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*Technical Note*

# SEISMIC RISK ASSESSMENT BASED ON ATTENUATION RELATION

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## ABSTRACT

A micro level study of seismic risk assessment is proposed considering spectrum based on attenuation relation in Indian context. A seismic loss model using regional ground motion attenuation relation which allows specifying hazard on micro-seismic level in terms of source-site parameters of the scenario earthquake is used. The advantage of using attenuation relation in defining hazard scenario is an improvement over the code defined response spectra which assumes the ground motion response as elastic curve which is unrealistic. The damage probability of the buildings is calculated from the performance point obtained by using capacity spectrum approach. The loss model as per HAZUS is adopted for the risk estimation. The proposed methodology is used to estimate the seismic loss of an institutional campus of India as a case study and the estimated direct economic loss is found to be 3,70,70,067 (INR). The methodology can also be used as an effective tool for disaster preparedness.

**Keywords:** Seismic risk assessment; attenuation relation; vulnerability: seismic loss.

## 1. INTRODUCTION

Seismic risk assessment is vitally important for earthquake hazard mitigation programme. In general, risk may be defined as the chance of occurrence of an event that will have an impact upon objectives. It is measured in terms of consequences and likelihood. The objective of an earthquake risk assessment is to quantify the potential losses due to future earthquakes and their probabilities of occurrence in a given period. Several studies have proposed different risk assessment methodologies using a variety of seismic hazard and vulnerability parameters. Conventionally, seismic risk assessment have been developed mainly based on intensity and PGA (Peak Ground Acceleration) approach because of the fact that it bypasses the problems associated with relating damage to physical measures of ground motion. The

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physical parameters of ground motion are effectively hidden, and the difficulties associated with quantifying damage as a function of such parameters simply do not arise [1]. Various softwares have also developed and applied to many areas of the world. RADIUS [2] defines hazard scenario by earthquake parameter such as magnitude, epicenter, and time of earthquake and in some cases its location from which PGA is generated. The net PGA after considering the soil type is converted to intensity scale which is then linked to vulnerability function using Damage probability. RISK.iitb [3] defines Seismic hazard in terms of PGA at the building site which is then change to MSK scale and the structural vulnerability is given in terms of damage probability matrices (DPMs) that provide the level of damage corresponding to ground motion intensity as a conditional probability factor. IVARA [4] considers hazard in terms of seismic intensity scale and for vulnerability function, the 'Upper Bound' and 'Lower Bound' DPMs have been implemented.

Some researchers have linked the seismic vulnerability of the buildings to response spectra obtained from the ground motions and have been implemented in many seismic loss estimation tools. Such type of approach follows performance based seismic analysis. The software HAZUS-MH MR2 [5] provides a powerful technique for earthquake loss estimation in which capacity-spectrum method (CSM) as per ATC-40 [6] is used, which is a performance-based seismic analysis. However, it is so intimately connected to environments in the U.S. and that it is not easy to apply to other countries. Similarly, SELENA [7] is also a performance-based seismic analysis like HAZUS-MH MR2 [5] but this method implements a modification version of ATC40 [6] and DCM (Damage Co-efficient Method) of FEMA-356 [8] along with ATC-40 [6]. The advantage of this method is it employs weighted logic tree scheme which considers epistemic uncertainties of the different input parameters and, thus, providing the final results with corresponding accuracy levels. Seisvara [9] has considered intensity based approached as well as spectrum based approach. The author has pointed out the limitation of code based response spectra in conjunction of PGA and has implemented the inelastic response spectra using next generation ground motion equations. Both the empirical as well as the analytical based vulnerability function approach have been implemented in the method.

A slightly different analytical loss estimation approach is implemented in the software Dbela [10], which computes demand and capacity of building classes in terms of displacement at different damage limit states. Capra [11] also uses probabilistic risk assessment and allows evaluating losses on exposed elements using probabilistic matrices, such as the loss exceedance curve, the expected annual loss and the probable maximum loss, which are useful for multi-hazard risk analysis.

In the present study, a seismic loss methodology is given considering Indian context in which an attenuation-based spectrum is used without considering the codal based design spectrum. The use of attenuation relation in defining hazard scenario is an improvement over the code defined response spectra which assumes the ground motion response as elastic curve which is unrealistic.

## 2. RISK METHODOLOGY USING ATTENUATION BASED SPECTRUM APPROACH

The approach seismic loss model allows specifying hazard on micro-seismic level in terms of source-site parameters of the scenario earthquake using regional ground motion attenuation relation given by of Raghu Kanth and Iyengar [12]. The attenuation relation provides response spectra for the period range up to 4.0 s for Indian region and is given by Eq. (1).

$$\ln(y_{br}) = C_1 + C_2(M-6) + C_3(M-6)^2 - \ln(r) + \ln(\varepsilon_{br}) \tag{1}$$

Here, $\ln(y_{br})$ = the ratio of spectral acceleration at bedrock level to acceleration due to gravity. The coefficients $C_1$, $C_2$, $C_3$ and the standard error $\varepsilon_{br}$ for Western–Central (W–C) region, Koyna–Warna (K–W) region and Southern India (SI) region are given by the author. The parameters required for the attenuation relationship are moment magnitude (M) and hypocentral distance (r). This attenuation equation is derived for 5% damped response spectra corresponding to bedrock conditions in Peninsular India. Three soil types are considered in which the amplification factors are 1, 1.2 and 1.4 for hard, medium and soft soil respectively where the soil classification is as per IS-1893[13] for the approach methodology.

The vulnerability function is provided by the damage probabilities of the defined buildings obtained from the performance point of the buildings and the fragility curve. The analytical capacity spectrum- based approach is used to find out the performance point. The elastic capacity curve of a building has been modified using coefficient $C_1$ and $C_2$ [14], Where, $C_1$ is modification factor to relate the expected maximum displacements of an inelastic single degree of freedom oscillator with hysteretic properties to displacements calculated for the linear elastic and $C_2$ is modification factor to represent the effect of pinched hysteretic shape, stiffness degradation and strength deterioration on the maximum displacement response. The modification factor $C_1$and $C_2$ is given in Eqs. (2) and (3) respectively.

$$C_1 = 1 + \frac{R-1}{aT_e^2} \tag{2}$$

Where, 'a' is a constant term which values is 130, 90 and 60 for hard, medium and soft soil respectively. $T_e$ is the fundamental period of the building and R is the strength ratio of spectral acceleration at performance point to the spectral acceleration at yield point.

$$C_2 = 1 + \frac{1}{800}\left(\frac{R-1}{T_e}\right)^2 \tag{3}$$

For any building, capacity curve upto yield point is given by relation given in Eq. (4).

$$\frac{S_a}{S_d} = C_1 C_2 (\frac{2\pi}{T_e})^2 \tag{4}$$

Where, $S_a$ is the spectral acceleration and $S_d$ is the spectral displacement upto yield point.

A systematic flowchart of the approach seismic loss model is given in the fig. 1. and the procedure of the seismic loss methodology is as below :

- Define all the possible sources to cause significant hazard at a site from historic tectonic, geologic or geotechnical data. The earthquake data can be generated from historical earthquake catalogue where each catalogue will be for an arbitrary period (say 100 years). Add 0.5 magnitude units to the largest historical earthquake [15].
- Estimate ground motions via ground motion attenuation curve at the site in terms of spectral ordinates using attenuation relationship of Eq. (1). From the ground motion response spectra, demand curve is obtained by using the formula given in Eq. (5).

$$\frac{S_a}{S_d} = (\frac{2\pi}{T})^2 \tag{5}$$

- Where $S_a$ and $S_d$ are the spectral acceleration and spectral displacement respectively of the ground motion and T is the time elapsed during motion.
- Find out the fragility function from the building capacity curve and damage state definition. In the developed methodology, fragility function is defined for 6 damage states as per kappos et al. [16] based on yield ($s_{dy}$) and ultimate displacement ($s_{du}$) parameters of the capacity curve of building. The fragility curves distribute damage among undamaged, slight, moderate, substantial to heavy damage, very heavy and collapse damage states. The probabilities of exceedence of any given damage state is given by Eq. (6).

$$P[\frac{d_s}{S_d}] = \phi[\frac{1}{\beta_{ds}} \ln(\frac{S_d}{S_{d,ds}}) \tag{6}$$

Where $S_{d,ds}$ is the performance point or median value of spectral displacement ($S_d$) at which the building reaches the threshold of damage state ($d_s$);

$\beta_{ds}$ is the standard deviation of the natural logarithm of spectral displacement for damage state, $d_s$; and $\phi$ is the standard normal cumulative distribution function.

- Find out the performance point which is the intersection point of demand spectra and building capacity curve. The capacity curve use here is the modified capacity curve as per Eqs. (2), (3) and (4).
- Find out the seismic loss from the loss function which is given in term of damage probabilities of different damage sate, obtained from fragility curve and performance point. After finding corresponding damage probabilities of different damage sate, the total economic losses of a given MBT (Modified building typology) is estimated by Eq. (7).

Total loss direct economic of a MBT = ∑ (probability of loss of given damage state and MBT)*(% loss corresponding to damage state and MBT)*Total cost. (7)

For a group of similar buildings, the total number of injuries or life loss can be obtained by multiplying the probability of severity level with the total number of occupants. The probability of severity level is given by Eq. (8).

$$P(Si)_{MBT} = \sum_{j=1}^{n} (P(Si / Gr_j) XP(Gr_j)_{MBT} \quad (8)$$

Where, $P(Si)_{MBT}$ = Probability of Severity Level 'i' in a MBT; $P(Si / Gr_j)$ = Casualty rate of severity 'i' for damage grade 'j'; $P(Gr_j)_{MBT}$ = Probability of occurrence of damage grade 'j' in a MBT.

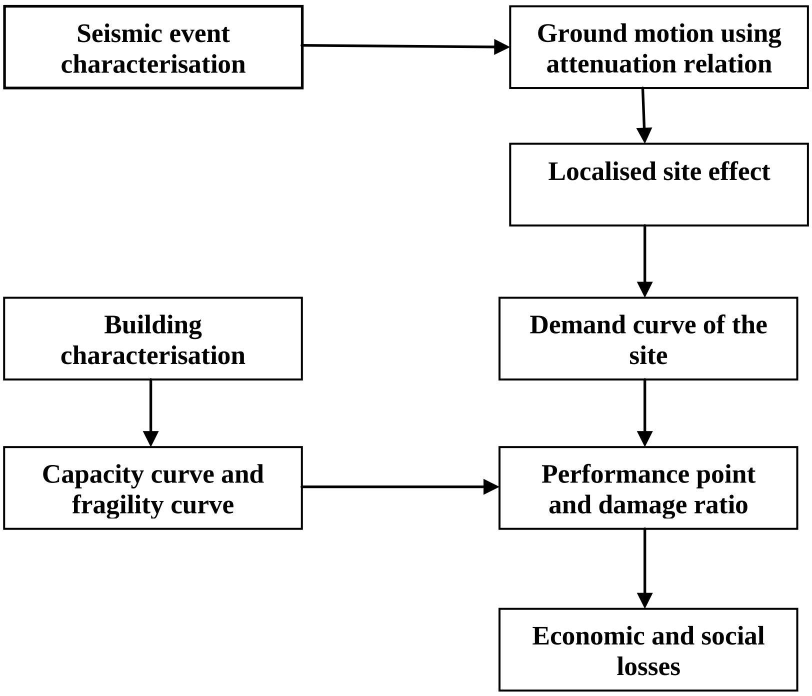



Figure 1. Schematic flowchart of the Risk methodology

## 3. A WORK EXAMPLE

In this example, a simple risk assessment is prepared for a selected site of an institutional building of NIT Durgapur campus in India located at 23.5483° N, 87.2914° E. The location is shown in fig. 2. The description of the building occupancy, inventory type and population has been evaluated with the help of detail survey work of the campus and using satellite data. The occupancy class and the building types found in the area are shown in fig.3.

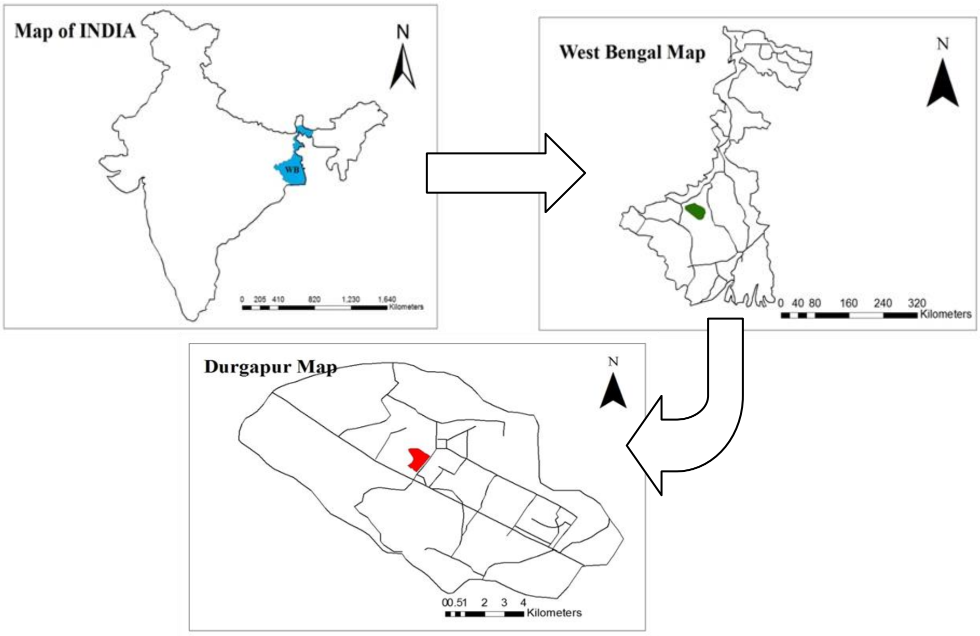



Figure 2. Location of NIT Durgapur Campus

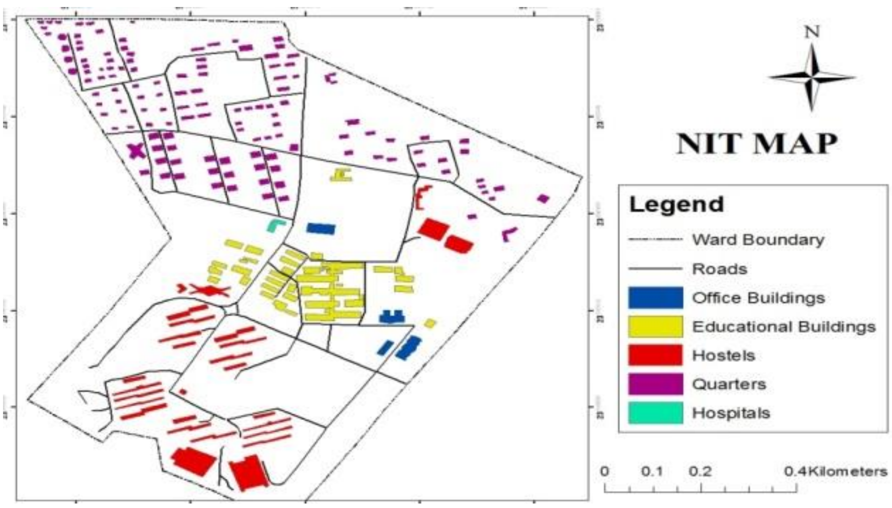


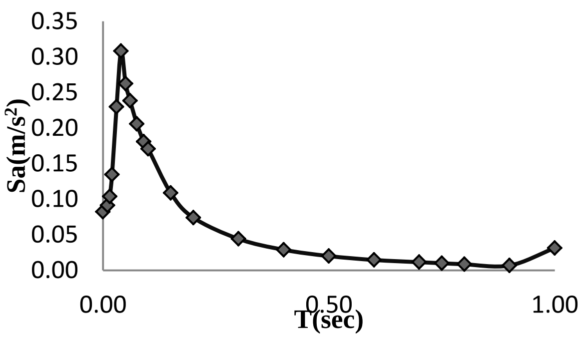

Figure 3. Building occupancy classes found in NIT Durgapur Campus

The building type consists of mainly concrete frame with URM infill, steel frame with URM infill and masonry bearing wall frame. The building features are compared with MBTs with available literatures and the buildings are found to be similar with building classification of Jaiswal K and Wald DJ [17]. The details of building inventory are given in Table 1.

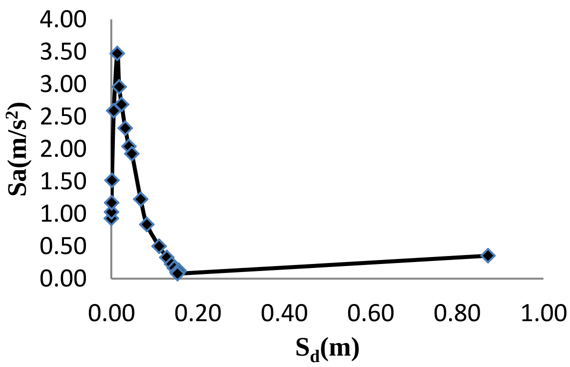
Table 1: Building inventory detail of the case study

| Occupancy class | MBT | Area ($m^2$) | Day time population | Night time population |
|---|---|---|---|---|
| Residential | RC3L-MC | 77749 | 256 | 2647 |
| | RC3M-MC | 67496 | 0 | 1515 |
| | RC3H-MC | 7065 | 0 | 0 |
| Educational | RC3L-MC | 22174 | 2650 | 0 |
| | RC3M-MC | 23928 | 2234 | 0 |
| | ME1L1 | 1453 | 12 | 0 |
| | ST1L | 5474 | 22 | 0 |
| Commercial | RC3L-MC | 2400 | 2 | 0 |

For hazard analysis, a detailed catalogue of historical and recent seismicity within 400 km radius around the institute has been compiled for the earthquake data. In the study, largest historical earthquake of moment magnitude 4.2 has been used for the hazard analysis which is then increased by 0.5 magnitude units. Using Eqs. (1) and (5), the generated response spectra and demand curve due to the defined earthquake is shown in fig.4.




(a)




(b)

Figure 4. Derived ground motion curve using attenuation relation: (a) Response spectra; (b) Demand curve

Table 2: Capacity curve parameters of MBTs [18]

| MBT | Capacity curve parameters | | | |
|---|---|---|---|---|
| | $S_{ay}$(m/sec$^2$) | $S_{au}$(m/sec$^2$) | $S_{dy}$(m) | $S_{du}$(m) |
| RC3L-MC | 3.237 | 3.924 | 0.0049 | 0.0511 |
| RC3M-MC | 2.256 | 2.943 | 0.0103 | 0.068 |
| ST1L | 0.981 | 1.961 | 0.003048 | 0.03048 |
| ME1L1 | 5.47 | 5.47 | 0.00228 | 0.02518 |
| RC3H-MC | 0.618 | 1.402 | 0.018796 | 0.10492 |

For finding out the fragility curve, the capacity curve as per [9] has been taken and the details are shown in table 2. The building performance point has been found out as explained in Section 2 and the performance point of RC3H-MC is shown in fig.5. Similarly, the performance point of other MBTs is found and is given in table 3.

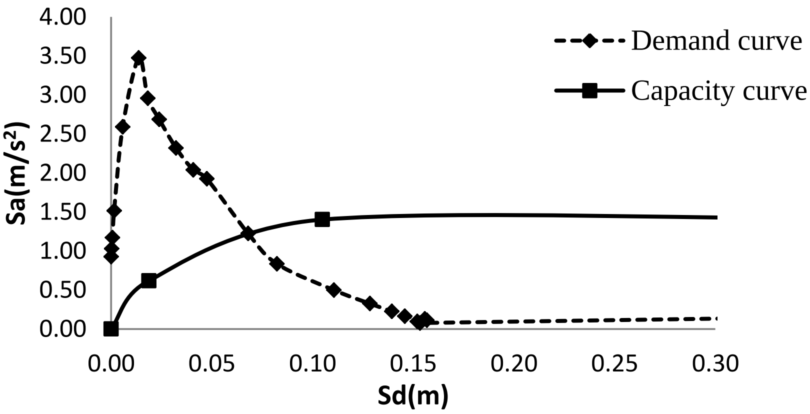



Figure 5. Performance point for RC3H-MC

Table 3: Performance point of the MBTs

| MBT | RC3L | RC3M | ST1L | ME1L1 | RC3H-MC |
|---|---|---|---|---|---|
| Calculated $S_{dp}$ (m) | 0.0027889 | 0.0286925 | 0.0365423 | 0.0004596 | 0.0723739 |

The loss ratios in terms of percentages of building replacement cost for all the damage types are taken from HAZUS-MH MR2 [5]. In the present methodology, the loss ratios for structural and non-structural loss (%) in terms of building replacement cost adopted are 2, 10, 50, 100 and 100 for slight, moderate, Substantial to heavy, very heavy and collapse damage state respectively while the content loss (%) in terms of building content values are 1, 5, 25, 50 and 50 for slight, moderate, Substantial to heavy, very heavy and collapse damage state respectively. The HAZUS-MH MR2 [5] model of life and injury losses is adopted and the severity level description is given in Table 4. Applying the loss models given in Eqs. (7) and (8) on the available exposure condition, the losses are estimated and given in table 5. A total direct economic loss 3,70,70,067 (INR) was estimated for the said campus and can be used for disaster preparedness.

Table 4: Injury Severity Level definition [5]

| Severity Level | Description |
|---|---|
| Severity 1 | Injuries requiring basic medical aid that could be administered by Para-professionals. These types of injuries would require bandages or observation. |
| Severity 2 | Injuries requiring a greater degree of medical care and use of medical technology such as X-rays or surgery, but not expected to progress to a life-threatening status. |
| Severity 3 | Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously. |
| Severity 4 | Instantaneously killed or mortally injured. |

Table 5: Estimated losses using the method

| Estimated Parameters | Total Direct Economic Loss (INR) | Casualties loss (day time) | Casualties loss (night time) | Injuries (day time) | Injuries (night time) |
|---|---|---|---|---|---|
| Approached method | 3,70,70,067 | 0 | 0 | 23 | 4 |

## CONCLUSIONS

The use of attenuation based seismic hazard studies is currently not use widely, probably due to unavailability of regional attenuation which can defined the suitable ground motion characterisation of the area to be assessed. The advantage of using attenuation relation in defining hazard scenario is an improvement over the code defined response spectra which assumes the ground motion response as elastic curve which is unrealistic. In the present study, a seismic loss model is given mainly for India context in which attenuation based spectrum approach for risk analysis is adopted. A step by step procedure is also shown along with an example analysis of institutional buildings of India to illustrate the approach seismic risk methodology. The attenuation relation used here defines a suitable hazard scenario for Indian condition with moment magnitude and location of the earthquake as parameters. The direct economic loss, life loss and injuries at day and night time of the area taken into consideration are estimated. The methodology has been evaluated considering an educational campus in Indian region but it can be easily adopted for any region by changing an appropriate seismic risk parameter definitions. A total direct economic loss of 3, 70, 70, 067 (INR) was estimated for the said campus and can be used for disaster preparedness.

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