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# Slope Stability Analysis on Bener Dam Cofferdam Using PLAXIS Application to Ensure Main Dam Work is Not Disturbed

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## Abstract

*Slope stability is one way to obtain the safety factor value of a water structure, such as a cofferdam. The cofferdam holds water and diverts it towards the diversion channel as a cofferdam or tunnel. Assessment of the safety factor value of the cofferdam is critical considering the smoothness of the dam body filling work. Research on the stability of the dam body slope has been widely conducted, but the stability of the cofferdam slope is still very little. This study aims to analyze the slope stability of the Bener Dam cofferdam work using the finite element method with the PLAXIS application to ensure that the safety of the main dam is not disturbed. The data used in this study came from the Bener Dam Final Report and several literatures. Slope stability modelling is reviewed from three conditions: empty water level/after construction, flood water level, and rapid drawdown. The results of this study indicate that the safety factor value in the three conditions is greater than the required safety factor value. Respectively 1,369; 1,824; and 1.215 for after construction, normal and flood water level conditions. The results of the safety factor values state that the main and work are not disturbed*

**Keywords***: stability, cofferdam, safety factor, and praxis*

## 1. Introduction

Slope stability is one of the indicators to assess the safety of a building. Stability assessment can be carried out under various conditions adjusted to applicable norms, guidelines, standards, and manuals. Dams are one of water structures built across rivers that can accommodate large amounts of water. Dams consist of materials with a particular slope and height so that they can accommodate water in the upstream where this has the potential for the dam's stability.(Laksono, Sundari, and Subhy, 2020). While implementing the dam body work, a cofferdam is first built. A cofferdam is a water structure that also consists of certain constituent materials and functions to divert water flow into the diversion channel. The cofferdam will also receive a relatively large water load, which has the potential to endanger its stability. Research on slope stability on dams has been widely studied, but slope stability on cofferdams is still very little. Researchet al., 2021)In Semantok Dam using the Geostudio application produces FK value on upstream and downstream slopes greater than the FK required under conditions without an earthquake and OBE earthquake. Gongseng Dam produces an FK value greater than the FK required using Geostudio and Plaxis application under conditions after construction, steady state, and rapid drawdown (Imron et al., 2017). Other research fromet al., 2023)at Jlantah Dam also produced FK values greater than the FK values required using the Geostudio application in conditions without OBE earthquakes. Research on cofferdam stability can be found in bridge work(Sari et al., 2024). The cofferdam is intended to retain the embankment, protect it from river erosion, and as a foothold for heavy equipment. The embankment behind the cofferdam is intended to protect part of the foundation on the river slope. The safety factor of the unreinforced cofferdam embankment is 1.36, while the safety factor obtained with a combination of reinforcement for each condition is 1.68 (static condition), 1.59 (drawdown condition), and 1.19 (earthquake condition). The safety factor obtained can generally be categorised as safe and meets the minimum safety requirements of 1.5 for static and 1.1 for earthquake conditions.

The research location is in the Serayu Opak River Area, precisely on the Bogowonto River in Purworejo Regency, Central Java Province. Geographically, it is at

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coordinates 7°36'4.44"S and 110° 1'18.31"E, as seen in Figure 1.


**Figure 1**. Research Location.

To get to the location can be reached from Yogyakarta City to the west to Purworejo Regency using a car with a travel time of +2 hours and a distance of +65 km or from Semarang City, it takes +4 hours with a distance of +140 km. The cofferdam on the Bener Dam is under construction and is almost complete. The cofferdam is designed separately from the main dam body, generally designed to be integrated with the dam body. Research on the stability of the main dam body, which is integrated with the cofferdam, is conducted at the Semantok Dam (Pratama et al., 2021). Another study of the Bendo Dam also designed a cofferdam that is integrated with the main dam body.(Dhyaksaputra et al., 2019). Other research also from(Asmaranto et al., 2007) on the stability of the main dam body, which is designed to be integrated with the cofferdam.

*Cofferdam intended to protect the main dam bodywork* designed with the concrete face rockfill dam (CFRD) type. This type of dam has a high level of difficulty, and the height of the main dam body is also designed to be over 150 m. Therefore, the cofferdam must be safe through the safety factor value in the slope stability analysis under certain conditions, namely when construction is completed, the normal water level and the flood water level. The cofferdam breaking occurred when the flood water level occurred at the Karalloe Dam cofferdam(Simatupang et al., 2020). Analysis of slope stability has been widely conducted. However, slope stability on cofferdam dams designed separately from the main dam body is still very little and is a novelty in this study. This study aims to analyze slope stability to obtain a safety factor value to ensure that the work of the main dam body is not disturbed. The cofferdam on the Bener Dam will be analysed at the end of construction, including the maximum water level and rapid drawdown.

## 2. Materials and Methods

Data is an important element used to perform modelling and analysis. Data was collected from the Serayu Opak River Basin Center and several other literatures. The cofferdam at Bener Dam is designed with a rock embankment and a sloping core equipped with a filter. The cofferdam design and material properties of the constituent materials from the laboratory can be seen in Figure 2 and Table 1.

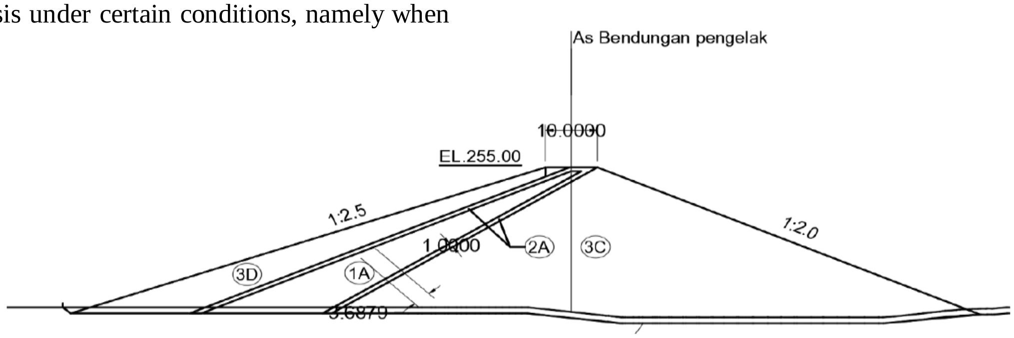


**Figure 2**. Cofferdam Design
Source: BBWS Serayu Opak, 2015

**Table 1**. Laboratory Result Materials.

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| Zone | Material | Unsaturated (kN/m3) | Saturated (kN/m3) | Cohesion (kN/m3) | Internal Friction Angle (0) | k (m/day) | E' | *Poisson Ratio* |
|---|---|---|---|---|---|---|---|---|
| 3C | Andesite & Breccia Rockfill | 21 | 22 | 0 | 45 | 86.4 | 140000 | 0.35 |
| 3D | Andesite Rockfill | 22 | 23 | 0 | 50 | 86.4 | 140000 | 0.35 |

Source: BBWS Serayu Opak, 2015

Other required parameters, such as sand and clay parameters, are obtained from several existing literatures, as shown in Tables 2 to 7.

**Table 2**. Correlation of Soil Specific Gravity (Yunsat) for Cohesive Materials and Non-Cohesive Materials

| Description | Non Cohesion | | | | |
|---|---|---|---|---|---|
| N | 0-10 | 11-30 | 31-50 | >50 | |
| Unit Weight (kN/m3) | 12-16 | 14-18 | 16-20 | 18-23 | |
| Φ | 25-32 | 28-36 | 30-40 | >35 | |
| State | Loose | Medium | Dense | Very Dense | |
| Description | Cohesion | | | | |
| N | <4 | 4-6 | 6-15 | 16-25 | >25 |
| Unit Weight (kN/m3) | 14-18 | 16-18 | 16-18 | 16-20 | >20 |
| Φ | <25 | 20-50 | 30-60 | 40-200 | >100 |
| State | Very Soft | Soft | Medium | Stiff | Hard |

Source:(Lambe & Whitman, 2023)

**Table 3**. Correlation of Saturated Soil Specific Gravity (Ysat) for Non-Cohesive Soil

| Description | Very Loose | Loose | Medium | Dense | Very Dense |
|---|---|---|---|---|---|
| Saturated Unit Weight (kN/m3) | 11-16 | 14-18 | 17-20 | 17-22 | |

Source :(Lambe & Whitman, 2023)

**Table 4**. Typical Values of c' and Φ'

| Land Group | Typical Soil | C' | Φ' |
|---|---|---|---|
| Bad | Soft and firm clay with medium to high plasticity; silty clay; loose variable clay content; loose sandy silt | 0-5 | 17-25 |
| Currently | Stiff sandy loam; gravelly loam; dense loamy sand; sandy silt; dense lampung | 0-10 | 26-32 |
| Good | Gravelly sand; compacted sand; gravel and crushed sandstone filling; well-graded compacted sand | 0-5 | 32-37 |
| Very good | Ground-laid stone; controlled road base fill; recycled gravel and concrete | 0-25 | 36-43 |

Source :(Lambe & Whitman, 2023)

**Table 5.**Relationship between Soil Type and Poisson Ratio

| Soil Type | *Poisson's Ratio* |
|---|---|
| Saturated clay | 0.4-0.5 |
| Unsaturated clay | 0.1-0.3 |
| Sandy loam | 0.2-0.3 |

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| | |
|---|---|
| Silt | 0.3-0.35 |
| Sand | 0.1-1.0 |
| Rock | 0.1-0.4 |
| commonly used for land | 0.3-0.4 |

Source:(DAS, 1995)

**Table 6.**Relationship between Soil Type and Permeability

| Soil Type | K (mm/sec) |
|---|---|
| Coarse grain | 10 - 103 |
| Fine gravel, coarse grain mixed with medium grain sand | 10-2 – 10-3 |
| Fine sand, loose silt | 10-4 – 10-2 |
| Dense silt, clayey silt | 10-5 – 10-4 |
| silty clay, loam | 10-8 – 10-5 |

Source:(Hardiyyatmo, 2002)

**Table 7.**Relationship between Soil Type and Modulus of Elasticity

| Soil Type | K (mm/sec) |
|---|---|
| CLAY | |
| - Very Soft | 3-30 |
| - Soft | 20-40 |
| - Currently | 45-90 |
| - Sandy | 300-425 |
| SAND | |
| - Silty | 50-200 |
| - Not dense | 100-250 |
| - Congested | 500-1000 |
| Sand and Gravel | |
| - Congested | 800-2000 |
| - Not Solid | 500-1400 |
| SILT | 20-200 |
| LOSSES | 150-600 |
| CADAS | 1400-14000 |

Source:(Bowles, 1996)

The method used in the analysis is the finite element method using the PLAXIS application. PLAXIS is a software used in the geotechnical field to solve problems of stability, seepage, etc. To create a slope stability model and conduct analysis to approach actual conditions, PLAXIS uses the basic principles of FEM or Finite Element Method development. The Strength Reduction Method is a method used to obtain the FK value. The cohesion value (c) and the friction angle (φ), according to Brinkgreve (2016), are used in this approach to gradually reduce the shear strength value of the soil until failure occurs. Equation 1 below shows the equation used to calculate the FK value(Pratiwi, Yakin, and Mahaputra, 2022).

$$\Sigma MFK = \frac{C}{CRF} = \frac{\tan \varphi}{\tan \varphi r} \quad (1)$$

where

$\Sigma MFK$ =safety factor

c = cohesion (kN/m2)

cr =reduction cohesion (kN/m2)

φ = friction angle (o)

φr = reduction shear angle (o).

The steps taken to analyse slope stability using PLAXIS are as follows:

- Creating slope modeling geometry;
- Enter soil and rock parameters;
- Conducting two analyses, such as gravity loading and safety analysis. Gravity loading takes into account the weight of the soil above it. The Strength Reduction Method is used to calculate the Safety Factor (FK) value in the safety analysis.
- The analysis results are in the form of a Safety Factor value.

The flowchart of this research from start to finish can be seen in Figure 3.

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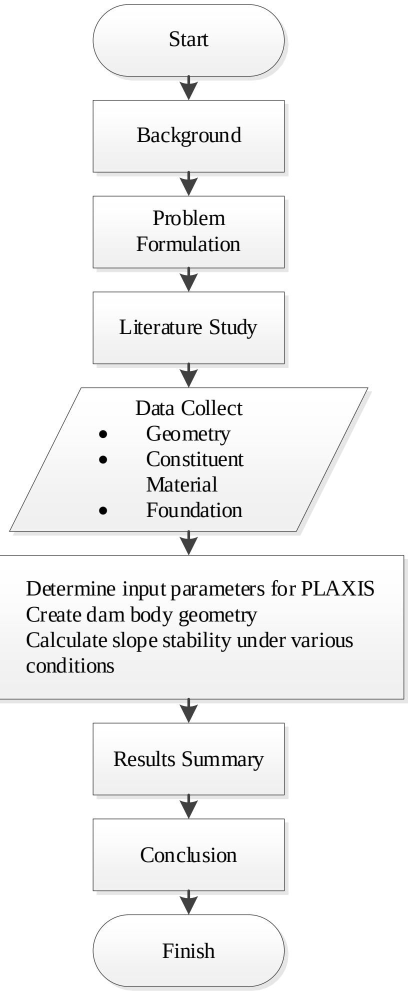


**Figure 3**. Flowchart of Slope Stability Analysis on Bener Dam Cofferdam.

## 3. Results and Discussion

### 3.1. Design Parameters

The use of design parameters is based on laboratory results and literature. The parameters based on the literature are the modulus of elasticity of unsaturated and saturated sand weight as a fine filter, permeability value, Poisson ratio, and effective shear strength parameters (cohesion and shear angle in the clay core. The geotechnical parameters used can be seen in Table 8.

**Table 8.** Design Materials

| Zo ne | Material | Unsaturated (kN/m3) | Saturated (kN/m3) | Cohesion (kN/m3) | Internal Friction Angle (0) | k (m/da y) | E' | *Poisson's Ratio* |
|---|---|---|---|---|---|---|---|---|
| 3C | Andesite & Breccia Rockfill | 21 | 22 | 0 | 45 | 86.4 | 140 000 | 0.35 |
| 3D | Andesite Rockfill | 22 | 23 | 0 | 50 | 86.4 | 140 000 | 0.35 |
| 1A | Clay | 17 | 20 | 5 | 25 | 0.000 0864 | 120 000 | 0.35 |
| 2A | Sand | 18 | 20 | 1 | 37 | 8.64 | 800 00 | 0.35 |

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### 3.2. Modelling Results

The first analysis was conducted on the after-construction condition with an empty water surface. The results are shown in Figure 4.

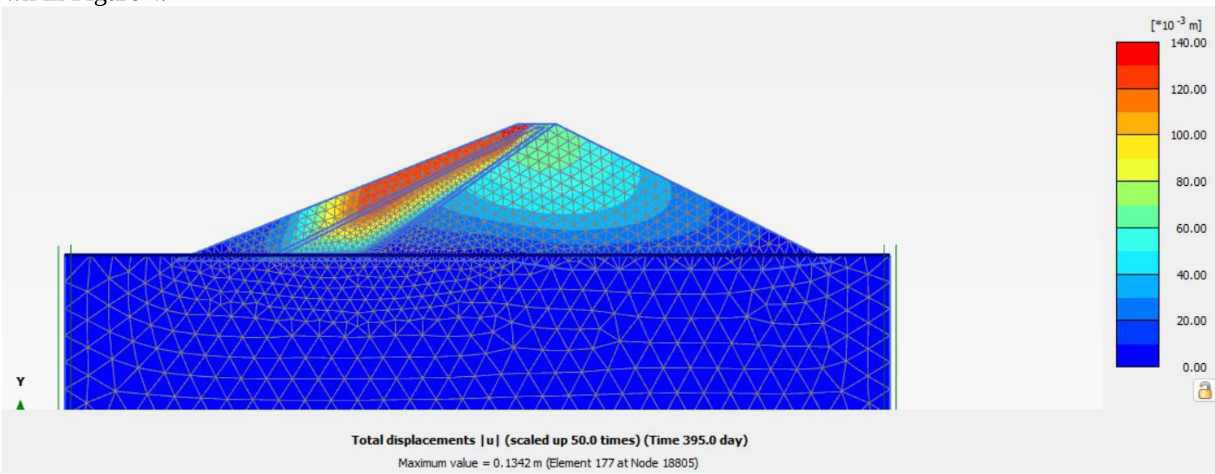


**Figure 4**. Slope Stability After Construction.

Based on Figure 4, the most significant decrease occurred in the upstream section of 13.42 cm with an FK value of 1.369 > 1.3 (as required by SNI M-3-2002). These results indicate that the condition of the cofferdam is still "safe" if no water is stored. This condition usually occurs in the dry season with very low river water elevation. After that, the analysis continued at the flood water level conditions at +253.00 masl and was assumed to last quite a long time. The water level elevation will persist throughout the construction of the dam body. The results of the analysis can be seen in Figure 5.

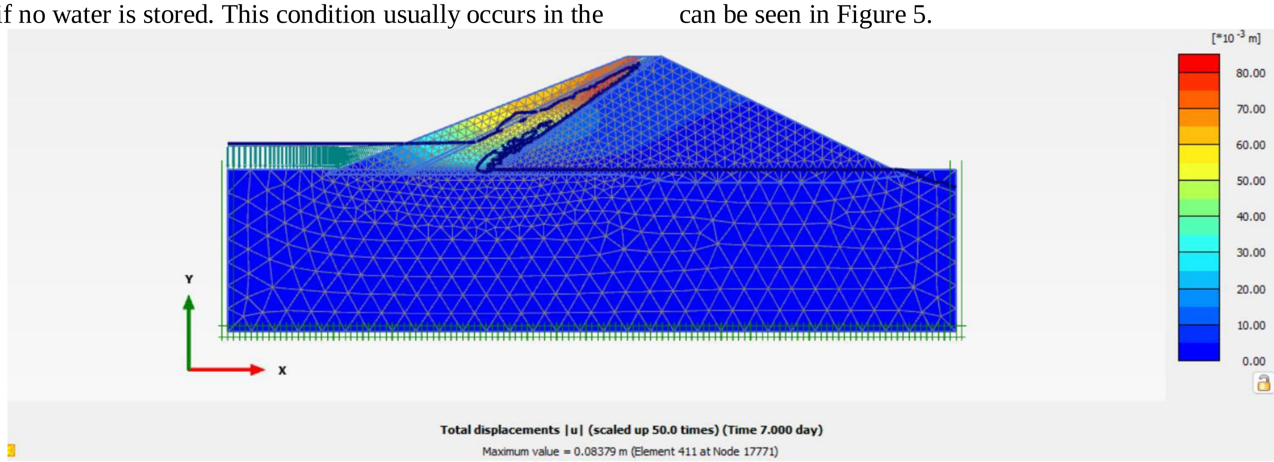


**Figure 5**. Stability of Flood Water Slope.

Based on Figure 5, the FK value is 1.824 > 1.5 (as required by SNI M-3-2002). Modelling in this scenario also shows that the cofferdam is still in a “safe” condition. The last stage is to analyze the slope stability under rapid drawdown conditions. Modelling of rapid drawdown conditions starts from an elevation of +253.00 masl to an elevation of +228.00 masl for 20 days. Results The results of the analysis can be seen in Figure 6.

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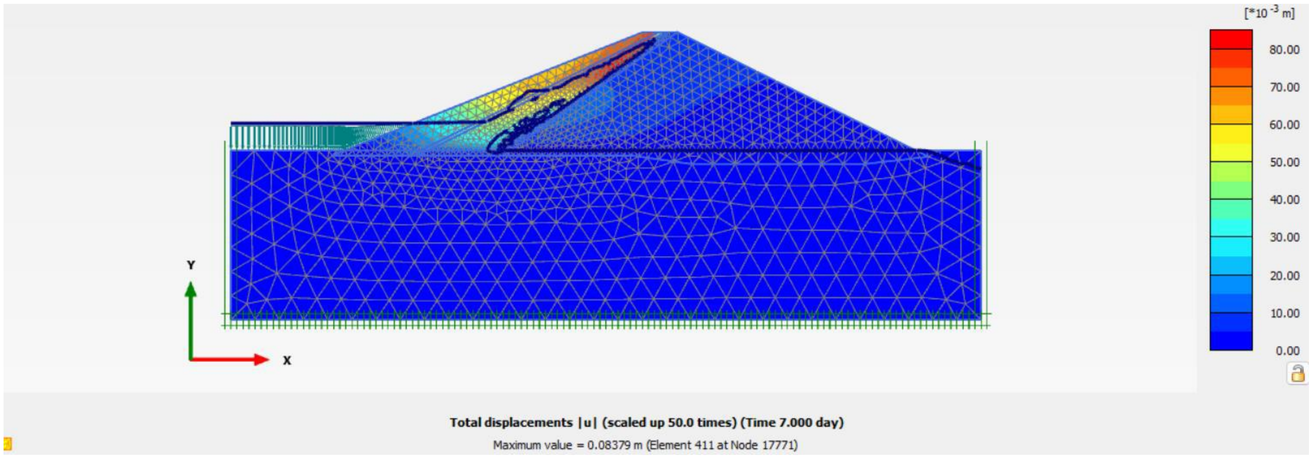


**Figure 6.**Rapid Draw Down Slope Stability.

Based on Figure 6, the FK value is 1.215 > 1.2 (as required by SNI M-3-2002). The calculated FK value obtained from the after-construction condition to rapid drawdown shows a decrease but is still within the required limits. This is due to the different loads in each modelling condition. Research on the stability of the cofferdam at the Cijurey Dam(Fakhrulloh et al., 2023)using the studio application in empty, normal and flood conditions produces safety factor values of 2.311, 2.231, and 1.935, respectively. Other research on slope stability comes from the main dam body that has been integrated with the cofferdam, as research from(Lontoh, Manoppo, and Sompie, 2020)at Lolak Dam shows that there is a decrease in the calculated FK value from the after-construction condition and flood water level with each FK value of 2.23 and 2.08 while at fast ebb it is greater than the flood water level condition, which is 2.18. At Karalloe Dam, the FK value is 2.15 on the upstream slope and 2.10 on the downstream slope in the after-construction condition, and in the flood water level condition, it has an FK value of 8.40 on the upstream slope and 7.20 on the downstream slope(Rakhim & Sirajuddin, 2020). According to research(Sugiharti & Susantin, 2022), Cipanas Dam has an FK value of 2.190 on the upstream slope and a downstream slope of 1.857 in the after-construction condition in the maximum water level condition. It has an FK value of 2.552 on the upstream slope and a downstream slope of 1.613, and in the fast-receding condition, it has an FS value of 1.721 on the upstream slope. Other research from(Thirafi et al., 2017)at Way Apu Dam produced Fk values of 1.399, 1.253, and 1.086 in empty, regular water and flood conditions. At Raknamo Dam, with flood water level conditions and rapid drawdown for 7 days, FK values are 1.890 and 2.032(Putra & Susantin, 2018). In addition, the Beringin Sila Dam produced FK values of 4.34 and 2.13 in empty and flood water conditions. (Margaretha et al., 2020). At Saradan Dam, the FK values were 2.069, 2.186, and 1.899 at flood, standard, and rapid draw-down conditions.(Saidillah & Kusuma Artati, 2022). Other research from Teritip Dam produced FK values of 2.34 and 2.33 at normal and flood water levels.(Laksono et al., 2020). Of all the studies above, only the Cijurey Dam studied the stability of the cofferdam slope, and the rest studied the stability of the dam body slope. All of the studies above can produce FK values above those required to ensure that the condition of the cofferdam or dam body is stable under several conditions. The results of FK values exceeding the specified requirements will ensure the sustainability of the dam work as a whole, especially the main dam body. The main dam body is more complex and requires high precision and accuracy. To obtain more accurate analysis results, earthquake analysis and sampling parameters of other zones are required. In addition, during construction, a stage-by-stage stability analysis is also carried out, which is combined with reading the results of instrumentation to ensure the stability of the cofferdam at all times.

## 4. Conclusion

Some of the descriptions above show that the FK value decreases in the after-flood water level and rapid draw-down conditions, but the stability of the upstream and downstream slopes of the cofferdam at Bener Dam is still within safe limits (as required) in all modelling conditions. Therefore, the work of the main dam body at Bener Dam will not be disturbed because the cofferdam can withstand loads in empty, normal, and flood conditions. Testing of other zone samples, earthquake effects, and reading of instrumentation results on the cofferdam embankment is needed to obtain better and more accurate calculation results.

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