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Environmental Assessment of Energy Dissipation over Submerged Dams Using MATLAB Simulation

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ABSTRACT

In this study, a MATLAB simulation model was developed for the purpose of calculating the energy dissipation of runoff over submersible dams. A laboratory model of a submersible dam with standard dimensions was used, and two angles of inclination of the dam surface 16° and 24.5° were used downstream. In the laboratory work, the discharge and water depth were measured, in addition to the length of the hydraulic jump and the distance from the source, and by using the basic flow equations, the percentage of flow energy dissipation was calculated for both models, and the discharges were counted. The values of the Froude number ranged from 3.612 to 10.784. A simulation model was built in the MATLAB program using the basic equations of flow, finding the values of energy dissipation percentage and comparing them with the laboratory results. Then drawing the relationships between each of the discharge (Q), energy dissipation percentage ($E\%$), Froude number (F_r), hydraulic jump length (L_j), and the distance of the hydraulic jump from the submerged dam (D_j). The numerical and experimental data have been compared, and it has been determined that there is an acceptable agreement between them. The results also showed the efficiency of using the MATLAB simulation method to obtain accurate and fast results.

Keywords: energy dissipation, submerge dams, MATLAB Simulation, computational fluid dynamics, computational fluid dynamics, Froude number.

INTRODUCTION

It is very necessary to mention that energy dissipation of flow over submerged dams and spillways is one of the most typical features of these obvious structures. Furthermore the amount of energy that is dissipated depended on some fundamental factors, mail, dam's height, velocity of flow, and the surface roughness. The major purpose of using submerged dams is to lift and control the upstream water level in revers and channels. It should be one of the most significant characteristics of these realized structures is the energy dissipation of flow over submerged dams and spillways (Al-Hafith et al., 2011). In this way researchers have developed equations and charts to forecast energy dissipation and also residual energy at the downstream. Moreover submerged dams are most generally used to prevent erosion that caused by height flow velocity in downstream. Many previous studies have developed laboratory experiments using different types of submerged dams in order to measure discharge and water flow level in channels (Simões et al., 2011). With regard to this, researcher have developed formulas and graphs to predict energy dissipation at the bed of revers or channels. In this way submerged dams can be widely employed so as to prevent scouring in downstream by distributing flow energy in channels. One of the most important factors that is taken into consideration in designing submerged dams and spillways is the flow velocity (Irzooki and Yass, 2015). In investigating dams, inclined surface Submerged dams are employed to prevent scouring downstream by distributing flow energy over the weirs (Shehab and Jasim, 2020). Researchers investigated characteristics of flow over different types of submerged dams based on laboratory trials where they employed measuring discharge and manage the water level on channels (Kim et al., 2021; Ikinciogullari, 2021).

MATLAB Simulink is one of the most software widely used for modelling and simulation for dynamic systems. It discussed by (Salmasi and Özger, 2014). Energy dissipation of flow over submerged dams was calculated using different mathematical models and equations (Ahmad and Srisvastava, 2014). These various models take into account main typical factors, as the velocity of flow, height of dam, slope in the downstream, and lastly the roughness of the surface. It is important to say that understanding these major factors is essential for designing dams that can effectively withstand maximum flow rates and minimizing energy dissipation (Goodarzi et al., 2012). Kim et al. (2021) studied how to reduce energy loss by roughening the surface with stone arrangements. This study aims to reduce energy loss by roughening the surface with stone arrangements. Data from 54 models was used to develop regression and AI models. The most appropriate models predict energy loss over the chute, with D50/yc having the most impact.

In all researches on the rate of energy dissipation of flows along submerged dams that were studied by the author, the advantages of using MATLAB Simulink or Fuzzy inference system and the high accuracy of their use for prediction the percentage of energy losses were demonstrated. However, at the same time, all previous models had long mathematical equations that require a long time to solve, as a result of which the forecasting accuracy could not be increased. As a result of studying previous studies, the current study aims to eliminate this shortcoming, namely to develop and propose a block diagram of MATLAB Simulink model that will be better than the previous ones.

EXPRIMENTAL MEASUREMENT

Tests were conducted in a horizontal, glass-walled rectangular laboratory channel 12 m long, 50 cm wide, and 45 cm deep. Discharge was measured by a pre-calibrated sharp-crested weir at the inlet of the channel. Water surface levels are measured at any section of the channel by an accurate point gauge, as shown in Figure 1. On a submerged dam model of 26 cm depth, 50 cm width, and 8 cm side thickness made of a thermo-stone supported by an inclined surface at 16° and 25.4° slope with the channel surface, 60 experiments were conducted. A general view of the laboratory channel with one of the weir models is shown in Figure 2. For the two models the following data has been measured:

- h_o – represents the depth of water in the channel's side basin,
- Y_1 – represents the depth of water in front of the jump,
- Y_2 – represents the depth of water behind the jump,
- L_j – represents the hydraulic jump length,
- D_j – represents a hydraulic leap from the submerged dam.

Formula for calculating velocity [15]:

$$V = \frac{Q}{y.B} \tag{1}$$

To calculate the discharge:

$$Q = \frac{K \times {h_0}^{5/2}}{60} \tag{2}$$

where:

$$K = 81.44 + (0.24/h_o) - (6.81 \times h_o) + 47.34 \times {h_o}^2 \tag{3}$$

Velocity head h:

$$h = \frac{V^2}{2g} \tag{4}$$

Froude number is:

$$Fr = \frac{V}{\sqrt{gy}} \tag{5}$$

To calculate the total energy:

$$E = y + \frac{V^2}{2g} \tag{6}$$

Then,

$$E\% = \left(\frac{E1 - E2}{E1}\right) \times 100\% \tag{7}$$

Fig. 1. Laboratory channels

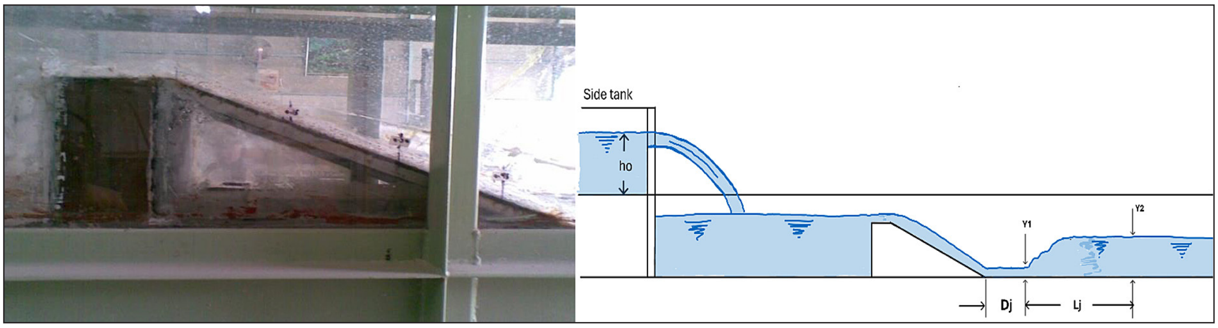

Fig. 2. General view of the laboratory channel with one of the weir models

In the laboratory work, the two models were examined to study the effect of the slope of the submerged dam in the downward direction. The length of the hydraulic jump and the depth of the water were measured at the beginning and end of the jump, and then the Froude number was calculated and the relationship among the water discharge and the energy dissipation was drawn for both models in Figure 3. It is found that the maximum value for Fr_1 = 7.705 with a discharge of 0.015 m^2/s, while this value reached 9.025 at the same discharge using a model of a submerged dam at an angle of 16° in the downstream. It was also found that the value of *Lj* decreases clearly with the increase in the value of the Froude number, which means an increase in the percentage of energy dissipation (*E*%). Figure 4 shows the relationship among *E*% and F_r. It is found that *E*% is increasing and has reached 68% for the model at an angle of 16°. The relationship between F_r and the length of the hydraulic jump L_j was drawn in Figure 5.

MODELING AND SIMULATIONS

In recent years, MATLAB Simulink has considered as one of the most widely-used software for modelling and simulation for dynamic systems and validating simple mathematical models (Ahmad and Abdul-Hussain, 2017; Behbahani-Nejad and Bagheri, 2010). Modeling and simulation systems has grown in recent years, providing easier access to user in design, construct, and verify mathematical models. A block diagram of the MATLAB Simulink model, has been built as shown in Figure 6, to show how these factors in equations (1, 2, 3, and 4) affected the energy dissipation. The Simulink model is versatile and applicable to a wide range of hydraulic irrigation structures. In this study the Simulink model was tested using the laboratory data obtained from experiments, the depth of the water (h) was measured at the side basin of the channel and the discharge (Q) represent the inputs while the energy value represents the output of the circuit. This Simulink model can be

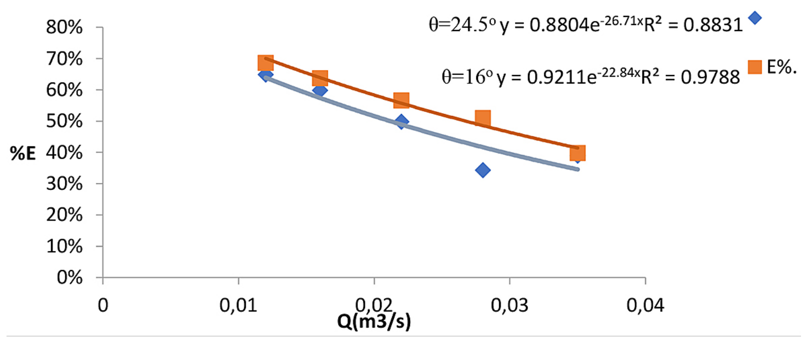

Fig. 3. The discharge with percentage energy dissipation for the two models

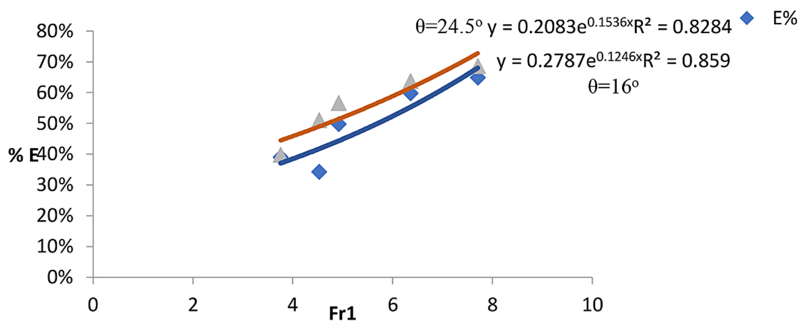

Fig. 4. Froude No.1 with percentage energy dissipation correlation for the two models

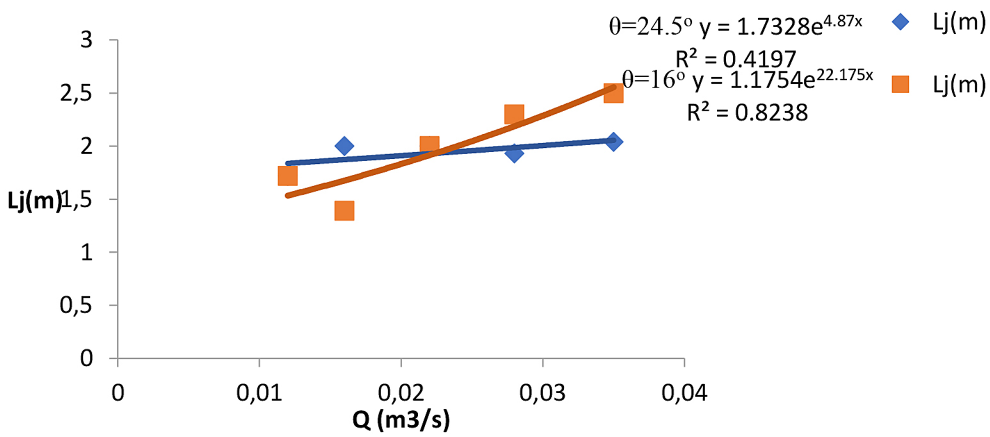

Fig. 5. The discharge with the length of the hydraulic jump for the two models

utilized in a variety of research projects in this sector because it reduces the time spent solving equations. The computational fluid dynamics application was used to construct longitudinal sections of flow over the two models. Figures 7 and 8 demonstrate the theoretical findings obtained from (CFD) for each discharge.

DISCUSSION

In the study of Ahmad and Srisvastava (2014), the Matlab Simulink model used, and the accuracy of their forecast was at the level good. At the same time, the model developed in the current study showed the best result in forecasting the energy dissipation of flow over submerged dams. This was achieved by using a new technology that included a block diagram of the MATLAB simulation model. In another study Mojtahedi et al. (2020), the proposed model required a long time to solve the problem, in contrast to this model, which requires several seconds to show the result. In the study Behbahani-Nejad and Bagheri (2010), scientists used the Matlab Simulink model method to build

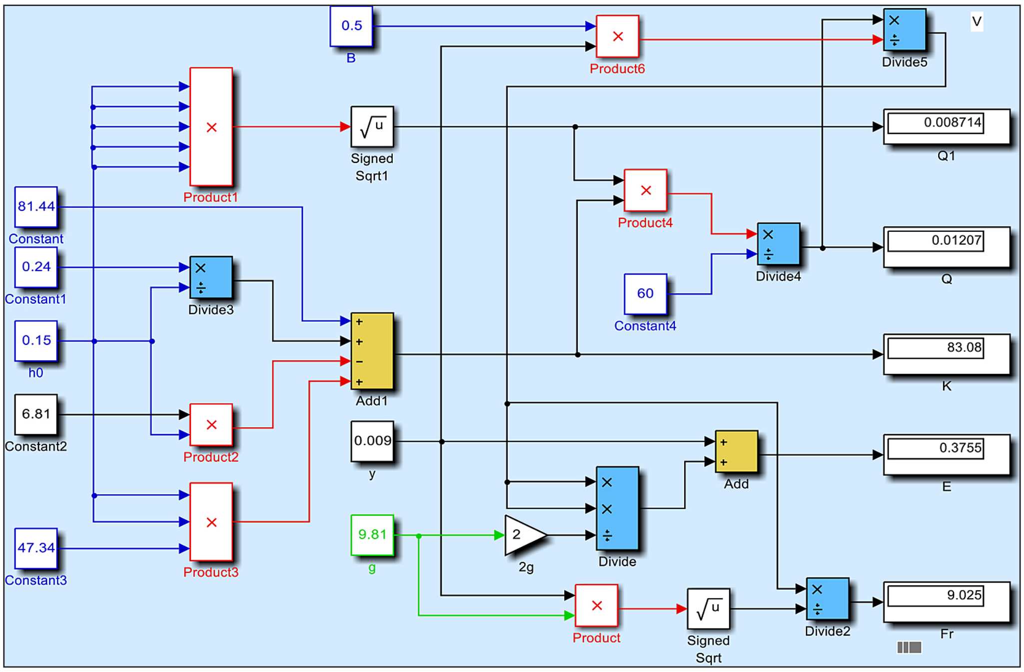

Fig. 6. Block diagram of MATLAB Simulink

Table 1. Laboratory data for a submerged dam with downstream slop of 24.5°

Run No.	*h* (m)	Q (m³/s)	y_1 (m)	F_{r1}	E_1	y_2 (m)	F_{r2}	E_2	*E* (%)
1.	0.230	0.035	0.033	3.775	0.267	0.160	0.120	0.170	36
2.	0.210	0.028	0.025	4.517	0.281	0.148	0.098	0.155	45
3.	0.190	0.022	0.020	4.959	0.265	0.130	0.165	0.136	49
4.	0.170	0.016	0.014	6.071	0.281	0.117	0.193	0.121	57
5.	0.150	0.012	0.010	7.879	0.316	0.105	0.227	0.108	66

Table 2. Data for a submerged dam with downstream slop of 24.5° from simulation model

Run No.	*h* (m)	Q (m³/s)	y_1 (m)	F_{r1}	E_1	y_2 (m)	F_{r2}	E_2	%*E* (%)
1.	0.230	0.035	0.033	3.757	0.266	0.160	0.120	0.161	39
2.	0.210	0.028	0.025	4.530	0.281	0.148	0.098	0.185	34
3.	0.190	0.022	0.020	4.921	0.262	0.130	0.164	0.132	50
4.	0.170	0.016	0.014	6.360	0.297	0.117	0.193	0.120	59
5.	0.150	0.012	0.010	7.705	0.307	0.105	0.227	0.108	64

Table 3. Laboratory data for a submerged dam with downstream slop of 16°

Run No.	*h* (m)	Q (m³/s)	y_1 (m)	F_{r1}	E_1	y_2 (m)	F_{r2}	E_2	*E* (%)
1	0.230	0.035	0.033	3.720	0.263	0.159	0.122	0.169	36
2	0.210	0.028	0.025	4.517	0.281	0.148	0.155	0.155	45
3	0.190	0.022	0.018	5.550	0.303	0.136	0.160	0.141	53
4	0.170	0.016	0.013	6.762	0.321	0.122	0.183	0.126	61
5	0.150	0.012	0.009	8.491	0.347	0.108	0.220	0.111	68

the block diagram to show that the proposed simulation extremely reduces the computational time compared the other numerical schemes. The model was tested for several cases and realistic practical models, and the method proved efficient and accurate, with an error rate of less than 1%.

Table 4. Data for a submerged dam with downstream slop of 16° from simulation model

Run No.	h (m)	Q (m³/s)	y_1 (m)	F_{r1}	E_1	y_2 (m)	F_{r2}	E_2	E (%)
1	0.230	0.035	0.033	3.757	0.266	0.159	0.121	0.160	40
2	0.210	0.028	0.025	4.530	0.281	0.148	0.154	0.137	51
3	0.190	0.022	0.018	5.769	0.317	0.136	0.154	0.138	56
4	0.170	0.016	0.013	7.106	0.341	0.122	0.181	0.124	64
5	0.150	0.012	0.009	9.025	0.376	0.108	0.217	0.111	69

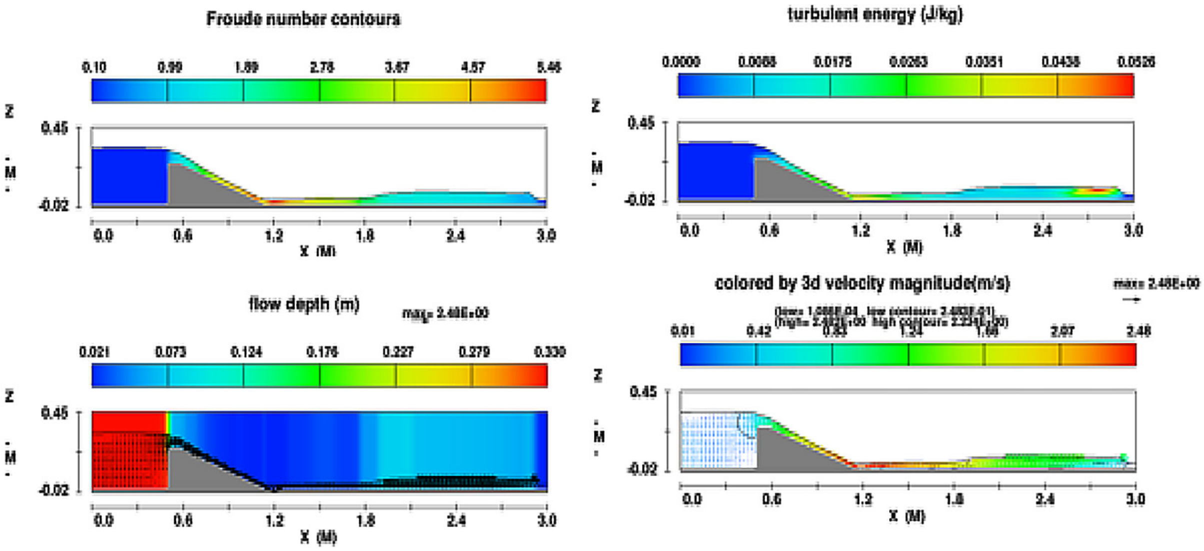

Fig. 7. Surface profile using CFD for Q = 0.03 m³/s

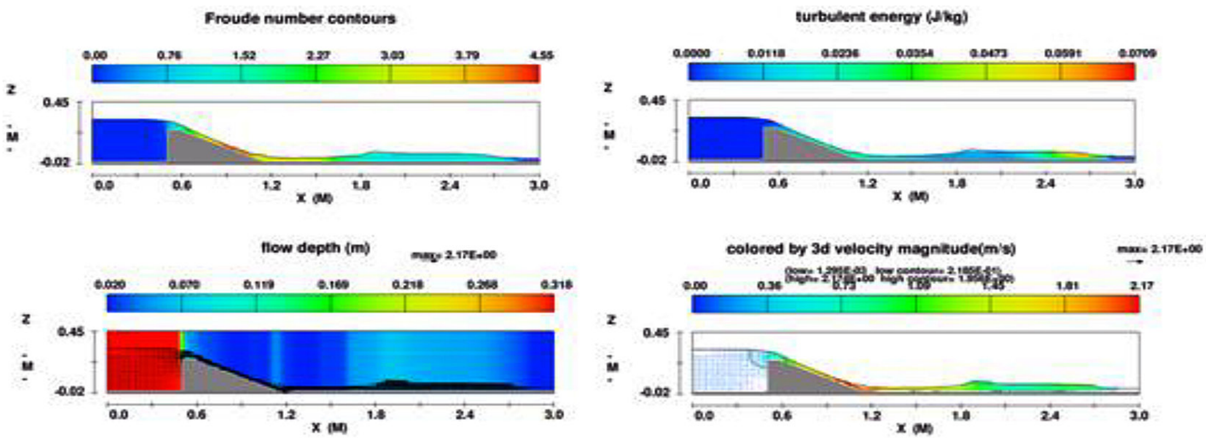

Fig. 8. Surface profile using CFD for Q = 0.028 m³/s

CONCLUSIONS

The current study aimed at comparing the energy dissipation of flow over submerged dams using both MATLAB Simulink simulation and laboratory experimentation, added to that, the use of physical model of the submerged dam with the help of an inclined plan with downstream angles of 16° and 24.5°. the results of both remarkable method were analyzed and compared to specify the accuracy and reliability of the simulation. The results indicated that the MATLAB Simulink simulation model effectively predicted the energy dissipation over submerged dams. This simulation model was capable to providing significant insight and revealing main critical information about the valued efficiency of dam design. It can be noted that the relation between the flow dissipation rate and (Fr1) can be observed the flow dissipation ratio is clearly increased by creasing (Fr1) at the minimum discharge. Being a part of the study, the Laboratory experiment has proved to be more reliable and valid. However, the experiment was based on time-consuming and demanded particular essential resource to carry out, making it less cost-effective than simulation-based approached. Moreover, this useful comparative study shed some sufficient light on the distinctive benefit of using MATLAB Simulink simulation models over laboratory experimentation. Furthermore, it can be observed that the simulation can be carried out repeatedly to perform optimizations and analyzed various design scenarios. It can be seriously concluded that this useful study mainly reveals the potential of simulation-based approaches such as MATLAB Simulink for assessing the required performance of major complex systems. Last but not least, the fundamental simulation models can be adopted to help researchers to investigate many different situation and scenarios and it can necessarily assess the design and operational efficiency of the system without the use of costly and time-consuming experiments.

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