# SITE-SPECIFIC ANALYSIS OF DELHI REGION FOR SCENARIO EARTHQUAKES

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**ABSTRACT :**

The importance of site-specific analysis for Delhi region has been explored in this paper. Seismologists have estimated the probability of occurrence of great earthquake of moment magnitude 8.5 from the large unbroken segment called central seismic gap of Himalayan region in the next 100 years is 0.59. Delhi capital city of India is situated roughly 200 to 300 km from central seismic gap. In this paper, rock outcropping motions have been generated for a reference site at Delhi Ridge observatory, for the scenario earthquakes of moment magnitude $M_w$ = 7.5, $M_w$ =8.0 and $M_w$ = 8.5 from central seismic gap. Equivalent linear one dimensional wave propagation analyses have been carried out for three actual sites at Delhi for which borelog details are available upto the bedrock. The site-specific spectra and the corresponding building response have been estimated and the importance of site-specific analysis for Delhi region has been brought out.

**KEYWORDS:** Site-specific analysis, Strong motion generation, Delhi, Soil amplification

## 1. INTRODUCTION

The importance of the effect of sediments above bedrock in modifying the strong ground motion has been long recognized (Seed and Idriss 1969, Dobry 1991, Boore and Joyner 1997, Tezcan et al. 2002, Bakir et al. 2005) in the literature. The nature of soil that changes the amplitude and frequency content has a major influence on damaging effects of earthquake. It has been reported (Iyengar and Ghosh 2004; Sharma et al. 2003) that Delhi capital city of India had been subjected to damaging earthquakes. Seismologists (Singh et al. 2002; Bilham et al. 1998) have reported that three major thrust planes viz., Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) exist in Himalayas due to the relative movement of Indian plate by 5 cm/year with respect to Eurasian plate. Khattri (1999) has estimated the probability of occurrence of a great earthquake of moment magnitude 8.5 from the large unbroken segment called central seismic gap (Fig. 1) between MBT and MCT in the next 100 years to be 0.59. Delhi is situated at a distance of roughly 200 km from MBT and 300 km from MCT. In the present study (Kamatchi, 2008), rock outcropping motions have been generated for a reference site at Delhi Ridge observatory, for the scenario earthquakes of moment magnitude $M_w$ = 7.5, $M_w$ =8.0 and $M_w$ = 8.5 from central seismic gap of Himalayan region. The rock outcrop motions simulated above have been propagated through the soil strata of the three actual sites at Delhi for which borelog details are available upto the rock. The free field motions and the site-specific spectra are obtained. A three storey building is assumed to be situated on the three sites and the storey shears are compared and observed that the response varies significantly.

## 2. STRONG GROUND MOTION GENERATION USING STOCHASTIC FINITE FAULT MODEL

Prediction of exact time and location of future earthquake is extremely difficult and hence physical models for generation of strong ground motion for engineering applications become unavoidable. Recorded ground motions help in understanding the physics of the process and seismologists have developed models for simulation of strong ground motion. Stochastic simulation with the point source model (Boore, 1983, 2003) which includes physics of source-path has found wide applications in earthquake engineering. Though the point source model is found successful in explaining the salient features of recorded ground motions, it is valid only when the distance is large compared to the fault dimension. Further, the finiteness of the fault cannot be neglected for larger earthquakes of 8.0 and 8.5 hence the finite source model developed by Beresnev and Atkinson (1997, 1998) has been adopted in the present study. The seismological parameters involved in the simulation of scenario earthquakes of moment magnitude $M_w$ = 7.5, $M_w$ =8.0 and $M_w$ = 8.5 are broadly adopted from Singh et al. (2002) and are given in Table 1. The fault dimensions, depth of focus assumed, the number of sub-faults assumed and the number of sub-sources summed for the three magnitudes of earthquake considered are given in Table 2. In order to minimize the noise due to random fault rupture in the simulation, 15 ground motions have been generated for each earthquake magnitude. The key parameters of the time history of ground motions viz., the peak ground acceleration, duration and pseudo spectral acceleration are compared (Kamatchi et al., 2007) with one rupture scenario of ground motion supplied by Singh (2005) through personal communication.

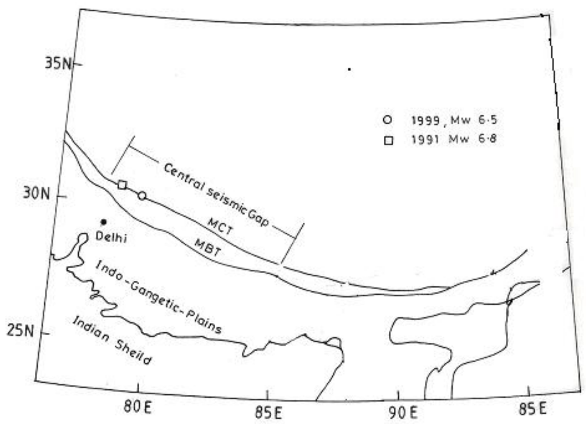



Figure 1 Central seismic gap of Himalayan region


Figure 2 Three typical soil sites in Delhi

**Table 1 Seismological parameters for strong motion generation**

| Parameters | Model/value |
|---|---|
| Fault orientation | Strike 300° Dip 7° |
| Stress parameter (bars) | 50 |
| Duration Model | $1/f_c$ +0.05R |
| Quality factor | $508f^{0.48}$ |
| Windowing function | Saragoni-Hart |
| $f_{max}$ (Hz) | 15 |
| Crustal shear wave velocity (km/sec) | 3.6 |
| Crustal density (kN/m$^3$) | 2.8 |
| Radiation strength factor | 1.4 |

**Table 2 Fault dimensions and number of sub-faults**

| Parameter | $M_w$ = 7.5 | $M_w$ = 8.0 | $M_w$ = 8.5 |
|---|---|---|---|
| Fault dimension along strike and dip (km) | 56 by 56 | 125 by 80 | 240 by 80 |
| Depth of focus (km) | 11 | 16 | 16 |
| No. of sub-faults | 5x5 | 8x5 | 16x5 |
| No. of sub-sources summed | 28 | 57 | 339 |

## 3. ONE DIMENSIONAL WAVE PROPAGATION: EQUIVALENT LINEAR ANALYSIS

One dimensional equivalent linear vertical wave propagation analysis is the widely used numerical procedure for modeling soil amplification problem (Idriss, 1990, Schneider et al. 1993, Balendra et al. 2002). The equivalent linear analysis program SHAKE (Schnabel et al. 1972, Ordonez 2000) has been adopted in the present study.

## 4. TYPICAL SOIL STRATA FOR DELHI REGION

Three actual soil sites designated as site 1, site 2 and site 3 located in Delhi (Fig.2) have been chosen for studying the building response. The layer wise soil characteristics information including the variation of $N$ values with depth are available from the geotechnical investigation reports as given in Tables 3 to 5. The shear wave velocity, $V_s$ measurements are not available for the sites chosen. The variation of shear wave velocity along the depth in the present study is obtained by using the correlations suggested for Delhi region by Rao and Ramana (2004) as given in equations 1 and 2.

$$V_s = 79\, N^{0.43} \quad \text{(sand)} \tag{1.0}$$
$$V_s = 86\, N^{0.42} \quad \text{(silty sand/sandy silt)} \tag{2.0}$$

The modulus reduction ($G/G_{max}$) and damping ratio ($\zeta$) curves have been adopted from Vucetic and Dobry (1991) depending on the plasticity index of different soil strata.

**Table 3 Geotechnical profile at Site 1**

| Layer No. | Description | Thickness (m) | SPT (N values) | Plasticity Index (%) | Total unit weight (kN/m³) |
|---|---|---|---|---|---|
| 1 | Sandy silt of low plasticity | 3.5 | 13 | 7<br>Non Plastic | 16.3 |
| 2 | | 1.5 | 17 | | |
| 3 | | 1.5 | 20 | | |
| 4 | | 1.5 | 23 | | |
| 5 | | 1.5 | 28 | 7 | 16.9 |
| 6 | | 1.5 | 32 | Non Plastic | |
| 7 | | 1.5 | 35 | | |
| 8 | | 1.5 | 37 | 6 | 18.1 |
| 9 | | 1.5 | 42 | Non Plastic | 18.5 |
| 10 | | 1.5 | 47 | | 18.5 |
| 11 | Rock | - | - | - | 24.0 |

**Table 4 Geotechnical profile at Site 2**

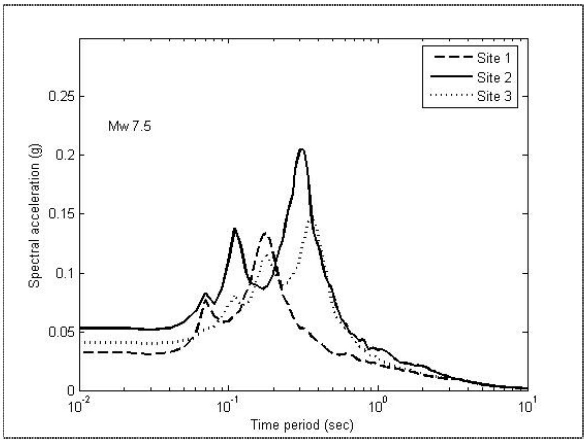
| Layer No. | Description | Thickness (m) | SPT (N values) | Plasticity Index (%) | Total unit weight (kN/m$^3$) |
|---|---|---|---|---|---|
| 1 | Clayey silt of | 1.5 | 9 | 11 | 16.9 |
| 2 | low plasticity | 1.5 | 9 | 15 | 17.4 |
| 3 | Sandy silt | 1.5 | 12 | Non Plastic | 17.4 |
| 4 | Fine sand | 1.5 | 12 | | 17.2 |
| 5 | | 1.5 | 12 | | 17.1 |
| 6 | | 1.5 | 13 | | 17.1 |
| 7 | | 1.5 | 15 | Non Plastic | 17.1 |
| 8 | | 1.5 | 19 | | 17.1 |
| 9 | | 1.5 | 20 | | 17.7 |
| 10 | | 1.5 | 21 | | 17.7 |
| 11 | | 1.5 | 26 | | 17.7 |
| 12 | Sandy silt of low | 1.5 | 31 | | 17.7 |
| 13 | plasticity | 1.5 | 41 | | 17.7 |
| 14 | | 1.5 | 41 | 6 | 19.8 |
| 15 | | 1.5 | 41 | | 19.8 |
| 16 | Rock | - | - | - | 24.0 |

**Table 5 Geotechnical profile at Site 3**

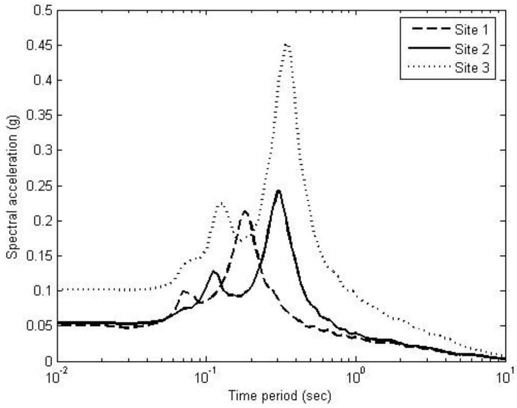
| Layer No. | Description | Thickness (m) | SPT (N values) | Plasticity Index (%) | Total unit weight (kN/m$^3$) |
|---|---|---|---|---|---|
| 1 | Sandy silt | 3.5 | 5 | Non Plastic | 16.3 |
| 2 | | 1.5 | 6 | | 16.3 |
| 3 | | 1.5 | 7 | | 16.3 |
| 4 | | 1.5 | 9 | | 17.1 |
| 5 | | 1.5 | 11 | | 17.1 |
| 6 | | 1.5 | 14 | | 17.1 |
| 7 | | 1.5 | 13 | | 17.4 |
| 8 | | 1.5 | 27 | | 17.4 |
| 9 | Clayey silt | 1.5 | 36 | 15 | 17.7 |
| 10 | | 1.5 | 32 | 15 | 17.7 |
| 11 | | 1.5 | 13 | 15 | 17.7 |
| 12 | | 1.5 | 28 | 15 | 17.7 |
| 13 | Sandy silt | 1.5 | 45 | Non Plastic | 18.1 |
| 14 | | 1.5 | 28 | | 18.1 |
| 15 | | 1.5 | 42 | | 18.1 |
| 16 | | 1.5 | 44 | | 18.5 |
| 17 | | 1.5 | 47 | | 18.5 |
| 18 | | 1.5 | More | | 18.5 |
| 19 | | 1.5 | than 50 | | 19.8 |
| 20 | | 1.5 | | | 19.8 |
| 21 | | 1.5 | | | 19.8 |
| 22 | | 1.5 | | | 19.8 |
| 23 | | 1.5 | | | 19.8 |
| 24 | | 1.5 | | | 19.8 |
| 25 | Rock | - | | - | 24.0 |

## 5. RESPONSE OF THREE SITES FOR THE SCENARIO EARTHQUAKES

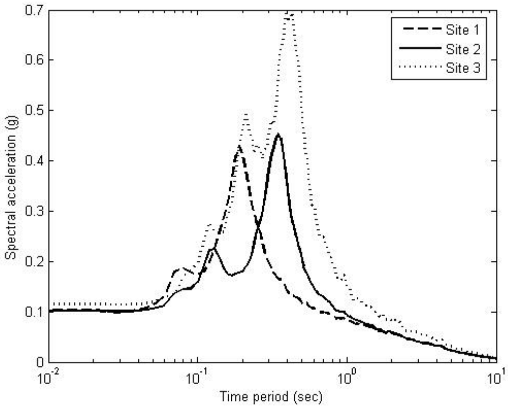
The fundamental time period of site 1, site 2 and site 3 are 0.18 sec, 0.31 sec and 0.38 sec respectively. The time period of the sites does not get altered much while experiencing the earthquakes of $M_w$ = 7.5, $M_w$ = 8.0. However the time periods of the site 1, site 2 and site 3 are observed as 0.19 sec, 0.35 sec and 0.42 sec respectively for $M_w$ = 8.5 earthquake due to the nonlinearity of soil. The average Fourier amplification ratios of the three sites are in the order of 5.3 to 6.5, however the PGA amplifications of the sites are in the order of 2.02 to 3.3. The average ratios of PGA of free field motion to the PGA of bedrock motions for the three sites are shown in Table 6. The comparison of average (15 random simulations) response spectra for the three sites for the earthquake magnitudes $M_w$ = 7.5, $M_w$ = 8.0 and $M_w$ = 8.5 are shown in Figure 3. From the comparisons it can be inferred that the shapes of the response spectra vary quite significantly for the three sites under the same earthquake.




**(a) $M_w$ = 7.5**




**(b) $M_w$ = 8.0**




**(c) $M_w$ = 8.5**

**Figure 3 Comparison of average response spectra or the three sites**

## 6. RESPONSE OF BUILDING ON THE THREE SITES

A three storey building with plan details as shown in Figure 4 is chosen for the present study. The building is assumed to be situated on the three soil sites chosen at Delhi. The earthquake is applied in y direction. The building is assumed to be having frames as stiffening elements with uniform beam and column sections along the height of the building. The in-plane rigidity of slabs are assumed to be infinite. All the columns are square and the moment of inertia of the columns of frames 1, 8 and frames 2 to 7 are equal to $11.1\text{x}10^{-4}$ $\text{m}^4$ and $21.0\text{x}10^{-4}$ $\text{m}^4$ respectively. The storey height is 3 m, the mass of the 1st and 2nd floor is equal to 410 kN-sec$^2$/m and the mass of the top floor is equal to 205 kN-sec$^2$/m. The first three time periods of the building are 0.30, 0.11 and 0.08 sec. The storey shears have been obtained by response spectrum method. In the evaluation of storey shears response reduction factor (IS 1893-2002) has been taken equal to one.

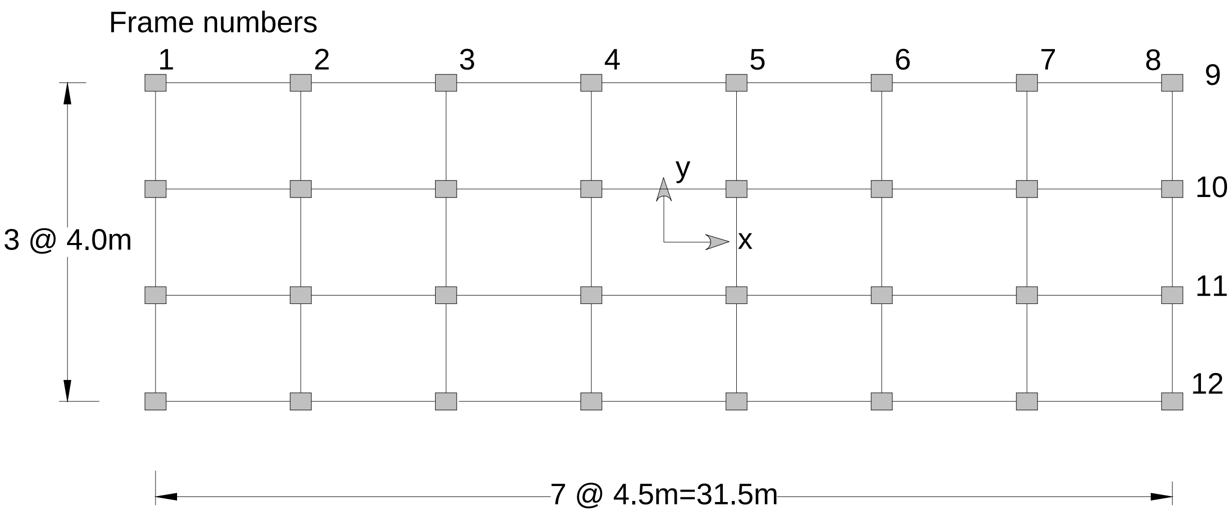



**Figure 4 Plan of building**

The variations of storey shears for the building are given in Table 7. From the comparison of the storey shears it is seen that, for $M_w$ = 7.5 the highest response for site 2 and for $M_w$ = 8.0 and $M_w$ =8.5 the highest response for site 3 are explained by the highest spectral acceleration values for the fundamental time period of the building. It is seen that the spectral accelerations for the three sites differ significantly at the fundamental time period of the building.

**Table 6 Average PGA of bedrock motion, free field motions and average PGA amplification of the three sites**

| $M_w$ | Average PGA (cm/sec$^2$) | | | | Average PGA amplification | | |
|---|---|---|---|---|---|---|---|
| | Bedrock motions | Free field motions | | | | | |
| | | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 |
| 7.5 | 15.74 | 31.73 | 51.73 | 39.60 | 2.02 | 3.29 | 2.52 |
| 8.0 | 23.36 | 53.48 | 53.10 | 60.10 | 2.29 | 2.27 | 2.57 |
| 8.5 | 46.47 | 100.82 | 100.01 | 113.32 | 2.17 | 2.15 | 2.44 |

**Table 7 Storey shears in kN**

| Storey No. | $M_w$ = 7.5 | | | $M_w$ = 8.0 | | | $M_w$ = 8.5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 |
| 3 | 138.78 | 521.35 | 291.14 | 247.21 | 611.04 | 965.43 | 507.31 | 965.63 | 1150.20 |
| 2 | 361.84 | 1404.19 | 783.30 | 652.67 | 1654.72 | 2616.45 | 1348.78 | 2616.49 | 3114.62 |
| 1 | 492.86 | 1917.44 | 1069.53 | 889.88 | 2260.46 | 3574.44 | 1839.98 | 3574.45 | 4254.75 |

## 7. CONCLUSIONS

In this paper rock outcrop motions have been generated for Delhi for the scenario earthquakes of magnitude, $M_w$ = 7.5, $M_w$ = 8.0 and $M_w$ = 8.5. Three actual soil sites have been modeled and the free field surface motions and the response spectra have been obtained. It has been observed that the PGA amplifications and the response spectra of the three sites are quite different for the earthquakes considered.

Further, the response of a three storey building has been studied for the three sites for the three scenario earthquakes. It has been observed that, for the three sites considered the response of the building varies significantly. From the studies made, it can be concluded that, it is necessary to perform the site-specific analyses of buildings considering the scenario earthquakes and actual soil conditions for Delhi region.

## ACKNOWLEDGEMENTS

The first author gratefully acknowledges the support and encouragement provided by Dr. Nagesh R. Iyer, Advisor (Management), SERC and Shri. J. Rajasankar, Scientist, SERC during the preparation of this paper. The work reported in this paper is part of her Doctoral work at IIT Delhi on deputation from Structural Engineering Research Centre, Chennai. The support and facilities provided by IIT Delhi for her Ph.D. work is greatly acknowledged.

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