ZIBELINE INTERNATIONAL PUBLISHING

SSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.01.2020.19.22

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RESEARCH ARTICLE

IMPROVEMENT OF THE HYDRAULIC JUMP FEATURES USING INCOMPLETE CIRCULAR PILES

Nassar M.A

Department of Construction Engineering, College of Engineering in Al-Qunfudhah, Umm Al-Qura University, KSA, on leave from Water Engineering and Water Structures Department, Faculty of Engineering, Zagazig University, Egypt.
****Corresponding Author Email: manassar@uqu.edu.sa***

ARTICLE DETAILS

Article History:

Received 16 April 2020
Accepted 21 May 2020
Available online 11 June 2020

ABSTRACT

The roughness elements are efficient tools to control the features of the hydraulic jump in the rectangular stilling basins. The present study suggests the use of modified elements to control the features of the free jump. The proposed tool is an incomplete circular pile. The use of piles in a one row with the different setup has been investigated. The measurements showed that the case of piles with the comparative summation areas A/Δ=6.72 and the comparative distances between piles X/H_1 =0.0 reduced the comparative height and length of the free jump by 11% and 24.6%, respectively. The paper detected the necessary helpful statistical formulas for the phenomenon.

KEYWORDS

Hydraulic jump, characteristics, Piles, open channels and gates.

1. INTRODUCTION

The hydraulic jump features were examined using the lab measures over the years by many investigators (Aal et al., 2013; Abdel-aal et al., 2014; Abdel-Aal et al., 2016; Mohamed, 2010; Nassar, 2014; Parsamehr et al., 2012). Many novel philosophies have been presented to investigate the roughness elements. A scientific paper presented U-shape elements as a roughness to reduce the length of the basin (Ezizah et al., 2012). A scientific paper discussed the consequences of the use of a triangular strip on the features of the jump (Ahmed et al., 2014). The elements amplified the efficiency of the jump by the percent of 50.31.

A scientific paper discussed the consequences of the use of the boundary roughness on the features of the jump (Hughes and Flack, 1984). It was specified that the boundary roughness reduced the jump length and depth. A scientific paper discussed the use of the lozenge shape as a roughness element on the features of the jump (Parsamehr et al., 2017). The height of the elements was explored. It was specified that the increase of the height of the elements reduced the depth and the length of the jumps. The used of the rough canal beds on the features of the jump (Neluwala et al., 2013). The studied significances of the use of the T-shape as the roughness elements on the features of the jump (Aboulatta, et al., 2011). The optimum intensity and length of the elements were defined.

A scientific paper discussed the use of the fiberglass sheets as the roughness elements on the jump features (Elnikhely, 2014). The proposed elements reduced jump depth and length by the percent of 22 and 8.1, respectively. A scientific paper discussed the consequences of the use of the curved steel sheets elements on the features of the jump (Habib and Nassar, 2013). The proposed elements reduced the jump depth and length by the percent of 15.5 and 19, respectively. In contrast, it increased the lost energy of 17%. A scientific paper discussed the use of the cubes as roughness elements on the features of the jump (Esfahani and Bejestan, 2012). It was specified that the height of the proposed elements has a very remarkable consequences on the features of the jump. The proposed elements reduced the jump depth by the percent of 5.3:12.76.

A scientific paper discussed theoretically the features of the hydraulic jump in the sloped rectangular basin including roughness elements (Alhamid and Negm, 1996). The developed theoretical model was verified using experimental measurements. Chanson and Montes discussed the consequences of the use of the various types of the H. jumps (Chanson and Montes, 1995). It was specified that the undular jumps formed for Froude numbers varied within 1.5: 2.9. Nassar discussed a tool of pipes to guide the flow to the side boundaries (Nassar, 2019). The proposed tool decreased the length of the jump by 31%. In contrast, it magnified the lost energy by the percent of 4.0.

The present research provides measurements for the jump features under the effect of incomplete circular piles in the rectangular stilling basin. The consequences of piles have been studied under many circumstances of the free hydraulic jump. The theoretical equation describing the parameters of the free hydraulic jump was introduced. A set of statistical formulas were developed.

2. THE GOVERNING EQUATIONS

The study applied the dimensional analysis to describe the main formulas controlling the free jump features at the existing of the incomplete circular piles in a rectangular basin, see figure (1). Formula (1) describes the various relations between the jump features and the independent features.

$$\frac{H_2}{H_1}, \frac{L}{H_1} \text{ and } \frac{\Delta E}{E_1} = \text{Function of}\left(F, \frac{A}{\Delta}, \frac{X}{H_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where: $\frac{H_2}{H_1}$ is the comparative height of the free H. jump; H_2 is the water

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height at the end of the free H. jump; H_1 is the water height at the start of the free H. jump; $\frac{L}{H_1}$ is the comparative length of the free H. jump; $\frac{\Delta E}{E_1}$ is the comparative lost energy through the free H. jump; E_1 is the total energy at the start of the free H. jump; F is the factor defined by Froude, $F=\frac{v_1}{\sqrt{gH_1}}$; v_1 is the average flow velocity at the start of the free H. jump; A is the summation areas of the incomplete circular piles es; $\Delta = H_1^2$; X is the length between two consecutive incomplete circular piles.

3. Laboratory Work

3.1 The Laboratory Device

The measurements were collected in the laboratory of fluid mechanics in Alqonfudhah city. The laboratory follows the Dept. of construction engineering, college of engineering, Umm Al-Qura University, KSA. The device of the investigational works is a flume. The dimensions of the flume include the followings: Length is 43.3071 in; width is 3.0315 in and the depth is 5.9055 in. The incomplete circular piles are made of the plastic pipes of a 0.3937 in diameter. It was situated at 7.0866 in downstream the gate. The length between the piles and the gate was fixing for all tests.

3.2 The laboratory Phases

The measurements were collected in two consecutive phases. The 1st phase researches for the effect of the comparative summation areas of the incomplete circular piles A/Δ on the features of the free H. jump. The 1st phase includes of the 3-different following cases A/Δ=6.72, A/Δ=3.91 and A/Δ=2.44. The distance between the piles were fixing for all tests. The investigated setups of incomplete circular piles for the 1st phase was presented in Figure (1C).

The measurements were collected in the 2nd phase to detect the consequences of the distances between of the incomplete circular piles on the features of the free H. jump. The 2nd phase includes of the 2-different following cases X/H_1=0.0 and X/H_1=1.96. The number of the piles were 3-piles for the all tests in 2nd phase. The different setup of piles for the 2nd phase was presented in Figure (1D).

4. Results

4.1 Phase one

The 1st phase of the measurements includes surveys of the effect of the comparative summation areas of the incomplete circular piles A/Δ on the features of the free H. jump. The results are plotted in figures (2 to 10). The relationships between the different features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus the factor defined by Froude (F) for the value of the comparative summation areas of the incomplete circular piles A/Δ=6.72 as shown in Figures (2, 3 and 4).

It is clear that, the measurements are fitted efficiently using the proposed curves with the minimal R^2=88.3%. The relationship between the different features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus (F) for A/Δ=3.91 as shown in Figures (5, 6 and 7). It is clear that, the measurements are fitted efficiently using the proposed curves with the minimal R^2=95.6%. The relationship between the different features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus (F) for A/Δ=2.44 as shown in Figures (8, 9 and 10). It is clear that, the measurements are fitted efficiently using the proposed curves with the minimal R^2=98.1%.

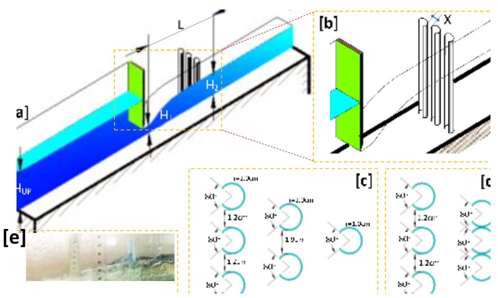

Figure 1: [a] the isometric of the laboratory model [b] the used incomplete circular piles [c] the different arrangements of incomplete circular piles for the first phase stage of the work. [d] the different arrangements of piles for the second phase of the work [e] a photo for the model.

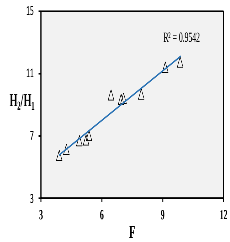

Figure 2: The relationship between $\frac{H_2}{H_1}$ and F for A/Δ=6.72

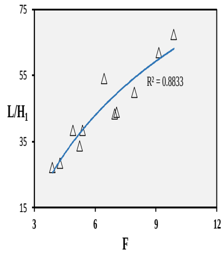

Figure 3: The relationship between $\frac{L}{H_1}$ and F for A/Δ=6.72

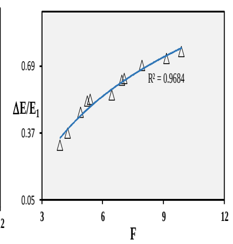

Figure 4: The relationship between $\frac{\Delta E}{E_1}$ and F for A/Δ=6.72

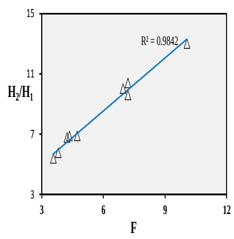

Figure 5: The relationship between $\frac{H_2}{H_1}$ and F for A/Δ=3.91

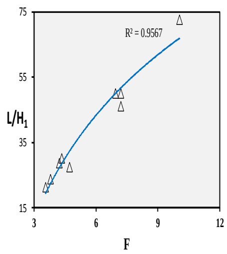

Figure 6: The relationship between $\frac{L}{H_1}$ and F for A/Δ=3.91

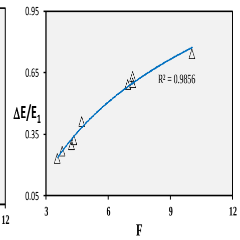

Figure 7: The relationship between $\frac{\Delta E}{E_1}$ and F for A/Δ=3.91

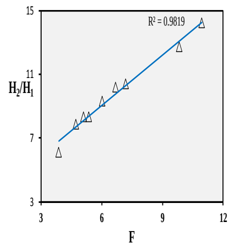

Figure 8: The relationship between $\frac{H_2}{H_1}$ and F for A/Δ=2.44

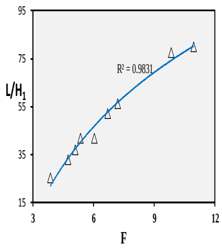

Figure 9: The relationship between $\frac{L}{H_1}$ and F for A/Δ=2.44

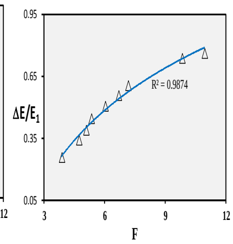

Figure 10: The relationship between $\frac{\Delta E}{E_1}$ and F for A/Δ=2.44

4.2 Phase Two

The 2nd phase measurements surveys of the effect of the comparative distances between the two successive incomplete circular piles $\frac{X}{H_1}$ on the features of the free H. jump. The results are plotted in figures (11,12 and 13). The relationships between the different features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus (F) for X/H_1=0.0 as shown in Figures (11, 12 and 13). It is clear that, the measurements are fitted efficiently using the proposed curves with the minimal R^2=92.7%.

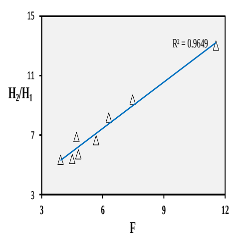

Figure 11: The relationship between $\frac{H_2}{H_1}$ and F for X/H_1=0.0

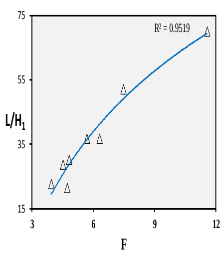

Figure 12: The relationship between $\frac{L}{H_1}$ and F for X/H_1=0.0

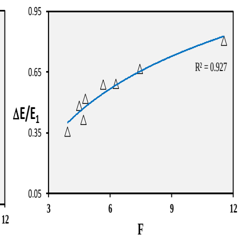

Figure 13: The relationship between $\frac{\Delta E}{E_1}$ and F for X/H_1=0.0

5. Analysis and Discussion

The relationships between the different features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus the factor defined by Froude (F) for the different values of the investigated $\frac{A}{\Delta}$ as shown in Figs (14, 15 and 16). It is clear that, the case of the comparative summation areas of the incomplete circular piles $\frac{A}{\Delta} = 6.72$ gives the smallest values of $\frac{H_2}{H_1}$ and $\frac{L}{H_1}$. In the contrary, it gives the largest values of $\frac{\Delta E}{E_1}$.

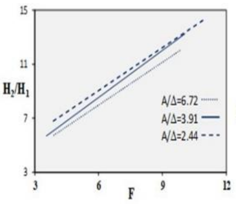

Figure 14: The relationship between $\frac{H_2}{H_1}$ and F for the different investigated values of $\frac{A}{\Delta}$

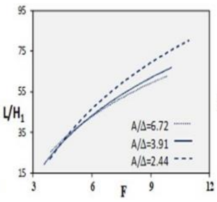

Figure 15: The relationship between $\frac{L}{H_1}$ and F for the different investigated values of $\frac{A}{\Delta}$

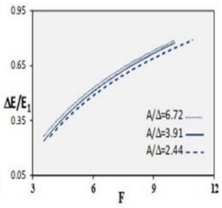

Figure 16: The relationship between $\frac{\Delta E}{E_1}$ and F for the different investigated values of $\frac{A}{\Delta}$

The relationships between the features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus the factor defined by Froude (F) for the different values of the comparative distances between two successive incomplete circular piles $\frac{X}{H_1}$ as shown in Figures (17, 18 and 19). It is clear that, the case of the comparative distances between two successive incomplete circular piles $\frac{X}{H_1} = 0.0$ gives the smallest values of $\frac{H_2}{H_1}$ and $\frac{L}{H_1}$. In the contrary, it gives the largest values of $\frac{\Delta E}{E_1}$.

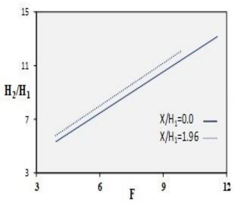

Figure 17: The relationship between $\frac{H_2}{H_1}$ and F for the different investigated values of $\frac{X}{H_1}$

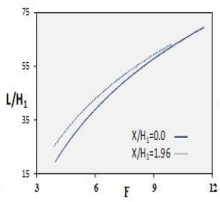

Figure 18: The relationship between $\frac{L}{H_1}$ and F for the different investigated values of $\frac{X}{H_1}$

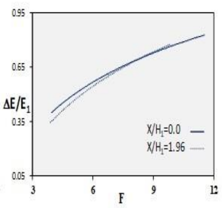

Figure 19: The relationship between $\frac{\Delta E}{E_1}$ and F for the different investigated values of $\frac{X}{H_1}$

The relationship between the features of the studied free H. jumps ($\frac{H_2}{H_1}$, $\frac{L}{H_1}$ and $\frac{\Delta E}{E_1}$) are plotted versus the factor defined by Froude (F) for the traditional free H. jump and the proposed the basin case (A/Δ=6.72 & X/H_1=0.0) as shown in Figures (20, 21 and 22). It is clear that, the case of the proposed the basin case (A/Δ=6.72 & X/H_1=0.0) reduced the comparative height of the free H. jump $\frac{H_2}{H_1}$ by 11.0%. In addition, it reduced the comparative length of the free H. jump $\frac{L}{H_1}$ by24.6%, while it increased the comparative lost energy; $\frac{\Delta E}{E_1}$ by 1.0%.

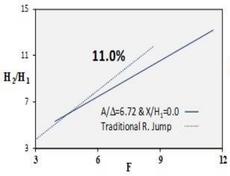

Figure 20: The relationship $\frac{H_2}{H_1}$ and F for the case of (A/Δ=6.72 & X/H_1=0.0) and the Traditional R. Jump.

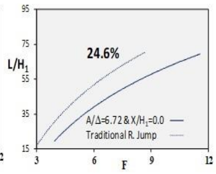

Figure 21: The relationship between $\frac{L}{H_1}$ and F for the case of (A/Δ=6.72 & X/H_1=0.0) and the Traditional R. Jump.

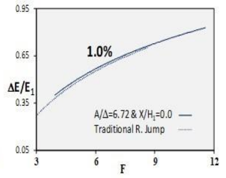

Figure 22: The relationship between $\frac{\Delta E}{E_1}$ and F for the case of (A/Δ=6.72 & X/H_1=0.0) and the Traditional R. Jump.

6. STATISTICAL WORK

The present paper introduced statistical equations for the free H. jump features at the presence of the proposed piles, see equations (2, 3, and 4). The measurements are divided into two-parts. The first is 75% and it was used to build the equations. The second part was used to validate the equations. Figures (23, 24 and 25) present the relationship between the values calculated by Eqs. (2, 3 and 4) and the measurements (the training case). There is a good agreement between the outputs of the three equations and the measurements. The minimal R^2 is 92.6%. Figures (26, 27 and 28) present the relationship between the residuals versus the calculated values by Eq. (2, 3 and 4). It is clear that, the residuals are haphazardly distributed around the zero-line. It indicates that, residuals do not follow a trend.

$$\frac{H_2}{H_1} = 3.154 + 1.078\,F - 0.281\frac{A}{\Delta} + 0.047\frac{X}{H_1} \qquad \text{.......................... (2)}$$

$$\frac{L}{H_1} = 2.358 + 7.333\,F - 1.257\frac{A}{\Delta} + 0.240\frac{X}{H_1} \qquad \text{.......................... (3)}$$

$$\frac{\Delta E}{E_1} = -0.0015 + 0.07\,F + 0.018\frac{A}{\Delta} - 0.0106\frac{X}{H_1} \qquad \text{.......................... (4)}$$

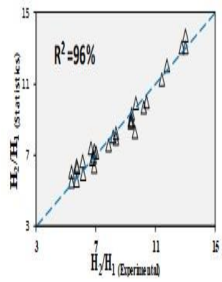

Figure 23: The relationship between the training values of the comparative height of the free H. jump Eq. (2) and the experimental measurements.

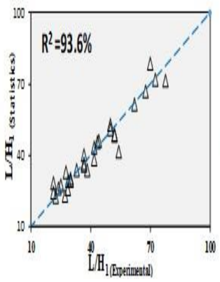

Figure 24: The relationship between the training values of the comparative length of the free H. jump Eq. (3) and the experimental measurements.

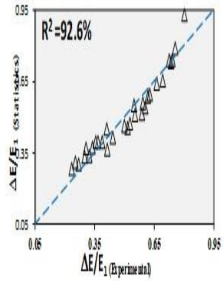

Figure 25: The relationship between the training values of the comparative lost energy Eq. (4) and the experimental measurements.

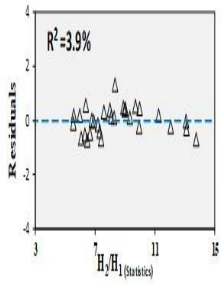

Figure 26: The relationship between the residuals' values versus the statistical training comparative height of the free H. jump Eq. (2).

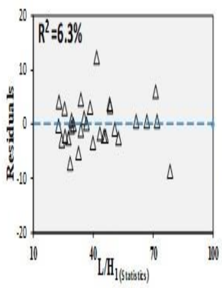

Figure 27: The relationship between the residuals' values versus the statistical training comparative length of the free H. jump Eq. (3).

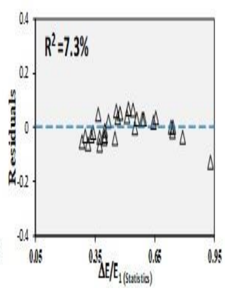

Figure 28: The relationship between the residuals' values versus the statistical training comparative lost energy over the free H. jump Eq. (4).

Figures (29, 30 and 31) present the relationship between the calculated validating values by Eq. (2, 3 and 4) and the experimental measurements. There is a good agreement between the outputs and the measurements. The minimal R^2 is 90.2%. Figures (32, 33 and 34) present the relationship between the residuals versus the validating values of Eq. (2, 3 and 4). It is clear that, the residuals are haphazardly distributed around the zero-line.

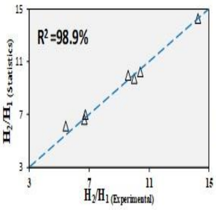

Figure 29: The relationship between the validating values of the comparative height of the free H. jump Eq. (2) and the experimental measurements.

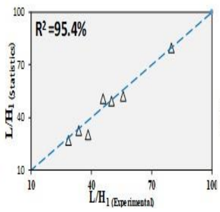

Figure 30: The relationship between the validating values of the comparative length of the free H. jump Eq. (3) and the experimental measurements.

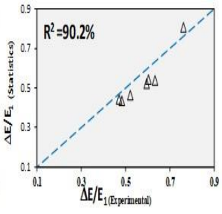

Figure 31: The relationship between the validating values of the comparative lost energy Eq. (4) and the experimental measurements.

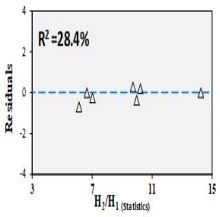

Figure 32: The relationship between the residuals' values versus the statistical validating comparative height of the free H. jump Eq. (2).

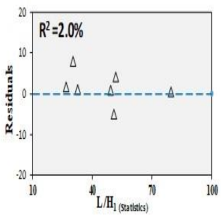

Figure 33: The relationship between the residuals' values versus the statistical validating comparative length of the free H. jump Eq. (3).

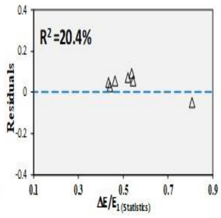

Figure 34: The relationship between the residuals' values versus the statistical validating comparative lost energy Eq. (4).

7. Conclusions and Recommendations

The measurements and results of the present work indicated the following conclusions:

- The case of the comparative summation areas of the incomplete circular piles $\frac{A}{\Delta} = 6.72$ gives the smallest values of $\frac{H_2}{H_1}$ and $\frac{L}{H_1}$. In the contrary, it gives the largest values of $\frac{\Delta E}{E_1}$.
- The case of comparative distances between the two consecutive incomplete circular piles $\frac{X}{H_1} = 0.0$ gives the smallest values of $\frac{H_2}{H_1}$ and $\frac{L}{H_1}$. In the contrary, it gives the largest values of $\frac{\Delta E}{E_1}$.
- The proposed case of the incomplete circular piles (A/Δ=6.72 & X/H_1=0.0) reduced the comparative height of the free H. jump $\frac{H_2}{H_1}$ by 11.0%. It reduced the comparative length of the free H. jump $\frac{L}{H_1}$ by24.6% and it increased the comparative lost energy over the free H. jump $\frac{\Delta E}{E_1}$ by 1%.
- The developed statistical equations for the free H, jump features at the presence of the incomplete circular piles, are efficient to represent the measurements with the minimal R^2 = 90.2%.

The showing laboratory works may indicate to the following recommendations for the future work. It can be abbreviated as the followings:

- Investigation of the submergence ratios effect of the incomplete circular piles,
- Investigation of the percentage effect of the removed part of the incomplete circular piles,
- Investigation of the shape effect of the incomplete circular piles.

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