Seismic Hazard Assessment of Padang City Using Probabilistic Method

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***Abstract*—This paper presents the seismic hazard assessment which involved spectral hazard for 10% probability of exceedance in 50 years or correspond to return period of approximately 475 years for bedrock of Padang city. The analysis was performed using the total probability theorm with 2D seismic source model. Time history data for this site was generated synthetically by modifying the existing time history data using spectral matching analysis. In this study, design response spectra were developed by applying the methods proposed by 1997 NEHRP. The final result are the spectral accelaration and the synthetic time histories on the bedrock, and the design response spectra on Padang ground surface for 475 years return periods.**

***Index Terms*— Seismic hazard, Total Probability Theorm, Response spectra, Synthetic time histories.**

I. Introduction

Padang, the capital of West Sumatera province, may well represent the classic examples of area with high seismic hazard. The city is located on the Eurasian plate. In the last few years, tremors were felt several times in buildings in Padang due to large earthquakes in Sumatra.

Seismic hazard analysis was conducted in order to predict peak ground acceleration (PGA) and spectral acceleration at bedrock of Padang. The analysis was carried out using probabilistic method and appropriate attenuation relationship. The seismic hazard for PGA was calculated with 10% probabilities of exceedance in 50 years. As part of the effort to assess the seismic hazards of Padang, representative bedrock motion prediction models and design response spectra have to be established.

II. Tectonic setting of Sumatra

Padang is situated close to most seismically active plate boundaries namely; the inter-plate boundary between the Eurasian Plates and Indo-Australian Plates on the south.

Generally tectonic features that affect Padang can be divided into two classifications. The first classification is subduction zone. All of those earthquakes that occurred near convergent boundaries where Indo-Australian plate is being subducted under Eurasian plate are classified into this zone. The second classification is fault zone. All of those earthquakes occurred due to strike slip movement along clearly defined fault in the frontal arc area such as Sumatra Fault are classified as transform fault. The Sumatra fault is about 1900 km long structure that accommodates right lateral strike slip associated with the oblique convergence along the plate margin.

III. Source Models

A. Earthquake Catalog

Estimation of future seismicity is based on the rate of past earthquake as determined from earthquake catalog. In this study, we compile a catalog of instrumentally recorded by combining several sources such as Preliminary Determination of Epicenters (PDE) catalogs of U.S. Geological Survey [12], ISC catalog (various bulletin of the International Seismological) [10] and EHB (Engdahl, van der Hilst and Buland) [5]. From these source catalogs overlap considerably. Since the earthquake data have been reported in different magnitude and intensity scale by source catalogs, all data converted to moment magnitude [9]. The combined catalogue covers an area from 90°E to 112°E longitude and from 8°S to 10°N latitude. The minimum moment magnitude (M_w) is 5.0 and maximum focal depth is 200 km. The catalogue covers the range of events between 1900 and 2007. The location of earthquake epicenter during that period of observation is shown in Figure 1.

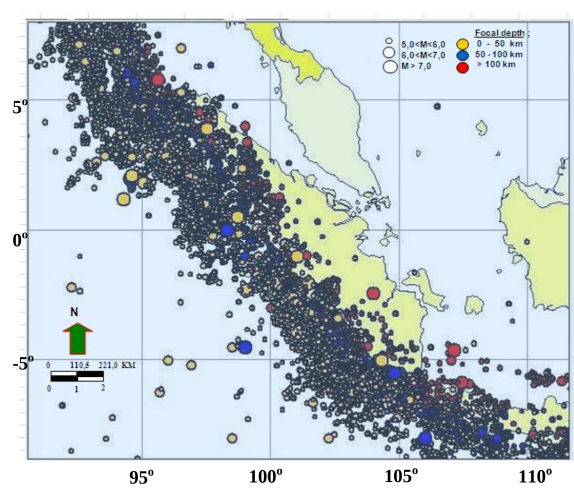

Fig. 1. Epicenter distribution of earthquake events from 1900 to 2007 [5, 10, 12].

According to Gardner and Knopoff [7], catalogs that are used to estimate future seismic activity must free of dependent

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events such as foreshock and aftershock. In this study, we consider the main shock, foreshock and after shock removed from catalog (Figure 2). Gardner and Knopoff indentified duration, D, and dimension, S, of aftershock sequence as function of main shock magnitude, M, from this conditions, we can scan for events within a D(M), S(M) window.

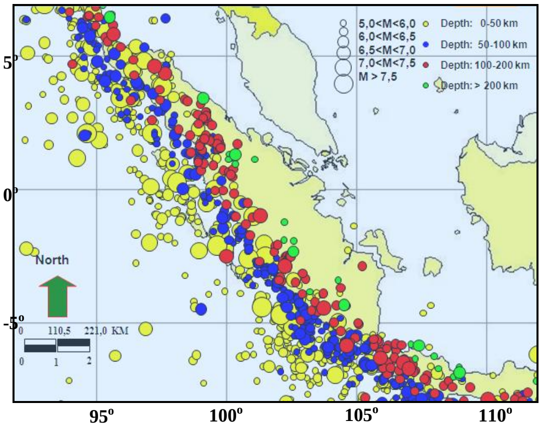


Fig. 2. Epicenter distribution of main earthquake events from 1900 to 2007 [5, 10, 12].

Knowledge of the earthquake history and homogeneity of the earthquake catalogue are factors that play a key role in the evaluation of recurrence interval and evaluation of seismic hazard risk for a particular site. The small events are usually incomplete in earthquake catalogues. This is due to the limited sensitivity and coverage of the earth by seismographic networks. The problem is solved by performing catalogue completeness analysis. In this study, historical earthquake data that occurred between 1900 and 2007 have been analyzed for completeness using Stepp method [14]. Based on the catalogue completeness analysis of the general southeast Asia regions, the earthquakes within interval $5.0 \leq M_w < 7.0$ are completely reported only during the most recent 42-year interval and magnitude more than 7.0 are completely reported over 107-year sample interval (Figure 3).

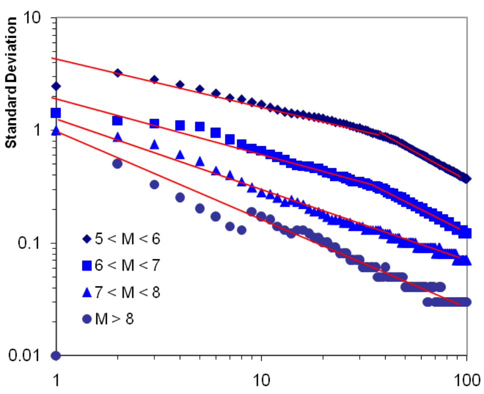


Fig. 3. Completeness time of earthquake.

B. *Seismic Source Zones*

A seismic source zone is defined as a seismically homogenous area, in which every point within the source zone is assumed to have the same probability of being the epicentre of a future earthquake. Source zones are defined on the basis of the distribution and focal mechanisms of the cataloged earthquakes, and on the locations of the earthquakes with respect to the boundaries of major tectonic plates.

The two source zones used in this study are: subduction zones and transform/shallow crustal faults zones. Based on the focal depth and dip angle, subduction zones were divided into interplate (megathrust) zones and intraplate (benioff) zones. Megathrust zone earthquake events occurred at depth less shallow than 50 km and depth of 50-200 km were represented as Benioff zone. The background earthquake was generally assumed to occur throughout the site region and is incorporated into the hazard through the use of an area source zone representing the stable interior of plate.

There are three parameters that are most commonly considered in seismic hazard assessment, i.e., a–b parameter, recurrence rate, and maximum size of future earthquakes for each source. The simplest method to obtain a–b value is the least square method (LS method). The disadvantage of the LS method is that it cannot be used directly to calculate the mean annual rate of exceedance from combining different completeness catalogues. Other researchers such as Dong *et al*. [4] has proposed alternative methods to obtain a–b values and to minimize bias. The method has accounted the relationship between earthquake data and interval time when the catalogues are homogeneous. In this study, a-b parameters are obtained using Gutenberg-Richter equation [8] and Dong *et al*.

The Sumatra interplate subduction zone is a very active feature that has ruptured in 91 independent events with magnitude greater than or equal to M_w 5 within the past 42 years. The largest of these events was M_w 8,6 which occurred on December 9, 2007. Using a range of magnitudes between 5 and 9, the calculated b-value is 0,64 for this distribution.

The Sumatra intraplate subduction zone is a very active feature that has ruptured in 130 independent events with magnitude greater than or equal to M_w 5 within the past 42 years. The largest of these events was M_w 7,0, which occurred on April 1983 near Aceh. Using a range of magnitudes between 5 and 9, the calculated b-value is 1,03 for this distribution.

The transform zone encompasses the area around the Sumatran fault in the highlands and to the north of the fault. Fifty-eight events with magnitude greater than or equal to M_w 5 have occurred during the last 42 years. The largest of these events was M_w 7,2. This zone has not been as productive as the Sumatra subduction zone. A b-value of 0,75 was calculated between M_w 5 and 8 for this zone.

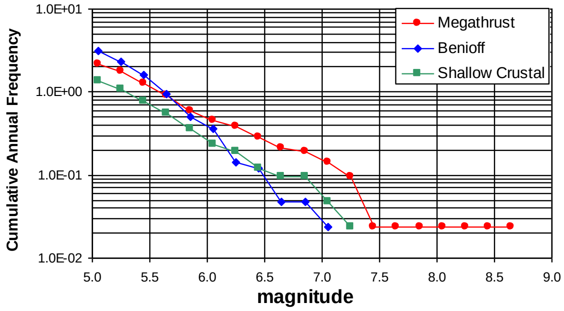


Fig. 4. Frequency of earthquake event.

Three different models were developed to account for seismicity on the Sumatra Subduction zone and the Sumatran fault zone (Figure 7). The first model were represented as megathrust zone that accounts for smaller earthquakes less than M_w 9,0 can occur anywhere along the interface.The average calculated a-value is 3,54. The model is based on rupture zone in west coastal Sumatera (Figure 5). The second model were represented as Benioff zone that accounts for smaller earthquakes less than M_w 9,0 can occur anywhere along the interface.The average calculated a-value is 5,72. The third model were represented as shallow crustal faults zone that accounts for smaller earthquakes less than M_w 7,9 can occur anywhere along the interface. The average calculated a-value is 3,91. The third model is based on the segments of the Sumatran fault system (Figure 6).

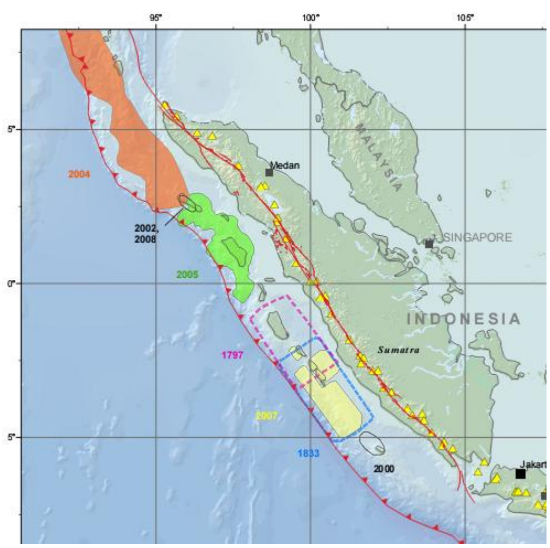


Fig. 5. Rupture zone offshore west coastal Sumatera [2].

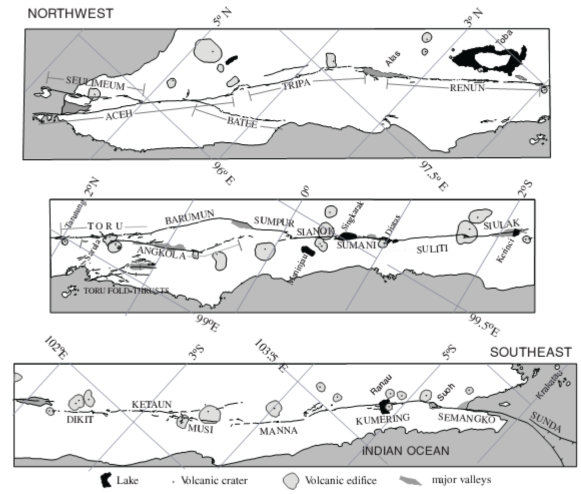


Fig. 6. Segments of the Sumatran fault system [13].

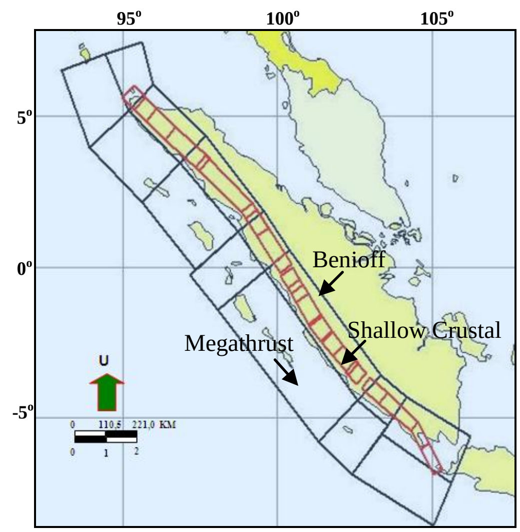


Fig. 7. Seismic source zones for site location.

C. *Attenuation Models*

There have been a number of attenuation functions derived in the last two decades. Most of them were derived in a certain region where peak ground acceleration records had been available. We adapt attenuation function derived in other region, which is similar to Indonesia region tectonically and geologically. It is of importance that the selection was based on earthquake mechanism, which is generally categorized into subduction zone earthquake and shallow crustal earthquake.

In this study, the attenuation relationships for subduction zone at rock sites developed by Young *et al.* [15] and that for shallow crustal developed by Boore *et al.* [1] are selected.

D. *Seismic Hazard Analysis*

The total probability theorem developed by McGuire [11] is based on the probability concept that developed by Cornell [3], which assumed the earthquake magnitude M and the hypocenter distance R as a continuous independent random variable.

The total probability theorem can be represented in the most basic form as follows,

$$P_{(a\geq a^*)} = \int_M \int_R P_{(a\geq a^*;m,r)}\, f_{M(m)}\, f_{R(r)}\, drdm \qquad (1)$$

where :

f_M = density function of magnitude

f_R =density function of hypocenter distance

$P(a \geq a^*; m, r)$ = conditional probability of (random) intensity *a* exceeding value *a** at the site for a given earthquake magnitude m and hypocenter distance r

The annual total probability of earthquakes with intensity *a* equal or greater than *a** at a particular site is determined by totaling the probability of each source. It can be written in mathematical form as follows,

$$\lambda(a \geq a^*) = \sum_{i=1}^{Ns} \nu_i . P(a \geq a^*) \qquad (2)$$

where :

$P(a \geq a^*)$ = the risk of single event with intensity *a* equal or greater than intensity *a** for one seismic source

ν_i. = the annual earthquake occurrence with magnitude M equal or greater than magnitude m for one source zone

Logic tree are used in this study in order to allow uncertainty in selection of models for recurrence model to be considered. The logic tree model is illustrated in Figure 8 and Figure 9, respectively.

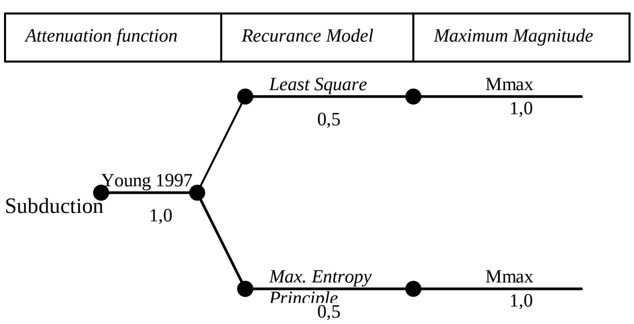


Fig. 8. Logic tree used in this study for Subduction zone.

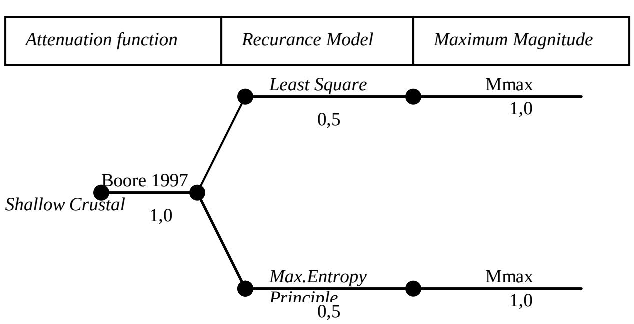


Fig. 9. Logic tree used in this study for Shallow Crustal zone.

Spectral acceleration of difference return period for Padang is shown in Figure 11. Respons spectra hazard at bedrock for PGA, T=0.2 and T=1.0 seconds is shown in Figure 10. From PGA response spectra hazard, the mean spectral acceleration is 0,30g for return period of 475 years. From T=0.2 and T=1.0 seconds response spectra hazard, the mean spectral acceleration are 0,65g and 0,25g for return period of 475 years, respectively.

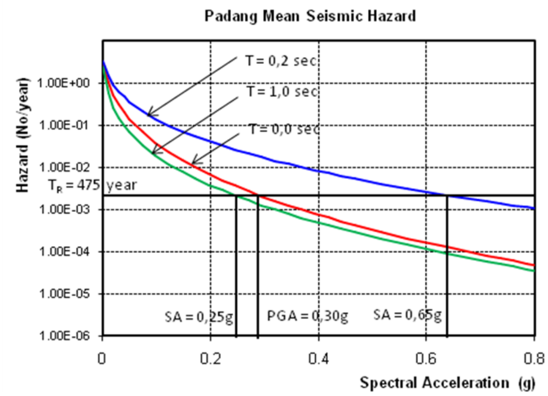


Fig. 10. Probabilistic hazard for T=0.0 seconds, T=0.2 seconds and T=1.0 seconds, 5% damped response spectra.

Uniform hazard spectrum is a spectrum of which each point has the same probability of being exceeded (Figure 12). Deaggregation of the tentative uniform hazard spectra resulting from a probabilistic seismic hazard assessment (PSHA) is used to determine which sources that contribute most to the hazard at site by identifying the mean magnitude and distance of earthquakes that control the ground motions at these response spectral frequencies. This information will be used to generate scaled response spectra at bedrock of Padang.

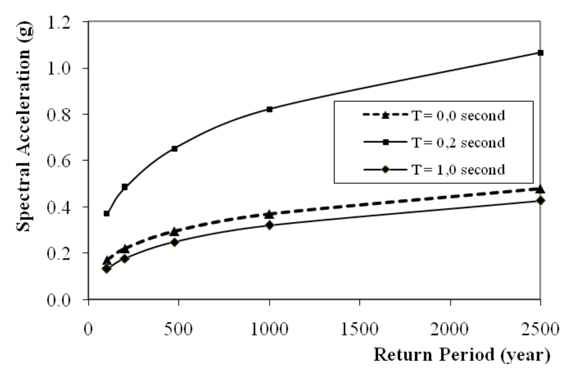


Fig. 11. Seismic hazard exposure for various return period.

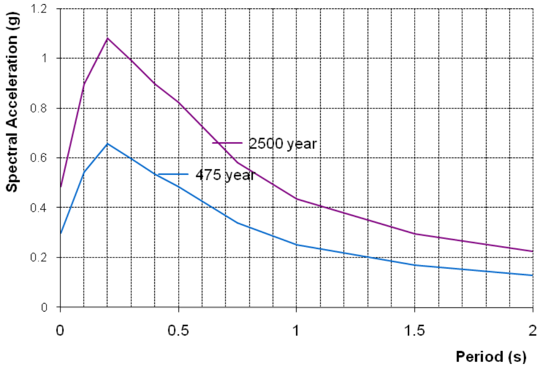


Fig. 12. Uniform hazard spectra at bedrock of Padang.

Since the hazard is computed independently for each spectral period, in general, a uniform hazard spectrum does not represent the spectrum of any single earthquake. It is common to find that the short period (T<0.2 second) ground motions are controlled by nearby moderate magnitude earthquakes, whereas, the long period (T>1 second) ground motions are controlled by distant large magnitude earthquakes. Hence, the seismic hazard curves for T=0.2 and T=1.0 seconds were deaggregated to determine the controlling magnitudes and distances. The deaggregation hazard for 475 years return period are shown in Figure 13 and 14, respectively. The results of deaggregation hazard are summarized in Table 1.

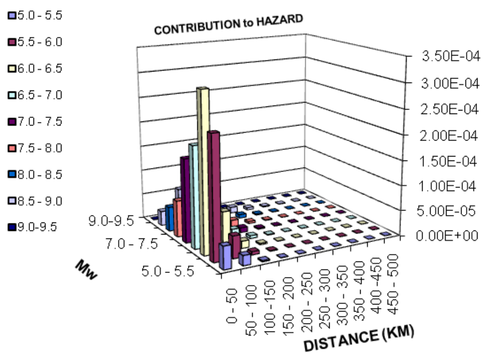


Fig. 13. Deaggregation hazard for T=0.2 seconds and 475 year return period from all sources.

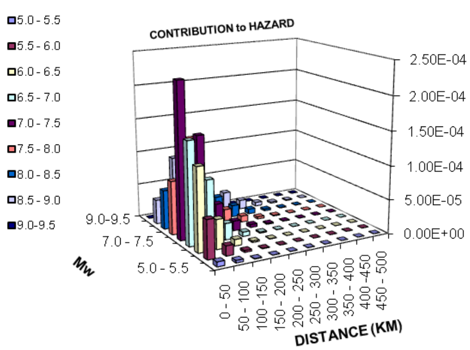


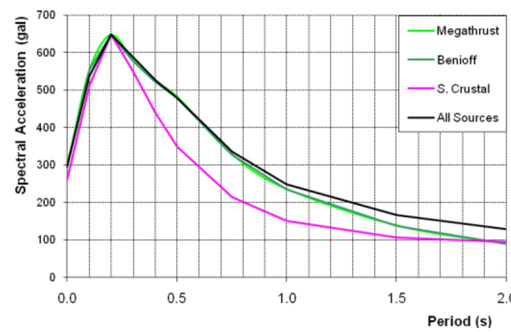
Fig. 14. Deaggregation hazard for T=1.0 seconds and 475 year return period from all sources.

TABLE I

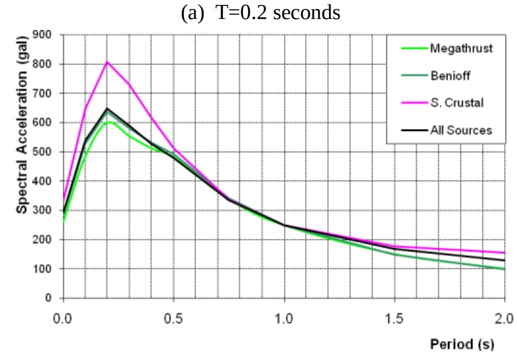
SUMMARY OF CONTROLLING EARTHQUAKE FROM DEAGGREGATION RESULT FOR 475 YEAR RETURN PERIOD

Seismic Sources	(T = 0,2 seconds)		(T = 1,0 seconds)	
	R (km)	M_w	R (km)	M_w
Megathrust	78	7.3	100	7.9
Benioff	148	7.2	158	7.5
Shallow crustal	31	6.3	35	6.8

The information from the analysis may instead be used to assist in the development of ground motion time histories. To do this, the ground motion amplitudes (and possibly frequency content) is scaled such that the spectrum of the scaled ground motion closely matches the uniform hazard spectrum. Figure 15 shows the response spectra for these events scaled to the T=0.2 and T=1.0 seconds, respectively.



(a) T=0.2 seconds



(b) T=1.0 seconds

Fig. 15. Spectra for dominant events for the 475 year return period of hazard.

Acceleration time histories are required in the analysis of shear wave propagation in soil deposits. Selection of time histories appropriates for specific geological and seismological conditions play an important role for obtaining accurate results. In this study, the selection and generation of time histories are based on their similarity of their characteristic with the most likely and mean contribution magnitude-distance combinations to give the seismic hazard level 475 year return periods. Two sets of time histories were recommended to simulate the rock motion at site location. The time histories data represent subduction event was obtained from 1999 Duzce earthquake (Figure 16). The time histories data represent shallow crustal event was obtained from 1980 Livermore earthquake (Figure 19). These record were downloaded from Pacific Earthquake Engineering Research (PEER) Strong Motion Database Record (*http://peer.berkeley.edu/smcat/search.html*).

Synthetic time histories were generated based on estimated target spectrum at bedrock. The results of the synthetic time histories can be seen in Figures 17, 18 and 20, respectively.

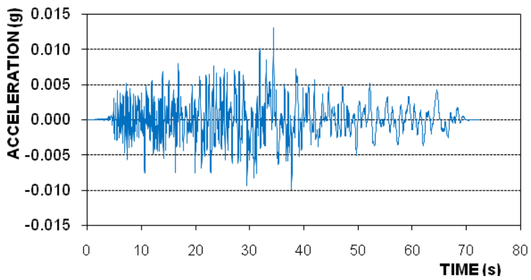


Fig. 16. Bedrock time histories of Duzce Earthquake 1999.

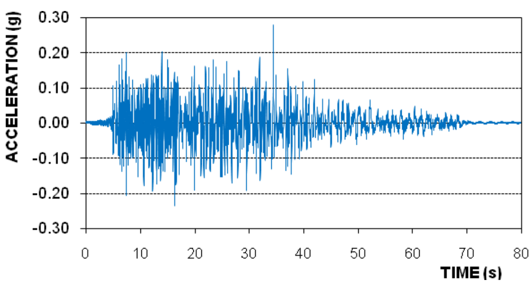


Fig. 17. Synthetic bedrock time histories represent megathrust event for 475 year return period of hazard.

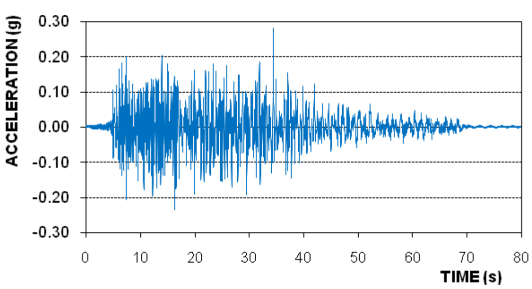


Fig. 18. Synthetic bedrock time histories represent benioff event for 475 year return period of hazard.

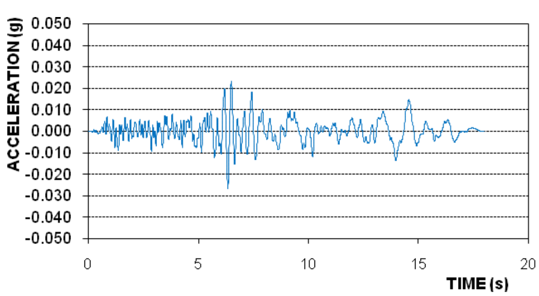


Fig. 19. Bedrock time histories of Livermore Earthquake 1980.

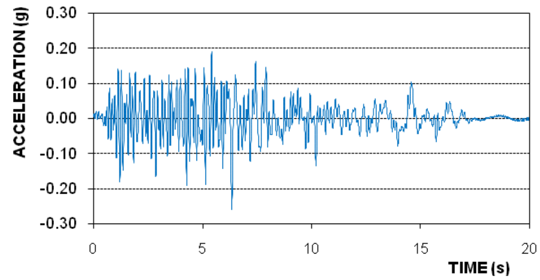


Fig. 20. Synthetic bedrock time histories represent shallow crustal event for 475 year return period of hazard.

IV. Design Response Spectra

The influence of soil conditions on the ground motion can be translated into the modification of response spectra shapes by using spectral amplification factors. Since the amplification factors are very sensitive to the reference site conditions, the application of amplification factor must appropriately consider the site conditions corresponding to the reference motion. Therefore, in most building codes or provisions, the influence of local soil conditions is considered by using spectral amplification factors for different soil classes.

In this research, design response spectra were developed by applying the methods proposed by 1997 NEHRP [6]. Based on Vs−30 or N_{SPT}−30 or Su−30, the soil data can be classified as soil class S_C (very dense soil), S_D (stiff soil) or S_E (soft soil) (Figure 21).

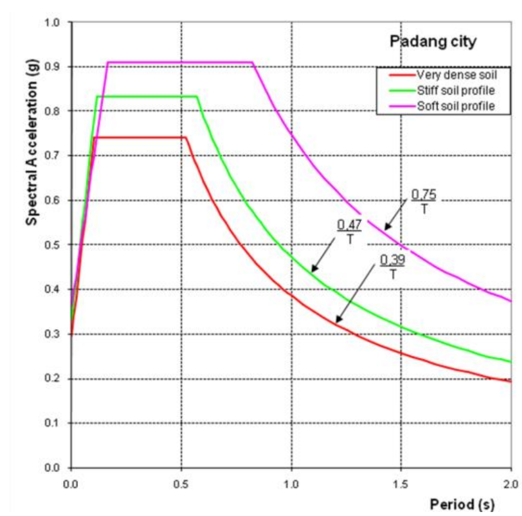


Fig. 21. Surface spectral response for Padang, 5% damping, 475 years return period.

V. Summary and Conclusion

Seismic hazard analysis was conducted in order to predict peak ground acceleration (PGA) and spectral acceleration at bedrock of Padang. Analysis was carried out using probabilistic method for hazard levels of 10% probability of exceedance in 50 years. Based on the analysis, the PGA is 0,30g for return period of 475 years.

As part of the effort to assess the seismic hazards of Padang, representative bedrock motion prediction models were generated. Also, design response spectra developed based on 1997 NEHRP have to be established.

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