The Influence of Seismic Load to Deformation of Dam

Undayani Cita Sari
Sultan Agung Islamic University, Department of Civil Engineering
Jl. Raya Kaligawe Km.04, Semarang, Central Java, Indonesia
undayanicita@yahoo.com

Abdul Rochim
Sultan Agung Islamic University, Department of Civil Engineering
Jl. Raya Kaligawe Km.04, Semarang, Central Java, Indonesia
abdulrochim@unissula.ac.id

Windu Partono
Diponegoro University, Department of Civil Engineering
Jl. Prof. Soedarto, SH, Semarang, Central Java, Indonesia
windu_bapake_dila@yahoo.com

Abstract- Disaster mitigation due to seismic load (earthquake) needs to be considered. This is especially for dam structure used as a reservoir and water resource. Because of the main function, and building dimension is too large, thus if the dam collapse it will cause a significant catastrophe for the surrounding community and environment. One of the seismic damages to the dam is deformation. This paper presents the effect of seismic load on deformation of dam model simulation. This study took place on the Sermo Dam, Yogyakarta which is located close to Opak Fault –as the suspicious cause of the earthquake in Yogyakarta. Seismic loads used in this study in terms of acceleration time histories. Therefore model can be carried out using PLAXIS simulation. This selected seismic load variations are on the range 5.0-7.0 Mw and epicentrum distance is also restricted in 15-31 Km based on the nearest epicentrum distance between Sermo Dam and Opak Fault.

Keywords**:** seismic load, deformation, dam, modeling

1. Introduction

Disaster mitigation due to earthquake needs to be considered because it can cause structural damage that affect the surrounding community. Particularly for the dam structure used as a reservoir and water source for the community. Because of the main function and dimension of the building is too large, then if the dam collapse it will cause significant impacts for the community and the surrounding environment. Islam and Faruque (2013) stated that the possibility of damage that can occur due to the earthquake are slope failure, fault displacement/ reactivation, crest settlement, and permanent deformation of the dam body/ foundation.

Indonesia is a country which is prone to earthquakes. Aceh earthquake (2004) and Yogyakarta earthquake (2006) are two examples of the larger earthquake that impact to local area (Aceh and Yogyakarta province). The Aceh Earthquake on 26 December 2004 was an earthquake in the sea and had a magnitude of 9.2 Mw which also caused a tsunami (Natawidjaja, 2007). Although it had large magnitude, it had a deep hypocentrum and far epicentrum that resulted in major damage.

On the other hand, the Yogyakarta earthquake was happened on 27 May 2006 with magnitude moment, 6.3 Mw (USGS in Sulaeman et al. (2008)) or 5.9 Mb (BMG in Sulaeman et al. (2008)). Although the magnitude was smaller than the Aceh earthquake, the distance from the epicenter was very close and depth of focus was shallow which made the huge damage to Yogyakarta area. The impact of the Yogyakarta earthquake based on its geology and geotechnical aspects were analyzed and based on field observations, it was known that geotechnical earthquake impact were landslide, liquefaction, and fluctuation of water level and quality of wells (Rosyidi et al., 2008). The other side effect from geotechnical aspects that can not ignore is deformation of the structure. The excess deformation will lead to instability of structure.

To understand actually how seismic load affects to dam structure can be implemented through physical models and simulations. Therefore this study will attempt on simulation model using PLAXIS 2D. According to these reasons, this study will discuss the impact of dams with dynamic earthquake load which is expected to provide an understanding thought of how the seismic load effect on dam structure. This research took a study on Sermo Dam, Yogyakarta, so this review study is also conducted based on the occurrence of Yogya Earthquake and Opak Fault as the suspicious cause of that earthquake.

2. Seismic Vulnerability on the Dam

Disaster is an event or series events that threaten and disrupt lives and livelihoods of people caused by natural factors and/ or non-natural factors or human factors resulting in casualties, environmental damage, property loss, and psychological impact (Indonesian National Board for Disaster Management/ BNPB, 2013). These natural disasters can be tsunami, volcanoes, floods, droughts, landslides, and earthquakes.

Indonesia is one of the disaster-prone countries. Maplecroft (2010) in BNPB (2013) puts Indonesia in ranking two, as a country at extreme risk. Since the impact is enormous, which may also lead to national instability of a country, this disaster needs to be taken into account, mainly in the design of civil buildings. According to these reasons, then in this study will discuss about one of the disaster that is prone to occur in Indonesia, earthquake disaster.

Earthquake is an event of the release of energy due to the sudden shift of the earth's crust (BNPB, 2013). Indonesia’s location is very vulnerable to the earthquake. This is because of the following reasons :

a. Natural factors, Indonesia located at meeting of tectonic plates, so that it is above the earthquake path.
b. Volcanic earthquake due to volcanic eruption which Indonesia has 127 active volcanoes or about 13% of the world's active volcanoes in Indonesia (BNPB, 2016).

Dam is a large-dimensional civil structure used as water storage. The important role that the dam structure has, must be followed by design and maintenance well in order to provide sustainable benefits. Nevertheless, there are several problems with the dam that are important to be studied further in the current era, landslide, leakage, and earthquake as example. However, this study focuses on the issue of seismic load in dams. Because of the location of Indonesia which prones to earthquake, failure of dam because of earthquake can affect serious problem for community and civil building in the vicinity.

The detriment of dam building due to earthquake can be caused by several factors. For exampe, lifespan of dam construction and the position of dam is right on the tectonic quake path. These reasons can give negative impact to the dam, make the dam is unable to withstand also because of the load of the building (water and seismic load).

In addition, the possible forms of failure of earth dams because earthquakes have been obtained by Sherard (Raja and Maheshwari, 2016). Several of them are disruption of dam caused by major fault movement at base; and loss induced freeboard, due to the difference of the movements of tectonic ground. Based on these impacts, then need to be contemplate as precaution or mitigation how the effect of seismic load on the behavior of the dam and how to handle it. Some aspects to consider include the following reasons :

a. The type of material which also affects its strength
b. The level of elasticity of the structure
c. Stability during and after the earthquake
d. Deformation happens

3. Research Method

Several previous studies become references in the implementation of this study. Thus, it is hoped that later it will be able to provide accurate results and close to the actual conditions in the field. In this study there are several steps that must be done. There are data collection and numerical modeling which are explained in Sub 3.1 and Sub 3.2. Moreover, the final step for data analysis which includes result and discussion will be explained in Sub 4.

3.1. Data Collection

Data collection is an important step for conducting study, because if the data used is not suitable it will affect the results of the study. Data used in this study include the geometry of the dam, the material of the dam, the water level, and the time histories of the earthquake used.

This study took on Sermo Dam which is located in Ngrancah River, a child of Serang River in Hargowilis village, Kulon Progo Regency, Yogyakarta. The location of this study can be seen in Fig. 1. In addition, in this study focused on sta 12 of Sermo Dam, which can be seen in Fig. 2. Sermo Dam is a rockfill dam which comprises of several zones, core, filter, transition, shell, and bedrock making up the body dams from upstream to downstream.

Determining of material parameters in this study was based on previous research which used back analysis method (Sari, 2016). This was done by calibrating the results of the PLAXIS model with the instrumentation in the field in the form of V-Notch (part of dam structure used for detecting seepage of dam) and settlement gauge. In addition, the data used was also a test data from field implementation. Moreover for bedrock's parameter using design data from the Department of Public Works (1985). The material parameters used in this study can be seen in Table 1.

The dam analysis conducted with condition that construction of this dam had been completed. Also, it was used water level of 136.60 meters to facilitate normal condition water level when dam operates in the field. Therefore, phreatic line used in PLAXIS input identification, was a phreatic line due to the water level of 136.60 meters. Formation of phreatic line by forming a line from the upstream point of the dam to the filter zone and bedrock (downstream). Boundary condition was used at the base of the dam, so it was assumed that water can flow horizontally but not vertically.

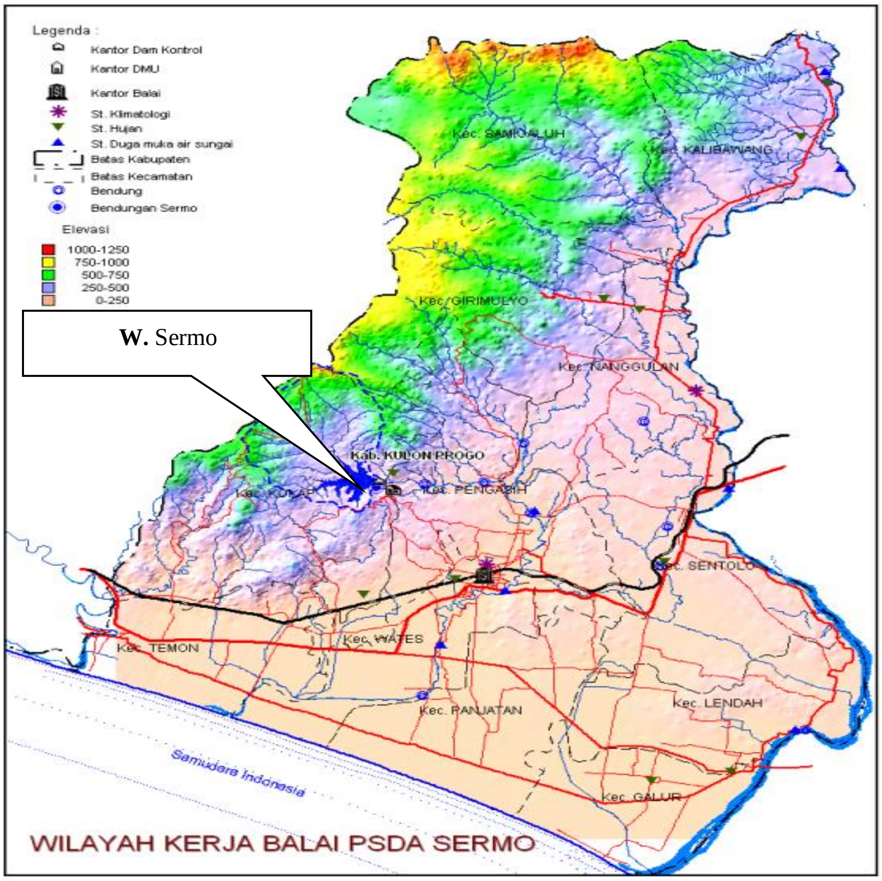

Fig. 1. Location of Study
(Department of Public Works, 2015)

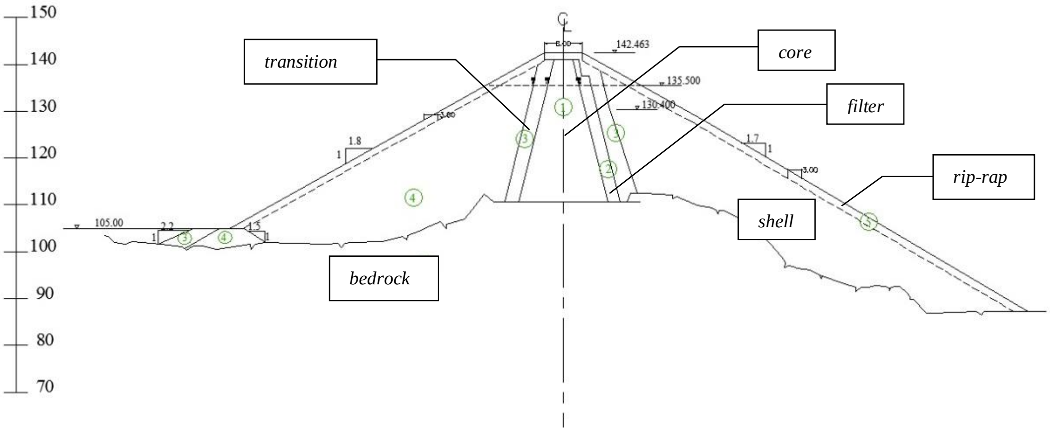

Fig. 2. Cross Section of Sermo Dam
(Department of Public Works, 1994)

Table 1. Sermo Material Modeling Parameters Sta 12

No	Parameter	Unit	*Core*	*Filter*	*Transition*	*Shell*	*Bedrock*
1	$\gamma_{saturated}$	kN/m^3	18.74	21.00	21.70	21.00	21.82
	$\gamma_{unsaturated}$	kN/m^3	15.41	18.50	21.60	20.00	20.12
2	Cohesion (*c*)	kN/m^2	8.3	0.001	0.001	0.001	680
3	Friction Angle (ø)	°	32	35	35	43	55
4	Coeff. of Permeability (*k*)	m/day	2.32 x 10^{-4}	134.10	14.292	12154.69	8.53
5	Young's modulus (*E*)	kN/m^2	5500	6000	8000	200000	210000
6	Poisson ratio (*v*)	-	0.45	0.30	0.30	0.35	0.45

Sources: Sari, 2016

The result of the soil response due to the earthquake waves that propagate will be a vibration, which is called the time history data. Data on earthquake recording, particularly the magnitude and Peak Ground Acceleration (PGA) values, which is the highest point in the time history data graph. Example of time history data can be seen in Fig. 3 which was the earthquake recording data in Nisqually, Washington, with magnitude moment, 6.8 Mw Peak Ground Acceleration value of 151.70 cm/ sec^2 or 0.15 g, and 15.6 of epicentrum distance (CESMD).

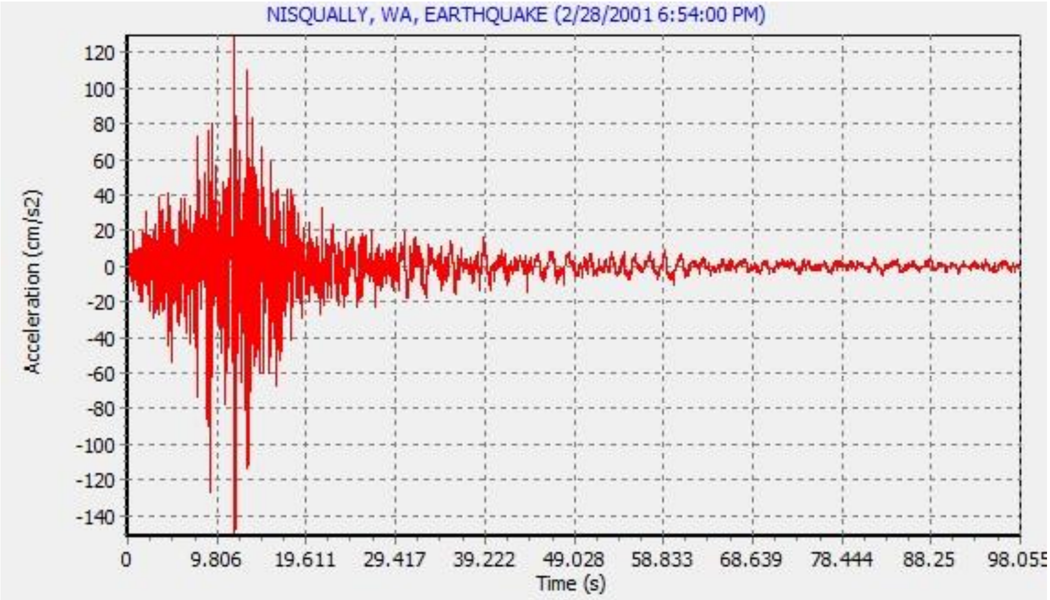

Fig. 3. Time History of Nisqually, Washington
(Stong Motion Data Center)

In this study, analysis was carried out using PLAXIS 2D which used earthquake loads in the .smc format. Seismic data can be obtained easily in various online data providers. In this study, due to the limitation that the data used in the .smc format, the earthquake time history data used in the study was taken from the Center for Engineering Strong Motion Data (CESMD) that was obtained online from www.strongmotioncenter.org.

However, not all data from CESMD can be used, this is adjusted to the restriction of the problem in this study, which also refers to the earthquake of Yogyakarta. These restrictions include this following data.

a. Type of Earthquake

As it happened in the Yogyakarta earthquake which was estimated due to fault. Thus, in this study was determined using type of fault which located on the land. Earthquake data commonly comprises of two horizontal and one vertical data. In this research the earthquake load used was horizontal earthquake load, because the wave of vertical seismic load was smaller specifically when applied on the dam structure.

b. Epicentrum distance

Epicentrum distance was determined based on the closest distance between Opak Fault and Sermo Dam coordinates -as study review. The Sermo Dam coordinates are at 6^0 42' LU and 110^0 55' BT (110,167: -7,833). Meanwhile, Opak fault has five coordinates that can be mapped, which can be seen in Table 2.

Table 2. Coordinates of Opak Fault (Indonesia Earthquake Map Revision Team, 2010)

No	Coordinates	
	x	y
1	110.3131	-7.9948
2	110.3601	-7.95
3	110.3938	-7.8929
4	110.4249	-7.8635
5	110.4941	-7.7762

Based on these data, the nearest distance of epicentrum can be obtained from the location of the Sermo Dam and Opak fault using the modified program by Partono (2015), as far as 24.06 km. Then the range of distance allowed for the selection of earthquake loads based on CESMD is at 15 Km to 30 Km.

c. Magnitude

The Yogyakarta earthquake on May 27, 2006 was at 6 Mw. Therefore, for observing the effect on this Dam's study, the magnitude range was determined of 5.0 Mw to 7.0 Mw.

d. Earthquake Amplification

Goro (2007) stated that on soft soils with large layer thickness, the amplification will become larger so that the earthquake acceleration on the surface (PGA) becomes larger and eventually the safety factor becomes smaller. The base material in Sermo Dam is bedrock, so that it is not using earthquake amplification factor.

According to these above provisions, then in this study used two earthquake loads, there were 5.2 Mw and 6.8 Mw.

3.2. Numerical Modeling

PLAXIS 2D used in this study for aiding its analysis. Initial step to carry out this program was modeling the geometry structure of dam. Sermo Dam has complex geometry, especially in the bedrock section. Therefore, in this study, a simplification of bedrock geometry of the Sermo Dam model had been performed, but had a resemblance to the original geometry. Besides, simplification was also used in materials as the second step for modeling to identify the material used. It was on the rip-rap zone where the material parameter values were made equally to the material values in the shell zone. Moreover, materials model in this study applied Mohr-Coulomb model with very fine meshing type.

Furthermore, in this study had two load which were applied in dam model, water level and earthquake. Water level which was used in the 136.60 meter for confering simulation in the normal condition (normal water level in the dam's operation based on Department of Public Works, 2015). Whereas, the second load was earthquake load which was applied based on the CESMD's data. As it has been explained in the Sub 3.1, the horizontal seismic load used in this study was 5.2 Mw and 6.8 Mw.

The other significant aspect and the last step that must be considered was giving boundaries. This is because boundaries can influence the behavior and result of model. The boundaries which were applied in this study were boundary due to flow of water and earthquake load. The boundary due to flow of water was applied in the bottom of model, so that it was assumed that water can flow horizontally but not in vertically. The absorbent boundaries due to earthquake were applied on the right, left, and bottom side of the model, so it was expected that the seismic load applied at the simulation did not cause the reflection effect on the modeling result.

After determining these points above, thus the model can be simulated. In brief, there were four simulation phases done in this study model :

a. Phase 1, the original condition where there was only bedrock as the original rock from Dam (plastic). In this beginning phase, geometry of bedrock was carried out and so does the material parameters.
b. Phase 2, the condition where the dam had been built (plastic). Not only geometry of dam but also material parameters of zones in dam that turned in this phase 2.
c. Phase 3, the condition which was given normal water level of 136.60 meters (plastic). The boundary due to water flow was applied in this phase 3.
d. Phase 4, the condition of the earthquake load (dynamic). The boundaries due to earthquake were given in this final phase.

4. Result and Discussion

This study observes the deformation of the dam. The zone position of dam to be reviewed is located in the core zone. Specifically, on the as dam or center of dam which can be seen in Fig. 4. Therefore, the deformation result that was taken according to the maximum horizontal deformation that occured in this location of as dam. The selection of this core zone position is based on the consideration that in the core zone is a zone in soft soil forming and potentially influences the deformation occures due to water storage and seismic load.

The simulation results of the dam model with a water level of 136.60 meters and the phreatic line which was occured can be seen in Fig. 4. Also, its includes the stresses due to seismic load which is given on the dam structure.

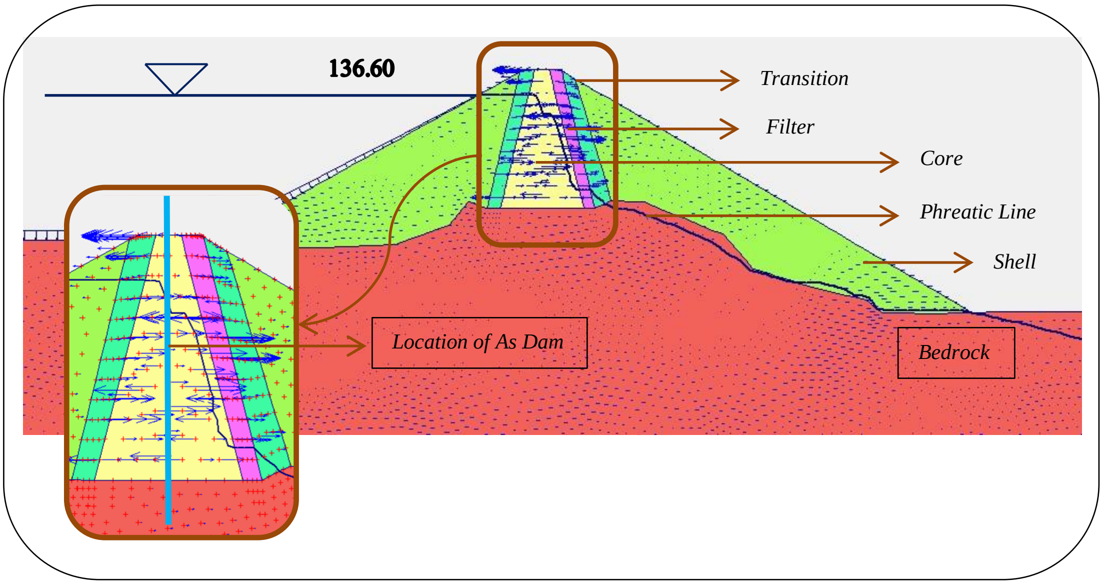

Fig. 4. Stress Direction Dam Simulation Caused by Seismic Load

Fig. 4 shows that due to horizontal seismic force, afterwards there are turn up stresses to the right and left that occurs at the core zone of dam. On the other hand, the result of the dam's maximum horizontal deformation in the as dam after the horizontal seismic load can be seen in Table 3.

Table 3. Maximum Horizontal Deformation in As Dam

No	Magnitude (Mw)	Epicentrum Distance (Km)	Horizontal Deformation (x 10^{-3}) m
1	Without seismic load	-	145.25
2	Earthquake with 5.2	18.2	145.49
3	Earthquake with 6.8	15.6	146.01

Table 3 presents the deformation result of dam by conducting seismic load condition in 5.2 Mw and 6.8 Mw and compare with original or normal condition without earthquake. It could be seen from Table 3, the horizontal deformation rises with the increases-given seismic load. Its also enhancement value of horizontal deformation from not seismic load condition to seismic load condition in Magnitude of 5.2 Mw and 6.8 Mw. The greater the magnitude of seismic load which is given, the horizontal deformation that occurs is also greater. The deviation occured in earthquake with magnitude of 6.8 Mw, which has the largest horizontal deformation, compared with unloaded seismic load condition is 0.52% (146.01 x 10^{-3} m compared with 145.25 x 10^{-3} m). The maximum deviation is 5%, so that Sermo dam still strong to retain the simulation of seismic load which was applied.

For this reason, the more data result in various magnitude, epicentrum distance, and PGA for analysing this condition is needed to give better trend and more comprehension about this study. Therefore, further study is necessity and expected for drawing out this study.

5. Conclusion

This study presents two conclusions from the analysis which was conducted for performing effect of seismic load in deformation of dam :

1. In terms of horizontal deformation, Sermo dam is strong enough to resist earthquake force which was applied in simulation due to magnitude of 6.8 Mw.
2. The analysis of this study was performed by using finite element method and conducting PLAXIS software to obtain the deformation of dam.

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