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EARTHQUAKE ATTENUATION MODELS AND ITS RESPONSES TO EARTH ZONE DAM IN UPPER NORTHERN PART OF THAILAND

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ABSTRACT: The upper northern part of Thailand is mountainous area which classified as moderate risk by earthquake. This study was focused on the earthquake attenuation model of Abrahamson and Silva (2008). Exciting quake source from the Chiang Rai 2014 earthquake was recorded at earth zone dam site study. The accelerometer was installed in the bottom of dam which is 59 m height, 9 m width and 1,950 m length. The attenuation model is the relationship between acceleration, distance, size of earthquake, period of stabilization, characteristics of seismic sources and geological conditions. This research aims to compare the peak ground acceleration (PGA) between the attenuation models and the data measurement at the dam to check the accuracy of the model. And to study the dynamics analysis in the dam by using two selected time history records with different wave characteristics as: short period (EQ1) and long period (EQ2) to analyze the behavior of the pore water pressure, the stress and displacement in the dam. The results of this study revealed that the Peak Ground Acceleration (PGA) from the attenuation model of Abrahamson and Silva equal to 0.017787 g. And the percentage error of calculated PGA when compared to the PGA from measurement was 6.38. The analysis of the dynamics by using seismic waves with different time duration. EQ1 have made the pore water pressure on the dam higher when the effective stress in the dam decrease, which makes the displacement of the dam more than EQ2.

Keywords: Earthquake Attenuation Model, Finite Elements Method, Dynamic Analysis, Dam Behavior

1. INTRODUCTION

Earthquakes are natural disasters that cause direct damage to engineered constructions such as buildings, roads, bridges, and dams, causing loss of life and property. And in the northern part of Thailand has many active faults that causing earthquake. From seismic records, in the North part has more frequent earthquakes than the other part. But currently, Thailand still does not have much research on the decreasing energy of seismic that depends on the distance. In the past, Warnitchai [1] studied the attenuation model of foreign soil compared with Bangkok soil. And Attapon [2] studied for the attenuation model, but also focus on the areas in Chiang Mai.

When the earthquake occurred. The building structure had effected, particularly the building is located close to the epicenter of the earthquake. So this research aims to study the attenuation model by using the Chiang Rai (6.3 on Richter scale) earthquake that has epicenter in Phan district, Chiang Rai province (Latitude 19.748 ºN Longitude 99.692 ºE) on May 5, 2014. The data has collected by Seismological Bureau of Thai Meteorological Department as shown in Fig. 1.

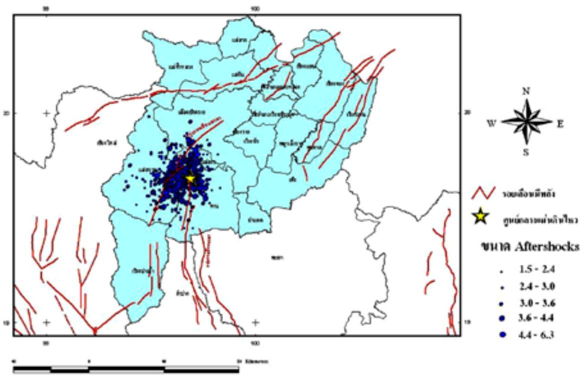

Fig.1 The Chiang Rai earthquake datas (Main shock and aftershock) have collcted by Seismological Bureau, TMD

The Abahemsan equation is the attenuation model that has been used in the research. The calculated PGA has been compared with the dam instrumentation (accelerometer) that is installed in the Mea Ngud Somboon Chon Dam. After that, the dam model will be used to analysis the dam behaviors (pore pressure, stress and displacement) after effected by using the earthquake waves that have short-period and long-period waves. The Hardening-Soil Model will be used in this analysis.

2. SITE DESCRIPTION

2.1 Mae Ngat Dam

Mae Ngat Dam was an earth-filled embankment dam with a clay core. It is a zoned earth dam consisting of 4 parts: (1) Core zone, (2) Random Zone, (3) Miscellaneous, (4) Filter zone and (5) Rock fill zone. The dam was built to block the Mae Ngat waterway at Cho lae sub district, Mae Taeng district, Chiang Mai. The dam's height is 59 meters and the length is 1,590 meters. The types of soils used in the construction of Mae Ngat Dam were CL and MH. The dam's construction began in 1977 and was completed in 1984. The cross section of the main dam and its layout is shown in Fig. 2.

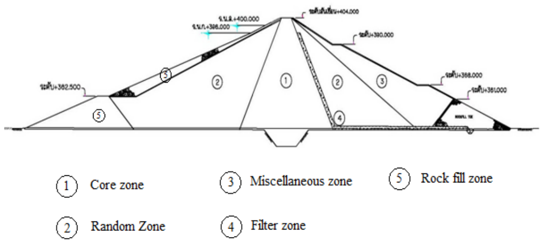

Fig.2 Typical cross section of the Mae Ngat Dam.

2.2 The Dam's Materials and Properties

The data of the zoned-earth dam in this study was collected to acquire detailed information of both the construction and the timing of water retention by testing the qualities of the materials both on the field and in the laboratory by Vikrom [3] and collecting the samples of soil in the core zone for additional laboratory testing. The acquired information was analyzed to select representatives of the current materials to be able to set properties in creating a model that is the closest to the current soil conditions, so it can be used to analyze the behavior of the dam when affected by Dynamic force. Properties of materials of the dam are displayed in Table 1 and Table 2.

Table 1. Properties of soil in Mae Ngat Dam

Zone	E	C	ϕ	μ	γ	Ψ
Clay Core	8,171	49	16	0.48	19.72	0
Random	9,620	32	30	0.350	18.56	0
Miscellaneous	22,750	0	42	0.3	19.0	5
Filter	9,620	18	28	0.350	15.5	5

Note: γ = Unit weight (kN/m^2) ; E = Young's modulus (kN/m^2) ; v = Poisson's ratio, φ = Friction angle (°) ; c = Cohesion (kN/m^2) ; ψ = Dilatancy angle (°)

Table 2. Properties of soil in Mae Ngat Dam (continue)

Zone	Permeability (cm/sec)	Permeability Ratio
Clay Core	0.13 x 10-6	1
Random	0.96 x 10-6	1
Miscellaneous	0.94 x 10-6	1
Filter	1.3 x 10-4	1

2.3 Instrumentation

With the cooperation of Royal Irrigation Department, the dam instrumentations (accelerometers) were installed to measure the acceleration at Mae Ngat Dam in January 2014 in the middle, on the crest of the dam and the mountain next to it as shown in Fig. 3.

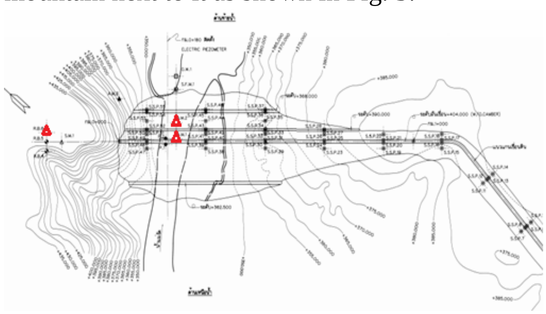

Fig.3 Position of Accelerometer installation

The accelerometer model is the 130-SMA (Standard) (Fig. 4). The collected data from installed instrument can be output in Acceleration-Time graph. The Peak Ground Acceleration (PGA) can be analyzed at time period = 0.01. For the Chiang Rai earthquake (magnitude 6.3 on Richter scale), PGA can be measured equal to 0.187 m/s^2 or 0.019g (Fig. 5).

Fig.4 The accelerometer model

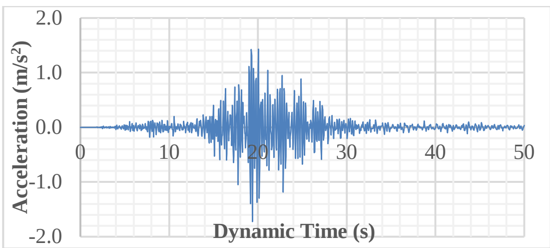

Fig.5 The acceleration-time graphs from accelerometer.

From the earthquake (magnitude 6.3 on the Richter scale), which has a distance from the epicenter to Mea Ngud Somboon Chon Dam about 110 kilometers, shown in Fig. 5. The acceleration in the dam can be measured while the earthquake acted to the dam. The acceleration-time data records are shown in Fig. 6.

Fig.6 The distance between the Epicenter to Mea Ngud Somboon Chon Dam

For this event. The analysis results from Global CMT Catalog conclude that the type of fault is strike slip and show the parameter of strike, dip, slip and moment tensor, as shown in Fig. 7.

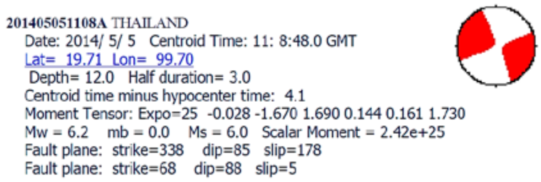
201405051108A THAILAND
Date: 2014/ 5/ 5 Centroid Time: 11: 8:48.0 GMT
Lat= 19.71 Lon= 99.70
Depth= 12.0 Half duration= 3.0
Centroid time minus hypocenter time: 4.1
Moment Tensor: Expo=25 -0.028 -1.670 1.690 0.144 0.161 1.730
Mw = 6.2 mb = 0.0 Ms = 6.0 Scalar Moment = 2.42e+25
Fault plane: strike=338 dip=85 slip=178
Fault plane: strike=68 dip=88 slip=5

Fig.7 Analysis of earthquake mechanisms from Global CMT Catalog [4].

3. THEORY

In this research was conducted to study the appropriate model for attenuation equation in the northern part of Thailand. The previous research, Nutapong [5] studied the attenuation model and concluded that the equations of Abrahamson and Silva [6], the one of the NGA model developed from the Abrahamson and Silva model (1997), is suitable for use to analyze the attenuation model in the northern part of Thailand.

So the Abrahamson and Silva equation shows in Eq. (1).

$$ln(PGA) = f_{base} + f_{fault+AS} + f_{site} + f_{TOR} + f_{dist} \quad (1)$$

The 1st function is the variant of the magnitude and distance term (f_{base}), as shown in Eq. (2).

$$a_1 + a_4(M - c_1) + a_8(8.5 - M)^2 + [a_2 + a_3(M - c_1)]\ln(\sqrt{R_{rup}^2 + c_4^2}) \quad (2)$$

The 2nd function is the pattern of impact fault and aftershocks ($f_{fault+AS}$) as Eq. (3).

$$a_{12}F_{RV} + a_{13}F_{NM} + a_{15}F_{AS} \quad (3)$$

The 3rd function is the soil characteristics that set (f_{site}), shown in Eq. 4.

$$(a_{10} + bn)\ln\left(\frac{V_{s30}}{V_{LIN}}\right) \quad (4)$$

The 4th function is the effect of depth to the moving plane (f_{TOR}), as Eq. 5.

$$a_{16}F_{RV} + a_{17}(1 - F_{RV})(\frac{Z_{TOR} - 2}{8}) \quad (5)$$

The 5th function is the affected for small to medium earthquake at long distances (f_{dist}), shown in Eq. 6.

$$a_{18}(R_{rup} - 100)(6.5 - M) \quad (6)$$

When M=Moment magnitude, R_{rup}=Rupture distance (km), R_{jb}=Joyner-Boore distance (km), R_x=Horizontal distance (km) from top edge of rupture, Z_{top}=Depth-to -top of rupture (km), F_{RV}=Flag for reverse faulting earthquakes, F_{NM}=Flag for normal faulting earthquakes, F_{AS}=Flag for aftershocks, F_{HW}=Flag for hanging wall sites, Dip=Fault dip in degrees, V_{S30}=Shear-wave velocity over the top 30 m (m/s) $Z_{1.0}$=Depth to V_S=1.0 km/s at the site (m), $P\hat{G}A_{1100}$=Median peak acceleration (g) for V_{S30}=1100 m/s and W=Down-dip rupture width (km). The value for the Peak Ground Acceleration (PGA) that comes from the definition of Abrahamson and Silva (2008)

Calculation of the PGA of an earthquake in Chiang Rai.

$$f_{base} = -4.28256$$

$$f_{fault+AS} = 0$$

$$f_{site} = -0.10833$$

$$f_{TOR} = 0.375$$

$$f_{dist} = -0.0134$$

$$\ln(PGA) = (-4.28256) + (0) + (-0.10833) + (0.375) + (-0.0134)$$

$$PGA = 0.017787$$

Table 3. The coefficient of Peak Ground Acceleration (PGA) [4]

c_1	c_4	a_3	a_4	n	V_{LIN}	b	a_1	a_2	a_8
6.75	4.5	0.265	-0.231	1.18	865.1	-1.186	0.725	-0.968	0

a_{10}	a_{12}	V_{S30}	a_{13}	a_{15}	a_{16}	a_{17}	a_{18}
0.9485	-0.12	1100	-0.05	-0.405	0.65	0.6	-0.0067

4. RESULTS

4.1 Attenuation Model

From using the Abrahamson and Silva equation in the attenuation model analysis, the PGA from Chiang Rai earthquake at Mea Ngud Somboon Chon can be resolve. The parameters that were used in the calculation consists of M is equal to 6.3 on the Richter scale, ZTOR equal to the depth of 7 km, RRUP than 110 km from the spot. The Chiang Rai earthquake occurred at Payao fault which is horizontal movement (Strike slip). The result found that the Peak Ground Acceleration (PGA) from calculation equal to 0.017787 g. And the percentage error of calculated PGA when compared to the PGA from measurement was 6.38.

4.2 Dynamic Analysis

The data used in the analysis came from the soils used in the dam construction which were tested in the field and the laboratory. The datas were used to create the model dam by using the Hardening-Soil model (2D shear plane) with the Finite Element Method to study the response of the dam under earthquake loads. The PLAXIS program [7] was used to analyze the model. The selected elements were triangular with 15 Nodes and 12 Stress points (Fig. 8) from Brinkgreve and Vermeer [8]. The water level in the dam was analyzed while the water retention level was normal. The water pressure was set to Hydrostatic Pressure. Then, the experiment was analyzed under Dynamic force.

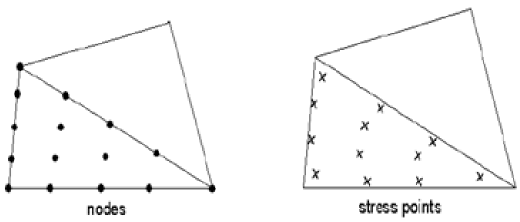

Fig.8 Triangular elements with 15 Nodes and 12 Stress points.

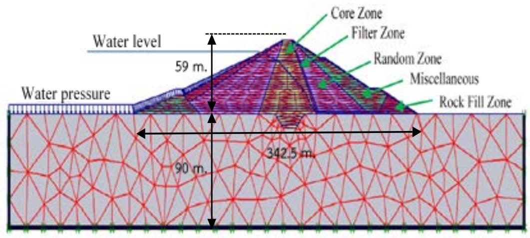

Fig.9 Mae Ngat Dam model using finite element method (FEM) consists of 845 elements and 6947 nodes.

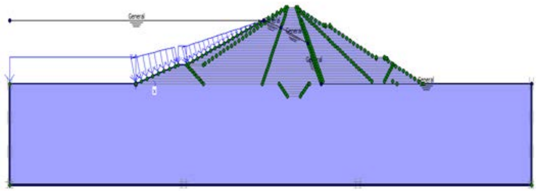

Fig.10 The model using finite element method shows the Phreatic line of Mae Ngat Dam.

The 2 difference earthquake waves (short-time period; EQ1 and long-time period; EQ2) (Table 4) was used to analyze for study the behavior of pore water pressure, stress and displacement that occurs in the dam during earthquake occurs. The excess pore water pressure was considered at 37 m depth from the dam crest. The results were shown in Fig. 11-18.

Table 4 The data of seismic waves used in the analysis.

Earthquake	Victoria Mexico (EQ1)	Borrego Mth. (EQ2)
Year (A.C.)	1980	1968
PGA (g)	0.130	0.120
Time (sec)	15.58	40
Magnitude (M)	6.33	6.63
Distance (km.)	58.87	70.75
Predominant period	0.30	0.33
Type of earthquake	Short period	Long period

The study found that the pore water pressure in the dam was increasing during the seismic force acted to the dam. The long period of earthquake (EQ2) make the pore water pressure is worth more than the short period of earthquake (EQ1) when the PGA of two difference waves are similar. In Fig. 11-12, the range of changing in pore water pressure of approximately 102.5-107.5 kPa under EQ1 and 116.75-121.5 kPa under EQ2. The excess pore water pressure occurring in the dam of EQ1 is equal to 66.48 kN/m^2 and EQ2 is equal to 89.17 kN/m^2, respectively in Fig. 13-14.

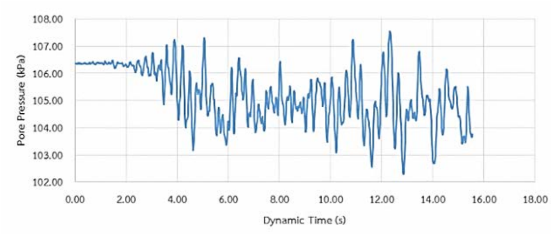

Fig. 11 The pore water pressure changing under short period earthquake (EQ1).

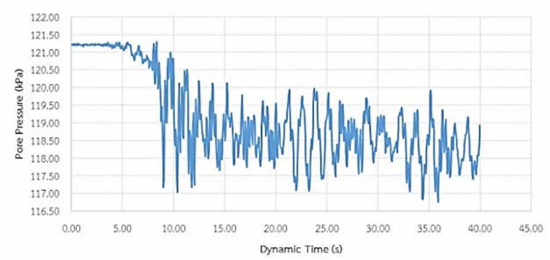

Fig. 12 The pore water pressure changing under long period earthquake (EQ2).

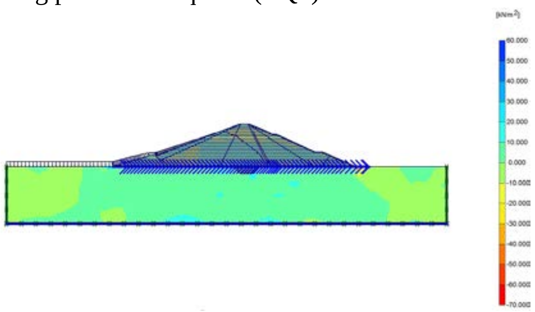

Fig. 13 The excess pore water pressure occurring in the dam under short period earthquake (EQ1).

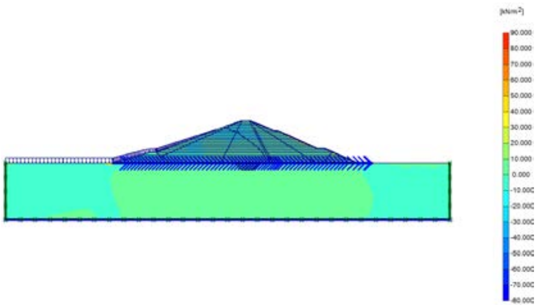

Fig. 14 The excess pore water pressure occurring in the dam under long period earthquake (EQ2).

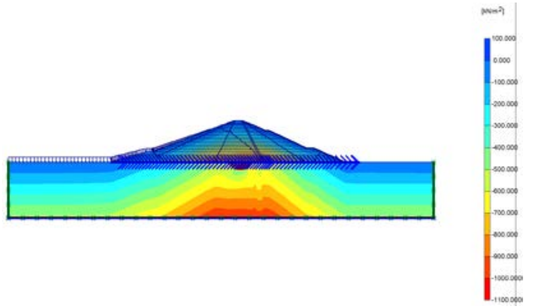

Fig. 15 The effective stress of the dam under short period earthquake (EQ1).

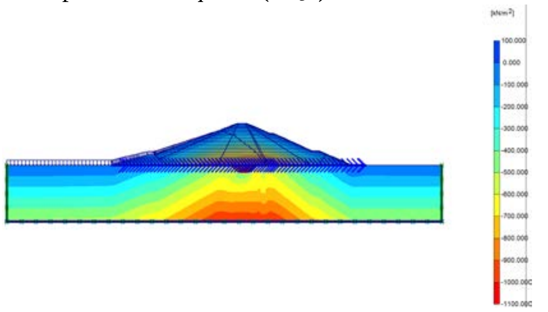

Fig. 16 The effective stress of the dam under long period earthquake (EQ2).

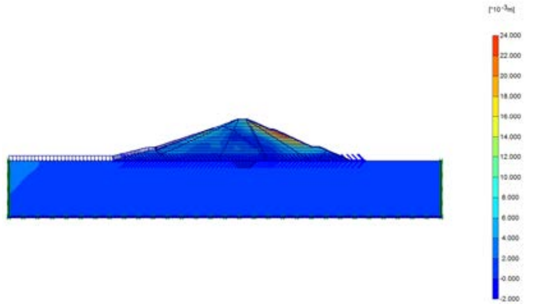

Fig. 17 The total displacements of the dam under short period earthquake (EQ1).

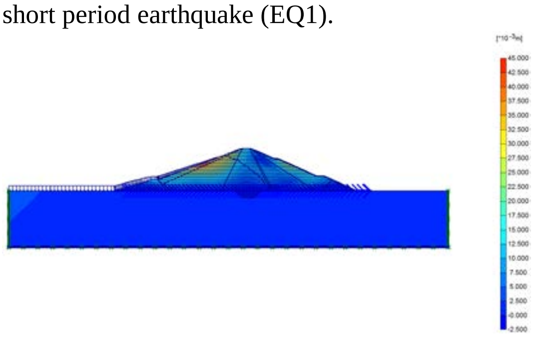

Fig. 18 The total displacements of the dam under short period earthquake (EQ2).

From the seismic force, not only caused the pore water pressure in the dam increase but it also affects to the effective stress. The maximum effective stress that could be calculated at core zone at the base of the dam during the earthquake was 1980 kN/m^2 for EQ1 and 1080 kN/m^2 for EQ2. In Fig. 15-16 show the shade area to present the effective stress in the earth zone dam.

The maximum total displacements equal to 23.23 mm and 43.01 mm for EQ1 and EQ2 condition respectively. The displacement from these earthquakes are shown in Fig. 17-18. The results showed that the maximum total displacement of the model affected by the short period of earthquake occurred in the downstream side of random zone and changed to upstream side when it affected by the long period of earthquake.

5. CONCLUSION

After comparing the analysis results with the measurement value from the accelerometer found that the attenuation model of Silva and Abrahamson (2008) can calculated the Peak Ground Acceleration (PGA) equal to 0.017787 g and the percentage error was 6.87.

From study the pore water pressure in the zone earth dam in dynamic condition by using finite element method found that the pore water pressure in dam under the long period earthquake wave (EQ2) is greater than the short period earthquake wave (EQ1). Under the seismic waves that have the PGA about 0.12-0.13g, they make the excess pore water pressure the pore water pressure increases about 12-15%, the maximum effective stress is equal to 1980 kN/m2 and 1080 kN/m2 for EQ1 and EQ2 respectively. When the pore water pressure and stress in the dam were changed by the seismic force, they are important factors that cause the displacement of the dam and cause a decrease in the strength of the soil. So the total displacement can be analyzed equal to 43.01 mm. and 23.23 mm. for EQ1 and EQ2 respectively.

6. ACKNOWLEDGEMENTS

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