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Studying The Effect of Triangular Sill on Hydraulic Jump

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الملخص العربى :

تعتبر القفزة الهيدروليكية واحده من أفضل وسائل الطاقة حيث تقلل السرعات العالية فوق الفرش لتصل بها إلي سرعه مأمونة تعمل علي استقرار المجري خلف منشآت الري. ويهدف البحث إلى تحديد أنسب موقع للعتب لتحقيق أقل طول للقفزة الهيدروليكية باستخدام أعتاب مثلثية الشكل. حيث أجريت التجارب على نموذج لعتب على شكل مثلث على بعد نسبى عن البوابة (X/L) = (0.70 – 0.60 – 0.50 – 0.40) وتم دراسة تأثير هذه النسب على تخفيض طول القفزة الهيدروليكية ، كما أجريت التجارب مرة أخرى فى عدم وجود العتب للمقارنة . وقد تمت هذه التجارب فى معمل الهيدوليكا – بكلية الهندسة – جامعة الأزهر بالقاهرة وأجريت علي قناة مربعه بقطاع (30 سم ×30 سم) وطول 4.00م ذات جوانب رأسيه شفافة .وقد تم إستخدام جهازين موجات فوق صوتيه لقياس مناسيب وأعماق المياه . وتم تحليل تلك القياسات وتمثيلها بيانيا. كما تم مناقشتها. وقد تم الوصول فى هذا البحث الي تحقيق أقل عمق (Y_1) وأقصى عمق (Y_2) عندما تكون النسبة (X/L) = 0.50. كما يتناقص طول القفزة الهيدروليكية (L_j) عندما تكون نسبة 0.40 = (X/L). كما أن النسبة (Y_2/Y_1) تنخفض عنما تكون نسبة موضع العتب (X/L) = 0.50.

ABSTRACT:

The hydraulic jump is one of the best means of energy consumption as it reduces the high velocity above the apron to reach a safe velocity that stabilizes the stream behind the irrigation structures. The research aims to determine the most appropriate site for the lintel to achieve the least length of the hydraulic jump using triangular sills. This was achieved by carrying out experiments on a model with a triangular shape placed at a relative distance from the gate (i.e. X / L = 0.40, 0.50, 0.60, 0.70) to investigate the impact of these ratios in reducing the hydraulic jump length. For comparison purposes, trials were conducted without any sill. The experiments were carried out in the Hydraulic Laboratory of the Faculty of Engineering - Al-Azhar University in Cairo. The experimental channel is 4.0m long and is of a squared cross-section (30 cm × 30 cm) with transparent vertical sides equipped with two ultrasounds, one mono, and the other multi to measure the levels and water depths as well as the levels and depths of the channel bottom. The research concluded that the maximum increase in the initial water depth Y1 and maximum decrease in the tailwater depth Y_2 were achieved at (X/L) = 0.50. the relative length of jump L_j/Y_1 decreases as the relative sill position X/L decreases till it reaches the value X/L =0.40. the relative Y_2/Y_1 decrease as the relative sill position X/L decreases till it reaches the value X/L = 0.5.

KEYWORDS:
Hydraulic Jump, Control of Jump, Energy Dissipations, Sills.

1. INTRODUCTION

One of the most common examples of rapidly fluctuating flows is the hydraulic jump. This happens when a supercritical flow transitions to a subcritical flow, which is necessary to preserve the regime conditions in mobile boundary channels. Due to the constrained waterway and strong hydraulic gradient, which causes the water to quickly transition from low stage to high stage, water flowing through sluice gates or over spillways has an extremely high velocity. Water surface pileup occurs quickly as a result. This local phenomenon is known as the hydraulic jump. Thus, the hydraulic jump is one of the most common examples of quickly varying flows. When a supercritical flow transitions to a subcritical flow, which is necessary to preserve the regime conditions in mobile boundary channels, this happens.

This study used experimental methods to examine the hydraulic effectiveness and efficiency of using a triangular sill. The experimental study was conducted in a glass wall flume of a length of 4 m. Four relative distances (X / L= 0.40, 0.50, 0.60 and 0.70) were examined.

Primarily, literature was reviewed. Then theoretical and experimental investigations were conducted. Results were analyzed and discussed. Based on this analysis, conclusions were deduced, and recommendations were given forward. This is presented in this paper under the following headlines:

- Literature Review
- Theoretical investigation
- Experimental Investigation
- Analyzing, presenting, and discussing the results
- Conclusions and recommendations

2. LITERATURE REVIEW

Many researchers investigated the required length to ensure the safety of the foundation of the hydraulic structures. Among them, for example, are the following:

V. K. Safranez [24] observed that the hydraulic jump in the narrower flume was noticeably shorter than that in the broader flume. The length of the hydraulic jump was thus shown to be unaffected by friction. He suggested the following formula to determine the hydraulic jump's length:

$$L_j = 5.2Y_2 \tag{1}$$

Where;

Lj is the hydraulic jump's length.

In 1936, Bakhmetef and Matzke [11] constructed a project in the hydraulic laboratory of Colombia University to determine the general relationships that apply to hydraulic jumps of every size and nature. The investigators arrived at the same conclusion made by Safranez. The following equation was suggested to calculate the jump's length:

$$L_j = (Y_2 - Y_1) \tag{2}$$

The U.S. Bureau of Reclamation conducted a series of measurements in 1954 to establish the hydraulic jump's length [13]. Froude's number ranged in these tests from 2 to 20. An examination of the experimental data revealed a strong correlation between the hydraulic jump's length and height, with the length being 6.90 times the height.

$$L_j /(Y_2 - Y_1) = 6.90 \tag{3}$$

In 1957, Bradley, J. N., and Peterka, A.J. [12] carried out several tests to connect the Froude's number to the hydraulic jump and stilling basin designs. This number has been correlated with the conjugate depth ratio, the jump length, the expected jump type, and the losses involved. The main benefit of this kind of presentation is that it allows for quick and easy calculation-free viewing of the complete picture.

In 1964, Richard Silvester [25] developed a relationship to describe the length of the hydraulic jump in a smooth horizontal bed of rectangular channels. He conducted several tests and investigations to get out all parameters or constants that are in the numerical relationship.

After he studied his experimental results and investigations, he gave a relationship in the following form:

$$L_j / Y_1 = 9.75(F_1 - 1)1.01 \tag{4}$$

In 1965, Rajaratnam, N. [22] offered research on the submerged hydraulic jump as the situation of an opposing pressure gradient and turbulent water jet with the upward flow in the water. An approach has been developed to forecast the surface profile, the fall of the pressure plus momentum, and the energy in the submerged hydraulic jump using the experimental results of the author for the forward flow and those of Liu and Henry for the backward flow. Also studied was the boundary shear stress, which was determined using a Preston tube.

In 1970, Sharp [26] presented a non-dimensional design as a diagram for the determination of conjugate depths of a hydraulic jump in parabolic channels. The chart provides a simple and direct method of determining the upstream or downstream conjugate depth in a channel of a known cross-section.

In 1973, Sarma, K.V.N., and Newnham, D.A [25] used their laboratory in experiments to evolve equations and graphs in the design of optimum surface profiles in rectangular, horizontal channels as for Froude’s numbers below four. The results of the experimental study showed that at low Froude’s numbers energy loss in the hydraulic jump is considerably reduced.

In 1977, Ali, K.H.M., and Ridgway, A [9] established theoretical relationships between the initial and subsequent depths as functions of the first Froude's number for a hydraulic jump in trapezoidal and triangular channels. The effects of friction and velocity dispersion were taken into consideration. The distributions of pressure and water profiles were measured in great detail. We acquired the velocity distributions upstream and downstream of the jump as well as along its length. A general design diagram was offered for the hydraulic jump solution. The effectiveness of several strategies for defining jump length was examined.

In 1984, Isaacs, L. T. [17] described a computer program for composite backwater profiles in a trapezoidal channel. Its feature includes the u**se** of accurate numerical integration. identification of potential controls and location of hydraulic jumps. The program has practical applications in teaching, research, and design.

In1987, Pavlov, B. A. [21] created a mathematical model using the statistical techniques of experimental design theory and Buckingham's theory. This model takes the form of a regression equation and links the Froude's number of the flow coming onto the hydraulic jump, the first conjugate depth, the average velocity of the oncoming flow, the acceleration of gravity, and the kinetic energy correction factor, has been used to calculate the length of a direct hydraulic jump in a prismatic rectangular horizontal channel.

In 1989, Hager, Willi H [15] the U-shaped conduits that the hydraulic jump used were described. There are slight variations in flows in U-shaped and circular channels based on the subsequent depth’s ratio. There are several different surface profile kinds covered. The hydraulic jump has a normalized length of around Lj/h2=61. The findings relating to the internal leap phenomenon are the most intriguing. A clear bottom separation can be seen at shallow relative inflow depth Y1. There are descriptions of several flow zones and typical axial velocity distributions. This peculiarity's application to stilling basins with brief protected bottom lengths is examined. Larger Y_1 exhibit a flow pattern that resembles hydraulic leaps in channels.

Mohamed S. Abedelmoaty and Mahmoud Zayed [27] employed side flow jets downstream of a sluice gate as a scour prevention strategy. The findings demonstrated that the local scour hole characteristics and energy dissipation were significantly influenced by the side flow jets. Due to improved energy dissipation, side flow jets were used to lower the scour hole by around 11, 16, and 25% for scour depth, 9, 13, and 15% for scouring length, and 19, 31, and 40% for scouring volume at jet angles of = 90°, 120°, and 150°, respectively.

3. THEORETICAL INVESTIGATION

In this research, a theoretical study was executed.

The analysis of the free hydraulic jump using different sill positions is developed theoretically by two methods, Dimensional analysis, and the Macroscopic approach

DIMENSIONAL ANALYSIS

Fig. (1) defines the variables used in dimensional analysis and are classified into three groups as follows:

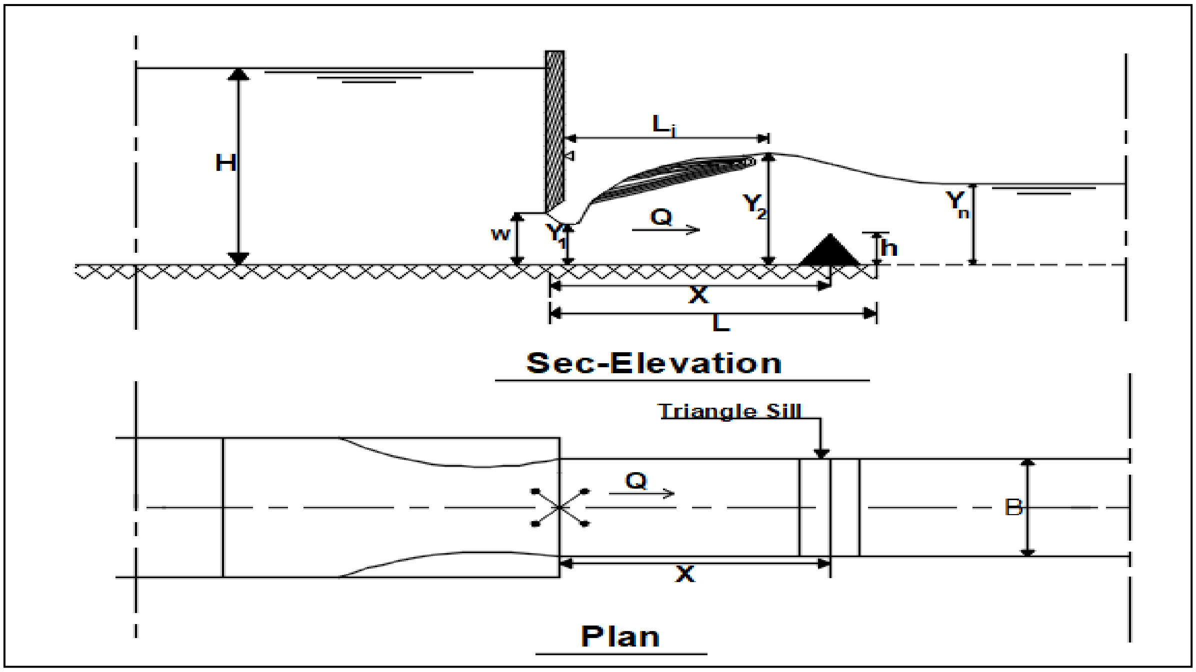

Figure (1) Definition Sketch

<u>Geometric Characteristics</u>

X = Distance from the vertical gate at the outlet to the summit of the triangular sill,

W= Gate opening.

B = Flume width (sill width).

L = Length of the apron.

h =Height of sill.

Flow characteristics

Y_1 = Initial water depth, Y_2= Sequent depth, q = (Q/B) discharge passing per unit width of flume, Lj = Length of hydraulic jump and V = Velocity value at any section.

Fluid properties

ρ = Mass density, g = Gravitational acceleration and μ = Dynamic viscosity

The general functional relationship between the above variables can be written

$$f(q, B, L, h, Y_1, Y_2, L_j, V, X, g, \mu, p) = 0 \tag{5}$$

In order to find the dimension analysis between above variable we will be used the dimension analysis system. This system according to Buckingham π theory and we can get the following equation:

$$f\left(\frac{X}{L}, \frac{L_j}{X}, \frac{Y_1}{Y_2}, \frac{h}{B}, \frac{q}{vX}, F_r, R_n\right) \tag{6}$$

3.EXPERIMENTAL INVESTIGAT

Experiments were conducted in the hydraulic laboratory of the Faculty of Engineering, AL Azhar University. The experimental equipment includes the flume, sluice gate, tailgate, and measuring carriage. Also, devices for measuring discharge, water depths, surface water profiles, and horizontal distances were used.

The dissipater sill was a triangular sill from steel with a height of 3cm and 2 cm in width. The triangular sill was placed in the channel bed in a concave position in the flow direction.

EXPERIMENTAL EQUIPMENT

The flume has a rectangular cross-section 30 cm.x30 cm. 4.0m long, made of steel truss provided with glass sides. The shape and main dimensions of the flume are shown in Fig. (2) as well as Photos (1).

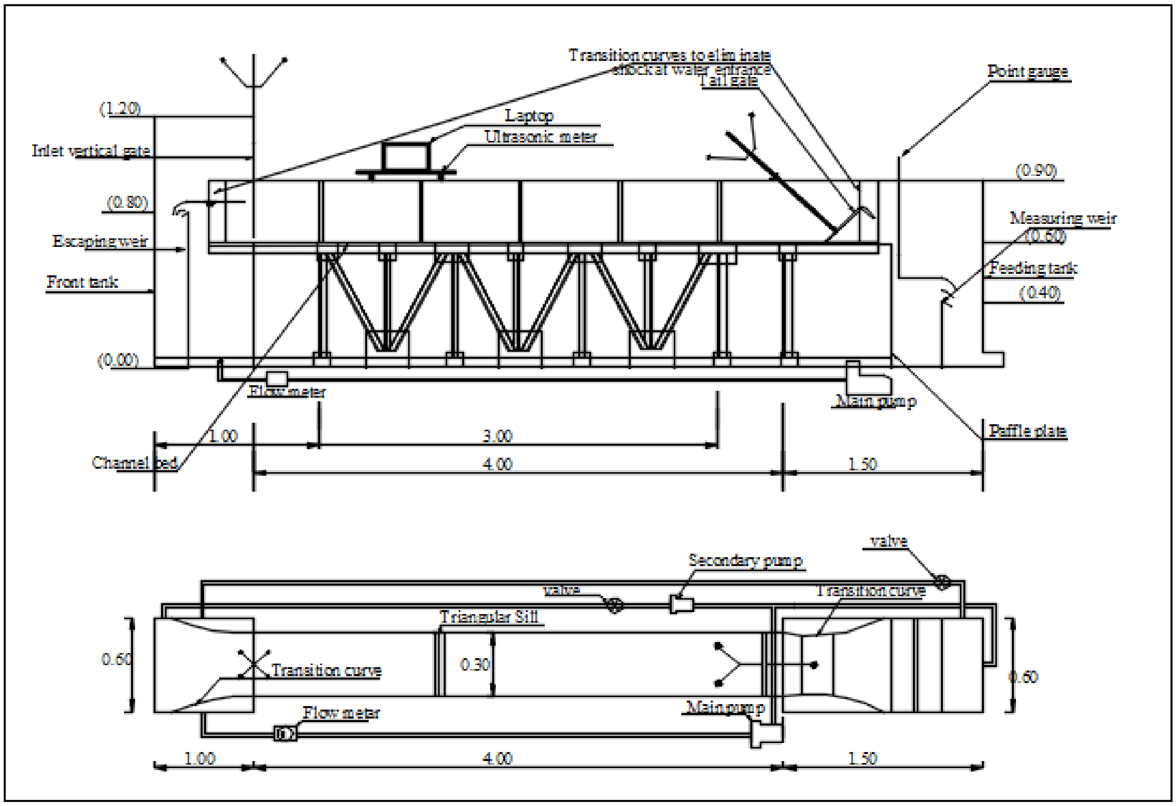

Figure (2) Experimental Channel

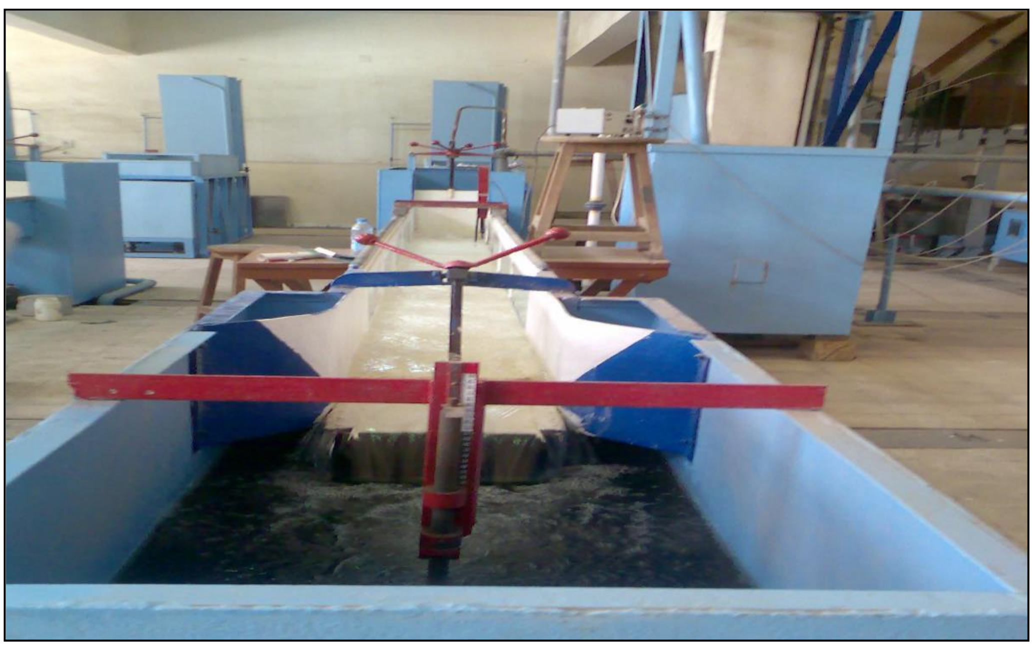

Photo (1)

The Feeding Tank

Water is allowed into the channel through a vertical gate from a feeding tank. This tank is provided with an overflow weir that maintains a constant head upstream of the gate.

The Collecting Tank

Water flowing over the tailgate is collected in a collecting tank provided with a well-calibrated rectangular sharp crested weir.

The Tail Gate

The downstream depth is adjusted using a tailgate located at the end of the flume.

The Sluice Gate

A sluice gate nearly at the end of the inlet part is fitted vertically.

The Measuring Carriage

A carriage is constructed to facilitate the measurement of water depths. It is composed of point prop supported on four wheels carrying a steel frame and running on two steel bar tracks fixed over the top angle of the flume.

Supply of Water to the System

Water is supplied to the system through the 2-in diameter perforated pipes at the bottom of the feeding tank.

TESTED MODEL

The dissipater sill used was a triangular shape made of steel with dimensions 3 cm and 2cm in width. The model was placed at the positions relative to the inlet gate, at distances X/L = 0.4, 0.50, 0.60, and 0.70 respectively. At this location, all the hydraulic jump characteristics were measured and related in curves and charts. The flow characteristics also included the head over the sill and the discharge flow. Different values of the gate opening, and accordingly, values of discharge were tried within the range allowing the hydraulic jump formation under the condition of free flow downstream of the gate and the formation of a stabilized jump.

Waterproofing with rubber and consolable paste was provided at the side and under the sill to ensure that water flows only over the sill.

As mentioned before, four tests were carried out using the triangle sill positions with five gate openings (1.0, 1.5, 2.0, 2.5, 3.0cms) and consequently five Froude Number (F_{r2}) varying from 0.15 to 0.35.

5. ANALYSIS, PRESENTING, AND DISCUSSING THE RESULTS

Twenty-five (25) experiments were executed to four (4) different relatives (X/L) = (0.40 - 0.50- 0.60 - 0.70) using five (5) different discharges. The following conclusions are related to the experimental studies made using five gate openings and four sill positions.

5.1 WATER SURFACE PROFILES

The study of the jump's water surface profiles shows that as the jump reaches the beginning of the sill, the initial water depth Y_1 increases while the tailwater depth Y_2 decreases. as shown in figures (4) to (13). The height of the hydraulic jump was increased by the maximum difference between Y_1 and Y_2, As the same cases whenever changing the height of the gate opened to 1.5, 2, 2.5, and 3 cm the values of Y_1 increased and Y_2's normal water level increased respectively because of the water flow regimes changed from supercritical flow to subcritical flow at normal water height. Comparing the water surface profiles for different positions, we can see that both the length of jump and the tailwater depth decrease whenever the sill moves towards the opening gate.

5.2 THE RELATIVE JUMP LENGTH L_j/X

As shown in Figure (14), the relation between F_{r2} at normal water height with the subcritical flow and relative depth of jump length L_j/X explained that the Froude number increased respectively increasing in the relative depth of jump length, all runs conducted with values of Freud numbers range from 0.15 to 0.35

5.3 THE RELATIVE DEPTH Y_2/Y_1

Refer to figure (15) the relation drawn between conjugated depth and F_{r2}, the curves explained that whenever, the values of conjugated depth increased also the values of Freud number increased, the conjugated depth effect by changing of flow regimes from supercritical flow at the close of the gate and subcritical flow at normal water height, the distance ratio of X/L at 0.40 was the best effect on decreasing the jump length and values of Froude number.

5. CONCLUSIONS .

Based on the above investigation phases, In general, the conclusions are as follows:

- The triangular sill form possesses a reasonable ability to a reduction in the length of the jump.
- The best position of triangular sill decreasing the length of the jump at ratio, X/L was 0.40 distance measured from the gate to the sill.
- The position of triangular sill X/L decreases the relative depth of L_j/X at X/L 0.40.
- The position of triangular sill X/L decreases the conjugated depth of Y_1/Y_2 at X/L 0.50.

Based on the above, the following recommendations were foreseen and are given, as follows:

- Other innovative sill forms are to be investigated and tested.
- The ratio between the base of a triangle and its height to be investigated and tested.
- A relative position of the sill, Froude number, and discharge is to be tested**.**

6. LIST OF REFERENCES

1. Abdel-Azim M. Negm and Others: "Effect of Asymmetric Side Sill on Scour Characteristics Downstream of Sudden Expanding Stilling Basins". Faculty of Engineering, Zagazig University, Zagazig, Egypt, 2003.

2. Abdel-Azim M. Negm and Others: "Effect of Location of Negative Step on Hydraulic Characteristics of Jump in Radial Stilling basins Under Free Flow Conditions" Faculty of Engineering, Zagazig University, Zagazig, Egypt, 2003.

3. Abdel-Azim M. Negm and Others: "Effect of Supercritical Flow on Scour Characteristics Downstream of Sudden Expanding Stilling Basins". Faculty of Engineering, Zagazig University, Zagazig, Egypt, 2003.

4. Abdel Lateef M.: "Energy Dissipation D.S. Low Head Irrigation Structures Using Bed Rougheness". Unpublished Ph.D. Thesis, Ain Shams University, Cairo, Egypt, 1984.

5. Abdel Lateef M.: "Investigate Floor Jets for the Case of the Submerged Jump". Unpublished, Ain Shams University, Cairo, Egypt, 1994.

6. Aboul Atta N.: “Hydraulic Jump Controlled By Jets” Unpublished Ph.D. Thesis, Ain Shams University, Cairo, Egypt, 1990.

7. Aboul Atta N.: “Radial Free Jump Controlled by Jets Downstream Low Head Hydraulic Structures”. Bulletin of the Faculty of Engineering, Ain Shams University, Vol. 29, No 1, March 1994, pp.79-95.

8. Aboul Atta, N.: "Study of the Effect of Location and Length of Roughened Beds on Flow Characteristics in Stilling Basins", Unpublished M.Sc. Thesis, Ain Shams University, Cairo, Egypt, 1986.

9. Ali, K.H.M., and Ridgway, A.: "Hydraulic Jumps in Trapezoidal and Triangular Channels". University of Liverpool, England, Proc. Inst. Of Civil Engineering, London. V.63, pt.2 March 1977, pp. 203-214.

10. Baines, W. D., Peterson, E. G. (1951): “An Investigation of Flow through Screens.” Transactions of the ASME, Vol. 73, No. 5, 467-480.

11. Bakhmeteff, B.A., and Matzke A.E.: "The Hydraulic Jump in Terms of Dynamic Similarity". Transactions ASCE, 1936.

12. Bradley, J. N., and Peterka A.J.: “The Hydraulic Design of Stilling Basins and Hydraulic Jumps on a Horizontal Apron”. Journal of The Hydraulic Division, ASCE, Vol. 83, no.HY5, Oct. 1957.

13. Bureau of Reclamation, U.S. Dept, of the Interior: "Hydraulic Design of Stilling Basins and Bucket Energy Dissipators". Monograph No. 25, Washington, D.C. 1958

14. Hager, Willi H.: "Hydraulic Jump in U-Shaped Channels". Journal of the Hydraulics Division, ASCE, Vol. 115, No. 5, May 1989, pp. 667-75.

15. Hager, Willi H.: "Hydraulic Jump in Non-Prismatic Rectangular Channels". Journal of Hydraulic Research Vol. 23, No. 1, 1985, pp. 21-35.

16. Hager, Willi H.; Basler, Bruno and Wanoschek, Robert: "Incipient Jump Condition for Ventilated Sill Flow". Journal of Hydraulic Engineering, Vol. 112, No. 10, Oct. 1986, pp. 953-63.

17. Isaacs, L. T.: "Calculation of Composite Backwater Profiles in Channels of Trapezoidal Cross-Section". National Conference Publication, Institution of Engineers, Australia No. 84/7, pp. 13-16.

18. Mostafa Ali "The Efficiency Of Using Parabolic Sill As An Energy Dissipation Tool Downstream Hydraulic Structures". M.Sc.Thesis. Al-Azhar University, Faculty Of Engineering, Cairo, Egypt. 2004.

19. Mostafa Ali: "The Using Aprons Of Formed Surfaces As Energy Dissipaters Down Stream Hydraulic Structures". Ph.D. Thesis. Al-Azhar University, Faculty Of Engineering, Cairo, Egypt. 2008.

20. Mahmoud Saad:" Unconventional Submerged Sills As Energy Dissipaters Downstream Hydraulic Structures". M.Sc. Thesis. Al-Azhar University, Faculty Of Engineering, Cairo, Egypt. 2008.

21. Pavlov, B. A.: "Length of a Direct Hydraulic Jump". Hydrotechnical Construction Vol. 21, No. 4, April 1987, p. 198.

22. Rajaratnam, N.: "Submerged Hydraulic Jump". Journal of the Hydraulics Division, ASCE, Vol. 91, No. HY4, Proc. Paper 4403, July 1965, pp. 71-96.

23. Richard Silvester: "Hydraulic Jump in All Shapes of Horizontal Channels". Journal of Hydraulics Division, ASCE, Vol. 90, No. HY1, January 1964.

24. V. K. Safranez., Stilling Basin Design for Low Froude's Number, Journal of the Hydraulics Division.

25. Sarma, K.V.N., and Newnham, D.A.: "Surface Profiles of Hydraulic Jump for Froude's Numbers less than Four". Indian Institute of Science, Bangalore. Water Power Vol.25, No.4, April 1973, pp. 139-42.
Sharp, J. J.: "Hydraulic Jump in Parabolic Channels". Water Power Vol. 22 No. 7-8
July-Aug. 1970, pp. 265-67.

26. Sharp, J. J.: "Hydraulic Jump in Parabolic Channels". Water Power Vol. 22 No. 7-8 July-Aug. 1970, pp. 265-67.

27. 27._Mohamed S. Abedelmoaty and Mahmoud Zayed:: "Using side flow jets as a scour countermeasure downstream of a sluice gate". Beni-Suef University Journal f Basic and Applied Science, (2021) 10:88.

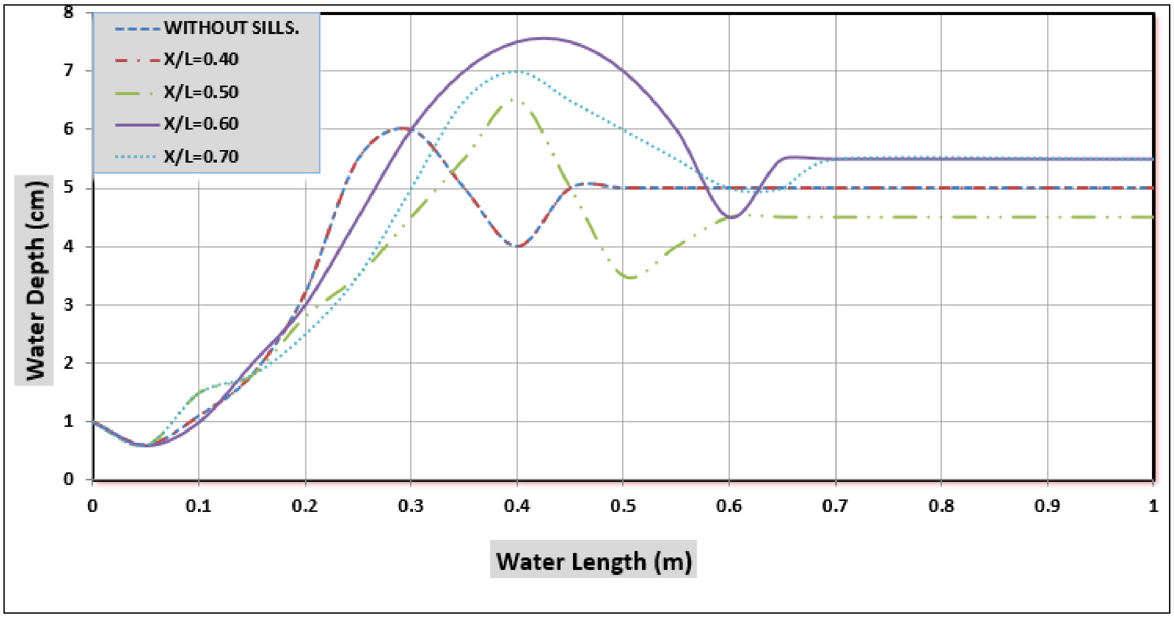

Figure (4) Changing of water surface profile at different sill positions at W = 1 cm

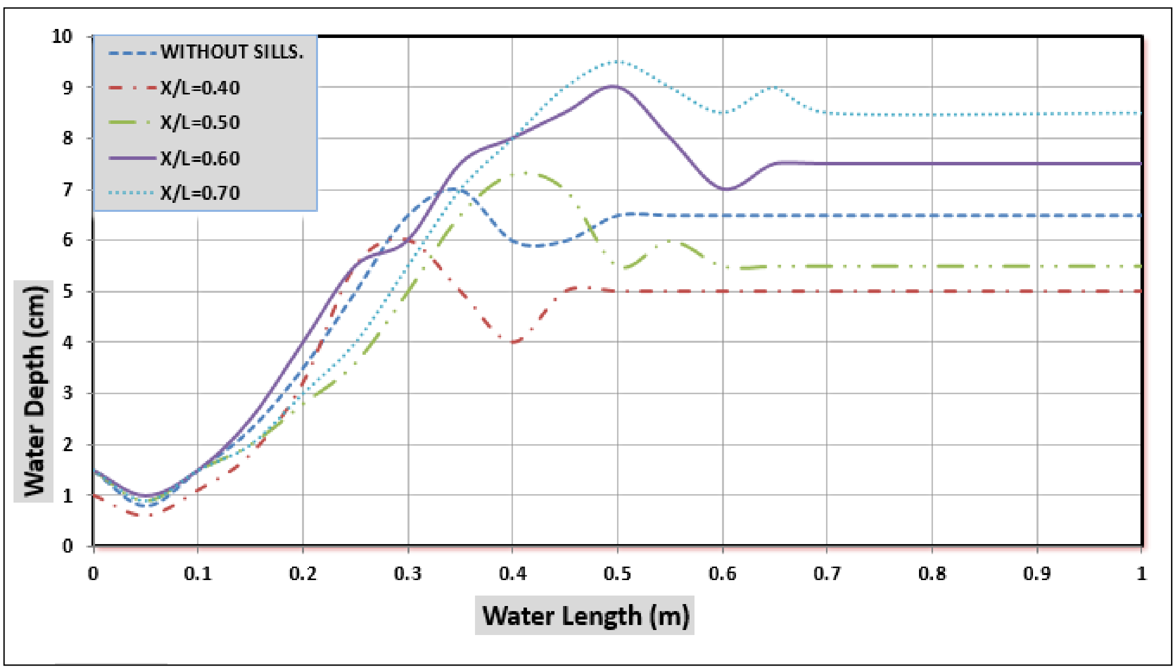

Figure (5) Changing of water surface profile at different sill positions at W = 1.5cm

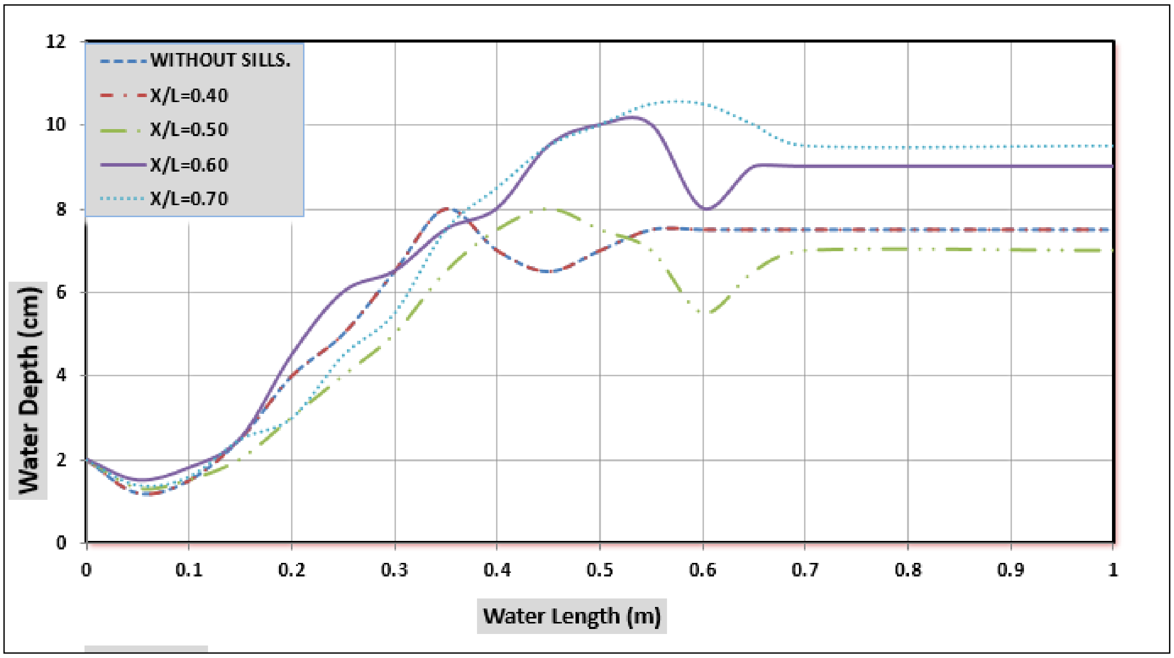

Figure (6) Changing of water surface profile at different sill positions at W = 2 cm

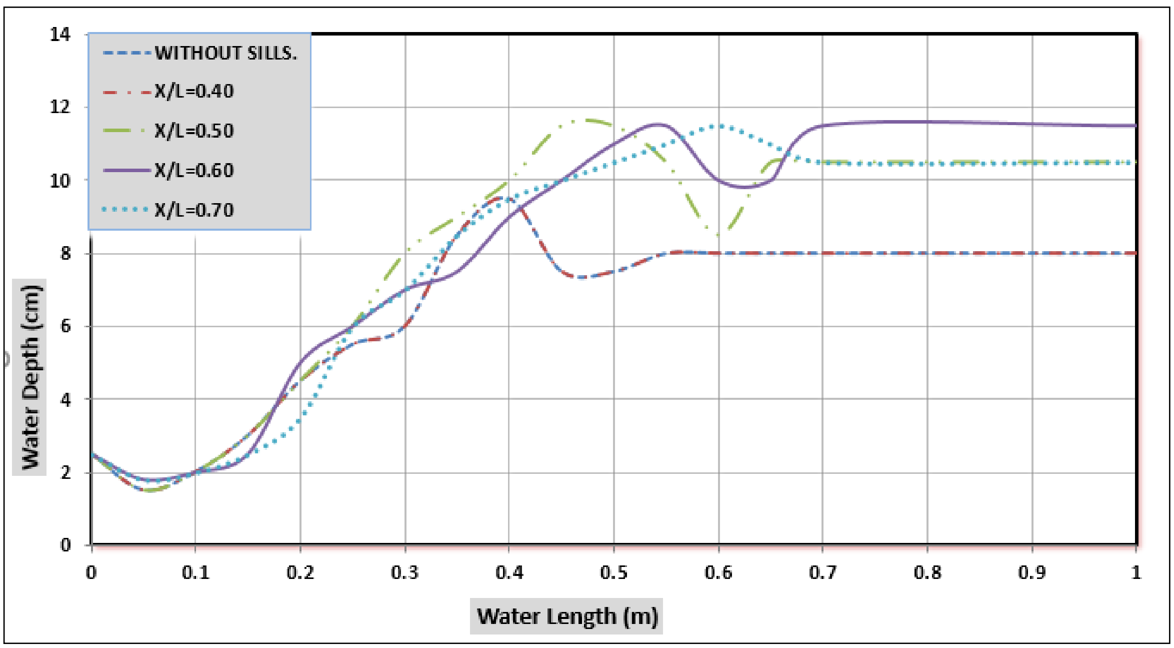

Figure (7) Changing of water surface profile at different sill positions at W = 2.50 cm

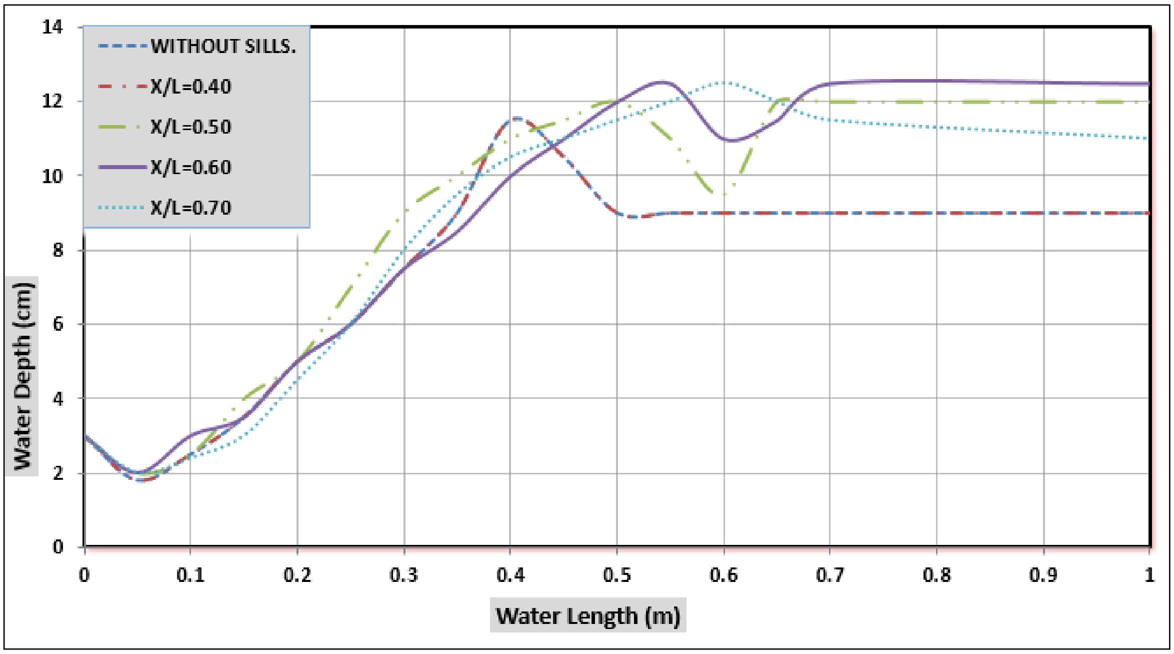

Figure (8) Changing of water surface profile at different sill positions at W = 3cm

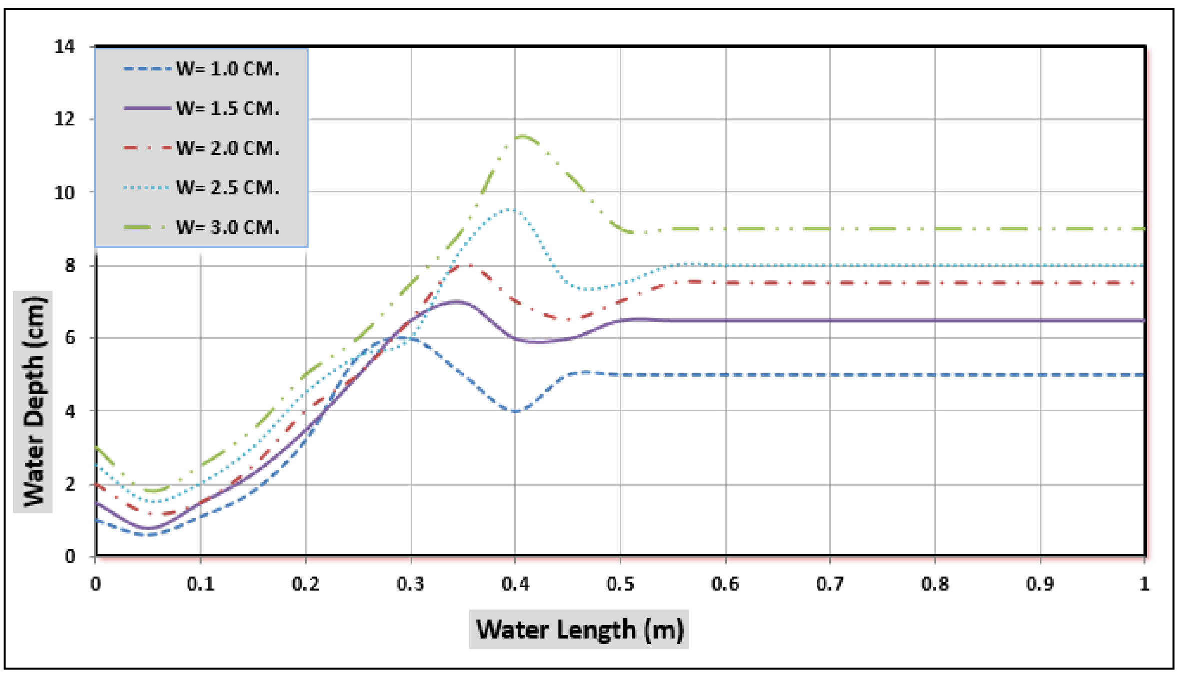

Figure (9) Changing of water surface profile without sill

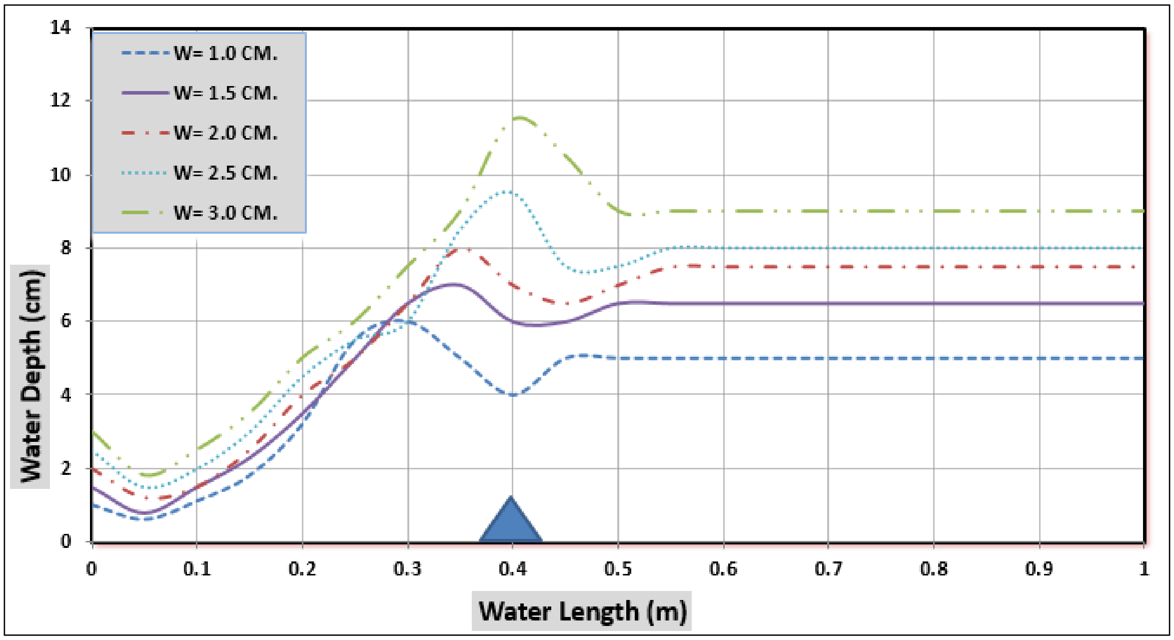

Figure (10) Changing of water surface profile at different sill positions at (X/L = 0.40)

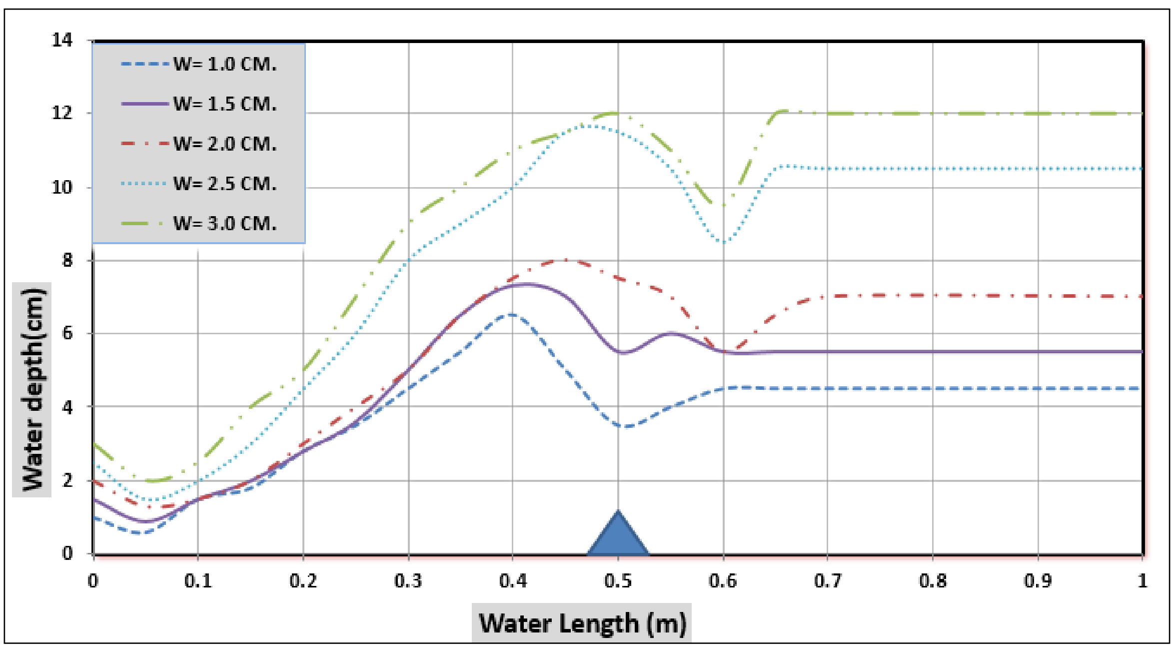

Figure (11) Changing of water surface profile at different sill positions at (X/L = 0.50)

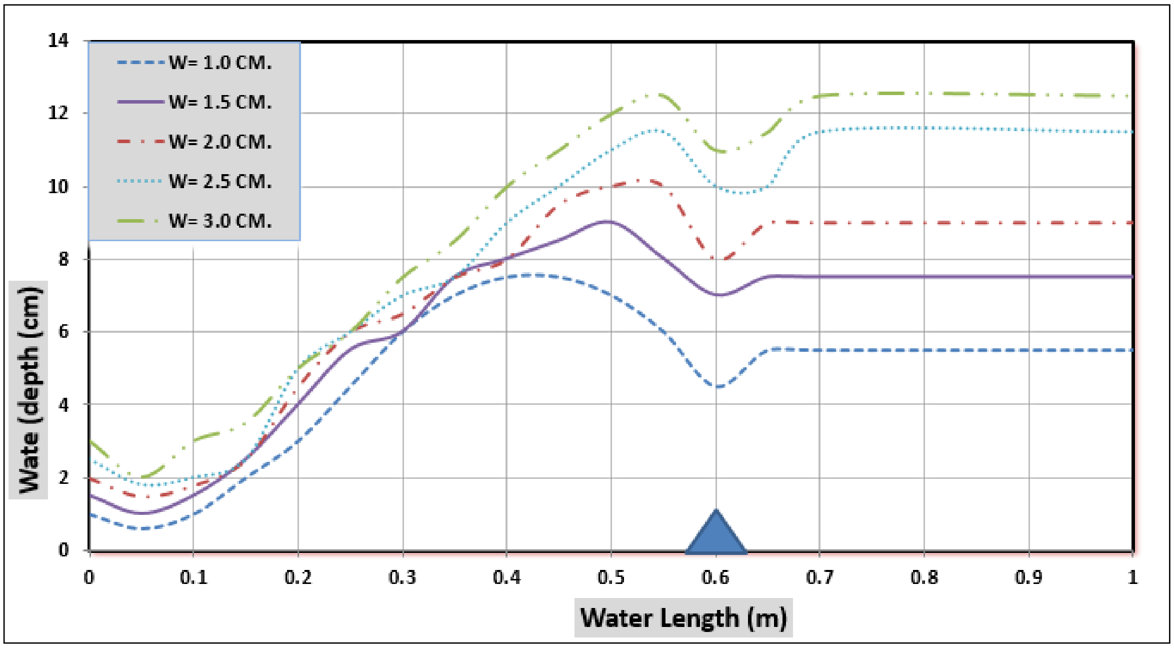

Figure (12) Changing of water surface profile at different sill positions at (X/L = 0.60)

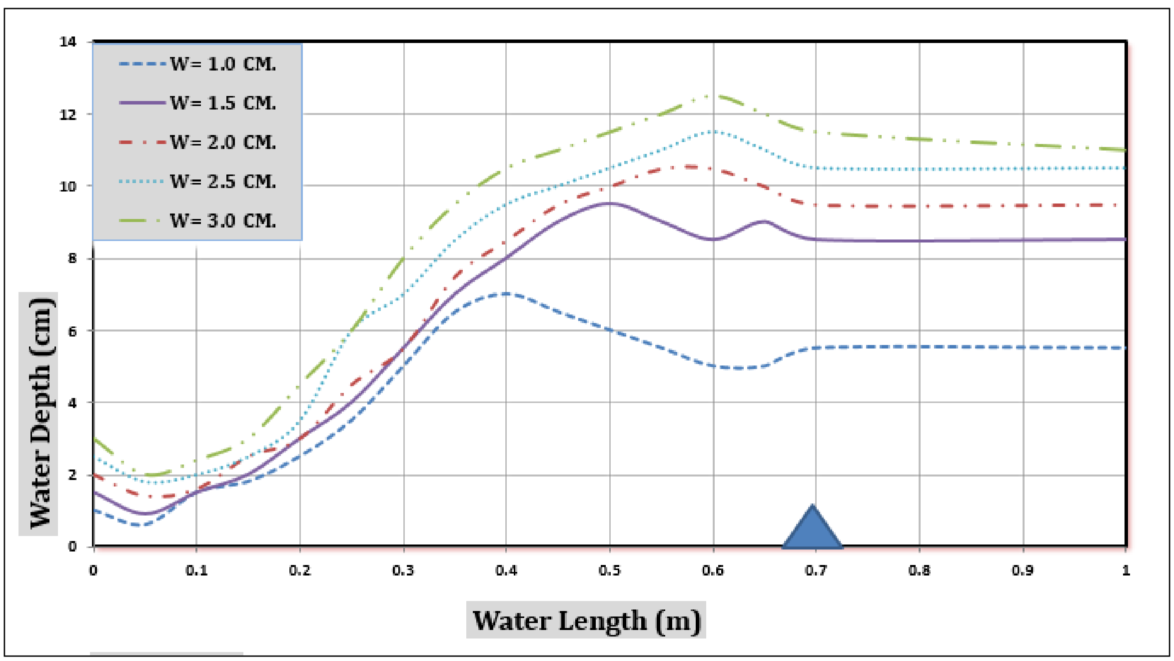

Figure (13) Changing of water surface profile at different sill positions at (X/L = 0.70)

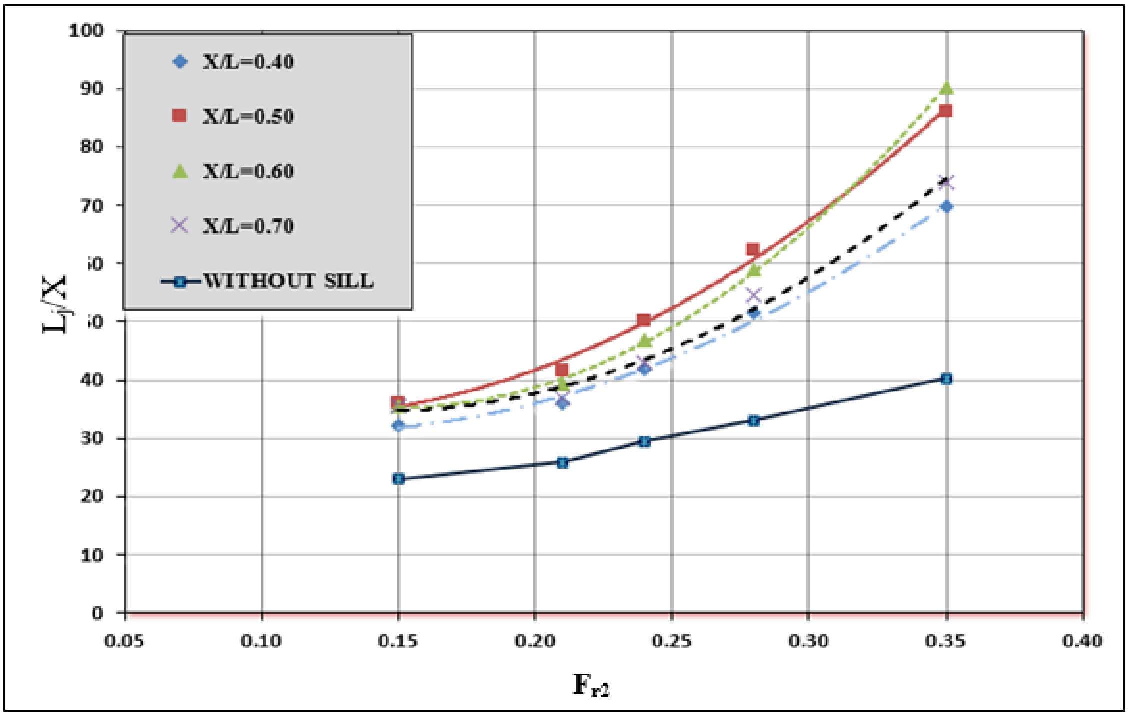

Figure (14)).Relation between (F_{r2}) and (L_j/X)

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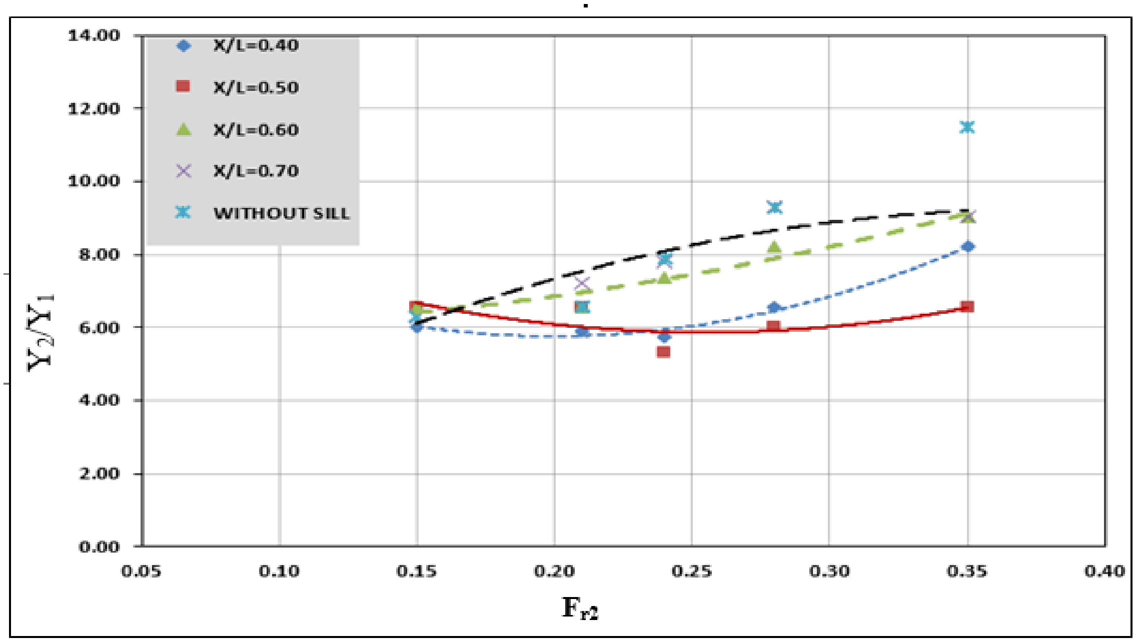

Figure (15).Relation between (F_{r2}) and (Y_2/Y_1)