ESTIMATION OF SURFACE PGA AND DETERMINATION OF TARGET VALUES FOR NO LIQUEFACTION AT GUWAHATI CITY

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ABSTRACT

Active regions in the North-east India evidence moderate size earthquakes (EQ) very frequently. A complex tectonic setting exists in the Shillong plateau as a combination of Naga Thrust in the south east, the Himalayan Subduction zone in the north and the Burmese arc in the east. As a result, many damaging earthquakes had occurred in the past. These include 1869 Cachar EQ (M-7.8), 1897 Shillong EQ (M-8.7), 1918 Srimangal EQ (M-7.6), 1931 Assam EQ (M-7.6) and 1950 North Assam EQ (M-8.7). Damage reports during 1869 Cachar earthquake, 1819 Srimangal earthquake and 1950 Assam earthquake had clearly stated large scaled destruction of almost all the buildings and life loss in Guwahati city. Also widespread ground fissures and liquefaction were also reported during these events. In the present work, an attempt has been made to locate typical sites for detailed site specific geotechnical and geophysical studies by comparing the past reported damages and other analytical works done for the study area. Also, sites selected are also validated using empirical correlations and methodology proposed by the corresponding author of this paper.

Keywords: *North-East India, ground fissures, liquefaction, geotechnical and geophysical work.*

INTRODUCTION

North-East seismicity of India is a combined effect of Indian-Eurasian Plate boundary in the north and the Burmese arc in the east. The region has been considered among the top six most seismically active regions of the world. Other similar seismicity regions include San Andreas in United States, Guerrero region in Mexico and regions of Japan, Taiwan and Turkey. As per the report by United Nations published under International Decade for Natural Disaster Reduction (INDNDR) for the year 1991-2001, more than 18 earthquakes (EQ) of magnitude greater than 7 have occurred in the north east India in the last century [1]. Some of these reported earthquakes include 1869 Cachar EQ (M-7.8), 1897 Shillong EQ (M-8.7), 1918 Srimangal EQ (M-7.6), 1931 Assam EQ (M-7.6) and 1950 North Assam EQ (M-8.7). Since no seismographs were available for any of these earthquakes, no recorded ground motions are available. However, felt intensities in terms of building damages and other observations are available which gives an indirect view about the kind of devastation felt during each of these events. Oldham earthquake catalogue has always been a significant source of past earthquake data.

SEISMICITY OF NORTH-EAST INDIA

The active seismicity of the North-East India is due to the subduction zone in the north which is called the Himalayan arc and in the east which is called as the Burmese arc. The point of intersection of these two tectonic setting is the Syntaxis zone. Based on the discontinuities from the Himalayan arc and the Burmese arc, two kinds of thrust exist in this Syntaxis zone. These are Mishmi thrust/ discontinuity and the Lohit thrust/ discontinuity. Subduction of Indian Plate under the Eurasian plate in the north has contributed to the building up of strains at various segments of this plate boundary and so in the north of the Syntaxis zone. Similarly in the Burmese arc, the Indian Oceanic lithospheric plate is active down to a depth of 150 to 200 km [2]. This Syntaxis zone can be understood as the junction of Indian Plate, Eurasian plate and the Burmese plate. Naga Fault is another discontinuity in the Syntaxis zone running between Tapu thrust in the south with the Dauki Fault in the east which further continues till Mishmi thrust at its junction with the Andaman-Nicobar ridge. Shillong Plateau is a complex seismotectonic province which is surrounded by Naga Thrust in the south-east, Dauki Fault in south and south-west and Main Boundary Thrust (MBT) in the north. The plateau is a continuous source of moderate to great earthquake occurrence. Majority of the events occurring in the Shillong Plateau are referred as Plate boundary earthquakes due to their close proximity to both the Himalayan arc in the north and the Burmese arc in the east. This region has a quite different seismicity compared to the counterpart Peninsular India which is attributed to the presence of Dauki fault as a separator between the two tectonic provinces [2, 3].

Above discussion highlights the complex seismic setting in the North-East India. **S**ource characterization, identification of vulnerable sources and determination of seismotectonic parameters of various regions in India and also for seismic hazard assessments on regional and macro levels have been attempted in many of the research work. To understand the past damages felt during each of the major EQ in the north-east India, various published reports by Oldham are followed. Amount of devastation evidenced during some of the great and major earthquakes in the North-East India are discussed below;

1869 Cachar Earthquake (M-7.8)

This event was occurred on 10th of January 1869. The epicenter was located at about 9.4 km north of Kumbhir Assam[4] Number of report of 1869 Cachar EQ are available. The visual experience as per [5] reported a linear feature of tree swaying as the waves passed followed by falling of some of the trees. Further, sudden change in the atmospheric condition before and after the earthquake was mentioned by [5]. The epicenter was located near the Haflong-Disang thrust. The earthquake was so severe that the shocks were felt in an area of 1,00,000 sq. km extending up to Patna in the west, northern Burma in the east, Chittagong in the south of the epicenter to Darjeeling in the north (Oldham, 1882). Reports state that large fissures were formed in the ground along the banks of the Surma River and sand and water were spewed out from sand vents [4]. This was the first earthquake in which damage details and other features were collected by the Geological Survey of India from the field survey [5]. Total destruction of many masonry buildings as well as wooden construction was observed. Ground characteristics in the form of wide fissures were also evidenced on the bank of Brahmaputra at many locations in the epicentral region. Reports are also available where even some of the graves which were built by stone masonry were totally damaged highlighting the extent to surface motion experienced during the earthquake.

1897 Shillong EQ (M-8.7)

On 12th June 1897 Assam and its neighboring areas were hit by a massive earthquake of estimated magnitude Mw 8.1. This earthquake was found to have been originated on a south-southwest dipping fault called the Oldham Fault [4]. The towns of Shillong, Guwahati, Dhubri and Goalpara were among the worst hit. The damages caused by the earthquake were recorded by two British Raj officers of Geological Survey of India Mr.T.D. LaTouche and Mr. Richard Dixon Oldham. The event caused complete collapse of buildings within 48, 000 sq. km. Since the event occurred around 5:15 pm when most of the people were outdoor [6, 7], the numbers of casualties were relatively less (close to 1500). The extent and the amount of damage reported during 1897 Shillong EQ were too very enormous. Railway lines and road were severely damaged during the earthquake between Tezpur and Balipara [4]. The event triggered landslides at many locations. Reports of liquefaction and wide fissure formation are also available during this event at Rowmari in Assam [6].

1918 Srimangal Earthquake (M-7.6)

Similar damage observations as above were made during the 1918 Srimangal EQ (M-7.6). The event occurred on July 8, 1918 six years after the 1912 Burmese EQ. Shocks due to this event were felt in the eastern regions of Bengal and Assam. Since the event occurred in the afternoon, the numbers of casualties reported were extremely low since most people were out of their house for work [8]. Others who were inside the building might were awake and could run out of the house into open area before the building collapsed. Many of the bungalows and tea houses were completely shattered. Other structures with steel frames/bracing could sustain the event but the masonry walls between the frames were completely collapsed. An area of about 4500 sq. km had undergone damage [8]. Isoseismal map for this event was produced following the guidelines used to develop isoseismal map for 1897 Shillong EQ. The developed map shows 6 isoseist with isoseist 1 resembling most affected area and 6 showing least affected area [8]. It was observed that isoseist 6 was protracted to Lucknow, Allahabad, Bilaspur and even Rangoon. Observations such as sudden burst out of sand and water up to a height of several feet were observed at Phulcherra Tea Estate. Similar cases of sand and water burst were reported in Agartala and Kishoreganj areas [8]. These observations are clear instances of large scale liquefaction which was observed during this event. Even railway lines and tram lines were reported a shift by several feet in their alignment [8].

1950 Assam EQ (M-8.7)

The Assam earthquake which had occurred on 15th August 1950 of magnitude Mw 8.7 is reported to have lasted for more than 4 minutes causing maximum damage to Upper Assam, the Abor Hills and the Mishmi Hills. The earthquake caused large fissures on the ground damaging railway lines, roads and bridges. The railway track from Dibrugarh to Saikhoaghat, the Upper Assam Trunk Road and the Assam Bridge over Ranganadi had suffered the most [4]. The tremendous shaking led to liquefaction and formation of sand vents at Jorhat, Margherita, Saikhoaghat, Sadiya, North Lakhimpur and Nizmaghat. The worst devastation was caused by the floods that had occurred after the earthquake. During the earthquake huge landslides caused soil and rock from the mountains to fall into the tributary rivers of the Brahmaputra creating a natural dam which blocked the flow of water. These natural dams were breached in some of the rivers without causing much damage but in Subansiri when the dam broke after 8 days the river created flash floods that submersed several of the villages [9]. This event was felt over an area of 4.5 million sq. miles and caused a total casaulties of about 1500. The event also caused collapse of North Lakhimpur bridge in Assam [4].

Thw above discussion has highlighted the extent and type of damages reported during some of the EQ that had occured in the north-eastern India. This discussion only highlights limited events. Similar damage scenario were also evidenced during other earthquakes of the region such as 1932 Meghalaya EQ (M-7.1), 1930 Dhubri EQ (M-7.1), 1941 Tezpur EQ (M-6.5), 1943 Hojai EQ (M-7.2), 1947 Arunachal Pradesh EQ (M-7.7), 1954 Arunachal Pradesh EQ (M-7.7), 1957 Arunachal Praedsh EQ (M-7.0) and 1988 Manipur EQ (M-7.3). Extent of damage felt during each of these events are well documented in the literature [4]. This highlights that North-East India has always been a source of frequent major to great earthquake. Further, based on strain accumulation and non-occurence of event between 1897 Shillong EQ and 1950 Assam EQ, this stretch has been highlighted as a possible seismic gap called as “Assam Gap” by [10]. Based on similar slip distribution for probable future earthquake as reported during 1950 Assam earthquake [11] determined probability of 21% of great event in Assam gap in the next 100 years. In other words, probability of 5 % of occurence in the next 25 years or 2 % probability of occurence in the next 10 years since 1999 [12]. Thus, in the light of past reported damages and considering a high population density in the North-East forecasting the level of ground shaking at bedrock as well as surface will be very helpful in synthesizing the probable earthquake scenario.

GUWAHATI AND ITS SEISMICITY

The city of Guwahati is the largest industrial and business centre of the entire North-east India. Further, the city is well known for its ancient history, pilgrimage, education, sports and handlooms. Because of number of famous temples, it is also called as the city of Temples. The city is located on the bank of river Brahmaputra covering an area of apporximately 600 sq km with its centre at $26^{O}08$’N and $91^{O}40$’ E. As per census 2011, the city holds a population of approxitately 1 million residents. The city is approchable by all means of transportation such as road, rail, water and air. The city lies in between the river Brahmputra and the Shillong Plateau. Considering the seismic scenario of the city, it is surrounded by the Main Central thrust in the north, Dhubri fault in the west, dauki fault in the south and Naga thrust in the east. Thus, the city of Guwahati lies in between the active Himalayan belt and the Shillong pateau. Some of the important earthquakes that had occured in and around of Guwahati includes 1869 Cachar EQ and 1897 Shillog EQ. The city lies in seismic zone V as per [13] which highlights it as among the most seismically active regions of the country with a zonation factor of 0.36. A close observation of reported damages during the past earthquake suggest wide scattered damages in different parts of Guwahati. 1869 cachar EQ (M-7.8) caused building damages at many locations such as Pan Bazaaar. Even at several locations the ground water was raised to the ground surface which is a possible case of liquefaction at Guwahati as reported by the Geological Survey of India [4]. Colonel Davis, Chief Engineer of Guwahati reported that the walls of the jail in Guwahati were cracked; brick buildings, church piers and graveyards had undergone partial to complete collapse [5]. Similar observations of damages were drawn from 1897 Shillong EQ (M-8.7). As reported by Oldham, this event caused ground subsidence along the bank of river Brahmputra in Guwahati. Typical observations of liquefaction in several water vants were also observed during the event. Ground fissuring in a small stream located at the western end of Guwahati bazaar were observed. As a result of this, 18 inch shortening of a three girder bridge was reported in Guwahati [4]. Again, all the temples which were located in the hill top were completely shattered during this event. Also, risen in the level of water up to 7.6 m as well as reversal in the direction of flow was reported in the river Brahmaputra during this event [4]. Another observation from the reported scenario show fall of rocks from the hill top into the river Brahmaputra causing blockage in te flow as well as liquefaction and ground subsidence at various places during 1950 Assam EQ.

In addition to active sources in the Shillong Plateau, the city of Guwahati also consists of local faults runing across the city. These include 1) a 15 km long fault running between Nilanchal and Fatasil hills; 2) another 10 km fault running NE-SW between the Kalapahar and Fatasil hills; 3) 20 km fault running between the southern foothills and the river Brahmaputra and 4) fault existing between the southern foothills and the Kalapahar-Fatasil range [12, 14]. It is clearly evidenced from the above discussion that in addition to the seismicity of north-east India, regional active faults also exist on local scale for the Guwahati city. Also the city is vulnerable to induced effects causing building damages and failure of other utilities considerably in the light of past reported damages.

SUBSOIL CONDITION

Presence of subsoil alters the ground motions developed during an earthquake and is responsible for induced effects such as ground shaking, landslides and liquefaction. Hence detailed studies should be performed for correct assessment of subsoil response in the light of probable future earthquake. Number of water bodies in and around the Guwahati airport have been filled in the last decade in order to use the site for construction purposes. Such filling of water bodies will yield a challenging site of construction in the light of seismic potential of Guwahati. Similar observations can be made from other parts of the city. Assessing the subsoil properties for the Guwahati region based on large number of borehole data were attempted by [12] in the light of synthetic ground motions. As per [12], the city consists of mixed geology comprising of granitic rocks as outcrop at different locations across the city followed by alluvial deposits with the altitude range between 200 to 400 m above mean sea level. Rock outcrop can be evidenced at several locations such as Kalapahad, Guwahati zoo, Guwahati University and Phatasil etc [12]. Similarly, subsoil deposits are available in the thickness range of less than 100 m to greater then 300 m on the landmass of Guwahati. Based on borehole reports available by different geotechnical firms [12] as well as [15] found that the subsoil at Guwahatai is composed of silty sand, sandy silt and silty clay. Out of 100 boreholes used in the work, it was found that more than 92 borehole sites fall under site class E as per [15], 7 boreholes belongs to site class D and one borehole corresponding to site class C. Site class E are most prone to liquefaction which is also evidenced for Guwahati city during past earthquakes as highlighted earlier. Borehole reports suggest N-SPT variation in the range of 8 to 15 at 2 m depth to a value of 12 to 50 at 20 m depth [15]. However majority of the locations show N-SPT variation in the range of 12-16 in the top 10 m.

LIQUEFACTION POTENTIAL OF GUWAHATI SOIL

[12] performed the liquefaction potential estimation as per [16] for the Guwahati subsoil in the light of three seismic scenarios namely 1897 Shillong earthquake, 1950 Assam EQ and probable future EQ having bedrock PGA (Peak Ground Acceleration) of 0.15g, 0.19g and 0.25g respectively. Based on the analyses, [12] found that the enitre city of Guwahati is susceptible to liquefaction at a depth of 1.5 m, 5, and 10m for all the three seismic scenarios. Similarly [15] performed the liquefaction potential estimation of Guwahati subsoil following the methodology by [17]. A PGA value of 0.36g was considered in the analysis by [15] and found that soil at Guwahati is susceptible to liquefaction even at 12 m depth below the ground surface.

DEVELOPMENT OF SURFACE PGA MAP FOR GUWAHATI

In both of the above studies, the PGA is considered as the bedrock PGA and no site response analysis was performed in order to determine the surface level of acceleration. Highlighting this limitation, present work consists of determining the surface PGA map for the Guwahati city in the light of possible bedrock scenarios used in earlier studies. In another research work, determination of surface level PGA for liquefaction potential in a moderate seismicity region, was attempted by the author [18]. Based on this work, an empirical correlation has been proposed by the corresponding author relating the amplification factor with the bedrock PGA and average 30m SPT-N value (N_{30}). The same proposed correlation is used in this work to determine the surface PGA values for the city of Guwahati. The N_{30} values for the Guwahati city is taken as per [15] and bedrock value of 0.25g as per [12] for the possible future earthquake is considered. Since the proposed correlation is applicable for the N_{30} values range between 15 and 35. Hence, sites with N_{30} lesser than 15 as per [15] are not considered in estimating surface level PGA values in this work. Figure 1 shows the surface PGA map for the Guwahati city estimated in this work. It can be observed from Figure 1 that the surface PGA is varying from lower value of 0.30 g to 0.90g. Surface PGA in the range of 0.30g to 0.40g can be found in the areas of Kalapahad, Silpukuri and G S Road while higher values of surface PGA in the range of 0.98g to 0.90g can be found in the areas of Chandmari, Zoo Hill and Nabagraha parts of Guwahati city. These value of surface PGA are compartively larger than the values used in the earlier studies. Since, N_{30} <15 was reported by [15] in most of the locations of the city, surface PGA cannot be estimated using the proposed correlation. However based on the borehole data and past reported damages, it can be concluded that such soil deposits may undergo liquefation in future. Once, the surface PGA values are known as shown in Figure 1, assessment of liquefaction potential can be performed. [19] developed another empirical correlation between corrected N value and the surface PGA ascertaning no liquefaction condition for different depths of overburden. Using the proposed correlation by [19] another map showing the corrected N-SPT [$(N_1)_{60CS}$] to be achieved at 1.5 m depth in the Guwahati region ascertaning no liquefaction condition is developed as shown in Figure 2. These values are developed in accordance of surface PGA shown in Figure 1. It can be observed from the Figure 2 that [$(N_1)_{60CS}$ at 1.5m depth needed to avoid liquefaction in the city varies from 22 to 32. Keeping in mind the liquefaction possibility in the city, any selected site can be treated usig suitable ground improvement techniques. Figure 2 provides the target values to be achieved at the site of interest to be achieved at the end of ground improvement. Values presented in figure 2 needs to be corrected for various corrections which can be estim-

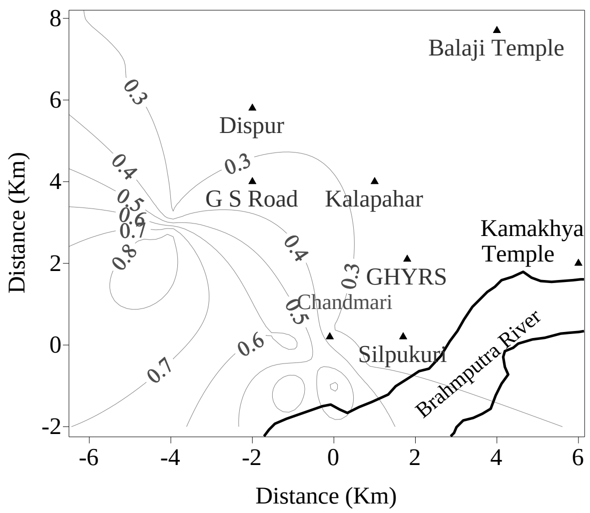

Figure 1: Surface PGA map for the city of Guwahati

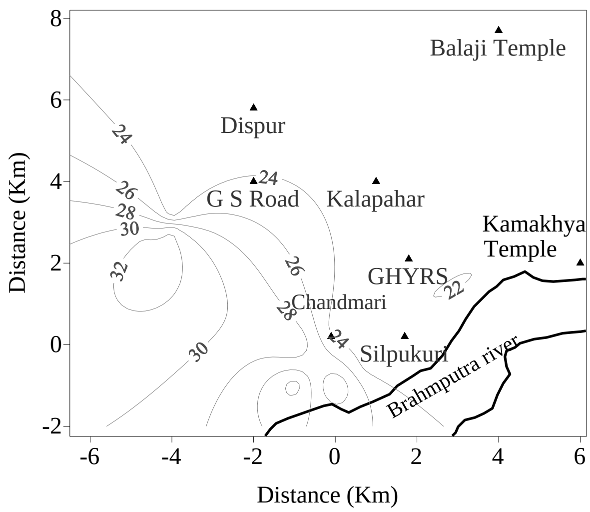

Figure 2: $(N_1)_{60CS}$ at 1.5 m depth for no liquefaction condition for the city of Guwahati (For bedrock PGA=0.25g)

-ated as per borehole reports. It has to be highlighted here that similar to Figure 1, values of $[(N_1)_{60CS}$ in Figure 2 are only estimated in locations where surface PGA is known as per Figure 1. For other locations considering these values may not be appropriate.

CONCLUSION

This paper presents the complex seismic settings of North-East India, damages reported during various major and great earthquakes since the last century in the form of building damages, ground fissures, liquefaction, falling of rocks, cracks in the walls, cracks in the railway lines and many more. Such discussion presents damage scenarios already been felt in the North-East India. Thus, in the light of possible Assam Gap, studies related to seismicity estimation are very much demanding. The city of Guwahati is a major attraction of the entire North-East India from the business, education, infrastructure and religious point of view. Considering the past damage reports, the city of Guwahati has undergone immense catastrophes due to regional earthquakes. In addition, numbers of seismic sources are running through the city. In the light of past research work highlighting the liquefaction potential of Guwahati city, two maps are developed in this work. The first map presents the surface PGA values for the city of Guwahati in the range of 0.30g to 0.90g which are much higher than the previously reported values used in liquefaction assessment. Further using proposed surface PGA values second map is developed giving target values to be achieved in the field at 1.5m depth from suitable ground improvement techniques. The values presented in Figure 2 assure no liquefaction condition at that depth. Similarly for other depths, the value of $[(N_1)_{60CS}$ can be calculated as can be used for guidelines. Further, the $[(N_1)_{60CS}$ contours are corrected values and hence *in-situ* values to be achieved should be estimated for the site based on borehole data. Since both the surface PGA contours and $[(N_1)_{60CS}$ contours are presented for part of the city, similar study for rest of the city can be attempted in the near future.

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