ($g^{0,5}$ $(d_{50})^{3/2}$)]
31,51	8,777	17,55	7,88	0,7	0,89	-0,15
25,73	6,504	13	6,43	0,519	0,81	-0,28
22,23	5,009	10,02	5,55	0,399	0,74	-0,4
17,16	3,397	6,79	4,29	0,271	0,63	-0,57
15,44	2,967	5,93	3,86	0,237	0,58	-0,62
12,4	2,096	4,19	3,1	0,167	0,49	-0,77
10,65	1,581	3,16	2,66	0,126	0,42	-0,89
8,89	1,205	2,41	2,22	0,096	0,35	-1,02

Table 3. Flow regime through self-spillway dam poorly-graded river aggregates d_{50}=33 mm

Upstream water depth (h_s) cm	Discharge (Q) L/sec	Discharge per unit width (q) L/sec	h_u / d_{50}	q/ ($g^{0,5}$ $(d_{50})^{3/2}$)	Log (h_u/d_{50})	Log [q/ ($g^{0,5}$ $(d_{50})^{3/2}$)]
27,5	10,43	20,86	8,33	1,111	0,92	-0,046
24,78	9,112	18,22	7,51	0,97	0,87	-0,01
23,2	7,973	15,95	7,03	0,849	0,85	-0,07
20,35	6,435	12,87	6,16	0,685	0,79	-0,16
16,38	4,629	9,26	4,96	0,493	0,69	-0,31
13,28	3,51	7,2	4,02	0,374	0,6	-0,43
9,62	2,238	4,47	2,91	0,238	0,46	-0,62

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Figure 3. Hydraulic gradient through Self-Spillway dam at low discharge value

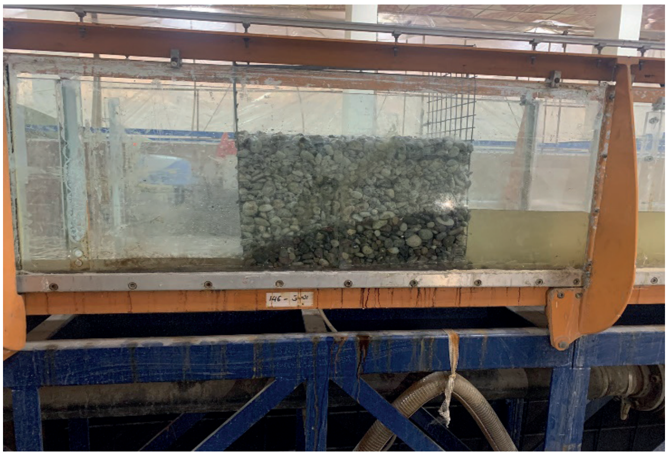

Figure 4. Hydraulic gradient through Self-Spillway dam at an increment of discharge value

Figure 5. Hydraulic gradient through Self-Spillway dam at the maximum given discharge

By dividing discharge through the dam on canal bed width, it results q which is flowrate per unit width then plot the relation for all samples between q (L/sec/m) and u (cm), figures 6, 7 and 8.

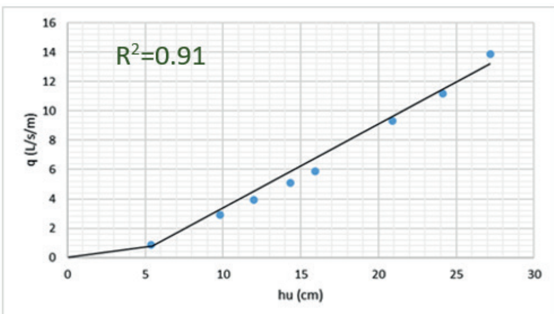

Figure 6. Upstream water depth versus water discharge per unit width for d50 = 56 mm river aggregates

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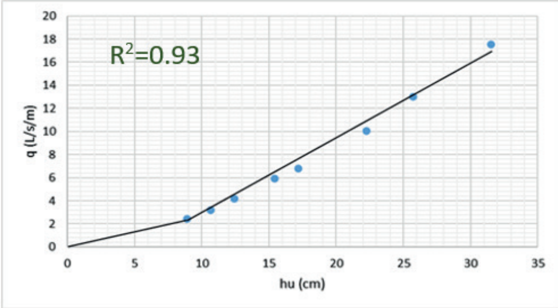

Figure 7. Upstream water depth versus water discharge per unit width for d50 = 40 mm river aggregates

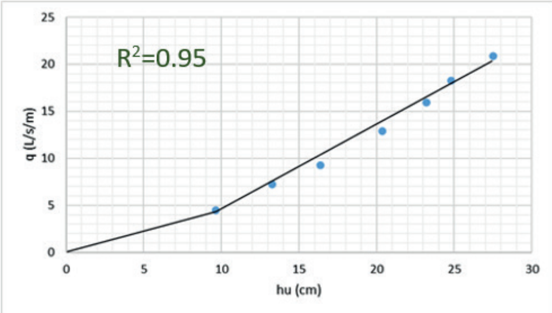

Figure 8. Upstream water depth versus water discharge per unit width for d50 = 33 mm crushed stone

All figures show a linear relationship between hu and q and that agree with[12,5] for the same flow through aggregate dams characters, stating the relationship between q and hu is linear for flow through self-spillway dams with and without impermeable core inside the dam.

The experiment resulted the below graph equation as a relation between q and hu: for each sample.

$$q = b_0 + b_1 h_u \qquad (4)$$

Where b_0 and b_1 are non-dimensional variables. These variables are derived from figures 6,7 and 8 after refraction point and obtaining the equations 5, 6 and 7. The findings demonstrated a convergence in values for b_1 of river aggregates samples and differential for crushed-stone samples.

q = -3.1+0.59 hu, for d50 = 56 mm (5)
q = -3.3+0.61 hu, for d50 = 40 mm (6)
q = -3.4+0.83 hu, for d50 = 33 mm (7)

By examine the non-dimensional equation 1 to represent the data of this experiment for the three samples, and by substitution the water depth above the cut-off wall (hc) with hu, to draw a relationship between h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$, a non-linear relationship was resulted from the graphs, see figures 9,10, and 11. In contrast to Mohamed et al.[2] and Bazargan et al.[7] who showed a linear relationship for the same variables of weirs with impermeable core.

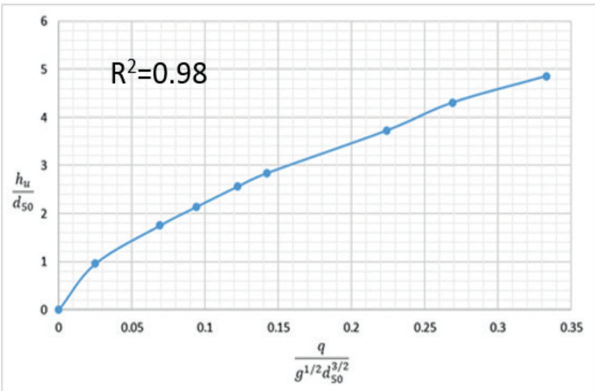

Figure 9. Relationship graph between h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ for d50 = 56 mm river aggregates

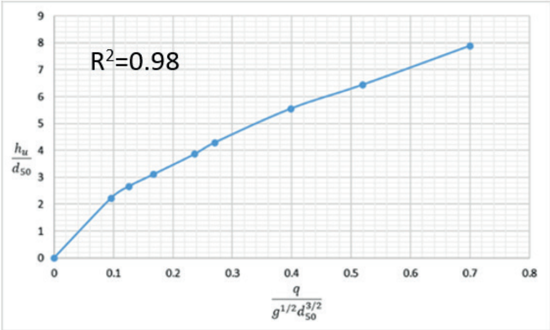

Figure 10. Relationship graph between h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ for d50 = 40 mm river aggregates

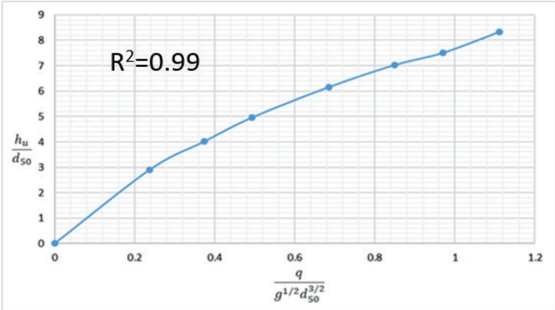

Figure 11. Relationship graph between h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ for d50 = 33 mm crushed stone

In addition, by presenting the relationship h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ on a logarithmic scale figures 12, 13 and 14 with assuming the relationship in equation 8.

$$\frac{q}{g^{1/2}d_{50}^{3/2}} = a_0\left(\frac{h_u}{d_{50}}\right)^{a_1} \quad (8)$$

Where a0 and a1 have been derived from graphs in figures 4, 5 and 6 as followed:

$$\frac{q}{g^{1/2}d_{50}^{3/2}} = 0.0316\left(\frac{h_u}{d_{50}}\right)^{1.44} \quad (9)$$
$$\frac{q}{g^{1/2}d_{50}^{3/2}} = 0.027\left(\frac{h_u}{d_{50}}\right)^{1.59} \quad (10)$$
$$\frac{q}{g^{1/2}d_{50}^{3/2}} = 0.053\left(\frac{h_u}{d_{50}}\right)^{1.4} \quad (11)$$

See figures 7, 8 and 9 represents the above relationship in equations 12, 13 and 14.

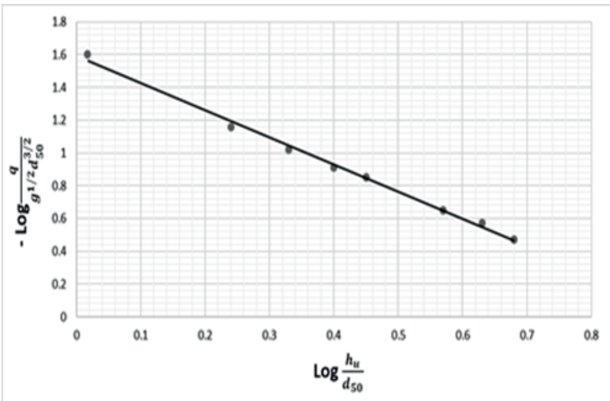

Figure 12. Non-dimensional relationship for log h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ d50 = 56 mm river aggregates

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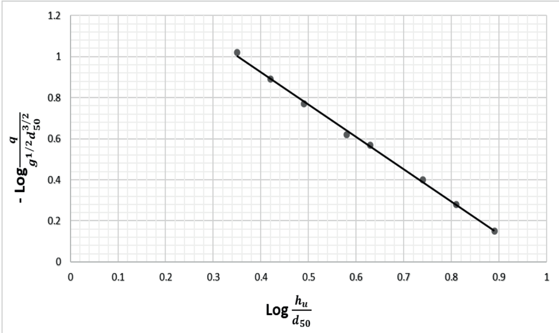

Figure 13. Non-dimensional relationship for log h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ d50 = 40 mm river aggregates

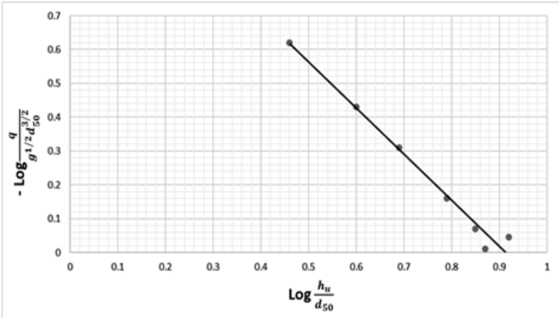

Figure 14. Non-dimensional relationship for log h_u/d_{50} and $q/(g^{(1/2)}d_{50}^{(3/2)})$ d50 = 33 mm crushed stone

CONCLUSIONS

In the present study, three different aggregates were used in order to investigate the hydraulic gradient through self-spillway dam under different flow conditions. The obtained results show that due to the porosity of the gabion containing the aggregates, the hydraulic gradient line dropped down significantly where it is inversely proportional to the porosity. In addition, a linear relationship has dominated on the relation between upstream water depth and discharge through the self-spillway dam with and without impermeable core. However, the same experiment stated a non-linear relationship in non-dimensional equation for all samples.

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CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

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Formal analysis: Abdullah Ahmed Shekho, Dheyaa Ghanim Abdulrazzaq, Mohammad Akram Saadi AL-DABBAGH.
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Methodology: Abdullah Ahmed Shekho, Dheyaa Ghanim Abdulrazzaq, Mohammad Akram Saadi AL-DABBAGH.
Drafting - original draft: Abdullah Ahmed Shekho, Dheyaa Ghanim Abdulrazzaq, Mohammad Akram Saadi AL-DABBAGH.
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