Jurnal Teknologi, 52 Mei 2010: 41–48

APPLICATION OF FUZZY LOGIC IN THE ASSESSMENT OF RIVER FLOW CHARACTERISTICS AT THE PIER SCOUR

PONSELVI JEEVARAGAGAM[1*], AHMAD KHAIRI[2] & TAHIR AHMAD[3]

Abstract. Currently, there is no well-established technique for a bridge inspector to follow when assessing the river flow effect to the scour depth at a bridge pier. The assessment of a bridge scour is normally based on subjective procedures that are costly, time consuming, uncertain and has a personal bias. Therefore, the purpose of this research is to propose the fuzzy logic technique in assessing the river flow characteristics at the upstream of the bridge (flow depth (Y_1); discharge (Q_1); velocity (V_1); and flow area (A_1)), which are resulted scouring at the pier foundation. In order to achieve the objective of this research, an example problem is presented to illustrate the use of the proposed methodology on a hypothetical bridge model across Cherul River at Ban Ho, Terengganu, Malaysia. From the research, the severity of scour condition at the pier foundation can be determined and this information will be useful for a bridge engineer to provide the relevant countermeasure or prevention method. Finally, this approach can assist a bridge engineer in making a rational decision for carrying out the bridge maintenance programme based on data taken from regular bridge inspection.

Keywords: Bridge scour assessment; pier scour condition; river flow effects; uniform decision-making model; uncertainty modeling

Abstrak. Pada masa kini, tiada pembangunan teknik yang rasional untuk seseorang jurutera jambatan mengikutinya sebagai panduan apabila menilai kesan kerokan disebabkan aliran sungai pada penapak tiang jambatan. Biasanya penilaian kerokan pada jambatan adalah berdasarkan prosedur subjektif yang mana kosnya adalah mahal, pengambilan masa, ketidakpastian dan mempunyai bias oleh seseorang individu. Oleh itu, tujuan penyelidikan ini adalah untuk memperkenalkan teknik logik kabur dalam menilai sifat-sifat aliran sungai pada hulu jambatan (kedalaman aliran (Y_1); kadaralir (Q_1); kelajuan (V_1); dan luas aliran (A_1)), yang mana menyebabkan kerokan pada penapak tiang jambatan. Dalam mencapai objektif kajian ini, satu contoh masalah telah diperkenalkan untuk menggambarkan penggunaan metodologi terhadap hipotesis model jambatan yang merentangi Sungai Cherul di Ban Ho, Terengganu, Malaysia. Daripada penyelidikan ini, tahap keadaaan kerokan pada penapak tiang boleh ditentukan dan maklumat ini dapat digunakan kelak oleh seseorang jurutera jambatan dalam menyediakan kaedah kawalan yang sesuai. Seterusnya, kaedah ini boleh membantu jurutera jambatan untuk membuat keputusan yang lebih rasional semasa menjalankan program pembaikan jambatan berdasarkan data pengawasan jambatan.

Kata kunci: Penilaian kerokan jambatan; keadaan kerokan tiang jambatan; kesan aliran sungai; model kata putus seragam; permodelan ketidakpastian

---

[1–3] Information Technology Unit (ITUCE), Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, 81310 Johor Bahru, Malaysia
* Corresponding author: Email: Ponselvi@fka.utm.my

1.0 INTRODUCTION

Usually, after the completion of a bridge construction, a regular inspection and maintenance programme must be carried out. This is to ensure that the bridge foundation is always in a serviceable state. Exposure or undermining of the bridge foundation can endanger the stability of the overall bridge structure, causing transportation problems and even loss of life.

Generally, the pier and abutment scouring can be more significant during flood events because the accelerated flow has more energy and higher turbulence to lift and transport soils and rocks. A study by Chang [1] for the Federal Highway Administration United States (FHWA) concluded that there are about 383 bridge failures out of the 950 bridges inspected in the USA. They include 25 percent involving pier and 72 percent involving abutment damages. A study conducted by Brice *et al.* [2] indicated that the problem of local scour at bridge piers to be of almost equal magnitude to abutment scour problems. The collapse of the Interstate 90 crossing of Schoharie Creek near Amsterdam, New York, on April 5, 1987 is one of the most severe bridge scour failures in the United States. U.S. Geological Survey [3] reported the accident claimed 10 lives. In 1993, floods in the upper Mississippi basin caused 23 bridge failures and in 1994, flooding from storm Alberto in Georgia, caused scour damages to over 500 state and locally owned bridges [4]. Furthermore, for The National Axle Load Study (Phase II) 1990 conducted by JKR, Norzan [5] stated 5 out of the 58 bridges inspected to be having scouring problems. Abdul Aziz [6] also cited a few case histories of bridge failures caused by scour in Malaysia from unpublished sources such as Mercang Bridge, Bailey Bridge and the bridge across Sungai Sayong. The partial collapse of Mercang Bridge in Kelantan that occurred in 1983 was due to the collapse of the abutment that had been scoured by the changing regime of the river. The Bailey Bridge crossing Tuaran River, in Kota Kinabalu collapsed in June, 1994. Close inspection on this bridge indicated the possibility of pier scour that could be triggered by strong flow in the river as a result of heavy downpours. A bridge across Sungai Sayong in Johor collapsed due to local scour at one of the bridge piers

The bridge inspection work is commonly done by a small group of specialists. The problems encountered in bridge scour assessment works are numerous and often complex. The bridge inspector must know very well the relevant subject areas such as bridge scour, sediment transport, geotechnical condition (soil properties and subsurface soil), site investigation, structural condition (design and construction), hydraulic and hydrology conditions, operations and maintenance of the bridges. Furthermore, the bridge inspector has to evaluate the impact of scour depth at the bridge foundation to the overall stability of the bridge structure. Only then can the bridge inspector plans for a rational corrective maintenance programme and recommendations. Therefore, an advanced technique known as fuzzy logic can be applied to link the imprecise objective information and the subjective engineering judgement of the bridge inspector. This will lead to a rational and systematic approach to the solution. In this study, fuzzy logic technique will be used as a decision making tool for assessing the several conditions of river flow characteristics that resulted in the scour at the bridge pier foundation support. The river flow characteristics at the upstream section of the bridge pier are the flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1). This technique will also be used to determine the more significant river flow parameter at the pier foundation. Basically, the fuzzy system consists of four components namely database, fuzzification, defuzzification and recommendations.

This paper discusses some results of a study to determine the overall severity condition of pier supports due to river flow scouring. The overall severity condition was evaluated through examining the several severity membership conditions of flow characteristics at the upstream of bridge.

2.0 FUZZY MODELLING

In the study, bridge pier foundation with 6 m embedded length in a fine lateriate (D_{50} = 0.0055 mm) over Cherul River at Ban Ho, Terengganu, Malaysia was simulated and modeled. The total scour at the pier foundation was estimated from the scour prediction equations given by Richardson and Davis [4].

The effect of flow characteristics at the bridge pier scour was determined by applying the fuzzy logic via the membership functions. The membership function represents numerically the degree to which an element belongs to a set. When dealing with objective information, Zadeh [7] and Tahir Ahmad [8] mentioned that the degree of membership could take on values between 0 and 1. The membership functions presented in this study were developed on the basis of structural, geotechnical, hydrology and hydraulic analyses, sediment transportation and information extracted from the literatures and personal discussions. Therefore, the information contained in the fuzzy models was developed from past experiences and established theories in the field to scour engineering. They can constantly update with the most recent development. The various conditions of river flow characteristics occurred at the pier foundation were described through the membership functions. The magnitudes of flow characteristics and their membership values were determined and classified from the literature studies. Flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1) are the membership functions of flow characteristics at the upstream of the hypothetical bridge model as shown in Figure 1 to Figure 4.

2.1 Illustrative Example

An illustrative example is presented to demonstrate the use of fuzzy logic in the combined interaction of flow characteristics. The magnitude of flow characteristics is assumed at the upstream section of bridge: Flow depth (Y_1) = 1.20 m; Discharge (Q_1) = 24.40 m^3/s; Velocity (V_1) = 0.655 m/s; Flow area (A_1) = 37.27 m^2.

The condition of pier foundation in this hypothetical example is modelled, based on a combined effect of the flow depth (Y_1); discharge (Q_1); velocity (V_1); and flow area (A_1). The effects corresponded to the complete interaction of the severity of the flow characteristics. The combined assessment for this study is the modification of the assessment on the condition of concrete slab bridges conducted by Tee *et al.* [9]. Firstly, let A, B, C, and D stand for the fuzzy sets representing flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1), respectively. The effect of each flow characteristics acting individually is indicated by the union of fuzzy sets of A, B, C and D.

Whereas, the effect of all the flow characteristics acting together is given by their algebraic sum and it is set as shown in Equation 1:

$$\mu_{A \cup B \cup C \cup D} \leq \mu_E \leq \mu_{A+B+C+D} \qquad \text{(Equation 1)}$$

Where, μ_A, μ_B, μ_C, μ_D, and μ_E are the grades of membership for fuzzy sets A, B, C, D and E, respectively.

By using the severity of flow characteristics and their membership functions, the overall flow condition is determined. From Figure 1, the flow depth (Y_1) with value of 1.20 m has 0.45 as its membership grade for "medium", 0.08 for "low" and 0 membership grade for both "high" and "very high" conditions. In this manner, the "medium" flow condition at the pier foundation is evaluated for all the severities of flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1) such as follows:

$$\mu_{vp}(A) = 0.45$$

$$\mu_{vp}(B) = 0.39$$

$$\mu_{vp}(C) = 0.55$$

$$\mu_{vp}(D) = 0.43$$

Where, $\mu_{vp}(A)$, $\mu_{vp}(B)$, $\mu_{vp}(C)$, and $\mu_{vp}(D)$ are the grades of membership of evaluated all severities of fuzzy sets of flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1), respectively.

Then, the flow condition can be evaluated using the maximum values:

$$\mu_{A \cup B \cup C \cup D} = \max [\mu_{vp}(A), \mu_{vp}(B), \mu_{vp}(C), \mu_{vp}(D)]$$

$$= \max [0.45, 0.39, 0.55, 0.43] = 0.55$$

$$\mu_{A+B+C+D} = 1 - [1 - \mu_{vp}(A)]\,[1 - \mu_{vp}(B)]\,[1 - \mu_{vp}(C)] \times [1 - \mu_{vp}(D)]$$

$$= 1 - (1 - 0.45)\,(1 - 0.39)\,(1 - 0.55)\,(1 - 0.43) = 0.914$$

Consequently, the membership value for medium condition of river flow at the pier foundation classification falls in the range of $0.55 < \mu_{vp}(E) < 0.914$.

The lower and upper bound of fuzzy value such as 0.55 and 0.914 in this range can be viewed, as the degree of "belief" that the overall flow condition is medium. It resulted from interactions between flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1). The same procedure can be repeated to define the upper and lower limits of the remaining flow characteristics conditions. The grades of membership for the fuzzy sets A, B, C and D, and the upper and lower limits of fuzzy sets E are presented in Table 1 as illustrated in Figure 1 to Figure 4, respectively. Based on the Table 1 results, the highest membership value of algebraic sum for the overall flow

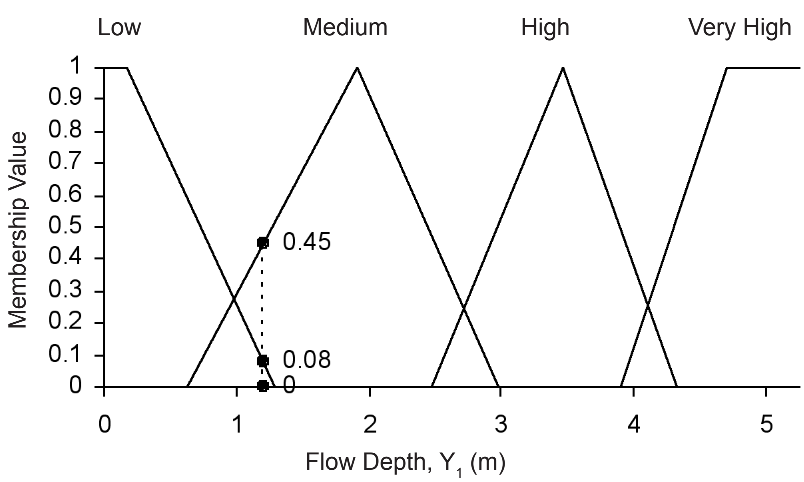

Figure 1 Flow depth (Y_1) membership function

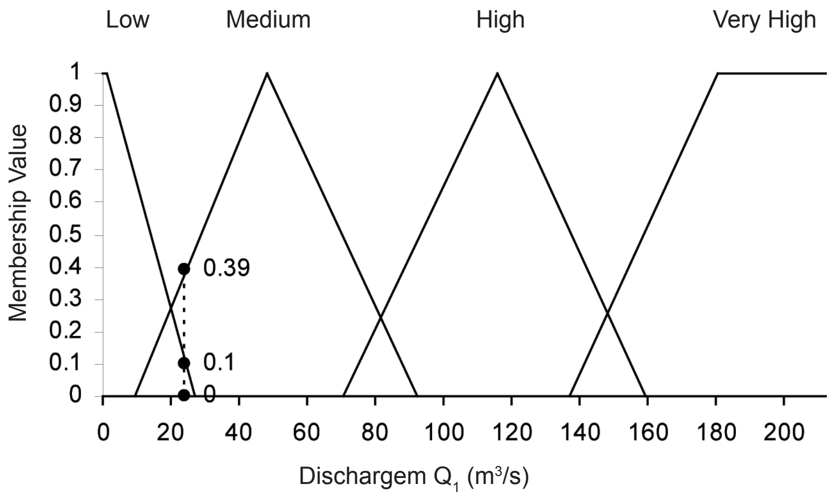

Figure 2 Discharge (Q_1) membership function

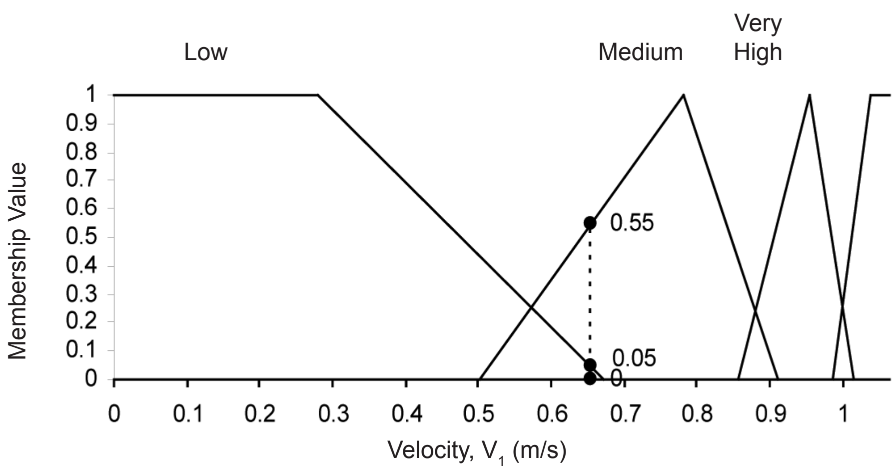

Figure 3 Velocity (V_1) membership function

condition at the pier foundation is 0.914, which is close to the "medium" condition of flow characteristics. Therefore, from the output rule of the uniform decision making, if the flow depth (Y_1) and; discharge (Q_1) and; velocity (V_1) and flow area (A_1) are in the medium condition then the pier foundation needs monitoring.

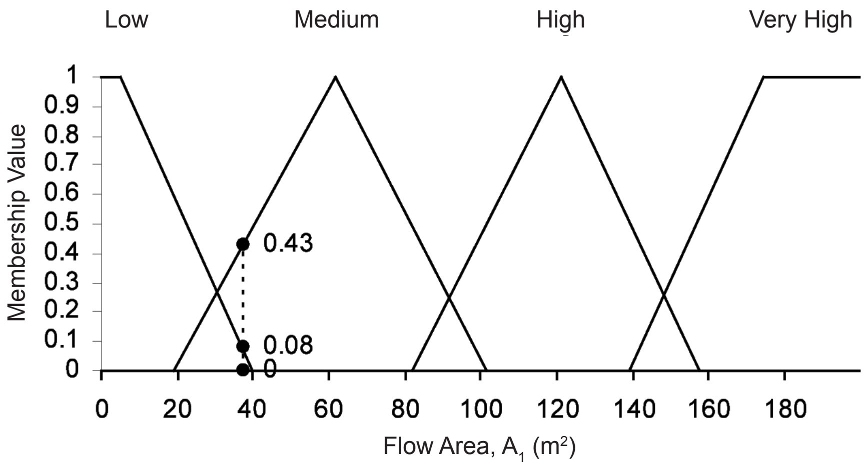

Figure 4 Flow area (A_1) membership function

Table 1 Flow condition membership grades for the pier foundation

Membership	Flow depth (Y_1), m	Discharge (Q_1), m^3/s	Velocity (V_1), m/s	Flow area (A_1), m^2	Union Sum	Algebraic
Very High	0	0	0	0	0	0
High	0	0	0	0	0	0
Medium	0.45	0.39	0.55	0.43	0.55	0.914
Low	0.08	0.10	0.05	0.08	0.10	0.276

3.0 CONCLUSION

Generally, the river flow characteristics that are causing scour at the pier support are flow depth (Y_1), discharge (Q_1), velocity (V_1) and flow area (A_1). By using fuzzy logic technique, the combined effect of flow characteristics resultant scour condition at the pier support can be assessed. However, the successful use of this fuzzy procedure is usually depended on the development of adequate membership functions. This proposed fuzzy model could be further formulated or improved later through knowledge gained from bridge engineer's experiences by monitoring on actual case of the bridge scour and from the proposed recommendations for the next step of actions.

REFERENCES

[1] Chang, F. F. M. 1973. A Statistical Summary of the Cause and Cost of Bridge Failures. Federal Highway Administration. USA.

[2] Brice, J. C. and J. C. Blodgett. 1978. Countermeasures for Hydraulics Problems at Bridges. Vol. 1 and 2. FHWA/RD-78-162 & 163. Federal Highway Administration Washington, D. C.

[3] U.S. Geological Survey. 1999. Scour at Schoharie Creek at Interstate 90 (west pier). [Online] Available From http://wwwdnyalb.er.usgs.gov/projects/scour/text.html, September 10.

[4] Richardson, E. V. and S. R. Davis. 1995. Evaluating Scour at Bridges. Hydraulic Engineering Circular No. 18 (HEC 18), Rep. No. FHWA-IP-90-17. 3. Federal Highway Administration, Washington, D. C.

[5] Norzan Mohd. Yusof. 1996. Bridge Appraisal Rehabilitation and Maintenance - General Failure of Malaysia Bridges From the Annual Mandatory Bridge Inspection Perspective. Unit Jambatan (Cawangan Jalan), Ibu Pejabat Jabatan Kerja Raya, Kuala Lumpur.

[6] Abdul Aziz Ibrahim. 1995. Malaysian Bridges Stability: An Eye Opener. Course on Bridge Scour. Coastal and Offshore Engineering Institute, Universiti Teknologi Malaysia. Malaysia. 10–12.

[7] Zadeh, L. A. 1965. Fuzzy Sets. *Information and Control*. 8: 338–353.

[8] Tahir Ahmad. 1998. Mathematical and Fuzzy Modelling of High-Speed Interconnections in Integrated Circuits. PhD. Thesis. Sheffield Hallam University, United Kingdom.

[9] Tee A. B., M. D. Bowman and K. C. Sinha. 1992. Application of Fuzzy Logic to Condition Assessment of Concrete Slab Bridges. Transportation Research Record 1184. 22–30.