Qualitative assessment of deterioration embankment dam using index condition and annual probability of failure (APF) using event tree method

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Abstract. The construction of dams can offer many advantages, but their major deterioration could result in failure, including loss of life and property destruction. The purpose of this study is development of the model to predict deterioration using condition index and determine the risk of the failure using Event Tree Analysis. This method is combined between ICOLD and Public Work and Public Housing (PWPH) Guidelines. The results of condition index in Sagung is good condition. The results of annual probability of failure (APF) using Event Tree method is $1.1111 \times 10^{-5}$.

Keyword: assessment, index condition, APF, event tree

1. Introduction

The construction of dams can offer many advantages, but their major deterioration could result in failure, including loss of life and property destruction [1]. The construction of dams can offer many advantages, but their failure could result in major damages including loss of life and property destruction [2]. Therefore, an assessment of the deterioration dam is required to predict the probability of failure. There several methods to achieve this purpose are Analytical Hierarchy Process (AHP), Artificial Neural Network (ANN), Fuzzy Logic and Condition Index Assessment.

To develop a method is depend of the analysis phase, A preliminary condition assessment phase of portfolios of dams, particularly those with a large number of dams, requires the utilisation of methods based on indexes is an appropriate practise [3] and for risk analysis (single dam) using event tree analysis (ETA) [3]. ETA is a systematically method to assess the annual risk failure probability [4]. The procedure and observation for both method is qualitative method. The different of this method is:

1. Indexes condition: simple, easy to be implemented and qualitative method
2. Event Tree Analysis: quantitative risk analysis.

There 8 dam components to assess the condition: dam body, spillway, inlet, outlet, hydromechanical including turbine equipment, access road, instrumentation and environmental. The standard for component dam is Operation and Maintenance Dam Guidelines [5] [6]. This standard was published by Ministry of Public Works and Public Housing (MPWH) and International Commission on Large Dam (ICOLD) [5] [6] [7]. The result of this assessment is very important for the owner to find the potential deterioration.
2. **Research Methodology**

The location of the study is Saguling Dam and Djuanda Dam. Condition index assessment is based on visual inspection. The flow chart of the research as follows below (Fig. 1).

![Flow Diagram](image)

**Figure 1. Flow Diagram**

3. **Result and Discussion**

3.1. **Assessment Criteria**

Saguling Dam and Djuanda Dam consist of various dam components that have different functions. Components of the dam include dam body, spillway, inlet, outlet, hydromechanical equipment, access road, instrumentation, environmental conditions. The components that have a particular function must be assigned an assessment according to their function (Figures 2-3).

![Saguling Dam Component](image)

**Figure 2. Saguling Dam Component [9]**
The criteria of assessment is based on the priority of the function. It is stated that the percentage of assessment of the function of the building is based on the suitability of the priority of the building in the performance of the building. As for the weight of the assessment are:

1. The body of the dam has an assessment weight of 20%. The value of this weight is because the body of the dam is the main part of each component in the dam based on the performance of the dam. Where the body of the dam has a sub-component consisting of the top of the dam serves to find out the normal limits of the dam in overtopping conditions, upstream slopes, downstream slopes, right pedestal, and left pedestal to keep the body condition of the dam stable to earthquake, the reservoir area serves to keep the water entering in the dam through spillway in good condition and there is no sedimentation.

2. Spillway has a 15% weight rating. The value of this weight is because the overflow building is the main building in each component in the dam based on the performance of the dam. The overflow building functions to regulate water discharge.

3. Inlet has a rating weight of 15%. The value of this weight is because the building is the main building for each component in the dam based on the performance of the dam. Inlet serves to regulate the taking of water according to the needs of irrigation.

4. The outlet has a rating weight of 10%. The amount of this weight is because the bottom outlet is a complementary building on each component that is in the dam based on the performance of the dam. The bottom outlet serves to regulate the minimum amount of water needed for irrigation.

5. Hydromechanical have a 10% weight rating. The amount of this weight is because turbines and auxiliary equipment are complementary buildings in each component of the dam based on the performance of the dam. Turbines and auxiliary equipment function as a power plant.

6. The entrance/ Road Access has a 5% rating weight. The value of this weight is because the entrance is a complementary building for each component in the dam based on the performance of the dam. The entrance works to enter the dam.

7. Instrumentation has a rating weight of 15%. The amount of this weight is because instrumentation is the main component of the dam, where instrumentation is found in each component of the dam. Instrumentation serves to find out the condition of the dam.

8. Environmental conditions have a 10% weight rating. The magnitude of this weight value is because the environmental conditions are complementary buildings for each component in the dam based on the performance of the dam. Environmental conditions function to keep water entering the dam through the spillway in good condition and there is no sedimentation.
The condition of the dam component is used as an assessment of the level of damage that occurs to the dam facilities and infrastructure. The condition index criteria use the scale of 1-5 with the physical that can be seen in Table 1.

**Table 1. Component Condition Assessment Using OM-PWPH Standard [6]**

| Condition Index | Condition Description | Physical Condition |
|-----------------|-----------------------|--------------------|
| 5               | Good condition        | Physical: New building  
|                 |                       | Have not experienced significant physical changes  
|                 |                       | Can function properly 90-100%  
|                 |                       | damage <10% |
| 4               | Mildly Damaged Conditions | The physical form of the building has undergone a slight change  
|                 |                       | There are minor cracks  
|                 |                       | There is stripping plaster  
|                 |                       | Physical stability of the building is still maintained  
|                 |                       | Function properly: 80-90% or,  
|                 |                       | Damage: 10% and 20% |
| 3               | Moderately Damaged Conditions | The physical form of the building has undergone significant changes  
|                 |                       | There are moderate cracks  
|                 |                       | There is stripping of plaster to make small holes  
|                 |                       | There are loose stone pairs  
|                 |                       | Function properly 60% to 80% or,  
|                 |                       | Damage : 21 to 40%. |
| 2               | Severely Damaged Conditions | Physical form has undergone serious changes  
|                 |                       | The physical stability of the building is very disturbed until it is unstable again  
|                 |                       | If the condition value is <60 or,  
|                 |                       | Damage > 40% |
| 1               | Collapsed             | No function or can not operate |

**Table 2. Component Condition Assessment Using ICOLD Standard [7]**

| Conditions Index | Condition Description | Physical Condition |
|------------------|-----------------------|--------------------|
| 5                | Good condition        | Other deterioration can be categorized as minor damage and even though the dam does not suffer serious damage, but can cause damage or minor damage is not repaired the condition of the dam has the potential failure. |
| 4                | Mildly Damaged Conditions | Medium failure and occur due to occurrence of leaks that carry colored or turbid material which can result in disrupting the performance of the dam function. The occurrence of erosion holes and wall collapse downstream. |
3.2. Results of the Assessment of the Saguling Dam Condition Index

The following are the results of the condition index using the PUPR and ICOLD OP standards that are carried out in the saguling dam building. This can be seen in Tables 3-6 as follows.

**Table 3. Result Assessment of the Condition of the Saguling Dam Index Using Standard OP-PWPH [5] [6]**

| No | Building            | Condition Scale |
|----|---------------------|-----------------|
| 1  | Dam Body            | 1               |
| 2  | Spillway            | 2               |
| 3  | Inlet               | 3               |
| 4  | Outlet              | 4               |
| 5  | Hydromechanical     | 5               |
| 6  | Entrance            | 1               |
| 7  | Instrumentation     | 3               |
| 8  | Environmental       | 4               |

| Building | Condition Scale |
|----------|-----------------|
| Dam Body | √               |
| Spillway | √               |
| Inlet    | √               |
| Outlet   | √               |
| Hydromechanical | √           |
| Entrance | √               |
| Instrumentation | √     |
| Environmental | √          |

**Table 4. Results of Calculation of Saguling Dam Condition Index Using Standard OM-PWPH [5] [6]**

| No | Component         | Weight (%) | Index Scale (Cn) | Index Condition Wn x Cn |
|----|-------------------|------------|------------------|-------------------------|
| 1  | Dam Body          | 20         | 4                | 0.80                    |
| 2  | Spillway          | 15         | 4                | 0.60                    |
| 3  | Inlet             | 15         | 5                | 0.75                    |
| 4  | Outlet            | 10         | 4                | 0.40                    |
| 5  | Hydromechanical   | 10         | 5                | 0.50                    |
| 6  | Entrance          | 5          | 4                | 0.20                    |
| 7  | Instrumentation   | 15         | 3                | 0.45                    |
| 8  | Environmental     | 10         | 4                | 0.40                    |

\[ \text{Index Condition (Wn x Cn)} = 4.10 \]
Table 5. Result Assessment of the Condition of the Saguling Dam Index Using Standard ICOLD [8]

| No | Component                  | Condition Scale |
|----|----------------------------|-----------------|
|    |                            | 1   | 2   | 3   | 4   | 5   |
| 1  | Dam Body                   |     |     |     |     | ✓   |
| 2  | Spillway                   |     | ✓   |     |     |     |
| 3  | Inlet                      |     | ✓   |     |     |     |
| 4  | Outlet                     |     | ✓   |     |     |     |
| 5  | Hydromechanical            |     | ✓   |     |     |     |
| 6  | Entrance                   |     | ✓   |     |     |     |
| 7  | Instrumentation            |     | ✓   |     |     |     |
| 8  | Environmental Conditions   |     | ✓   |     |     |     |

Table 6. Results of Calculation of Saguling Dam Condition Index Using Standard ICOLD

| No | Component                  | Component Weight (wn) % | Component Weight (wn) % | Component Condition Index Scale (Cn) | Component Condition Index Wn x Cn |
|----|----------------------------|-------------------------|-------------------------|--------------------------------------|----------------------------------|
|    |                            | To=n                    | Ke=n                    | Index Condition                      |                                  |
| 1  | Dam Body                   | 20                      | 5                       | 1.00                                 |                                  |
| 2  | Spillway                   | 15                      | 4                       | 0.60                                 |                                  |
| 3  | Inlet                      | 15                      | 5                       | 0.75                                 |                                  |
| 4  | Outlet                     | 10                      | 5                       | 0.50                                 |                                  |
| 5  | Hydromechanical            | 10                      | 5                       | 0.5                                  |                                  |
| 6  | Entrance                   | 5                       | 5                       | 0.25                                 |                                  |
| 7  | Instrumentation            | 15                      | 5                       | 0.75                                 |                                  |
| 8  | Environmental Conditions   | 10                      | 4                       | 0.40                                 |                                  |
|    |                            | 100%                    |                         | Index Condition                      |                                  |
|    |                            | Wn x Cn                 |                         | = 4.75                               |                                  |

3.3. Results of the Assessment of the Djuanda Dam Condition Index

The following are the results of the condition index using the OM-PWPH and ICOLD Standards that are carried out in the saguling dam building. This can be seen in Table 7-10 as follows

Table 7. Result Assessment of the Condition of the Djuanda Dam Index Using Standard OM-PWPH

| No | Building                          | Condition Scale |
|----|-----------------------------------|-----------------|
|    |                                   | 1   | 2   | 3   | 4   | 5   |
| 1  | Dam Body                          |     | ✓   |     |     |     |
| 2  | Spillway                          |     | ✓   |     |     |     |
| 3  | Inlet                             |     | ✓   |     |     |     |
| 4  | Access Gallery                    |     | ✓   |     |     |     |
| 5  | Left Chopsticks Drainage and Right Chopsticks Drainage |     | ✓   |     |     |     |
| 6  | Generating Room                   |     | ✓   |     |     |     |
| 7  | Instrumentation                   |     | ✓   |     |     |     |
| 8  | Environmental Conditions          |     | ✓   |     |     |     |
Table 8. Results of Calculation of Djuanda Dam Condition Index Using Standard OM-PWPH

| No | Component                          | Weight % (wn) Component To=n | Index Scale (Cn) | Index Condition Wn x Cn |
|----|------------------------------------|------------------------------|-----------------|------------------------|
| 1  | Dam Body                           | 20                           | 4               | 0.80                   |
| 2  | Overflow Building                  | 15                           | 5               | 0.75                   |
| 3  | Retrieval Building                | 15                           | 5               | 0.75                   |
| 4  | Access Gallery                     | 10                           | 4               | 0.40                   |
| 5  | Drainage                           | 5                            | 4               | 0.20                   |
| 6  | Generating Room                   | 10                           | 5               | 0.50                   |
| 7  | Instrumentation                    | 15                           | 4               | 0.60                   |
| 8  | Environmental Conditions           | 10                           | 5               | 0.50                   |
|    | 100%                                |                              |                 | Index Condition (Wn x Cn) = 4.50 |

Table 9. Result Assessment of the Condition of the Djuanda Dam Index Using Standard ICOLD

| No | Building                        | Condition Scale |
|----|---------------------------------|-----------------|
| 1  | Dam Body                        | 1               |
| 2  | Spillway                        | 2               |
| 3  | Inlet                           | 3               |
| 4  | Access Gallery                  | 4               |
| 5  | Drainage                        | 5               |
| 6  | Generating Room                | 1               |
| 7  | Instrumentation                 | 2               |
| 8  | Environmental Conditions        | 3               |

Table 10. Result Assessment of the Condition of the Djuanda Dam Index Using Standard ICOLD

| No | Component                          | Weight % (wn) Component To=n | Index Scale (Cn) | Index Condition Wn x Cn |
|----|------------------------------------|------------------------------|-----------------|------------------------|
| 1  | Dam Body                           | 20                           | 5               | 1.00                   |
| 2  | Spillway                           | 15                           | 5               | 0.75                   |
| 3  | Inlet                              | 15                           | 5               | 0.75                   |
| 4  | Access Gallery                     | 10                           | 4               | 0.40                   |
| 5  | Drainage                           | 5                            | 4               | 0.20                   |
| 6  | Generating Room                   | 10                           | 5               | 0.50                   |
| 7  | Instrumentation                    | 15                           | 5               | 0.75                   |
| 8  | Environmental Conditions           | 10                           | 5               | 0.50                   |
|    | 100%                               |                              |                 | Index Condition (Wn x Cn) = 4.85 |

3.4. Results of the Event Tree Analysis (ETA) of the Saguling Dam and Djuanda Dam

Event Tree Analysis is a method that shows the impact that might occur, beginning with identifying potential events and processes in each stage that cause dam damage. So that in Event Tree Analysis it
is necessary to know the potential of the event and the function of the security system Dam or the available priority to find corrective steps caused by the potential for damage.

### 3.5. Standard Assessment of Event Tree Analysis of Saguling Dam and Djuanda Dam

Based on standard it is stated that Dam risk assessment is obtained by separating each component of the dam in the analysis process based on the criteria that apply to each component [11]. This can be seen in Table 11 as follows.

| Determination of Event Tree | Probability Value |
|-----------------------------|-------------------|
| Almost Certain              | 0.999             |
| Very Likely                 | 0.99              |
| Maybe                       | 0.9               |
| Neutral                     | 0.5               |
| Impossible                  | 0.1               |
| Very Impossible             | 0.01              |
| Almost Impossible           | 0.001             |

Standard assessment event tree analysis (Figures 4-8) is used to identify and evaluate the sequence of events in a potential damage scenario. The probability value is used in the event tree analysis on any potential damage to the Dam. Each probability value at times to determine the percentage probability value at each potential damage, the percentage value of each damage is added to find out the Annual Probability of Failure (APF) to determine the priority risks that cause failure of the dam.

**Table 11. Standard Assessment Event Tree Analysis**

**Figure 4.** Earthquake Event Tree Analysis

**Figure 5.** Seepage Event Tree Analysis

**Figure 6.** Scour Event Tree Analysis

**Figure 7.** Instrumentation Event Tree Analysis
3.6. Annual Probability of Failure (APF) Saguling Dam and Djuanda Dam

Annual failure opportunities or annual probability of failure (APF) is obtained by adding up all the probabilities of potential hazards that will be identified in the dam component.

\[
\text{APF} = \sum \text{APF}_i
\]

- APF Dam Body (Earthquake) = $1 \times 10^{-5}$
- APF Dam Body (Seepage) = $1 \times 10^{-6}$
- APF Building pelimpah (Peluapan) = $1 \times 10^{-9}$
- APF Building Instrumentation (damage) = $1 \times 10^{-7}$
- APF fondasi (liquefaction) = $1 \times 10^{-8}$

So that the total APF is obtained

\[
\text{APF} = 1 \times 10^{-5} + 1 \times 10^{-6} + 1 \times 10^{-9} + 1 \times 10^{-7} + 1 \times 10^{-8}
\]

\[
= 1.1111 \times 10^{-5} < 10^{-4}
\]

4. Conclusions

Based on the results of this study, it can be concluded that:

- Condition of the Saguling Dam condition index uses the OP-PUPR 4.10 standard, the results of the Saguling Dam condition index using ICOLD 4.75 standard, the Dam condition index results Djuanda uses OP-PUPR 4.50 standard, the results of the Djuanda Dam condition index use the ICOLD standard 4.85. The results of the event tree analysis of Saguling Dam and Djuanda Dam $1.1111 \times 10^{-5}$.
- It can be concluded that the condition of the Djuanda Dam is better than the Saguling Dam based on the condition index assessment using the standard OP-PUPR and ICOLD.
- Based on the results of the event tree analysis the condition of the risk that occurs in the Saguling dam and Djuanda dam is the same, namely $1.1111 \times 10^{-5}$

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