[TH-05]IN-DIRECT ESTIMATION OF LOCAL SOIL RESPONSE IN THE LIGHT OF PAST AS WELL AS RECENT EARTHQUAKES IN THE SHILLONG PLATEAU

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ABSTRACT: The northeastern region of India is a seismically active zone. The Shillong Plateau (SP) located in the south-western portion of northeast India surrounded by an intense network of active tectonic faults. The 1897 Assam earthquake (EQ) (M_W 8.1) and other major EQs ($M_W \geq 7.0$) had originated in the faults surrounding the SP, thus highlighting the SP as a zone of high seismicity. During these past major to great EQs, widespread damages in the form of destruction to buildings, excessive ground shaking, uneven settlements, occurrence of ground fissures and sand vents were reported across the SP and its adjoining regions. Such large scale catastrophes during an EQ are the combined effect of the ground motions generated during an EQ and its modification by the subsoil at a site. Presence of local soil influences the frequency content, duration and amplitude of the ground motions generated during an EQ. To understand the ground motion amplification potential at a site due to local soil, recorded ground motions, dynamic soil properties, in-situ subsoil characteristics etc. are required to be known at the site of interest. For majority of location however, regional dynamic soil properties and in-situ subsoil properties are not readily available. In the absence of regional dynamic soil properties, site response studies considering available dynamic soil properties from other regions are followed worldwide.

In the present study, response of local soil in the SP is assessed considering the observed ground motion scenario during different EQs at selected sites. Ground motion amplification during each EQ is determined considering the Peak Horizontal Acceleration (PHA) at the bed rock level and the Peak Ground Acceleration (PGA) at the ground surface level. The PHA during each EQ is estimated using regional Ground Motion Prediction Equations (GMPEs). The PGA on the other hand is derived based on felt intensities during various EQ at considered sites from isoseismal maps. Thus, the response of in-situ soil over a wide range of ground motions is assessed based on actual scenario developed at the surface. This work will be helpful to understand the response of soil during probable future EQs in the absence of regional dynamic soil properties for the SP.

Keywords: Shillong Plateau, local soil effects, isoseismal maps, amplification factor

1. Introduction:

The northeastern region of the Indian subcontinent consists of a number of tectonic faults. The intraplate tectonic movements along these faults have led to the origin of several EQs in the past (Baro and Kumar, 2015). Along with the occurrences of these EQs, the fault movements had also led to the formation of the Shillong Plateau (SP) within the region (Baro and Kumar, 2015). The SP is thus surrounded by active faults which have evidenced numerous EQs in the past. The 1897 Assam EQ (M_W-8.1) is one of the great EQs of India which had originated on a fault lying towards the northern boundary of the SP. The tectonic activity of the faults surrounding the SP makes it essential to understand the seismic hazard potential of the plateau (Baro and Kumar, 2016).

Seismic hazard analysis of a region involves the estimation of level of ground shaking that could occur at a site due to the presence of seismic sources surrounding the site. The level of ground shaking at a site is expressed in terms of ground motion parameters such as Peak Ground Acceleration (PGA) or Peak Horizontal Acceleration (PHA). To arrive at a particular ground motion parameter, Ground Motion Prediction Equations (GMPEs) are used. GMPEs express above ground motion parameters as functions of magnitude, epicentral or hypocentral distances, fault type, site class etc. Further, GMPEs are developed by performing regression analysis of the recorded ground motions within a region and hence are best suited for that region. Instrumental recording of EQs is a recent phenomenon, especially in India which began only after 1986. In case of non-availability of recorded ground motion data, multiple GMPEs developed for other regions with similar tectonic characteristics are selected to estimate the ground motion parameter for a particular region. Nath and Thingbaijam (2011) emphasized that even though several GMPEs have been developed for India, however while performing seismic hazard analysis for Indian regions during past studies, due consideration was not given to the selection of GMPEs matching the tectonics of the region. Further, Nath and Thingbaijam (2011) based on the log-likelihood (LLH) method of Scherbaum et al. (2009) considered multiple GMPEs and ranked these GMPEs according to their suitability for the Himalayan, northeastern and peninsular regions of India. For the northeastern region which is an intraplate region, Nath and Thingbaijam (2011) selected eight GMPEs which were developed for various intraplate regions of the world. Among eight GMPEs selected by Nath and Thingbaijam (2011), the top three are used in this study to estimate the PHA at bedrock level for the SP. These include GMPEs given by Hwang and Huo (1997), Raghukanth and Iyengar (2007) and Nath et al. (2009). In addition, the GMPEs given by NDMA (2010) and Anbazhagan et al. (2013) are also employed to estimate the PHA for the SP. The GMPE proposed by NDMA (2010) was developed for the entire country with separate set of coefficients for seven different regions within the country including northeast India. Anbazhagan et al. (2013) developed a GMPE for the Himalayan region considering both recorded and synthetically generated ground motion data. The synthetic EQ data was developed for past EQs with no ground motion records, which also included the 1897 Assam EQ originating on the northern edge of the SP. The GMPEs proposed by NDMA (2010) and Anbazhagan et al. (2013) are capable of estimating the PHA for EQs of $M_W \geq 8.0$.

Present work also tests the suitability of the GMPEs proposed by NDMA (2010) and Anbazhagan et al. (2013) for the SP by comparing with the three highly ranked GMPEs for northeast India as per Nath and Thingbaijam (2011).

2. Analysis:

The five GMPEs mentioned above are used to estimate the PHA values at selected sites within the SP at the bedrock level. The PHA values thus estimated could be used for hazard estimation of the SP in the future. However, such seismic hazard analysis performed without taking into consideration the effects of the local soil is of limited use. The local soil has the characteristics to modify the EQ ground motion as it travels from the bedrock to the ground surface. Hence it is essential to consider the local soil effects when estimating the hazard potential of a region. In this study the effect of local soil is taken into consideration by estimating the ground motion parameter PGA at the surface level for the SP. Thus the PGA values of some of the past major EQs originating in the faults around the SP are estimated in this study.

To estimate the PGA values, a correlation is developed between MMI and PGA in the absence of any correlation existing at present for the SP. Proposed correlation is developed taking into account MMI and PGA values obtained during the 2016 Myanmar EQ (M_W-6.9) and the 2016 Imphal EQ (M_W-6.7) as per United States Geological Survey (USGS) (https://www.usgs.gov/). Even though these two EQs had not occurred on the faults surrounding the SP, the shaking due to the EQs was felt within the plateau. Further, there are no recent major EQs in the vicinity of the SP to develop such correlation. Using the MMI and PGA values reported during the above mentioned EQs a MMI versus PGA plot is developed as shown in Figure 1. Figure 1 also shows the correlation developed between MMI and PGA for the SP.

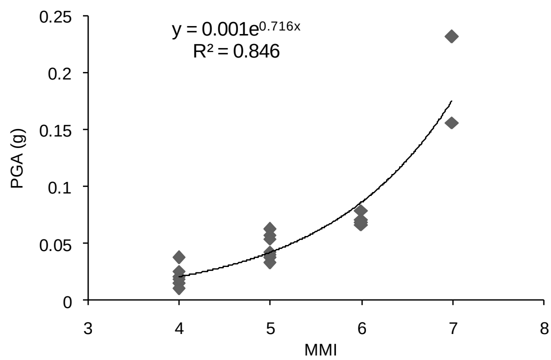

Fig.1 Correlation between MMI and PGA for the SP

The developed correlation shown in Figure 1 is used to estimate PGA values during 1885 Bengal EQ (M_L-7.0), 1869 Cachar EQ (M_W-7.5), 1918 Srimangal EQ (M_S-7.6), and 1930 Dhubri EQ (M_S-7.1) based on reported MMI values. It has to be highlighted here that above mentioned four EQs had originated on faults lying at a close vicinity of the SP and had caused damages in the SP. The MMI felt within the SP during the above mentioned past EQs are collected from isoseismal maps. The isoseismal maps were developed by the Geological Survey of India. The Geological Survey of India developed the isoseismal maps for each of these EQs in different intensity scales. Sabri (2002) re-evaluated the intensities for each of the EQs and redrew the isoseismal maps using the European Macroseismic Scale (EMS). In this study the isoseismal maps developed by Sabri (2002) are used and the EMS scale is converted to MMI scale as per Musson et al. (2010). It was observed from the isoseismal maps that during the various past EQs different sites across the SP experienced different shaking intensities. MMI of VI and V were felt across Shillong city during the 1869 Cachar EQ and 1918 Srimanagal EQ respectively. Similarly during the same

1918 Srimanagal EQ, MMI of VI was felt in Cherrapunji. Further, MMI of V and VI during the 1885 Bengal EQ and the 1930 Dhubri EQ respectively were reported in Cherrapunji. At Tura as well, MMI of V was reported during the 1885 Bengal EQ. It can be observed from Figure 1 that the proposed correlation is valid only till a MMI value of 7. For this reason, the PGA value for the 1897 Assam EQ is not estimated using the proposed correlation since a MMI of X was reported due to this EQ within the SP. Thus employing various MMI values from the isoseismal maps into the proposed correlation, PGA values at the surface level across the SP are estimated.

It has been mentioned earlier that five GMPEs proposed by Hwang and Huo (1997), Raghukanth and Iyengar (2007), Nath et al. (2009), NDMA (2010) and Anbazhagan et al. (2013) are selected in this study to estimate the PHA values at the bedrock level. Using these five GMPEs, PHA values within the SP are estimated as listed in Table 1. It has to be highlighted that soil response which is examined earlier from MMI values is a function of PHA as highlighted by Kumar et al. (2015). In addition, from Table 1 it can be observed that a wide range of PHA from 0.02g to 0.19g has been considered in the present work representing a wide range of ground motion scenario. Taking into account PHA estimated using each of the five selected GMPEs and above estimated PGA, amplification factor (AF) which is the ratio of the PGA to PHA are estimated. Table 1 lists PHA and AF values estimated at various sites within the SP during different EQs.

Kumar et al. (2016b) highlighted that overall soil response can be understood by analyzing collectively the response of soil during different bedrock scenario known as dynamic soil response curve (DSRC). In order to generate an overall understanding about the soil response, DSRC from this work is shown in Figure 2.

Table 1 PHA and AF values estimated for the past EQs in the SP

Site		Shillong city	Shillong city	Tura	Cherrapunji	Cherrapunji	Cherrapunji
EQ / GMPEs		1869 Cachar	1918 Srimangal	1885 Bengal	1885 Bengal	1918 Srimangal	1930 Dhubri
Hwang and Huo (1997)	PHA	0.14	0.13	0.07	0.04	0.20	0.06
	AF	0.51	0.28	0.54	1.00	0.37	1.26
Raghukanth and Iyeger (2007)	PHA	0.12	0.10	0.02	0.01	0.16	0.02
	AF	0.59	0.37	1.93	4.31	0.45	3.80
Nath et al. (2009)	PHA	0.19	0.17	0.11	0.06	0.12	0.10
	AF	0.38	0.21	0.34	0.56	0.64	0.72
NDMA (2010)	PHA	0.02	0.11	0.05	0.03	0.14	0.05
	AF	3.86	0.34	0.66	1.04	0.52	1.34
Anbazhagan et al. (2013)	PHA	0.07	0.06	0.03	0.02	0.09	0.03
	AF	1.08	0.56	1.30	2.11	0.78	2.61

It can be observed from Figure 2 that for higher PHA values lower values of AF is obtained. This is in accordance to the findings of EPRI (1993), Romero and Rix (2005) and Kumar et al. (2016a, b) where it was found that higher values of PHA give lower values of AF. EPRI (1993) and Kumar et al. (2016a) reported that for PHA higher than 0.5g deamplification of AF occurs. From Figure 2 it can be observed that in this study the deamplification of AF has started to occur at 0.05g. It has to be highlighted here that most of the sites across the SP are of site classes of A (firm or hard rocks) or B (soft to firm rocks) as per Mittal et al. (2012). The sites Shillong, Tura and Cherrapunji chosen in this study are of site classes A, B and A respectively. Since the sites are mostly rocks the ground motion amplification is very less within the SP. Hence in Figure 2 as the PHA value begins to increase the AF starts to decrease.

Another observation which can be made from Figure 2 is that the GMPEs proposed by NDMA (2010) and Anbazhagan et al. (2013) are closely matching with the other three highly ranked GMPEs.

Nath and Thingbaijam (2011) did not considered GMPEs proposed by NDMA (2010) and

Anbazhagan et al. (2013) for northeast India. However, collectively based on PHA observed from Table 1 as well as DSRC from Figure 2 it can be concluded that the GMPEs proposed by NDMA (2010) and Anbazhagan et al. (2013) are also equally suitable for northeast India both in arriving at seismic hazard values as well as to understand soil response. Similar validation for PHA>0.2g has not been attempted here and can be attempted during future works.

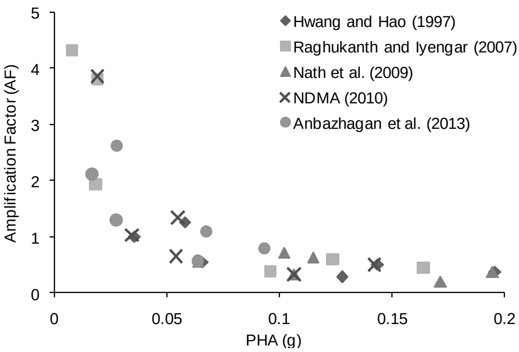

Fig. 2 PHA versus AF obtained from present work

3. Conclusion:

The SP has experienced several damaging EQs in the past. To reduce the risk of damages from similar EQs in the future it is essential to understand the level of ground shaking which occurred within the SP during the past EQs. Hence, in this study an attempt is made to estimate the PHA values at the bedrock level with the help of GMPEs as well as the PGA at the ground surface from isoseimal maps of past EQs. A total of five GMPEs are used to estimate the PHA values. Three of the GMPEs are found to be suitable for northeast India by previous works. Suitability of the remaining two GMPEs for the SP however is tested in this study. Further in-situ soil response is studied over a wide range of PHA which is in accordance with existing literature.

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