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Investigation Seismic Response in Phitsanulok Province

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Abstract

Phitsanulok, located in the lower northern region of Thailand, has historically shown no hidden fault lines. However, on June 29, 2023, an unexpected earthquake with a magnitude of 4.5 occurred, with its epicenter just 5 km beneath Phitsanulok. Scientists believe the quake may have been triggered by a previously undetected fault in the area. Despite this, seismic data is limited, and much of the available data is static, consisting of Atterberg limits, unit weight, soil classification, and standard penetration test (SPT) results. Although SPT data has its limitations, it is the only consistently recorded field parameter and can provide estimation of soil cohesion and friction angle. Additional seismic data was sourced from related studies, with waveform data generously provided by the Earthquake Observation Division of the Meteorological Department. The soil profile in the study area displays two main characteristics: one where clay and sand layers alternate, and another where a sand layer lies at the bottom, overlain by clay. Analysis of three borehole logs indicates that the amplitude of acceleration ranges from two to three times of the original acceleration, as determined by the finite element method. While many engineers in Thailand favor the pseudo-static approach, this study aims to investigate the behavior of the soil profile in the Phitsanulok area during an earthquake event, focusing on aspects such as liquefaction potential, shear failure, and soil amplification capacity. For practical purposes, the horizontal coefficient used to represent earthquake forces in the pseudo-static method could be 0.07 for earthquake magnitude of 4.5.

Keywords: Amplitude, Seismic response, Earthquake, Hidden fault line, Phitsanulok

1. NOMENCLATURE

There are many terminologies, used specifically for this paper. The terminologies are as follows.

The acceleration time history means the acceleration amplification of seismic forces varying with time.

The velocity time history means the velocity amplification of seismic force varying with time.

The displacement time history means the displacement amplification of seismic force varying with time.

Seismic properties means the properties of a maximum shear strength, damping ratio, shear strength reduction ratio.

Uncertainty properties mean the parameters that are not test in laboratory.

Parameters are a maximum shear strength (Gmax), damping ratio, ratio of shear stress over maximum shear strength.

Hidden fault is fault never know the peak ground acceleration and maximum capacity.

2. INTRODUCTION

Previous attention was focused on the northern region of Thailand due to the presence of several active fault lines, as well as the impact of earthquakes from neighboring Myanmar, such as the 2011 Tarlay earthquake, which also affected Thailand.

The Phitsanulok area had never been considered an earthquake prone area in the past, and no fault lines were identified. However, on June 29th, 2023, an earthquake occurred with its hypocenter located just 5 meters beneath Phi- lom sub-district, Bangkratum, Phitsanulok. This event led scientists and geologists to believe that a hidden fault beneath the region was responsible. The soil profile in Phitsanulok consists of layers of silt, sand, and clay, with clay typically forming the uppermost layer and sand lying beneath it. The soil profile in the area can be categorized into two main patterns: one where sand and clay alternate, with clay always positioned above the sand, and another where a thick clay layer lies over the sand. In some profiles, a thin layer of silt can be found between the sand and clay as shown in figure 1.

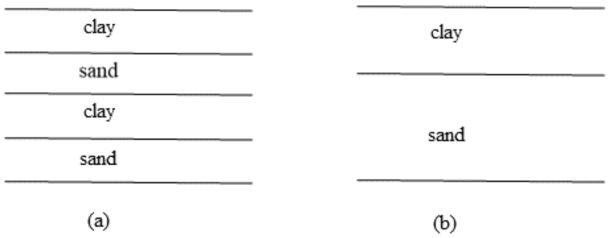

Figure 1 Two typical types of soil in Phitsanulok area

Thai regulation 1301/1302-61 from the Department of Public Works and Town & Country Planning permits the use of both the finite element method and the pseudo-static method to predict the seismic response in a regional area. Additionally, seismic parameters from previous studies can be utilized. While the finite element method is more complex and generally more accurate than the pseudo- static method, the latter, despite being less accurate, is still acceptable for estimation purposes under the law.

This study has one purpose that is investigated response of soil in Phitsanulok under seismic activity in mode of liquefaction, shear stress and amplification capacity.

The analysis in this study employs the 2-dimensional Finite Element Method. The parameters are derived from boring logs, with three logs utilized in the study. Static parameters are obtained from field investigations conducted by the Department of Public Works and Town & Country Planning.

Most of seismic parameters are based on blow counts by The Standard Penetration Tests (SPT) and data from available databases of other researchers. The methodology of the study can be shown in figure 2. The epicenter of this event has occurred at Phi- lom sub-district, Bangatum, thus soil profile at Phi-lom sub-district is used in the analysis including other two soil profiles near Nan river. Seismic properties data in this study are pull out from avaialble database of other researcher. The properties from the database such as G/Gmax, damping ratio which are depend on plasticity index, mean effective stress. The database maximum shear wave velocity and Maximum shear modulus are estimated from the blow count from the Standard Penetration test of selected boring log. The boundary of soil profile are fixed in horizontal direction (fixed in x axis and y axis) and wave assumely travels in one direction (up to surface). The working process of the study can be summarized shown in figure 2.

2.1 Pseudo static analysis

Pseudo- static analysis is a method that uses inertial forces to represent earthquake forces. These inertial forces are the result of constant horizontal and/or vertical acceleration acting on mass (Force = mass multiplied by acceleration), as shown in Equation 1.

$$F_h = k_h W \qquad \text{equation 1}$$

Where k_h represents the dimensionless horizontal pseudo-static coefficients, and W is the weight of the mass. The main challenge in this method lies in selecting the appropriate value for the horizontal coefficient, k_h. The accuracy of the pseudo-static analysis output depends mainly on the correct determination of k_h.

2.2 Acceleration time history

In this study, the acceleration time history was kindly provided by the Earthquake Observation Division of the Meteorological Department, as shown in Figure 3. Numerous stations are capable of capturing ground acceleration during seismic events, and in this case, the study uses the ground motion data from Phitsanulok.

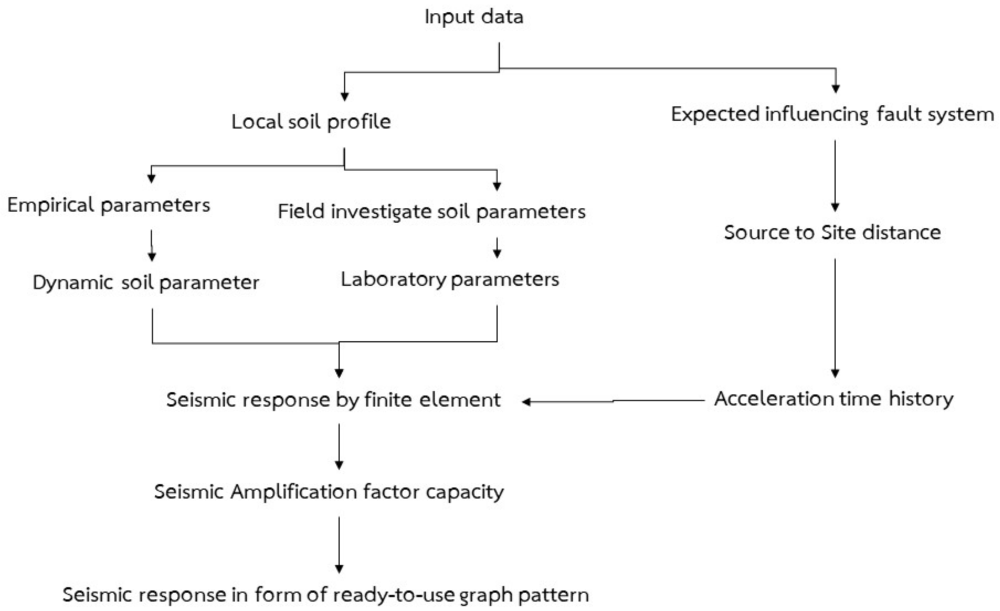

Figure 2 Flow chart of seismic response study

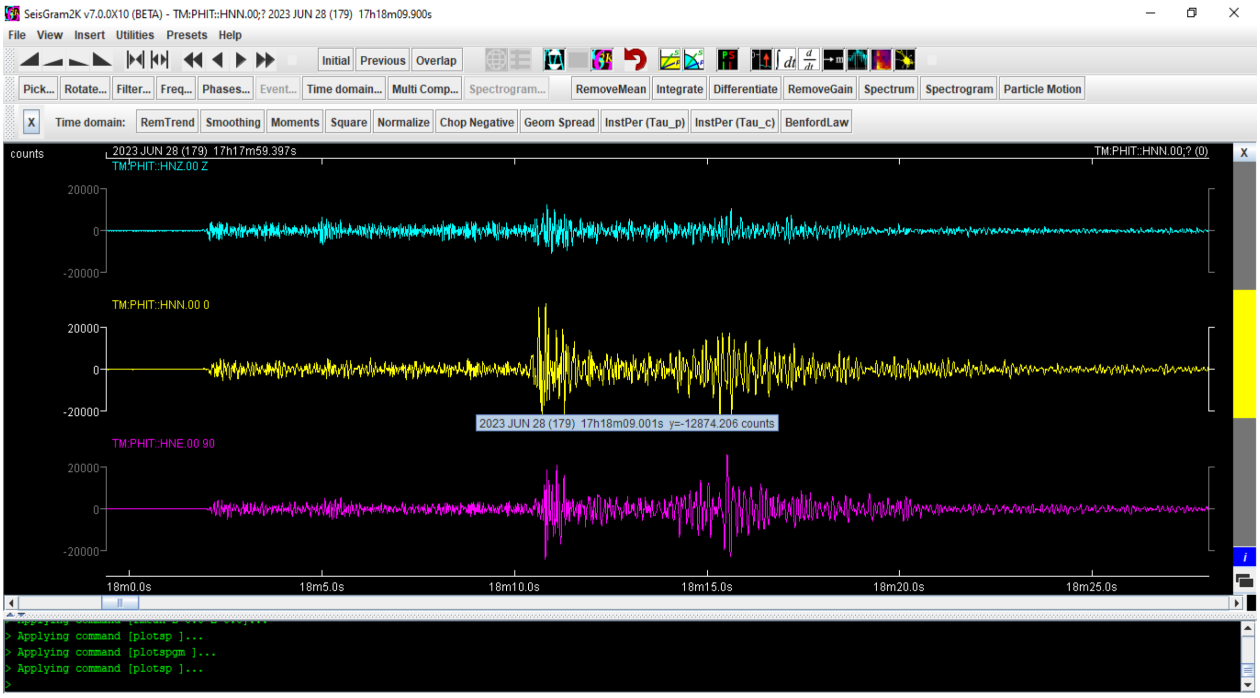

Figure 3. Acceleration time history in three dimensions

Generally, a seismograph is designed to measure three directions: North-South, East-West, and Vertical. In this research, the maximum amplitude in the North-South direction is used, as shown in Figure 4.

The results, as shown in Figure 4, display time on the X-axis and amplitude in the form of acceleration on the Y-axis. The peak acceleration amplitude is 0.025 g, occurring at a peak time of 14.51 seconds, with a total duration of 39.9 seconds.

The response spectrum of the study motion is shown in Figures 5 through 7.

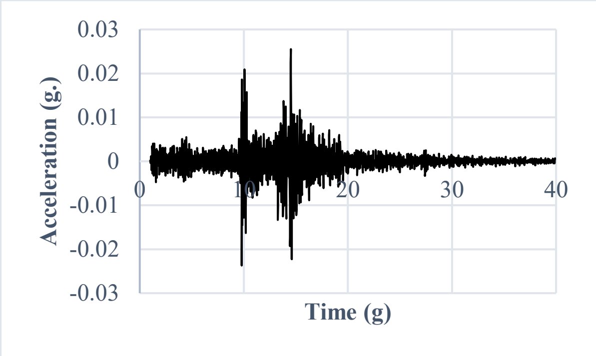

Figure 4 Ground motion (acceleration time is 0.025 g)

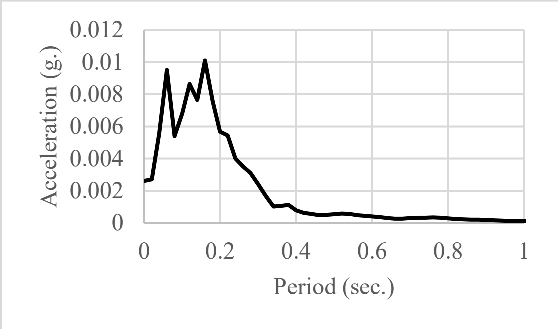

Figure 5. Response spectrum of Phi-lom sub-district (Damping = 0.05%)

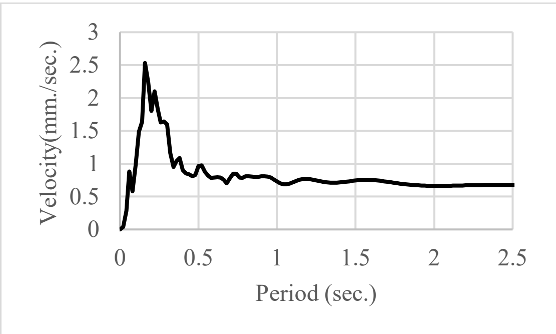

Figure 6. Velocity spectrum of Phi-lom sub-district (Damping = 0.05%)

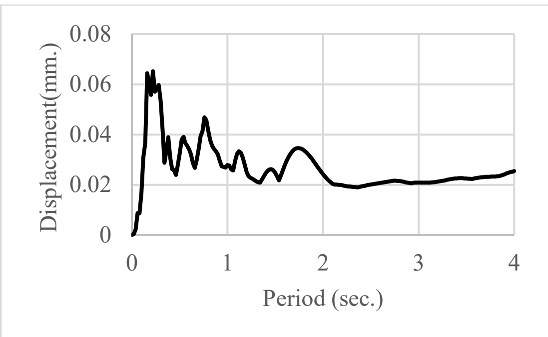

Figure 7 Displacement response spectrum (Damping = 0.05%)

3. RESULTS

3.1 Liquefy potential

Several criteria are currently employed to assess the potential for liquefaction. As previously mentioned, this study includes the data obtained from Department of Public Works and Town & Country Planning such as Atterberg's limits and grain size distribution. These parameters will be utilized to evaluate the liquefaction potential.

The first criterion specifies that the fraction finer than 0.005 mm must be less than 15%. The second criterion requires that the liquid limit should be less than 35%. The third criterion states that the natural water content should be higher than 0.9 times of the liquid limit. Finally, the liquid index must be less than 0.75. For clay, all of these criteria are violated.

However, the grain size distribution is examined to assess the potential for liquefaction based on the criteria of Iwasaki (1986) and the Overseas Coastal Area Development Institute (OCDI, 2009), as shown in Figure 8. According to the sand criteria, the grain size distribution indicates a potential for liquefaction, placing it within the liquefaction boundary, as shown in the Figure 8. However, no signs of liquefaction were observed during the field survey of this event. This may be due to the fact that the sand layer was located much deeper beneath the surface.

3.2 Amplitude amplifications

Although blow counts are influenced by various factors, such as the amount of human effort involved, they are the only available data. In this study, blow counts are used to estimate cohesion and the friction angle. The reduction in G_{max} (G/G_{max}) and damping are estimated based on normal stress and the plasticity limit from previous databases.

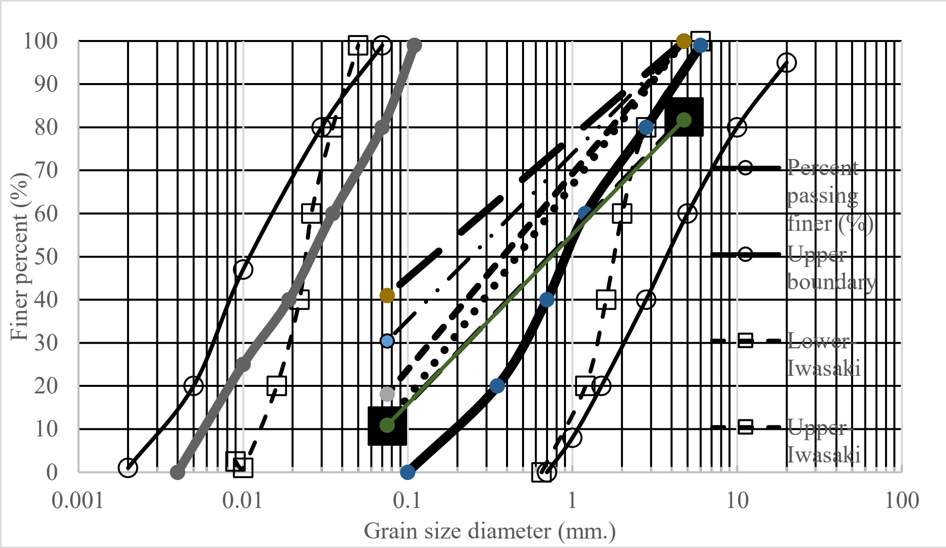

Figure 8 Grain size distribution of Phi-lom sub-district, Bangkratum, Phisanulok

Three boring logs of the Phitsanulok area are used to assess amplitude capabilities. The three boring logs are at the Electricity Office, Wat Sunthonpradit, and Phi-lom sub-district. Based on the finite element method, it was found that the soil in Phitsanulok can amplify acceleration by approximately 2 to 3 times the original value, as shown in Figure 9.

The study found that Phi-lom sub-district reveals the maximum amplitude, approximately 2.8 times of the original value, as shown in Figure 9 and Table 1. This represents the maximum capacity.

Currently, the finite element method is the primary approach relied upon by engineers; however, the pseudo-static method, which uses inertia forces, is relatively simpler. For example, at a depth of 3.45 m beneath the soil surface, the coefficient of inertia force is approximately 0.070 times the weight, as shown in Table 1.

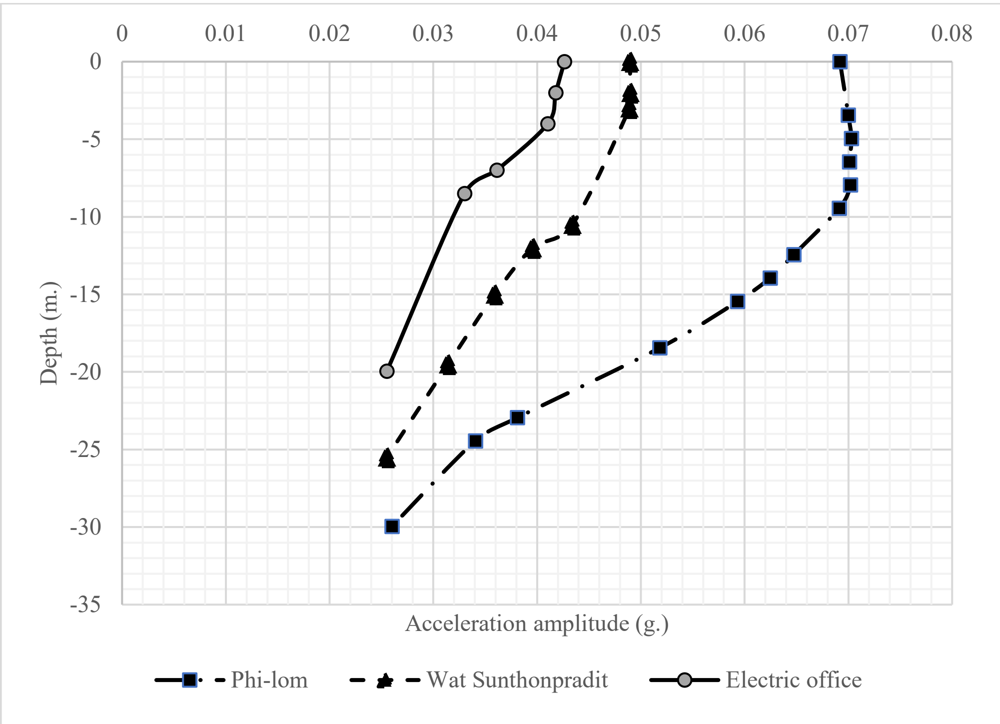

Figure 9. Acceleration amplitude with depth

Table 1. Induced acceleration at epicenter at Phi-lom sub-district

Depth (m.)	Maximum Induced acceleration (g.)	Amplification capacity
0	0.069	2.77
-3.45	0.070	2.8
-4.95	0.070	2.81
-6.45	0.070	2.8
-7.95	0.070	2.81
-9.45	0.069	2.76
-12.45	0.065	2.59
-13.95	0.062	2.5
-15.45	0.059	2.37
-18.45	0.052	2.07
-22.95	0.038	1.52
-24.45	0.034	1.36
-29.95	0.026	1.04

3.3 Shear stress

Nevertheless, induced shear stresses were investigated and it was found that they never exceed the available shear strength. As a result, there are no signs of sliding or cracking on the soil surface in any of three areas.

3.4 Response spectrum of surface at Phi-lom sub-district

The surface response spectrum is crucial as it provides essential data for structural engineering. Structural engineers rely on this information to design safe and effective structures. The surface response spectrum is illustrated in Figure 10.

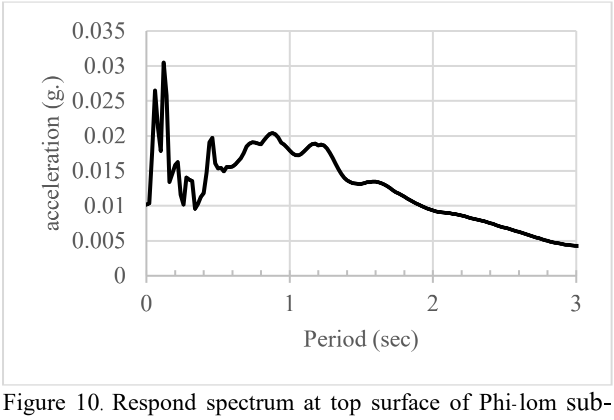

Figure 10. Respond spectrum at top surface of Phi-lom sub-district

4. CONCLUSIONS

Based on the survey, the surrounding areas do not show any sign of liquefaction, structure damage that is consistent with the finite element analysis.

Based on finite element analysis, the soil profile has the potential to amplify the acceleration magnitude by approximately 2-3 times of the original value. Shear failure was not observed for earthquake magnitudes 4.5, which aligns with field investigations. Regarding liquefaction analysis, only the grain size distribution was considered due to data limitations. The results indicate that the soil has the potential to liquefy.

The earthquake event had a magnitude of 4.5. The survey revealed no structural damage, although people could feel the tremor. This study and the survey findings are consistent. However, this study investigates an earthquake with a magnitude of 4.5 caused by a hidden fault, which raises concerns about the maximum capacity of such a fault, a capacity that remains unknown. Therefore, structures in Phitsanulok should be designed with consideration for potential earthquakes.

5. RECOMMENDATIONS

During construction, at least one seismograph should be installed to monitor seismic activity at each stage. The pseudo-static method may be used for preliminary design. Seismographs should be installed on existing high-rise buildings, such as hospitals, bridges, and other critical structures. Additionally, earthquake drills should be incorporated and regularly practiced.

For research, the existing earth structures should be re-evaluated with a focus on seismic forces, particularly regarding the stability of riverbanks.

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