J. SE Asian Appl. Geol., Sep–Dec 2010, Vol. 2(3), pp. 242–250

LOCAL SITE RESPONSE ON SIMULATED STRONG EARTHQUAKE MOTION AT LAEM CHABANG PORT, THAILAND

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Abstract

Laem Chabang port, located in Chonburi province in the upper Gulf of Thailand, is similar to many of the ports around the world. Some areas of Leam Cha bang port were layered by backfill materials which are highly suspected to soil liquefaction phenomena from the moderate to strong earthquakes. After one of the world's largest earthquakes of December 26th, 2004 (Magnitude 9.1) occurred in the region off the west coast of northern Sumatra, various existing active faults have been reported to have more potential to generate future earthquakes. Among those active faults, Ranong and Khlong Marui fault zone, distributed around the south and the upper Gulf of Thailand, have been evidenced to have more seismic activities than December 2004. The closet distance between Leam Chabang port and the extension of Ranong fault zone to the upper Gulf of Thailand is approximately 180-200 km. Though not too close, it is still probable to generate strong earthquakes. This study, for that reason, aims to investigate the local site responses of the filled area at Laem Chabang port due to afresh seismic Ranong active fault by employing the equivalent linear ground response analysis. The complete strong earthquake motion time history from the Ranong fault would be synthetically generated and inputted as a bedrock motion underneath the site of interest. The simplified analysis of liquefaction potential assessment based on the results from local site response would be additionally adopted to evaluate the liquefaction susceptibility around this site. The simulation results indicated that some backfill soil layers which have the very low SPT N-value were significantly suspected to liquefy under strong earthquake motions.

Keywords: *Local site response, synthetic accelerogram, liquefaction potential, backfill, Laem Chabang port*

1 Introduction

Laem Chabang port is one of the top deep-sea ports in Southeast Asia, positioned as the most efficient gateway to Thailand and the greater Indochina region. The port covers an area of around 2,536 acres (6,340 rais). Laem Chabang port situates approximately 110 km in the southeast of Bangkok in Tungsukhla, Si Racha and Banglamung district of Chonburi province. All of 11 berths at Basin 1 (Phase I) were leased out for private sector's investment, management and operation. At present, all berths have been operated and are able to handle containers totaling 4.0 million T.E.U.s/year. 4 berths out of 7 berths at Basin 2 (Phase II) have been operated since July 2004. Meanwhile, the rest of the berths are expected to be in operation in 2011 for accommodating containers totaling 6.8 million T.E.U.s/year. Upon the full operation in 2011, the overall berths at Basin 1 and 2 will have the maximum container accommodation capacity of 10.8 million T.E.U.s/year. The developments of Laem Chabang port consist of 3 phases: 1) the construction period of the first

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phase (I) had been started from 1987 to 1991, the backfill (reclaimed land) of this phase can be shown in the dark shaded area in Figure 1, 2) the second phase (II) construction period had been started from 1997 to 2000, this area shows in Figure 1 shaded by slightly gray color and 3) the third phase (III) will be commenced in the near future.

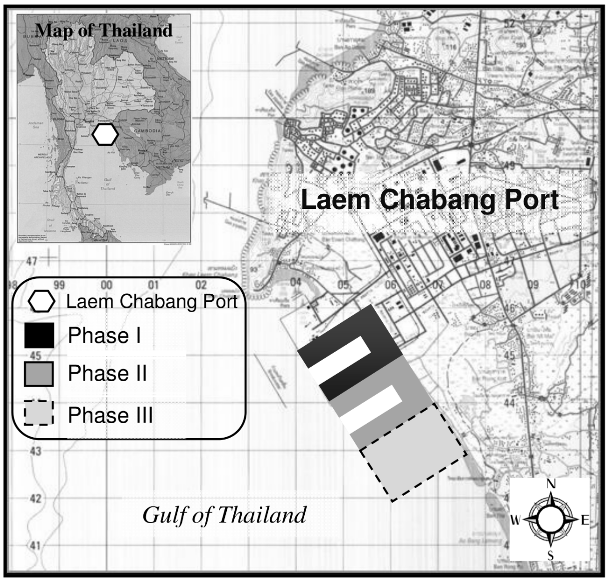

Figure 1: Layout of the reclaimed land of Laem Chabang port in phase I, II and III.

1.1 Backfill soil characteristics at site

The locations of the bored holes were around the Basin 1 (Phase I) area which had been constructed since almost 20 years ago. From the boring logs and the developing generalized soil profile it can be seen that most types of backfill soil in that area are mostly silty sand (SM) and clayey sand (SC) with very loose to medium conditions. The SPT *N*-value, from top of the backfill ground surface to seabed, varies from about 2-28 blows/ft. Below the seabed up to 25 m deep, the SPT *N*-value increases drastically, i.e. 35 blows/ft. to 50 blows/25 cm. The ground water level measured 24 hours after completion of the boring is approximately -0.8 m below the backfill ground surface. The natural water content is averagely 20%. The complete generalized backfill soil profile, with SPT *N*-value and soil density, can be shown in Figure 2. The elevation of the backfill ground surface with respect to the dredging seabed is approximately 14-16 m.

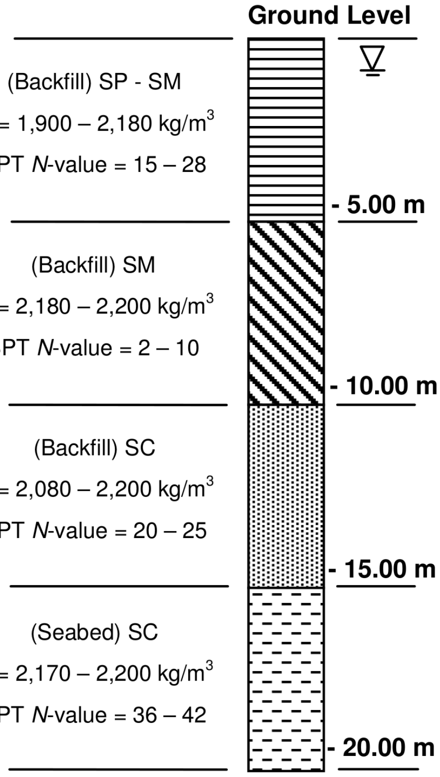

Figure 2: The generalized backfill soil profile at Laem Chabang port (Phase I).

1.2 Earthquake activities in Thailand

It is widely known that Thailand is situated in a low-seismicity region; most of the recognized active faults have been shaking in the northern and western parts of Thailand, especially around Thailand-Burma boundary. Those active faults are for example Moei, Mae Chan, Si Sawat and Three Pagodas active faults. Most of them have the total fault length of more than 200 km and can trigger the earthquake of 7.5 magnitude in Richter scale, Peterson et al. (2007). The prominent active faults in the southern region are Ranong and Klong Marui faults. Most of these main active faults in Thailand are reported as the strike-slip fault.

However, the earthquake activities which have epicenter within Thailand are somewhat low and small to moderate in magnitude (M =

4.5-6). Many events had been documented in the western and northern regions of the country. The moderate earthquake, 5.9 in Richter scale, shook the middle Kanchanaburi in 1983. However, it could be interpreted that this earthquake was closely related to the construction of massive reservoir, Wachiralongkorn Dam, from 1979 to 1982. In 1995, the 5.2 Richter earthquake hit Chiang Mai, no severe damages occurred.

After the incidence of the devastating megathrust earthquake of December 26th, 2004 (Magnitude = 9.1) and the continuing earthquakes in the region off the west coast of northern Sumatra and owing to more seismometer installations by various organizations, many researchers, i.e. Duerrast et al. (2007) and Yoshihiro et al. (2007), could observe more seismic activities of active faults around the south and upper Gulf of Thailand. The small to medium earthquakes, 2.5 to 5.0 Richter scale, had been detected between 2005 to 2007. These events distributed along the Ranong and Khlong Marui Fault Zone (FZ) in Prachuab Kirikan, Ranong and Surat Thani provinces. The most remarkable events had occurred 20-30 km off the east coast of Prachuab Kirikan in the Gulf of Thailand, previously classified as the low-seismic area, between September 2006 to March 2007. The earthquakes that ranged between M = 3.5–5.0 with the hypocenter depth within 40 km could be noticed by USGS and the Department of Mineral Resources (DMR) of Thailand (Figure 3). The epicenter of these events are believed to be the extension of the northern part of Ranong FZ. Though the necessity of more observations has to be continuously carried out to noticeably realize the seismic activities around these FZs, but it could be understood to some extent that these FZs, e.g. Ranong and Khlong Marui, have more movement activities. According to the location of Laem Chabang port (Figure 3), it situates near Ranong FZ; the source-to-site distance is around 180-200 km. As a result, the effect of the potential earthquakes from Ranong fault should be profoundly examined to prevent the possible severe damages which might be occurred to the port structures and in the vicinities.

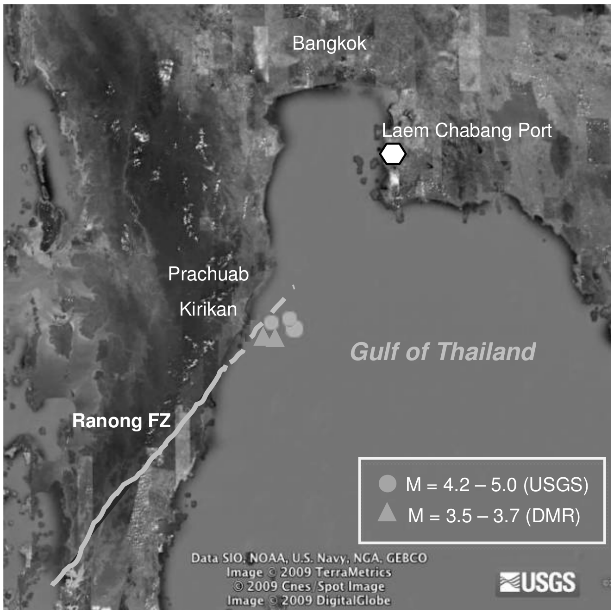

Figure 3: The location of epicenter of the earthquake events reported by USGS between Sep. – Oct. 2006 and by DMR in Mar. 2007.

Thailand Fault Parameters Table 1 details the fault parameters, i.e. total rupture length and slip rate, reported by Peterson et al. (2007) and the corresponding fault characteristics and Magnitude figured out by several empirical formulas, i.e. Somerville et al. (1999), Wells and Coppersmith (1994) and Hanks and Kanamori (1979). Most of those active faults can approximately activate the earthquake of more than Mw = 7.8 in magnitude. It should be noted that even some of the faults, i.e. Ranong and Khlong Marui faults, might be divided into various segments by many geologists, however, to simulate the worst case scenario, the entire rupture length will be used to estimate the possible maximum magnitude of earthquake as well as to generate the synthetic strong ground motion time history. The estimation of the rupture width, W, was fairly rational. The predictable width of all faults from this study is around 32-40 km. Yoshihiro et al. (2007) reported that the hypocenter depth of the series of earthquake events generated by Ranong fault in September 2006 in the upper Gulf of Thailand varied between 10-30 km.

Table 1: Parameters and corresponding magnitude of major faults in Thailand

Parameters	Active faults				
	Moei	Si Sawat	Three Pagodas	Ranong	Khlong Marui
Slip rate	0.36	0.60	0.56	0.10	0.01
Length of surface rupture, L (km)	226	209	380	523	348
Width of rupture, W (km)	32	34	37	34	32
Rupture area$^{(a)}$, s (km^2)	7,298	7,049	14,041	17,667	11,163
Moment magnitude$^{(b)}$,M_w	7.8	7.8	8.1	8.2	8.0
Seismic moment$^{(c)}$, M_o (dyne-cm)	5.62x10^{27}	5.62x10^{27}	1.58x10^{28}	2.23x10^{28}	1.12x10^{28}

(a) The rupture area can be derived from the formula of Somerville et al. (1999) [$s = 2.23\text{x}10^{-15}(M_o)^{2/3}$]

(b) The moment magnitude, M_w, derived from the relationship by Wells and Coppersmith (1994) [$M_w = 5.08 + 1.16 \log (L)$]

(c) The seismic moment, M_o, calculated from Hanks and Kanamori (1979) [$M_w = (2/3)\log M_o - 10.7$]

2 Methodology

To perform a complete local site response analysis, strong ground motion time history is one of the main inputs. Though lots of recorded strong earthquake motion databases are available online nowadays, due to the difference in the geologic conditions between site of interest (local) and site of actual earthquake (regional), the synthetic strong ground motion time history (in some cases) has many advantages in an engineering point of view, especially in the low-seismicity area like Thailand. Moreover many parameters of synthetic earthquake motion can be easily changed to be consistent with the target parameters of engineering design.

There are numerous simulation techniques of strong ground motion for engineering purposes. Among these are: 1) the method of Empirical Green's Function (EGF), e.g. Hartzell (1982), Irikura (1986) and 2) the method of stochastic simulation of high frequency ground motion, e.g. Boore (1983), Boore and Atkinson (1987). The EGF technique utilized the small events of earthquake records, i.e. foreshocks and aftershocks, near the target fault as a Green's function to simulate the main shock motions. This particular method already gathered the effect of source model, path propagation and site effect because the actual record data is employed in the simulation. However, in the area of inadequate and inappropriate small to medium earthquake records, this deterministic simulation is actually difficult to complete or cannot be achievable.

Another method, stochastic simulation, is based on the theoretical spectrum as specified by simple seismological model of source and propagation process. Despite success in many cases, this stochastic point source model sometimes breaks down in the case of near-fault simulation. The effect of large finite source, including rupture propagation as well as directivity can extremely influence the amplitude, frequency and duration of ground motion. To overcome this deficiency, the finite-source model has been introduced by summation of small point events into the large one. The target fault plane will be divided into a certain number of sub-elements which act as the point source and summing their contributions at the observation point. The main advantages of this stochastic simulation are that this technique can generate a high frequency strong motion and does not require the actual record data of earthquakes.

It is commonly recognized that site response analysis can describe, to some extent, the performance of the local soil conditions in a specific area when it has been shook by a medium to strong earthquake. Some soil especially soft clay might amplify (though some might de-amplify) the earthquake ground motions to about 3-6 times of Peak Ground Acceleration (PGA). For sand or cohesionless soil, the medium to strong ground shaking might lead to the liquefaction phenomena because soil lose its strength and stiffness in a short period of time but long enough to activate liquefaction. Therefore, after the completion of 1D equivalent linear site response analysis, the simplified method of liquefaction potential assessment would be adopted to evaluate the liquefaction susceptibility based on some parameters, i.e. peak ground acceleration (PGA), of site response analysis results as well as the inherent backfill soil characteristics of the site.

2.1 Simulation of probable strong earthquake motion generated by Ranong Fault

The simulation technique of strong ground motion time history used in this study would be based on a simple but powerful stochastic point source model by Boore (2003). This method is widely known to be useful for simulation of the high frequency ground motions of most interest to engineers, i.e. $f > 0.1$ Hz, and it is extensively used to predict ground motions for regions in which recording of earthquake motion is scarce.

Though, a number of seismometers have been extensively installed and networked throughout Thailand, especially in the northern, central and southern parts of Thailand by various government organizations and institutions, the utilization and interpretation of that recorded data are really limited and rarely published. A few of common source parameters, i.e. fault length and slip rate of major faults in Thailand could be reviewed and attained from the various papers published by the geologists. The complete source parameters are, in fact, scant. Moreover, it is almost impossible to accurately determine the source process and parameters of a future earthquake. Therefore, several parameters, such as the seismic moment and rupture area, would be estimated from the classical empirical formulas reported by many seismologists and geologists as in Table 1. It can be seen that Ranong fault, because of the relatively long entire rupture length, can trigger the earthquake of Mw = 8.2. Although this magnitude is somewhat very strong earthquake, it is the objective of this study to simulate the worst case scenario for the site response analysis at Laem Chabang port.

To simulate the strong motion by stochastic method, many fault parameters are required, for example: length = 523 km, width = 34 km, crustal density = 2.7 g/cm^3, crustal shear wave velocity = 3.5 km/s. Another parameter that is important in stochastic ground motion simulation is stress drop ($\Delta\sigma$) or the compactness of the earthquake rupture. Stress drop is the amount of stress which is relieved at the rupture front during an earthquake and has a larger effect on shortperiod ground motion. Theoretical studies had shown that higher stress drop results in higher ground motion. Stress drop is usually estimated between 10 and 100 bars. Moreover, various empirical relations and calculations found that the stress drop of the interplate events has somewhat lower value than intraplate events.

Because of the complexity of the source process and the scarcity of the recorded and published data for empirical relations of the stress drop within Thailand, this parameter consequently cannot be accurately defined for this study. Peterson et al. (2007) employed the stress drop of 140 and 200 bars in their crustal intraplate attenuation relations for the South-East Asia region. However, the static stress drop for this study was estimated from the relationship between stress drop versus seismic moment obtained from seismic data in Kanamori and Heaton (2000). The approximate value of stress drop of Ranong fault was about 100 bars. The typical value of the rest of required parameters from various resources would be adopted in the generation of the strong motion time history.

The synthetic strong motion time history of Ranong fault with the appropriate input of source parameters is shown in Figure 4. The maximum acceleration of the strong ground motion time history from the stochastic synthesis method is about 0.014 g.

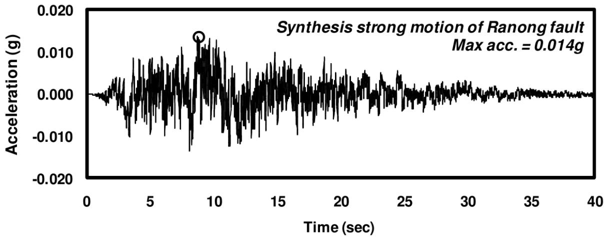

Figure 4: The synthesis strong ground motion time history of Ranong fault by stochastic method.

2.2 Site response analysis at Laem Chabang Port

The 1D site response analysis program, DEEPSOIL V3.7, developed at the University of Illinois at Urbana-Champaign by Professor Youssef M.A. Hashash and his students was adopted in this study. Generally, the complete and ideal ground response analysis can be categorized into 3 major steps: 1) the analysis of the rupture mechanisms, i.e. fault characteristics and the direction of rupture propagation 2) the analysis of the propagation of shear waves triggered by the fault through the bedrock below the site of interest and 3) the analysis of the surface ground motion influenced by the local soil conditions above the bedrock. For this study, the first and the second steps of the analysis were already included in the strong ground motion simulation by stochastic technique from the previous section. Therefore, this synthesis of strong motion time history of Ranong fault was then inputted in the site response analysis to observe the responses of the local soil conditions.

The shear wave velocity (Vs) profile was correlated from the generalized SPT N-value of the in-situ tests at the site. Many empirical formulas have been proposed by compiling SPT N-Value and Vs values. Among them, the following relationship employed by the Japanese Highway Bridge Design Code appeared the easiest to be adopted in this study;

$$V_s = 80\,N^{1/3} \tag{1}$$

where V_s = shear wave velocity (m/s) and N = insitu SPT N-value. It should be note that this correlation is used only for sand. The modulus reduction curve as well as the damping curve of sand model would follow the previous work by Seed and Idriss (1970). Moreover, the elastic bedrock was simplified to be just under the generalized soil profile of Laem Chabang port and had the unit weight of 23.60 kN/m^3 with the Vs of about 1,000 m/s.

2.3 The liquefaction potential assessment by simplified analysis at Laem Chabang Port

Liquefaction is defined as the transformation of granular materials from a solid to a liquefied state as an outcome of increasing pore water pressure and decreasing of effective stress inside granular soil. The methodology called "simplified procedure" is generally employed in the liquefaction potential estimation by engineers and researchers. This simplified method, though based on empirica,l is capable to evaluate and has been originally developed by Seed & Idriss since 1971, following the destructive earthquakes in Alaska, USA and in Niigata, Japan in 1964. Calculation of two variables is required for evaluation of liquefaction potential of suspected soil: 1) The level of cyclic loading on the soil caused by earthquake, expressed in terms of cyclic stress ratio or CSR and 2) The capability of the soil to resist liquefaction, expressed in terms of cyclic resistance ratio or CRR.

In practice, the calculation of CSR will follow the derivation of Seed and Idriss (1971) as expressed in (2) with some revisions in a stress reduction coefficient, r_d.

$$CSR = \frac{\tau_{av}}{\sigma'_{vo}} = 0,65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right) r_d \tag{2}$$

where a_{max} = Peak Ground Acceleration (PGA) generated by earthquake source; g = gravitational acceleration; σ_{vo} and σ'_{vo} are total and effective vertical stress, respectively; and r_d = stress reduction factor calculated by Equation (3).

$$r_d = \frac{(1.000 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5})}{1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^{2}} \tag{3}$$

where z = depth beneath surface in meters.

The evaluation of CRR can be retrieved and tested from the undisturbed soil specimens in the laboratory. Unfortunately, sampling techniques and testing granular soil samples in laboratory are too chaotic to obtain meaningful results. To avoid the difficulties associated with sampling and laboratory testing, field or in-situ tests have become the state-of-practice for routine liquefaction investigations. Several field tests become common usage for evaluation of *CRR*, including the standard penetration test (SPT *N*-Value), the cone penetration test (CPT), shearwave velocity measurements (V_s). SPT *N*-Value and CPT are generally preferred because of the more extensive databases and past experiences. A promising alternative or supplement to the penetration test approaches is provided by in-situ measurements of small-strain shear wave velocity, V_s. The use of V_s as an index of liquefaction resistance is soundly based because both V_s and liquefaction resistance are similarly influenced by many of the same factors; e.g. void ratio, stress state, stress history and geological age. A recent up-date of these simplified methods had been documented in Youd et al. (2001).

3 Results

The acceleration time history at the ground surface of Laem Chabang port from site response analysis could be shown in Figure 5. The maximum acceleration output of the top layer of backfill soil was approximately 0.025g which indicated the amplified action of the response. However, the frequency content of the ground shaking at the site was lower than the input bedrock motion due to the influence of the damping characteristic of the soil. In Figure 6, the response spectra at 5% damping was displayed. The highest Peak Spectral Acceleration (PSA) occurred at the period of 0.4 sec (2.5 Hz).

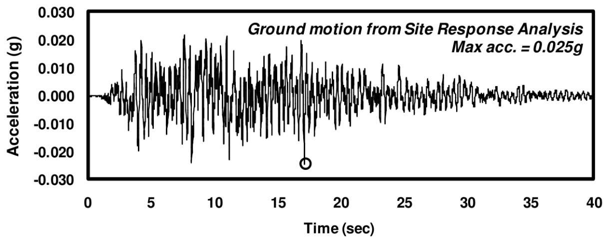

Figure 5: The acceleration time history at the ground surface of backfill layers at Laem Chabang port hit by the simulated Ranong active fault at the magnitude of Mw = 8.2.

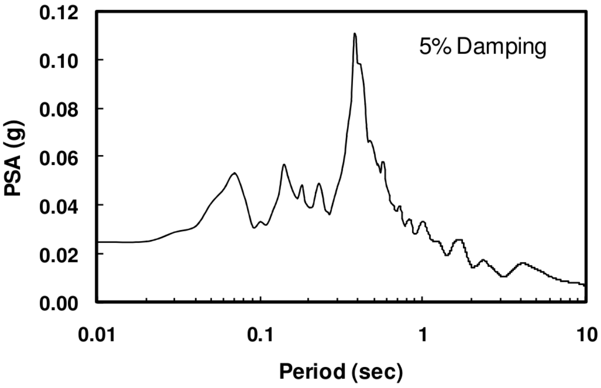

Figure 6: The response spectra versus period at 5% damping of backfill soil at Laem Chabang port.

The results also revealed that the backfill soil around the site could amplify the strong ground motion up to about 5 times of the bedrock motions at the frequency in the range of 2 to 3 Hz (Figure 7). Figure 8 shows the profile of the maximum PGA throughout the entire depth of the backfill soil. The maximum PGA of the response of the backfill at the ground surface was approximately 0.025g which was almost the same as in the layers of the very low SPT N-Value, i.e. at the depth of -8.00 to -9.00 m. below ground surface. This maximum PGA profile would be subsequently adopted in the liquefaction potential assessment around the site.

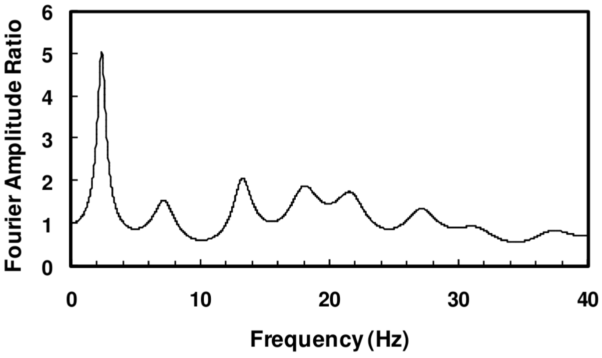

Figure 7: The Fourier amplification ratio (surface/input) against frequency at the ground surface of backfill soil at Laem Chabang port.

The evaluation of the liquefaction potential assessment by simplified method in terms of Factor of Safety (FS) of the backfill soil showed that due to the greatly low number of SPT NValue of the backfill layers at the depth of

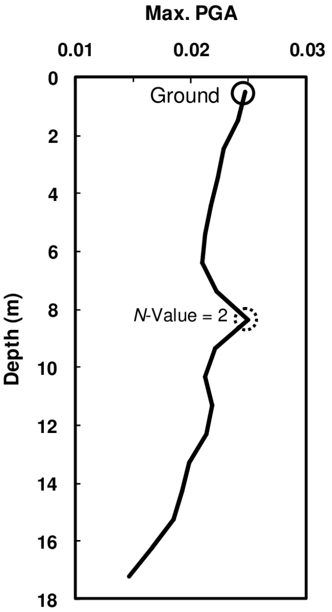

Figure 8: The maximum PGA profile along the entire depth of the backfill soil at Laem Chabang port from 1D equivalent linear site response analysis.

-8.00 to -9.00 m below ground surface, Laem Chabang port was highly suspected to liquefy under some medium to strong earthquakes. The calculated FS is actually low, e.g. about 1.4, at -9.00 m deep. The assessment result also unveiled that the PGA higher than 0.035g could cause the liquefaction phenomena around the port. The small performance to resist liquefaction of some backfill soil layers at this study may be explained by a number of reasons as follows: 1) this simplified study did not include the effect of fine contents, which can apparently increase the value of CRR in soil layers and 2) the high level of water table, i.e. -0.8 m, below surface, could generate excess pore water pressure when subjected to strong shaking.

4 Conclusions

Laem Chabang port (Phase I) had constructed, in some areas, by backfill materials for more than 20 years ago. The generalized soil profile shows that several layers of these backfills have the very low number of the penetration resistance, e.g. SPT N-Value = 2, which is greatly suspected to liquefy under medium to strong ground motion. Moreover, the active faults in Thailand, i.e. Ranong and Klong Marui faults, have been reported to have more seismic activities as a result of the giant earthquake and its aftershocks since December 26th, 2004 (Magnitude 9.1). Some of the epicenters of these earthquakes were occurred in the upper Gulf of Thailand in which the nearest distance between these epicenters to Laem Chabang port was about 200 km.

The simulated strong earthquake motion of Ranong fault with the magnitude Mw = 8.2 was then carried out by using the stochastic simulation technique. The possible acceleration time history, caused by Ranong fault, propagated to the bedrock underneath Laem Chabang port was attained with the maximum acceleration 0.014g. After that 1D equivalent linear site response analysis was performed by using that simulated acceleration time history as the bedrock motion in the analysis. The results showed that the backfill soil layers could magnify the maximum acceleration of the input earthquake motion of the frequency around 2-3 Hz. to 5 times. At the ground surface, the maximum PGA was about 0.025g which was almost similar to the layers of low SPT N-Value, depth of -8.00 to -9.00 m. Though this acceleration (from the simplified method of liquefaction potential assessment) could not activate the liquefaction phenomena at Laem Chabang port, some layers of backfill soil which had the very small performance to resist liquefaction were greatly suspected to liquefaction if subjected to the earthquake with the maximum PGA of the motion about 0.035g.

The remediation of potential liquefiable soil should be undertaken by either increasing the liquefaction strength of the soil, i.e. preloading, cementation and replacement, or lowering the underground water level. This remediation can help dropping the damage of structures and facilities around the ports.

Acknowledgements

The authors acknowledged Kasetsart University, Si Racha campus for supporting a research grant of this study. The authors also would like to heartily thankful to express a sincere gratitude to Professor Masayuki Hyodo, Department of Civil and Environmental Engineering, Yamaguchi University, Ube, Japan, for having accepted the first author as a foreign researcher and inspiring him to complete this work.

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