

## The Development of Dam Infrastructure Condition and Safety Assessment

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### Abstract

*The management and regulation of large inventories of embankment dams requires the use of tools and analytical techniques that can provide a uniform basis for comparison. Index Condition and Risk Assessment were two of those tools. Those two assessment can be combined to make an comprehensive assessment because it's main data are visual condition of dam. With those similarity, how to develop dam assessment based on dam's condition and safety are the main goals of this research. On these research, Condition Index with index from 1 to 5 are used for the condition assessment. Meanwhile, ICOLD Modified Method are used as safety evaluation aspect. Those two assessment system were combined using Analytic Hierarchy Process (AHP) to find it's weight for the assessment model. AHP were used to analyze AHP's linear scale questionnaire as primary data. These research obtain that the developed model had some limitations, so the assessment aren't comprehensive enough.*

**Keywords:** Infrastructure, assessment, condition, safety, dam, condition index, ICOLD modified, AHP.

### Abstrak

*Manajemen dan regulasi dari inventaris bendungan besar membutuhkan alat dan teknik analisis yang dapat memberikan dasar yang seragam untuk perbandingan. Penilaian Kondisi berbasis Indeks Kondisi dan Kajian Keamanan berbasis Indeks Risiko merupakan beberapa contoh dari alat tersebut. Kedua penilaian ini sebenarnya bisa digabungkan untuk mendapatkan penilaian yang komprehensif karena menggunakan kondisi visual sebagai salah satu data utama. Dengan adanya kesamaan tersebut, bagaimana cara mengembangkan penilaian kondisi dan keamanan bendungan merupakan tujuan utama dari penelitian ini. Dalam penelitian ini, Indeks Kondisi dengan indeks nilai 1 sampai 5 digunakan sebagai penilaian dalam aspek penilaian kondisi. Sedangkan dalam aspek kajian keamanan, digunakan Metode ICOLD Modifikasi. Dalam menggabungkan kedua sistem penilaian tersebut, Analytic Hierarchy Process (AHP) digunakan untuk mendapatkan bobot penilaian bendungan. Berdasarkan hasil analisis, model yang dikembangkan memiliki beberapa limitasi sehingga penilaian belum cukup komprehensif.*

**Kata-kata Kunci:** Infrastruktur, penilaian, kondisi, keamanan, bendungan, indeks kondisi, ICOLD modifikasi, AHP.

## 1. Dam Condition and Safety Assessment

The management and regulation of large inventories of embankment dams requires the use of tools and analytical techniques that can provide a uniform basis for comparison (Andersen dkk., 2001). One of the tools is the dam infrastructure rating used in the United States. The assessment in the form of rating that they have and they publish under the name *Report Card for America's Infrastructure* by American Society of Civil Engineers is published regularly and was last published in 2017. Ratings are used by many countries because the indicators, that was produced, generate strong messages to politicians or stakeholders who make decisions about the needs and urgency of infrastructure investment in the context of national priorities (Amekudzi dkk., 2013). The aspects reviewed in the

rating research (ASCE, 2013) are conditions, capacity, operations, and safety. The security aspect also includes hazards, risk management, comprehensive approach, and internal and external integration. In Indonesia, such rating research has not yet been conducted. The research conducted to assess the condition of a dam is only using a condition index and risk index (Jayadi dkk., 2017).

*Condition index* is a method that is widely used to assess the condition of a building (Mersianty, 2015). The data used in the condition index is a visual inspection. Visual inspection results are converted to condition index. The condition index value for each sub-component is based on the subjectivity of the researcher. Each condition index in the sub-component is given a weight, so that it can be summed to become

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a total condition index. Risk Index is used to see indications of the potential level of risk of a dam collapse. The Risk Index method requires parameters to be used for analysis and the results are in the form of a weight/score which is then sorted according to the level of risk priority (Center for Water Resources, 2006). Based on the risk index and the initial importance factor of the dam, the dam safety value is obtained ( $N_{\text{safety}}$ ). The method used in previous studies conducted by the Center for Water Resources Research (2006) and Ishbaev et al. (2014) in calculating the dam safety value was the Andersen Method. In the Andersen Method, one of the data needed to produce a risk index is a visual inspection in the field (Jayadi et al., 2017). With the similarity of the data used in the condition index and risk index, a study that can combine the two methods can be developed. So the main purpose of this research was to develop a condition assessment based on the condition and safety aspects of the dam infrastructure.

## 2. Proposal for Development of Dam Condition and Safety Assessment in Indonesia

Proposal for development of assessment in this study has been published previously in a study conducted by Jayadi et al. (2017). So that in this study the main objective was to find out how to develop a condition and safety assessment model of dam infrastructure. The development of condition and safety assessment of dam infrastructure should be done at embankment dams. At embankment dams, a KKB (*Komisi Keamanan Bendungan*/Dam Safety Commission) session was conducted for the operation certification process based on the safety of the dam. Safety was reviewed through a Great Inspection every 5 years. Based on this, the Great Inspection Report could be used as secondary data and the KKB members could be used as study respondents (Jayadi et al., 2017). The condition indeks was recommended to use the scale of 1 – 5, with the condition assessment criteria that can be seen in **Table 1**. Meanwhile, the risk indeks was recommended to use the Modified ICOLD method, with risk class division that can be seen in **Table 2**.

Based on the result of an interview with geologists who are KKB members, the reservoir component also needs assessment. This is because if there is a

**Table 1. Condition assessment criteria** (Mersianty 2015)

Condition Index	Condition Description
5	Good condition
4	Mildly damaged condition
3	Moderately damaged condition
2	Severely damaged condition
1	Collapsed

**Table 2. Risk class division in the modified ICOLD** (Purnomo, 2013)

Risk Class	I (Low)	II (Moderate)	III (High)	IV (Extreme)
Risk Value	0-15	16-45	46-75	76-90

reservoir area that is wet and has the potential to cause large landslides in the reservoir area, then this can cause overtopping at the dam. In addition, the trashrack/trashboom conditions need to be assessed as a part of the reservoir component. Based on the interview, it was found that the existing assessment system still does not include assessments from a geological point of view. This is necessary so that no earthquakes occur due to filling of reservoirs (Reservoir Triggered Earthquake or Reservoir Induced Earthquake) that can make local residents feel unsafe. While based on the results of an interview with other KKB members, it is recommended that the assessment model should include the HR factor. The HR factor in question is the absence of experts who are able to read the results of instrumentation readings well. This needs to be included in the assessment because in Indonesia this often happens (Jayadi et al., 2017).

In combining the two types of assessment, MCDM (Multi Criteria Decision Making) can be used to get the weight of the assessment. Respondents, who are KKB members, are expected to give a good weighting according to their perception. From the results of the MCDM weighting, an additional analysis in the form of sensitivity analysis can be done so the effect of changes in weighting on the final value of the condition index and safety index can be seen (Jayadi et al., 2017).

## 3. Development of Dam Condition and Safety Assessment Model

The development of the assessment model was done through three stages. The first stage was the identification of assessment components. The next stage was to develop a condition assessment indicator based on previous studies and the results of interviews with experts. Then, the last stage was to calculate the weight of the assessment using the AHP (Analytic Hierarchy Process). Those three stages can be seen in **Figure 1**.

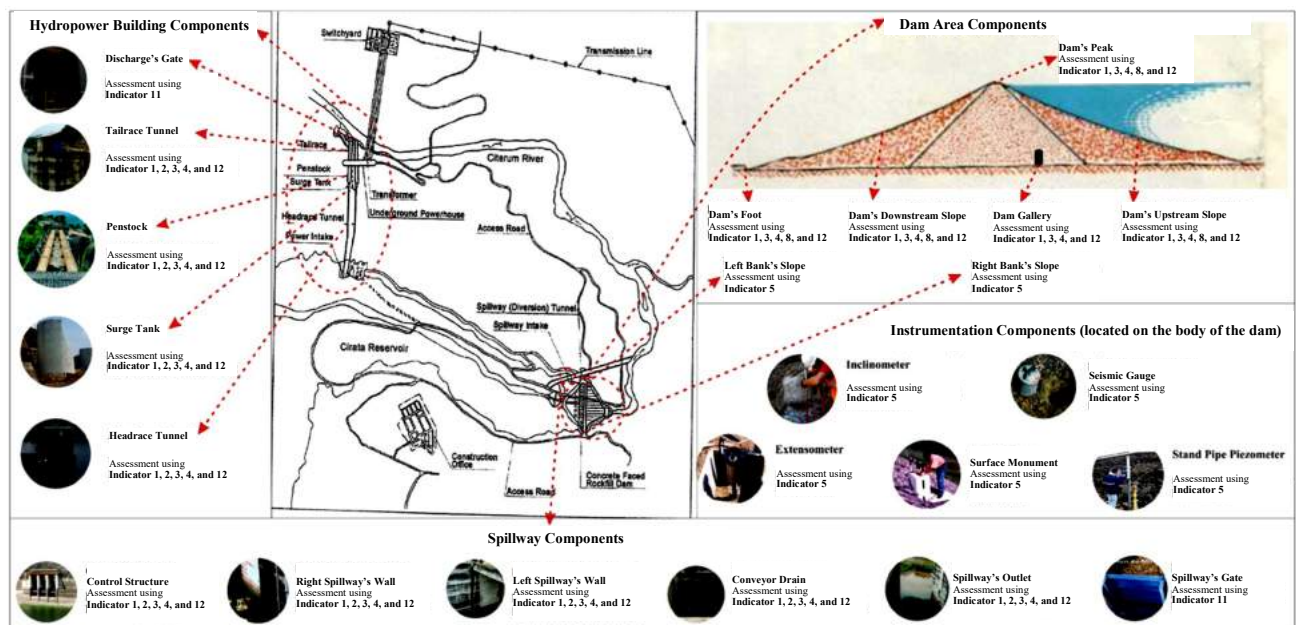
### 3.1 Assessment components identification stage

In the first stage, the dam component components were assessed in a developed condition assessment model. In assessing the condition, the method used was the Condition Index. The components assessed using the Condition Index can be seen in **Figure 2**. The development of components assessed was based on literature studies, results of secondary data analysis, and pilot surveys. The literature used was the literature regarding dam design so that there would be no errors in the sub-component grouping. The books referred were *Teknik Bendungan* (Soedibyo, 1993), *Bendungan Type Urugan* (Sosrodarsono & Takeda, 1989), and *Advanced Dam Engineering for Design, Construction, and Rehabilitation* (Jansen, 1988). The secondary data referred to were the Consultancy Services Inspection Report for Saguling Hydroelectric Dam Certification/ and the Final Report of the Great 5-Year Inspection of the Dams/Underwater Inspection & Certification of Feasibility of Cirata Dam Operations.

Not only through secondary data and books, but the

Stage 1 Rating's Components Identification	Stage 2 Development of Rating's Indicators	Stage 3 Rating's Weights Simulation
Based on literature study, secondary data, and pilot survey: Dam Area Component Dam Instrumentation Component Spillway Component Hydropower Building Component	Based on literature study, secondary data, and pilot survey: Indicator 1 Indicator 2 Indicator 3 ⋮ Indicator 12	Simulation using AHP: Dam Rating's Aspects Total Weight = 1,000 1) Condition Aspect : 0,5000 2) Safety Aspect : 0,5000  Dam Rating's Component Total Weight = 1,000 1) Dam Area : 0,5175 2) Dam Instrumentations : 0,0611 3) Spillway : 0,3080 4) Hydropower Building : 0,1176

Figure 1. Stages of development of dam condition and safety assessment model

Figure 2. Components for the condition assessment of saguling dam and cirata dam  
(Modified from PT. Kwarsa Hexagon j.o. Newjec Inc., 2006)

assessed components were also asked during the pilot survey to the experts. The result was the Bottom Outlet component did not need to be included in the assessment component. This was because the Bottom Outlet was an additional building and the function was no longer optimal. The function referred was the sediment flushing function on the dead storage. In addition, some Instrumentation components could not be compared directly because of the core typical of different dams. Namely, the Saguling Dam has a core, while the Cirata Dam has a concrete face so that no instrumentation can be absolutely compared. In addition, according to the experts, there was no emergency spillway at the Saguling Dam and Cirata Dam due to the flood discharge plan using PMF 10000.

Based on the pilot survey, there was a component that needed to be added in the assessment. The component was Dam Gallery. Based on an assessment by the expert, the dam gallery needed to be included due to its very significant function: it allows grouting through the dam gallery if there is a crack. In addition, another function is to measure pore pressure from the dams. Based on this, the dam gallery component was included in the components to be assessed. Based on the pilot survey,

the dam gallery was included in the Dam Area component group.

Some other notes related to this assessment model were that some components could not be assessed, this was due to the limited data available in the Consultancy Services Inspection Report for Saguling Hydroelectric Dam Certification/ (PT. Indra Karya, 2011) and Final Report of the Great 5-Year Inspection of the Dams/ Underwater Inspection & Certification of Feasibility of Cirata Dam Operations (PT. Indra Karya, 2015). The data limitation referred was the existence of components or sub-components that were inspected at the Cirata Dam but not inspected at the Saguling Dam, so that the components or sub-components could not be assessed. In addition, there were several different dam characteristics, especially the spillway components used and the type of instrumentation installed at the dam. Meanwhile, in terms of the inspection period for components, all components assessed were inspected every 5 years. This was because the secondary data used was a Great Inspection Report. With the different dam components used, it could not make a more complete assessment of dam components. Meanwhile, with different instrumentations, not all types of

instrumentation installed on each dam could be accommodated. The instrumentation installed itself was due to different dam types. Saguling Dam is an embankment dam with a core type, while Cirata Dam is an embankment dam with a concrete face type.

In terms of the dam types that could be assessed, this assessment system could only be used on hydropower functioned embankment dam without an emergency spillway. This was because the assessment model was based on Saguling Dam which is a dam with a core and Cirata Dam which is a dam with a concrete face. As for the spillway type, there were no limitations because the sub-components assessed were made public. From the instrumentation side, dams that could be assessed were only dams with piezometer standpipe, sliding stakes, inclinometers, extensometers, and seismic gauges instrumentations.

### 3.2 Development of indicators stage

The second stage in the development of dam condition and safety assessment models is the development of indicators to determine the Condition Index. The Condition Indicators were based on previous studies conducted by Mersianty (2015) for the spillway component, and for the other components were based

on the Modified Andersen Method (Andersen, 2001; Purnomo, 2013; Center for Water Resources Research, 2006; Indrawan et al., 2013), Andersen Condition Index (Andersen, 1999) and Visual Inspection Manuals (Directorate of Technical Development), 2004; Dam Safety Commission, 2003<sup>a</sup>; Dam Safety Commission, 2003<sup>b</sup>). The Condition Index indicators can be seen in **Table 3**.

The Modified Andersen Method itself was included in the assessment indicators because the basis of the Dam Safety Study of the Andersen Method is the Condition Index. At the time of the pilot survey, this method was recommended for reference by experts. In addition, experts also recommended using Visual Inspection Guidelines as a basis for assessment so that the methods and guidelines above were used as a reference in the making of assessment indicators.

In the making of assessment indicators, a value equalization was done. The Condition Indicator I5 is the example. In a study conducted by Andersen, et al (1999), it was stated that if the instrumentation produces data or there is no indication of malfunction, the Condition Index value is 100. Meanwhile, if it does not produce data or the data generated is inaccurate, or does not function, the Condition Index value is 0. In

**Table 3. Condition index indicators**

Indicator Type	Good Condition (5)	Mildly Damaged Condition (4)	Moderately Damaged Condition (3)	Severely Damaged Condition (2)	Reference
<b>Condition Indicator 1 (I1)</b>	The existence of water plant sediment/tree trunks/ waste of 0 – 10%	The existence of water plant sediment/tree trunks/ waste of 10 – 30%	The existence of water plant sediment/tree trunks/ waste of 30 – 50% of the channel area	The existence of water plant sediment/tree trunks/ waste of more than 50%	Mersianty, 2015
<b>Condition Indicator 2 (I2)</b>	The existence of sediment deposits of 0 – 10%	The existence of sediment deposits of 10 – 25%	The existence of sediment deposits of 25 – 50%	The existence of sediment deposits of more than 50%	Mersianty, 2015
<b>Condition Indicator 3 (I3)</b>	No holes on the wall	Holes in the wall that do not expand or <15% with a hole width of <2 mm	Holes in the wall of 15% - 30% with a hole width of 2 – 5 mm.	Holes in the wall that expand more than 30% with a hole width of > 2 – 5 mm	Mersianty, 2015
<b>Condition Indicator 4 (I4)</b>	No cracks on the wall	Hairline cracks on concrete surfaces of <1 mm and are not widespread (spread <15%)	Cracks on the concrete surface structures with a width of 1 mm – 2 mm and spread of 15 – 30%	Cracks on the concrete surface structures with a width of > 2 mm and widespread (spread < 30%)	Mersianty, 2015
<b>Condition Indicator 5 (I5)</b>	No signs of malfunction in instrumentation, produces accurate reading data	-	Instrumentation functions and produces accurate reading data, but no operator can read the reading results in the field <sup>1</sup>	Instrumentation is damaged or does not produce accurate data	Andersen dkk., 1999; <sup>1</sup> Hasil Pengembangan Indikator
<b>Condition Indicator 6 (I6)</b>	Downstream dam foot area can be inspected	-	-	Downstream dam foot area cannot be inspected	Andersen dkk., 1999
<b>Condition Indicator 7 (I7)</b>	Downstream dam slope area can be inspected	-	-	Downstream dam slope area cannot be inspected	Andersen dkk., 1999
<b>Condition Indicator 8 (I8)</b>	Peak of the dam can be inspected	-	-	Peak of the dam cannot be inspected	Andersen dkk., 1999
<b>Condition Indicator 9 (I9)</b>	Upstream dam slope area can be inspected	-	-	Upstream dam slope area cannot be inspected	Andersen dkk., 1999
<b>Condition Indicator 10 (I10)</b>	Abutmen surface can be inspected	-	-	Abutment surface cannot be inspected	Andersen dkk., 1999
<b>Condition Indicator 11 (I11)</b>	Flood gates and valves in the drain outlet function properly or have just been repaired	Flood gates and valves in the drain outlet rarely operate lately	Flood gates and valves in the drain outlet are not operated	Flood gates and valves in the drain outlet cannot be opened	Puslitbang SDA, 2006; Andersen dkk., 2001
<b>Condition Indicator 12 (I12)</b>	Increased water pore pressure as a result of seepage; Vegetation growth on the surface of the dam	Increased water pore pressure as a result of seepage; The emergence of a wet place on the surface of the dam	Increased water pore pressure as a result of seepage; A constant surface flow	Increased water pore pressure as a result of seepage; An increased surface flow	Puslitbang SDA, 2006; Andersen dkk., 2001

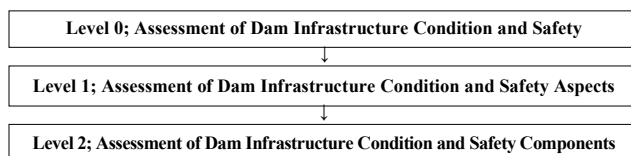


this study, the Condition Index ranged from 2 to 5. Therefore, a value equalization was performed.

As another example, the reference used was the research of Andersen et al in 2001. In that study, it was stated that if vegetation grows as a result of an increase in water pore pressures, the Condition Index value ranges between 5 to 10. The indicator was equalized to 5. If a wet place/area appears on the dam surface, the Condition Index value ranges from 4 to 8, so the indicator is equal to the Condition Index of 4. The existence of a constant surface flow as a result of an increase in water pore pressure makes the Condition Index value range from 2 to 7, so that it is equal to the Condition Index value 3. Meanwhile, if the increase in surface flow caused by an increase in water pore pressure makes the Condition Index value range from 0 - 4, it is equalized to the Condition Index value 2.

### 3.3 Development of assessment model stage

The final stage in this study is a weight assessment simulation. The weight assessment simulation was obtained through primary data in the form of linguistic variables. Through the literature study conducted, data processing methods were used which were considered appropriate in quantifying linguistic variables in the form of respondents' answers with the Analytic Hierarchy Process (AHP) scale. The hierarchy used in this study can be seen in **Figure 3**.



**Figure 3. Assessment hierarchy**

Primary data was then processed using AHP to obtain the weights. AHP is one of the MCDM methods that is often used. AHP was used as a data processing method since its main input was the perception of human as experts (Saaty and Vargas, 2012). Experts here referred to KKB (*Komisi Keamanan Bendungan/Dam Safety Commission*). Weights were tested for the hierarchical consistency of Saaty and Vargas (2012). The hierarchy consistency was tested by calculating  $\lambda_{max}$  using the formula of  $[A][x] = \lambda_{max}[x]$ . Then the CI (Consistency Index) was calculated using the formula of  $\frac{\lambda_{max} - n}{n - 1}$ . Next,

CR (Consistency Ratio) was calculated using the formula of  $\frac{CI}{RI}$ . The value of RI (Random Consistency Index)

corresponds to the number of pairwise comparisons. The value of RI can be seen in **Table 4**. The expected consistency was the one that is near perfect in order to produce a decision that is near valid with a consistency ratio of less than or equal to 10%. If it does not meet the criteria of  $CR < 0.100$  then the assessment must be repeated (Saaty and Varga, 2012).

Primary data processing was continued with sensitivity analysis. Sensitivity analysis was done by giving a

coefficient  $\alpha \geq 0$ . The coefficient  $\alpha$  was then raised to the comparison matrix (matrix A) or if written in the equation  $A = (a_{ij})$  became  $a_{ij}^{\alpha}$  (Hurley, 2001).  $\alpha > 1$  is for more distributed weight, meanwhile  $\alpha < 1$  is for more concentrated weight (Cabala, 2010).

Based on the results of data collection, the two respondents answered that each component and aspect of the assessment were equally important. Equally important means that the two components or aspects have the same importance level. But this is contrary to the answers from experts after question and answer (QnA) after filling out the questionnaire. The contradiction is an answer regarding the importance of each component or sub-component which is contrary to the advice of experts who state that if one component is heavily damaged, then the final value of the dam should also be included in the heavily damaged category. So there is a contradiction between the questionnaire's answers and the questions' answers.

With this contradiction, an interview was conducted with one of the experts to clarify the answer. In the interview, the expert stated that each component was equally important. However, after in-depth QnA about what components were the main concerns in the KKB Meeting/*Sidang KKB*, it was found that the importance of each component was different. The level of importance based on interviews is used as a basis in the weighting simulation. The assessment weight of Andersen (1995) was used as a reference basis so that the weighting of the dam area component has a stronger basis. Weight simulation results based on interviews with experts can be seen in **Table 5**.

In **Table 4** it can be seen that no weight has a CR > 0,1000. This shows that all weights are consistent. The simulation results are continued with sensitivity analysis (*sensitivity analysis*). The sensitivity analysis was not carried out on weights that had the same level of importance. In the sensitivity test of the assessment weight, a final simulation was carried out on the final value of the developed assessment model. The final value of the assessment model was obtained using the following equation:

$$CSI = \sum_{i=1}^n (w_j \times I_j) \quad (1)$$

**Table 4. RI values** (Saaty and Varga, 2012)

n	1	2	3	4	5	6	7	8	9	10
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

Information:

CSI = Total Condition and Safety Index

$W_j$  = Weight of the j-th index from the assessment

$I_j$  = The j-th index from the assessment

The final CSI was obtained by testing an assessment model developed for the Saguling Dam and Cirata Dam. Saguling Dam and Cirata Dam were chosen because the model was developed based on the Saguling Dam and Cirata Dam.

Table 5. Assessment weight

No.	Aspect/Component/ Sub-component	CI	CR	Weight	No.	Aspect/Component/ Sub-component	CI	CR	Weight
<b>Dam Assessment Aspects</b>					<b>Dam Instrument Components</b>				
1	Condition Aspect	-	-	0,5000	9	Surface Monument	-	-	0,2000
2	Safety Aspect	-	-	0,5000	10	Inclinometer	-	-	0,2000
1	Dam Area	0,0052	0,0575	0,5175	11	Extensometer	-	-	0,2000
2	Dam Instrumentation	0,0052	0,0575	0,0611	12	Seismic Gauge	-	-	0,2000
3	Spillway	0,0052	0,0575	0,3080	<b>Spillway Components</b>				
4	Hydropower Building	0,0052	0,0575	0,1176	13	Control Structure	0,0494	0,0399	0,3630
<b>Dam Area Components</b>					14	Right Spillway Wall	0,0494	0,0399	0,0849
1	Dam's Peak	0,1192	0,0930	0,2598	15	Left Spillway Wall	0,0494	0,0399	0,0849
2	Dam's Upstream Slope	0,1192	0,0930	0,1293	16	Conveyor Drain	0,0494	0,0399	0,0815
3	Dam's Downstream Slope	0,1192	0,0930	0,0802	17	Outlet Spillway	0,0494	0,0399	0,0443
4	Dam's Left Bank	0,1192	0,0930	0,0408	18	Spillway's Gate	0,0494	0,0399	0,3413
5	Dam's Right Bank	0,1192	0,0930	0,0408	<b>Hydropower Building Components</b>				
6	Dam's Foot	0,1192	0,0930	0,4074	19	Headrace Tunnel	0,0178	0,0159	0,0732
7	Dam Gallery	0,1192	0,0930	0,0418	20	Surge Tank	0,0178	0,0159	0,0732
<b>Dam Instrument Components</b>					21	Penstock	0,0178	0,0159	0,1916
8	Stand Pipe Piezometer	-	-	0,2000	22	Tailrace Tunnel	0,0178	0,0159	0,0732
					23	Discharge Door	0,0178	0,0159	0,5887

#### 4. Discussion of Dam Infrastructure Condition and Safety Assessment Model

By conducting a trial, the final values of the Saguling Dam and Cirata Dam were obtained and some limitations were found in the model developed. In **Figure 4**, the results of the sensitivity test to the trial final assessment model value. In the sensitivity test results, the final value of the Cirata Dam is very sensitive to changes in assessment's weight, meanwhile, the Saguling Dam tends to be insensitive to changes in assessment's weight.

After the weight simulation was done, we can see how sensitive the weight change was to the final assessment using the model made. The weight in the dam infrastructure condition and safety assessment model was based on the first calculation. The assessment model weights can be seen in **Table 6**. With the assessment weight, the assessment trial test can be conducted to get an in-depth analysis of the developed assessment model.

Based on the assessment model trial, some limitations of the developed assessment models were found. One limitation of this model is the high value of risk even though the impact of deficiency on dam failure is entirely 0. This high value is due to both the Saguling Dam and Cirata Dam having a risk class II (moderate). This is due to its large seismic risk as a result of large reservoir capacity, high dam height, high potential downstream damage, and business risk for owners as a result of high dam failure. Evidence that both dams have a risk class II (moderate) can be seen in **Table 7**. Because of this, even a new dam even will not reach the value of 5 if the seismic risk is large as a result of

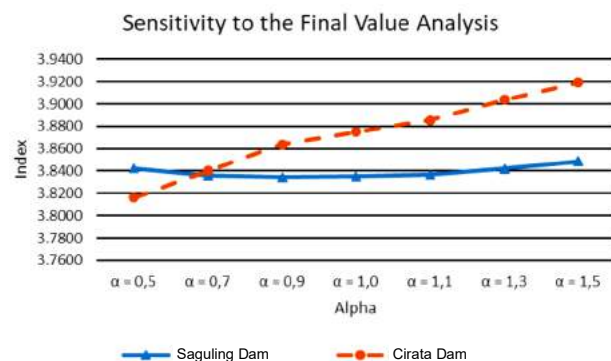


Figure 4. Results of the sensitivity analysis of the assessment weight to the final value

large reservoir capacity, high dam height, high potential of downstream damage, and business risk for owners as a result of high dam failures.

This study also has not fully assessed the functional safety of the dam. One of them is sedimentation that occurs in reservoirs. Functional assessment in this study is difficult to accommodate because there are no indicators of sedimentation in previous studies. From the structural side of the dam, deformation indicators that occur in dam components cannot be included in the model. Deformation itself is often mentioned in the Great Inspection Report.

In the trial of this assessment, there was still a high level of subjectivity. So it can be said that the level of accuracy is still not high. This is proven by the filling of the form of the risk index based condition and safety assessment. In filling out the condition assessment form, a difficulty in assessing Condition Indicator 1 on a sub-component was found. This is due to the great

inspection report that did not mention what percentage of the area contained vegetation so that the subjectivity of the inspector played a big role in providing values according to existing indicators. Meanwhile, in filling out the risk index-based safety forms, several factors filled with high subjectivity were found. The factors

referred to are the potential downstream damage (to existing structures), business risks to owners as a result of dam failures, and the development of new or future downstream. Without a clear boundary, the assessment of these three factors are very subjective.

Based on these things, if there will be further research on the dam infrastructure assessment system, it should pay attention to several things. Dam infrastructure assessment systems should be different between dams because each dam has different characteristics. So if there is further research on the dam infrastructure assessment system, it should be reviewed in detail for one dam to get a more comprehensive assessment system.

## 5. Conclusions

This study was not aimed to produce the most comprehensive dam condition and safety rating. Based on that, these are the conclusions:

- The developed model could only be used on hydropower functioned embankment dam without an emergency spillway.
- The dam type that can be accommodated by this assessment is reservoirs (both the core type and the concrete face type).
- The complementary building is in the form of a spillway and it can be used on all types of spillway.
- From the instrumentation side, dams that could be assessed were only dams with piezometer standpipe, sliding stakes, inclinometers, extensometers, and seismic gauges instrumentations.

## 6. Acknowledgements

Acknowledgments are given to many parties who provided assistance during this study.

**Table 6. Assessment model weight**

No.	Sub Component	Weight	No.	Sub Components	Weight
<b>Dam Assessment Aspects</b>			<b>Dam Instrument Component</b>		
1	Condition Aspect	0,5000	2	Surface Monument	0,2000
2	Safety Aspect	0,5000	3	Inclinometer	0,2000
<b>Dam Assessment Components</b>			4	Extensometer	0,2000
1	Dam Area	0,5175	5	Seismic Gauge	0,2000
2	Dam Instrumentation	0,0611	<b>Spillway Components</b>		
3	Spillway	0,3080	1	Control Structure	0,3630
4	Hydropower Building	0,1176	2	Right Spillway Wall	0,0849
<b>Dam Area Components</b>			3	Left Spillway Wall	0,0849
1	Peak of the Dam	0,2598	4	Conveyor Drain	0,0815
2	Dam's Upstream Slope	0,1293	5	Spillway's Outlet	0,0443
3	Dam's Downstream Slope	0,0802	6	Spillway's Gate	0,3413
4	Left Bank's Slope	0,0408	<b>Hydropower Building Components</b>		
5	Right Bank's Slope	0,0408	1	Headrace Tunnel	0,0732
6	Dam's Foot	0,4074	2	Surge Tank	0,0732
7	Dam Gallery	0,0418	3	Penstock	0,1916
<b>Dam Instrument Components</b>			4	Tailrace Tunnel	0,0732
1	Stand Pipe Piezometer	0,2000	5	Discharge Door	0,5887

**Table 7. Basic risk recapitulation of Saguling dam and Cirata dam**

Risk Class		Saguling Dam Assessment Results		Cirata Dam Assessment Results	
		Parameter	Value	Parameter	Value
Contribution to risk					
Reservoir capacity (million m <sup>3</sup> )		611	6	769	6
Dam height		99	6	127	6
Evacuation requirements (number of people)		3141	4	1801	4
Potential downstream damage (on the existing structure)		High	12	High	12
Business risk for owners as a result of dam failure (additional consequences for ICOLD)		High	6	High	6
Additional factors for existing dams	The availability of construction and maintenance data	High	0	High	0
	Availability of instrumentation that has been processed and the observational data	High	0	High	0
	The level of effort done in the previous safety evaluation	High	0	High	0
	new or coming downstream development	High	0	High	0
The effect of deficiencies on dam failures					
Additional factors for overcoming structural defects	Deficiencies related to flood capacity	Moderate	0	Moderate	0
	Deficiencies related to static stability	Moderate	0	Moderate	0
	Deficiencies related to earthquake	Moderate	0	Extreme	0
Dam risk value based on consideration		34		37	
Risk Class (I,II,III,IV) - Ref. Pp.41 ICOLD Buletin No. 72		II Moderate		II Moderate	

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