Application of Logic Fuzzy Method to Estimate Hydraulic Jump Characteristics in Divergent Rectangular Section on Inverse Slope

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ABSTRACT: Stilling basins are the important energy dissipater placed at the end of spillways and any source of supercritical flow to control the hydraulic jump. Due to its importance and high construction cost modeling of stilling basins are necessary prior to construction. Physical modeling of stilling basins are time consuming and costly, therefore up until now attempt was made to relate hydraulic jump characteristics such as jump length, energy loss etc., to the parameters such as Fraude number, divergence and the inverse slope. In this study hydraulic jump characteristics such as jump length and energy loss in divergent rectangular sections on inverse slopes were modeled as a function of Fraude number, angle of divergence and inverse bed slope, using Logic Fuzzy Method (LFM). The accuracy of the model in estimating different hydraulic parameters was also verified. The results obtained indicated that the model is capable of predicting hydraulic parameters with high accuracy. Furthermore the weight of each parameter in estimating hydraulic characteristics was determined. Data Fit software was used to produce relationships between the parameters. The relationships found to be accurate enough to predict the hydraulic jump characteristics.

Key words: Hydraulic jump, Logic Fuzzy Method, Inverse Slope and Divergent Channel Sections.

INTRODUCTION

Given the importance of determining the exact design and dimensions of pool relaxation in supercritical flow control and and depreciation of its energy, While creating a hydraulic jump phenomenon in the lower structures, such spillovers, fast water and valves, Predict the structural properties of these phenomena need to be designed according to the dimensions. One method of determining the profile dimensions and design characteristics of the hydraulic jump basin relaxation model in the lab is to design desired. Given that this experimental model is time-consuming and high cost and On the other hand, in some cases due to limited conditions in the laboratory cannot be run on some models. In many cases the initial study design, the existing empirical relationships are used. Regardless of the complexity of these relationships, An issue that should be considered in their use, Is that any empirical relationships may be considering a set of assumptions is obtained in the laboratory and If this hypothesis is not considered the use of existing relationships, Estimates that there may properly be placed in an aura of ambiguity. Designed to calm ponds, secondary depth and length are important parameters of the hydraulic jump that Using these figures could be bottom of the depth and length of the pool's design. The hydraulic jump in rectangular sections, the secondary depth using theoretical relationships derived from the laws of continuity and momentum are calculated. The long jump and the amount of energy it can be determined by resulted equations. But Non-rectangular cross section in particular predicted diverging characteristics of hydraulic jump, just consider the simple hypothesis will be possible (verki,2005). Hydraulic jump from 1820, which was evaluated by Bedoon. (Abrishami,2005) Since many studies have been done on this phenomenon. (Klvsyvs and Ahmad,1961) assuming a linear variation between primary and secondary depth jump in a rectangular cross section diverges and Using the laws of continuity, energy and momentum, Relationship to depth ratio of secondary to primary energy loss of depth offered. (Arbeha-bahirama and Abla,1971), Their characteristics of hydraulic jump with a fourth oval is considered to have a profile and offered Relationship to depth ratio of secondary to primary energy loss of depth. (Khalifa and Mac Krokdal, 1979) with regard to radial flow lines, deep ties to the energy loss of primary and secondary depth in rectangular channels offered divergent. The jump in the pool with a reverse slope by Rose (Chamani & Beyramie, 2006)
and (Stevens ,1944) studied and then (KhedroJagubal,1972). (Abrishami and Saneie,1994) continued that led to the empirical relations. (Posey- Hsing 1938), the slope side of the jump in the pool to check the traps. Quoting (Omid Ismaili 1984). With regard to the content above, the application of simple mathematical models that can solve problems in different conditions are related to the hydraulic jump, help to design more accurate the ponds will be relaxed in different modes. In a recent article, I have been using fuzzy logic model that is widely used in various sciences such as hydraulic engineering, Model can be presented that Using the properties of hydraulic jump in rectangular cross-section diverges with the inverse slope is predicted with great accuracy.

**Fuzzy Logic**

Fuzzy theory was proposed first by LotfiZadeh. Fuzzy inference system in 1975 as one of the branches of fuzzy theory, by obtain and later in 1986 by Takagy, Sugino and Kung were presented. The fuzzy model consists of three parts: the input parameters, the fuzzy rules of inference and output parameters. Fuzzy models of different ways to describe the input and output and how compound Pramthay uses rules to conclusions. Fuzzy models, as input variables are considered expressive fuzzy rules and fuzzy (if the line was away with), then the output of the fuzzy terms are defined as variables, are connected. So, using the rules of the relationship between input variables to output variables achieved. Fuzzy logic is a great feature that deals with fuzzy sets , That sets its members to determine their membership have only two values True and False. The infinity between these two modes are that Membership and membership functions are defined by degrees. Membership function values to a set of linguistic variables and values are recorded. Then, the linguistic variables based on the rules they have been produced Are used to derive the fuzzy control. Finally, for the system under control, the exits are used. The secret to successful is in fuzzy systems, implementation simplicity, ease of understanding, stability in storage and cheap. Two major deficiencies of fuzzy systems, a lack of learning capabilities in these systems and the other is not always easy to determine and adjust the membership function. Of course, the latter depends on the level of understanding of the system is under review. Fuzzy systems are estimated to result, especially in systems that are difficult to create mathematical models are useful. In this study, the data is sub classified folder layout-c were used. First by Dunn (1973) and then Bazdak (1981), clustering-c was developed. This method extends the form of hard-average clustering c (HCM) is method that Data is very useful method for fuzzy clustering. In general, the results of fuzzy clustering with classical clustering is a membership degree in fuzzy clustering, a minor point in more than one group has . The membership degree of a given number belongs to a category can range from (0, 1) is. In this way, the set of matrices Afrazfazy, M for sorting n data sets be defined c.

\[
M = \left\{ U \left| \mu_k \in [0,1], \sum_{i=1}^{n} \mu_k = 1, 0 < \sum_{k=1}^{n} \mu_k < n \right. \right\}
\]  

So that \( i = 1,2,3, \ldots, c \) and \( k = 1,2, \ldots, n \) for each \( \mu \in MA \) fraz fuzzy a-c are characterized by overlapping categories will follow and To describe the degree of memberships an infinite amount may be considered. Thus, M is an infinite subset (9). In this way, the first step is to model that Based on the number of measured data (about 70% of data) is done. Secondly, the model with measured values of about 20 to 30 percent, are verified. With the help of fuzzy logic in modeling, Depending on the input variables and their relationship with the desired parameters of the model is, About 10% of the data to test and evaluate the model and estimate the critical points such as point or points of maximum and minimum of a curve are used. The training model to a model of training is required.

**Methodology**

The training model to a model of training is required. To this end, the results of tests conducted on the phenomenon of hydraulic jump in rectangular sections diverges with an inverse slope of the hydraulic tests were performed at Tabriz University, was used. In total, 160 series of data for modeling were obtained. This information includes the depth, the depth of primary, secondary energy failure is a long jump for For divergence angles of 0 to 25 degree reverse slope and Froude number 2.6 to 6 0 to 6.7%. As already mentioned, The purpose of this research is Model specification includes hydraulic jump conjugate depth ratio and the ratio of length to depth ratio of primary energy to energy loss of primary and proportion to the depth of the secondary in rectangular cross-section diverges with an inverse slope that initial Froude number and slope parameters as a function of divergence angle of the floor and is using fuzzy logic. Therefore, the following functions can be considered.

\[
\frac{y_2}{y_1} = f_i(Fr_i, \alpha, \theta)
\]  

\[
\begin{align*}
L_j &= f_2(F_r, \alpha, \theta) \quad (3) \\
y_1 \\
L_j &= f_3(F_r, \alpha, \theta) \quad (4) \\
y_2 \\
E_j &= f_4(F_r, \alpha, \theta) \quad (5) \\
E_1 
\end{align*}
\]

In these equations, the initial depth equal to \(y_1\) and \(y_2\) equal to the depth of secondary jump and long jump \(L_j\) and the Froude number \(F_r\) and the divergence angle \(\alpha\) and \(\theta\) equal to the inverse slope of the floor are equal. It should be noted that to use the model for all systems, Hydraulic profile of the study is considered to be dimensionless. Among 160 cases of data measured, 110 series for 30 series and 20 series for the final test model was verified. Also, using existing data and model results in determining the significance of each parameter in the estimation of hydraulic properties. The hydraulic jump hydraulic relations for the profile in this study as a function of the parameters were extracted using Data Fit software.

RESULTS AND DISCUSSION

In order to accurately determine and analyze the hydraulic jump profile in the research lab and estimated by the model, the statistical methods that were used are presented below.

1- R2 and \(\alpha\) are respectively the squared correlation coefficient and slope of the regression line (\(\alpha = \frac{\sum mi}{\sum pi}\)). Forecast accuracy of each parameter depends on the above parameters. In this case, the R2 and \(\alpha\) are closer to 1, then the relationship can better estimate the compression index values.

2- Percent error (% \(E\)) which is defined as follows.

\[
\% E = \frac{\sum \left| C_{mi} - C_{pi} \right|}{\sum C_{mi}} \times 100 \quad (6)
\]

3- The mean square value of square error (RMSE) which is defined as follows.

\[
RMSE = \sqrt{\frac{\sum (C_{mi} - C_{pi})^2}{N}} \quad (7)
\]

In this relation, \(n\) = number of data, \(C_m\) = hydraulic properties measured in the laboratory, \(C_p\) = the amount of estimated hydraulic properties of fuzzy logic.

Statistical results of the survey and testing procedures and health education for measured for data in the laboratory by fuzzy logic for hydraulic profile will be checked. And the average of these three steps for each of them is presented in Table 1.

<table>
<thead>
<tr>
<th>(RMSE)</th>
<th>(% E)</th>
<th>(\alpha)</th>
<th>(R^2)</th>
<th>Hydraulic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>4.29</td>
<td>1.01</td>
<td>0.97</td>
<td>(y_2) (y_1)</td>
</tr>
<tr>
<td>0.06</td>
<td>8.58</td>
<td>1.01</td>
<td>0.90</td>
<td>(L_j) (y_1)</td>
</tr>
<tr>
<td>0.04</td>
<td>4.94</td>
<td>1.03</td>
<td>0.96</td>
<td>(E_j) (E_1)</td>
</tr>
<tr>
<td>0.07</td>
<td>10.78</td>
<td>0.97</td>
<td>0.89</td>
<td>(L_j) (y_2)</td>
</tr>
</tbody>
</table>

Due to the hydraulic characteristics (\(y_2/y_1\)) with higher accuracy and the error is less than the other. The model accuracy in estimating the hydraulic properties (\(E_j/E_1\)) is also fairly good. On the other hand, (\(L_j/y_2\))
and (Lj/y1) with higher accuracy and less error than the other. This could be due to read error during the tests due to the turmoil, he said. Another method has been used in Table 2, where Cp and Cm is the hydraulic profile of the hydraulic profile is measured. In this table, hydraulic profile in the range C = ± 20% change is mentioned, so as to better judge the forecasting model. The numbers in the table are in percentage (y2/y1) with 98% of predicted in the range of exposure modes have the highest accuracy (Lj/y2) with 78% of predicted values with the lowest accuracy is. In general, fuzzy logic can be used to predict the hydraulic profile with very high accuracy.

<table>
<thead>
<tr>
<th>Cp/Cm</th>
<th>Percentage of predicted hydraulic profile desired by fuzzy logic in the range 20% ±</th>
<th>hydraulic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1</td>
<td>6 89</td>
<td>E_j/E_i</td>
</tr>
<tr>
<td>0.8 ≤ Cp/Cm ≤ 1.2</td>
<td>13 84</td>
<td>L_j/y1</td>
</tr>
<tr>
<td>&lt;0.8</td>
<td>12 78</td>
<td>L_j/y2</td>
</tr>
<tr>
<td>&lt;0.8</td>
<td>2 98</td>
<td>y2/y1</td>
</tr>
</tbody>
</table>

In Figures 1 to 4, hydraulic profile of the desired values measured in the laboratory and the estimated model is shown in the test procedure. Given these figures, as can be observed very good correlation between measured and calculated values by model exists.

![Figure 1](image1.png)

Figure 1. Calculate the hydraulic characteristics (y2/y1) measured in the routine test network.
Figure 2. Calculate the hydraulic characteristics ($L_i/y_2$) measured in the routine test network.

Figure 3. Calculate the hydraulic characteristics ($E_j/E_1$) measured in the routine test network.
After implementing the fuzzy logic model, the estimation of parameters in each of the hydraulic characteristics of the study, was evaluated. Importance of each parameter results in terms of participation in the creation of fuzzy logic is presented in Table 3.

As can be seen in the table, estimate the hydraulic profile (y2/y1), (Ej/E1) and (Lj/y1) most important parameter Fr1 (initial Froude number) with a value of about 80 percent and 50 percent and 45 percent and the hydraulic characteristics (Lj/y2), with a turnout of around 57% of the parameter α is capable of. Also, the parameter θ with the lowest value of about 6 percent and 21 percent and 10 percent and 12 percent for hydraulic profile (y2/y1), (Ej/E1) and (Lj/y2) is required. It should be noted that the predicted hydraulic characteristics (Lj/y1) and (Lj/y2) by model, The significance level α (angular divergence) having a value of about 43 percent and 57 percent for this profile is greater than Parameter θ (the inverse slope of the floor) with a value of about 10 percent and 12 percent.

<table>
<thead>
<tr>
<th>Importance of parameters</th>
<th>α</th>
<th>y_2/y_1</th>
<th>(Ej/E_1)</th>
<th>(Lj/y_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fr1</td>
<td>79.17</td>
<td>6.21</td>
<td>14.62</td>
<td>82.21</td>
</tr>
<tr>
<td>θ</td>
<td>49.05</td>
<td>21.12</td>
<td>29.83</td>
<td>49.05</td>
</tr>
<tr>
<td>α</td>
<td>45.45</td>
<td>10.78</td>
<td>43.77</td>
<td>57.54</td>
</tr>
<tr>
<td></td>
<td>29.58</td>
<td>12.88</td>
<td>57.54</td>
<td>45.45</td>
</tr>
</tbody>
</table>

After determining the parameters considered by Moore logic model phase, the estimation of hydraulic profile, and also using the data collected, the derived relations to determine the hydraulic profile of the Data Fit software.

This is the first software for each of the hydraulic profile, a function that is capable of predicting the properties to be determined with high precision. The functions for hydraulic profile (y2/y1) and (Lj/y1), and the exponential function for hydraulic profile (Ej/E1) and (Lj/y2) is a linear function as follows.
Given the constant coefficients in the above relations, can be seen that the Data Fit software based on the percentage of effective parameters in the forecasts has a lower coefficient that Fuzzy logic was determined by the effective parameters with a higher coefficient and the parameters that have less impact. To determine the accuracy of these relations in the hydraulic profile of the study, the results of statistical analysis are presented in Table 4 that Hydraulic profile with reasonable accuracy are desired.

<table>
<thead>
<tr>
<th>RMSE</th>
<th>%E</th>
<th>α</th>
<th>R²</th>
<th>hydraulic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.06</td>
<td>5.27</td>
<td>1.05</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>0.09</td>
<td>12.58</td>
<td>1.14</td>
<td>0.80</td>
<td>( \frac{L_j}{y_1} )</td>
</tr>
<tr>
<td>0.10</td>
<td>6.94</td>
<td>0.74</td>
<td>0.83</td>
<td>( \frac{E_j}{E_1} )</td>
</tr>
<tr>
<td>0.07</td>
<td>5.78</td>
<td>0.98</td>
<td>0.95</td>
<td>( \frac{L_j}{y_2} )</td>
</tr>
</tbody>
</table>

**RESULTS**

In this study some properties of the hydraulic jump as dimensionless ratios include \( \frac{y_2}{y_1} \), \( \frac{L_j}{y_1} \), \( \frac{E_j}{E_1} \) and \( \frac{L_j}{y_2} \) by fuzzy logic based on the model parameters \( \alpha \) and \( \theta \) and \( Fr_1 \) each of these characteristics in the model accuracy was estimated based on the desired parameters have been investigated.

The results of this research:

1. Fuzzy logic is able to accurately predict the hydraulic properties is very high
2. The hydraulic profile in this model \( \frac{y_2}{y_1} \) with higher precision \( \frac{L_j}{y_2} \) can be estimated with accuracy lower than other specifications.
3. Most effective in predicting the properties of hydraulic parameters \( \frac{y_2}{y_1} \), \( \frac{L_j}{y_1} \) and \( \frac{E_j}{E_1} \) \( Fr_1 \) parameter in predicting hydraulic characteristics \( \frac{L_j}{y_2} \) is having the greatest impact parameter \( \alpha \).
4. A parameter in predicting the hydraulic profile \( \frac{L_j}{y_1} \) and \( \frac{L_j}{y_2} \) parameter \( \theta \) is more of an impact.
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