RESEARCH ON EARTHQUAKES INDUCES LIQUEFACTION IN PADANG CITY

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ABSTRACT: Awareness and research on earthquake building resistant design was intensively carried out after fatal earthquakes in Indonesia in recent decades. However, less attention has been addressed on the phenomena of liquefaction since lack of ground motion information and record at the hazards area. In this paper, seismic ground response after two deadly earthquakes shocked Sumatera (Indonesia) in 2009 was evaluated based on the CPT datasets. Based upon back-calculation results, the possible ground accelerations were expected to be about 0.14g in the liquefied areas at Padang (West Sumatera). Those accelerations are likely to make 50% of sand layer liquefied and induced about 1% ground settlement.

Keywords: liquefaction, steady state line, state parameter

1 INTRODUCTION

In recent decade, notable earthquakes that greater than Mw 6 occur frequently in Indonesia. Several earthquakes caused fatalities, such as Mw 9.1 earthquake on 26 December 2004 in Aceh, Mw 6.4 earthquake on 26 May 2006 in Yogyakarta, Mw 7.7 earthquake on 17 July 2006 in West Java, Mw 8.5 earthquake on 12 September 2007 in Bengkulu, Mw 7 earthquake on 2 September 2009 in West Java and Mw 7.5 earthquake on 30 September 2009 in West Sumatera, and lastly Mw 6.5 earthquake in Aceh at early July 2013. Some earthquakes followed by large tsunamis, claimed lives of hundreds of thousands people and damaging half a million structures in total.

Awareness and research on earthquake building resistant design was intensively carried out after those earthquakes. Irsyam et al. (2008) initiated research on the development of spectral hazard maps for Sumatra and Java islands to propose a revision of the seismic hazard map in Indonesian Seismic Code SNI 03-1726-2002 (Figure 1). Some improvements in seismic hazard have been implemented in the analysis by considering the recent seismic activities around Java and Sumatra. But, less attention has been addressed on the phenomena of liquefaction. Figure 2 illustrated liquefaction phenomena after earthquake. Liquefaction potential evaluation in Padang has been early studied by Putra et al. (2009) and Tohari et al. (2011). Those researches focused on the estimation of liquefaction and liquefaction induces ground. The records on ground surface acceleration in the hazard areas during earthquakes event was limited or unavailable, hence liquefaction analysis based upon force equilibrium concept cannot be directly performed in this study. Therefore, this paper is aiming to investigate the critical peak ground acceleration that triggering the liquefaction by back-calculation from CPT data.

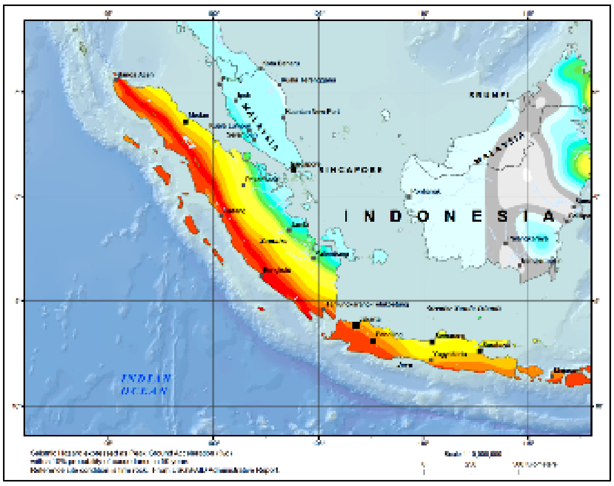

Figure 1 Seismic hazards of Java and Sumatera

Figure 2 Silty sand liquefaction at Padang airport during 2009 West Sumatera earthquake

2 ESTIMATION OF SEISMIC GROUND RESPONSE

A fatal earthquakes event, M_w 7.6 of Padang on 30 September 2009, was investigated in this paper. The ground acceleration was estimated from the CPT data collected from hazards area at Agus Salim sport complex and Lapai area in Padang (Figure 3). The calculated accelerations is then assigned as critical peak ground acceleration ($a_{max(cr)}$) to cause liquefaction at depth.

The procedure of analysis was based on the liquefaction estimation as proposed by Robertson and Wride (1998). The total of 27 CPT datasets was collected of Padang sites. The sample of the CPT profiles at Agus Salim sport complex and Lapai sites is shown in Figure 4a and 4b respectively. Grain size distribution test of the investigated area, which was collected from depth 4 to 8 m, showed the sand deposit was easily liquefiable as shown in Figure 5. Most of the CPT datasets were collected from the liquefied area.

The factor of safely against liquefaction is defined as:

$$FS_L = MSF\left(\frac{CRR_{7.5}}{CSR}\right) \quad (1)$$

where CSR is the cyclic stress ratio, CRR is the cyclic resistance ratio of the ground, and MSF is the Magnitude Scaling Factor to convert the CRR7.5 for M = 7.5 to the equivalent CRR for the design earthquake. The recommended MSF is given by Equation (2) based on the NCEER Workshop in 1996 (Youd et al. 2001).

$$MSF = \frac{174}{M_w^{2.56}} \quad (2)$$

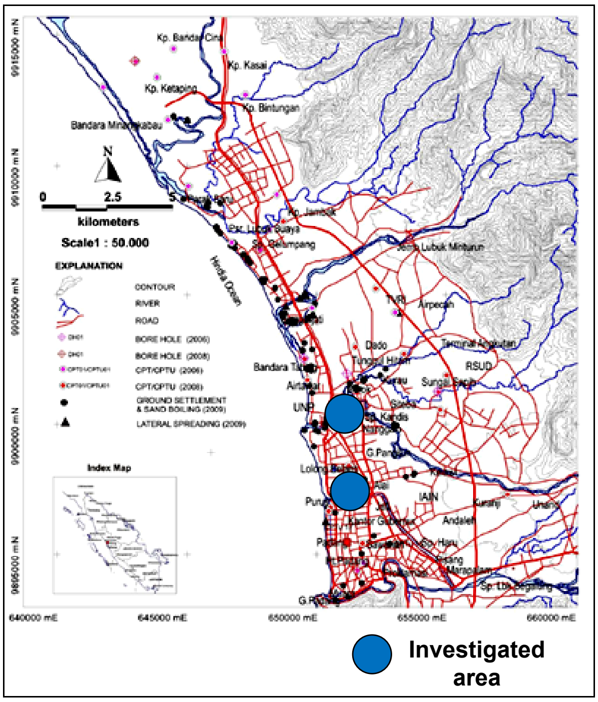

Figure 3 Location of the investigated area.

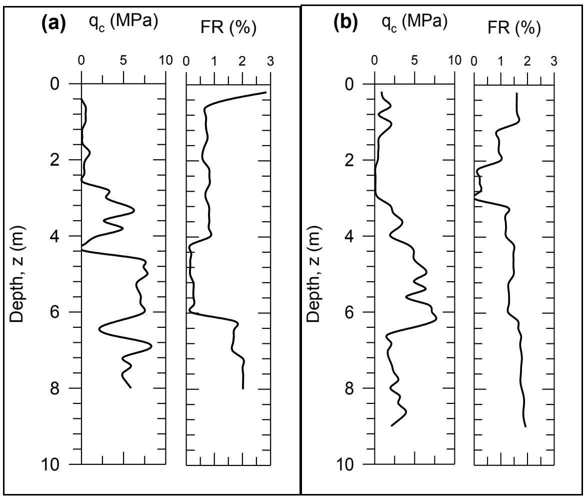

Figure 4 Typical of CPT data (a) at Agus Salim sport complex, (b) at Lapai area.

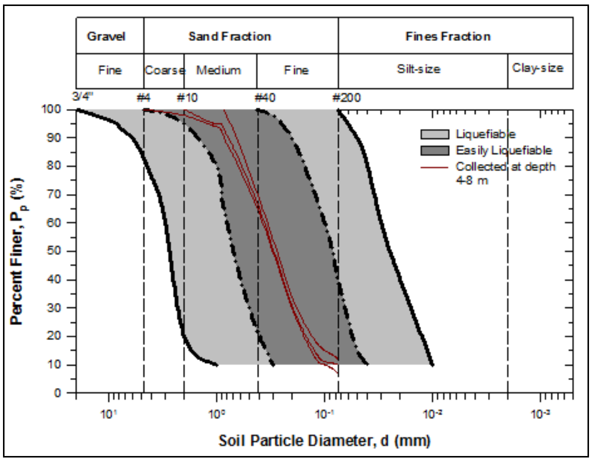

Figure 5 Grain size distribution of boiled sands at various locations in the earthquake affected region

Then, acceleration was simultaneously by assuming liquefaction occurs at the observed soil depth which FS_L is lesser than 1. The variation of ground accelerations ($a_{max(cr)}$) with the depth is shown in Figure 6.

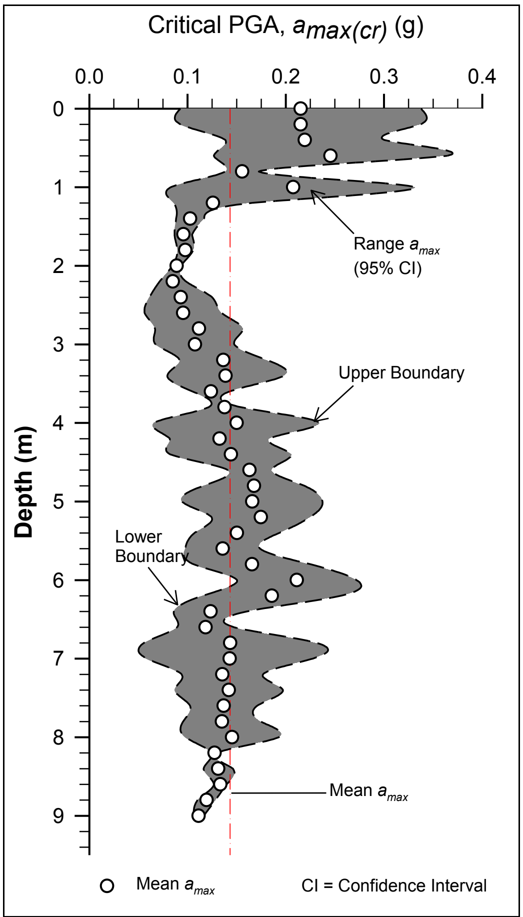

Figure 6 The estimated critical ground acceleration

3 LIQUEFACTION INDUCED GROUND SETTLEMENT

Liquefaction potential at Padang sites has been earlier investigated by Tohari et al. (2011) respectively. Tohari et al. (2011) applied the Mw 7.6 earthquake and a_{max} of 0.4g for liquefaction evaluation and indicated that liquefaction occurred in all sand and silt soil layers at Padang city area. However, it has been noted in the previous section that the acceleration records varies with local soils conditions. Therefore, the evaluation of liquefaction potential for those investigated area is local and site specific. Hence, it is important to look into the effect of varying acceleration on the liquefaction potential and ground settlement. Estimation of liquefaction induced ground settlements was calculated by the procedure proposed by Zhang et al. (2002). The effect of variation of acceleration on the liquefaction potential and ground settlement is presented in Figure 7 for selected sites in Padang.

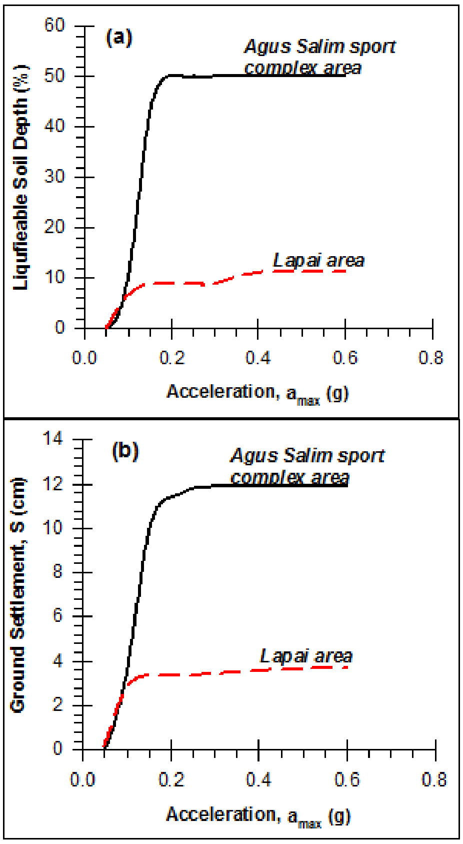

Figure 7 Variation of ground acceleration and (a) percent of liquefiable soil layers, (b) estimated ground settlement.

4 DISCUSSION

4.1 *Critical peak ground acceleration*

The critical accelerations at observed sites in Padang is between 0.07g to 0.38g. The largest a_{max} 0.38g is located near ground surface. The values of mean and mode of all critical accelerations are 0.14g and 0.12g respectively. It is observed that soft soil was deposited at the hazard area of Padang. It implies that an earthquake with a small acceleration will make the soil layer liquefied easily. The mean value of acceleration at Padang sites is smaller than the PGA recorded at nearest hazard area. There was only one strong ground motion record for the M_w7.6 earthquake of Padang region on 30 September 2009 (EERI 2009), which shows about 20 seconds of strong shaking with a peak ground acceleration of 0.3g (Figure 8). Since the instrument site was located at the base of the hill sides, about 12 km in from the coast and on stiff soil, the ground motions in the center of Padang, on softer deeper soil deposits, are likely to have been larger. Superimposed with the measured spectral accelerations are design earthquake spectra, described later. Median PGA values from attenuation models for subduction earthquakes for M_w 7.6 yield PGA of 0.4g to 0.6g for soil sites (Young et al., 1997; Zhao et al., 2006; Atkinson et al., 2003), which are consistent with the strong motion record.

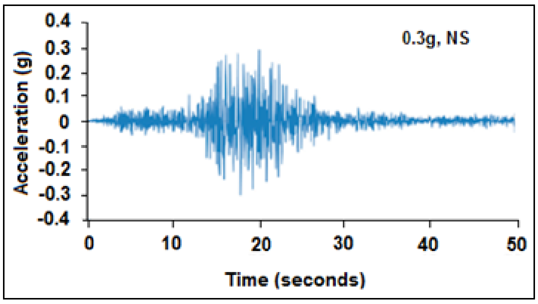

Figure 8 Acceleration record (NS component) of M_w 7.6 earthquake on 20 September 2009 in Padang.

4.2 *Effect of peak ground acceleration on the liquefiable layer and ground settlement*

The estimated acceleration is likely affected by local site conditions. The recorded acceleration from instruments maybe affected by near-surface conditions of importance include the thickness of soil layers, the small-strain stiffness and material damping of soil layers, the variation of stiffness and material damping with shear strain amplitude, and the site topography (Seed et al. 1986, Youd and Carter 2005, Loye et al. 2013). The acceleration profile shown in Figure 5 indicates that the soil stiffness and damping varies nonlinearly with the depth. This nonlinearity may be contributed by fines fraction such as silt or clay in the sands deposit (Beresnev and Wen 1996).

Figure 7a presents the liquefaction potential which represented with percent liquefiable soil depth for selected sites. The relationship is clearly shown that the percent of liquefiable layers will vary with the local sites. The results show that generally the percent of liquefiable layers increases with the increases in acceleration at the selected sites. The Padang sites were highly susceptible to liquefaction since the area experience to liquefy at small acceleration. In general, there was no liquefaction if the acceleration is smaller than 0.05g. Typically for Padang sites, percent of liquefiable depth increases drastically at acceleration of 0.15g, and then there is no additional liquefaction at the rest depth if the acceleration exceeds 0.15g. It indicates that an acceleration of 0.15g is the critical acceleration to make liquefaction at Padang city.

Figure 7b presents the variations of ground settlement with the increasing acceleration. It seems to have similar characteristic with Figure 7a. Hence a correlation of the percent of liquefiable layers and relative ground settlement can be presented in Figure 9. According to Idriss and Boulanger (2008), the behavior of silty sand with higher fines content is largely governed by the matrix of fines, with the sand particles essentially floating with the matrix. Use of the correction for fines content may be applicable to evaluate post-liquefaction reconsolidation settlement. While Wang and Wang (2010) noted that beyond the critical value of fines content of 30% the liquefaction resistance increases with increasing fines content.

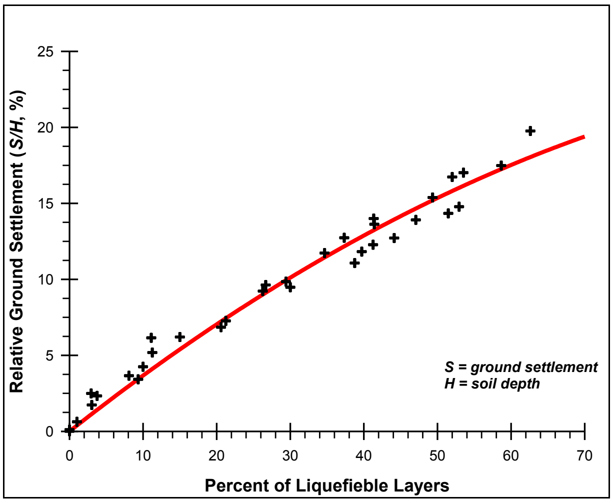

Figure 9 Relationship between ralative ground settlement and percent of liquefiable layers

5 CONCLUSION

Seismic ground response in Padang area has been estimated using CPT profiles. Generaly, seismic response analysis was typically performed using a rigorous dynamic model based on suite of rock acceleration-time histories prescribed at the base of a soil column and propagated to the ground surface. The estimated acceleration was likely affected by local site conditions. For the investigated area, the mean value of ground accelerations was 0.14g for Padang city. This ground acceleration was acceptable with the available estimates from instruments. The back-calculated acceleration from CPT dataset can be a practical method to estimate ground acceleration profiles in the absence of more reliable data.

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