AMPLIFICATION FROM ISOSEISMAL MAP AND SITE RESPONSE ANALYSIS

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ABSTRACT

Devastating earthquakes have caused large causalities in the early 20th century in Himalayan region. Owing to the increase in population and with the increase in the infrastructure, compared to the past the damages will be catastrophic is case of any future event. Many researchers have highlighted the possible existence of seismic gap along the Himalayan region both in terms of time and location. Understanding of site effects and amplification become mandatory in this region. Site amplification depends on the dynamic properties of soil, thickness above rock/ hard layer and input ground motion. Limited attempt has been made in India to measure and understand site effects in deep basic due to paucity of recorded ground motion data at rock and ground. Hence in this paper an attempt has been made to estimate amplification from past event isoseismal map and compared with the surface PGA (Peak Ground Acceleration) obtained from site response analysis for selected sites.

INTRODUCTION

Loss of lives, devastation and economy loss due to the occurrence of the earthquake events worldwide are frequently reported and necessitates the understanding of earthquake and related hazards to reduce these losses. Studies of such consequences are important in urban area where unpredictable population growth and development in infrastructures and other area of important facilities are undergoing. Himalayas are one of the most earthquake prone regions in the world rising due to the collision of Indian and Eurasian plate. The rate of collision between plates is about 5 mm to 21 mm per year (Khattri, 1987; Bilham et al., 2001). In the light of built-up strains and probable seismic gaps in this region, it is expected large earthquake in near future (Khattri, 1999; and Bilham and Gaur, 2000, Anbazhagan et al., 2010).

Major earthquake damages are reported worldwide due to earthquake geotechnical hazard of site effects, liquefaction and landslides. Many classical examples are available of damage due to thick soil deposits world wide. Two well known examples of site effects in India are building damages in Delhi due to Chamoli earthquake and severe collapse of structures in Ahmedabad and other places due to Bhuj earthquake in 2001. Both the regions are far from the earthquake epicenter but still suffered damages due to the site effects a caused by thick soil deposits.

Instrumentation and study of site effects due to thick soil deposit are well understood in developed countries, which helped them to reduce seismic damages even for large earthquake like Chile 2010. But limited attempt has been made to understand the site effects due to soil layers in India. Instrumentation and understanding of site effects are in sapling stage in Asia particularly in India even after many years of major earthquake damages. Understanding of site effects and amplification of soil layers can help to reduce the damages due to modified ground motions. In country like India where strong motion (SM) data is very limited (Singh et al 2003), actual estimation of surface motion, site effects and amplification is really a difficult task. Here, an alternate approach is attempted in study by combining Isoseismal Map of past earthquake, region specific synthetic ground motion and soil profile with ground motions. An Isoseismal map covers areas having equal level of damages reported. Scale is approximate as Intensity values depend upon the sensation of person which can vary from one to another. Isoseismal maps are indirect inactive of geological feature and modified ground motion at particular location. Hence, the surface acceleration has been estimated from isoseismal map in absence of actual ground motion data. Further these are used to estimate site effects and amplification in this region by carrying out site specific response site. Isoseismal map and soil profile with SPT N values has been collected at three different locations from various sources. Synthetic motions for same earthquake were generated at these locations at bed rock level using Finite Fault Simulation (FINSIM) model (Atkinson and Beresnev, 1997) for 1999 Chamoli earthquake. Site response analysis has been carried out using synthetic ground motion and soil profiles. Surface PGA obtained from site response analysis was compared with the PGA values obtained from isoseismal map, it is found that amplification values are comparable from both approaches.

Chamoli Earthquake in 1999

A devastating earthquake of mb 6.4 rocked Garwal Himalayas on 29th March 1999. The shocks were felt far till Nepal in east, Pune in southwest, Punjab, Himachal Pradesh and Haryana in North West as well as Uttar Pradesh and Bihar in the east. This event killed about 64 people and heavy loss to the properties. Damages in Alakhnanda and Mandakini valley had been reported a intensity of VIII (Mahajan and Virdi, 2001). The region lies in the vicinity of Main Central Thrust (MCT) (Gansser, 1964) and is more prone to landslides. During this event also, many landslides were reported which was active for several days. Wide cracks were noticed dip direction of Mawana, thus has been given an intensity of VII. Land fissures were observed near village Nejimula and Senji which can cause more problems in monsoon season were assigned to region VII (Sarkar et al., 2000). On the basis of damage pattern, many isoseismal maps are present in the literature (Mahajan and Virdi, 2001; Sarkar et al 2001). However, in order to compare surface generated ground motion with observed intensity, isoseismal map presented by Mahajan and virdi (2001) has been considered.

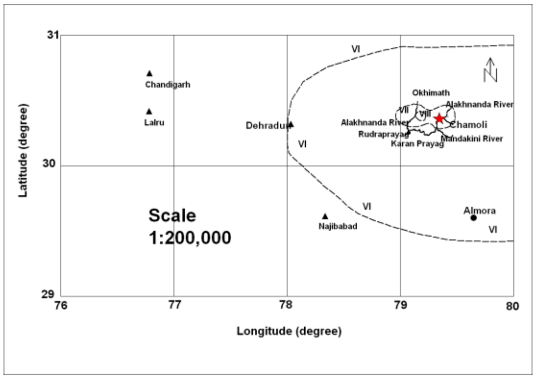

Figure 1: Isoseismal map of Chamoli earthquake modified after Mahajan and Virdi (2001).

Seismotectonic Parameters

1999 Chamoli earthquake happened in western seismic gap was recorded by number of stations in the near by areas. These actual ground motions were taken from Atlas of Indian Strong Ground Motion Records published by Shrikhande (2001). Source parameters for this earthquake were collected from Singh and Mittal (2005) as listed below in Table 1. Same parameters have been used to generate synthetic ground motion for 3 stations in order to validate the synthetic model and parameters used.

Table 1: Source parameters for Chamoli Earthquake (Singh and Mittal, 2005)

Parameters	**Chamoli Earthquake**
Fault Length (km)	36
Fault Width (km)	20
Focal Depth (km)	15
Dip of Fault (degree)	8
Strike (degree)	274
Rupture Velocity (km/s)	2.50
Maximum Slip (cm)	160
Seismic Moment 9dyne-cm)	$1.8X10^{26}$

With these source parameters obtained from the literature, synthetic motion have been at Barkot, Ghansiali and Almora have been simulated and compared with recorded ground motion. Figure 2 shows typical recorded at Ghansiali, which is located 74 km from epicenter.

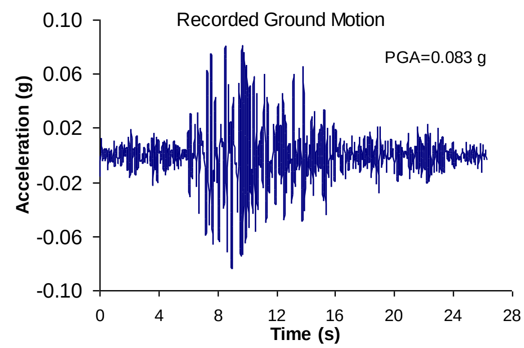

Figure 2: Typical recorded Chamoli earthquake at Ghansiali site

Synthetic Motion model

Stochastic methods for modeling ground motion have been widely used in a number of studies (Boore; 1983; Boore and Atkinson; 1987 Anbazhagan *et al.*, 2010). In the absence of actual ground motion due to past events, synthetic models becoming popular for attenuation and Seismic hazard studies (Iyenger and Ghosh, 2004) in India. Sitharam and Anbazhagan (2007) generated synthetic ground motion for maximum credible earthquake for understanding local site effects for Microzonation of Bangalore. In this Study, Stochastic Finite Fault Simulation model (FINSIM) proposed by Beresnev and Atkinson (1997) has been used. It uses a traditional Finite Source model with rupture starts at hypocenter and radiates through other parts. The rupture velocity is taken as 0.8 times the shear wave velocity of source. A rectangular fault is used and is whole divided into number of subfaults such that each subfault ruptures when rupture mechanism reaches its centre. Ground motion at the observation point is evaluated with the mean of geometric model attenuation (Q) model (Boore and Atkinson, 1987; Beresnev and Atkinson, 1997). The corner frequency f_c and sub-fault moment (m_o) is derived from the following equation.

$$f_c = \left(\frac{yz}{\pi}\right)\left(\frac{\beta}{\Delta l}\right) \quad (1)$$

$$m_o = \Delta\sigma\, \Delta l^3 \quad (2)$$

$$\Delta\sigma = \frac{3}{2} u \frac{\mu\eta}{2r} \quad (3)$$

$$\text{Where, } r = \left(\frac{A}{\pi}\right)^{\frac{1}{2}} \quad (4)$$

$\Delta\sigma$ is the stress drop (Kanamori-Anderson, 1975), β is the shear wave velocity in km/s, y is the ratio of rupture velocity to shear wave velocity taken as 0.8 (Singh et al., 2003), z is parameter representing high frequency radiation.

The value of strength factor (S_{fact}) was established by varying the value in entire range from 1-2 and comparing the results with the actual data. It has been observed that for S_{fact} of 1.2, both the observed and observed ground motion matches well. Synthetic ground motion at Ghansiali has been generated using this models and parameters discussed above. Figure 3 shows synthetic ground motion at Ghansiali site.

ACCELERATION FROM INTENSITY

In the absence of local subsurface soil profiles close to epicenter. Site specific response study has been carried out at locations where subsurface soil profiles available with intensity map. Selected three locations are shown in Figure 1 as solid triangles. These locations are reported moderate damages with modified intensity values of V to VI.

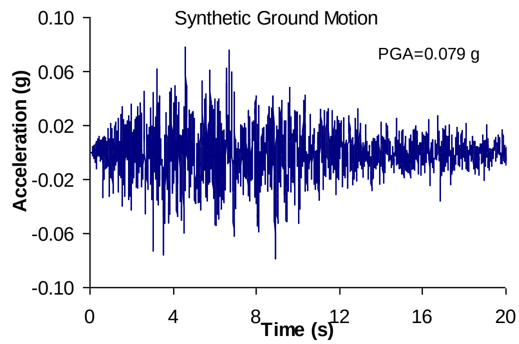

Figure 3: Typical synthetic ground motion for Chamoli earthquake at Ghansiali site

Lalru belongs to MMI of V whereas Dehradun and Najibabad belong to MMI of VI. Intensity values are good indicator of local site effects, but which can not be used for any engineering applications because these are not quantitative. In view of this fact, intensity values are converted to acceleration values using the following equations (Murphy and O'Brien, 1977);

$$\log a_H = 0.25 I_{MM} + 0.25 \quad (5)$$

Where, a_H is peak horizontal acceleration in cm/s^2 and I_{MM} is (MMI) Modified Mercalli Intensity scale. Surface acceleration are estimated from the Isoseismal map for selected locations and tabulated Table 2. In the absence of recorded rock level ground motion data in the selected three locations, synthetic ground motion data for three locations at rock level has been generated. Rock level and surface spectrum from the synthetic ground motion at Lalru site is shown in Figure 4 obtained from site response study.

GEOTECHNICAL DATA

In total 3 bore logs were obtained from different agencies and literature for the regions of Najibabad, Dehradun and Lalru. Locations of these boreholes are shown in Figure 1. Soil strata details collected in Dehradun belongs to PTCUL (Power Transmission Corporation of Uttarakhand Limited) Dehradun. Borehole reports shows poorly graded sand along with clay of medium to high plasticity. Uncorrected N value varies from 6 to 54 with water table at 2.0 m depth from surface. Soil data collected from Najibabad belong to BPCL (Bharat Petroleum Corporation limited) Najibabad. Borehole report shows clayey type of soil with intermediate layers of silty sand in between clay. Water table lies at shallow depth of 1.5m. Uncorrected SPT N value variation ranges from 7 to 50. It can be noted here that researchers are reported activation of Najibabad-Chamoli pipalkoti lineament during the Chamoli earthquake and followed aftershocks (Mahajanand and Virdi 2001). Lalru which is located 15 km from Ambala on Ambala-Chandigarh Road were also suffered similar damages to Chandigarh. Borehole data collected from Lalru shows mostly clayey type of soil will low to high plasticity. Observed uncorrected N value varies from 6 to 40. Figure 5 shows SPT N value profiles used for the analysis.

Site Response Study

Site response studies were carried out by equivalent approach using SHAKE 2000. The input soil properties were defines as per the strata detail obtained from borehole chart. Clay with plasticity index ranges from 10-20 was encountered in addition to sand. Standard curves for average sand given by Seed and Idriss (1970) and for clay based on plasticity index value (PI) given by Sun et. al. (1988) has been used in the analysis. Equation No 3 available in SHAKE has been used for estimation of Gmax from N value. Soil column was generated using soil details in Shake. Synthetic ground motions developed in the above section were

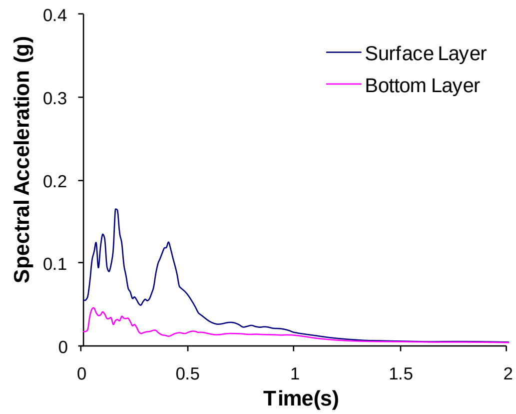

Figure 4: Typical response spectrum at rock from synthetic ground motion and surface by site response analysis at Lalru.

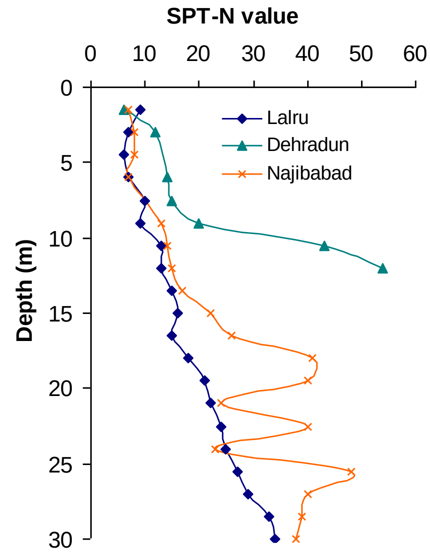

Figure 5: Selected soil profiles used for site response analysis

assigned at the base of soil column and surface motions were calculated. Typical amplified spectrum is shown in Figure 4 from site response analysis. Amplification factor defined as the ratio of Surface motion to the base motion for the soil column for all site varies from 1.2 to 3.3. PGA variations with depth for all the locations are shown below. Surface PGA obtained for Dehradun, Lalru and Najibabad were 0.068g, 0.054g and 0.049g respectively, which are more that 2 to 3 times of input PGA values. Obtained surface PGA for these sites are converted to intensities as per equation 5 and the number rounded off gives MMI of VI to all sites. This way it can be justified site specific response results are matching with the observed and reported intensity values. Hence regional synthetic ground motion model and site response results are suitable for region.

CONCLUSION

Site response studies are being carried out in many parts of world in particularly in Indian cities using synthetic ground data or recorded earthquake data for other places. But limited validations are presented due to lack of surface and bed recorded ground motions. In this study an attempt has been made to understand site effects and amplification using Isoseismal map of past earthquake. Study shows that PGA obtained from site response study using synthetic ground motion is very well matches with reported intensity values. The study also shows that amplification values of 2.0 to 3.5 have been expected in this region. Methodology used in this study can be used as alternate method to understand site effects. This study also highlighted that Isoseismal maps can be used to understand site effects of the region.

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