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A REVIEW OF SITE SPECIFIC ESTIMATION OF SEISMIC DESIGN PARAMETERS

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ABSTRACT

The earthquake ground motion for safe and economical design of important structures like dams, nuclear power plants, long span bridges is required to be estimated in a site-specific manner. To estimate the site-specific seismic design parameters, one has to perform a seismic hazard analysis for a project site of interest. The process of evaluating the design parameters of earthquakes ground motion is called seismic hazard assessment. It can be performed deterministically, when a particular earthquake scenario is considered, or probabilistically, when the likelihood of specified earthquake size and location are evaluated. The deterministic seismic hazard analysis (DSHA) proposes the design of a structure for a maximum considered earthquake. The probabilistic seismic hazard analysis (PSHA) takes into consideration that the likelihood of occurrences should also be considered by assuming that the life of a structure is generally much shorter compared to the recurrence intervals of large earthquake events. The present paper gives an account of the methodologies involved in the seismic hazard assessment.

1. INTRODUCTION

The site-specific nature of ground motion may be attributed to two main aspects: first the characteristics of the seismicity and second the geological condition at the site and the surrounding area. It becomes necessary to have an explicit and physically realistic modelling of both these influences to have a site-specific estimation of the design ground motion. The difference between seismic hazard and seismic risk assessment needs to be noted despite the fact that in everyday usage these two phrases have the same meaning. Seismic hazard is used to characterize the severity of ground motion at a site regardless of the consequences, while the risk refers exclusively to the consequences to human life and property loss resulting from the hazard caused due to collapsing of structures. Thus, even a strong earthquake can have little risk potential, if it is far from human development and infrastructure, while a relatively smaller seismic event at an unfortunate location may cause extensive damage to property and loss of life. The common practice in seismic hazard assessment, is to first specify the design ground motion in terms of a smoothed target response spectrum and synthesize the design acceleration time-histories to be compatible with this spectrum. However, depending upon the location of various active tectonic features and the spatial distribution of the past earthquakes, the site-specific response spectrum will differ significantly from site to site within a broad seismic zone. It is, therefore, necessary to have site-specific studies to evaluate the seismic design parameters for all important projects. Irrespective of the methodology used, two different levels of ground motion are generally considered for the design of important engineered structures. These correspond respectively to a rare but plausible event termed as the Maximum Credible Earthquake (MCE) and a more likely event during the life of a project, termed as the Design Basis Earthquake (DBE). MCE is the largest reasonably conceivable earthquake along a recognized fault or within a geographically defined tectonic province under the presently known or presumed tectonic framework. The MCE is generally defined as an upper bound of expected magnitude with little regards to its probability of occurrence. The ground motion associated with MCE is used only to check that a structure of interest does not collapse in a sudden and uncontrolled manner but may suffer few non structural damages. If the damage of a project may lead to high-level of off-site hazard, all the systems and components necessary for ensuring the safety of the project are required to be functional during and after the occurrence of this earthquake. For example, in case of nuclear power plants, it is necessary to ensure the integrity of the reactor coolant pressure boundary and the functional operability of all the equipment and systems necessary to shut down the reactor and maintain it in a safe shutdown condition. Whereas, in case of dams, some damage, which does not impair the ability of the dam to hold the impounded water, is permitted under MCE level of ground motion. On the other hand, a structure is required to safely withstand the ground motion due to DBE.

2. DETERMINISTIC METHODOLOGY

In the deterministic approach, the design ground motion is estimated for a fixed earthquake magnitude and source-to-site distance combination. Although there is no generally accepted DSHA approach for all parts of the world and all application areas (e.g.; design of dams, nuclear power plants or ordinary structures), in its most commonly used forms, it intends to obtain the most severe ground motion by maximizing the magnitude and minimizing the distance (Anderson, 1997; Gupta, 2002). To obtain the deterministic MCE level of ground motion, it is first necessary to assess the maximum possible earthquake magnitude (M_{max}) for each of the seismic sources within an area of about 300 km radius around a project site. The M_{max} for each source is assumed to occur at a location, which makes the distance from the project site as the shortest possible. The ground motion is then predicted by using empirical attenuation relation. The highest of the ground motions corresponding to all the sources is taken as the deterministic estimate of the design ground motion. A typical DSHA can be described as a four-step process consisting of (a) Identification and characterization of all sources (b) Selection of source – site distance parameter (c) Selection of "controlling earthquake" and (d) Definition of hazard using controlling earthquake.

2.1 Identification of Seismic Sources

A seismic source represents the zone of the earth's crust with distinctly different characteristics of earthquake activity from those of the adjacent crust. The source zones in a region are identified on the basis of some sort of geological, geophysical, geodetic and seismotectonic uniformity. The seismic potential of a source zone has to be distinctly different from the other adjacent sources. However, due to lack of knowledge about all the faults and wide dispersion of the epicenters of past earthquakes in relation to the known faults, broad area sources encompassing several faults are used commonly in real practice. Such seismic sources may be associated with the geological structures like uplifts, rifts, folds and volcanoes, which release the tectonic stresses and localize the seismic activity. Another type of seismic source used in practical applications is the "tectonic province", which generally covers a large geographic area of diffused seismicity with no identifiable active faults or geological structures. Mostly line sources and areal source zones can be considered sufficient for most practical applications.

2.2 Estimation of Maximum Magnitude M_{max}

Estimation of the maximum potential for each seismogenic sources in terms of M_{max} is the most important aspect of DSHA method. However, due to limited earthquake history and incomplete understanding of the earthquake generating processes in most cases, this task is rendered very difficult and suffers from considerable subjective decisions. However, addition of an increment of 0.5 to 1 unit to the largest historical earthquake and use of fault rupture parameters after Wells and Coppersmith (1994) are generally used to get an estimate of the maximum shock for a source zone.

2.3 Estimation of Target Spectrum

To obtain the deterministic target response spectra, it is necessary to assign the shortest possible source-to-site distance to the M_{max} for each of the seismic sources. It is straightforward to define this distance for the line and dipping plane sources. For an area source, if the site lies outside the source, the distance is defined to the point on the boundary of the seismic source closest to the site. On the other hand, if the site happens to be within the source, it may be more rational to consider a non-zero minimum distance based on past seismicity or tectonic considerations. Also, for the source zone of the project site it may be necessary to consider the known tectonic features in the vicinity of the project site and their seismic potential, if the M_{max} for the entire source zone is considered to occur on some distant tectonic feature. Using all the M_{max} and their minimum distances defined in this way, the target response spectra of horizontal and vertical components with damping ratio of 5% are obtained using suitable frequency-dependent attenuation relationship. For the purpose of design, the largest of all the response spectra is selected in some suitable way as the deterministic target spectra, because none of the response spectra may be the largest over the entire frequency range.

The median estimate of the response spectrum has about 50% chance of being exceeded due to future earthquakes. Therefore, to take into account the effect of random scattering of the observed data around the median attenuation relationship, the MCE level of target response spectrum is commonly taken as the median plus one standard deviation estimate (84 percentile). All the systems and components necessary for ensuring the safety of a dam (e.g., bottom outlet and/or spillway gates) are required to be functional during and after the occurrence of MCE level of ground motion. The notion of using the 84 percentile values is based on the fact that if the consequences of failure are greater, the frequency of exceeding the design ground motion should be very low. As the recurrence period of the maximum possible magnitude is not known in most cases, the deterministic method is generally unable to quantify the return period of the ground motion.

The DBE level of deterministic target response spectra of horizontal and vertical ground motion are commonly taken subjectively as a fraction (say, 1/2) of the corresponding MCE level of spectra. Alternatively, they may be taken as one standard deviation less the MCE level of spectra. The basis for DBE lies in its reality and economy. There should be no significant damage to a dam and the appurtenant structures, and equipments should remain functional and damage easily repairable during and after the occurrence of this level of ground motion.

2.4 Illustrative Example of DSHA Methodology

To illustrate the application of the foregoing DSHA methodology, Fig. 1 shows an area of 6° Lat × 6° Lon around a project site shown by solid triangle in the highly seismic Garhwal Himalayan region. The tectonic features in the region of the site are shaped by the collision of the Indian plate with the Eurasian plate under the framework of plate tectonics. The major tectonic features in the region can be divided longitudinally into five major crustal formation zones identified from south to north as (i) outer zone of the fore-deep, (ii) inner zone of the fore-deep forming the Himalayan foot-hills (iii) Lesser Himalaya formed by superposition of a series of tectonic nappes and probably thrusted over the fore-deep, (iv) the High Himalaya and (v) the Indus-Tsangpo Suture zone. The first four of these zones are separated from each other by large thrust faults. The Main Frontal Thrust (MFT) runs at the boundary between the outer and the inner zones of the fore deep. The Main Boundary Thrust (MBT) separates the napped-folded complex of the Lesser Himalaya from the Himalayan foothills. A thick stratum of crystalline rock comprising the High Himalaya is thrusted over the metamorphosed deposits of the Lesser Himalaya along the MCT. The belt north of High Himalaya and bound by Indus-Tsangpo Suture is known as Tethys Himalaya, which consists of fossiliferrous sedimentary rocks.

In addition to the major structural discontinuities of the Himalayan region, there are a number of other faults/lineaments in the region. In the northwestern part of the region, several subsidiary thrusts exist between MBT and MFT, some of which have considerable spatial extent, viz. Jwalamukhi and Drang Thrusts. A number of transverse faults also exist within the Himalayan ranges as well as to the south in the Indo-Gangetic planes, which are associated with varying levels of seismicity. To get an idea about the association of past earthquakes with various tectonic features in the region, the epicenters of past earthquakes superimposed on the major tectonic features is also shown in Fig. 1. Considering the spatial distribution and correlation of seismic activities with the tectonic features, following four broad seismic sources have been identified in the area: Trans-Himalayan (TRH) area north of ISZ, Tethys Himalayan (THH) area between MCT and ISZ, Main Himalayan Thrusts (MHT) area of MCT, MBT, Aravalli Fold Belt (AFB) area in the Indo-Gangetic Plains.

There is a marked concentration of epicenters along the Kaurik Fault system (KFS) in the THH main source, which has been therefore defined as a separate sub-source. All the identified seismic sources are shown demarcated in Fig. 2 along with the epicenters of past earthquakes. To define all the contending MCE magnitudes and their closest distances for the various seismic sources, it is also necessary to analyze in detail the seismic potential of the tectonic features in close vicinity of the project site in the MHT source zone in which the site is located. The tectonic features in the vicinity of the site are the Srinagar Thrust at a distance of about 0.5 km south of the project site, the E-W trending Alaknanda Fault at a distance of about 11 km north of the project site, and the north Almora thrust (NAT) at a distance of 20 km. Though, the 1905 Kangra earthquake of M8.0 has occurred in the MHT source zone, these nearby faults/ thrusts in this source are characterized by much lower seismic potential. The north Almora Thrust is known to have produced a maximum earthquake magnitude of 6.0, and enhancing it by 0.5 magnitude units, the MCE for it can be taken as 6.5. The Srinagar

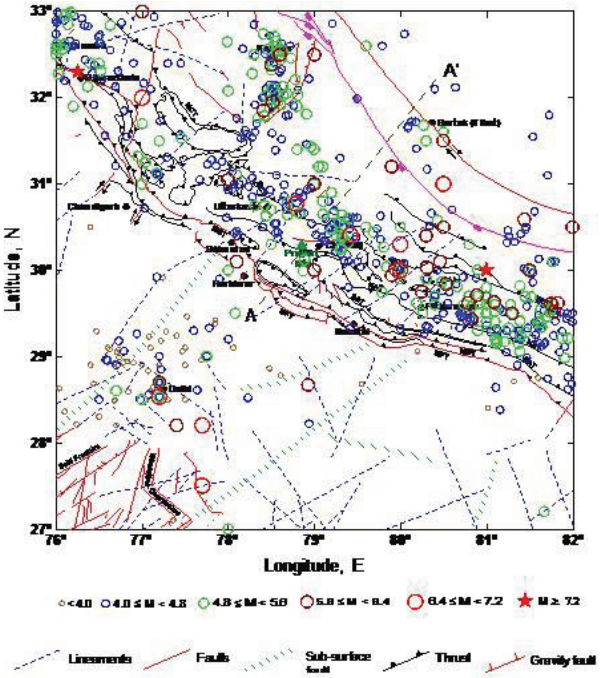

Fig. 1: Major tectonic features in the area of the project site along with the epicenters of past earthquakes.

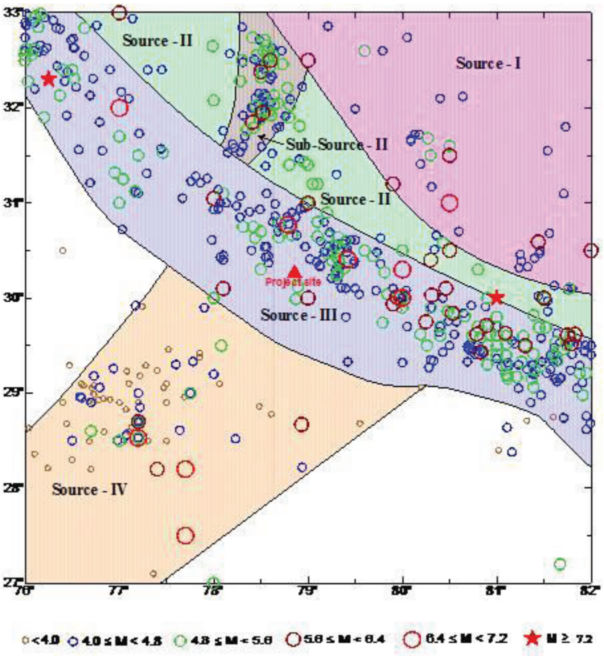

Fig. 2: Identified seismic source zones along with the epicenters of the past earthquakes.

Thrust is known to have produced a maximum magnitude of 4.8 only. However, this may be considered a westward extension of the north Almora Thrust, and is thus assigned an MCE of 6.0. The MCE for Alaknanda Fault is also taken as 6.0, though it has produced a lower maximum magnitude of 4.5, than that for the NAT. For the MHT source zone as a whole, enhancing the magnitude of Kangra earthquake by 0.5 magnitude units gives an MCE magnitude of 8.5. However, the likely location of such a great earthquake is expected to be between MBT and MFT. Thus, the closest distance of 60 km of MBT to the project site is assigned to the MCE of 8.5. Further, the seismicity in MHT source is seen to be mainly concentrated north of the MCT, with two largest magnitudes as 6.6 and 6.8 due to Uttarkashi and Chamoli earthquakes, respectively. The MCT passes at a closest distance of about 35 km from the project site. Enhancing the largest known magnitude in this area by 0.5 magnitude units leads to an MCE of 7.3. In view of the above analysis, a magnitude of 7.7 is considered quite conservative estimate of MCE at a distance of 35 km, representing the closest distance to the MCT.

The closest distance to the fault rupture, R_{rup}, for the various MCE magnitudes is defined using the above-mentioned closest possible epicentral distance and the assumed depth to the tip of the fault rupture. All possible combinations of MCE magnitude and closest distance from the fault rupture are listed in Table 1.

The 5% damped mean plus one standard deviation target response spectra for each combination of MCE magnitude and its closest distance to fault rupture have been evaluated using the frequency-dependent attenuation relation due to Abrahamson and Silva (1997). All the spectra thus obtained for the horizontal component of motion are shown in Fig. 3. The response spectrum for the MCE magnitude of 6.5 occurring at a closest distance of 9.7 km on the Srinagar fault is found to be the highest, which is therefore taken as a basis for the deterministic estimate of the MCE level of target response spectrum.

Table 1 : Magnitude – distance combinations for DSHA

Sr. No.	Tectonic Feature	Type of Faulting	Magnitude of MCE	Epicentral Distance (km)	Closest Distance, R_{rup}, (km)
1.	Main Central Thrust	Thrust	7.7	35.0	36.4
2.	Alaknanda Fault	Strike	6.0	11.0	13.6
3.	Srinagar Thrust	Thrust	6.0	0.5	9.7
4.	North Almora Thrust	Thrust	6.5	20.0	22.2
5.	Main Boundary Thrust	Thrust	8.0	60.0	60.8

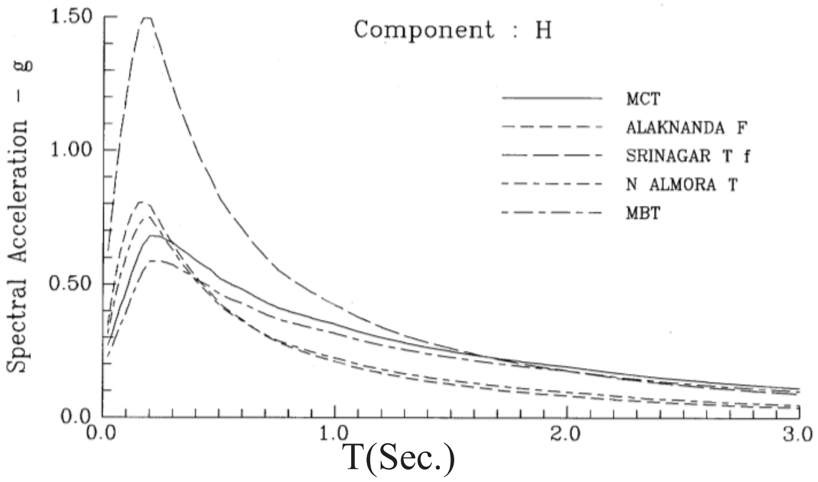

Fig. 3 : The 5% damped mean + σ response spectra for all contending MCE magnitudes and distances n the project area.

3. PROBABILISTIC METHODOLOGY

The use of probabilistic concepts has allowed uncertainties in the size, location, and rate of recurrence of earthquakes and in the variation of ground motion characteristics with earthquake size and location to be explicitly considered in the evaluation of seismic hazards. *Probabilistic seismic hazard analysis* (PSHA) provides a framework in which these uncertainties can be identified, quantified, and combined in a rational manner to provide a more realistic picture of the seismic hazard. The PSHA can also be described as a procedure of four steps , each of which bears some degree of similarity to the steps of the DSHA procedure. The first step, identification and characterization of earthquake sources, is identical to the first step of the DSHA, except that the probability distribution of potential rupture locations within the source must also be characterized. In most cases, uniform probability distributions are assigned to each source zone, implying that earthquakes are equally likely to occur at any point within the source zone. These distributions are then combined with the source geometry to obtain the corresponding probability distribution of source-to-site distance. The DSHA, on the other hand, implicitly assumes that the probability of occurrence is 1 at the points in each source zone closest to the site, and zero elsewhere. Next, the seismicity or temporal distribution of earthquake recurrence must be characterized. A *recurrence relationship,* which specifies the average rate at which an earthquake of some size will be exceeded, is used to characterize the seismicity of each source zone. The recurrence relationship may accommodate the maximum size earthquake, but it does not limit consideration to that earthquake, as DSHAs often do. The ground motion produced at the site by earthquake of any possible size occurring at any possible point in each source zone must be determined with the use of predictive relationships. The uncertainty inherent in the predictive relationships is also considered in a PSHA. Finally, the uncertainties in earthquake location, earthquake size, and ground motion parameter prediction are combined to obtain the probability and to the mechanics of the probability computations.

By maximizing the magnitude and minimizing the distance, the deterministic approach intends to get an upper limit for the MCE level of ground motion, which may sometimes be unduly conservative. More rational lower levels of ground motion are thus required to be used in practical applications. In this regard, the ICOLD (2010) and CBIP (2007) suggests the use of Safety Evaluation Earthquake (SEE) or Maximum Design Earthquake (MDE) level of ground motion defined probabilistically with different recurrence periods, depending upon the risk class associated with the failure of a dam. For dams whose failure would present a great social hazard (i.e., extreme and high risk class) the MDE/ SEE level of ground motion is defined with return period of about 10,000 years. The return period for dams with moderate risk class may be 3,000 years and with low risk class as 1,000 years. The probabilistic seismic hazard analysis (PSHA) approach provides a powerful tool to obtain such estimates of the design ground motion.

The PSHA approach is based on an altogether different philosophy and differs from the DSHA approach in two major aspects. First, a single scenario earthquake in DSHA is not able to provide a true picture of the seismic hazard at a site, because different combinations of magnitude and distance contribute more significantly in different frequency bands. Small magnitude local earthquakes often dominate the high frequency spectral amplitudes, whereas large magnitude earthquakes at even very large distances may dominate the low frequency amplitudes. The PSHA approach takes into account the effect of all the earthquakes between specified lower and upper bound magnitudes distributed appropriately over the entire area around a project site to provide all expected combinations of magnitude and distance. Second, the DSHA defines the MCE level of target response spectra with 84 percentile level without any consideration for the recurrence period of the MCE magnitude. Thus the return period of the deterministic spectra remains undefined. The PSHA, on the other hand, considers the annual occurrence rate of all possible magnitude and distance combinations, along with all possible ground motion probability levels. The probabilistic ground motion is then defined for a specified return period, such that it is not exceeded due to any of the expected earthquakes.

The early history and evolution of PSHA approach is described in a paper by McGuire (2007). Most of the developments in PSHA are based on the classical paper of Cornell (1968), who considered peak ground acceleration as the ground motion parameter. Cornell's original formulation has not considered the randomness in the ground motion attenuation relationship. Anderson and Trifunac (1977, 1978) generalized the PSHA formulation by modeling the seismicity in more realistic way. Details on the currently used PSHA approach can be found in Cornell and Vanmarcke (1969), US Army Corps of Engineers (1999), Gupta (2002), McGuire (2004), etc.

The basic PSHA approach is based on computing the following probability distribution of a specified measure of the ground motion amplitude (e.g., the acceleration response spectrum amplitude *SA(T)* at natural period *T)*:

$$P[SA(T)] = 1 - \exp\left\{ -Y \sum_{n} \sum_{j} \sum_{i} q_n[SA(T) \mid M_j, R_i] \cdot \upsilon_n(M_j, R_i) \right\} \qquad ...(1)$$

In this expression, Y is the exposure time; $\upsilon_n (M_j, R_i)$ is the annual occurrence rate of earthquakes of magnitude M_j at distance R_i in the nth seismic source zones around the project site, and $q_n [SA(T) \mid (M_j, R_i]$ is the probability of exceeding the spectral amplitude $SA(T)$ due to magnitude and distance combination (M_j, R_i) in the nth source zone. The probability distribution of Eq. (1) can be used to estimate the spectral amplitudes with a desired probability of exceedance due to any of the earthquakes expected to occur anywhere in the region around the project site during a specified exposure period. The combination of the desired probability (P_E) and the specified exposure period (Y years) is equivalent to a return period T_R (years) = $-\ Y / \mathrm{In}\ (1 - P_E)$ for the occurrence of the estimated ground motion. The probabilistic ground motion can thus be defined for a desired return period by using suitable combination of exposure period Y and the probability of exceedance P_E.

A suitable earthquake recurrence relationship with lower threshold and upper bound magnitudes is defined for each seismic source zone using available past earthquake data. This is then used to obtain the occurrence rate $n(M_j)$ of earthquakes in magnitude interval $(M_j - \delta M_j, M_j + \delta M_j)$, which is then distributed among different distance intervals $(R_j - \delta R_j, R_j + \delta R_j)$, to get the seismicity rate $\upsilon (M_j, R_i)$. An attenuation relationship suitable for the region of interest is selected in step 3, which describes the response spectral amplitudes in terms of earthquake magnitude, source-to-site distance, and site geologic condition. Such a relation is able to provide the median estimate and the corresponding probability distribution of the residuals for specified earthquake magnitude M_j and source-to-site distance R_i, which can be used readily to estimate the probability $q [SA(T) \mid (M_j, R_i]$.

By carrying out the summations over all the magnitudes and distances in all the source zones, probability distribution $P[SA(T)]$ of Eq. (1) is computed in the fourth and the final step. The plot of $P[SA(T)]$ versus $SA(T)$ is termed as the hazard curve. A complete response spectrum can be obtained by computing the hazard curves for all the natural periods and estimating the spectral amplitude at each period with the same probability of exceedance during a specified exposure period. Such a spectrum is known as "uniform hazard response spectrum". The MCE level of probabilistic response spectrum is commonly defined for 2% probability of exceedance in 50 years, which represents a return period of about 2500 years for the ground motion.

3.1 Illustrative Example of PSHA Methodology

To illustrate the application of probabilistic seismic hazard analysis (PSHA) approach, the same example is considered as that for the DSHA method, for which the various seismic source zones are shown in Fig. 2. The available data on past earthquakes are used to fit the Gutenberg and Richter (GR) relationship

$$\log \lambda\ (m) = \mathrm{a} - bm$$

Where $\lambda(m)$ is the cumulative number of events with magnitude $\geq m$ and 'a' and 'b' are the constants estimated by regression analysis of the data. To define the Gutenberg-Richter's (1944) earthquake recurrence relationship for each of the source zones, the annual rate $\lambda(m)$ of earthquakes with magnitude '*m'* or greater is estimated using the available past earthquake data in the source zone after homogenization of the earthquake catalogue (Scordilis (2006), Sipkin (2003), Heaton *et. al.* (1986), Kartal *et. al.* (2016)), de-clustering the catalog to remove the dependent events (Gardener and Knopoff, 1974; Uhrhammer, 1986), and accounting for the incompleteness of earthquakes in different magnitude ranges (Stepp, 1972). Using the annual number of earthquakes of different magnitudes as obtained from the periods of complete recording, the maximum likelihood method of Weichert (1980) has been used to obtain the parameters '*a*' and '*b*' of the Gutenberg-Richter's recurrence relationship. The recurrence parameters thus obtained along with the maximum magnitude used for the various seismic sources in the region of the project site are given in Table 2.

Table 2 : Values of recurrence parameters for different Seismic Source Zones

Sr. No.	Seismic Source	*a*	*b*	$\mathbf{M_{max}}$
1.	Trans-Himalayan Zone	2.91	0.71	7.0
2.	a. Tethys Himalayan Zone	3.39	0.82	8.0
	b. Kaurik Fault Zone	3.78	0.81	6.5
3.	Main Himalayan Thrust Zone	5.40	1.06	8.5
4.	Area of Aravalli Fold Belt	2.26	0.71	7.0

The exponentially decaying recurrence relation is then defined with a threshold magnitude $M_{min} = 4.4$ for each source.

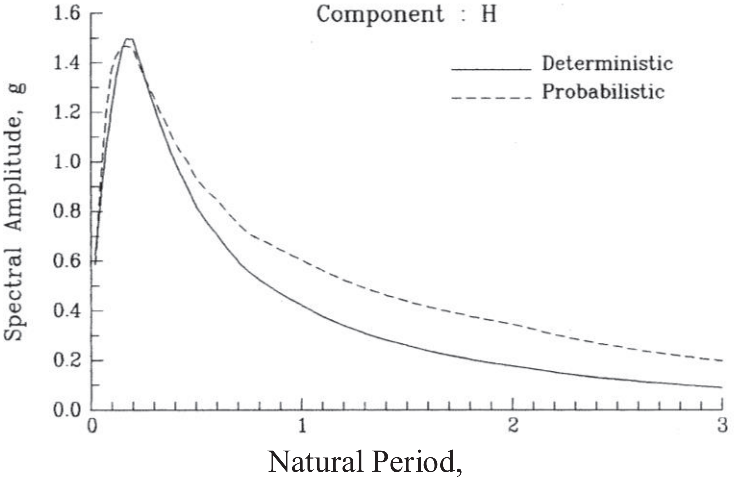

Fig. 4 : Comparison of the example target response spectra obtained by the DSHA and the PSHA approaches.

The seismicity rates $\upsilon(M_j, R_i)$ and the probabilities $q\,[SA(T)\,|\,M_j, R_i]$ for all combinations of M_j and R_i in all the seismic source zones are used to compute the probabilistic target response spectra. The MCE level of target response spectra for horizontal and vertical components are estimated with 2% probability of exceedance in an exposure period of 50 years (return period of about 2500 years), which are plotted in Fig. 4 along with the corresponding deterministic spectra.

4. CONCLUSIONS

The DSHA and PSHA methods have been described to arrive at site-specific design target response spectra for a project site of interest. The DSHA method aims at finding the largest possible ground motion by maximizing the magnitude and minimizing the source-to-site distance. The process of deterministic seismic hazard analysis (DSHA) involves the initial assessment of the maximum possible earthquake magnitude for each of the various seismic sources. Unfortunately this straightforward and intuitive procedure is overshadowed by the complexity and the uncertainty in selecting the appropriate earthquake scenario, creating the need for an alternative, probabilistic methodology, which is free from discrete selection of scenario earthquakes. Probabilistic seismic hazard analysis (PSHA) quantifies as a probability whatever hazard may result from all earthquakes of all possible magnitudes and at all significant distances from the site of interest. Deterministic earthquake scenarios, therefore, are a special case of the probabilistic approach (Kijko 2011).

The DSHA approach lacks a rational scientific basis and selecting the most "pessimistic scenario" is neither likely to represent reality nor is a good engineering decision. DSHA does not provide a means to quantify risk. In the PSHA approach, the maximum possible earthquake in each seismic source is assigned a finite probability of occurrence during a specified time interval, to account for the fact that the recurrence interval of such an event is normally much longer than the time periods of interest in practical applications. To account for the random spatial distribution of all these earthquakes for each of the sources, they are distributed appropriately within the entire source zone. Then, a strong-motion parameter of interest is estimated at the selected site with a desired confidence level by defining a composite probability distribution function as a result of the total expected seismicity in all the source zones, with the observed scattering in the strong motion parameter taken into account. Thus, by incorporating the effects of various random uncertainties in the input parameters, the PSHA approach provides an avenue to arrive at a more objective and cost-effective engineering decisions. Further, it may be noted that the seismic hazard at a site for different frequency ranges is governed by earthquakes with different magnitude and distance combinations. Thus, a single deterministic pair of magnitude and distance (the worst case scenario) is unable to provide the design response spectrum with a desired confidence level for all the natural periods. The uniform hazard response spectrum computed by the PSHA approach has the property that with a specified confidence level, it will not be exceeded at any of the periods due to any of the earthquakes expected during a given time interval, thus taking the randomness of earthquake occurrences in space, time and magnitude into account. Thus, PSHA approach provides a scientifically more sound method for seismic hazard analysis (Gupta, 2002).

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