ANALYSIS OF THE STABILITY OF DAM BUILDING
AFTER COUNTERWEIGHT ADDITIONS
(A Case Study: Gonggang Dam, Magetan Regency)

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Abstract. The Gonggang Dam was first planned to be a rock filled dam, but due to the economic consideration, in the construction, the materials were changed from rock piles to random heaps with the fixed degree of slope. After being operated for a year with the observation on the possibility of seepage, no seepage was found. Therefore, to increase the stability of the dam body, a counterweight in the form of random pile completed with a filter and rip-rap was added to the lower part of the body of dam. The height of counterweight was determined based on the safety needs from the flow (surface) of the seepage line and the stability of the dam. The calculation results of stability analysis of the dam body with counterweights was considered effective as the downstream safety. Safety factors obtained from empty conditions, flood water levels and rapid drawdown without seismic load show the equation: security factor $\geq 1.2$, which was in accordance to the permitted safety factor: $sf \geq 1.2$. Meanwhile, the calculation result of the analysis of stability of the dam body with Operation Base Earthquake (OBE) and Maximum Design Earthquake (MDE) in empty condition and flood water level, the safety factors obtained were still above the permitted limit, $\geq 1.2$. However, for rapid drawdown conditions with the effect of the MDE seismic load was not yet safe (collapse), so it was necessary to modify the design of the upstream leg section. The design modification was carried out by adding a random land fill structure that blends with the body of the main dam. The method was expected to be able to withstand the tension occurring upstream, thus increasing the stability of the dam body. This was proven to be effective based on the calculation results obtained by the safety factor of 1.115. The number was still included in the permitted Maximum Design Earthquake (MDE) safety number of load effect ($sf \geq 1$).

1. Introduction
The Gonggang Dam that began operating in 2011 is located on the Gonggang River in Poncol Village, Poncol Sub-district, Magetan Regency, East Java. The Gonggang Dam is a central core embankment dam, with the height of 60.00 m, peak length of 226.00 m, peak width of 10.00 m, upstream slope of 1: 2.50 and downstream slope of 1: 2.00. The Gonggang Dam was at first planned to be a rock filled dam, but due to economic considerations, in the realization, the material was
changed from rock piles to random piles with a fixed slope. After being operated for a year with the observation on the possibility of seepage, no seepage was found. Therefore, to increase the stability of the dam body, a counterweight in the form of random pile completed with a filter and rip-rap was added to the lower part of the body of dam. The height of counterweight was determined based on the safety needs from the flow (surface) of the seepage line and the stability of the dam.

2. Safety Factor Requirements

The assessment of minimum safety factors for stability of embankment dam is based on Pedoman Konstruksi dan Bangunan Sipil Analisis Dinamik Bendungan Urugan (Construction and Civil Building Guidelines of Embankment Dam Dynamic Analysis) No 27/KPTS/D/2008 dated 31 January 2008, page 115. The following is the table of requirements of the safety factors.

| No | Condition                                                                 | Pore Water Pressure                                                                 | SF Without earthquake | SF With earthquake |
|----|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------|---------------------|
| 1. | Finished construction depends on:                                         | The increase in pore water pressure in piles and foundations is calculated using laboratory data and instrument monitoring | 1.30                  | 1.20                |
|    | 1. Development schedule                                                   | **With an earthquake without damage used 50% coefficient**                           |                       |                     |
|    | 2. Relationship between Pore pressure and time U/S and D/S slopes        | **Earthquake design**                                                               | 1.40                  | 1.20                |
|    |                                                                           | **Items just without instrument supervision**                                       |                       |                     |
|    |                                                                           | **Only on heaps without lab data. and with / without supervision of instruments**   | 1.30                  | 1.20                |
|    |                                                                           | **Without instrument**                                                             | 1.30                  | 1.20                |
| 2. | Lasting flow depends on:                                                  | From seepage analysis                                                               | 1.50                  | 1.20                |
|    | 1. Normal water level next to the bumpkin                                 |                                                                                     |                       |                     |
|    | 2. U/S and D/S slopes.                                                    |                                                                                     |                       |                     |
|    | 3. With an earthquake without damage used 100% coefficient.               |                                                                                     |                       |                     |
|    | 4. Earthquake design                                                      |                                                                                     |                       |                     |
Table 1. Requirements for minimum safety factors for the stability of the embankment dam (b)

| No | Condition | Pore Water Pressure | SF Without earthquake | SF With earthquake |
|----|-----------|---------------------|-----------------------|--------------------|
| 3  | Operation of the reservoir depends on:  
1. Maximum water level upstream  
2. Minimum water level upstream (dead storage). Slope U/S must be analyzed for fast receding conditions | Fast recede from normal water level to minimum water level. U/S and D/S slopes. | 1.30 | 1.10 |
|    |  | Fast recede from maximum MA elevation to minimum MA elevation. The effect of the earthquake was taken 0% of the coefficient Earthquake design | 1.30 | - |
|    | Emergency conditions depend:  
1. Stacking the drainage system  
2. Low tide because the use of water exceeds needs  
3. Fast receding emergency needs | Fast recede from maximum water level to the lowest elevation of expenditure buildings. The effects of the earthquake are ignored | 1.20 | - |

Note: check the standards about the method of dynamic gravity dam analysis  
*) For OBE; while **) for MDE, FK ≥ 1

3. Imposition
According to Suyono Sosrodarsono, in the embankment dam, there are three loading conditions in calculation of the stability of the dam body, namely:

3.1. Initial condition of the dam  
It is condition where tension and strain occur due to the load of the dam before being filled with water.

3.2. Dam condition after being filled with water  
It is condition where tension and strain occur due to dam and water loads (maximum load of water at surface).

3.3. Rapid drawdown conditions  
It is condition where tension and strain occur due to a decrease in reservoir water on the dam.

4. Method
The data collection is basic means to determine the resolution of a problem scientifically. The data collected comprise primary data and secondary data.
4.1. Primary data
Primary data refer to data obtained from direct observations of researchers at research locations such as:
- Survey on the location with the aim of observing the situation of the research location
- Taking photos of research locations for observation and analysis.

4.2. Secondary data
Secondary data refer to data obtained from laboratory at the time the research is carried out on the location. The secondary data cover information on soil, such as Soil Properties and Soil Engineering. Soil Properties include soil content weight ($\gamma$), water content (w), void ratio ($\varepsilon$), porosity (n), specific gravity ($G_s$), Dry density, Saturation density, Porosity, Poisson ratio, Young's modulus, Cohesion, Friction angle, Dilatancy angle, Horizontal permeability, and Vertical permeability, while Soil Engineering comprise the results of Direct Shear Test, Triaxial Test, and Unconfined Test.

4.3. Image Data
Image data cover the image of floor plan, image of cross sections of the dam body, and image of elongated pieces of the dam body.

4.4. Technical Data
Technical data comprise data of main dam and inundation area. Data of main dam include type of dam, height of dam, length of peak, width of peak, elevation of peak of dam, elevation of river bed, slope of upstream, slope of downstream, and body volume of the dam. Data of inundation area consist of water catchment area, river length, maximum water level elevation, minimum water level elevation, dam reservoir volume, sediment reservoir volume, and inundation area.

Stage 1 – collecting data in the forms of:
- properties of soil obtained from the results of the Gonggang Dam Lab,
- map,
- floor plan,
- cross section, and
- elongated pieces.

Stage 2 – calculating the safety factor of the dam body without seismic load or with seismic load in a condition when:
- the dam is empty
- the dam is in flood water level, and
- the dam is in rapid drawdown condition.

Stage 3 – calculating stability, which is:
- calculating stability $SF \geq 1.2$

Stage 4 – with calculated stability before < after the implementation of Counterweight and Stability is safe, if it is not safe then recounting is done with design modifications.

Stage 5 – Determining the decision.
Below is the flow chart of the stages above.

![Flow Chart](image)

**Figure 1.** Chart of Research Flow
5. **Result and Discussion**
The following are the results and discussion of the calculations of the three loadings, with and without seismic loads.

**Table 2. Calculation of safety factor in rapid drawdown condition**

| No | Condition               | SF With earthquake Before | SF With earthquake After | Total Displacement Before with counterweight | Total Displacement After with counterweight |
|----|-------------------------|---------------------------|--------------------------|---------------------------------------------|--------------------------------------------|
| 1  | Rapid Drawdown (OBE)    | 1,184 (OBE)               | 1,109 (OBE)              |                                             |                                            |

**Caption:**
- Conditions at the time of the dam are Rapid Drawdown
- Filtration flow is in the center of the dam's body
- The collapse mechanism is shown in red arrows, which are at the top of the dam's body towards the lower upstream
- The tension does not reach the foundation

**Caption:**
- Conditions at the time of the dam are Rapid Drawdown
- Filtration flow is in the center of the dam's body
- The collapse mechanism is shown in red arrows, which are at the top of the dam's body towards the lower upstream
- Tension due to seismic loads, to foundation parts
- With the presence of counterweight the greater the tension that occurs, especially on the foundation

**Picture 1**
- Collapse (MDE)

**Picture 2**
- Collapse (MDE)

**Picture 3**
- With the MDE earthquake the tension generated reaches the foundation

**Picture 4**
- With the MDE earthquake the tension generated on the foundation is greater than without counterweight
From the results of analysis of the Safety Factor that has not met the conditions in Rapid Drawdown with earthquakes Maximum Design Earthquake (MDE), a design modification is needed to increase the stability of the dam body. The design modification is focused mainly on the upstream part of the dam body, by adding a random embankment structure that blends with the existing heap.

The following is a modification of the dam body design calculation on the condition of Rapid Drawdown with seismic load Maximum Design Earthquake (MDE), to find the safety number required by using Plaxis Method.

Table 3. Calculation of safety factor in rapid modification condition

| No. | Conditions of MDE Seismic Load | Captions |
|-----|-------------------------------|----------|
|     | Before with Counterweight | After with Counterweight | Depiction of design modification, by adding landfill upstream |
| 1   | Figure 5. Standart fixities |          | |
| 2   | Figure 6. Total deformation after design modification and without counterweight | Figure 7. Total deformation before design modification | The calculation result of safety factor with the counterweight is higher than without counterweight, which is 1.115 > 1.00 |
|     | Figure 8. Total deformation after design modification |          | The tensions which occur without counterweight, with design modification is higher both upstream and downstream |

6. Conclusion

Conclusion from the Safety Factor Calculation Table above can be elaborated as follows:
1. Counterweight is considered effective when there is no seismic load in all three conditions. It can be seen from the increasing safety factor.
2. Counterweight is effective when loading occurs downstream, in the presence of seismic loads.
3. Counterweight does not give any role at the time of loading which occurs upstream (rapid drawdown condition), especially in MDE earthquake conditions. Conversely, with the presence of counterweight, there is a large tension on the foundation.
4. In the operation of the reservoir, the speed of water level reduction is set to prevent rapid drawdown (the pattern of reservoir operations contains at least the procedure for removing water from the reservoir in accordance to the conditions of water reservoir volume and elevation and the water capacity and river capacity downstream of the dam)
7. Recommendation
To follow up this research, further research is needed regarding the development of the theme and methodology. The suggestions for further research include:
1. The necessity to do more detailed calculations of design modifications both in analysis and modeling in the laboratory, so that the best and most efficient alternatives can be determined to be applied in the field,
2. The necessity to study further about the technical implementation of design modifications.

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