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Hydraulic Performance for Al-Dhuloyia Spillway Using Physical Model

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ABSTRACT

A study was completed to compare flow parameters over a modified ogee-crested spillway which represent an existing project (Al-Dhuloyia Spillway) using a physical model and existing literature. The physical model was constructed by wood with smoothness surface and placed in a test flume. Pressure taps were installed along the entire length of the spillway. Discharge and pressure data were recorded for 10 different flow conditions. Data interpolated from U.S. Bureau of Reclamation and U.S. Army Corps of Engineers design monographs provided discharge and pressure data from the literature. Non dimensional discharge curves are used to compare the results for both physical model and those of literature. Pressures are compared at low, mid, and high flow conditions. Also water surface profile for Al-Dhuloyia Spillway was compared with those of literature and for different discharge condition. It is shown that there is reasonably good agreement between the physical and that those for literature for pressures, discharges and water surface profile.

Introduction

The ogee-crested spillway, because of its superb hydraulic characteristics, has been one of the most studied hydraulic structures. Its ability to pass flows efficiently and safely, when properly designed, with relatively good flow measuring capabilities, has enabled engineers to use it in a wide variety of situations. Although much is understood about the general ogee shape and its flow characteristics, it is also understood that a deviation from the standard design parameters such as a change in upstream flow conditions, slightly modified crest shape, or construction variances can change the flow properties. These small changes often require engineers to evaluate the crest and determine whether or not the change or deviation will be detrimental to the spillway’s performance. Such is the case when an updated probable maximum flood calculation requires a spillway to pass a larger flow than it was designed to handle. With the rapidly changing advances in computational modeling for solving the governing equations of fluid flow, engineers now face the decision of which method(s) to use in evaluating existing and proposed spillway designs. The choice of a physical model, computational model, or interpolating/extrapolating the needed information from the U.S. Army Corps of Engineers (USACE) or the U.S. Bureau of Reclamation (USBR) design/performance curves can be a daunting task. This is especially true if an engineer is unfamiliar with the capabilities and limitations of state-of-the-art computational modeling or if the effects of extrapolating are not fully understood and thereby one method cannot be justified over the other. To correlate this study with existing USBR and USACE data, a modified ogee-crested spillway design (Al-Dhuloyia Spillway) was used. The physical model was constructed using wood with smooth surface which cut to a desired shape. Non dimensional design parameters, performance data were interpolated from USACE (1990) and USBR (1987) published reports.

Crest Shape of Overflow spillway

The shape of spillway in the dam is designed such that it fits the underside of a well-ventilated free nappe shape for design head. The shape is desired by separating it into two quadrants, one is upstream face and the other is downstream face from the highest point of the lower nappe surface Bazen from 1886 to 1888 made the first comprehensive laboratory investigation of nappe shapes; he constructed a base curve representing the results of the experiments. The shape of the unit nappe may then be recalculated according to geometric similarity to any design head. Muller 1908 proposed that overflow spillways should be constructed to conform to the lower surface of the nappe formed by flow over sharp crested ventilated weir. The proposed equation is:

$$X^2=-2.3\ H_d\ Y$$

Where Y,X horizontal and vertical coordinates of the crest profiles with origin at the highest points of the crest and H_d the design head excluding velocity head of the approach.

USBR from 1932 to 1948 conducted extensive experiments on the shape of the nappe over a sharp crested weir. Based on Bazen's experimental data USBR has developed coordinate of nappe surface for vertical and various slope faced weirs. The USBR defined the downstream crest face as simplified curve with equation:

$$X^2=-2H_d\ Y$$

Where X, Y and H_d are defined above. In this paper the downstream face crest of physical model is used simplified USBR method using equation

$X^2=-5\,Y$ where the design head is 2.5m. and the upstream face of spillway with arc ($5/16\ H_d$) which equal 0.78m. The crest geometry is shown in Fig.(1).

Coefficient of Discharge for overflow spillways

The theoretical discharge equation for spillway is defined as:-

$$Q=\frac{2}{3}B\sqrt{2g}\,H^{3/2}$$

Where Q discharge L^3/T, B the length of the spillway (L), g gravity acceleration (L/T^2) and H the head above crest excluding velocity head (L). For above equation discharge coefficient (C_o) is used to correct, the energy losses between the head measurements location and control section, the non-uniformity in velocity distributions and the stream line curvature. Therefore; equation becomes

$$Q=\frac{2}{3}C_o B\sqrt{2g}\,H^{3/2}$$

With ($\frac{2}{3}$ and $\sqrt{2g}$) are constant and divide by *B* which represents width of spillway the equation can be re-written as:

$$q_d=C_d H^{3/2}$$

Where q_d is the discharge per unit width

Also the discharge coefficient C_o is not constant. It is influenced by a variety of factors including the depth of approach, relation of the actual crest shape to the ideal nappe shape, upstream face slope, downstream apron interference, and downstream submergence.

The Physical Model

The model is made of special wood cut to design shape and smoothened. Six simple peizometers are staggered in one row. The peizometer diameter is 2.5 mm which is drilled perpendicular to the surface, steel tube of the same diameters are inserted in and connected by plastic hose to a manometer board. To ensure that sidewall effects did not influence the pressure data, the main pressure taps were located at the center of the cross sectional model. The model is placed perpendicularly across the full width of a flume. The flume is constructed using 10 mm thick Perspex side wall to visualize the flow from both sides. The flume was (3.5 m) long (0.2 m) wide and (0.3m) deep. (Fig. (2) show the flume with the spillway model) the discharge was controlled by flow meter, which is possible to obtain fine adjustment to the flow using careful manipulation. Also there was a sharp crested weir in the end of the flume to calibrate the flow measurements. For water nappe profiles and water level measurements, two point gauges with a vernier scale of (0.1 mm) accuracy are used. Each gauge is supported by plastic base on a carrier move on two rails along the side of the channel. The gauge has three directional movements.

Description of spillway model

In order to evaluate radii lengths for upstream portion of crest, and the function of downstream portion of crest, hydraulic information about the design discharge, head and the crest height must be available, these are taken from Al-Dhuloyia Headwork Project produced by Al-Furat Center for Studies and Designs for Irrigation project 1997. Where Q=1150 m^3/s, H_d=2.5 m, P(crest height)=5.5 m and L (length of spillway)= 137.4 m. Depending on USBR specification for modified spillway the upstream arc for crest is (5/16 H_d) which equal 0.78 m and the downstream function is with equation $X^2=-5\,Y$ The model with scale 1/50 in both X and Y direction with 0.2m in Z direction.

Experimentation

This study is done in the Hydraulic Laboratory, College of Engineering Al-Mustansiria University in Baghdad (Salahddin,1998). In this study a total of 10 runs are conducted with different discharges, at the beginning of each run air is vented in order to avoid blockage in the hose of manometers. The pressure head is then measured directly from the manometer board. After that by using point gauges the water surface profiles are measured each 2 cm interval. Table (1) and (2) show the hydraulic measured data for pressure head distribution above the spillway model and water nappe profiles respectively.

Results

The main purpose of this study was to compare the results of the physical model obtained by (Salahddin, 1998) with that of existing USACE and USBR data for flow over an uncontrolled ogee crest. An evaluation of the pressure taps data from the physical model indicated that the 3D effects are relatively small and has an influence only on the flow near the wall. It was observed visually that there was a slight rise in the water surface elevation near the wall, due to the viscous effect of the wall. Similar to the

physical model, an increase in water surface elevation was noted near the wall. It was also noted that pressures changed laterally across the crest. However, the variation was not significant. The results have been non-dimensionalized to allow a comparison in their simplest form. The design parameters— H_d = design head (m) and q_d = design flow rate per unit length [m3/(s.m)]—from the physical model are used as the basis. The design head was set at 0.05 m which equal (2.5 m) in prototype and the corresponding design flow, as determined from the model, was 0.0233 m3/(s.m) which equal 8.305 m3/(s.m) in prototype. Fig.(3) shows the discharge relationships. The effective head H_e, which includes the velocity head, is non-dimensionalized by the design head H_d and shown on the abscissa. The discharge q is non-dimensionalized by q_d and shown on the ordinate. Table (3) contains the actual non dimensional discharge values for physical model, USACE and USBR. Fig.(4) provides a comparison of average crest pressures for three different flow heads(0.5 H_d, 1.04 H_d and 1.28 H_d) for the physical and those existing for USBR and USACE. Crest pressures were interpolated at these heads from the USACE data (Maynord,1985) . The pressure position on the spillway is shown non-dimensionally as X/Hd, with X being the horizontal distance from the crest axis. The pressures are shown nondimensionally as Hp /Hd on the ordinate, where Hp is the pressure head. A comparison of the physical to either the USBR or the USACE data along the tangent was not possible because neither the USBR nor the USACE present this pressure data in their design nomographs. In fact, the USACE indicates that model studies are likely required to obtain pressures on the tangent sections of spillways
(USACE, 1990). Another comparison for water surface profiles for three different flow heads (0.5 H_d, 1.04 H_d and 1.28 H_d) for the physical model to those existing from USBR as shown in Fig.(5) the water nappe profiles on the spillway represented dimensionless as Y/H_d on Y-axis, and X-axis being horizontal distance from the crest axis. Table (4) contains the interpolated water profile data for USBR data

Discussion

The dimensionless discharge (q/qd) curve via dimensionless operation head (He/Hd) show that the physical model (Al-Dhuloyia Spillway model) is similar to those of USBR and USACE with very small difference. For example; the dimensionless discharge (q/qd) for flow rate (He/Hd=1.0) gave (q/qd=1.048) for the physical model and (0.998) for USACE and

(0.956) for USBR, which mean that the coefficients of discharge for all three methods are almost equals. For the pressure distributions curves, the physical model gave good agreement with those of USACE especially on the downstream portion of the crest, but the upstream portion and the top of crest is gave slight difference than those of USACE. This small difference of pressure can be decreased by increasing the scale of the model. Finally, the water nappe profiles for the physical model are similar to those of USACE, and the shape of upper nappe profiles is significant in the design of the spillway abutment walls. Generally, the physical model is good agreed with the USBR and USACE literature. So, the physical model even it cost more and take more time to complete, but it stills the best way to check the design of the hydraulic structures.

Table (1):Measured Pressure Data for The Model (Where H is Measured Head Above Crest Excluding Velocity Head and H_p Pressure Head)

H/H_d	0.44	0.5	0.54	0.66	0.74	0.78	0.84	0.94	1.04	1.28
X/H_d	H_p/H_d									
-0.3	0.5	0.49	0.485	0.48	0.46	0.44	0.42	0.38	0.3	0.08
-0.1	0.424	0.414	0.404	0.394	0.384	0.364	0.344	0.304	0.204	-0.2
-0.0	0.31	0.308	0.305	0.28	0.26	0.24	0.22	0.16	0.040	-0.095
0.18	0.18	0.176	0.175	0.165	0.16	0.143	0.132	0.128	0.04	-0.1
0.74	0.12	0.13	0.113	0.105	0.095	0.093	0.087	0.081	0.075	-0.09
0.96	0.05	0.08	0.08	0.078	0.06	0.056	0.053	0.05	0.045	-0.03

Table(2):Measured Water Nappe Profile Data for The Model

H/H_d	0.44	0.5	0.54	0.66	0.74	0.78	0.84	0.94	1.04	1.28
X/H_d	Y/H_d									
-2.0										-1.28
-1.6							-0.84	-0.94	-1.04	-1.228
-1.2	-0.44	-0.5	-0.54	-0.66	-0.74	-0.78	-0.816	-0.902	-1.006	-1.206
-0.8	-0.436	-0.464	-0.538	-0.644	-0.694	-0.7	-0.794	-0.88	-0.96	-1.166
-0.4	-0.432	-0.43	-0.48	-0.582	-0.66	-0.69	-0.742	-0.822	-0.906	-1.104
0.0	-0.142	-0.348	-0.388	-0.484	-0.558	-0.602	-0.644	-0.72	-0.8	-0.948
0.4	-0.068	-0.158	-0.188	-0.29	-0.35	-0.428	-0.442	-0.532	-0.618	-0.828
0.8	0.202	0.21	0.130	0.04	-0.066	-0.128	-0.15	-0.32	-0.296	-0.542
1.2	0.674	0.59	0.562	0.482	0.366	0.342	0.272	0.194	0.058	-0.246
1.6	1.052	1.016	0.996	0.892	0.816	0.754	0.71	0.632	0.548	0.202
2.0	1.45	1.362	1.41	1.296	1.252	1.128	1.2	1.068	1.002	0.752
2.4	1.842	1.832	1.808	1.732	1.7	1.61	1.598	1.504	1.458	1.118
2.8	2.598	2.252	2.214	2.112	2.128	1.936	1.996	1.96	1.86	1.452
3.2	2.732	2.576	2.55	2.478	2.45	2.294	2.344	2.32	2.256	1.892
3.6	2.854	2.702	2.702	2.668	2.63	2.552	2.574	2.524	2.468	2.242

Table(3):The Actual Non Dimensional Discharge Values for Physical Model, USACE and USBR.

	MODEL	USBR	USACE
H_e/H_d	q/q_d	q/q_d	q/q_d
0	0	0	0
0.44	0.28	0.25	0.25
0.5	0.353	0.32	0.322
0.54	0.397	0.35	0.355
0.66	0.536	0.48	0.5
0.74	0.643	0.57	0.59
0.78	0.688	0.63	0.645
0.84	0.784	0.705	0.725
0.94	0.934	0.85	0.885
1.04	1.124	1.00	1.035
1.28	1.373	1.385	1.44

Table (4): The Experimental Data for Interpolated Water Nappe Profile for USBR Model

H/H_d	0.5	1.04	1.28
X/H_d	Y/H_d		
-1.0	-0.49	-0.967	-1.168
-0.8	-0.484	-0.948	-1.144
-0.6	-0.475	-0.924	-1.112
-0.4	-0.460	-0.894	-1.073
-0.2	-0.425	-0.85	-1.024
0.0	-0.371	-0.784	-0.963
0.2	-0.3	-0.71	-0.883
0.4	-0.2	-0.614	-0.785
0.6	-0.075	-0.494	-0.668
0.8	0.075	-0.35	-0.531
1.0	0.258	-0.177	-0.37
1.2	0.47	0.027	-0.178
1.4	0.705	0.258	0.043
1.6	0.972	0.524	0.291
1.8	1.269	0.817	0.58

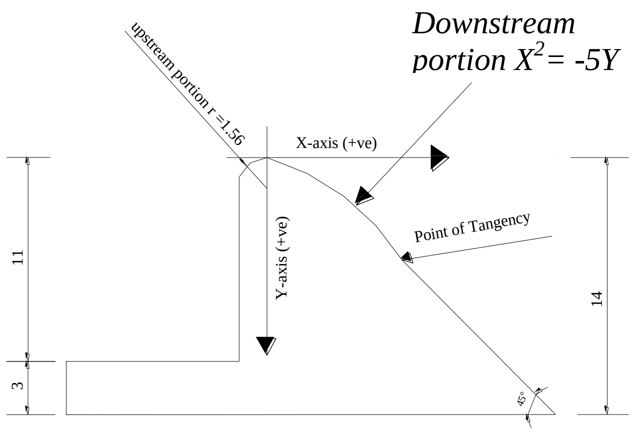

Fig.(1):The Crest Geometry for Al-Dhuloyia Spillway Model (All Dimensions in Cm)

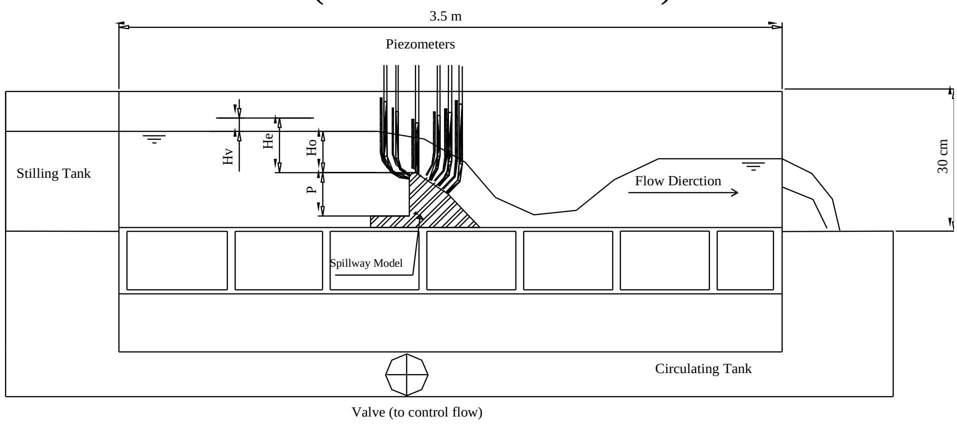

Fig. (2):The Flume and the Spillway Model

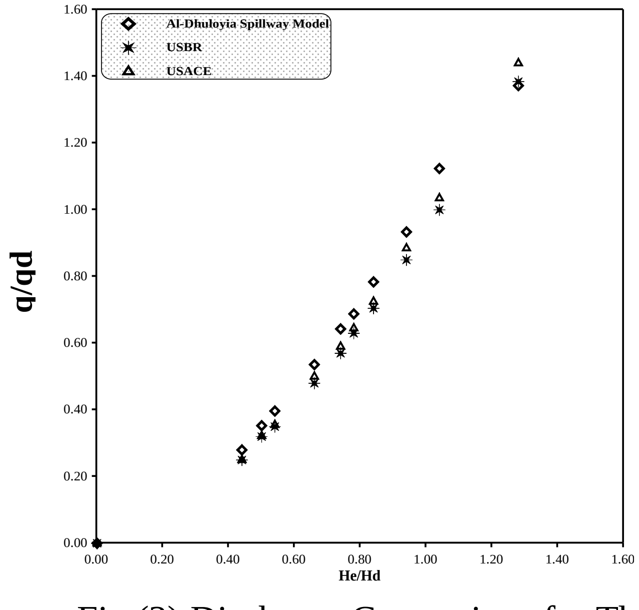

Fig.(3):Discharge Comparison for The Physical Model, USACE and USBR

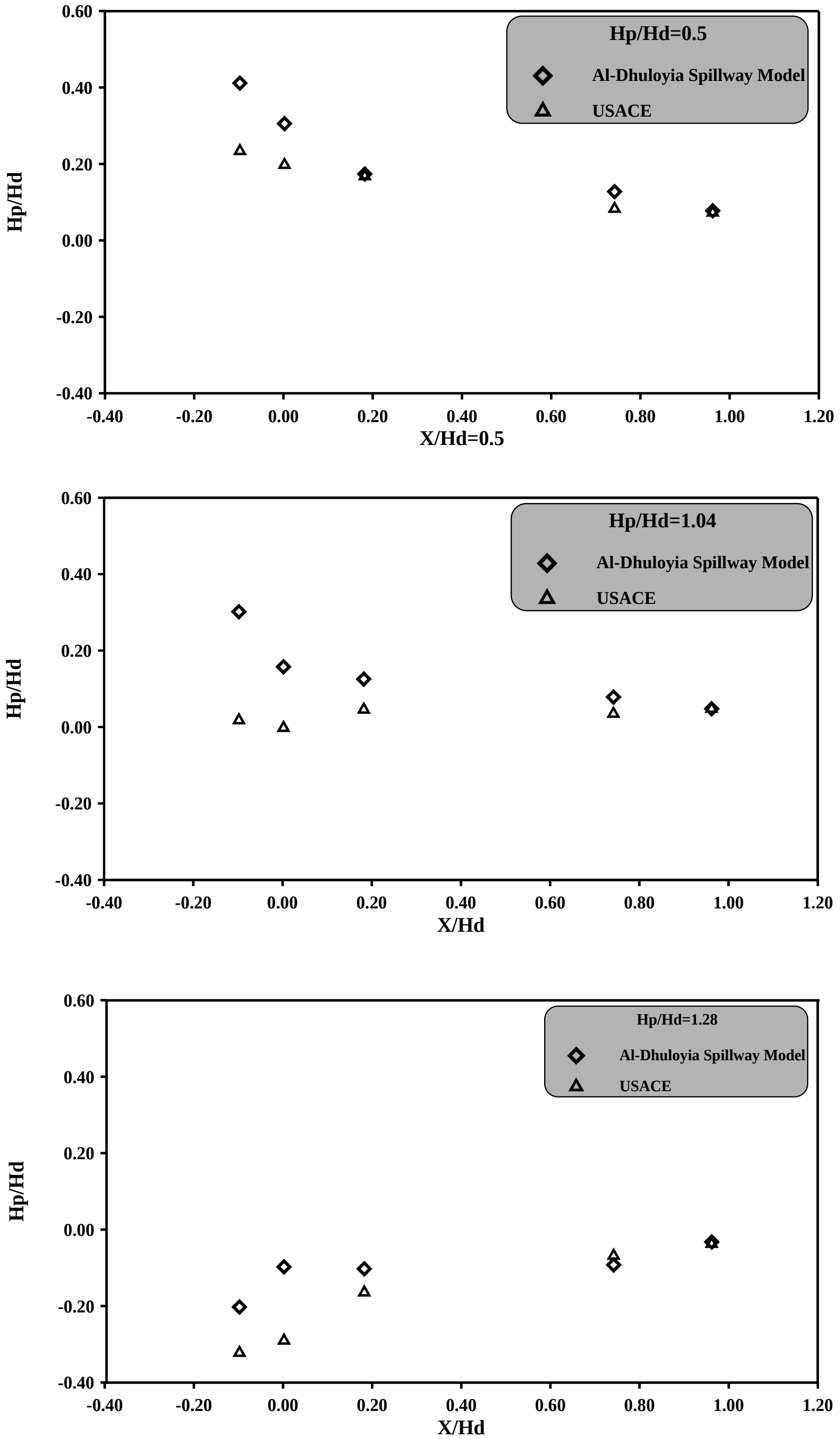

Fig.(4):Crest Pressure Distribution Comparison for Interpolated USBR and Al-Dhuloyia Spillway Model

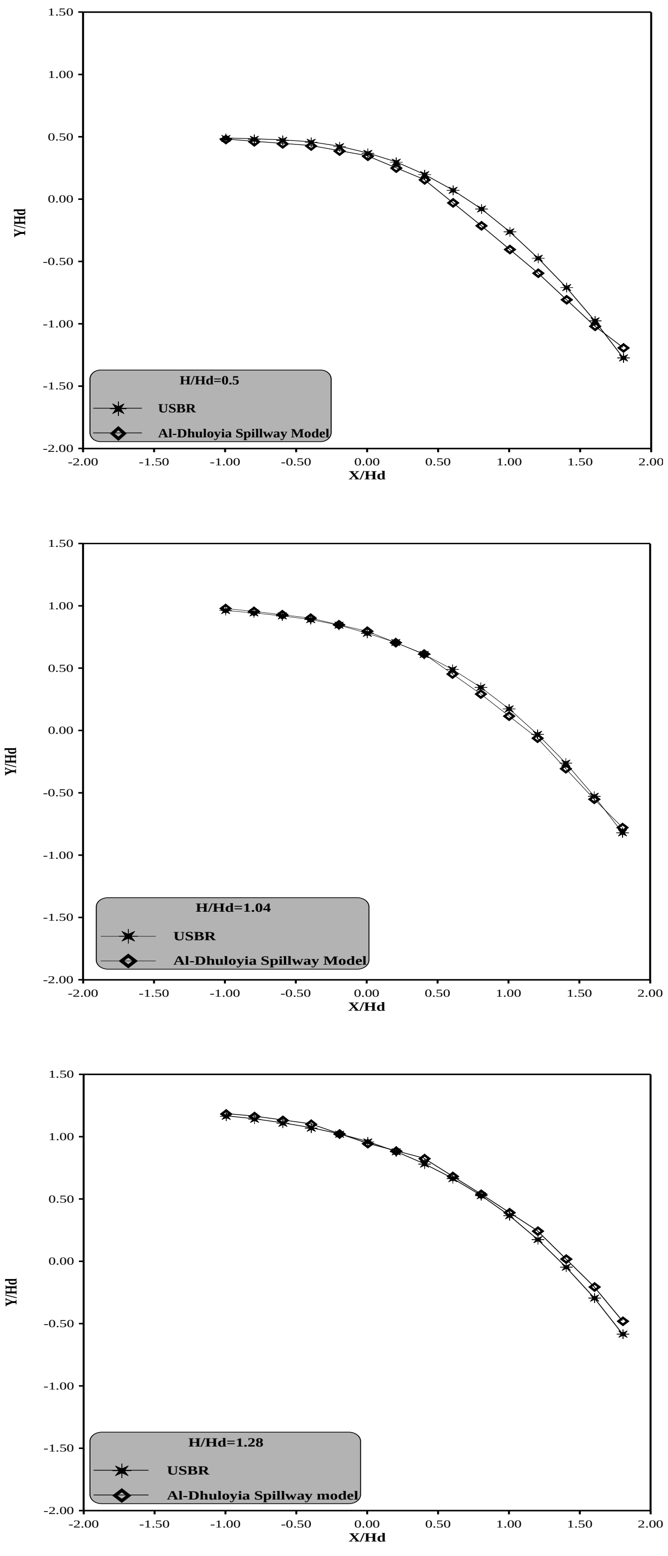

Fig.(5):Water Surface Profile Comparison for Interpolated USBR and Al-Dhuloyia Spillway Model

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Notation	symbols
B	the length of the spillway;
C_0	nondimensional discharge coefficient;
C_d	modified nondimensional discharge coefficient;
g	acceleration due to gravity;
H_d	design head above the crest excluding velocity head;
H_e	operating head above crest including velocity head;
H_o	static head above crest;
H_p	pressure head;
H_v	velocity head, u2/2g; u = velocity in x-direction;
P	height of dam at crest axis;
X	horizontal distance from crest axis;
Y	vertical distance from crest axis;
Q	discharge rate;
Qd	discharge rate at design head;
q	discharge rate per unit width;
q_d	discharge rate per unit width at design head.

الأداء الهيدروليكي لمسيل الضلوعية الغاطس باستخدام نموذج فيزيائي

من إعداد

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ايلول ٢٠٠٧

الخلاصة: هذه الدراسة أُجريت لمُقَارَنَة خصائص الجريان على المسيل من النوع اوجي (والذي يُمثّلُ مشروعاً منفذاً مسيل الضلوعية الغاطس) باستعمال نموذج فيزيائي مع البيانات من دراسات أخرى. النموذج الفيزيائي تم تصنيعه من الخشبِ وتم صقل سطحه بصورة جيدة ووَضعَ النموذج في مجرى القناة. مآخذ الضغطِ رُكّبتْ على طول المسيل،وتم اخذ بيانات الضغطَ والتصريف ل(١٠) قياسات مختلفة. البيانات عدلت مِنْ المكتبِ الأمريكي للاستصلاح والفيالق العسكرية الأمريكيةِ وذلك مِنْ دراساتِ تصميمِ المهندسين. تم استعمال التصريف اللابعدي لمُقَارَنَة النَتائِجِ لكلا من النموذج الفيزيائي وتلك مِنْ المكتبِ الأمريكيِ للاستصلاح والفيالق العسكرية الأمريكيةِ، الضغوط تم مقارنتها لحالات تصريف العاليةِ والوسطِ والمنخفضةِ. وأخيرا مستوى سطح الماء فوق مسيل الضلوعية قُارنتْ مع بيانات الفيالق العسكرية الأمريكيةِ ولتصاريف مختلفة.وبصورة عامة النتائج لكلا من النموذج الفيزيائي والمتمثل بالمسيل الضلوعية الغاطس والبيانات مِنْ المكتبِ الأمريكيِ للاستصلاح والفيالق العسكرية الأمريكيةِ قد أعطى نتائج مقبولة من حيث أداء الهيدروليكي.

كلمات المفتاح: مسيل الضلوعية الغاطس،مسيل من نوع اوجي، معامل التصريف، توزيع الضغط، مستوى سطح الماء.