Seismic Performance Assessment of Murum Dam Under Various Seismic Event

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ABSTRACT

Dams are considered as vital assets for countries; therefore, the dam must be built to withstand natural disasters. However, the performance of the dam structure comes to attention since the Ranau earthquake occurrence in 2015 is the strongest earthquake recorded in Malaysia. The behavior of the dam became deteriorated across the year due to earthquake motion which caused damage to the dam. This study aims to assess the performance of Murum dam using Incremental Dynamic Analysis (IDA) which subjected was subjected to a set of 6 ground motion records scaled to increasing intensity levels by using ABAQUS. A different scale Peak Ground Acceleration (PGA) of 0.05 g, 0.10 g, 0.15 g, 0.20 g, and 0.30 g were applied in this study. Based on the results, the cracking area increases when the acceleration increases due to the high tensile stress. The maximum displacement value was located at the crest part of the dam. The findings revealed that the concentration of stresses in the dam body, especially heel and neck. The maximum normal stress was found at the heel zone of the dam. The trend of maximum shear stress shows a fluctuated value when the scale PGA increased. This showed that the performance level of the dam based on seismic loadings depend on ground motion pattern.

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Introduction

Dam systems are high value infrastructure projects with significant importance. Building a dam in earthquake prone countries is increasingly demanding the safety of their structures. Inadequate seismic behavior of dams can lead to serious impacts on local communities. Dams constructed are considered vital assets for countries, and they must be built to withstand natural disasters, as dam failure would result in both human and financial losses [1]. However, the performance of the dam structure has deteriorated with the year due to earthquake occurrence which caused damages like a longitudinal or latitudinal crack of the dam due to land movement, floodway due to inundation of land, and more. In addition, the tremendous cost of dam construction and the severity of the implications caused by dam instability make dam protection, retention, and permanent evaluation a key issue since greater dam safety usually comes at a cost, it is vital to assure dam stability through design, implementation, and utilization procedures [2]. On top of that, the concern of less than one percent of the buildings in Malaysia are seismic resistant which can easily cause them damage when earthquake occurs [3]. Impact of earthquakes is one of the major concerns of scientists and engineers for a long time. Many studies have been made to mitigate the seismic responses of structures due to seismic loads [4-19].

Murum Hydro Power is placed at the top of Rajang River Basin on the Murum River, whereby Danum and Plieran Rivers, two of Murum's primary tributaries are combined to produce the Murum River. It has a power of 944 Megawatts and has produced 5952 Gigawatt-hours every year [20]. Murum Hydropower is made up of an RCC gravity dam with a tiered spillway, a water intake, a powerhouse, and an ecological power plant, which its ecological power plant is one of the company's distinguishing attributes. its goal is to maintain the downstream habitat by allowing for a regulated and continuous release of water while producing energy for Tegulang's resettlement. Next, the Murum dam is a massive concrete gravity in Belaga, Sarawak, Malaysia on the Murum River. The dam has a height of 141 meters, a length of 473 meters along the crest portion, a width of 75 meters transverse to the riverbed, and a depth of 135 meters [21]. The Murum dam is classified as a low seismic zone resulting in the dam facing any damaged occurrence caused by seismic gravity. Based on the previous researcher, the dam's static response recorded stresses at the dam body that were within acceptable limits. The result suggests that in the downstream segment, medium-level shaking (0.1 g) occurs, resulting in the maximum capacity of Murum dam has been determined to be up to 0.1 g, which is adequate for Sarawak's minimal seismicity.

The shape of a concrete gravity dam is triangular in section, with the top crest frequently enlarged to allow a walkway over the dam. Concrete mass helps in resisting the water pressure of the dam, and the dam is made of vertical concrete blocks that are not reinforced and have joints between them [22]. Therefore, the structure must be built on a solid foundation to support the load. Upstream slope sliding at the auxiliary dam is one of the slope stability failure scenarios which occur due to earthquake shaking. Alternatively, a fast drawdown collapse of the auxiliary dam's upstream slope might have been precipitated by the quick emptying of the tiny reservoir through the main dam's break. The apparent lack of severe damage to this embankment's downstream slope, as well as the multiple slips in natural land surrounding the reservoir rim, corroborate the latter option [23]. High tensile strains form at the dam's base, on its downstream face, and close to its change in slope. Because the dam's rock contact and the rock underneath are projected to have lower tensile strengths than concrete, the magnitudes of stresses are larger near the base dam [24].

Methodology

Description of dam

Murum dam, which is located in Sarawak, is selected for this study. The concrete gravity of the Murum dam has a dimension of 141 meters in height, 75 meters in width, and 18.68 meters at the crest of the dam as shown in Figure 1. The material properties of the Murum dam must be considered such as density, elasticity, Poisson's ratio, and other properties as shown in Table 1.

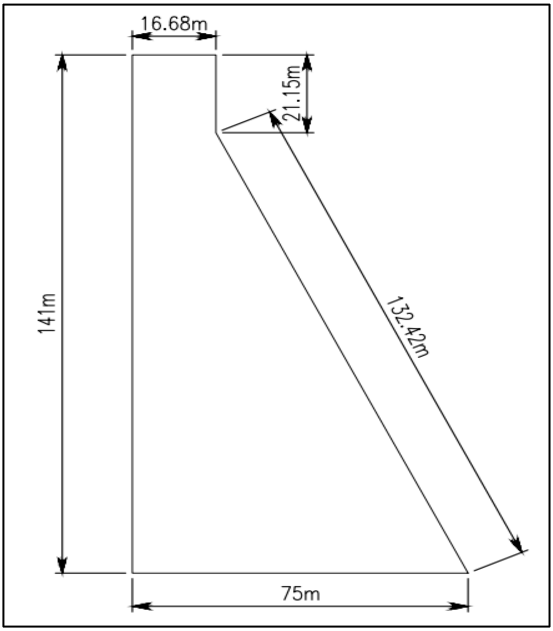

Figure 1: Cross sectional area of Murum dam in metre

Table 1: Properties of Murum dam

No	Parameter	Concrete
1	Density (kg/m^3)	2643
2	Elastic Modulus (GPa)	31.2
3	Poisson's Ratio	0.18
4	Compressive Strength (MPa)	24.10
5	Dilation angle	36.31

Model and analysis

In this study, six sets of earthquake motion were selected in various locations, which are Chichi, Chuetsu-Oki, Iwate, Northridge, Ranau, and Trinidad as shown in Table 2. The records were obtained from Pacific Earthquake Engineering Research Centre (PEER) data repository for various earthquake data. The data is then transferred into the SeismoSignal, which is Earthquake software for signal processing of strong-motion data to get the acceleration data in the horizontal and vertical directions and to obtain the maximum PGA as shown in Figure 2. Then, a scale PGA of 0.05 g, 0.10 g, 0.15 g, 0.20 g, and

0.30 g was selected. The Rayleigh stiffness proportional damping value is selected by using:

$$\beta = \zeta 1 / \omega 1 = 2(0.03)/18.61 = 0.00323 \ s \quad (1)$$

Table 2: Detail of earthquake data

Earthquake	Date	PGA (g)	Period (s)
Chichi (Taiwan)	1999	0.36	49.94
Chuetsu-oki (Japan)	2007	0.17	11.98
Iwate (Japan)	2016	0.12	23.98
Northridge (USA)	1994	0.56	39.98
Ranau (Malaysia)	2015	0.15	70.76
Trinidad (America)	2015	0.19	21.40

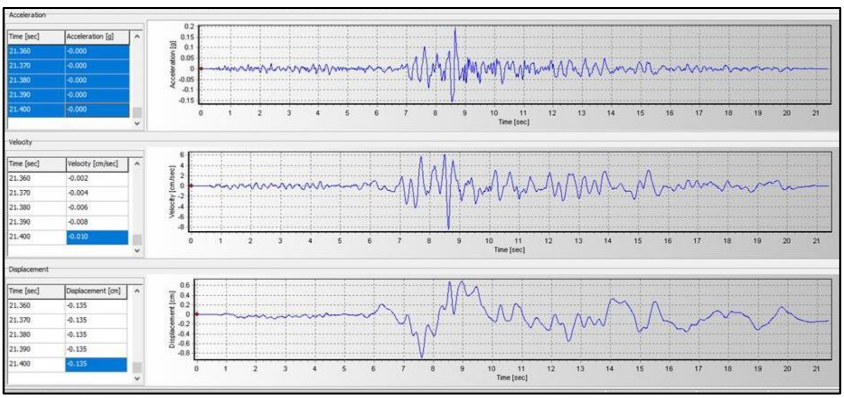

Figure 2: Ground motion in the horizontal and vertical direction of Trinidad earthquake

The initial design is started with the part module. A coordinate is used as it is easier to set up the initial point to draw the model and ease the meshing process to show valuable cues of each axis to the observer. Figure 3 shows a dam modeling, whereby a 2D planar is chosen in the modeling space of a solid shape with an approximate size of 300. The X-axis and Y-axis are used to set up the initial coordinate of (0,0) and continue until the dam is fully designed with a given dimension. In addition, the property module is selected to create the material by choosing the material behavior such as damping, density, elasticity, concrete tension damage, and concrete damage plasticity. The value of material properties collected such as Young’s Modulus, density, Poisson's ratio, and other properties are input under the property module. There are two steps used in this modeling, which are static and dynamic. These steps are used to select a range of incrementation of hydrostatic pressure toward the dam structure according to the incrementation of time. Step one, which is static or general is used with an incrementation of 100. Then, step two which is dynamic and implicit is used with the period of x seconds, whereas x depends on the period for each seismic loading selected in this study and the maximum number of increments is 100, 000. Next, two loads are used which are gravity and hydrostatic pressure. The first load, which is the gravity load, is selected as it indicates a self-weight load for step one. Then, the density load value of -9.81 kg/m^3 is input at y-axes with uniform distribution. Then, the second load which is the hydrostatic load is assigned with a magnitude formula $P= \rho gh$. Next, the first boundary condition is created, and displacement or rotation is selected for step one. Then, the requirement points or region are selected and the displacement values for both the x-axis and y-axis are considered 0 to indicate fixed support. The second boundary condition is created based on step two, and acceleration or angular acceleration is selected for step two. Then, the surface region is selected and the acceleration value at the x-axis is considered 9.81 kg/m^3. Amplitude is set as tabular, and the step time is selected to set the amplitude data according to the PEER ground motion database. Then, the step in the second boundary condition is repeated for the third boundary condition is created at the y-axis. Then, the data of seismic loading is applied to the amplitude data. Furthermore, a meshing module is created, whereby the independent mesh is used. A job module is created to submit and run the model.

Result and Discussion

The Murum dam has formed a major crack pattern when applied Ranau and Northridge’s seismic loading at a scale Peak Ground Acceleration (PGA) of 0.3 g as shown in Figure 4. Meanwhile, the minor crack patterns of the Murum have been obtained when applied to the Iwate’s seismic loading at a scale PGA of 0.3 g. A significant fracture appeared at the heel of the dam at the upstream surface as a general pattern indirectly as the cracking started at the dam from the neck of the dam on the downstream surface [25].

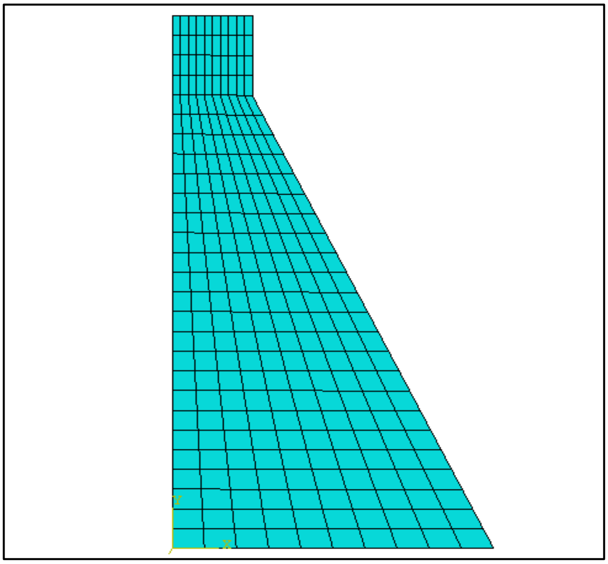

Figure 3: 2D of Murum dam using ABAQUS

When the PGA of the motion grew, fractures began to form at the dam's neck on the upstream surface, spread forward from both faces, and eventually united. the cracking area increases when the acceleration increases. The statement is because the strong earthquake shaking produced high acceleration, resulting in a high impact on the dam, particularly crack shapes. In addition, crack patterns started to occur on the dam at the lower PGA scale since the material of the dam was not able to cater to the seismic loading. Logically, the height of the dam might be influenced by its durability and stability of the dam. The higher the dam, the higher the tendency of cracks formation.

The maximum normal stress value for each seismic loading shows a fluctuated value when the PGA scale is increased as shown in Table 3. For example, the fluctuated value of maximum stress was found at Trinidad's seismic loading between scale PGA 0.15 g, 0.20 g, 0.30 g with the value are 98.50 kN/m^2, 5.31 kN/m^2, and 293.90 kN/m^2 respectively. The fluctuated values obtained by using ABAQUS are because each part of the dam structure such as the upstream, crest, downstream, heel, and toe of the dam experienced different pressure act on them. Figure 5 illustrates the maximum normal stress for Trinidad's seismic loading at a scale PGA of 0.30 g. The maximum tensile and compressive stresses are 293.90 kN/m^2 and 2375 kN/m^2 respectively. The maximum normal stress was formed around the heel zone of the dam due to the maximum pressure being located at the highest depth of the dam.

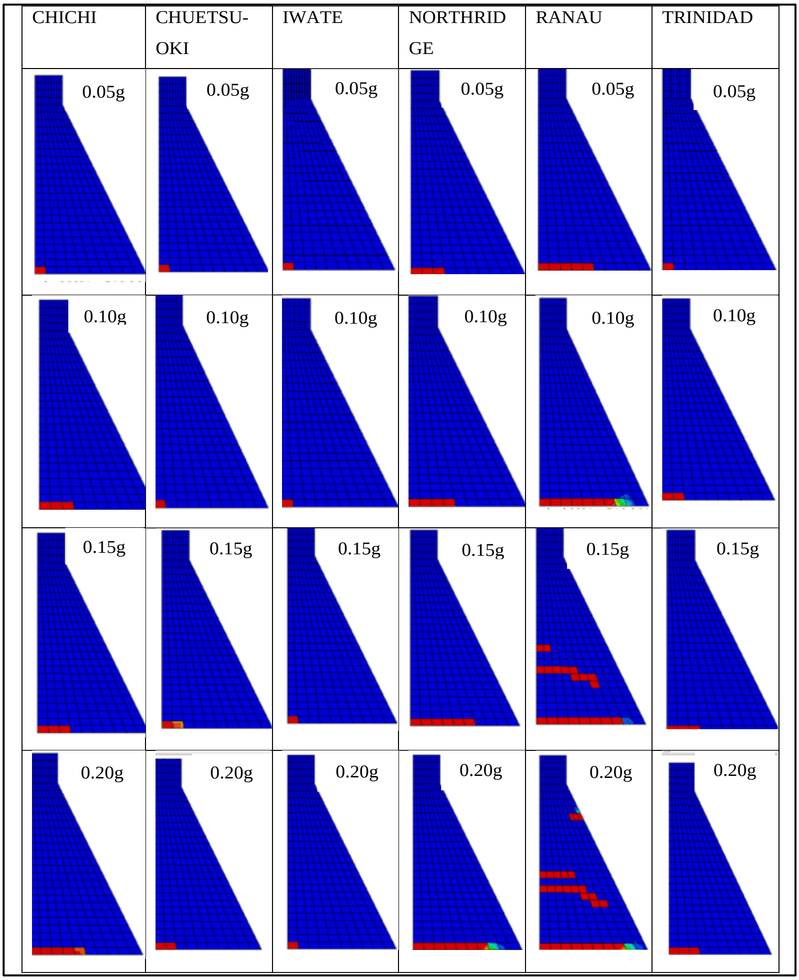

Figure 4: Crack patterns of Murum dam

Table 3: Maximum normal stress of Murum dam

Scale (g)	Chichi (kN/m²)	Chuetsu-oki (kN/m²)	Iwate (kN/m²)	Northridge (kN/m²)	Ranau (kN/m²)	Trinidad (kN/m²)
0.05	2.27	2.23	2.16	87.41	314.40	2.66
0.10	93.16	2.12	2.55	214.70	318.50	1.77
0.15	155.40	1.49	2.71	308.40	217.20	98.50
0.20	298.30	1.99	2.79	340.70	313.60	5.31
0.30	310.80	34.50	1.98	342.20	441.10	293.90

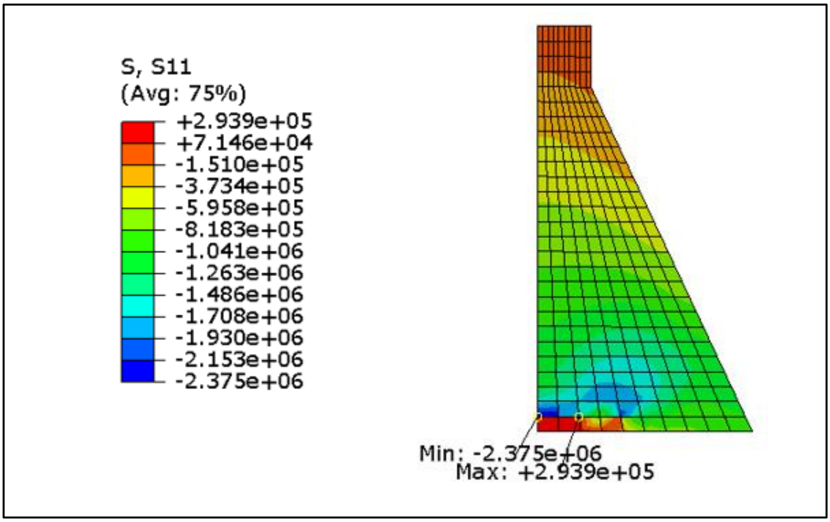

Figure 5: Contour maps of maximum normal stress under Trinidad's seismic loading

The formation of maximum shear stress for Trinidad's seismic loading can be found around the toe of the dam at a scale PGA of 0.30 g as shown in Figure 6. There are fluctuated maximum shear stress values as the scale PGA increased as shown in Table 4. For example, there are fluctuated maximum shear stress was found at Chuetsu-Oki's seismic loading between scale PGA 0.10 g, 0.15 g, and 0.20 g with the value of 1646.00 kN/m^2, 1640.00 kN/m^2, and 1717.00 kN/m^2 respectively. The fluctuated values obtained by using ABAQUS are because each part of the dam structure such as the upstream, crest, downstream, heel, and toe of the dam experienced different pressure act on them. The key static forces to be considered in a shear force situation are the self-weight of the dam, the hydrostatic pressure upstream, and the uplift pressure at the dam [26]. The maximum normal stress occurs on the major primary plane [27].

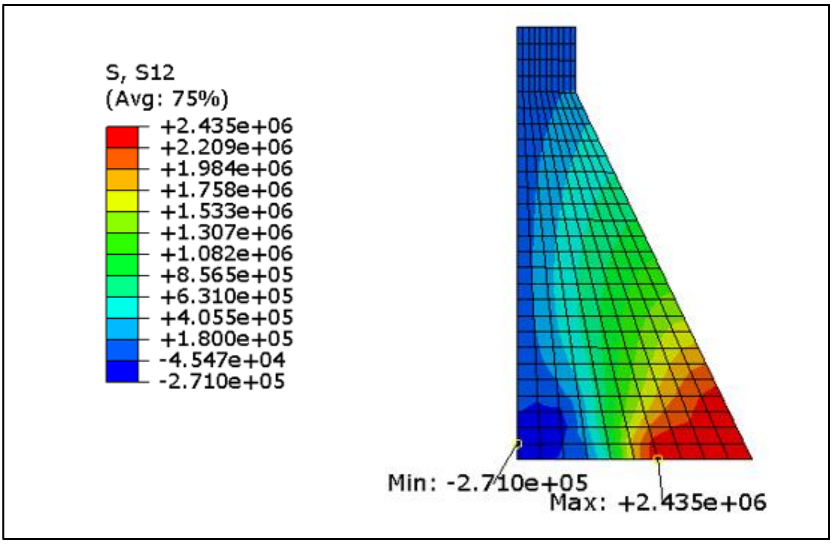

Figure 6: Contour maps of maximum shear stress under Trinidad's seismic loading

Table 4: Maximum shear stress of Murum dam

Scale (g)	Chichi (kN/m²)	Chuetsu-oki (kN/m²)	Iwate (kN/m²)	Northridge (kN/m²)	Ranau (kN/m²)	Trinidad (kN/m²)
0.05	1653.00	1650.00	1643.00	1803.00	2334.00	1669.00
0.10	1810.00	1646.00	1668.00	2222.00	4048.00	1648.00
0.15	1948.00	1640.00	1677.00	2976.00	5036.00	1745.00
0.20	2285.00	1717.00	1686.00	3744.00	6298.00	2023.00
0.30	2865.00	1886.00	1730.00	4872.00	7770.00	2435.00

The maximum displacement for each seismic loading was located at A which indicates as crest part of the dam. The scale PGA of 0.30 g with a maximum displacement value of 0.435 meters was found under Ranau's seismic loading. The trend in Figure 7 shows that the maximum displacement is increased as the scale PGA increases. For instance, the maximum displacement for Iwate's seismic loading is increased from 0.05 g to 0.30 g with its value of 0.063 g to 0.238, respectively. This is because the strong impact of seismic loading results in a higher value of crest displacement owing to the strength degradation of the material of the dam. Earthquake motion gives an impact on the dam in terms of displacement at the crest dam due to the joint opening and leads to cracks occurrence.

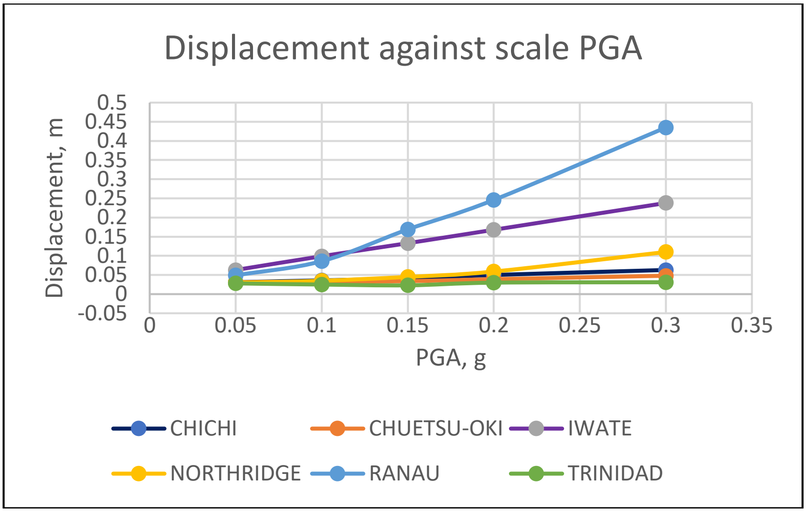

Figure 7: The relationship between maximum displacement and PGA

Conclusion

The study of seismic analysis by using the IDA method study of Murum dam provides insights into the performance or behavior of the dam under various sets of seismic loads with Rayleigh stiffness proportional damping of 3%. The 2D model of Murum dam by using ABAQUS displays the crack patterns of the structure due to seismic loads. The major crack pattern of the dam occurs under Ranau's seismic loads. In addition, the maximum normal stress and maximum shear stress distribution were identified. The formation of maximum normal stress occurs around the heel zone of the dam due to the maximum pressure produced at the highest depth of the dam. The trend for both maximum normal stress and shear stress presents a fluctuation value obtained by using ABAQUS since each part of the dam experience different pressure act on them. Next, the maximum displacement of the Murum dam occurs at the crest of the dam. The maximum displacement increases as the scale PGA increases due to the seismic motion, resulting in the joint opening.

Future studies will be highly interesting to conduct seismic analysis of the dam through the IDA method. Furthermore, utilization of a 3D finite-element method is necessary with a finer size of meshing to obtain the data accuracy. In addition, Rayleigh stiffness proportional damping value must be considered as it provides a reasonable estimate of dynamic response like seismic motion. The material properties of the dam must be correctly input in the ABAQUS to ensure the reliability of the data.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest

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