Dam failure risk factor analysis using AHP method

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Abstract. Bukit Merah Dam is Malaysia’s oldest dam and the risk of failure probability is rising as the dam aging physically. The number and magnitude of maximal precipitations caused by changes in weather have been increasing and directly increase the likelihood of developing a dam failure. Risk analysis usually incorporates the theory of probability and the mathematical statistics to obtain the risk of dam failure within the framework of dam safety. However, the experience and judgment of the dam experts are not considered in determining the risk of dam failure. This study aims to determine the risk factor of Bukit Merah Dam through the Delphi technique and to assess the risk factor impacts due to dam failures using the AHP method. There are three risk factors or criteria highlighted in this research which are structural, human and natural. According to the results for the structural criteria, the priority is seepage where the final weight is 70.1%. For the human criteria, the priority is operational mismanagement with the final weight of 31.45%. Lastly, for the natural criteria, the priority is flooding from high precipitation with a final weight of 48.57%. From the consistency ratio, the CR for structural factor is 0.041 while for the human factor is 0.014 and for natural criteria is 0.019. As all the CR value for this criteria is less than 0.1, all participants’ evaluations about dam failure criteria are consistent. In conclusion, the dam operators need to be more vigilant to seepage, operational mismanagement and flooding from high precipitation factors of failure for Bukit Merah Dam.

1. Introduction
The dam is used to stop or restrict the flow of river water or underground streams. The dam can be a structure with a multipurpose scheme designed to conserve water resources related to domestic or industry water supply, hydroelectric power production, flood mitigation, agricultural development or for tourism purpose.

There are 51 dams in Malaysia but most of the dams are old dam structures [9]. The dam failure effect is very catastrophic and can cause destruction of properties and environment and huge loss of lives. In 2013, the tragedy and disaster in Bertam Valley, Cameron Highland, Malaysia had become an eye-opener for Malaysian people about the safety of the dam to the environment. Three people were dead, nearly 100 houses were destroyed and over 100 vehicles were damaged. Therefore, the security of the dam is vital for safeguarding human life, socioeconomic and the environment.

Current risk analysis applied mathematical and mechanical methods which are the conventional ways in evaluating dam failure risks. Standard-based approach [4], Event tree analysis method[3, 6] and
Structural Reliability Analysis (SRA) [7] are three common methods used in evaluating the risk factors of a dam. These methods are important for dam safety monitoring but these methods usually have no strong emphasis on the learning of experiences and expert knowledge.

AHP is a method that emphasizes the experience and knowledge of the dam experts to identify risk factors of a dam failure is introduced in this paper. The objectives of this study are to assess the risk factors of Bukit Merah Dam through Delphi Technique and to evaluate the risk factors of a dam failure using the Analytic Hierarchy Process (AHP) method. This study is useful to the dam operators in improving the level of safety of the dam and preserve the long term value of the dam.

2. Study area
Bukit Merah Dam is located about 24 km east of Bagan Serai town, a town in Kerian District, Perak. Bagan Serai town is situated approximately 16 km southeast of the district capital Parit Buntar. Figure 1 shows the location of the Bukit Merah Dam. The dam is located on the upstream of the confluence of Sungai Kurau and Sg. Merah at the upper catchment within the Sg. Kurau basin. It was constructed from 1902 to 1906. The functions of Bukit Merah Dam are primarily for irrigation use of paddy farms and domestic water supply. The drainage area basin is about 408 km² [2].

![Figure 1. Location of Bukit Merah Dam.](image)

3. Methodology
This study involved field survey and data analysis by using AHP. During the field survey, two rounds of Delphi surveys were distributed to eight dam experts. The return questionnaires were tabulated and analyzed by using AHP software.

3.1 Analytic Hierarchy Process (AHP) method
The first step in AHP is to model the problem as a hierarchy [5]. Figure 2 shows the structure of the hierarchy with a goal and a group of criteria which was further narrowed down into sub-criteria or semi-sub criteria, etc. [9]. In this hierarchy, the goal of this research is to determine the risk factor of Bukit Merah Dam. The criteria consist of three main factors which are structural, human and natural. These criterions were broken down into a few sub-criterions.
3.2 Pairwise comparison and comparison matrix

At each level of the hierarchy, the comparison in pairs of criteria or sub-criteria are expressed using the Saaty scale. It is a scale of relative importance level for qualitative data such as preference, rankings and subjective opinions with intensity from 1 to 9. Table 1 shows the scale of intensity of importance.

| Intensity of importance | Definition          | Explanation                                                                 |
|-------------------------|--------------------|------------------------------------------------------------------------------|
| 1                       | Equal importance   | Both components contribute equally to the objectives.                        |
| 3                       | Moderate importance| One element has a moderate advantage compared to the other.                  |
| 5                       | Strong importance  | Strong favouring of one element compared to the other.                       |
| 7                       | Very importance    | One element is strongly favoured and has domination in practice, compared to the other element. |
| 9                       | Extreme importance | One element is favoured in comparison with the other, based on strongly proved evidence and facts. |

After the result from the second round, the Delphi survey has been collected, the comparison matrix was determined. From this matrix, the normalized principle eigenvector (Wi) of individual criteria was determined to show the most contributing factors to the failure Bukit Merah Dam. The final step in the AHP method is to determine the consistency ratio (CR) of each criterion. The method of determining the consistency ratio is as follows:

i. Largest eigenvalue, $\lambda_{\text{max}}$:

$$\lambda_{\text{max}} = \Sigma(Wi)(\text{sum})$$

where Wi is normalized principal eigenvector from pairwise comparison matrix.
ii. Consistency Index, $CI$:

$$CI = \frac{\lambda_{\text{max}} - n}{(n - 1)}$$

(2)

where $n$ is number of criteria or alternative.

iii. Consistency ratio, $CR$:

$$CR = \frac{CI}{RI}$$

(3)

Where $RI$ is random consistency index from RI table value that proposed by Prof. Saaty as in table 2 below [8].

Table 2. RI table value [8].

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0   | 0.58| 0.9 | 1.12| 1.24| 1.32| 1.41| 1.45| 1.49|     |

If the consistency ratio (CR) is less than 10%, the inconsistency of the judgement is acceptable and if the consistency ratio more than 10%, inconsistency needs to revise subjective judgement.

4. Results and discussion

Table 3 shows the normalized principal eigenvector for structural criteria that consist of three subcriteria which are seepage, settlement and erosion. The percentage of seepage is 70.10 percent followed by a settlement which is 16.08 percent and erosion which is 13.82 percent. Besides, the participant most preferred seepage, followed by settlement and erosion to identify the most contributing factor to dam failure. Therefore, the CR for structural is 0.041. As the CR value for this criteria is less than 0.1, the all participant evaluation about this dam failure criteria is consistent.

Table 3. Pair-Comparison and Normalized Principal Eigenvector of all Dam Expert according to Structural criteria.

|       | Seepage | Settlement | Erosion | Normalized principal Eigenvector (%) |
|-------|---------|------------|---------|-------------------------------------|
| Seepage | 1       | 38/7       | 4       | 70.10                               |
| Settlement | 1/5      | 1          | 13/9    | 16.08                               |
| Erosion | 1/4     | 2/3        | 1       | 13.82                               |
| Sum    | 29/20   | 149/21     | 58/9    |                                     |

$\lambda_{\text{max}} = 3.048$, $CI = 0.024$, $CR = 0.041$
Table 4. Pair-Comparison and Normalized Principal Eigenvector of all Dam Expert according to Human Criteria.

|                | Operational mismanagement | Negligence | Vandalism | Normalized principal Eigenvector (%) |
|----------------|---------------------------|------------|-----------|--------------------------------------|
| Operational mismanagement | 1                         | 2          | 28/5      | 58.46                                |
| Negligence      | 1/2                       | 1          | 13/4      | 31.45                                |
| Vandalism       | 1/6                       | 1/3        | 1         | 10.08                                |
| Sum            | 5/3                       | 10/3       | 197/20    |                                       |

\[ \lambda_{\text{max}} = 3.016, \ CI = 0.008, \ CR= 0.014 \]

Table 4 shows the normalized principal eigenvector for human criteria that consist of three subcriteria which are operational mismanagement, negligence and vandalism. The operational mismanagement has a higher factor by contributed 58.46 percent and followed by negligence (31.45%) and vandalism (10.08%). Therefore, the participant most preferred operational mismanagement followed by negligence and vandalism. Therefore, the CR for the human is 0.014. As the CR value for this criteria is less than 0.1, the all participant evaluation about this dam failure criteria is consistent.

Table 5. Pair-Comparison and Normalized Principal Eigenvector of all Dam Expert according to Natural Criteria.

|                | Flood from high precipitation | Flood from dam failure | Landslide | Normalized principal Eigenvector (%) |
|----------------|-------------------------------|------------------------|-----------|--------------------------------------|
| Flood from high precipitation | 1                             | 2                      | 13/7      | 48.57                                |
| Flood from dam failure          | 1/2                           | 1                      | 13/7      | 30.73                                |
| Landslide                     | 1/2                           | 1/2                    | 1         |                                       |
| Sum                          | 2                             | 7/2                    | 33/7      |                                       |

\[ \lambda_{\text{max}} = 3.022, \ CI = 0.011, \ CR= 0.019 \]

Table 5 shows the normalized principle eigenvector for natural criteria that consist of three subcriteria which are failure from high precipitation, failure from dam failure and landslide. The highest factor contributed to the Bukit Merah dam failure is a flood from high precipitation which is 48.6 percent. Secondly, it is followed by a flood from the dam failure which contributes 30.7 percent and landslide which is 20.7 percent. Therefore, all participants most preferred flood from high precipitation, followed by flood from dam failure and landslide. Therefore, the CR for natural is 0.019. As the CR value for this criteria is less than 0.1, the all participant evaluation about this dam failure criteria is consistent.

5. Conclusion
The results indicated that seepage contributes 70.1% to dam failure from structural criteria, operational mismanagement contributes 58.46% from human criteria and flood from high precipitation contributes 48.57% to dam failure from natural criteria. From the consistency ratio, the CR for structural is 5%, for
human is 0.1% and for natural criteria is 5.5. As all the CR value for this criteria is less than 10%, all participants’ evaluations about the dam failure criteria are consistent.

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