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Mahmoud El-Gamal
Lecturer at Irrigation and Hydraulic Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt., mmelgamel@hotmail.com

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BEHAVIOR OF HYDRAULIC JUMP ON A STILLING BASIN II

خواص القفزة الهيدروليكية فى حوض التهدئة نموذج (٢) .

By **Mahmoud M. El-Gamal**

Lecturer, Department of Civil Engineering, Faculty of Engineering,
El-Mansoura University, El-Mansoura, Egypt.

الملخص : تختص هذه الدراسة بحوض التهدئة نموذج (٢) الذى ينشأ خلف السدود ومنشآت الرى الكبرى وتم تصميم نموذج حوض التهدئة طبقا للمواصفات القياسية لمكتب الاستصلاح الامريكى بهدف دراسة تأثير ارتفاع الماء المحجوز خلف حوض التهدئة على تحريك موقع القفزة الهيدروليكية خلال حوض التهدئة وتأثير ذلك على خواص السريان والنحر خلف أحواض التهدئة ــ وأجريت تجارب هذا البحث بمعمل الهيدروليكا بقسم الهندسة المدنية بجامعة أريزونا ــ وأمكن بهذه الدراسة ربط العلاقات الناتجة عن تغيير قيم التصرف وسرعة السريان وارتفاع الماء المحجوز خلف حوض التهدئة نموذج (٢) المصمم طبقا للمواصفات القياسية لمكتب الاستصلاح الامريكى ونأمل أن تكون هذه الدراسة مفيدة لمصممى أحواض التهدئة خلف المنشآت الهيدروليكية فى المستقبل .

ABSTRACT- This study concerns stilling basins of type II which have been used in conjunction with high dam spillways, and large canal structures. A typical stilling basin is the Bureau of Reclamation basin II, designing to ideal function with specific tailwater levels. The goal of this study was to determine how higher and lower tailwater levels issue the jump to move up and downstream, changing flow characteristics and predictably resulting in undesirable scour.

Experiments are conducted in the hydraulic laboratory of the Department of Civil Engineering and Engineering Mechanics of the University of Arizona. The paper shows how establishing the relationship for different flow rates, different velocities and height of tailwater conditions for the U. S. Bureau of Reclamation stilling basin II. It is hoped that this study is useful to the designers of the stilling basin.

INTRODUCTION

The hydraulic jump stilling basin an outlet works is an effective device for decreasing high velocities to a tranquil case. A model study is often made to obtain additional knowledge of what to expect when a structure is work in the field. The U.S. Bureau of Reclamation has developed many types of stilling basins for different conditions (9,5). Many experiment tests on models with different scales have been made to determine the applicability of the hydraulic jump formula for the entire range of conditions experienced in design (3), and to investigate the efficiency of anti-scour designs downstream of hydraulic structures (1). Also much research has been done on the process of the hydraulic jump energy dissipation (4,8) and means to enhance the behavior of the hydraulic jump basin (2,6) however, there is considerable uncertainty in how well the basins will perform if the conditions are different from those assumed or computed One of the crucial factors in stilling basin performance is the elevation of the tailwater downstream from the stilling basin. Unfortunately, this frequently is the most difficult condition to estimate accurately because it is very likely to change with time as conditions in the large canal or the river below the hydraulic structure change.

These studies have contributed toward the eastablishment of the behavior changes with high and low tailwater, and the limiting range of tailwater for acceptable performance within stilling basin type II.

EXPERIMENTAL ARRANGEMENTS

Experiments were performed in rectangular flume which composed of several parts. This flume which is 2.2 feet wide and 41.8 feet total length, can be operated at maximum discharge of 4 cfs. as shows in Fig. 1. Each part played its own individual role in the experiments. The 24.8 feet test section of the flume accommodated the spillway, stilling basin and the sediment used to determine the scour. One side of the total length of this section was made of glass so that the results taking place in the reach are visible. The flume bed and other parts of vertical sides were made of steel sheets welded together. The downstream 10 feet of the flume contained the sediment settling tank. The tailwater depth was regulated by an adjustable tailgate at the end of the flume. The flume was equipped with a calibrated V - notch weir for flow metering in the return channel downstream from the flume, and three point gage for measuring the tailwater depth, height of water upstream of the V - notch weir and the conjugate depth of the flow. The depth of flow at the entrance of the stilling basin could be set as designed by the control gate was located in the sloping area of the spillway. The flume was connected by an overhead constant level storage tank founded 12 feet above the ground, which carried flow by gravity complete the system. Beginning to test the flume was initially filled from the downstream end by a secondary supply pipe extended from the storage tank to the sediment settling tank in order to avoid scour downstream of the stilling basin by initial flow over the spillway.

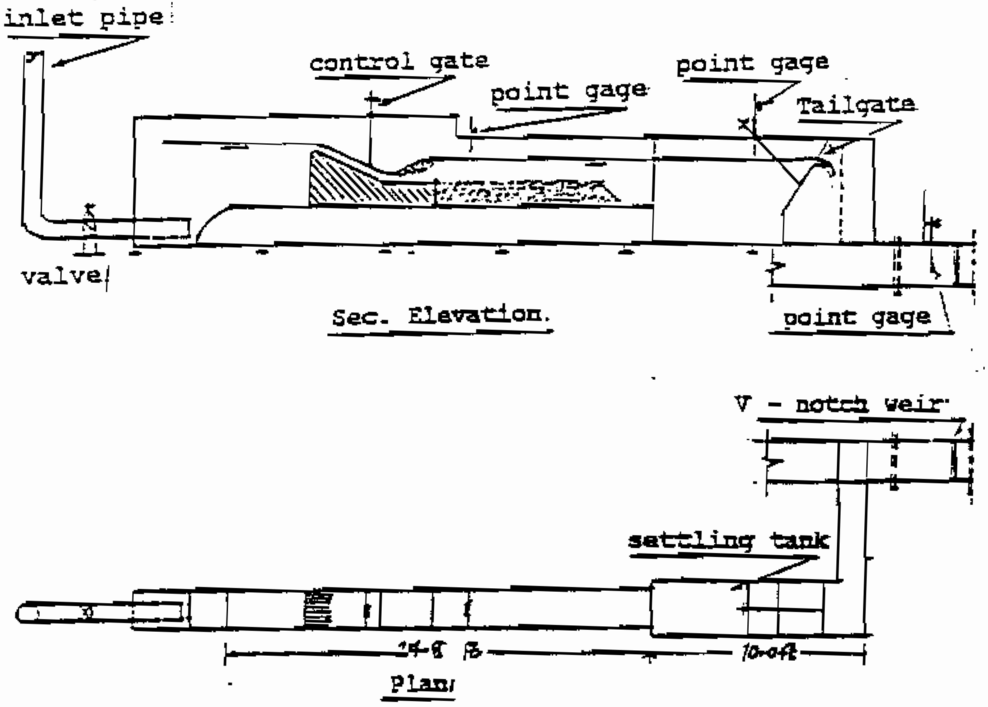

Fig. 1. Testing Flume

STILLING BASIN DESIGN

The jump form and flow characteristics in open channel can be related to the kinetic flow factor, V^2/gd or to the Froude number $V/(gd)1/2$. The law of similitude states that gravitational forces predominate the Froude number should have the same value in model and prototype. Therefore, a model shaped stilling basin jump in a test flume will have the identical exemplary of a prototype jump in a stilling basin if the Froude number of the incoming flows are the same. The length of the spillway was 4 feet, height 2 feet, and slope of the downstream face was 2:1. The model dimension of the stilling basin was determined for a particular Froude number of 4.5 and a depth of flow 0.125 feet upstream of jump. Since the Froude number and the depth of entrance flow are known and using the U.S. Bureau of Reclamation design criteria (9), the dimensions for the type II stilling basin were determined and are shown in Fig. 2.

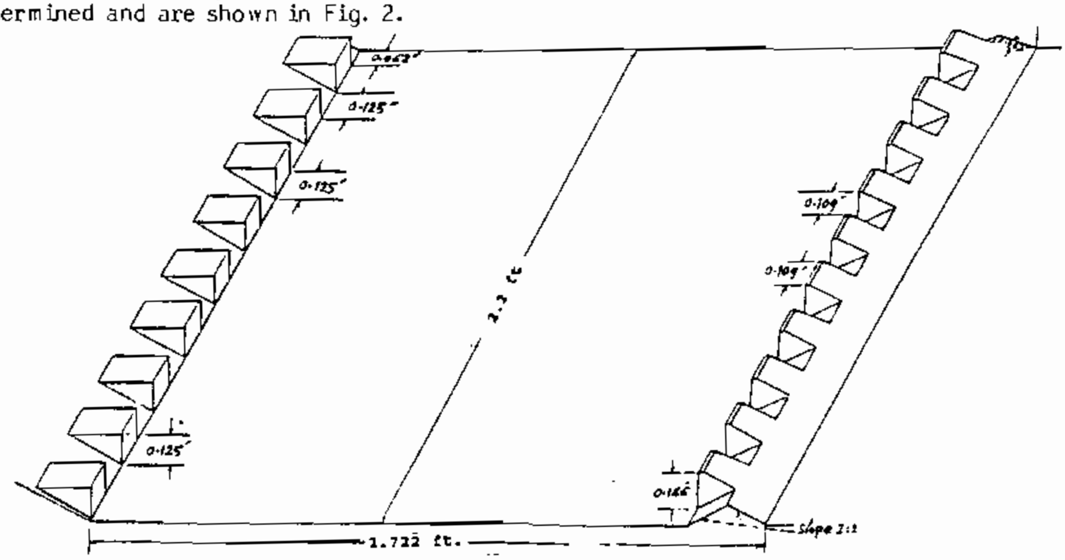

FIG. 2. Type II Basin Dimensions

TESTING PROGRAM AND RESULTS

The purpose of the study was directed toward determining the best elevation of the tailwater downstream from the stilling basin to minimize scour. Therefore the runs were made using different tailwater elevations for each three discharges. From the similitude condition where the dimensions of stilling basin model were determined, therefore, the design discharge was 2.48 cfs. which used in the first experiment. For the second experiment the discharge was 20% more than the design discharge, and the third experiment was based on a discharge of 20% less than design discharge. The characters of flow for the three discharges are summarized in table 1.

Each run was made by adjusting the discharge, depth at entrance of the stilling basin and the location of the hydraulic jump. For each discharge the hydraulic jump was adjusted at the beginning, at the middle and at the end of the stilling basin by setting different tailwater elevations. Also for the discharge of 2.48 cfs. the tailwater was raised up to sufficient depth to oceurring a submerged jump. For each run the scour profile, conjugate depth, length of hydraulic jump and tailwater elevation were measured. The measurements and computations are tabulated in tables 2, 3, 4, and 5. Also each of the figures from 3 to 5 show the scour profile curves for the jump ocourring at the beginning, at the middie and at the end of the stilling basin for the discharges 2.00, 2.48, and 2.75 cfs. The scour profile for submerged jump is shown in Fig. 6.

TABLE 1. Flow Characteristics at the Entrance of the Stilling Basin

H (ft)	Q (cfs)	d_1 (ft)	V_1 (fps)	F	n
0.915	2.00	0.109	8.29	4.43	0.0271
0.997	2.48	0.125	9.11	4.5	0.0271
1.041	2.75	0.133	9.41	4.54	0.0271

TABLE 2. Experimental Results for Q = 2.00 efs.

Location of jump	Conj. depth d_2 (ft)	Length of jump (ft)	Velocity V_2 (fps)	Tail-water T_w (ft)	$\frac{T_w}{d_2}$	Scour depth below lower edge of sill		Scour length from the end sill	
						at toe (ft)	max. (ft)	point of max. scour (ft)	total length (ft)
at beg.	0.692	2.55	1.31	0.719	1.03	0.03	0.35	1.25	3.75
at midi	0.579	2.4	1.57	0.603	1.41	0.05	0.39	1.75	3.91
at end	0.551	2.35	1.64	0.571	1.03	0.058	0.65	2.00	5.71

TABLE 3. Experimental Results for Q = 2.48 cfs.

Location of jump	Conj. depth d_2 (ft)	Length of jump (ft)	Velocity V_2 (fps)	Tail-water T_w (ft)	$\frac{T_w}{d_2}$	Scour depth below lower edge of sill		Scour length from the end sill	
						at toe (ft)	max. (ft)	point of max.scour (ft)	total length (ft)
at beg.	0.773	2.62	1.45	0.806	1.042	0.06	0.33	1.25	3.66
at mid.	0.767	2.55	1.46	0.797	1.039	0.08	0.46	1.75	4.9
at end	0.550	2.43	2.04	0.575	1.045	0.12	0.66	3.25	5.95

TABLE 4. Experimental Results for Q = 2.75 cfs.

Location of jump	Conj. depth d_2 (ft)	Length of jump (ft)	Velocity V_2 (fps)	Tail-water T_w (ft)	$\frac{T_w}{d_2}$	Scour depth below lower edge of sill		Scour length from the end sill	
						at toe (ft)	max. (ft)	point of max.scour (ft)	total length (ft)
at beg.	0.765	2.56	1.633	0.808	1.055	0.08	0.43	1.75	4.78
at mid	0.626	2.48	1.996	0.653	1.042	0.083	0.58	2.0	5.18
at end	0.509	2.32	2.455	0.529	1.038	0.15	0.75	4.0	6.78

TABLE 5. Experimental Results for Submerged Jump
Q = 2.48 cfs

Conj. depth d_2 (ft)	Velocity V_2 (fps)	tail-water T_w (ft)	$\frac{T_w}{d_2}$	Scour data		
				scour at toe (ft)	Max. scour (ft)	Total length (ft)
0.89	1.266	1.007	1.13	0.03	0.26	3.33

SHEAR FORCES AND SCOUR RELATIONS

Momentum equation is applied to the flow at the sections initial depth and conjugate depth in order to eliminate the distorting effects of the bed materials. By applying the momentum equation to the control volume shown in Fig. 7. assuming hydrostatic distribution of pressure and velocity distribution across the section is uniform, for the hydraulic jump contained at the beginning of the stilling basin.

$$F_1 - F_2 - \tau_{o1} + \beta M_1 - \beta M_2 = 0 \qquad \ldots (1)$$

The equation may be expressed as follow

$$F_1 - F_3 - \tau_{o2} + \beta M_1 - \beta M_3 - \tau_x = 0 \qquad \ldots (2)$$

for the hydraulic jump contained at the middle of stilling basin. With assumption, β is negligible and $\tau_{o1} = \tau_{o2}$, subtract equation (2) from equation (1)

$$F_2 - F_3 + M_2 - M_3 - \tau_x = 0 \qquad \ldots (3)$$

The difference between $(F_2 + M_2) - (F_3 + M_3) = \tau_x$
is due to the difference in tailwater depth.

The purpose of installing a stilling basin below a spillway is to reduce velocities and prevent erosion of the downstream channel bed. We can determine if the particles in the downstream bed will move from the relation τ_o / τ_c.
Where : τ_o is the shear stress on the particles on the bed and can be defined as (6)

$$\tau_o = (V_2)^2 (d_{50})^{1/2} / 30 (d_2)^{1/3} \qquad \ldots (4)$$

τ_c is the critical tractive force and can be approximated as,

$$\tau_c = 4\, d_{50}$$

A gravel available in the laboratory with a d_{50} = 0.0098 ft. (3 mm.) was chosen as the model bed material. for the design condition the shear stress and critical tractive force can computed, then $\tau_o / \tau_c = 0.482$

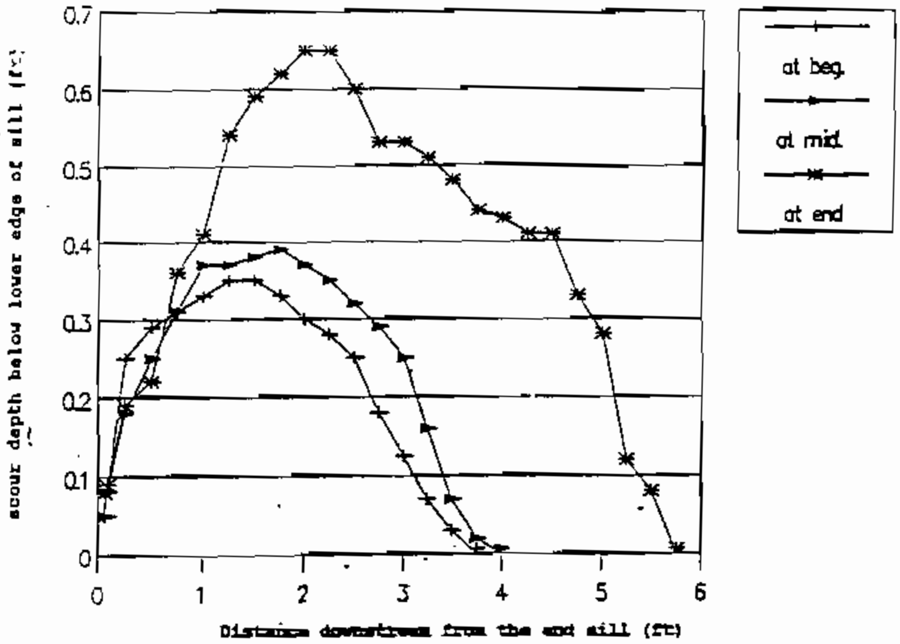

FIG. 3. Scour Profile for Q = 2.00 cfs.

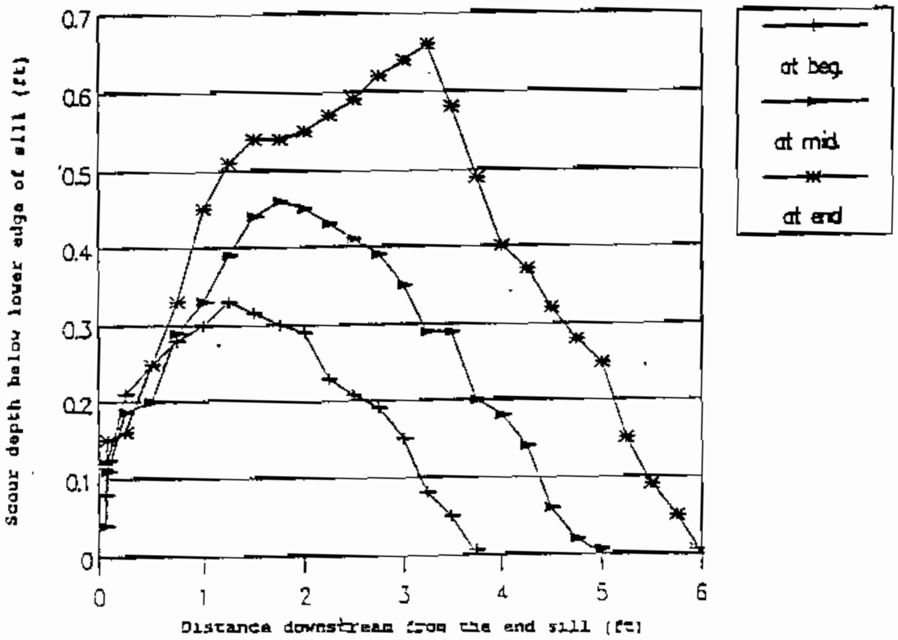

FIG. 4. Scour Profile for Q = 2.48 cfs.

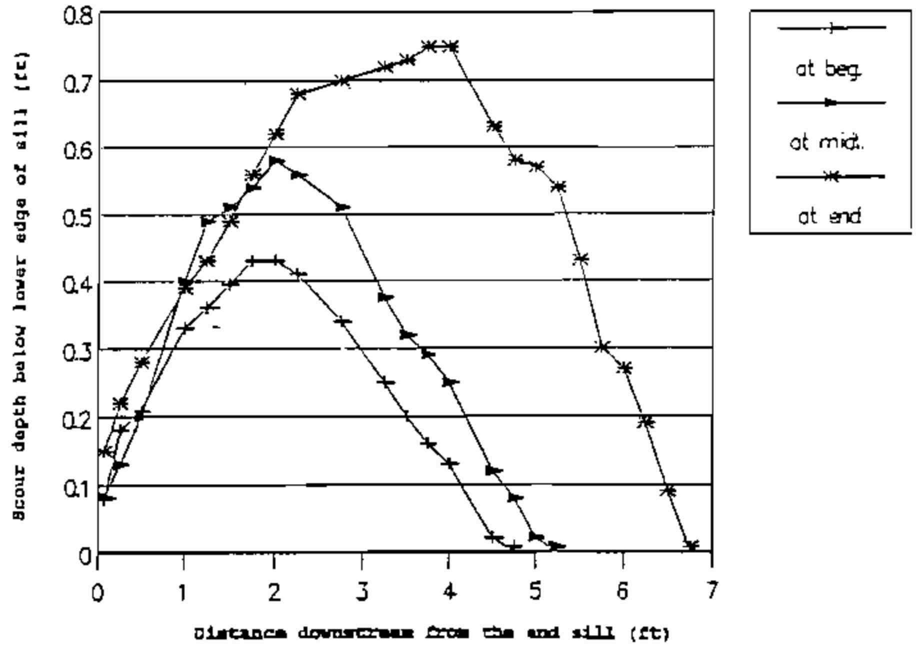

FIG. 5. Scour Profile for Q = 2.75 cfs.

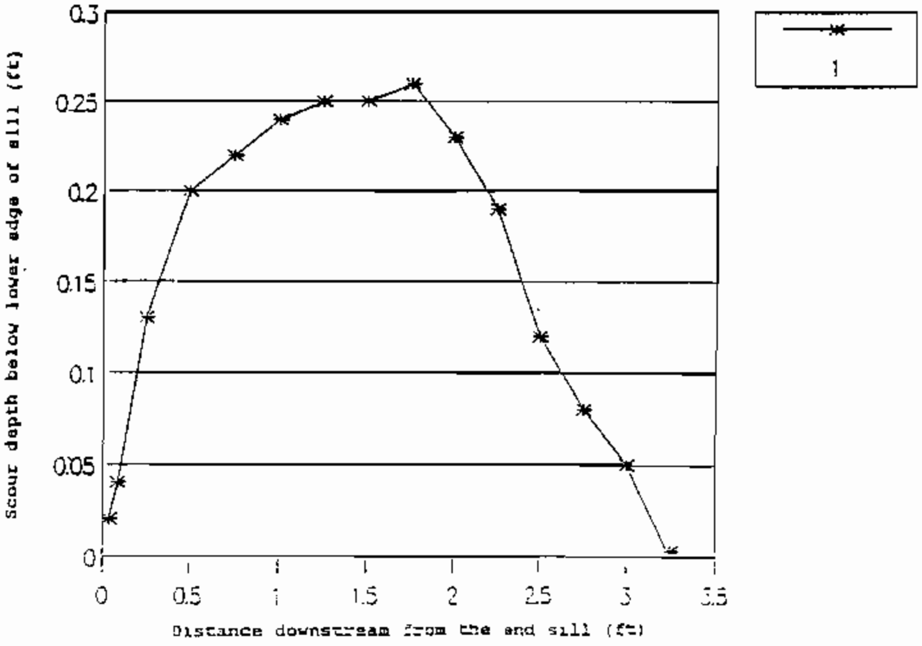

FIG. 6. Scour Profile for Submerged Jump Q = 2.48 cfs.

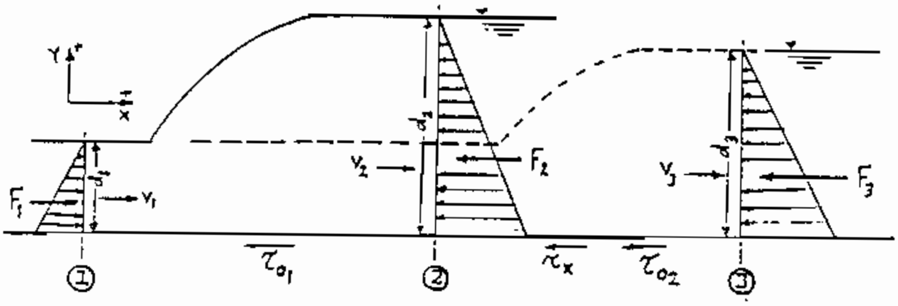

FIG. 7 Jump Contained at Beginning and at Middle of Basin

DISCUSSION OF RESULTS

The efficiency of the stilling basin was tested by the range of acceptable tailwater and the measured depths and extent of the erosion downstream from the stilling basin. Erosion depths may or may not scale to the prototype, depending on the choice of the model bed material however, the model when operated for a period of time sufficient to produce a stable bed, will indicate erosion tendencies and patterns in the prototype.

Also the results provide the information about the effect of variations in the tailwater elevation from that of standard design criteria shown on Fig. 8. corresponding to the summarized values of experimental and pure jump in table 6, the conjugate depth (d_2) from the momentum equation was 0.735 ft, and the experimental conjugate depth was 0.773 ft.

For the design discharge (Q = 2.48 cfs) the tailwater was 0.806 ft, as shows in table 3, when the jump oceurred at beginning of the stilling basin, and 0.575 ft, when the jump was about to be washed out of the basin. From the scour profile curves shown in Fig. 4. the depth of scour was 0.33 ft, when the jump contained at beginning of the stilling basin. When the jump was occurred at middle of the stilling basin by lowered the tailwater 0.009 ft, the depth of scour was 0.46 ft. The maximum depth of scour occurred when the jump was swept out of the stilling basin and was 0.66 ft, corresponding to a tailwater of 0.575 ft.

For a discharge 20% higher than design discharge the scour was insignificant at the toe of the stilling basin, but maximum depth of scour was larger as shown in Fig. 5. When the discharge was 20% less than design discharge the scour was less but started immediately downstream of the toe Fig. 3.

A submerged hydraulic jump occurred when the tailwater was raised to a depth of 1.007 ft, which consider 37% greater than d_2, for this condition the maximum scoure depth was 0.26 ft, which consider insignificant as shown in Fig. 6, and higher tailwater levels might have performed equally as well.

TABLE 6. Experimental and pure jump Comparative Results

Q	F	Exp. results		Pure jump	
		d_2	T_w	d_2	T_w=1.05d
(cfs)	-	(ft)	(ft)	(ft)	(ft)
2.0	4.43	0.692	0.719	0.63	0.661
2.48	4.50	0.773	0.806	0.735	0.771
2.75	4.54	0.765	0.808	0.792	0.829

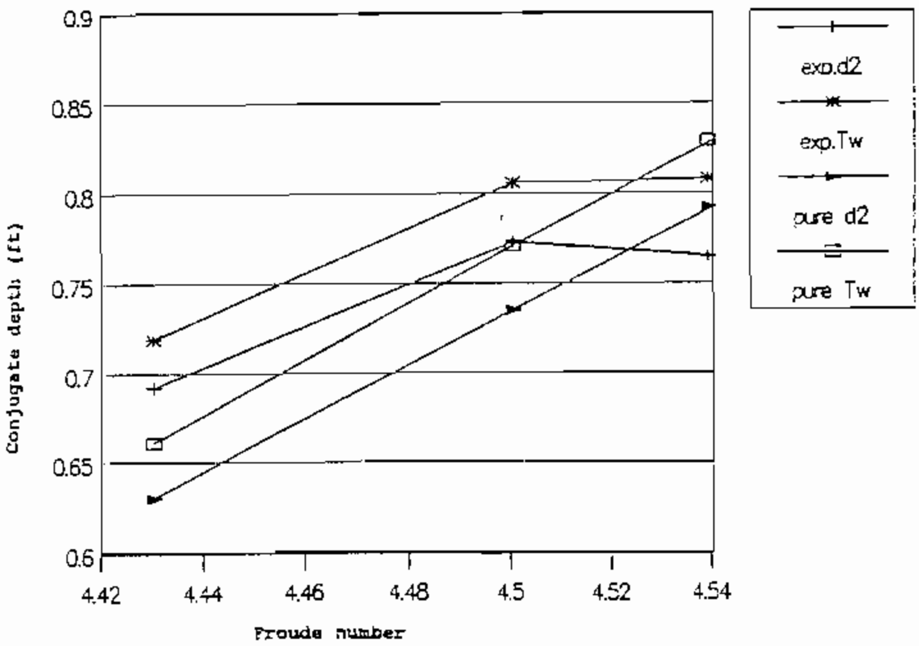

FIG. 8. Pure Jump and Experimental jump Results

CONCLUSIONS

Analysis of the experimental data from this study gives rise to the following conclusions with respect to evaluating the type II stilling basin performance:

1- For design operation the tailwater needs to he 9.6% greater than the conjugate depth (d_2) of the pure jump.

2- The jump escaped from the basin when the tailwater was 2.8% less than the conjugate depth of the pure jump.

3- When the flow was 20% greater than the design discharge the tailwater needed to be 2% greater than the conjugate depth for good operation.

4- When the flow was 20% less than design discharge the tailwater needed to be 14% greater than the conjugate depth.

5- When the tailwater was 37% greater than d_2 the hydraulic jump was submerged, but performance as a submerged jet, and the jet downstream of the basin is directd away from the bed so that scour is not threatening to safety of the basin.

6- When the jump was moved downstream and outside the stilling hasin, the maximum scour depth was increased and moved downstream of the toe of the stilling basin.

7- When the tailwater is low the jump will move downstream until the boundary shear of high velocity flow adds up to be this force.

ACKNOWLEDGMENTS

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APPENDIX II. NOTATION

The following symbols are used in this paper:

d = depth of flow at any section;

d_1 = initial depth of jump;

d_2 = conjugate depth of jump;

d_{50} = mean diameter of bed particles in feet;

F = Froude number;

F_1 = hydrostatic force in X - direction at section 1;

F_2 = hydrostatic force in X - direction at section 2;

F_3 = hydrostatic force in X - direction at section 3;

g = acceleration of gravity;

H = height of flow upstream of the V - notch weir;

M_1 = momentum in a section 1;

M_2 = momentum in a section 2;

M_3 = momentum in a section 3;
n = Manning,s roughness coefficient;
Q = flow rate;
T_w = tailwater depth;
V = velocity of flow at any section;
V_1 = average velocity of flow at initial depth;
V_2 = average velocity of flow at conjugate depth;
β = momentum correction factor;
τ_c = critical tractive force on particles on bed;
τ_o = shearing stress on the particles on bed;
τ_{o1} = shearing stress along the basin bed for jump at beginning of the basin;
τ_{o2} = shearing stress along the basin bed for jump at middle of the basin; and
τ_x = shearing stress along the basin bed due to drop in tailwater level.