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Using a Stochastic Model to Study the Ground Motion of Comprehensive Subsurface Structure

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ABSTRACT: The seismic response analysis of buildings and bridges use earthquake acceleration time histories as input data. But there is always a lack of earthquake time histories in regions where buildings are constructed, which makes ground motion simulation is one of the most important problems in civil engineering domain. In this study, the strong motion stations of boring log data collected within Lanyang plain have been combined with the subsurface layers of Lanyang plain obtained by using geophysical method to construct a comprehensive subsurface structure of Lanyang plain. Available papers and reports on nonlinear dynamic soil characteristics have been reviewed to determine appropriate soil parameters for representing soils in Lanynag plain. In this research, the stochastic seismic model developed by Boore (1983, 2005) will be used to simulate a set of rock-outcrop synthetic acceleration time histories. The acceleration time histories at the rock-outcrop from this study will be compared with the real earthquake record for all the soil sites, the acceleration time histories at the ground surface will be generated from nonlinear site response analyses using the computer program SHAKE91. For the strong motion station, we compare the earthquake spectrum and real earthquake spectrum to investigate the appropriateness in the Ilan area. These ground motions may be used in the field of disaster reduction, such as the calculation of the ground response subject to earthquakes using the SHAKE computer program or the evaluation of the safety of buildings and bridges.

KEYWORDS: Synthetic ground motion, Response spectra, Comprehensive subsurface structure.

1. INTRODUCTION

Taiwan is situated in the zollision zone of the Philippine area plate and Eurasian continental plate, and the degree of collision is most intense along the eastern coast and offshore. Consequently, large earthquake often occur in this region, especially in the Ilan area. Along with occurrence of earthquakes, structures like buildings and bridges are always damaged by earthquake induced strong motions. For the sake of safety, influence of seismic response should be considered on structure design, and earthquake acceleration time history is required as input data for the seismic response analysis of buildings and bridges. However, recorded ground motions around the study sites are spare, the synthetic acceleration time histories are used for analysis. The stochastic model is commonly used (Hwang, 2001; Tsai et al. 2000, Sokolov et al. 2000) to generate an earthquake acceleration time history at the rock outcrop.

In this study, a comprehensive substructure of Lanyang plain is established by combining the subsurface data inferred from geophysicist's investigation and detailed boring log data close to ground surface from engineers endeavor. Then a stochastic model is used to generate an earthquake acceleration time history at the rock outcrop. Finally, nonlinear dynamic properties of soils in Lanyang plain are analyzed to obtain response spectrum of acceleration time histories in Lanyang plain. Consequently, the synthetic response spectrum are compared with real response spectrum to investigate appropriates of the synthetic ground motion in Lanyang plain. Flow chart of this study is shown in Figure 1.

2. COMPREHENSIVE SUBSURFACE STRUCTURE OF LANYANG PLAIN

The Ilan County in Taiwan is surrounded by mountains on three sides southeastern side, Shiehshan Mountain Range in the northwestern side, Central Mountain Range in the southeastern side, and the county faces the Pacific Ocean in the east. The Shiehshan Mountain Range is mainly composed of slightly metamorphosed slate and argillite, while the Central Mountain Range is mainly composed of argillite, phyllite and slate. The Lanyang plain is sedimentary deposit from Lanyang River and its branches. The shape of Lanyang plain is an isosceles triangle with boundary length of 30 kilometer and the total area of Lanyang plain is about 360 square kilometer. The Lanyang plain is covered by a quaternary alluvium layer over other rock layer. The thickness of layers and the depth to the basement rock are varying from points to points in the Lanyang plain.

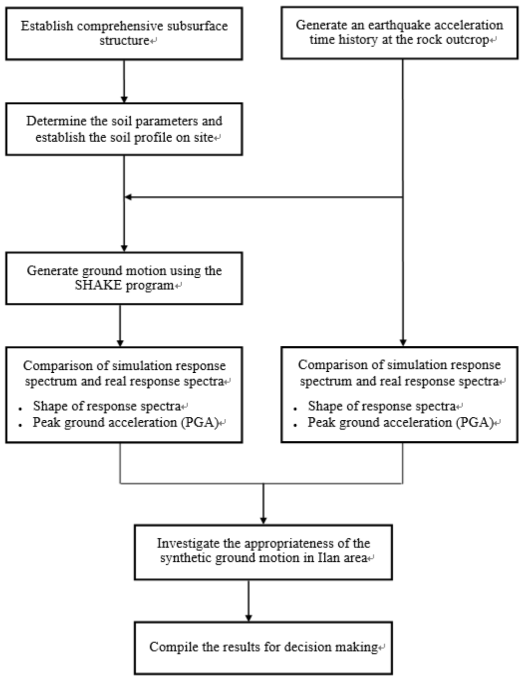


Figure 1 Procedure for synthetic ground motion in Lanyang Plain

Geophysicist usually investigates the physical properties of subsurface layers by using instrumental measurements of seismic wave, gravity, and magnetic force, etc. The investigation results in a rough division of subsurface layers, in particular, the subsurface layer close to the ground surface. On the other hand, engineers explore the subsurface layers by drilling boreholes to provide detailed information including the type of soil, layer thickness, standard perpetration test N-Value (SPT-N), groundwater level, etc. Because of drilling capacity and available resources, the drilling is usually limited to soil layers close to the ground surface, and the deeper soil and rock layers may not be explored. From above explanation, it is evident that geophysicists and engineers use different techniques to investigate the subsurface structure, and each of these techniques has its own advantages. In this study, the excellent results from these two gilds are selected and combined to provide a comprehensive profile of the subsurface structure of Lanyang plain.

Based on the subsurface shear wave velocity structures (Table 1) obtained from nine recording stations set up by Hwang (2003) in Lanyang plain, and digital boundary line data from the digital map published by central geological survey, a three dimensional subsurface structure of Lanyang plain is created by Hsu et al. (2012). Hwang (2003) and Hsu et al. (2013) results show that the subsurface structure of Lanyang plain can be divided into three layers. From top down, they are alluvium layer, Pleistocene formation, and Lushan layer. The interface between alluvium layer and Pleistocene formation is shown in Figure 2. While the interface between Pleistocene formation and Lushan layer is shown in Figure 3. The above methods can only roughly divide strata of Lanyang plain into three Layers; however, they cannot show detailed structure of each layer, especially the layer close to ground surface. Therefore, the boring log data are used to replace the alluvium layer. If the depth of boring log is shorter than the depth of the interface between the alluvium layer and the Pleistocene formation, the last layer of the boring log is extended downward to this interface. Consequently, a comprehensive subsurface structure of Lanyang plain is thus established by combining the subsurface data inferred from geophysicist investigation and the detailed boring log data close to ground surface from engineer's endeavor. For example, a comprehension profile of subsurface structure including a profile of shear wave velocity of boring log Ilan029 is shown in Figure 4.

Table 1 Layer depths and shear wave velocities of Lanyang Plain (Hwang 2003)

Stations	Layer 1 Alluvium layer		Layer 2 Pleistocene formation		Layer 3 Lushan layer	
	Depth (km)	Vs (km/s)	Depth (km)	Vs (km/s)	Depth (km)	Vs (km/s)
A	0.065	0.22	0.61	0.81	1.00 ↑	2.05
B	0.055	0.20	0.52	0.65	0.90 ↑	1.71
C	0.090	0.22	0.72	0.76	0.70 ↑	1.91
D	0.100	0.25	0.42	0.69	0.90 ↑	1.88
E	0.100	0.35	0.43	0.92	0.95 ↑	2.26
F	0.045	0.17	0.48	0.76	0.90 ↑	1.88
G	0.065	0.22	0.51	0.66	0.90 ↑	1.70
H	0.095	0.24	0.62	0.87	0.70 ↑	2.33
I	0.070	0.22	0.47	0.86	0.90 ↑	2.14

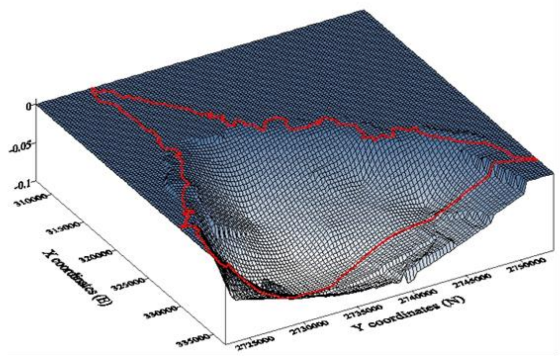


Figure 2 Topographic map of the depth of velocity interface 1 of Lanyang Plain

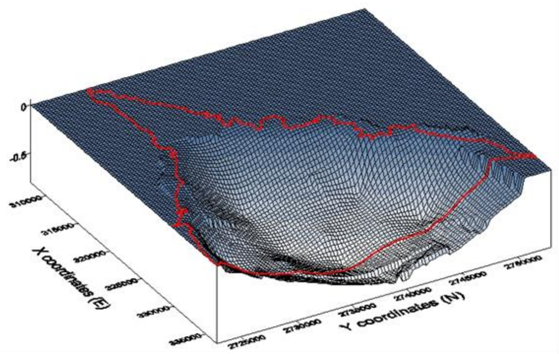


Figure 3 Topographic map of the depth of velocity interface 2 of Lanyang Plain

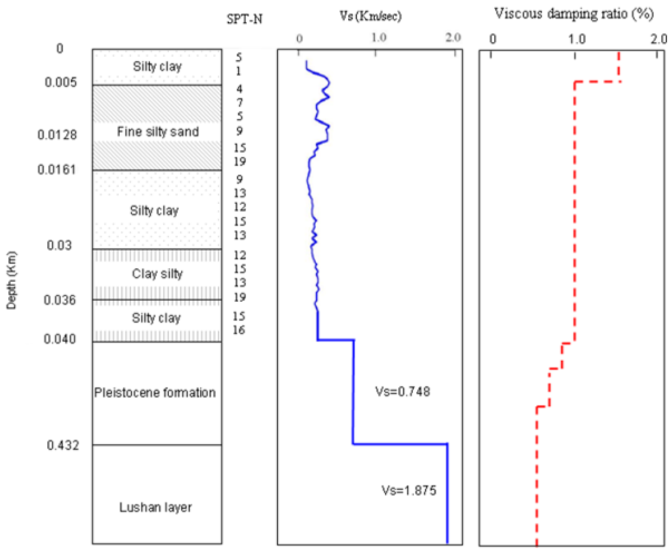


Figure 4 Comprehensive subsurface structure at IanB029 site in Ilan County

3. EARTHQUAKE TIME HISTORY AT ROCK OUTCROP GENERATED BY A STOCHASTIC MODEL

In the analysis of nonlinear dynamic properties of soils, proper earthquake acceleration time histories are required as input data. However, recorded ground motions around the study sites are sparse, synthetic acceleration time histories are usually used instead, To generate an earthquake acceleration time history at the rock outcrop, the stochastic model (Boore, 1983) is commonly used (Hwang, 2001; Tsai et al, 2000; Sokolov, 2000). In Hsu et al. (2013) research, strong motion data recorded by the strong motion station located on hard rock site in Ilan County are used in stochastic model to simulate earthquake response spectrum and acceleration time history. Comparison of the synthetic response spectrum generated by Hsu et al. (2013) and real response spectrum showed that most of the synthetic response spectra at the rock outcrop agree well with the real results. Therefore, in this study, a stochastic program SMSIM (Boore, 2005) is used to generate an acceleration time history at the outcrop of the rock site. Based on the stochastic method, the Fourier acceleration amplitude spectrum at the outcrop of a rock site can be expressed as follows:

$$A(f) = C \cdot S(f) \cdot G(r) \cdot D(f) \cdot AF(f) \cdot P(f) \quad (1)$$

where C is the scaling factor, $S(f)$ is the source spectral function, $G(r)$ is the geometric attenuation function, $D(f)$ is the diminution function, $AF(f)$ is the amplification function of rock layers above the bedrock, and $P(f)$ is the high-cut filter. Based on the moment magnitude and epicentre distance, required data, including the characteristics of seismic source, stress parameter, and shear wave velocity are input into the stochastic program SMSIM (Boore, 2005) to generate an acceleration time history at the outcrop of a rock site. Table 2 shows the seismic parameters used to generate synthetic ground motion in this study.

To illustrate the process for generation of earthquake time history at an outcrop of a rock site, a case study is taken as an example. Boring log ILA031 is located inside campus of Suao elementary school, Ilan County. The synthetic ground motion at the outcrop of the rock site generated by June 14, 2001 earthquake (which has a moment magnitude of 6.4 and a source distance of 28 km). Simulated response spectrum generated by stochastic program SMSIM (Boore, 2005) is also presented in Figure 5.

Table 2 Summary of seismic parameters

Parameters	Value
Crustal density (ρ_0) gm/c.c.	2.7
Crustal shear wave velocity (β_0) km/s	3.2
Radiation coefficient <$R_{\theta\varphi}$>	0.55
Stress parameter (Δ_σ)	100 bar
Geometric attenuation function G(r)	1 / r for r ≦ 50 km 1 / r^0 for 50 km ≦ r < 150 km 1 / $r^{0.5}$ for r ≧ 150 km Sokolov (2000)
Frequency-dependent quality factor Q(f)	Q(f) = 98 $f^{1.0}$ Chang and Yeh (1983)
The amplification function AF(f)	$AF(f) = \sqrt{\rho_0\ \beta_0\ /\ \rho_s\ \beta_s}$ Boore and Joyner (1991)
High-cut frequency (f_{max})	30 Hz
Motion duration (Te)	1 / f_c + 0.05 r
Window shape	Exponential

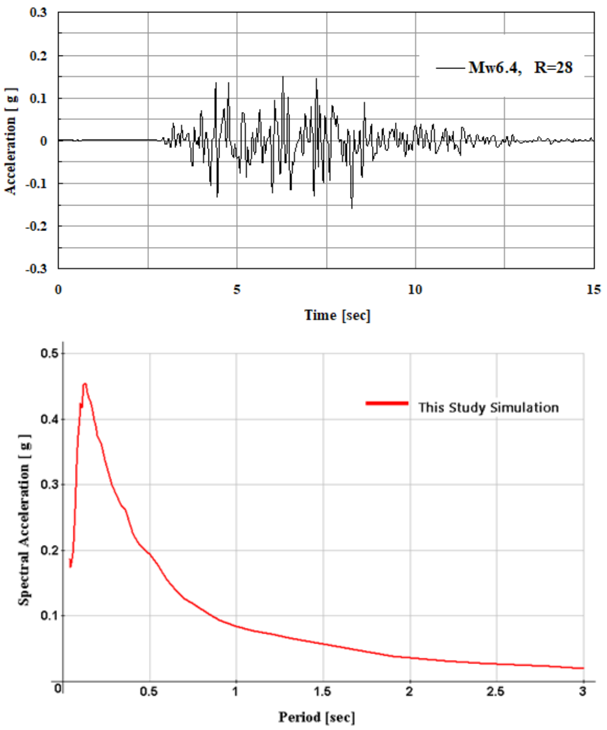


Figure 5 Acceleration time history and response spectra (M_w 6.4 R=28 km)

4. ANALYSIS OF NONLINEAR DYNAMIC PROPERTIES OF SOILS

Under synthetic ground motion, non-linear dynamic soil properties are analyzed by using computer program SHAKE91 (Idriss, 1992) in this study. In the SHAKE91 program, the soil profile consists of horizontal soil layers, required input parameters are soil profiles, soil parameters and acceleration time histories at outcrop of rock site. For boring log data from sites in Lanyang plain, non-linear dynamic soil properties are analyzed by using previously obtained acceleration time histories at outcrop of rock site.

4.1 The Simulation Station Selected in Lanynag Plain

The Lanyang plain is a sedimentary deposit covered by a Quaternary alluvium layer over other rocks. The thickness of layers and the depth to the basement rock are varying from points to points. The National Center for Earthquake Engineering Research (NCREE) has initiated a project to explore the characteristics of the sites where the strong motion instrument have been installed. The boring log data of 33 sites in Ilan County are determined for the use is this study. Site classification was determined based on the standard perpetration test (SPT-N) values and engineering geologies of the sites where the strong motion instruments were installed. The classification results show that among 8 selected sites, 3 (IlA014, ILA033, and ILA046) of them are classified as Type II sites, while 5(ILA003, ILA005, ILA026, ILA028, and ILA055) of them are classified as Type III sites (soft sites). Figure 6 shows the locations of these 8 boring logs that are uniformly distributed in Lanyang plain.

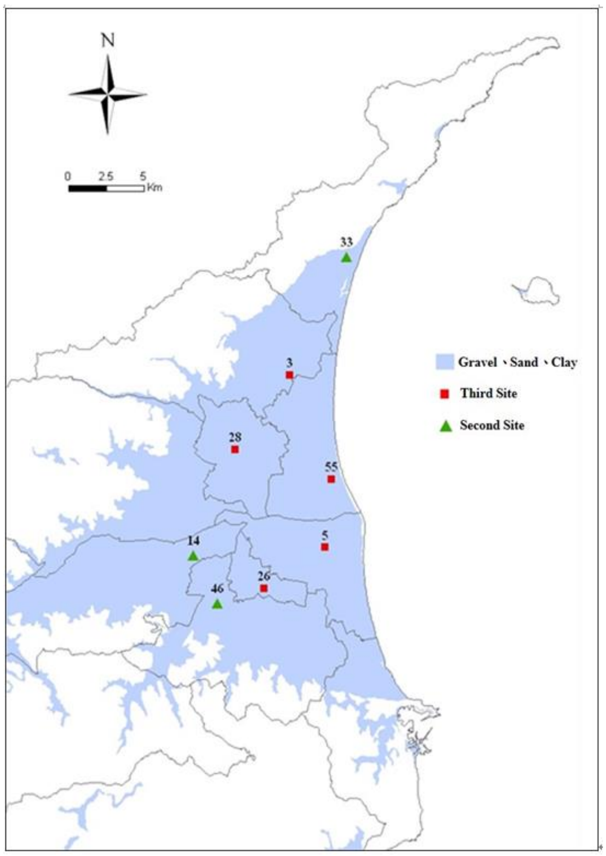


Figure 6 Distribution of boring logs located on the Lanyang Plain

4.2 Analysis of Earthquake Time History in Ilan Area

7 earthquake events that occurred around the Ilan area from years 2000 to 2002 are selected. The moment magnitudes of these earthquakes were larger than 6.0. Table 3 shows the 7 earthquakes events. The distribution of the earthquake epicentres is shown in Figure 7.

In addition to local soil conditions at a site, the characteristics of earthquake ground motion is significantly affected by magnitude of earthquake. In the analysis of earthquake ground acceleration time histories, the synthetic acceleration time history of rock outcrop at a site is simulated first, then the nonlinear dynamic properties of soils are studied, consequently, the earthquake time history and response spectrum are generated. In this study, 3 earthquake events are chosen for simulation in each of 8 selected sites, resulting in 24 sets of synthetic earthquake time histories.

Table 3 Earthquake events in the Ilan area (2000-2002)

EQ event	Time	Earthquake Epicentre		Focal depth (km)	Moment Magnitude (M_w)
1	Jun. 10, 2000	121.11°E	23.91°N	16.2	6.4
2	Jun. 13, 2001	122.61°E	23.41°N	64.4	6.4
3	Jun. 14, 2001	121.93°E	24.42°N	17.3	6.4
4	Dec. 18, 2001	122.65°E	23.87°N	12	6.7
5	Mar. 31, 2002	122.19°E	24.14°N	13.8	7.1
6	May 15, 2002	121.87°E	24.66°N	8.5	6.2
7	Jun. 16, 2002	122.39°E	25.12°N	175.7	6.8

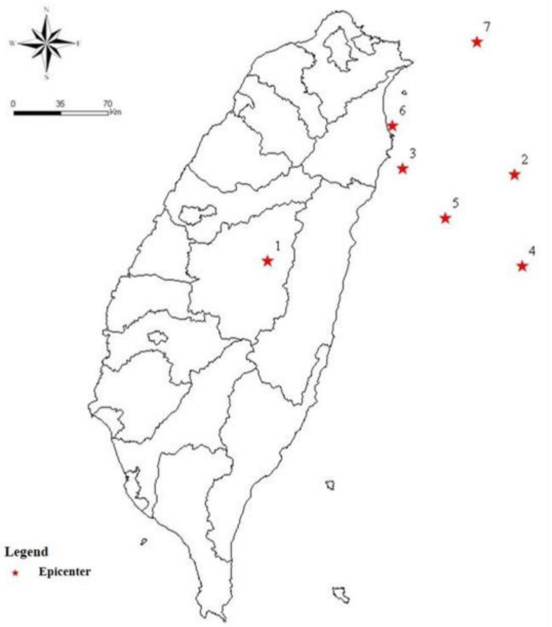


Figure 7 Distribution of the earthquake epicentres

4.2.1 Comprehensive Subsurface Structure of Site

Boring log Ila028 is located in campus of Jhongshan elementary school, Ilan city. At this location, 40 meters depth of alluvium layer is mainly composited by sand, clay and silt, with shear wave velocity of 0.159 to 0.344 km/sec. Beneath alluvium layer is Pleistocene formation with shear wave velocity of 0.733 km/sec. A complete profile of subsurface structure including a profile of shear wave velocity is shown in Figure 8.

4.2.2 Determiner Dynamic Properties of Soil

After comprehensive subsurface structure at a site is constructed, determination of dynamic characteristic curves is required for the study of nonlinear dynamic properties of soils. Comparing a number of available cyclic loading results, Hsu et al. (2015) suggested that the use of shear modulus reduction curves, and the damping curves presented by Vucetic and Dobry (1991) and Hashash and Park (2001) can provide a convenient basis for determining dynamic properties for cohesive soils and cohesionless soils (Figure 9, Figure 10), respectively. The relationships between the shear modulus and the damping ratio with the shear strain amplitude are consistent with the soil at sites of Lanyang plain, therefore, they are chosen for use in this study.

4.2.3 The Dynamic Characteristic of Soil Profile

Before performing nonlinear site response analysis by using SHAKE program, it is required to separate soil profile into several appropriate layers. For each soil layer, the required soil parameters include unit weight, shear wave velocity, initial damping ratio, and dynamic characteristic curves. As suggested by SHAKE program, separated layer thickness in alluvium is 3.048 m, while in Pleistocene formation is 15.24 m.

Since effective confining pressure is the primary factor affecting the dynamic characteristics of cohesionless soil, determination of dynamic characteristic curves should take the curve which effective confirming pressure is close to the effective overburden pressure is 219 kPa, then Hashash and Park (2001) curve with effective confirming pressure equal to 221 kPa is taken for analysis in this study. Shear modulus reduction curves and damping curves is Lanyang Plain studies by Chen et al (1993) were also collected, for effective overburden pressure smaller than 55.2 kPa, dynamic characteristic curves pressure by Chen et al. are taken for analysis in this study (Figure 11).

For cohesive soils, PI is the most dominant and consistent factor, dynamic curves with values close to that of soil layers are taken for analysis in this study. For example, if clay layers PI is 13, Vucetic and Dobry (1991) dynamic characteristic curve with PI equal to 15 is taken here. The complete profile and parameters of dynamic characteristics for boring log ILA028 is presented in Table 4.

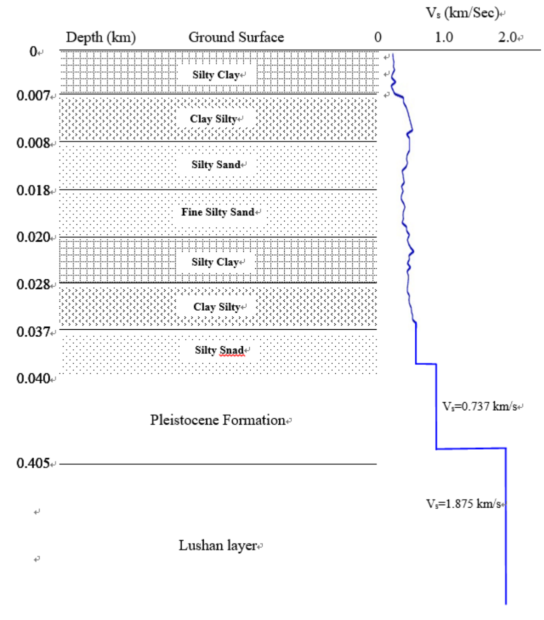


Figure 8 Comprehensive subsurface structure at IanB028

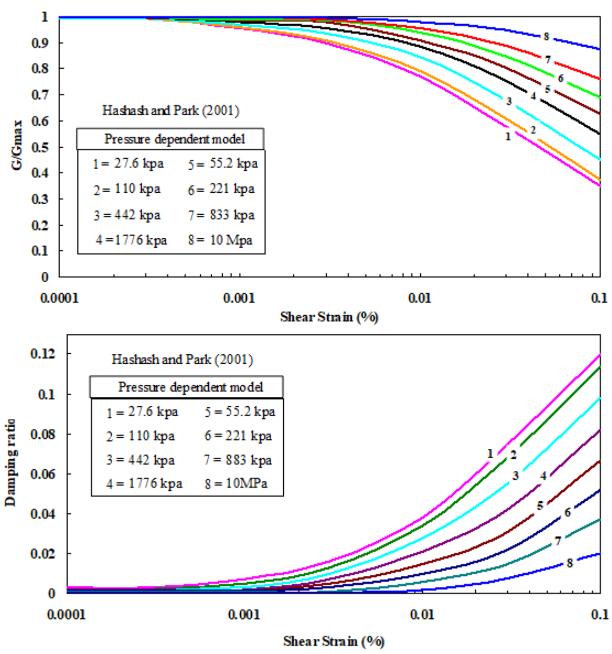


Figure 9 Influence of confining pressure for cohesionless soils: (a) shear modulus reduction curves, and (b) damping curves

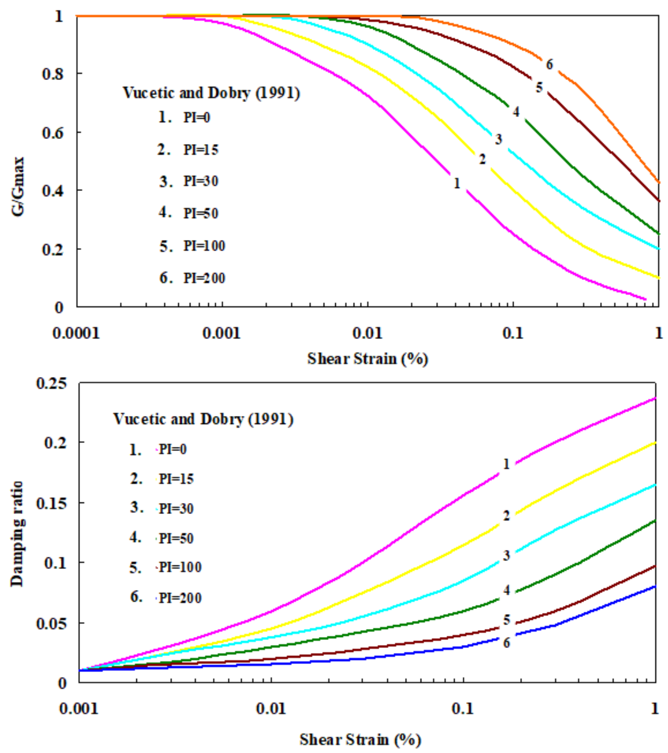
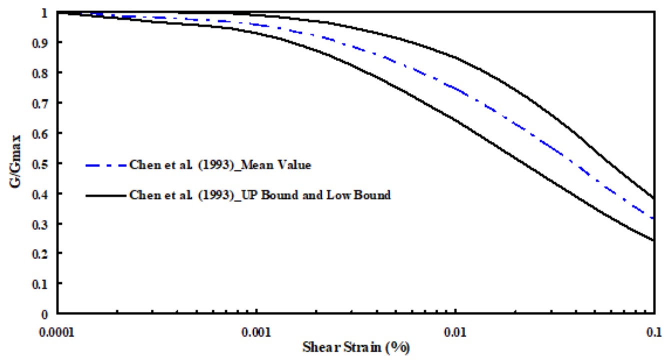
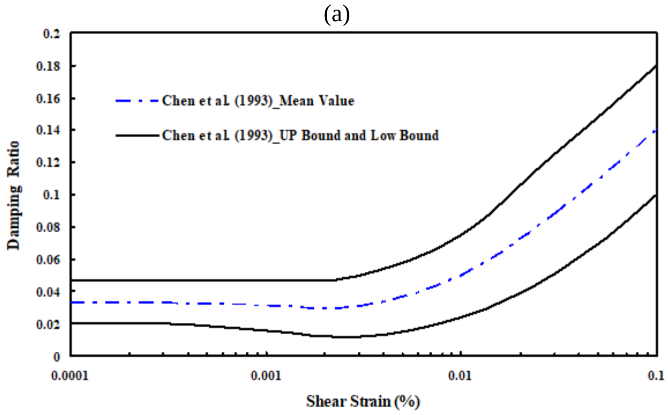


Figure 10 Influence of soil plasticity index (PI) for cohesive soils: (a) shear modulus reduction curves, and (b) damping curves



(a)



(b)

Figure 11 The shear modulus reduction curves and damping curves by Chen et al. (1993)

4.2.4 Generator Earthquake Time History of Rock Outcrop

Earthquake acceleration time history is an important parameter for the study of nonlinear dynamic properties of soils. By using a stochastic model to simulate the synthetic acceleration time history of rock outcrop, Hsu et al. (2013) shows that the synthetic response spectra at the rock outcrop agree well with the real results. In this study, a stochastic model is used to simulate earthquake ground motion at the outcrop of the rock located at boring log ILA028 site. Synthetic ground motion is generated by earthquake event 6 which has a moment magnitude of 6.2, focal depth of 8.5 km, epicenter distance of 15.9 km, and source distance of 18 km. Synthetic acceleration time history thus generated at boring log ILA028 site is shown in Figure 12.

Table 4 The soil parameters of site (ILA028)

Depth(m)		Ground Surface	
0	Clay V_s= 159 m/s, γ_s=18.834 KN/m^3, PI=8	Vucetic and Dobry (2001) Shear modulus reduction Curves PI = 5	Vucetic and Dobry (2001) Damping Curves PI = 5
7.2	Clay Silty V_s= 159 m/s, γ_s=19.422 KN/m^3, PI=8	Vucetic and Dobry (2001) Shear modulus reduction Curves PI = 5	Vucetic and Dobry (2001) Damping Curves PI = 5
8.4	Silty Sand V_s= 270 m/s, γ_s=20.211 KN/m^3, σ'_m =219 kPa	Hashash and Park (2001) Shear modulus Reduction Curves σ'_m=221 kPa	Hashash and Park (2001) Damping Curves σ'_m=221 kPa
18.4	Fine Silty Sand V_s=227 m/s, γ_s=22.530 KN/ m^3, σ'_m =264 kPa	Hashash and Park (2001) Shear modulus Reduction Curves σ_m=221 kPa	Hashash and Park (2001) Damping Curves σ'_m=221 kPa
20.7	Silty Clay V_s=264 m/s, γ_s=18.977 KN/m^3, PI=8	Vucetic and Dobry (2001) Shear modulus reduction Curves PI = 5	Vucetic and Dobry (2001) Damping Curves PI = 5
28.5	Clay Silty V_s=295 m/s, γ_s=19.233 KN/m^3, PI=13	Vucetic and Dobry (2001) Shear modulus reduction Curves PI = 15	Vucetic and Dobry (2001) Damping Curves PI = 15
37.5	Fine Silty Sand V_s=344 m/s, γ_s=19.464 KN/m^3, σ'_m=511 kPa	Hashash and Park (2001) Shear modulus Reduction Curves σ'_m=442 kPa	Hashash and Park (2001) Damping Curves σ'_m=442 kPa
40.0	Pleistocene Formation V_s=750 m/s, γ_s=24.531 KN/m^3 σ'_m=766.607 kPa~ 11238.621 kPa	Hashash and Park (2001) Shear modulus reduction Curves σ'_m=883 kPa~10 MPa	Hashash and Park (2001) Damping Curves σ'_m=883 kPa~10 MPa
737.0	Lushan Layer V_s=1870 m/s, σ'_m =10 MPa	Hashash and Park (2001) Shear modulus reduction Curves σ'_m=10 MPa	Hashash and Park (2001) Damping Curves σ'_m=10 MPa

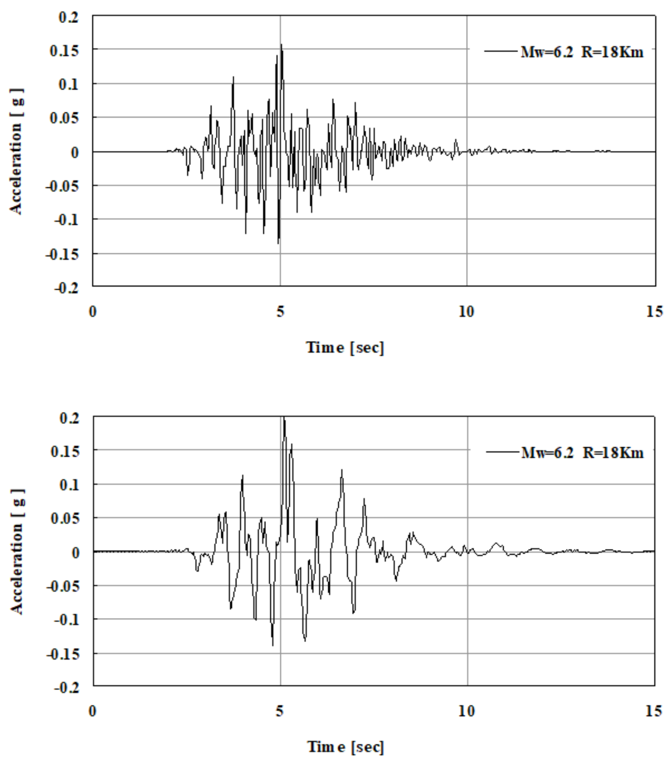


Figure 12 Acceleration time history and response spectra of rock outcrop (ILA028, EQ06)

4.2.5 Generator Earthquake Time History of Rock Outcrop

The synthetic acceleration time history generated by earthquake event 6 at boring log ILA028 site is then used for the calculation of the ground response subject to earthquake by using SHAKE computer program. Simulated response spectrum at rock outcrop and ground surface is shown in Figure 13. Following the same procedure as decided above, synthetic response spectrum for sites at boring logs ILA014, ILA033, ILA046, ILA003, ILA005, ILA026, ILA028, and ILA055 are also generated in this study. Three of above mentioned boring logs (ILA014, ILA033, and ILA046), their soil strata are categorized as Type II, and the others (ILA003, ILA005, ILA026, and ILA055) are categorized as type III. Earthquake response spectrum recorded at the above mentioned boring log sites and simulated ones by different earthquake event are shown in Figures 14 and 15.

4.3 Comparison of Simulated and Real Response Spectrum

4.3.1 Type II Soil Sites

Figure 14 shows simulated and recorded response spectrum for boring log sites (ILA014, ILA033, and ILA046) where soil layers are categorized as Type II as shown is Figure 14, for boring log site ILA014, simulated response spectrum agree well with recorded response spectrum for earthquake events 2 and 3. Simulated response spectra also agree well with recorded are for earthquake event1, if period is shorter than 0.5 sec. However, if period is longer than 0.5 sec, simulated response spectra are lower than recorded one.

Comparison of simulated and recorded response spectrum agree well with that of recorded ones. However, for earthquake event 5, simulated response spectra are lower than that of recorded one when period is grater than 0.5 second.

Figure 15 shows comparison of simulated response spectrum with recorded ones for boring log site ILA046 at shows that simulated response spectrum agree well with that of record ones for earthquake event 1, 3 and 6.

4.3.2 Type III Soil Sites

Five boring log sites (ILA003, ILA005, ILA026, ILA028, and ILA055) where soil layers are categorized. Comparison of simulated response spectrum with that of recorded ones is presented in Figures 17 to 19.

As shown in Figure 16, simulated response spectra agrees well with that of recorded one for boring log site ILA003 generated by earthquake event 2. However, simulated response spectrum are lower than recorded ones for boring log site ILA003 generated by earthquake by earthquake event 3 and 5, if periods are greater than 0.5 record. Comparison of simulated response spectrum and recorded ones generated by earthquake event 2, 3 and 7 at boring log site ILA005 are also shown in Figure 16 as shown in Figure 16, simulated response spectrum generated by earthquake events 3 and 7 agree well with that of real ones. Under earthquake event 2, peak value and period at period for simulated response spectra varies a little with that of real one. However, the difference is not significant.

Figure 17 shows simulated response spectrum and recorded ones produced by earthquake events 4, 5 and 7 at boring log site ILA026. at shows that simulated response spectrum agree well with of recorded ones also for earthquake events 4 and 5. under earthquake event7, simulated response spectra also agrees well with recorded one when period is smaller than 0.5 sec, however, simulated one is higher than recorded one when period is larger than 0.7 sec. Comparison of simulated response spectrum with recorded ones produced by earthquake events 4, 6 and 7 at boring log site ILA028 are also shown in Figure 17. At shows that simulated ones agree well with that of recorded ones.

Figure 18 shows comparison of simulated response spectrum with that of recorded ones generated by earthquake events 1, 4 and 6 at boring log site ILA055 at shows that simulated response spectrum agree well with that of recorded ones.

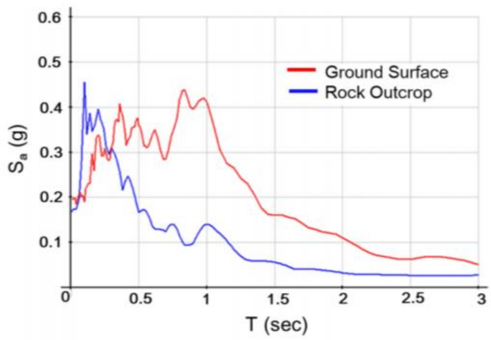


Figure 13 Earthquake response spectra (ILA028, EQ06)

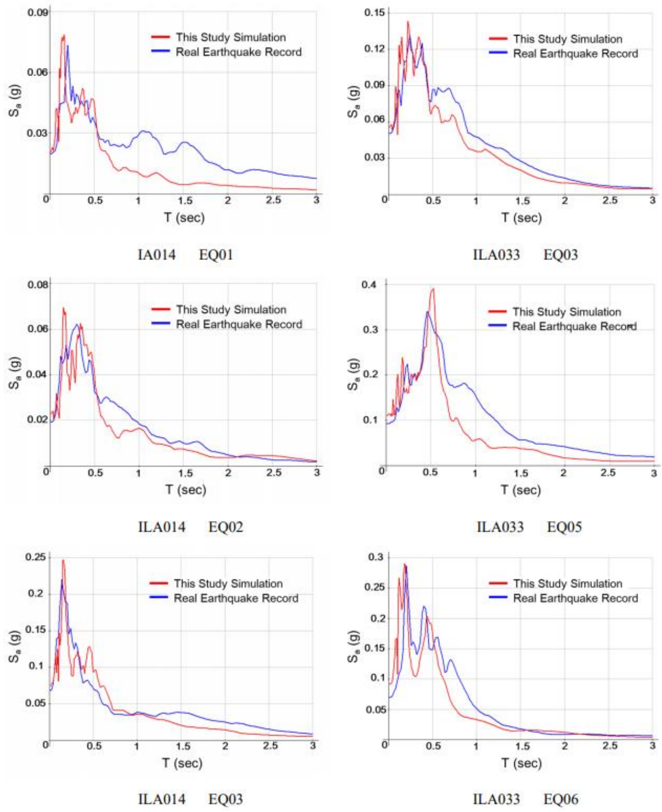


Figure 14 Comparison of simulated response spectrum and real response spectrum for different earthquake events (The second site class)

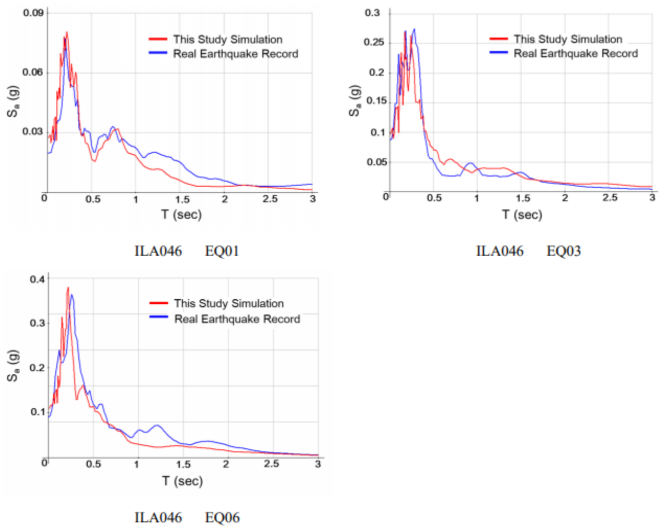


Figure 15 Comparison of simulated response spectrum and real response spectrum for different earthquake events (The second site class)

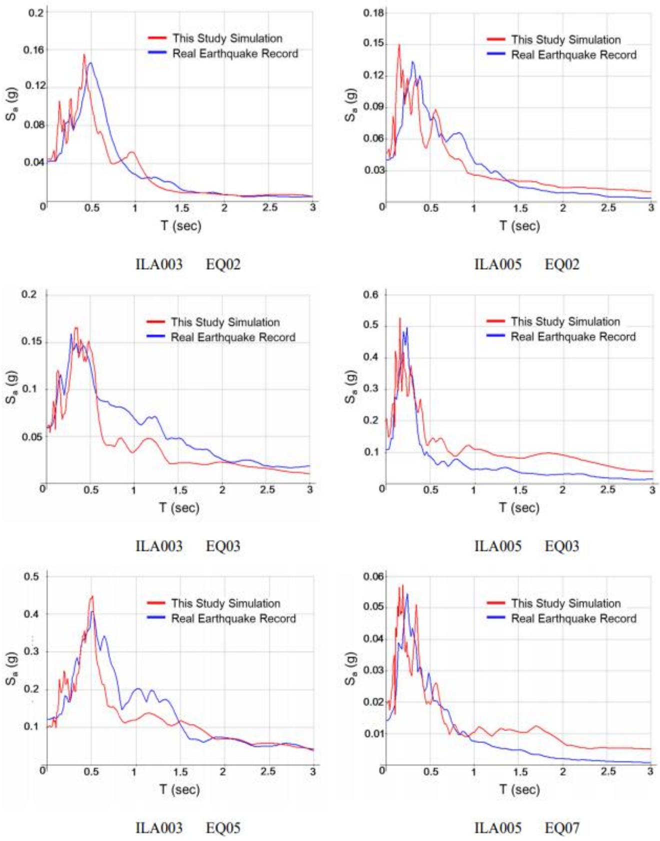


Figure 16 Comparison of simulated response spectrum and real response spectrum for different earthquake events (The third site class)

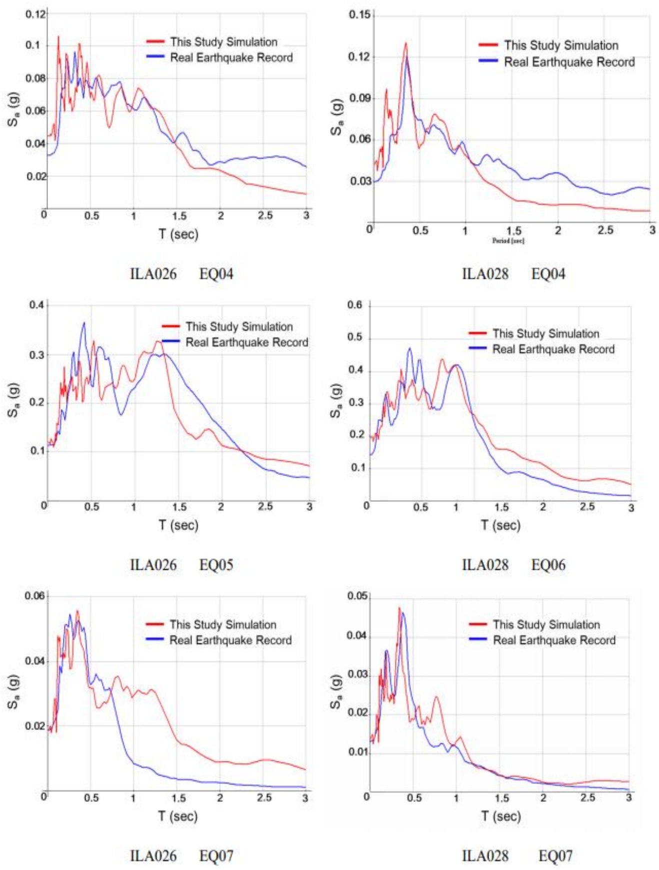


Figure 17 Comparison of simulated response spectrum and real response spectrum for different earthquake events (The third site class)

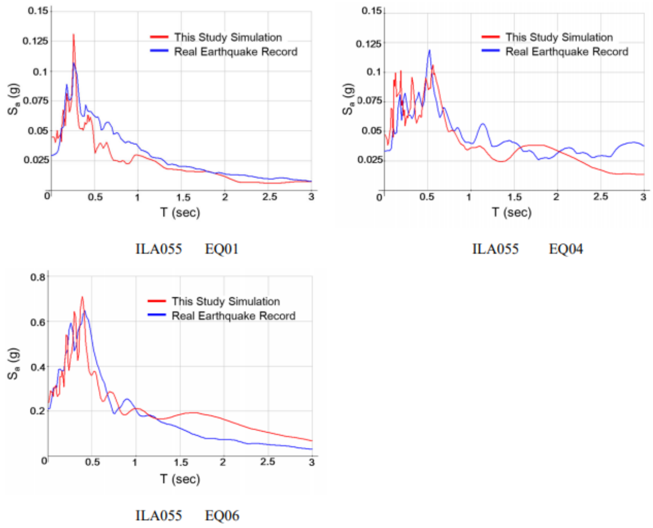


Figure 18 Comparison of simulated response spectrum and real response spectrum for different earthquake events (The third site class)

5. RESULTS AND GENERAL DISCUSSION

5.1 Type II Soil Sites

Among the boring log sites selected for simulation is Lanyang plain, 3 sites where soil layers are categorized as Type II, i.e. ILA014, ILA033 and ILA046. Table 5 summarizes comparison of simulated response spectrum with that of recorded ones generated by different earthquake events as shown in Table 5, 7 simulation results agree well, while 2 results agree partly well. Compared results show that, in general shape of simulated response spectrum agree well with that of record ones simulated peak ground acceleration (PGA) values also chose to that of recorded ones.

5.2 Type III Soil Sites

There are 5 selected boring log sites (ILA003, ILA005, ILA026, ILA028, and ILA055) where soil layers are categorized as Type III, as shown is Table 5, comparison of simulated response spectrum with that of recorded ones among 15 simulation results, 12 agree well, while 3 agree partly well. Based on the simulation results, it shows that simulated shape of response spectrum agree well with recorded ones. In addition differences of PGA values between simulated and recorded ones are not significant.

Table 5 Summary of acceleration response spectrum to earthquake

Stations	Earthquake event						
	1	2	3	4	5	6	7
ILA014 (Second Site)	△	○	○				
ILA033 (Second Site)			○		△	○	
ILA046 (Second Site)	○		○			○	
ILA003 (Third Site)		○	△		△		
ILA005 (Third Site)		○	○				○
ILA026 (Third Site)				○	○		△
ILA028 (Third Site)				○		○	○
ILA055 (Third Site)	○			○		○	

※ ○ The comparison result is in conformity

△ The comparison result is partly in conformity

6. CONCLUSIONS

In this study, strong motion stations of boring log data collected within Lanyang plain are combined with the subsurface layers of Lanyang plain obtained by using geophysical method to construct a comprehensive subsurface structure of Lanyang plain. Appropriate nonlinear dynamic soil characteristics are also determined. Then the stochastic seismic model is used to simulate a set of rock-outcrop synthetic acceleration time histories. Consequently, acceleration time histories at the ground surface are generated for nonlinear site response analysis using the computer program SHAKE 91. Based on the comparison between simulated response spectrum and that of recorded ones, the following conclusions one made:

1. In the selected boring log sites where soil layers are categorized as Type II and Type III in Lanynag plain, most simulated response spectrum agree well with that of recorded ones.
2. Reliable methods generate synthetic ground surface earthquake time history and response spectrum are developed in this study. The results of this study can be used in the guild of civil engineering.

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