STRONG MOTION AMPLITUDES IN HIMALAYAS AND DETERMINISTIC APPROACH TOWARDS FIRST ORDER MICROZONATION STUDIES IN A PART OF DELHI CITY

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Research Report CM 0105

SEPTEMBER 2001
Bangalore 560 037, India
Strong Motion Amplitudes in Himalayas and Deterministic Approach towards First Order Microzonation Studies in a Part of Delhi City

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Abstract:

The interdependence among the strong-motion amplitude, earthquake magnitude and hypocentral distance was established\textsuperscript{1} for the Himalayan region using the dataset of six earthquakes, two from western and four from Eastern Himalayas (Mw = 5.2-7.2) recorded by strong-motion networks in the Himalayas. The significant result of this study was that the level of peak strong motion amplitudes in the Eastern Himalayas are three fold larger than those in the Western Himalayas, in terms of both the peak acceleration and peak velocities. In the present study, we have included the strong motion data of Chamoli earthquake (Mw=6.5) of 1999 from the western sub-region to see whether this event supports the regional effects and we found that the new result fits well with our earlier prediction in Western Himalayas. The minimum estimates of peak acceleration for the epicentral zone of $M_w=7.5-8.5$ events is $A_{\text{peak}}=0.25-0.4$ g for the wetsern Himalayas, and as large as $A_{\text{peak}}=1.0 – 1.6$ g for the Eastern Himalayas. Similarly, the expected minimum epicentral values of $V_{\text{peak}}$ for $M_w=8$ are 35 cm/s for Western and 112 cm/s for Eastern Himalayas. The presence of unusually high levels of epicentral amplitudes for the eastern subregion also agrees well with the macroseismic evidence\textsuperscript{1}, and therefore, these results represent systematic regional effects, and may be considered as a basis for future regionalized seismic hazard assessment in the Himalayan region.

Many metropolitan and big cities of India are situated in the severe hazard zone just south of the Himalayas. A detailed microzonation study of these sprawling urban centres is therefore, urgently required for gaining better understanding of ground motion and site effects. An example of the study of site effects and microzonation of a part of metropolitan Delhi is presented based on a detailed 2-D modelling along NS cross sections from the Inter State Bus Terminal (ISBT) to Sewanagar. Full synthetic strong motion waveforms have been computed using the hybrid method, a combination of modal summation and finite difference techniques, for the earthquake source of July 15, 1720 (MMI=IX, M=7.4), and mapped all along the cross section. The response spectra ratio (RSR), i.e. the response spectra computed from the signals synthesized along the laterally varying section normalized by the response spectra computed from the corresponding signals synthesized for the bedrock reference regional model, have been determined as well.

Key words: strong-motion amplitudes, attenuation laws, seismic hazard, microzonation, Delhi city
Introduction:

Estimated values of the expected ground motion, as a function of hypocentral distance and earthquake magnitude constitute the fundamental quantities required for quantitative assessment of earthquake hazard. Predictive relationships for parameters that decrease with increasing distance (such as peak acceleration and peak velocity) are often referred to as attenuation relationships. Over the last two decades, many researchers\textsuperscript{2-10} have studied ground motion attenuation relationships for various regions of the world. Chandrasekaran\textsuperscript{11}, Singh \textit{et al.}\textsuperscript{12} and Sharma\textsuperscript{13} have proposed the attenuation relations for the Himalayan region. Most of these studies are, in essence, multiple regression models that permit prediction of a target parameter by means of an empirical relationship established on the basis of available strong motion data from a particular region. However, even for regions with long history of strong-motion observations, data are often insufficient for obtaining completely reliable average trends. The probabilistic approach, being unavoidably based upon the above mentioned generic attenuation laws, can be misleading as it cannot take into account, with satisfactory accuracy, some of the most important aspects which characterize the critical motion for base-isolated and standard structures (e.g. rupture process, directivity and site effects). Furthermore, the probabilistic analysis of the seismic hazard is basically conditioned by the definition of the seismogenic zones. Within each of them the seismogenic process is assumed to be rather uniform, however the critical assumption of homogeneity can introduce severe errors in the estimate of the seismic hazard in a given site.

In a very recent study, Parvez \textit{et al.}\textsuperscript{1} have estimated strong motion amplitudes from an analysis of the Himalayan array data, using the approach of Gusev\textsuperscript{14} and Gusev and Petukhin\textsuperscript{15,16}. In this study, the limited amount of available observations were combined with theoretically grounded attenuation laws to determine the peak horizontal acceleration and velocity relationships with magnitude and distance, rather than seeking purely empirical relationships based on “blind” multiple regression. The general approach that has been applied to the data includes the following steps: i) reduction of data to a common fixed distance, ii) reduction of the result to a common fixed magnitude and iii) analysis of the ground, sub-regional and station effects. In both reductions, a number of variants of the attenuation laws and magnitude trends have been investigated and the appropriate one, assumed to be near-optimal, was chosen. After accounting for the sub-regional effect, the attenuation relationships for two sub-regions, the
Eastern and Western Himalayas were derived. The results of Parvez et al.\textsuperscript{1} were based on two events from Western Himalayas (WH) and four events from Eastern Himalayas (EH). In the present study, we have extended their results by including the strong motion data of Chamoli earthquake (Mw=6.5) of 1999 from the Western Himalayas. This event gives us an opportunity to further check the prediction of Parvez et al.\textsuperscript{1} for the Western Himalayas. The new established attenuation curves obtained in the present study for Western Himalayas after including the Chamoli event fits very well with our earlier prediction.

A growing number of large industrial cities and urban centres in India face severe earthquake hazard. The recent Bhuj earthquake of January 26, 2001 has left thousands dead, hundreds of thousands injured and a much large number destitute. Damage to property apparently runs into billion of Rupees. This was a shocking event that generated untold misery and captured media attention around the world. Other megacities in India such as Delhi, Mumbai, Kolkata and Guwahati also face severe earthquake hazard. The most effective way to safeguard these cities from the adverse ground shaking that may be caused by a future earthquake is to evaluate the risk to which they may be subject, by carrying detailed deterministic site effects and microzonation studies, aimed at determining the estimates of seismic ground motion at specific sites. Fortunately, such estimates can be made without having to wait for earthquakes to generate measurable ground motion, if knowledge of the 3-dimensional structure of the region is generated through other geophysical investigations and from the assumptions about the nature of earthquake source on the basis of known tectonics. An example of such a study to determine site effects and microzonation on a part of Delhi city along the cross-section from ISBT to Sevanagar is presented in this study.

**Strong Motion Arrays and Data**

The Department of Earthquake Engineering, University of Roorkee\textsuperscript{17} installed three arrays during 1985-86 in the Himalayas. Figure 1 gives the location of these arrays, namely (1) Shillong array (in the state of Assam and Meghalaya), (2) Uttar Pradesh hills (UP) array (in the west of the state of Uttar Pradesh) and (3) Kangra array (in the state of Himachal Pradesh). Forty-five analog strong motion accelerographs have been installed in Shillong array with a spacing of 10-40 km; fifty similar accelerographs are installed in Kangra Array and forty in UP array with spacing of 8 to 30 km. The instruments are three-component SMA-1 of Kinematics,
USA. Figure 1 shows the location of stations with instruments that have been triggered at least once. The epicenters of the recorded events are shown as well. Four events with magnitude 5.2-7.2 were recorded by the Shillong array between 1986-1988 and three earthquakes with magnitude 5.5 and 6.8 were recorded separately by Kangra and UP arrays during 1986 - 1999 respectively. 138 horizontal component peak accelerations and velocities (including both components) from the events recorded by the Shillong array and 64 horizontal component peak accelerations and velocities from Kangra and UP arrays have been used to obtain the attenuation laws in Himalayas.

**Simple theory versus empirical formulae in strong-motion data analysis:**

In a region with a sufficiently large amount of recorded strong motion data, the average dependence of strong motion parameters (e.g. peak acceleration) on distance, magnitude and other parameters is usually determined on an empirical basis by means of multiple regression procedures. Such empirical formulae are then used for approximate forecasting of various parameters of strong ground motion related to a specific earthquake source, wave propagation path, and site geology. One difficulty with such formulae, among others, is related to the discrepancies between simple forms of traditional empirical regression relationships for various ground motion parameters on one side, and the actual, often non-linear, trends that are both seen in observations and may be expected even from a simple theory. For example, until 1985 the regression coefficient that defined amplitude attenuation was almost never (even implicitly) assumed to be magnitude dependent; whereas such a dependence is evident in the data, and it arises automatically in an adequate theoretical calculation. In many poorly studied and/or low-seismicity areas, the situation is frequently aggravated by the very limited amount of observations. To formally describe non-linearities or interactions between factors, one needs a considerable number of regression coefficients; whereas available data may be hardly sufficient to determine two or three. To replace the use of formulae, a simplified practical algorithm has been designed which is capable of determining approximate mean trends of strong ground motion parameters. To make these trends more reliable, we specify many properties of earth media and earthquake sources (where possible) in a way independent from the sparse strong-motion data. The trends calculated in this manner may be used instead of formulae, both in the analysis of observed ground motions and in the construction of predictive schemes that
interpolate or extrapolate the data. To implement this approach, a dedicated code has been developed and used by Parvez et al.\textsuperscript{1} to estimate strong motion amplitudes in the Himalayas. They determined the shape of the distance $R$ at a given magnitude on a theoretical basis and then only adjusted its absolute level to the data. Practically, an equivalent procedure has been applied: data have been reduced to a fixed distance and magnitude and then averaged.

**Attenuation of strong motion amplitudes in Himalayas:**

Parvez et al.\textsuperscript{1} have analysed very systematically the strong motion data from the Himalayan region and have also given step by step procedures. First, the data were analysed in a group for the whole Himalayan region after reducing to a hypocentral distance of 100 km. It was observed that the data were widely scattered when analysed in one group but showed greater coherence when divided into a group of western and Eastern Himalayas. The similar pattern is obtained in the present study when we include the strong motion data of Chamoli earthquake of 1999 (see Table 1). As expected, the residual rms deviation again shows that this event also belong to the western Himalayan group of events. In Figure (2a), our results for two families of $A_{\text{max}}(R)$ curves for a set of $M_w$ values have been presented. Thin solid curves are the predicted values for the EH and thin dashed ones represent WH\textsuperscript{1}. The thin dotted curves are the result of the present study and represent the new attenuation relationship for Western Himalayas. These curves are slightly above the earlier curves of Parvez et al., 2001 for Western Himalayas and once again confirm the adequate separation of western and eastern Himalayan attenuation laws. Each event of our very modest database is represented by its centroid (dot) and by a segment describing the data range by thick continuous and dotted lines for Eastern and Western Himalayas respectively. The curves represent quite a reasonable description of observational data for peak acceleration from both regions.

In Figure (2b) our results for the expected $A_{\text{max}}$ vs. hypocentral distance are compared with the results obtained by other researchers, for fixed $M_w=7$ (or $M_L=6.7$). The thick solid line represents our results for EH and the thick dashed line for WH. The result from Chandrasekaran\textsuperscript{11}, Singh et al.\textsuperscript{12} and Sharma\textsuperscript{13} for Himalayas, Trifunac\textsuperscript{2} and Joyner and Boore\textsuperscript{3} for Western US, Ambraseys\textsuperscript{7} for Europe, Atkinson and Boore\textsuperscript{8} for Eastern North America and Fukushima and Tanaka\textsuperscript{6} for Japan have also been shown in the same figure. One can see from this figure that our result for Eastern Himalayas is unusually high as compared to all the others.
except that of Chandrasekaran\textsuperscript{11}, whereas our results for Western Himalayas are quite comparable to others. Singh \textit{et al.}\textsuperscript{12} and Sharma\textsuperscript{13} have used the data from both the sub-regions jointly; their results for $M_w=$7 are close to our Eastern Himalayas results for distances above 150 km and to our Western Himalayas results for distances below 50 km. We believe that the main reason behind the differences between these results and ours is the separation of data set into two coherent groups. We therefore, consider our results more reliable. Our results for Western Himalayas are quite comparable to those of Ambraseys\textsuperscript{7} for Europe and of Joyner and Boore\textsuperscript{3} for California at $R<100$ km. However, at $R>100$ km the distance attenuation curve for California decays much faster than ours. At smaller distances, Fukushima and Tanaka’s\textsuperscript{6} results are slightly higher than ours for Western Himalayan, and definitely lower than ours for Eastern Himalayas. The distance decay of Fukushima and Tanaka\textsuperscript{6} trend at $R>100$ km is much faster than ours. The closest analog of our Eastern Himalayas result, both in terms of level and shape of attenuation curve, is the trend after Atkinson and Boore\textsuperscript{8} for eastern United States.

In a similar fashion, the relationships of peak velocity with distance and magnitude have also been determined. The established semi-empirical relationships $V_{\text{max}}(M_w,R)$ for EH and WH are represented in Figure (3a) as two families of $V_{\text{max}}(R)$ curves for $M_w=$5, 6, 7 and 8. The solid thin lines are the expected trends for Eastern Himalayas, and the dashed thin lines are those for Western Himalayas\textsuperscript{1}. The thin dotted curves are the results of the present study for the Western Himalayas, which fits very well with the earlier trend. The data centroids (dots) and the distance ranges as thick segments are also shown in this figure. The difference in the absolute levels of the expected peak velocity between regional groups is prominent, though not as large as that for peak accelerations (Figure 2a). The agreement between the predicted lines and the observed peak velocity from each event is quite acceptable. We can now compare our expected $V_{\text{max}}$ vs hypocentral distance relationship with other published trends for different regions, see Figure (3b), which completely follows the style of Figure (2b) for $A_{\text{max}}$. We believe that the ground is rock type for WH stations, and mixed rock and hard soil for EH stations, in agreement with Sharma\textsuperscript{13}. For comparison, we give curves of Trifunac\textsuperscript{2} (average for rock and medium ground) and from Joyner and Boore\textsuperscript{3} (hard soil) for Western US, Atkinson and Boore\textsuperscript{8} (typically rock type) for Eastern North America, Kawashima \textit{et al.}\textsuperscript{4} (average for hard and medium ground) for Japan, and world average of Campbell\textsuperscript{9} (presumably rock). We see again that our result for
Eastern Himalayas is unusually high, above all the others at distances in excess of 50 km, whereas our results for Western Himalayas look quite regular.

**Microzonation and site effect studies of Megacities and Large Urban Areas:**

One of the basic problems associated with the study of seismic zonation/microzonation is to determine the seismic ground motion, at a given site, due to an earthquake with a given magnitude or moment and epicentral distance from the site. The ideal solution for such a problem could be to use a wide database of recorded strong motions and to group those accelerograms that have similar source, path and site effects. In practice however, such a database is not available. Actually, the number of recorded signals is relatively low and the installation of local arrays in each zone with a high level of seismicity is too expensive an operation that requires a long time interval to gather statistically significant data sets. While waiting for data accumulation, a preventive tool is supplied by the realistic modeling, based on computer codes developed from the knowledge of the seismic source and of the propagation of seismic waves associated with the given earthquake scenario. Fäh et al.\textsuperscript{18,19} developed a hybrid method that combines the modal summation technique\textsuperscript{20-23} finite differences\textsuperscript{24-26}, and exploits both methods to their best.

This hybrid approach has been successfully applied, for the purpose of deterministic seismic microzoning, in several urban areas like Mexico City, Rome\textsuperscript{27}, Benevento\textsuperscript{28,29}, Naples\textsuperscript{30} and Catania\textsuperscript{31,32} in the framework of the UNESCO-IUGS-IGCP Project 414 “Realistic Modelling of Seismic Input for Megacities and Large Urban Areas”\textsuperscript{33}.

With this approach, source, path and site effects are all taken into account and a detailed study of the wavefield that propagates at large distances from the epicentre is possible. Several techniques have been proposed to empirically estimate the site effects using observations. As pointed out by Panza \textit{et al.}\textsuperscript{23}, those techniques supply reliable information about the site response to noninterfering seismic phases, but they are not adequate in most real cases when the seismic sequel is formed by several interfering waves. Recently, Lokmer \textit{et al.}\textsuperscript{34} demonstrated that the focal mechanism can play a much more important role in the amplification of ground motion than the local structure itself. Given the complexity of the problem of site response estimation, the realistic modelling can be considered the only way to assess the hazard, by means of
considering several scenario earthquakes and taking envelopes of averages and of upper extremes of the parameters describing the hazard itself.

**First order micorzonation and site effect studies of Delhi city:**

Delhi – the capital of India is a fast growing megacity that influences the economic and industrial developments of much of the country. The estimated population of urban Delhi is now expected to be around 12.2 million. Figure 4a shows the epicentres of some moderate and large earthquakes, which occurred in the Delhi region, as well as the events which occurred in the Himalayan region along the Main Boundary Thrusts (MBT) and Main Central Thrusts (MCT) that have been felt in Delhi. The Himalayan thrust zone just 250-350 kms north of it is presently one of the most hazardous areas of the world that constitutes a significant seismic gap in the Central Himalayas\(^{35}\). Delhi is therefore quite vulnerable to Himalayan earthquakes and its burgeoning population and industrial works face increasing risk from seismic hazard. To mitigate the seismic hazard, it is necessary to define a correct response in terms of both the peak ground acceleration and spectral amplification. These factors are highly dependent on the local soil conditions and the source characterization of the expected earthquakes.

The recent Bhuj earthquake of January 26, 2001 has left many thousands of dead, hundreds of thousands of injured and created billions of Rupees in property damage. This was a shocking event that generated untold misery and captured media attention around the world. We think that now it is the time to learn a lesson from the Bhuj earthquake, and to go for a detailed seismic ground motion modelling for microzonation studies of Delhi city. A first step to mitigate the seismic hazard is to correctly define a response in terms of two factors that are highly dependent on the local soil conditions and on the seismic source characteristics: the peak ground acceleration and the spectral amplification.

**Numerical Modelling of Seismic Ground Motion**

The aim of the present study is to estimate the seismic ground motion along an NS cross-section of Delhi city from ISBT to Sewanagar. The input data necessary for the ground motion simulation consist of the two dimensional structural model, the regional bedrock structures and the focal mechanism solution. Figure 4b shows the North-South cross section of 2-D model from ISBT to Sewanagar, which includes the structural parameters of the local soft soils above the
bedrock. This cross-section has been taken from Iyengar\textsuperscript{36}. This model initially available upto 30 meters of depth has been further extended upto approximate bedrock depth from Iyengar\textsuperscript{36}. A major event of intensity IX (MM) that occurred on 15\textsuperscript{th} July, 1720 has been used as source for modelling. The epicentre (28.7 N, 77.20 E) and magnitude (M=7.4) of this event is taken from Global Seismic Hazard Assessment Program (GSHAP) catalogue.

The synthetic seismograms (SH and P-SV waves) computed with the hybrid method are referred to an array of 100 receivers regularly spaced (every 100 meters) along the cross section. The three component accelerograms shown in Figure 5 clearly define the trend of the amplification effects and reflect the symmetry of the 2-D model. The peak acceleration (AMAX) of 1.6 g is estimated in the transverse component at the nearest receiver from the source at 10 km of distance. This is a quite big number in terms of seismic hazard but may be expected at the epicentre of an event of magnitude 7.4 at higher frequencies. We believe that the 10 kms of epicentral distance is saturated for a large event as far as the damage/ground motion is concerned. Such high values also validates the report of the damage caused by 1720 earthquake\textsuperscript{36}. The other components exhibit peak values in the range of 0.5 to 0.6g.

The response spectra ratio (RSR), i.e the response spectra computed from the signals synthesized along the heterogeneous medium normalized by the response spectra computed from the corresponding signals synthesized for the regional model, is another parameter relevant for earthquake engineering purposes. The distribution of RSR as a function of frequency and epicentral distance along the profile, up to a maximum frequency of 5 Hz, is shown in Figure 6 for the three components. The amplification reaches the largest values for frequencies above 2 Hz, and the maximum is seen in the transverse component (nearly 7), whereas for the vertical and radial components, the amplification is in the range from 4 to 6.

**Conclusions:**

Using strong-motion data available for Himalayan earthquakes, the relationship between strong motion amplitudes, hypocentral distance and magnitude have been established. A theoretical magnitude-dependent distance attenuation law is used for data analysis instead of the empirical regression, and data reduced at a standard distance of 100 km and of magnitude 7 is fixed accordingly. The most important conclusion of the present study is the separation of data into two sub-regions, the eastern and western Himalayan regions. Of these, the western
Himalayan region is comparable in terms of near-source amplitudes, to the Japanese region, whereas the amplitudes in the Eastern Himalayas are three times larger, and have no direct analogue amongst other seismically active region of the globe. Horizontal epicentral accelerations in excess of 1 – 1.5 g are typical here.

Given a certain earthquake scenario, and an appropriate structural model, based on detailed geological, geophysical and geotechnical data, it is possible to realistically evaluate the local amplification in the frequency range of interest for civil engineering, and to obtain valuable parameters for the realistic microzonation. This is possible by applying detailed numerical modelling that takes into account source, propagation and local site effects. An example of the first order ground motion modelling in the part of Delhi City in terms of both the peak ground acceleration and spectral amplification along the NS profile from ISBT to Sewanagar is carried out. The results show that the response spectra ratios are as large as about 7 for the frequency till 5 Hz.

Acknowledgement

The part of the study was carried out when IAP availed the fellowship under the framework of Training and Research in Italian Laboratory (TRIL) and Associateship program of ICTP, Trieste, Italy. Dr. Gangan Prathap, Scientist-in-Charge, C-MMACS has provided the facilities and given permission to publish this work. Chamoli Strong Motion data are provided by Dr. Manish Shrikhande of Department of Earthquake Engineering, University of Roorkee and Dr. S. Teotia from Kurukshetra University. We wish to thank Prof. V.K. Gaur for his valuable suggestion and constant encouragement. We also thank Prof. R.N. Iyengar for providing important data and literature.
Reference:


Table 1. List of events used in the study of $A_{\text{max}}$ and $V_{\text{max}}$

<table>
<thead>
<tr>
<th>No</th>
<th>Region</th>
<th>Date</th>
<th>Time (UT)</th>
<th>Lat. (°N)</th>
<th>Long. (°E)</th>
<th>Depth, km</th>
<th>Mw</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>W.Himalaya</td>
<td>April 26, 1986</td>
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<td>32.17</td>
<td>76.28</td>
<td>15</td>
<td>33</td>
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<tr>
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<td></td>
<td>Oct. 19, 1991</td>
<td>21:23:21</td>
<td>30.73</td>
<td>78.79</td>
<td>15</td>
<td>10</td>
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<tr>
<td>3</td>
<td></td>
<td>March 28, 1999</td>
<td>19:05:11</td>
<td>30.41</td>
<td>79.42</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>E.Himalaya</td>
<td>Sept. 10, 1986</td>
<td>07:50:25</td>
<td>25.42</td>
<td>92.08</td>
<td>_</td>
<td>43</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>May 18, 1987</td>
<td>01:53:59</td>
<td>25.27</td>
<td>94.20</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Feb. 6, 1988</td>
<td>14:50:43</td>
<td>24.64</td>
<td>91.51</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
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<td>Aug. 6, 1988</td>
<td>00:36:37</td>
<td>25.14</td>
<td>95.12</td>
<td>101</td>
<td>91</td>
<td>7.2</td>
</tr>
</tbody>
</table>
Figure 1. Generalized geological and topographical map along with the strong motion arrays and location of the events in Himalayas recorded by the network.

Figure 2 (A) The results of $\log_{10}$ peak acceleration for small distances and large magnitude. The thin solid curves are the predicted values for the Eastern Himalayas and the thin dashed curves are for the Western Himalayas. The thick solid and dashed lines are the segments of the observed data with their centroid for eastern and Western Himalayas, respectively. (B) Comparison of our results on expected $\log_{10}$ peak acceleration versus hypocentral distance with other authors. Our results are the thick solid lines for the Eastern Himalayas and the thick dashed lines for the Western Himalayas for $M_w=7$. The thin curves with solid symbols are from the Himalayan region, while the thin curves with empty symbols are given by different authors for different regions of the world.

Figure 3 (A) Same as Figure 2A but for $\log_{10}$ peak velocity. (B) Comparison of our results on expected $\log_{10}$ peak velocity versus hypocentral distance with other authors. Our results are the thick solid lines for the Eastern Himalayas and the thick dashed lines for the Western Himalayas for $M_w=7$. The thin curves with empty symbols are given by different authors for different regions of the world.

Figure 4 (A). The geological map of Delhi and surrounding areas with the epicentres of the earthquakes occurred in the region. (B) The NS cross-section of 2-D model from ISBT to Sewanagar with soil properties. The original model by Iyengar (2000) gives S-wave velocity and density; to be conservative we have assumed $V_p=2V_s$. The Q values for the different soils are taken from standard compilation.

Figure 5. The cross-section and corresponding synthetic strong motion records at every 100 meters.

Figure 6. The cross-section and corresponding the plot of response spectra ratio (RSR) with frequency.
\[
\begin{align*}
&\text{Hypocentral Distance, km} \\
&\log_{10} V_{\text{max}}, \text{ cm/s} \\
&\text{Mw} = 5 \\
&\text{Mw} = 7 \\
&\text{Mw} = 8
\end{align*}
\]