ASSESSING DOWNSTREAM VELOCITY DISTRIBUTION OF DIFFERENT SHAPES OF LABYRINTH WEIRS

Ahmed H. Shehata[1], Tahani F.Youssef [2], Ibrahim M.M. [3] and Hamada A. H. [4]

[1] Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza 12316, Egypt; ahmed-hussein@eng.cu.edu.eg
[2] Civil Engineering Department, Faculty of Engineering, Materia, Helwan University, Egypt; tahanyoussef@yahoo.com
[3] Civil Engineering Department, Faculty of Engineering-Shoubra, Benha University, Cairo 11629, Egypt; mohamed.ibrahim@feng.bu.edu.eg
[4] Pyramids Higher Institute for Engineering and Technology, Giza 12578, Egypt; Eng_hamada28@yahoo.com
** Correspondence: Eng_hamada28@yahoo.com ; Tel.: +2-01100112410*

ABSTRACT

*In terms of the significance of establishing mega hydraulic structures, while avoiding their serious implications at the **D**own **S**tream "D.S.", this study was initiated with the objective of assessing downstream **V**elocity **D**istribution "VD" of different shapes of **L**abyrinth **W**eirs "LW", in terms of its head, crest level and discharge, experimentally. Predominantly, literature about hydraulic structures was analyzed. An experimental program (60 experiments) was designed. It considered different weir shapes (i.e. linear weir and 4 apex angle (i.e. 20, 45, 60 so as 80º), where the weir crest height was altered (i.e. 30, 35 and 40 cm). A laboratory flume was set and measuring facilities were mounted along it. Miniatures were fabricated and an experimental scheme was designed. Also, discharges were altered (i.e. 200, 150, 100 and 50 l/s). Measurements were attained and results were plot on graphs. The research results accentuated that trapezoidal weir angle of 45 and 60º achieved the optimum VD. However, the results stressed that 60º weir provided superior scour values and VD. The results specified that reducing crest level enhanced both scour and VD.*

1. INTRODUCTION

Archaeologically, the eldest weir was established in Fayoum. It is rectangular in shape; figure (1). However, its remnants still exists; figure (2).
Weirs are obstacles placed across channels that changes flow characteristics and induce bed level changes. Water flows over their crests and spills at downstream "D.S.". They are employed to control the discharge, especially during high flows, where their gates are adjusted to change the water flowing to the D.S.
Accordingly, "VD" varies based on such an adjustment. Consequently, determining the VD at the weirs D.S. is of great significance, as it guarantees their efficient design so as their commission process. Moreover, its designation maintains the ecological balance in managing the sediment transport to enhance flood management policies. Moreover, VD designation is a pivot in managing water quality and in scheduling the agricultural process to attain sustainable management practices in water resources.
Consequently, this research was originated to assess VD at D.S for different weir shapes.

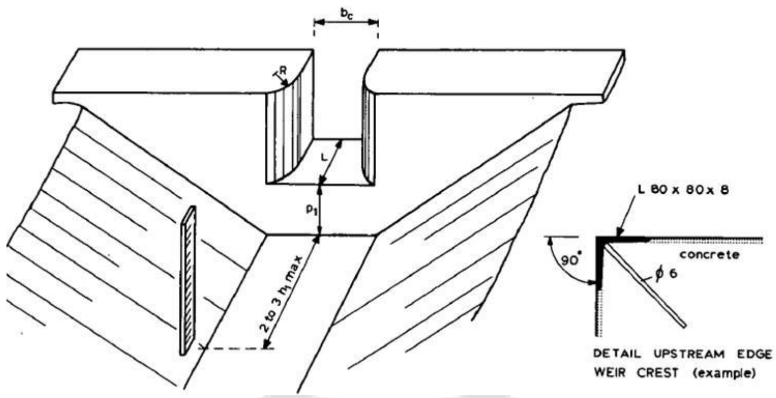

Figure (1) Fayoum Weir

Figure (2) Fayoum Weir

2. LITERATURE REVIEW

Literature in the last 3 years (2022-2024) within the domain of VD of LW was assembled and scrutinized. ***Based on the scrutinized literature, apparent was that many researches studied LW.*** Among them were the following:

Idrees, A.K.; Al-Ameri, R.2023 suggested that weirs with long crests improve weir efficiency in regulating flows, which reduces flooding risks and promotes the VD.

Likewise, ***Derakhshanifard, M.; Heidarnejad, M.; Masjedi, A.; Bordbar, A.2023*** achieved a large experimental campaign. They designated that crafting extra cycles of LW crest will develop the system performance, so as VD and will attenuate scour at D.S.

Similarly, ***Yasi et al 2023*** examined scour holes under 3 different scenarios. Their results emphasized that curved crests provide higher efficiency, with respect to VD. Their results designated that this will promote LW design.

However, ***Dehghani, H.S.; Varaki, M.E. 2022*** inspected influence of U.S., so as D.S. bed level on discharge coefficient “C_d”, where their results highlighted that changing the level of tail water, will alter the velocity, which signifies the changes in VD, especially at higher discharges.

Within the same context, ***Obaida, A.A.M.; Khattab, N.I.; Mohammed, A.Y 2023*** documented that apron performance and VD will change and will alter the attained scour length. Moreover, they established empirical equations to evaluate scour dimensions.

Furthermore, ***Fathi, A.; Abdi Chooplou, C.; Ghodsian, M. 2024*** signified that altering the Piano-key Weir’s design will affect the scour depth so as V.D. They suggested that the discharge dominates the scour.

Also, ***Abdi Chooplou, C.; Bodaghi, E.; Ghodsian, M.; Vaghefi, M. 2024*** explored scour evolution D.S. of Piano-key Weir, where they pointed out that, as Froude increases, scour rate will increase and VD will change. Moreover, they developed associations to relate scour behavior to other influencing parameters, which will signify for VD.

Accordingly**,** the surveyed literature indicated few studies investigated trapezoidal LW hydraulic design and its behavior at its D.S. its placement, in terms of scour geometry. This fortified the reason for initiating this study to focus on the important parameters incorporated in trapezoidal LW design and VD.

3. EXPERIMENTAL WORK

The laboratory work was achieved in Cairo University Experimental Hall. The laboratory has a rectangular flume (i.e. 2 m wide, 2.5 m long and 85 cm deep); figure (3). The flume has a moveable bed with a concrete base. Its sides are glass braced by steel frames, where the experiments monitored downstream hydraulic aspects (i.e. scour and VD). Moreover, figure (4) is provided to indicate the fixing process of water depth at weir D.S.

Primarily, an experimental program was planned; table (1), where it encompasses 60 experiments. The table designates that different weir shapes (i.e. linear weir so as 4 apex angles of 20, 45, 60 so as 80^o were considered. Moreover, weir crest height was changed to be 30, 35 and 40 cm. Also, the flow rate was varied to be 200, 150, 100 and 50 l/s.

3.1. CRAFTING REPLICAS

15 replicas were crafted, 12 of which were steel trapezoidal LW with different apex angle of 20, 45, 60 and 80^o. The other 3 replicas were steel linear LW. The replicas have different weir crest height of 30, 35 and 40 cm; figure (5).

3.2. MEASURING DEVICES AND MEASUREMENTS

The measuring facilities were placed along the flume, where they monitored different scour parameters at D.S of LW and VD; figures (6) to (9). Figure (6) presents the employed electromagnetic flow meter, while figure (7) presents the utilized point gauge. Moreover, figure (8) indicates the locations of velocity measurements, whereas figure (9) indicates the process of velocity measurements.

Figure (3) Cairo University rectangular flume

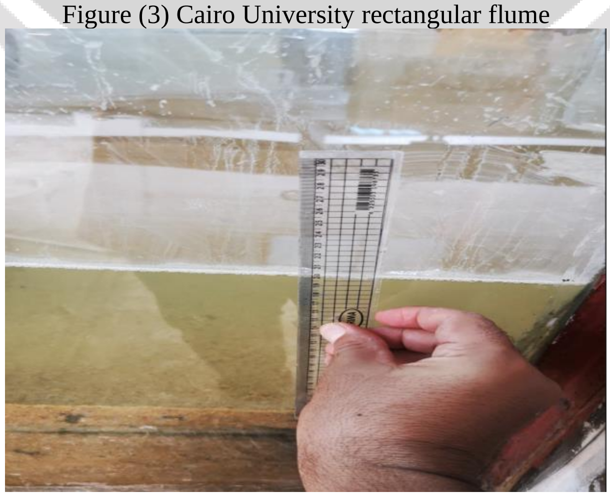

Figure (4) Fixing water depth at the D.S. of the weir

Table (3.1) Experimental program

Experimental code (-)	Apex angle (deg)	Crest level (m)	Discharge (l/s)
1	Linear	30	50
2			100
3			150
4			200
5		35	50
6			100
7			150
8			200
9		40	50
10			100
11			150
12			200
13	20	30	50
14			100
15			150
16			200
17		35	50
18			100
19			150
20			200
21		40	50
22			100
23			150
24			200
25	45	30	50
26			100
27			150
28			200
29		35	50
30			100
31			150
32			200
33		40	50
34			100
35			150
36			200
37	60	30	50
38			100
39			150
40			200
41		35	50
42			100
43			150
44			200

45		**40**	**50**
46			**100**
47			**150**
48			**200**
49	**80**	**30**	**50**
50			**100**
51			**150**
52			**200**
53		**35**	**50**
54			**100**
55			**150**
56			**200**
57		**40**	**50**
58			**100**
59			**150**
60			**200**


Figure (5) crafted replicas to trapezoidal LW

Figure (6) Employed electromagnetic flow meter

Figure (7) Utilized point gauge

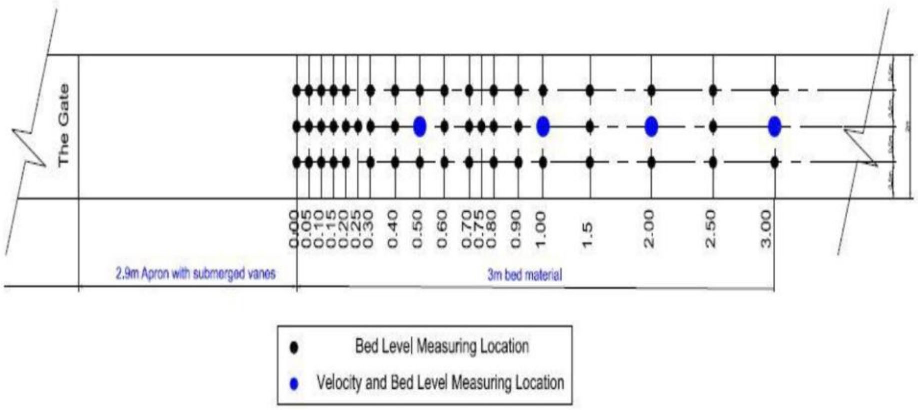

Figure (8) Location of velocity measurements

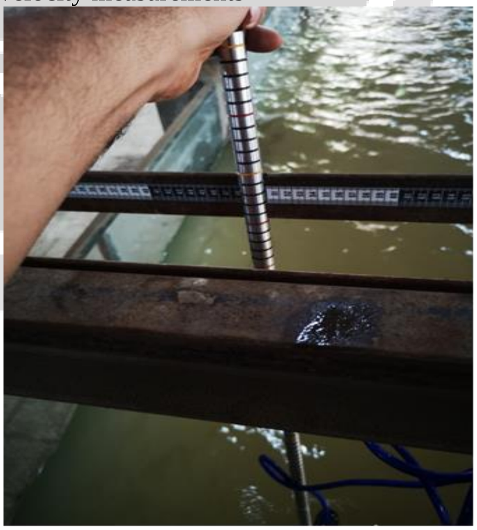

Figure (9) Velocity measurements

4. RESULTS ANALYSIS AND DISCUSSIONS

Measurements were documented, to which an in-depth analysis was achieved. This section is devoted to represent and discuss the analyzed results, as follows:

4.1. IMPACT OF LW APEX ANGLE ON VELOCITY DISTRIBUTION

Based on the analyzed results of the examined different shapes of the LW, the impact of apex angle was designated, where figure (10) presents the VD at the D.S. for the 5 examined weirs shapes (i.e. linear shape and trapezoidal LW with 4 apex angles 20, 45, 60 and 80º) at 200 l/s discharge and 40 cm is height of weir.

The horizontal axis represents the horizontal distance (L) away of the weir, while the vertical axis designates the ratio Y/Y_t, where "Y" is the water depth and "Y_t" is the tailwater depth.

The red curves present the velocity distribution for the linear weir. However, the green, black, blue and brick brown curves present the velocity distribution for the trapezoidal LW with apex angles of 20, 45, 60 and 80º, respectively.

The 4 groups of curves represent the velocity distribution along different distances from the weir apron (i.e. 0.5, 1, 2 and 3m).

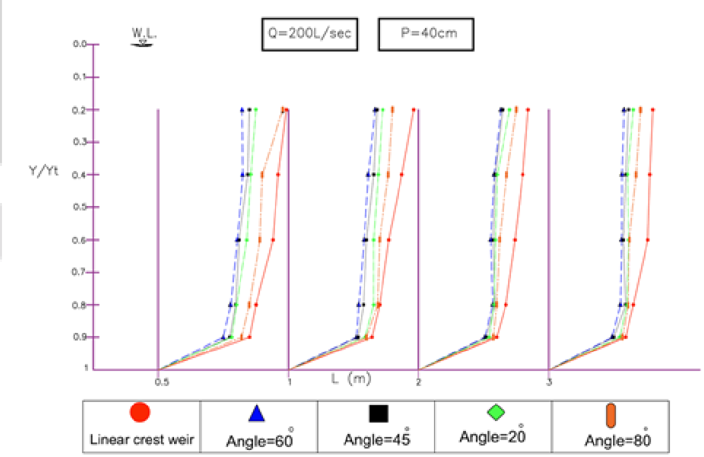

Figure (10) VD at 4 locations D.S the weir for the 5 investigated apex angle

4.2. IMPACT OF LW CREST LEVEL ON VELOCITY DISTRIBUTION

Based on the analyzed results of the examined different crest levels of the LW, the impact of crest level was determined, where figure (11) presents the VD at the D.S. for the 3 examined weirs crest height (i.e. 30, 35 and 40 cm).

The horizontal axis represents the horizontal distance (L) away of the weir, while the vertical axis designates the ratio Y/Y_t, where "Y" is the water depth and "Y_t" is the tailwater depth.

The green, red and blue curves present the velocity distribution for the trapezoidal LW with weir crest height of 30, 35 and 40 cm, respectively at 200 l/s discharge, angle is 60º .

The 3 groups of curves represent the velocity distribution along different distances from the weir apron (i.e. 0.5, 1, 2 and 3 m).

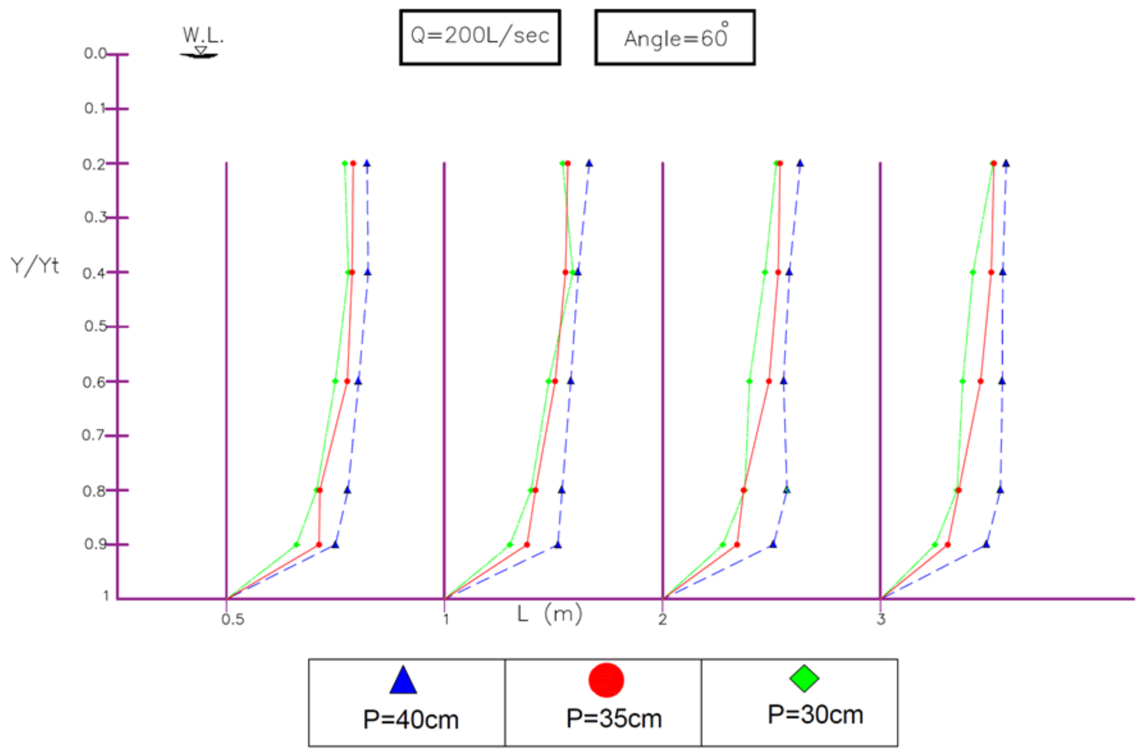

Figure (10) VD at 4 locations D.S the weir for the 3 investigated weir crest height

.

4.3. IMPACT OF LW APEX ANGLE ON WATER LEVEL OVER THE WEIR

Based on the analyzed results of the examined different apex angle of the LW, its impact of water level was determined, where figure (12) presents the water level above the weir along the longitudinal distance D.S. the weir.

The horizontal axis represents the longitudinal distance D.S. weir, while the vertical axis represents the water level in meters.

The red curve presents the water level for the linear weir. However, the green, black, blue and brick brown curves present the water level for the trapezoidal LW with apex angles of 20, 45, 60 and 80º, respectively. However, all the curves represent the water along the distance D.S. from the weir, where higher water levels were recorded at linear crest weir.

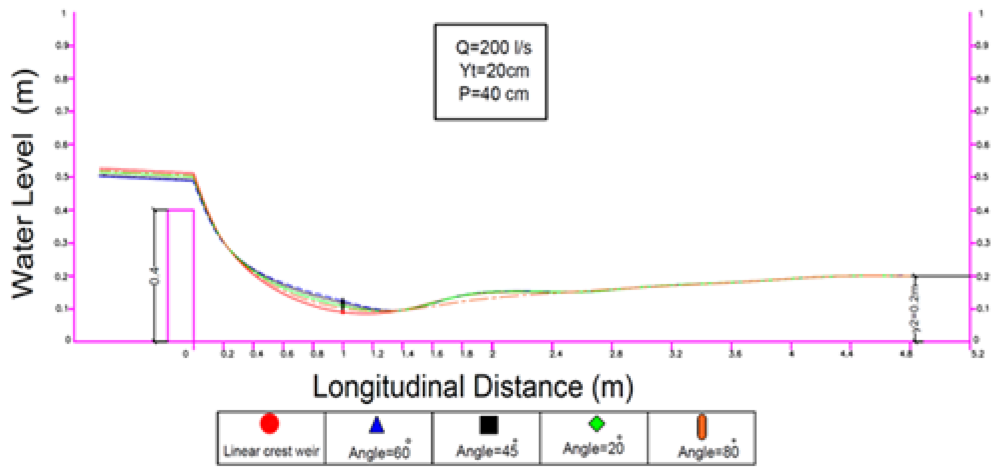

Figure (11) Impact of LW apex angle on the water level

4.4. IMPACT OF LW CREST LEVEL ON WATER LEVEL

Based on the analyzed results of the examined different crest levels of the LW, the impact of crest level on the water level was determined, where figure (12) presents the water at the D.S. for the 3 examined weirs crest height (i.e. 30, 35 and 40 cm).

The horizontal axis represents the horizontal distance (L) away of the weir, while the vertical axis designates the ratio Y/Y_t, where "Y" is the water depth and "Y_t" is the tailwater depth.

The green, red and blue curves present the water level for the trapezoidal LW with crest height of 30, 35 and 40cm, respectively. The curves represent the water level along different distances from the weir, where higher water levels were recorded at higher crest levels.

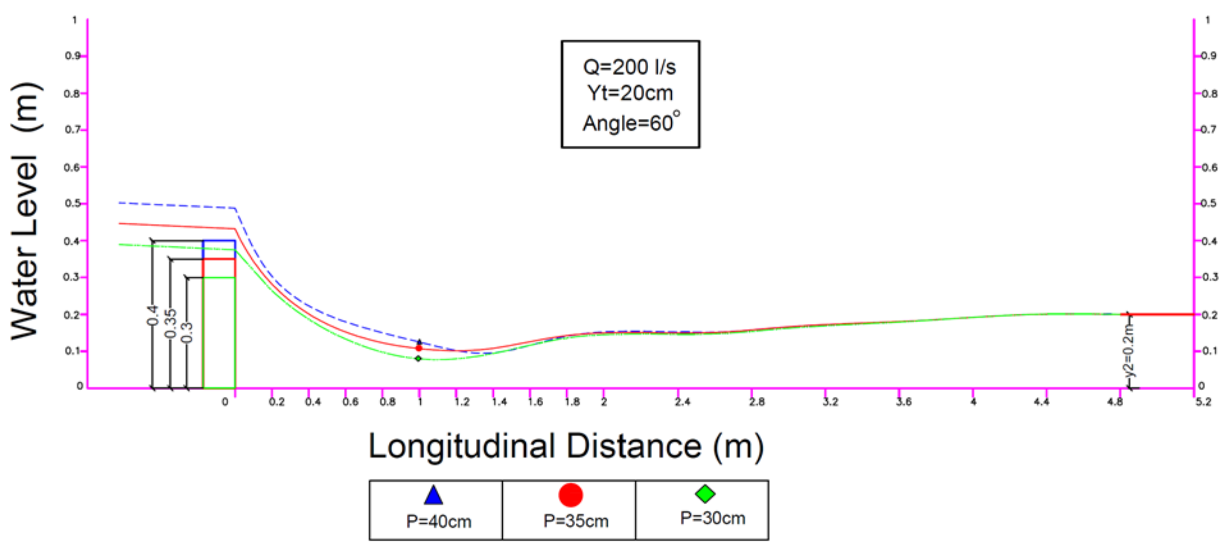

Figure (12) Impact of LW crest level on the water level

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the analyzed results, the following conclusions were deduced:

- At an apex angle of 60 degrees, the lowest speeds were recorded, relative to the other investigated angles. This is attributed to the angle directly affects the water flow and discharge.
- At an apex angle of 60 degrees, the acceleration due to gravity is reduced, resulting in the reduction of flow velocity. Accordingly, this angle promotes the energy dissipation and reduces the velocity.
- Regarding the velocity distribution along the horizontal direction, the following was observed:
    - ✓ The velocities gradually decrease as the distance D.S. weir increases, where the energy decreases after it passes over the weir
    - ✓ The velocity decreases along the distance D.S. the weir, especially at an apex angle of 60 degrees, which indicates the efficient energy dissipation and reduction in the velocity.
- As for the vertical velocity distribution, the following was observed:
    - ✓ At the apex angle of 60 degrees, the pressure is distributed more uniformly along the slope, which reduces the water velocity of the water.
    - ✓ At larger angles, water flow concentrates over the weir, which results in higher velocities.
- The height of a weir affects the velocity of water above the weir.
- As the weir height increases, the water velocity increases.
- As the height increases, the water potential energy increases, which is converted into kinetic energy with higher flow velocity.
- As the weir height increases, the gravity contributes in accelerating the water falling from greater heights, which boosts its speed. Moreover, at higher weirs, the influence of friction is reduced, which allows the water to flow more freely at higher velocities.
- Water level above the LW with an apex angle of 60 degrees is lower than all other investigated angles by 21.42%, under similar hydraulic conditions. This is attributed to the fact that the water flows more smoothly at the top than the other investigated angles.
- A balanced pressure distribution and flow distribution was noticed in the case of the LW with an apex angle of 60 degrees, which reduces the water accumulation above the weir and provides a better energy distribution.
- The increase in the weir height increases the generated kinetic energy, which induces turbulent flow after crossing to the D.S.

Based on the deduced conclusions, the following recommendations were suggested:

- Investigate a larger scope of LW apex angles.
- Inspect a wider range of discharge.
- Explore the impact of increasing the number of corrugation of the LW.

6. LIST OF REFERENCES

1. Abdi Chooplou, C.; Bodaghi, E.; Ghodsian, M.; Vaghefi, M. Temporal Evolution of Scouring Downstream of a Trapezoidal Piano Key Weir. International Journal of River Basin Management 2024, 22, 351–364, doi:10.1080/15715124.2022.2143513.
2. Dehghani, H.S.; Varaki, M.E. Experimental Investigation of Upstream Sedimentation and Downstream Bed Levels' Effects on Discharge Coefficients of Trapezoidal Labyrinth Weirs. Arabian Journal of Geosciences 2021, 14, 1999, doi:10.1007/s12517-021-08339-x.
3. Derakhshanifard, M.; Heidarnejad, M.; Masjedi, A.; Bordbar, A.; Egdernezhad, A. Experimental Study of Effect of Creating an Additional Cycle along the Lateral Crest of the Labyrinth Weirs. Flow Measurement and Instrumentation 2023, 90, 102306, doi:10.1016/j.flowmeasinst.2023.102306.
4. Fathi, A.; Abdi Chooplou, C.; Ghodsian, M. 2024 Local Scour Downstream of Type-A Trapezoidal Stepped Piano Key Weir in Sand and Gravel Sediments. ISH Journal of Hydraulic Engineering 2024, 30, 417–429, doi:10.1080/09715010.2024.2353612.
5. Goel, A.; Pal, M. Application of Support Vector Machines in Scour Prediction on Grade-Control Structures. Eng Appl Artif Intell 2009, 22, 216–223, doi:10.1016/j.engappai.2008.05.008.
6. Idrees, A.K.; Al-Ameri, R. Investigating a New Approach to Enhance the Discharge Capacity of Labyrinth Weirs. Journal of Hydroinformatics 2023, 25, 300–317, doi:10.2166/HYDRO.2023.097/1182375/JH2023097.PDF.
7. Ikinciogullari, E.; Emiroglu, M.E.; Aydin, M.C. Comparison of Scour Properties of Classical and Trapezoidal Labyrinth Weirs. Arab J Sci Eng 2022, 47, 4023–4040, doi:10.1007/s13369-021-05832-z.

8. Karbasi, M.; Azamathulla, H.Md. Prediction of Scour Caused by 2D Horizontal Jets Using Soft Computing Techniques. Ain Shams Engineering Journal 2017, 8, 559–570, doi:10.1016/j.asej.2016.04.001.
9. Masoudi, M.H.; Yari, A.; Sadeghian, J.; Norouzi, H. Experimental Investigation of the Discharge Coefficient of the Rectangular and Trapezoidal Labyrinth Weirs Considering Variable Congress Lengths. Model Earth Syst Environ 2024, doi:10.1007/S40808-023-01925-W.
10. Najafzadeh, M.; Saberi-Movahed, F.; Sarkamaryan, S. NF-GMDH-Based Self-Organized Systems to Predict Bridge Pier Scour Depth under Debris Flow Effects. Marine Georesources & Geotechnology 2018, 36, 589–602, doi:10.1080/1064119X.2017.1355944.
11. Obaida, A.A.M.; Khattab, N.I.; Mohammed, A.Y. Scour Depth Downstream Sharp-Crested Weir. Journal of Engineering and Applied Science 2023, 70, 1–11, doi:10.1186/S44147-023-00192-X/FIGURES/9.
12. Pagliara, S.; Kurdistani, S.M. Scour Downstream of Cross-Vane Structures. Journal of Hydro-environment Research 2013, 7, 236–242, doi:10.1016/j.jher.2013.02.002.
13. Yasi, M.; Azizpour, B. Comparative Experimental Study on Local-Scour Downstream of Labyrinth Weirs with Different Planforms. Iranian Journal of Science and Technology, Transactions of Civil Engineering 2023, doi:10.1007/s40996-023-01271-y.