



GOVERNMENT OF INDIA CENTRAL WATER COMMISSION



GUIDELINES FOR PREPARATION AND SUBMISSION OF SITE SPECIFIC SEISMIC STUDY REPORT OF RIVER VALLEY PROJECT TO NATIONAL COMMITTEE ON SEISMIC DESIGN PARAMETERS

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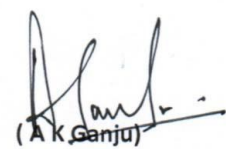
FOREWORD

Ministry of Water Resources had constituted a high level inter-disciplinary official body, the **“National Committee on Seismic Design Parameters (NCSDP) for River Valley Projects”** in 1991 (formerly known as Standing Committee) to recommend the site specific design seismic parameters for design of dams and other appurtenant structures of the river valley projects. The site specific reports for determination of seismic parameters involve estimation of seismic parameters either using the deterministic seismic hazard analysis (DSHA) method or the probabilistic seismic hazard analysis (PSHA) method. Since both the approaches have their own strengths and weaknesses, they are required to be used in combination to arrive at the most appropriate engineering decisions. It may thus be advisable to provide the results from both the approaches and the Committee may take a view in every particular case. Therefore, an attempt has been made to formulate a document: **“Guidelines for Preparation and Submission of Site Specific Seismic Study Report to National Committee on Seismic Design Parameters (NCSDP) for River Valley Projects”**, to have in general, a uniform approach by different expert organizations for carrying out site specific seismic studies. As the input data on tectonic features, past seismicity and strong ground motion characteristics required for such studies are scanty in many cases, these guidelines shall go a long way to overcome these limitations till the required information becomes available in times to come.

I express my sincere thanks to all the present and Ex-Members of NCSDP, officers from CWPRS, Pune, IIT, Roorkee and CWC for their invaluable contribution and cooperation in helping CWC to prepare these guidelines.

For this meticulous work, I express my gratitude for sincere and untiring efforts made by Dr I D Gupta, Director, CWPRS, Pune, Dr H R Wason, Prof & Head, DEE, IIT-R, Dr M L Sharma, Prof IIT-R, Shri Manish Shrikhande, Associate Prof, IIT-R, Shri C S Mathur, Chief Engineer (DSO), CWC, Dr B R K Pillai, Director, CWC and Shri S SBakshi, Director, CWC & Member Secretary NCSDP for formulation of these Guidelines. I am also happy to acknowledge the support and cooperation of officers and staff of FE&SA Directorate of Dam Safety Organization, Central Water Commission in preparation of this document.

I am sure that these Guidelines will be helpful for the designs of various river valley projects of the country.



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ABBREVIATIONS

DBE	Design Basis Earthquake
DSHA	Deterministic Seismic Hazard Analysis
ICOLD	International Committee on Large Dams
IS	Indian Standard
LET	Local Earthquake Tomography
MCE	Maximum Credible Earthquake
MCM	Million Cubic Meters
MPa	Mega Pascal
MT	Magnetotellurics
NCSDP	National Committee on Seismic Design Parameters
NGA	Next Generation Attenuation
OBE	Operating Basis Earthquake
PGA	Peak Ground Acceleration
PSHA	Probabilistic Seismic Hazard Analysis
Sa	Spectral acceleration
SEE	Safety Evaluation Earthquake
SGM	Strong Ground Motion
SSZ	Seismic Source Zones

GUIDELINES FOR PREPARATION AND SUBMISSION OF SITE SPECIFIC SEISMIC STUDY REPORT OF RIVER VALLEY PROJECT TO NATIONAL COMMITTEE ON SEISMIC DESIGN PARAMETERS

1.0 SCOPE

- 1.1 These guidelines deal with the preparation of site specific seismic study report of a river valley project and its submission to the National Committee on Seismic Design Parameters (NCSDP) for necessary approval. The guidelines will help in estimation of parameters to be used in seismic design, analysis and safety evaluation of new or existing dams and their appurtenant structures. It is also expected that the guidelines will bring uniformity in site specific seismic studies being carried out by different expert organizations.
- 1.2 The site specific seismic studies need to be carried out and submitted for the approval of NCSDP in respect of all such river valley project/dams that are classified under 'high' or 'extreme' hazard potential categories. However, the uniform hazard potential categorization criteria for dams in India are yet to be formulated and approved by the 'National Committee on Dam Safety'. Till such time the hazard categorization criteria is not in place, it will be mandatory, for the large dams¹ that fall in seismic zone III, IV or V to get the approval of NCSDP for site specific seismic studies for the assessment of design earthquake parameters. However, for the projects in seismic zone II, the approval of NCSDP for the site specific seismic studies will be mandatory for such dams that are more than 30 meters in height.
- 1.3 The basic provisions of the guidelines are applicable for the river valley projects and its appurtenants structures, and also for the powerhouse and such other structures located in the vicinity of dam whose failure can result in an uncontrolled release of water from the reservoir. The term 'dam' used here shall mean any artificial barrier meant to impound or divert water, and is inclusive of gravity dam, arch dam, embankment dam, barrage, weir, bund etc. However, the provisions of the guidelines need not be applied in case of project canals and canal structures, and also not in case of temporary structures such as coffer dams.
- 1.4 There is no intrinsic difference in the methodology of selecting earthquake parameters for design of new dams or safety evaluation of older dams. The rehabilitation of existing structures which are designed on the basis of standard earthquake principles may not call for fresh site specific seismic studies unless new seismic activity are reported in or around the project sites. However, rehabilitation cases involving dams that are not investigated or designed as per the modern engineering practices may require site specific seismic studies.
- 1.5 The site specific seismic studies which are not mandated as per above conditions need not be referred to NCSDP unless directed otherwise by a government or judicial authority. In all such exempt cases, the selection of seismic design parameters will continue to be governed by the Indian Standard 1893 (Part 1) – *Criteria For Earthquake Resistant Design Of Structures*².

¹ A large dam is one more than 15m high (above the deepest foundation level) or one between 10m and 15m high satisfying one of the following criteria: (a) more than 500m long; (b) reservoir capacity exceeding $1 \times 10^6 \text{ m}^3$; (c) spillway capacity exceeding $2000 \text{ m}^3/\text{sec}$

² Pending finalization of Parts 2 to 5 of IS 1893, provisions of Part I will be read along with the relevant clauses of IS 1893: 1984 for structures other than buildings

- 1.6 For design criteria other than those related to seismic design parameters, reference may be made to the Indian Standard IS 1893 (Part 1)³.

The terms used in the guidelines have standard meanings which are applicable generally to all seismic studies. Definitions of some of the key terms have been further elucidated in the Glossary given as **Annexure A**.

2.0 GENERAL CONCEPTS AND GUIDING PRINCIPLES

The site specific seismic study for a river valley project requires an understanding of the seismic scenario with regard to dam site, which includes geological setting of the area, tectonic features and the history of earthquake occurrence in the region. The study enables evaluation of design ground motion based on identifiable seismic source zones and appropriate ground motion attenuation laws. The general concepts and principles used in such study are given below.

2.1 Seismic Source Zones

For the assessment of design earthquake source parameters, it is necessary to identify the probable Seismic Source Zones (SSZ) where catastrophic ruptures will generate earthquakes at a site in prevailing tectonic environment, and adopt a pragmatic approach to evaluate the likely maximum magnitude of the event which could occur in future.

The delineated SSZ has to be considered to represent a zone of structural (tectonic) features for occurrence of future earthquakes. The probable maximum seismic potential of the SSZ is generally controlled by the area under strain build-up, governing the length and breadth of the seismic rupture, strength and deformation characteristics of the rock, stress drop, and failure mechanism. The seismic potential is rated in terms of the magnitude of the events, and the maximum magnitude thus corresponds to the probable maximum rupture parameters. If there are two, three or more seismogenic features which can influence the ground motion at the site, all these should be considered as potential sources for the purpose of analysis.

The damage due to earthquake is a measure of the earthquake intensity at any site, and it depends on the distance and energy released from the rupture within SSZ.

2.2 Design Earthquakes

- 2.2.1 The largest believable earthquake that can reasonably be expected to be generated by specific seismic sources (SSZ) in a given seismo-tectonic framework is referred to as Maximum Credible Earthquake (MCE) for that SSZ. This is the largest event that could be expected to occur in the region under the presently known seismo-tectonic environment; and the structural system, if designed on this basis, would prove to be highly uneconomical. Therefore a Design Basis Earthquake (DBE), which would have a reasonable chance of occurrence during the life time of the structure, is also evaluated keeping in mind the degree of safety required.

- 2.2.2 Maximum magnitude of the events which could occur in a SSZ is evaluated from data on earthquake occurrences. If data is available for sufficiently long duration, the highest magnitude of the known event of past with suitable increment is generally adopted as the maximum magnitude of MCE for that source. For regions with poor documentation of historical events, an appropriate increment is added to the highest magnitude of the known event for evaluation of MCE to account for the incompleteness of seismicity catalog. The

³ *ibid* 2

deterministic approach for determination of MCE practically ignores the return period of the event. The MCE level of ground motion can also be evaluated using an appropriate approach similar to that given in ICOLD bulletin 89 (revised).

- 2.2.3 The DBE represents that level of ground motion at dam site at which only minor and easily repairable damage is acceptable. Since the consequences of exceeding the DBE are mainly economic, theoretically DBE shall be determined from an economic analysis. However, from practical considerations the DBE is chosen for a certain return period of the ground motion. For the occurrence of earthquake shaking not exceeding the DBE, the dam, appurtenant structures and equipment should remain functional and damages should be easily repairable.
- 2.2.4 In the recently adopted ICOLD guidelines (Selecting Seismic Parameters for Large Dams, 2009), the terminologies of Safety Evaluation Earthquake (SEE) and Operating Basis Earthquake (OBE) have been used in place of MCE and DBE. There is no intrinsic difference in the definition or usage of OBE vis-à-vis DBE. However, the usage of SEE has been characteristically different than MCE on account of application of a probabilistic approach wherein the choice of return period of event is linked with hazard potential categorization of dam. Change over from MCE-DBE terminologies to SEE-OBE terminologies is considered desirable; but, the same has been deferred till adoption of the uniform hazard potential categorization criteria for dams in India.

2.3 Seismic Evaluation Parameters

- 2.3.1 Ground motion at any site is influenced by source, transmission path and local site conditions. The factors responsible for 'source effect' include fault type, rupture dimensions, mechanism and direction, focal depth, stress drop and amount of energy released. The 'transmission path effect' relates to the geometric spreading and absorption of earthquake energy as the seismic wave travel away from the source; and the responsible factors include rock type, regional geological structures including surface faults and folding, crustal in-homogeneities, deep alluvium, and directivity effects (direction of wave travel vs direction of fault rupture propagation). The 'local site effect' results from the topographic and soil conditions present at the site.

Ground motion can be characterized by peak values of expected acceleration, velocity, and/ or displacement. Ideally, all factors affecting ground motion should be considered for evaluation of these parameters; but this is not practical. Generally, one source factor (magnitude) and a single transmission path factor (distance) only are considered. The local site effects are often disregarded, or limited to simple distinction between rock and alluvial sites and possible consideration of near-field effects. Empirical relations derived from available earthquake data (attenuation relations) relate ground motion parameters to distance from the source and to magnitude.

- 2.3.2 **Attenuation relations:** Attenuation relations are empirical relations developed from Strong Ground Motion (SGM) measurements, and are used for the prediction of expected ground motion and its intrinsic variability at the project site. Such predictions are generally performed using ground-motion models that describe the distribution of expected ground motions as a function of a few independent parameters, such as magnitude, source-to-site distance and site classification. The distribution of expected ground motions described by any one ground-motion model is given in terms of median spectral amplitudes and associated standard error/deviation usually referred to as aleatory uncertainty. The seismic hazard studies should

need to account for both these uncertainties in the relations.

Ideally, the attenuation relation to be used for a particular site should be developed using the recorded strong-motion data in the region around the site of interest. However, due to paucity of strong motion data in India, such relations are not available for different parts of the country. In practical engineering applications, it thus becomes necessary to identify suitable relations from the published literature.

- 2.3.3 **Duration of shaking:** The strong motion duration is important from the point of view of response behavior of the structure being examined, and it largely depends on the earthquake magnitude and also on the distance and site condition to some extent. The strong-motion duration is a function of the frequency and represents the sum total of the durations of all the strong motion segments contributing 90% of the energy of complete motion (Trifunac and Brady, 1975). Duration of strong shaking is an important parameter for dam safety because of its direct relation to damages, especially in case of embankments.

- 2.3.4 **Response spectrum:** The response spectrum represents the maximum response (in absolute acceleration and relative velocity or relative displacement) as a function of natural time period, for a given damping ratio, of a set of single-degree-of-freedom (SDOF) systems subjected to a time dependent excitation.

It is customary to represent computed response of SDOF system to a particular ground motion in the form of elastic spectra. These spectra show the response quantity (e.g. absolute acceleration) against the natural periods of SDOF systems for different values of damping. Since there are peaks and valleys in the spectra thus computed, the vagaries are ironed out as far as possible by the smoothened spectra. Response spectrum characterizing the MCE or DBE has to be site specific.

The number of damping values for which response spectra should be specified to represent the MCE or DBE level of ground motion should encompass a range of values applicable to the type of dam and level of ground motion considered. Damping values for analysis of concrete and masonry dams may be taken as 5 and 7 percent respectively when the response is assumed to be predominantly elastic. Damping values for the analysis of embankment dams may be taken as 10 to 15 percent.

- 2.3.5 **Acceleration time histories:** The seismic parameters in terms of peak values and spectral characteristics are sufficient for analysis of many dams. However, in case of dams with high or extreme hazard potentials, and for use of non-linear analysis techniques, the specification of earthquake motion in time domain (as acceleration time history records) is also required. Acceleration time histories may be specified for horizontal and/or vertical motion and should preferably be represented by real accelerograms obtained for site conditions similar to those present at the dam site under consideration. However, since strong ground motion data currently available do not cover the whole range of possible conditions, this is essentially an exercise in generation of random waveforms (keeping in view the duration of the ground motion and the general pattern of ground motion history) which are synthetic in nature. Several time histories could be generated to match the same target response spectrum, and all of these would be equally acceptable from the point of seismic considerations.

2.4 Deterministic and Probabilistic Analysis Approaches

The two general approaches for developing the site-specific response spectra are the deterministic seismic hazard analysis (DSHA) and the probabilistic seismic hazard analysis (PSHA) methods. The basic inputs required for both the approaches are the same, which include data on past seismicity, knowledge of the tectonic features, geological and morphological setup, geophysical anomalies, information on site soil condition and the underlying geology of the surrounding area, and the attenuation characteristics of the strong-motion parameter to be used for quantifying the hazard. The treatment of seismicity data for homogenization, completeness with respect to time and size, and de-clustering are required before proceeding with any of the approaches.

- 2.4.1 In its most commonly used forms, the DSHA approach proposes design for the so-called "scenario" earthquakes (MCE). The underlying philosophy is that "scenario" earthquake of the seismic source is scientifically reasonable and is expected to produce most severe strong ground motion at the dam site. One of the most important issues is the reliable estimation of the MCE, for each of the identified seismic source zones, on the basis of the available data on past earthquakes and the seismotectonic and geological features of a SSZ. However, the delineation of the SSZ, the estimation of MCE magnitudes, as well as the estimation of the corresponding ground motion at a certain distance from the earthquake source, are commonly associated with large uncertainties. The DBE level of deterministic ground motion is generally taken as an appropriate fraction (say 0.5) of the MCE level of motion.
- 2.4.2 The PSHA approach provides a structure in which uncertainties can be identified, quantified and combined in a rational approach to provide a combined effect of several alternate seismic sources on seismic hazard at a site. Thus, there are multiple scenarios and models for hazard analysis applicable at a given site. The PSHA carries out integration over the total expected seismicity to provide the estimate of a ground motion with a specified return period. The MCE level of ground motion is proposed to be defined with a return period of about 2500 years, whereas DBE level of ground motion is defined with a much lower return period of about **475 years**.

3.0 DATA REQUIREMENTS

The primary data for identification of potential sources of earthquakes and evaluation of their characteristics pertain to the tectonic, geologic and seismic activity conditions at, and in the vicinity of, the dam site. The study should consider the regional aspects, and then focus on the local site conditions, so as to fully understand the overall geologic setting and seismic history of a particular site.

The below mentioned information need to be compiled by getting inputs from various organization or institute and published standard literature for the assessment of seismic design parameters.

3.1 Regional Geologic/ Seismotectonic Setting

- **Seismotectonic map:** A seismotectonic map of 1: 1000,000 or comparable scale, depicting geology, structures (with emphasis on nature and extent of major faults, shear zones etc) and seismicity (as detailed in para 3.2 & 4.1) for an area about 300 km radius from dam site should be used (i.e. about 6° latitude x 6° longitude with the dam site at the centre). Location and description of faults and shear zones and assessment of the capability of faults to generate earthquakes should be furnished. This should include documentation on the existence of or the lack of historical or pre-historical activity (paleoseismicity) for each major fault.
- **Seismotectonic section:** At least one regional seismotectonic section through the dam and across the major tectonic trend (based on para above under **Seismotectonic map**) of the region should be prepared. The section covering a minimum 50 km reach on either side of the dam should clearly show (if necessary, by vertical exaggeration) the subsurface disposition of the major faults and earthquake hypocenters.

3.2 Seismic History

- **Earthquake catalogue:** The earthquake catalogue should contain information about origin time (date/ time), location (latitude/ longitude/ depth), and size (magnitude / type of magnitude / intensity) of earthquake from the historical time to present time for an area of about 300 km radius from dam site. This data may be obtained from IMD and updated on the basis of other authentic sources. To the extent possible, information on focal mechanism, felt area, accompanying surface effects, known or estimated intensity of ground motion induced at the dam site, and the source of data and its reliability, should also be presented for all major events.
- **Micro earthquake investigations:** For dams exceeding the height of 100 m, the details of micro earthquake data recordings around the dam site within a radius of 50 km should be provided incorporating full catalogue information for a period of at least six months. Such data should be observed /collected by the project authorities.

3.3 Local Geologic Setting

- **Geological map:** For dams higher than 200m and located in seismic zone IV or V (as per IS 1893 Part 1 (2002)) a geological map (based on photo-geology/imagery studies and ground mapping) on 1:50,000 to 1:60,000 scales should be prepared for an area of 50 km radius from the dam site with special emphasis on gross lithological (or stratigraphical/tectono-stratigraphic) domains, structural details like faults, folds, shear zones, master joints, structural trend lines and lineaments etc. Geomorphic and/or evidence from Quaternary Geology (if any) within the influence area indicating presence of active fault should be documented. Geological evidences wherever available on the nature of movement along the fault vis-à-vis the age of such movement should be indicated. A short descriptive account on the various litho-stratigraphic units and structural elements should be included.

- **Surface and subsurface exploration:** The report of exploration should contain local geological map(s) of the dam site and other appurtenant structures on 1:1000 or larger scale along with topographic contours. The report should also include geological sections along and across dam axis. The geological sections should be derived through drilling and other geo-physical probing, and they should show depth to overburden, faults, shear zones etc. The compressional-wave velocity (V_p) and shear-wave velocity (V_s) of at least 30 m below the major structures (dam, power house etc.) should be provided.
- **Additional inputs on subsurface configuration of major faults:** For dams of height exceeding 200 m and located within seismic zone IV or V, additional inputs on the subsurface configuration of major faults within 50 km radius of the dam site should be provided based on Local Earthquake Tomography (LET) / Magnetotelluric (MT) studies or any suitable methodology may be adopted, details of which should also be furnished.

4.0 METHODOLOGY

The site specific seismic design parameters will depend on many variable factors. It is an extremely difficult task to determine the exact parameters in view of uncertainties related to: [a] choice of earthquake parameters (namely magnitude, distance, focal depth and mechanism) related to MCE and DBE; [b] choice of ground motion attenuation relationship for computing spectral accelerations and [c] the elastic modulus, shear modulus and damping characteristics of the material used in construction. In view of above, it is important to exercise a judicious balance in various steps involved in the study. The mentioned guidelines below are expected to facilitate this process for the meaningful, reliable and safe design of river valley projects in the given seismic environment.

4.1 Selection of Earthquakes for Analysis

All geological maps and data (as specified in section 6) should normally be studied to determine active seismic features.

A table giving the list of earthquakes with period wise break-up (historical to 1900; 1901 to 1963; 1964 to present) should be prepared. For earthquake data subsequent to 1964, the type of magnitude (i.e. M_w , M_s , m_b , M_L , M_b etc) and focal depth should be given; the 'a' and 'b' values from Gutenberg-Richter (G-R) relation should be calculated through regression analysis, preferably using maximum likelihood method and the M_{max} for a specified recurrence period should be indicated using 'a' and 'b' values for each identified seismic source zone as well as for the region as a whole.

The appropriate distance consistent with attenuation relationship from postulated scenario-earthquake from dam site should be tabulated. Efforts should be made to classify the corresponding faults based on its types of movement (i.e. normal, thrust, strike-slip [dextral/sinistral]) vis-à-vis the location of the structure (e.g., hanging wall, footwall, directivity in case of strike-slip etc.). A floating earthquake approach should be adopted where seismogenic features in the vicinity of dam site are not known.

4.1.1 **Magnitude of MCE:** The MCE for a particular SSZ can be estimated from the catalogue of earthquakes in the area of 300 km radius around the dam site (i.e. about 6° latitude x 6° longitude with the dam site at the centre), using several different methodologies. The magnitude for MCE can be estimated using methods as under :

- incrementing the worst recorded earthquake, to account for incompleteness of catalog
- using 'a' and 'b' values of Guttenberg-Richter relationship
- extreme value distribution using empirical relationship
- predicting magnitude of earthquake based on fault rupture dimensions⁴

The simplest method is to suitably enhance the worst recorded earthquake by an appropriate increment to account for incompleteness of data for arriving at MCE.

4.2 Selection of Attenuation Relations

Having chosen the design earthquake parameters of MCE or DBE shock in relation to project site, the next task is to obtain the ground motion characteristics at the site using empirical ground-motion models (attenuation relations) which relate the response spectral amplitudes at different natural periods or frequencies of the structure to the governing parameter like earthquake magnitude, source to site distance and site geological conditions.

The selection of appropriate ground motion models for a particular target area from large number of published attenuation relations for other regions is not that easy. The selection process becomes complicated because there may be systematic differences in terms of seismic sources, wave propagation or site response between the target region and host region from where the data used to derive the model was obtained.

The goal is to identify the smallest set of independent models (out of the large number of models available in published literature) that capture the range of possible ground motions in the region under study. The criteria recommended for shortlisting the ground motion prediction model, arranged in the order of descending hierarchy, are as under:

- Model should be for a similar tectonic regime as it would clearly not be appropriate to use an equation derived for a subduction zone for hazard analysis in a region of crustal seismicity, and vice versa.
- Model is published in an international peer-reviewed journal. The peer review process usually ensures that the models are clearly described and that basic tests (analysis of residuals, comparison with previous studies, etc.) have been performed. The models which have been extensively used and tested should be favoured.
- Documentation of model and its underlying dataset should be complete. The original dataset used in the study must be presented in the publication and the data processing must be described and the parameters used in regressions tabulated.
- Frequency range of the model should be appropriate for engineering applications. For some engineering applications where high frequencies (> 10 Hz) or low frequencies (< 0.3 Hz) are relevant, ground motion models derived from analog accelerograms may

⁴Wells and Coppersmith 1994

not provide reliable estimates, even if the authors of the model have presented regression coefficients for such frequencies.

- Model should be well constrained with dependence on all the governing parameters. The recently published models include a non-linear magnitude scaling term to model magnitude saturation and also effect of possible non-linear response of soil. Neglecting the non-linearity in soil response may distort the shape of the attenuation function for soil sites.

Some typical attenuation relations being used are listed in ***Bibliography***.

The choice of any particular attenuation relationship should be explained with complete references and narration of its merits. Further, the final selection should be based on the ranking criteria due to Scherbaum et al. (2004) using limited strong-motion data, if available in the region of interest. For this purpose, it is proposed to divide the country into three regions for the identification of separate sets of attenuation relationships that are best suited for each region. The targeted three regions are **(i) Himalayas, (ii) Ganga-basin and (iii) Shield regions**. Such an exercise will call for detailed examination of the geophysical criteria regarding the degree of similarity, or otherwise, between the host regions from where the candidate models have been derived and the three target regions.

Till the detailed study is carried out to identify the attenuation relations for the above mentioned three regions of India, the following information may be considered for the time being:

- The spectral acceleration values computed at various natural periods from different published attenuation relations when compared with the limited observed spectral amplitudes from a few Himalayan earthquakes, the relationships due to Abrahamson and Silva (1997) and Trifunac and Lee (1989) are seen to have the overall best matching with the observed data and may thus be considered suitable for the Himalayan region.
- Abrahamson and Silva have recently updated their relationship as a part of the Next Generation Attenuation (NGA) project using the PEER NGA database. The updated relationship has included the fault directivity and site effects more comprehensively, but it needs exact information about the fault rupture geometry, which is not available in most cases. The other NGA relations also need information on fault details to varying extent. Hence the NGA attenuation relations cannot be used without making some subjective assumptions leading to biased results. The earlier relation of Abrahamson and Silva may therefore have to be used for the Himalayan Region.
- Based on world wide data, Graizer and Kalkan (2009) have proposed an approach to obtain the response spectral shape considering the dependence on magnitude, distance, and site condition which can be scaled by the PGA. They have also developed an attenuation relation for PGA using the same database (Graizer and Kalkan, 2007). This approach is also considered suitable for the Himalayan region, because the PGA attenuation of Graizer and Kalkan (2007) is found to describe the available PGA data in Himalayan region quite well.
- The relationship due to Trifunac and Lee (1989) has considered the dependence on the magnitude and distance in a physically realistic way in that the magnitude and distance saturation effects as well as the geometric spreading with distance are accounted for at

each frequency. Also the influences of both the shallow local soil, as well as deep geological formations at the site, are included in this relationship. As no strong motion data is available for the Indo-Gangetic plains, the relationship of Lee is proposed to be used for the region due to physically realistic dependence on various governing parameters.

4.3 Development of Target Response Spectra

For estimating the site-specific design ground motion by deterministic as well as probabilistic approach, it is first necessary to obtain the response spectra of horizontal and vertical components of motion separately for a damping ratio of 5%. Such spectra are known as the target response spectra, and the ground motion acceleration time histories required for detailed dynamic response analysis are generated synthetically to be compatible with the target response spectra. Response spectra for other values of damping are then computed from these acceleration time histories. Target response spectra can be developed by the following three approaches:

(i) **Scaling a standard spectral shape by PGA:**

The response spectra of horizontal and vertical components of ground motion can be obtained conveniently by scaling a mean plus one standard deviation normalized spectral shape appropriate for the site of interest with the median peak ground acceleration. The standard spectral shape should be based on sufficiently large ensemble of strong motion records with magnitude and source-to-site distance close to the desired magnitude and distance of controlling MCE. The PGA can be estimated by deterministic or probabilistic approach.

(ii) **Using spectral amplitude at selected periods (say 0.2 and 1.0 sec):**

The response spectral amplitudes at natural periods of 0.2 sec and 1.0 sec along with PGA can be estimated using an appropriate attenuation relation from deterministic or probabilistic approach. Median or median plus one standard deviation values (depending upon the seismicity of the region) of all these parameters has to be used in the deterministic approach and with a return period of 2500 years in the probabilistic approach to get the MCE level of spectra.

The control period T_2 which marks the beginning of the constant velocity range is then obtained as the ratio of the pseudo-spectral acceleration at 1.0 and 0.2 sec as follows⁵:

$$T_2 = \frac{S_{pa}(1.0s)}{S_{pa}(0.2s)} \times 1s$$

⁵ P K Malhotra-Return period design ground motions. *Seismological Research Letters*, 76(6):693-699,2005.

The control period T_1 which marks the beginning of constant acceleration range is obtained as a fraction of T_2 depending on the soil classification as:

$$T_1 = \left(\frac{1}{2} \text{ to } \frac{1}{5} \right) \times T_2$$

with the factor 1/2 corresponding to very soft soil and 1/5 corresponding to massive rocks. For most of the project sites the actual factor will be between these two extreme values (0.2-0.5).

The psuedo-spectral acceleration is considered to increase linearly from PGA value at period $T_0 = 0.03$ sec to its maximum value at T_1 . The maximum value of the psuedo-spectral acceleration obtained at $T_n = 0.2$ sec is held constant from period T_1 to T_2 . For periods less than T_0 the psuedo-spectral acceleration is considered to be the same as the PGA.

The psuedo-spectral velocity is held constant at $S_{pv}(T_2) = S_{pa}(T_2) \times \frac{T_2}{2\pi}$ in the range from periods T_2 to T_3 . The constant velocity range is considered to extend upto $T_3 = (6 \text{ to } 9) \times T_2$, with the factor 6 corresponding to massive rocks and 9 corresponding to very soft soil, after which the constant displacement (or linear psuedo-spectral velocity with negative slope) range begins. For strong earthquakes, the constant displacement range of the response spectrum in the near field generally begins between 3sec and 4sec. The constant psuedo-spectral displacement is obtained from the psuedo-spectral velocity at T_3 as

$$S_d(T_3) = S_{pv}(T_3) \times \frac{T_3}{2\pi} = S_{pa}(T_2) \times \frac{T_2}{2\pi} \times \frac{T_3}{2\pi}$$

The tripartite plot of response spectrum is shown in fig 1

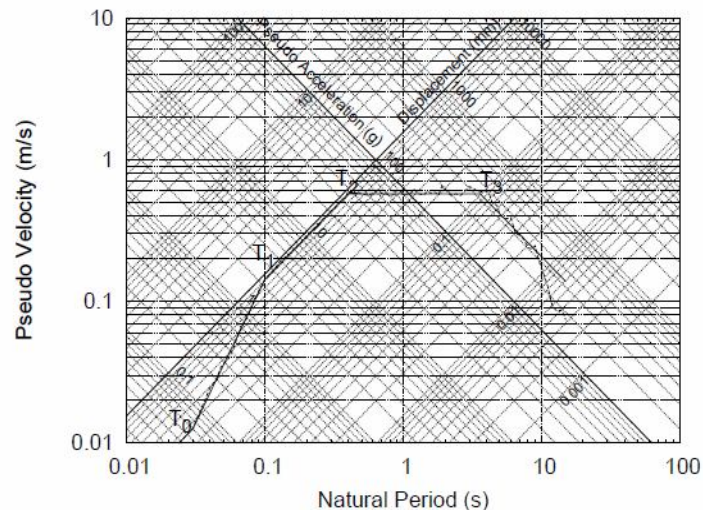


Figure 1: Response spectrum—tripartite plot (log scale)

The tripartite format of design spectrum is not very convenient to use in practice, and therefore, it is necessary to translate it into a linear plot of pseudo-spectral acceleration (Spa) versus natural period (T_n). For a response spectrum in tripartite format (as shown in Fig. 1), the pseudo-spectral acceleration (S_{pa}) may be prescribed as a function of the natural period (T_n) as:

$$S_{pa}(T_n) = PGA \times \begin{cases} 1 & ; T_n \leq T_0 \\ (T_n/T_0)^\alpha & ; T_0 \leq T_n \leq T_1 \\ A & ; T_1 \leq T_n \leq T_2 \\ V/T_n & ; T_2 \leq T_n \leq T_3 \\ D/T_n^2 & ; T_n > T_3 \end{cases}$$

The parameters α , A, V and D are described as below:

$$\alpha = \frac{\log(S_{pv}(T_1)) - \log(S_{pv}(T_0))}{\log(T_1) - \log(T_0)} - 1 ;$$

$$A = \frac{S_{pa}(T_1)}{PGA} = \frac{S_{pa}(T_1)}{S_{pa}(T_0)} ;$$

$$V = 2\pi \times \frac{S_{pv}(T_2)}{PGA} ;$$

$$D = 2\pi \times T_3 \times \frac{S_{pv}(T_3)}{PGA}$$

The pseudo-acceleration design spectrum specified by the above equation and coefficients is shown in Fig. 2. The positions of the control periods of the equation have been marked in these figures. It may be seen that while the pseudo-acceleration spectrum plot in linear scale has different curves, the tripartite plot in logarithmic scales is well defined by a set of straight lines between different pairs of control periods. Therefore, the above equation of pseudo-acceleration design spectrum is derived from the corresponding equations of straight lines of pseudo-velocity spectrum on the tripartite plot.

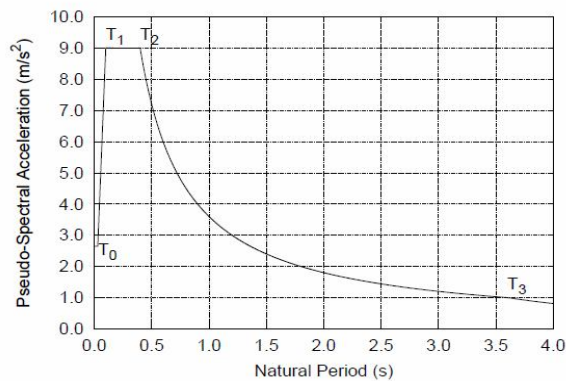


Figure 2 : Pseudo-spectral acceleration (linear scale)

(iii) **Using frequency dependent attenuation relationships:**

The attenuation relations used for estimating the PGA or spectral amplitude at 0.2 and 1.0 sec in the above two methods are generally defined for a large number of natural periods covering the entire frequency range necessary to define the complete response spectrum. Thus, by estimating the spectral amplitude at all the natural periods for which the attenuation relation is defined, it is possible to obtain the complete response spectrum without making any assumptions. This can be done by using both deterministic as well as probabilistic methodologies.

4.3.1 **DSHA Methodology for Developing Target Response Spectra**

In commonly used deterministic approach for developing the response spectra for a dam site, one has to first assess the maximum possible earthquake magnitude for each of the seismic sources (important faults, shear zones, thrusts etc) in the project area of interest (generally about 6° latitude x 6° longitude with the dam site at the centre). Such an earthquake is commonly termed as Maximum Credible Earthquake (MCE), which is the largest earthquake that can be supported by each source under the site specific seismotectonic framework. The MCE for each seismic source is then presumed to occur at a location that places the focus at the minimum possible distance to the project dam site which the source geometry permits. The response spectra for each MCE can then be developed using an appropriate attenuation relation. The zero-period spectral value is the peak ground acceleration, i.e., zero-period spectral acceleration (ZPA) = PGA. The worst combination of the magnitude and distance of MCE is normally considered to get the MCE level of design ground motion.

The target spectrum for MCE condition may be taken as at median plus one standard deviation level for project sites in regions of high seismicity (Seismic Zone IV and V as per IS:1893-2002) because of relatively short return periods of large earthquakes and to account for the scatter in recorded earthquake data. For the low seismicity regions (Seismic Zones II and III as per IS:1893-2002), the recurrence interval of MCE level earthquakes is very large and therefore the MCE target spectrum for project sites in these regions may be taken as median estimates. This is to maintain approximately uniform level of seismic risk across the entire country.

The target response spectra for Design Basis Earthquake (DBE) condition may be taken as one standard deviation less than the corresponding MCE target spectra, or half of MCE target spectra, whichever give higher amplitude at natural period of interest.

*An illustrative example of the foregoing methodology is given in **Annexure B***

4.3.2 **PSHA Methodology for Developing Target Response Spectra**

The probabilistic seismic hazard analysis (PSHA) approach is based on an altogether different philosophy and concept compared to the deterministic seismic hazard analysis (DSHA) approach for arriving at site-specific design earthquake ground motion for important engineered projects. The DSHA aims at estimating the possible maximum value of the ground motion amplitudes by considering a maximum magnitude of earthquake to occur at the shortest source-to-site distance, irrespective of the probability of such an occurrence, which remains unknown and unquantified. The PSHA on the other hand aims at estimating the

ground motion amplitudes having a desired annual probability (p) of exceedance due to any of the earthquakes expected to occur anywhere in the region around the project site. The return period T_r (years) is equal to reciprocal of the annual probability (p) of exceedance. Thus, a probability of exceedance equal to 0.001 represents a return period of 1000 years for the ground motion. The ICOLD guidelines (2010) specify the return periods of 10,000 years, 3,000 years and 1,000 years for the MCE level of ground motion for dams with three different risk levels to the downstream population. The PSHA approach can also be used to obtain the return period corresponding to the deterministic estimate of the ground motion for comparison with the return periods proposed by ICOLD guidelines and taking appropriate decisions about the suitability of the deterministic estimate.

Details on the currently used PSHA approach can be read from Cornell (1968), EPRI (1987), Reiter (1990), SSHAC (1997), USACE (1999), Gupta (2002), McGuire (2004), etc. The basic PSHA approach is based on computing the following annual probability of exceedance of a specified measure of the ground motion amplitude (e.g. the acceleration response spectrum amplitude SA(T) at natural period T):

$$p[SA(T)] = 1 - \exp \left\{ - \sum_n \sum_j \sum_i q_n [SA(T)|M_j, R_i] \cdot v_n(M_j, R_i) \right\}$$

Here, $p[SA(T)]$ is the annual probability of exceeding a spectral amplitude SA(T) due to any of the earthquakes in any of the source zones, $v_n(M_j, R_i)$ is the annual occurrence rate of earthquakes of magnitude M_j at source-to-site distance R_i in each of the seismic source zones around the project site, and $q_n[SA(T)|M_j, R_i]$ is the probability of exceeding the spectral amplitude SA(T) due to magnitude and distance combination (M_j, R_i) in the n^{th} source zone. The plot of SA(T) vs $p[SA(T)]$ is known as the 'Hazard Curve'. By computing the hazard curves for all the natural periods T, the design response spectrum can be obtained with a desired annual probability of exceedance (or recurrence period) at all the periods. Such a spectrum is known as "Uniform Hazard Response Spectrum".

The various steps involved in computing the hazard curves to implement the PSHA approach can be summarized as below:

Step-1: Delineation of Seismic Source Zones

The first step in PSHA is to identify and delineate various seismic source zones (SSZ) within a region of $6^\circ \text{lat} \times 6^\circ \text{long}$ with the dam site at the center, where a SSZ represents the portion of earth's crust with distinctly different characteristics of earthquake activity (in terms of frequency & max potential) from those of the adjacent crust. Though fault specific seismic sources can be used in some cases, due to lack of close correlation of observed seismicity with known faults, extended area type of sources is used more commonly in practical applications. It may be noted that delineation of seismic sources cannot be considered free from some element of subjectivity.

Step-2: Estimating Seismicity of a Source Zone

The Gutenberg and Richter's (1944) recurrence relationship $\log N(M) = a - bM$, where $N(M)$ represents the cumulative number of earthquakes per year with magnitude M or greater, is fitted to each seismic source in step 2 using available past earthquake data. The catalogue

data may be treated for removal of foreshocks and aftershocks, homogenization of magnitude to either M_w or M_s and correction for incompleteness in size and time. This is then used to obtain the occurrence rate $n(M_j)$ of earthquakes in magnitude interval $(M_j - \delta M_j, M_j + \delta M_j)$ by discretizing the complete magnitude range between a minimum threshold magnitude and the maximum upper bound magnitude. These numbers are finally distributed over the entire source zone by dividing it into a large number of small size elements to get the annual occurrence rate $v(M_j, R_i)$, where R_i refers to the distance to the center of the i^{th} source element.

Step-3: Estimation of Probability $q_n[SA(T) | M_j, R_i]$

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 least squares 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 readily be used to estimate the probability $q_n[SA(T) | M_j, R_i]$. A single attenuation relation may normally be applicable to all the source zones, but different relations may also be used, if necessary.

Step-4: Computation of Uniform Hazard Spectrum

The fourth and the final step in the PSHA approach is to compute the hazard curves, i.e. probability distribution $p[SA(T)]$, by carrying out the summations over all the magnitudes and distances in all the source zones. A uniform hazard response spectrum is obtained by computing the $p[SA(T)]$ for all the natural periods of interest and estimating the corresponding spectral amplitudes with a desired annual probability of exceedance (or return period).

An illustrative example of the foregoing methodology is given in Annexure C

4.4 Determination of Site-specific Seismic Coefficients

With the knowledge of the natural period of the dam section, the response spectra can be used to obtain the site-specific seismic coefficients. The type and preliminary section of the dam, the computational formula, and other assumption made in the computation of natural period should be furnished in the study.

- 4.4.1 **Horizontal seismic coefficient:** The horizontal seismic coefficient values (α_h) shall be computed as per the DBE level of response spectra using effective peak ground acceleration (EPGA) criteria. For a given return period (475 years for DBE condition) and desired damping (5% damped spectrum for the concrete/masonry dam and 10 % damped spectrum for earthen and rockfill dams), the EPGA is determined by dividing the corresponding short period spectral acceleration value by 2.5. The short period spectral acceleration corresponds to 0.2 second spectral ordinate of the selected damped spectrum (USACE EM 1110-2-6053). The horizontal seismic co-efficient is then arrived at by taking 2/3rd of the EPGA value. The horizontal seismic co-efficient (α_h) thus obtained shall be compared with α_h values arrived through the application of IS-1893 (1984) (i.e. 0.06 for Zone-II, 0.12 for Zone-III, 0.15 for Zone-IV and 0.24 for Zone-V) and the higher of the two values shall be adopted.

For the calculation of horizontal seismic co-efficient, the PGA value should be obtained directly from the actual response spectral amplitudes and not from the normalized spectra.

- 4.4.2 **Vertical seismic coefficient:** Vertical seismic co-efficient (α_v) shall be taken as $2/3^{\text{rd}}$ of the horizontal seismic co-efficient.

4.5 **Estimation of Duration of Shaking**

The duration of strong shaking being an important seismic evaluation parameter, should be reflected explicitly in the study, alongwith the total duration. Both these durations can be estimated using the scaling relations (e.g. Novikova and Trifunac, 1994), which defines the strong motion duration at each frequency as a function of earthquake magnitude, source-to-site distance and site condition. For generation of design accelerograms, the strong motion duration may be taken as the average duration corresponding to the highest frequency band (18-25 Hz) and the total duration can be taken as the average plus one standard deviation value corresponding to the lowest frequency band (0.10-0.15 Hz) but not less than 20 seconds. Local conditions may also affect the expected duration of earthquake shaking and should be considered on a case by case basis.

4.6 **Development of Acceleration Time Histories**

The acceleration time histories should preferably be represented by real accelerograms obtained for site conditions similar to those present at the dam site under consideration. Since the strong ground motion data currently available do not cover the whole range of possible conditions, such records may be supplemented by synthetic motions representing any earthquake size and seismotectonic environment. Synthetic earthquakes can be developed by superposition methods⁶.

It is recommended that several acceleration time histories be used to represent the ground motion as certain time histories have lower energy content at some frequencies and their use may result in an un-conservative analysis. When detailed time history analysis is necessary it is proposed to use atleast three sets of uncorrelated time histories of horizontal & vertical motions and the maximum response to all the three sets be considered for design purposes.

Acceleration time histories should be specified separately for the horizontal and vertical motions.

⁶Gupta & Joshi (1993). On synthesizing response spectrum compatible accelerograms, *Journal of European Earthquake Engineering*, 2, 25-33.

4.7 Factors to be considered while deciding the site specific Target Response Spectrum

Having obtained the target response spectrum from Deterministic as well as Probabilistic approach, the following considerations may be helpful in adopting the target response spectra in practical applications:

- For MCE condition :
If the spectral amplitudes obtained by the two approaches differ by 25% or less, the envelope of both may be adopted as the design target spectra. In other cases a weighted average of both the spectra may be adopted as the target spectra, with weights appropriately justified. If the difference in the spectral amplitude values obtained by two approaches happens to be very large (say more than 100%), then the possible technical reasons for such discrepancies shall be explained in the report.
- For DBE condition:
In the seismic zones IV and V, if the spectral amplitudes obtained by the two approaches differ by 25% or less, at the periods of interest, the design target response spectrum shall be obtained as the envelope of DSHA and PSHA DBE estimate (as described in paras 4.3.1 & 4.3.2). In other cases a weighted average of both the spectra may be adopted as the target spectra, with weights appropriately justified. However, for seismic zones II & III, the design target response spectrum shall be obtained as the envelope of the DSHA and PSHA DBE estimates.

The above comparisons are to be restricted for natural periods upto 1.0 sec

5.0 RECOMMENDATIONS ON DESIGN APPROACH

The site specific seismic study report should mention the design approach to be adopted for checking the stability of the dam and should also contain recommendations regarding the permissible stresses and sliding factors to be adopted. The earthquake performance of gravity dams has to be evaluated on the basis of stresses, sliding factor, demand-capacity ratios and the associated cumulative duration. The below mentioned points should be taken in to account while formulating recommendations.

- 5.1 Seismic analysis of concrete gravity dams can start with simplified methods using site-specific seismic coefficient for sliding and overturning stability, and progress to a more refined analysis as needed. The pseudo-static method of analysis may be used for computation of forces. Regarding permissible stresses, BIS code 6512: Criteria for design of Solid Gravity Dams may be made use of.

The DBE level of ground motion is used for the evaluation of the actual performance of gravity dams. Under DBE, the dam is required to be within linear elastic range with little or no damage. The spectra and time-histories for DBE level of ground motion can be used to evaluate the dynamic response of gravity dams by linear elastic response-spectrum method or the time history method. Under DBE condition, the demand-capacity ratios (DCR) are required to be less than or equal to 1.0. The DCR is defined as the ratio of induced tensile stress to tensile strength of the concrete. For this purpose, the tensile strength or capacity of the plain concrete can be obtained from the uni-axial splitting tension tests or from the static compressive strength, f_c , using the relation due to Raphael (1984), $f_t = 1.7 f_c^{2/3}$ where f_c is in psi or $f_t = 0.324 f_c^{2/3}$ where f_c is in MPa, as recommended in USACE Manual EM 1110-2-6051.

Under MCE condition, dams should not experience a catastrophic loss of the reservoir. Under the rapid loading of MCE conditions, sliding may occur at the dam foundation interface or at upper elevations at lift joints. Dams subjected to large lateral forces produced by the MCE ground motion may tip and start rocking and the resulting driving force may become so large that the structure breaks contact with the foundation or cracks all the way through at the upper elevation.

The dynamic response under MCE condition may first be evaluated using linear-elastic time-history analysis. The level of nonlinear response or cracking is considered acceptable if DCR are less than 2.0, and limited to 15 percent of the dam cross-section surface area, and the cumulative duration of stress excursions beyond the tensile strength of the concrete falls below the performance curve given in Figure 3. DCR of 2.0 corresponds to the apparent dynamic tensile strength of concrete (Raphel, 1984). The cumulative duration beyond a certain level of DCR is obtained by multiplying the number of stress values exceeding that level by the time-step used in the time-history analysis. When these performance conditions are not met, a nonlinear time-history analysis is required to estimate the damage more accurately under MCE condition.

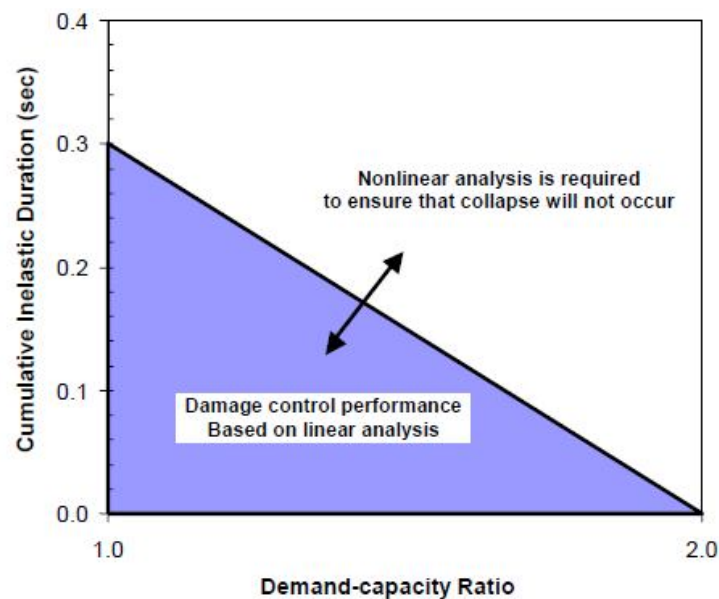


Fig.3: Performance curve for gravity dams

- 5.2 In case of earthen dams, the seismic slope stability analysis involves starting with a simpler analysis (Pseudo-static) and moving on to Sliding Block analysis and Dynamic analysis, where complexity of analysis increases in each stage. In pseudo-static slope stability analysis, earthquake forces are represented by the site specific seismic coefficient. Seismic inertial forces are estimated by multiplying weight of the potential sliding mass (W) with seismic coefficient as per IS 1893 (1984). Undrained shear strength of the soil is to be considered in the analysis. An index of stability, called factor of safety (FOS) is computed from the ratio of resisting moment to disturbing moment, for a potential sliding mass. A FOS of 1.0 or above is

considered acceptable under earthquake condition. Seed's simplified approach may be used to determine liquefaction potential of cohesionless soil strata. The liquefaction potential is ascertained from index properties as recommended by Seed (2003).

In sliding block analysis, permanent deformation in an earthen dam, due to an earthquake is evaluated based on Newmark concept. In this method, a potential sliding mass is assumed as a rigid body on a rigid base and contact between them as a rigid-plastic. The analysis involves determination of Yield acceleration (K_y) from slope stability analysis, maximum crest acceleration (U_{max}) and average acceleration- time history [$K_{av}(t)$] of sliding mass and estimation of permanent crest displacement by double integration of acceleration difference [$K_{av}(t) - K_y$]. If the crest displacement is within permissible limit (w.r.t Free Board) no further analysis is required. In case the sliding block analysis shows excessive deformation, the detailed dynamic analysis may be carried out.

Dynamic analysis is carried out for dams, failure of which may lead to high level of risk. The analysis involves determination of cyclic strength of soil from cyclic triaxial shear tests, induced shear stresses from dynamic finite element response analysis (equivalent linear or nonlinear) using site specific earthquake, evaluation of strain potential in each element by comparing induced shear stresses with shear strength of soils and then determination of overall deformation of dam from strain potential, which should be within permissible limit (w.r.t. Free Board provided).

The dynamic analysis procedure is followed to determine liquefaction potential of soil. In cyclic triaxial tests on undisturbed soil samples, the cyclic shear stress required to cause liquefaction is determined. The stresses that are likely to be induced in the ground are determined from dynamic response analysis. Comparing the "induced stresses" with "stress required to cause liquefaction" will indicate susceptibility for liquefaction.

6.0 SUBMISSION OF STUDY REPORT FOR NCSDP APPROVAL

The site specific studies for determination of design earthquake parameters shall have to be carried out by Deterministic as well as Probabilistic approach. However, where the available data on past seismicity is scanty, and even the data on tectonic features and geological processes are inadequate to have any meaningful application of probabilistic analysis, the deterministic analysis only shall be carried out by recording the proper justification for not adopting the probabilistic approach for analysis.

The report should also include a section/chapter giving the following information:

- Comparison of target response spectra obtained from Deterministic as well as Probabilistic approach for MCE and DBE conditions alongwith final target response spectra selected with justification
- Compatible acceleration time histories for MCE & DBE target response spectra
- Computed response spectra for different damping values ie 2%, 3%, 5%, 10% and 15% atleast
- Site specific horizontal and vertical Seismic coefficients

After completion of the site specific seismic study, the full study report should be compiled in a single dossier as per proforma given in **Annexure D**. The list of projects with seismic design parameters approved by National Committee on Seismic Design Parameters (NCSDP) from 1991 onwards is given in **Annexure E** for reference. The said proforma should also be filled-up reflecting the status of compliances (along with reasons for non-compliances) for different items of the study. This proforma, duly filled and signed, should be furnished as a check-list in the beginning of the study report.

Fifteen (15) bound volumes and one soft copy of the study report should be submitted to the NCSDP Secretariat (Foundation Engineering & Special Analysis Directorate, Central Water Commission, 712(S), Sewa Bhawan, R.K. Puram, New Delhi). In order to ensure consideration of study report in a particular meeting of the NCSDP, the study report should reach the secretariat at least two months ahead of that meeting. Only such study reports, which are found satisfactory (in terms of compliances of the guidelines) on preliminary inspection by the Secretariat, will be put up to the NCSDP for consideration and approval.

7.0 PRESENTATION OF STUDY REPORT BEFORE NCSDP

The date on which study report of a particular project will come up before NCSDP will be intimated by the Secretariat to the project authorities. It will be the responsibility of the project authorities to ensure presence of experts/ consultants connected with the study on the stipulated date and time. The project authorities will make a PowerPoint presentation of the study report before NCSDP, and answer to the queries of the members of the Committee.

The presentation should cover: (i) details of the project; (ii) regional geological & seismo-tectonic setting; (iii) seismic history; (iv) local geological setting; (v) study methodology and deviation, if any, from the recommended approach; (vi) evaluated parameters of the site specific seismic study; and (vii) recommendations on design approach.

AnnexureA

GLOSSARY

Attenuation: Decrease in amplitude and change in frequency content of the seismic waves with the distance because of geometric spreading, energy absorption and scattering. It also designates (i) a decrease of signal magnitude during transmission, and (ii) a reduction in amplitude or energy without change of wave form. Attenuation relations between earthquake intensity, distance and magnitude have been developed from Strong Ground Motion (SGM) measurements.

Critical Damping: The damping beyond which the free vibration motion will not be oscillatory.

Damping: The effect of internal friction, imperfect elasticity of material, slipping, sliding etc in reducing the amplitude of vibration of the structure, and is expressed as a percentage of critical damping.

Design Acceleration Spectrum: An average smoothened plot of maximum acceleration as a function of frequency or time period of vibration for a specified damping ratio for earthquake excitations at base of a single degree of freedom system.

Design Basis Earthquake (DBE): The largest earthquake which can reasonably be expected to occur at least once during the design life of the structure.

Epicenter: The geographical point on the surface of earth vertically above the focus (hypocenter) of the earthquake

Fault: A fracture or fracture zone in the earth's crust along which there has been displacement of the two sides relative to one another, parallel to fracture.

Floating earthquake: An earthquake that cannot be co-related with known geologic structure with a specified maximum magnitude.

Focal depth: The vertical distance between the epicenter and the hypocenter.

Focus (or Hypocenter): The originating earthquake source of the elastic waves inside the earth which cause shaking of the ground due to earthquake.

Magnitude of earthquake: A number, which is a measure of energy released in an earthquake. It is calculated from measurements on seismographs and it is properly expressed in ordinary numbers and decimals based on the logarithmic scale.

Maximum Credible Earthquake (MCE): The largest magnitude earthquake reasonably conceivable that appears possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. The ground motions associated with an MCE are generally defined as an upper bound of expected earthquake intensity at dam site due to that earthquake.

Natural Period (T): Natural Period of a structure is its time period of un-damped free vibration.

Peak Ground Acceleration (PGA): A measure of earthquake acceleration on the ground and an important input parameter for earthquake engineering. Peak ground acceleration is generally expressed in terms of g (acceleration due to gravity).

Predominant Periods: The range of system periods which are excited much more than others for the particular ground motion.

Response Spectra: Represents the maximum response (in acceleration, velocity or displacement) as a function of frequency, for a given damping ratio, of a single-degree-of-freedom system subjected to a time dependent excitation.

Seismic Source Zones (SSZ): An area in which earthquakes of a particular kind tend to occur. A Seismic source represents the zone of the earth's crust with distinctly different characteristics of earthquake activity from those of the adjacent crust.

Annexure B

Illustrative Example : DSHA method for developing target response spectra

Considering a scenario earthquake of magnitude 7.5 with closest distance from the site to zone of energy release as 14 km and with local geological conditions indicating massive rock, the following is estimated from a ground motion prediction equation for 5% damped horizontal acceleration spectrum:

Peak Ground Acceleration (at mean plus one standard deviation level) = 3.934 m/s^2

⁷Pseudo-spectral acceleration value for two periods ie 0.2 sec and 1.0sec

$$S_{pa}(0.2s) = 8.63 \text{ m/s}^2; S_{pa}(1.0s) = 5.782 \text{ m/s}^2$$

Thus the control period (T_2) for start of constant velocity range works out to 0.67 sec.

$$T_2 = \frac{S_{pa}(1.0s)}{S_{pa}(0.2s)} \times 1s; T_2 = 5.782 / 8.63 \times 1s = 0.67 \text{ s}$$

The control period for the beginning of constant acceleration (T_1) is obtained as a fraction of T_2 as :

$$T_1 = \left(\frac{1}{5}\right) \times T_2 = 0.134 \text{ sec}$$

The pseudo-spectral acceleration is considered to be same as the peak ground acceleration at control period $T_0 = 0.03 \text{ s}$.

The control period for constant displacement (T_3) (generally between 3 sec to 4 sec for strong earthquakes in near field conditions) is obtained by scaling the constant velocity control period (T_2) as

$$T_3 = 6.25 \times T_2 = 4.2 \text{ sec}$$

Thus we have:

$$PGA = S_{pa}(T_0) = 3.934 \text{ m/s}^2;$$

$$S_{pa}(T_1) = 8.63 \text{ m/s}^2 = S_{pa}(T_2)$$

The corresponding pseudo-spectral velocities may be obtained as:

$$S_{pv}(T_0) = S_{pa}(T_0) \times \frac{T_0}{2\pi} = 0.0188 \frac{\text{m}}{\text{s}}$$

$$S_{pv}(T_1) = S_{pa}(T_1) \times \frac{T_1}{2\pi} = 0.1868 \frac{\text{m}}{\text{s}}$$

$$S_{pv}(T_2) = S_{pa}(T_2) \times \frac{T_2}{2\pi} = 0.9315 \frac{\text{m}}{\text{s}}$$

$$S_{pv}(T_3) = S_{pa}(T_3) \times \frac{T_3}{2\pi} = 0.9315 \frac{\text{m}}{\text{s}}$$

⁷Boore-Atknison -Ground motion Prediction equations for the average horizontal component of PGA, PGV and 5%-damped PSA at spectral periods between 0.01s and 10.0s, Earthquake Spectra, 24(1):99-138,23008

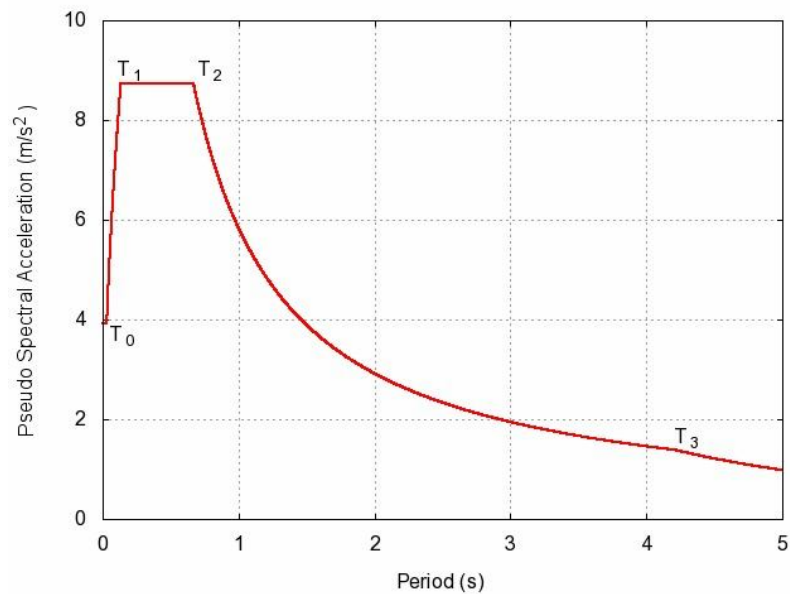
From these numerical values of pseudo-spectral velocity and the control periods, the parameters of the smooth acceleration design spectrum may be obtained as

$$\alpha = \frac{\log(S_{pv}(T_1)) - \log(S_{pv}(T_0))}{\log(T_1) - \log(T_0)} - 1 = 0.534 ;$$

$$A = \frac{S_{pa}(T_1)}{PGA} = \frac{S_{pa}(T_1)}{S_{pa}(T_0)} = 2.194 ;$$

$$V = 2\pi \times \frac{S_{pv}(T_2)}{PGA} = 1.488 ;$$

$$D = 2\pi \times T_3 \times \frac{S_{pv}(T_3)}{PGA} = 6.248$$



Target Response spectrum for Horizontal Acceleration (5% damping Level)

Annexure C

Illustrative Example :PSHA method for developing target response spectra

To illustrate the application of the PSHA approach, a typical site shown by solid triangle is considered in the highly seismic Kumaun-Garhwal Himalayan region (Fig. 1). 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 thrust over the fore-deep, (iv) the High Himalaya and (v) the Indus-Tsangpo Suture zone (Dasgupta, 2000). 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 foot-hills. A thick strata of crystalline rock comprising the High Himalaya is thrust 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 fossiliferous sedimentary rocks.

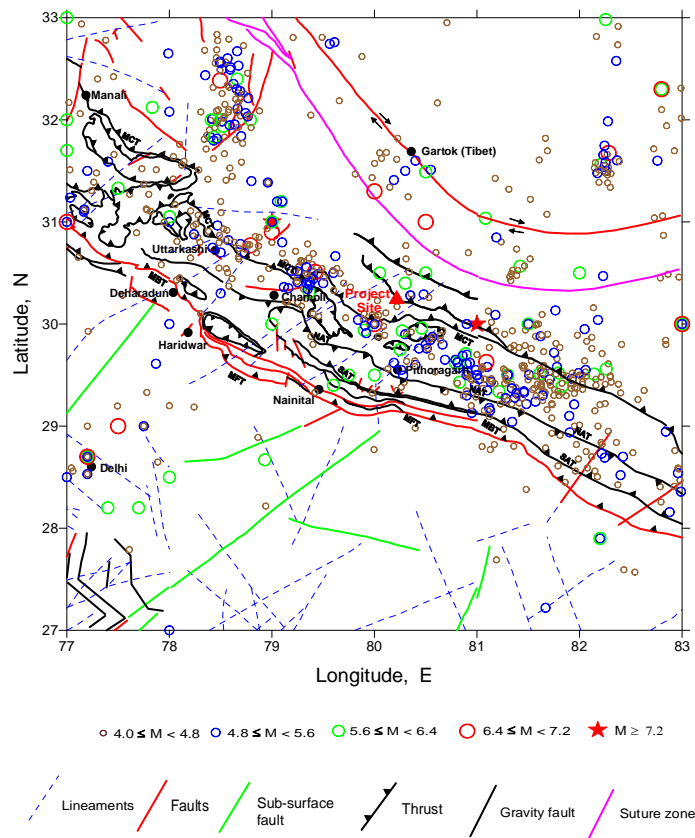


Fig. 1: Major tectonic features in the region of the project site along with the epicenters of available past earthquakes

In addition to the major structural discontinuities of the Himalayan region, there are a number of other faults/lineaments in the region. Within the main Himalayan belt, the high grade complex of the central crystallines is bound to the north and the south by Martoli Thrust and MCT, respectively. A similar high-grade complex, the Almoracrystallines, is delimited on either side by the North Almora Thrust (NAT) and the South Almora Thrust (SAT). Further north of the Martoli thrust is the dextral Karakoram Fault, subparallel to the Indus Suture Zone (ISZ). The belt between the Karakoram Fault and ISZ is occupied by cover rocks affected by the Himalayan orogeny. Neotectonic activity has been recorded along the Karakoram Fault, ISZ, MBT as well as MFT. A number of transverse faults also exist within the Himalayan ranges as well as to the south in the Indo-Gangetic planes. The transverse features are also associated with varying levels of seismicity.

The first step in PSHA is to identify and delineate the various seismogenic source zones (SSZ) in the region of about $6^\circ\text{lat} \times 6^\circ\text{long}$ around the project site. Considering the spatial distribution and correlation of seismic activity with the tectonic features in the region of the project, five broad seismic sources have been identified, viz. (i) Trans-Himalayan (TRH) area north of Karakoram Fault, (ii) Himalayan Fold (HF) area between ISZ and Karakoram Fault, (iii) Tethys Himalayan (THH) area between MCT and ISZ, (iv) Main Himalayan Thrusts (MHT) area of MCT, MBT, etc., and (v) Area of Aravalli Fold Belt (AFB) in the Indo-Gangetic Plains. These source zones are shown demarcated by thick solid lines in Fig. 2 along with the epicenters of the past earthquakes. There is a marked concentration of epicenters along the Kaurik Fault system (KFS) in the THH main source, which has been therefore defined by a separate sub-source. The other main sources are also characterized by varying concentrations of epicenters, which has been suitably accounted in distributing the expected seismicity over the complete source zone to estimate the occurrence rate $\nu(M_i, R_i)$ of earthquakes in different magnitude and distance intervals

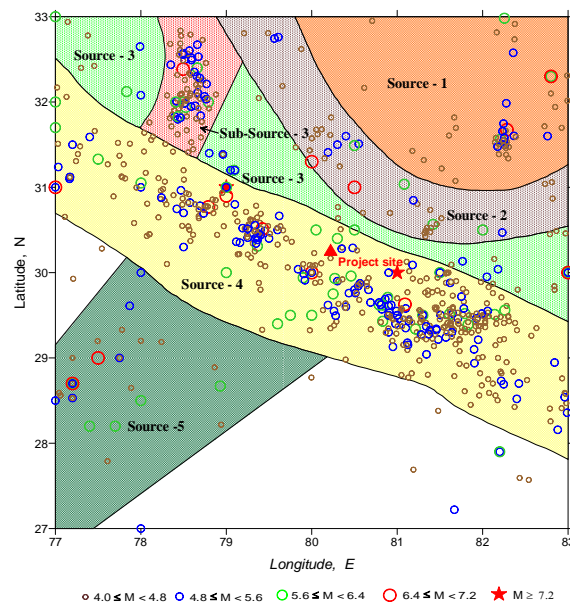
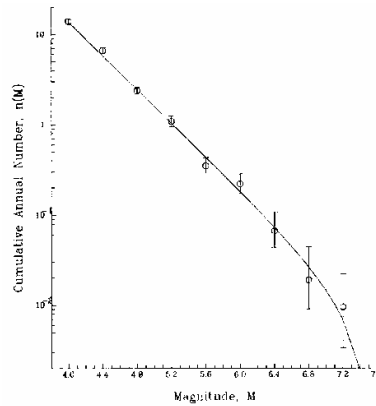


Fig.2: Possible seismic source zones in the region of the project site

The second step is to obtain $\nu(M_j, R_i)$ for each source zone. For this purpose, first the Gutenberg-Richter's earthquake recurrence relationship $\log N(M) = a - bM$ is defined for each source zone, by estimating the constants a and b using maximum likelihood method (Weichert, 1980). The $N(M)$ is obtained using available past earthquake data in the source zone by homogenization of the magnitude (Scordilis, 2006), declustering the catalog by removing fore- and after-shocks (Gardner and Knopoff, 1974), and accounting for the incompleteness of earthquakes in different magnitude ranges (Stepp, 1973). The recurrence relation is then suitably modified to consider an upperbound magnitude M_{\max} (Chinnery and North, 1975). Typical recurrence relationship thus obtained for source zone 4 is shown in Fig. 3

**Fig.3: Recurrence relation for source zone 4**

From the recurrence relationship for a source zone with an upper bound magnitude, the occurrence rate of earthquakes within a small magnitude range $(M_j - \delta M_j, M_j + \delta M_j)$ around central magnitude M_j can be obtained as

$$n(M_j) = N(M_j - \delta M_j) - N(M_j + \delta M_j)$$

These numbers are distributed appropriately using spatial smoothing of past seismicity over the entire source zone, to get the required number $\nu(M_j, R_i)$ within a small source-to-site distance range $(R_i - \delta R_i, R_i + \delta R_i)$.

In step three, the probability, $q(SA(T)|M_j, R_i)$, of exceeding a response amplitude $SA(T)$ at natural period T due to magnitude M_j at source-to-site distance R_i is obtained by assuming the $\ln SA(T)$ to follow a Gaussian probability distribution as:

$$F[SA(T)] = \frac{1}{\sqrt{2\pi}\sigma(T)} \int_{-\infty}^{\ln SA(T)} \exp\left\{-\frac{1}{2}\left(\frac{x - \ln\langle SA(T) \rangle}{\sigma(T)}\right)^2\right\} dx$$

In this expression $\ln\langle SA(T) \rangle$ is the least squares estimate and $\sigma(T)$ is the associated standard deviation of $\ln SA(T)$, which have been obtained from the empirical attenuation relation due to Abrahamson and Silva (1997), defined at 28 natural periods between 0.01 sec and 5.0 sec. The complementary of the probability $p[SA(T)]$ gives the required

probability, $q(SA(T)|M_j, R_i)$.

From knowledge of $q(SA(T)|M_j, R_i)$ and the number $\nu_n(M_j, R_i)$ obtained as above for all the main and sub-source, the hazard function of eqn. (1) is computed in step four for all the 28 natural periods for which the selected attenuation relationship is defined. Fig. 4 shows typical hazard curves for $T = 0.02, 0.2, 1.0$ and 3.0 sec periods, where 0.02 sec period corresponds to the PGA.

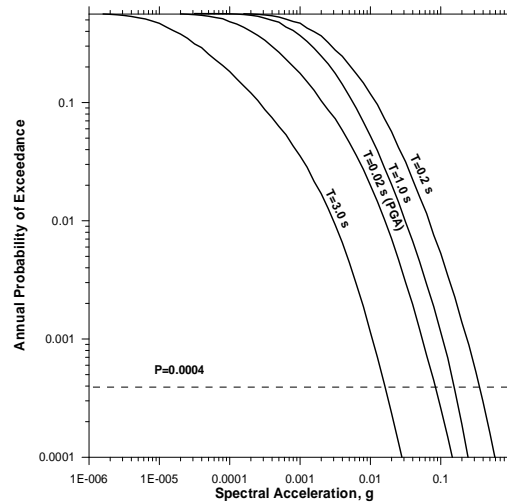


Fig. 4: Typical hazard curves at selected natural periods

The MCE level of target response spectra of horizontal and vertical components of motion with damping ratio of 5% are finally obtained by estimating the spectral amplitudes at all the natural periods with annual probability of exceedance equal to 0.0004 (return period 2500 years). The probabilistic response spectrum of the horizontal motion thus obtained for rock type of site condition is shown in Fig. 5. The corresponding mean plus one standard deviation deterministic response spectrum for MCE magnitude of 7.5 at shortest distance of 14 km to the fault rupture plane is also shown in Fig. 5 for the purpose of comparison.

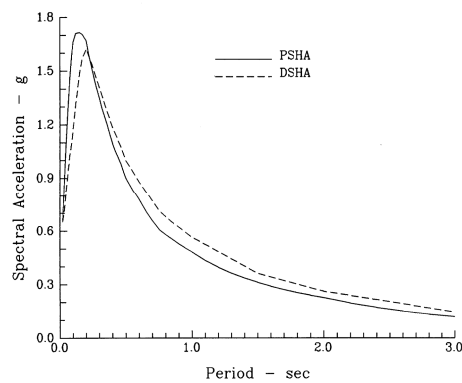


Fig.5: The 5% damped target spectra for MCE condition

Annexure D

PROFORMA FOR SUBMISSION OF STUDY REPORT TO NCSDP

The study report should be compiled in a single dossier as per *proforma* given below.

The *proforma*, duly filled and signed, should be furnished as a check-list in the beginning of the study report.

SI No.	Description	Compliance (Yes/No) w.r.t. Guidelines & Reasons for Non-compliance
1	Project Details	
(a)	Name of the Project	
(b)	Name of the River over which the project is proposed	
(c)	Brief Description of the Project Components	
(d)	Location of the Project: <i>State, District, Longitude & Latitude and Toposheet no. of each of the Project component (e.g. Dam/Barrage/Power House etc.) for which design seismic coefficient is required. Information to be given in tabular format.</i>	
(e)	Type of Project: <i>Multipurpose or irrigation Storage (area/ volume of reservoir) or Run of the River Scheme or Hydro Power Project (surface/ subsurface, Installed Capacity, number of units etc.)</i>	
(f)	Details of other projects in the vicinity(within 100 km): <i>(Refer Annexure-E)</i> <i>Name of project, Type of hydraulic structures, and seismic parameters (expected PGA for MCE) for projects constructed/ under construction.</i>	
(g)	Present Status of Investigation: <i>DPR submitted/ approved; Salient comments/ observations on DPR for ground exploration, relevant to Seismic design; status on environment clearance;pre-construction/ construction stage etc.</i>	
(h)	Nature of Foundation Material: <i>Nature of foundation material (including geotechnical properties of rock/ soil etc.) below different segments of dam and other project components.</i>	
(i)	Name and address of the Project Authority and Consultants/ Advisors: <i>Complete postal address with telephone/fax/e-mail of Project Authority and Consultants/ Advisorengaged by the Project Authority for various types of inputs [geological, geophysical, geotechnical, seismotectonics, seismic design etc] shall be given.</i>	
2	Regional Geological and Seismo-Tectonic Evaluation <i>(Refer Section 3.0 of the guidelines for details)</i>	
(a)	Tectonic Map:	
(b)	Seismo-tectonic section:	
(c)	Interpretation of regional tectonic mechanism and other details:	
(d)	Earthquake catalogue:	
(e)	Micro earthquake investigations:	

3	Local Geologic Setting <i>(Refer Section 3.0 of the guidelines for details)</i>	
(a)	Geological map:	
(b)	Surface & subsurface exploration:	
(c)	Additional inputs on subsurface configuration of major faults:	
4	Evaluation of site specific seismic parameters	
(a)	Methodology of the study: <i>The adopted study methodology, confirming to item 4 of the guidelines, should be briefly described. Any deviation from the recommended approach should be pointed out with adequate justifications.</i>	
(b)	Evaluated site specific seismic parameters: <i>The study should furnish the identified MCE (deterministic); recommended response spectra for the MCE and DBE conditions; recommended horizontal and vertical seismic coefficients along with computed natural period of the dam; estimated duration of shaking; and acceleration time histories for both horizontal and vertical motions.</i>	
5	Recommendations on design approach <i>(Refer Section 5.0 of the guidelines for details)</i>	
6	Submission of study report for NCSDP approval <i>(Refer Section 6.0 of the guidelines for details)</i>	

Date:

Signature & Seal
of authorized representative
of Project Authority

Annexure-E

TABLE-1

Seismic design parameters approved by National Committee on Seismic Design Parameters (NCSDP) from 1991 onwards

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
1	Nathpa/Jhakri	Himachal Pradesh	Sutlej	Conc. Gravity dam	60.5	31° 56' N/ 77° E	IV	NJPC	α_h for MCE = 0.23g α_h for DBE = ½ of MCE	IV - 03.05.1993
2	Renuka dam	Himachal Pradesh	Giri	Earthen/rockfill	178	30° 36' N/ 77° 27' E	IV	Himachal State Electricity Board	PGA(h) for MCE = 0.337g PGA(h) for DBE = 0.168g	VI - 20.09.1995
3	Largi	Himachal Pradesh	Beas	Conc. Gravity dam	49	31° 13.5' N/ 77° 14' E	V	Himachal State Electricity Board	PGA(h) for MCE = 0.23g PGA(h) for DBE = 0.115g	VI - 20.09.1995
4	Dhauli Ganga HEP-I	UP	Dhauli Ganga	Rock fill	56	29° 58' 42" N/ 80° 34' 27" E	V	NHPC	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	VI - 20.09.1995
5	Indira (Narmada) Sagar Dam	Madhya Pradesh	Narmada	Concrete gravity Dam	92	22° 17' 00" N/ 76° 28' 00" E	III	M.P Irrigation Department	PGA(h) for DBE = 0.12g	IX - 12.01.2000
6	Kalpong H.E. Project	Andaman & Nicobar	Kalpong	Concrete gravity Dam	31	10° 09' 35" N/ 92° 58' 15" E	V	N.H.P.C	PGA(h) for MCE = 0.39g PGA(h) for DBE = 0.195g	IX - 12.01.2000
7	Greater Shillong Water Supply Scheme.	Meghalaya	Umiew	Concrete gravity Dam	50	25° 26' 42" N/ 91° 46' 15" E	V	-	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	IX - 12.01.2000
8	Tattihalla Augmentation Scheme	Karnataka	Beathi	Earthen Dam	18	15° 01' 15" N/ 74° 53' 20" E	II	Karnataka Power Corp., Bangalore	α_h for DBE = 0.12g α_v for DBE = 0.08g	IX - 12.01.2000
9	Tala H.E. Project	Bhutan	Wangchu	Concrete gravity Dam	91	27° 02' 00" N/ 89° 36' 00" E	-	THEP. Bhutan	As per response spectra given in CWPRS Report no. 3690, march, 2000	X - 15.09.2000
10	Tuirial H.E. Project	Mizoram	Tuirial	Earthen Dam	77	24° 21' 30" N/ 92° 53' 12" E	V	NEEPCO	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	X - 15.09.2000
11	Middle Vaitharna	Maharashtra	Vaitharna	Concrete gravity Dam	102	19° 42' 00" N/ 73° 26' 00" E	III	BMC	PGA(h) for MCE = 0.21g PGA(h) for DBE = 0.105g	XI - 07.06.2001
12	Parbati H.E. P Stage-II	Himachal Pradesh	Parbati	Concrete diversion dam	91	31° 46' 30" N/ 77° 18' 30" E	V	N.H.P.C	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XII - 13.08.2002

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
13	Chamera Stage II	Himachal Pradesh	Ravi	Concrete Dam	39	32° 28' 30" N/ 76° 07' 30" E	V	N.H.P.C	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XII - 13.08.2002
14	Teesta Stage-V	Sikkim	Teesta	Concrete gravity Dam	96	27° 23' 08" N/ 88° 30' 20" E	IV	N.H.P.C	PGA(h) for MCE = 0.32g PGA(h) for DBE = 0.16g	XII - 13.08.2002
15	Pagaladiya Dam Project	Assam	Pagaladiya river	Earth fill Dam	28.75	26° 31' 37" N/ 91° 31' 0" E	V	Brahmaputra Board	PGA(h) for MCE = 0.306g PGA(h) for DBE = 0.18g	XIII - 18.12.2003
16	Parbati H.E Project Stage-III	Himachal Pradesh	Saing	Rock fill dam	43	31° 40' N/ 77° 15" E	V	N.H.P.C	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XIII - 18.12.2003
17	Chamera Stage III	Himachal Pradesh	Ravi	Concrete diversion dam	68	32° 30' N/ 76° 12' E	V	N.H.P.C	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XIII - 18.12.2003
18	Kishangan ga H.E. Project	Jammu & Kashmir	Kishan ganga	Concrete gravity Dam	101	34° 39' 0" N/ 74° 45' 08" E	IV	N.H.P.C	PGA(h) for MCE = 0.34g PGA(h) for DBE = 0.17g	XIII - 18.12.2003
19	Sewa HEP – Stage-II	Jammu & Kashmir	Sewa	Concrete gravity Dam	53	32° 40' N/ 75° 53' E	V	N.H.P.C	PGA(h) for MCE = 0.44g PGA(h) for DBE = 0.22g	XIII - 18.12.2003
20	Tungabhadra Dam	Karnataka	Tungabhadra	Masonry dam	49.38	15° 15' 19" N/ 76° 20' 10" E	II	Tungabhadra Dam Board	PGA(h) for MCE = 0.27g PGA(h) for DBE = 0.14g	XIII - 18.12.2003
21	Myntdu Leska H.E. Project	Meghalaya	Myntdu	Concrete gravity Dam	59	25° 12' 15" N/ 92° 15' 41" E	V	Meghalaya Elect. Board	PGA(h) for MCE = 0.44g PGA(h) for DBE = 0.22g	XIII - 18.12.2003
22	Rihand H.E. Project	Uttar Pradesh	Rihand	Concrete gravity Dam	91	24° 12' 18" N/ 83° 00' 37" E	III	Irrigation Dept. U.P	PGA(h) for MCE = 0.32g PGA(h) for DBE = 0.171g	XIII - 18.12.2003
23	Teesta low dam Stage-III	West Bengal	Teesta	Barrage	29.5	27° 00' 07.5" N/ 88° 26' 47" E	IV	N.H.P.C	PGA(h) for MCE = 0.33g PGA(h) for DBE = 0.165g	XIII - 18.12.2003
24	Lower Subansiri H.E. Project	Arunachal Pradesh	Subansiri	Concrete gravity Dam	133	27° 33' 15" N/ 94° 15' 30" E	V	N.H.P.C	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XIV - 29.04.2004
25	Kol dam	Himachal Pradesh	Sutlej	Rock fill Dam	163	31° 23' N/ 76° 52' E	V	N.T.P.C	PGA(h) for MCE = 0.19g PGA(h) for DBE = 0.095g	XV - 24.02.2005
26	Upper Beda Project	Madhya Pradesh	Beda (Tribu. of Narmada)	Earthen Dam	23.93	21° 45' 00" N/ 75° 58' 50" E	III	Narmada Devel. Madhya Pradesh	PGA(h) for MCE = 0.238g PGA(h) for DBE = ½ of MCE	XV - 24.02.2005
27	Kutni Feeder Reservoir Project	Madhya Pradesh	Kutni (Trib. of Ken)	Earth & Masonry Dam	30.36	24° 56' 32" N/ 79° 56' 54" E	II	Govt. Of Madhya Pradesh	PGA(h) for MCE = 0.13g PGA(h) for DBE = ½ of MCE	XV - 24.02.2005
28	Lower Goi Project	Madhya Pradesh	Goi (Tributary of Narmada)	Earthen Dam	43.8	21° 54' 30" N/ 74° 55' 30" E	III	Narmada Development, Madhya Pradesh	PGA(h) for MCE = 0.2473g PGA(h) for DBE = ½ of MCE	XV - 24.02.2005

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
29	Teesta low dams Stage-IV	West Bengal	Teesta	Concrete gravity Dam	45	26° 54' 22"N/ 88° 28' 34"E	IV	N.H.P.C	PGA(h) for MCE = 0.44g PGA(h) for DBE = 0.22g	XV - 24.02.2005
30	Shahpurkandi H.E. Project	Punjab	Ravi	Concrete gravity Dam	54.5	32° 23' 55"N/ 75° 40' 48"E	IV	Irrigation Works, Punjab	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XVI - 27.10.2006
31	Koteshwar	Uttarakhand	Bhagirathi	Concrete gravity Dam	97.5	30° 16' 00" N/ 78° 30' 00"E	IV	Tehri Hydro Development Corporation Ltd..	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XVI - 27.10.2006
32	Indira Sagar (Polavaram H.E. Project	Andhra Pradesh	Godavari	Earth cum Rock fill Dam	33	81° 46' 00"N/ 17° 13' 00"E	IV	Irrigation Dept. Andhra Pradesh	PGA(h) for MCE = 0.16g PGA(h) for DBE = 0.08g	XVII - 06.03.2007
33	Siang Middle (Siyom) Project	Arunachal Pradesh	Siyom	Concrete face rock fill Dam	154	28° 29' 12"N/ 94° 39' 51"E	V	N.H.P.C	PGA(h) for MCE = 0.45g PGA(h) for DBE = 0.225g	XVII - 06.03.2007
34 a)	Kameng H.E. Project	Arunachal Pradesh	Bishom	Concrete gravity Dam	75	27° 57' 30"N/ 92° 37' 39"E	V	NEEPCO Ltd.	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.155g	XVII - 06.03.2007
b)	Kameng H.E. Project	Arunachal Pradesh	Tenga	Concrete gravity Dam	27	27° 13' 46"N/ 92° 40' 07"E	V	NEEPCO Ltd.	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.155g	XVII - 06.03.2007
35	Karcham Wangtoo HEP	Himachal Pradesh	Sutlej	Concrete gravity Dam	98	31° 50' N/ 78° 17'E	IV	Jaiprakash Industries Ltd.	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XVII - 06.03.2007
36	URI-II H.E. Project	Jammu & Kashmir	Jhelum	Concrete gravity Dam	52	36° 06' N/ 73° 58'E	IV	N.H.P.C	PGA(h) for MCE = 0.39g PGA(h) for DBE = 0.20g	XVII - 06.03.2007
37	Nimoo Bazgo H.E. Project	Jammu & Kashmir	Indus	Concrete gravity Dam	57	33° 12' 55"N/ 77° 11' 07"E	IV	N.H.P.C	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XVII - 06.03.2007
38	Omkareshwar H.E. Project	Madhya Pradesh	Narmada	Concrete gravity Dam	73.12	22° 14' 25"N/ 76° 09' 45"E	III	Jaiprakash Industries Ltd.	PGA(h) for MCE = 0.20g PGA(h) for DBE = 0.10g	XVII - 06.03.2007
39	Loharinaga Pala H.E. Project	Uttarakhand	Bhagirathi	Barrage	15	30° 58' 00"N/ 78° 42' 00"E	V	N.T.P.C	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XVII - 06.03.2007
40	Tapovan Vishnugad HEP	Uttarakhand	Dhauliganga	Barrage	25	30° 29' 30"N/ 79° 37' 30"E	IV	N.T.P.C	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XVII - 06.03.2007

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
41	Malana H.E. Project Stage-II	Himachal Pradesh	Malana	Concrete Dam	51	32°05' N/ 77°16'E	IV	Everest Power Private Ltd.	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XVIII - 05.07.2007
42	Chutak H.E. Project	Jammu & Kashmir	Suru	Barrage	15	34° 27' 00"N/ 76° 05'E	IV	N.H.P.C	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XVIII - 05.07.2007
43	Chuzachen HEP	Sikkim (Two gravity dams)	Rangpo Chu	Concrete Dam	48	27° 12' 14"N/ 88° 39' 59"E	IV	Gati Infrastructures Ltd. New Delhi	PGA(h) for MCE = 0.40g PGA(h) for DBE = 0.20g	XVIII - 05.07.2007
			Rongli Chu	Concrete Dam	41	27° 14' 30"N/ 88° 42' 46"E		Gati Infrastructures Ltd. New Delhi		
44	Kotlibhel HEP-1A	Uttarkhand	Baghirathi	Concrete Dam	82.5	30° 10' 34" N/ 78° 35' 26"E	IV	N.H.P.C	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XVIII - 05.07.2007
45	Kotlibhel HEP-1B	Uttarkhand	Alaknanda	Concrete Dam	70.5	30° 09' 01" N/ 78° 30' 02"E	IV	N.H.P.C	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XVIII - 05.07.2007
46	Kotlibhel HEP-Stage-II	Uttarkhand	Ganga	Concrete Dam	58.6	30° 04' 05" N/ 78° 30' 02"E	IV	N.H.P.C	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XVIII - 05.07.2007
47	Pala Maneri H.E. Project	Uttarkhand	Bhagirathi	Concrete gravity Dam	74	30° 50' 25"N/ 78° 37'44"E	IV	Uttaranchal JalVidyut Nigam Ltd.	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XVIII - 05.07.2007
48	Tail Pond Dam	Andhra Pradesh	Krishna	Concrete Dam	29.5	16° 38' N/ 79° 29'E	III	APGENCO	PGA(h) for MCE = 0.185g PGA(h) for DBE = 0.092g	XIX - 11.04.2008
49	K.L. Rao (Pulichinthala) Sagar	Andhra Pradesh	Krishna	Concrete Dam	42.24	16°46'14 N/ 80° 03' 33"E	III	A.P.Govt.	PGA(h) for MCE = 0.18g PGA(h) for DBE = 0.09g	XIX - 11.04.2008
50	Dhankari Dam	Andaman & Nicobar	Dhankari Nallah	Concrete Dam	32.25	11° 32' 30" N/ 92° 40' 0"E	V	N.H.P.C	PGA(h) for MCE = 0.51g PGA(h) for DBE = 0.255g	XIX - 11.04.2008
51	Budhil H.E. Project	Himachal Pradesh	Budhil Stream	Concrete Dam	61.5	32°26'48"N/ 76°33'26"E	IV	LANCO Green Power Ltd.	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XIX - 11.04.2008

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
52	Kelo Project	Chattisgarh	Kelo	Earthen Dam	24.22	21° 57' 00"N/ 83° 23' 20"E	II	Chattisgarh State Govt.	PGA(h) for MCE = 0.199g PGA(h) for DBE = 0.0995g	XIX - 11.04.2008
				Masonry /concrete spill way	16				For DBE cond: $\alpha_h=0.119$, $\alpha_v=0.079$ (for Masonry portion) & $\alpha_h=0.093$, $\alpha_v=0.062$ (for Earthen portion)	
53	Upper Narmada Project	Madhya Pradesh	Narmada	Earthen Dam	30.64	22° 51' 50"N/ 81° 23' 20"E	III	Govt. Of M.P	PGA(h) for MCE = 0.144g PGA(h) for DBE = 0.072g	XIX - 11.04.2008
54	Pench Diversion Project	Madhya Pradesh	Pench	Earthen Dam	41	22° 07' 10" N/ 79° 10' 25"E	III	Govt. Of M.P	PGA(h) for MCE = 0.199g PGA(h) for DBE = 0.0995g	XIX - 11.04.2008
55	Rangit H.E. Project Stage IV	Sikkim	Rangit	Concrete Dam	44	27° 13' 10"N/ 88° 18' 10"E	IV	Jal Power Corporation Ltd.	PGA(h) for MCE = 0.457g PGA(h) for DBE = 0.228g	XIX - 11.04.2008
56	Teesta H.E. Project Stage III	Sikkim	Teesta	Concrete faced rock fill dam	60	27° 35' 50"N/ 88° 39' 30"E	IV	Erudite Engineers Pvt. Ltd.	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XIX - 11.04.2008
57	Vishnugad Pippalkoti H.E. Project	Uttarkhand	Alaknanda	Conc. Dam	45	30° 31' 00" N/ 79° 29' 37" E	IV	Tehri Hydro Dev. Corporation Ltd..	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XIX - 11.04.2008
58	SingoliBhatwari H.E. Project	Uttarkhand	Mandakini	Barrage	22	30° 30' 17" N/ 79° 05' 22" E	IV	L&T Ltd.	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XIX - 11.04.2008
59	Vyasi. H.E. Project	Uttarkhand	Yamuna	Concrete dam	86	30° 31' 00" N/ 77° 53' 00" E	IV	N.H.P.C	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XIX - 11.04.2008
60	Lata Tapovan H.E. Project	Uttarkhand	Dauli ganga	Barrage	16	30° 31' 30" N/ 79° 43' 30" E	V	N.T.P.C	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XIX - 11.04.2008
61	PakalDul (Drangdhu ran) H.E. Project	Jammu & Kashmir	Marsudar (Tributary of Chenab)	Concrete faced rock fill dam	167	33° 27' 30"N/ 75° 48' 50" E	IV	N.H.P.C	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XX - 23.09.2008
62	Mankulam H.E. Project 40MW	Kerala	Mela cherry	Concrete Dam	50	10° 07' 19" N/ 76° 55' 21"E	III	KSEB	PGA(h) for MCE = 0.199g PGA(h) for DBE = 0.0995g	XX - 23.09.2008
63	Alaknanda	Uttarakhand	Alaknanda	Barrage	20	30° 43.4' N/ 79° 29.7'E	IV	GMR Hydro Power Gen. Pvt Ltd.	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XX - 23.09.2008

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
64	Shrinagar H.E. Project	Uttarakhand	Alaknanda	Concrete Dam	90	30°14'N/ 78°50'E	IV	AHPCL.	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XX - 23.09.2008
65	Sapta Kosi Dam Sun Kosi dam Chhatra barrage Sun Kosi PH Kamala dam & Chisapani barrage	Nepal	Sapta Kosi Sun Kosi Sapta kosi Sun Kosi Kamla	Rock fill dam Concdam Barrage PH Rockfill & barrage	269 48.9 - - 51	26°53' 29"N/ 87°10' 14"E; 27° 06'15" N/ 86° 28'25" E; 26° 50'07" N / 87° 08'41"E 26° 53'52" N / 86°12'54 E	-	JPO-SKSKI, Nepal	mean PGA(h) = 0.43g mean PGA(v) = 0.34g mean PGA(h) = 0.41g mean PGA(v) = 0.29g mean PGA(h) = 0.37g mean PGA(v) = 0.27g mean PGA(h) = 0.39g mean PGA(v) = 0.26g mean PGA(h) = 0.33g mean PGA(v) = 0.23g	XXI - 08.09.2009
66	Bhairon Ghati H.E. Project	Uttarakhand	Baghirathi	Barrage	22	31°01'51"N/ 78°42'51.9E	IV	UJVNL	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XXI - 08.09.2009
67	Teesta H.E. Project Stage-VI	Sikkim	Teesta	Barrage	23.5	27°14' 42"N/ 88°29' 15"E	IV	Lanco Energy Pvt. Ltd.	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XXI - 08.09.2009
68	Dikrong/ Pare H.E. Project	Arunachal Pradesh	Dikrong	Concrete Diversion Dam	61	27°14' 13"N/ 93°48' 56"E	V	NEEPCO	PGA(h) for MCE = 0.33g PGA(h) for DBE = 0.17g	XXI - 08.09.2009
69	Rammam- H.E. Project Stage-III	West Bengal	Rammam	Barrage	20	27°08'N/ 88°10'E	IV	N.T.P.C	PGA(h) for MCE = 0.38g PGA(h) for DBE = 0.19g	XXI - 08.09.2009
70	Teesta H.E. Project Stage IV	Sikkim	Teesta	Concrete Dam	108.3	27°29'13"N/ 88°31' 22"E	IV	N.H.P.C	PGA(h) for MCE = 0.36g PGA(h) for DBE = 0.18g	XXI - 08.09.2009
71	Jamrani Multi Purpose Project	Uttarakhand	Gola	Roller compacted concrete Dam	130	29°16'15"N/ 79°36' 36"E	IV	Irrigation Deptt. Uttarakhand	PGA(h) for MCE = 0.31g PGA(h) for DBE = 0.16g	XXI - 08.09.2009
72	Ken-Betwa link project (Makodia dam)	Madhya Pradesh	Betwa	Earth dam with concrete spill way	27	23°14'05"N/ 77°41' 00"E	II	NWDA	PGA(h) for MCE = 0.08g PGA(h) for DBE = 0.04g	XXI - 08.09.2009

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
73	Ken-Betwa (Daudhan dam)	Madhya Pradesh	Ken	Earth & Concrete Dam	77	24° 36' 51" N/ 79° 50' 30" E	II	NWDA	PGA(h) for MCE = 0.11g PGA(h) for DBE = 0.06g	XXI - 08.09.2009
74	Dibang HEP	Arunachal Pradesh	Dibang	Concrete Dam	288	28° 20' 7" N/ 95° 46' 38" E	V	NHPC	PGA (h) for DBE = 0.19g α_h for DBE = 0.282 α_v for DBE = 0.188	23 rd - 20.11.2012
75	Lower Siang HEP	Arunachal Pradesh	Siang	Concrete Dam	85	28° 09' 8.8" N/ 95° 14' 00" E	V	JAYPEE Ventures Pvt. Ltd	PGA (h) for DBE = 0.18g α_h for DBE = 0.238 α_v for DBE = 0.159	23 rd - 20.11.2012
76	Panan HEP	Arunachal Pradesh	Talongchu/Rangyogchu	Concrete Dam	101	27° 33' 30" N/ 88° 26' 27" E	V	Himgiri Hydro Energy	PGA (h) for DBE = 0.18g α_h for DBE = 0.276 α_v for DBE = 0.184	23 rd - 20.11.2012
77	Rampur HEP	Himachal Pradesh	Satluj	Power House	-	31° 24' 00" N/ 77° 35' 40" E	IV	SJVNL	PGA (h) for MCE = 0.31g PGA (h) for DBE = 0.16g α_h for DBE = 0.14 α_v for DBE = 0.09 (for Power House)	23 rd - 20.11.2012
78	Gundia HEP	Karnataka	Gundia	Composite Dam	87	12° 47' 09" N/ 75° 40' 10" E	II	KPCL	PGA (h) for DBE = 0.114g α_h for DBE = 0.15 (for Conc. dam); α_h for DBE = 0.11 (for Earth dam); α_v for DBE = 2/3 rd of α_h	23 rd - 20.11.2012
79	Mangdechhu HEP	Bhutan	Mangdechhu	Concrete Dam	56	27° 28' 49" N/ 90° 29' 41" E	-	NHPC	PGA (h) for DBE = 0.18g α_h for DBE = 0.354 α_v for DBE = 0.236	23 rd - 20.11.2012
80	Phata Byung HEP	Uttarakhand	Mandakini	Concrete Dam	26	30° 37' 35" N/ 79° 00' 28" E	IV	LANCO Pvt. Ltd.	PGA (h) for DBE = 0.18g α_h for DBE = 0.255 α_v for DBE = 0.17	23 rd - 20.11.2012
81	Jelam Tanak HEP	Uttarakhand	Dhauliganga	Barrage	28	30° 37' 35.4" N/ 79° 49' 39.5" E	IV	THDC India Ltd.	PGA (h) for DBE = 0.18g α_h for DBE = 0.288 α_v for DBE = 0.192	23 rd - 20.11.2012
82	Sainj HEP	Himachal Pradesh	Sainj	Barrage	24.5	31° 46' 51" N/ 77° 24' 35" E	V	HPPC Ltd.	PGA (h) for DBE = 0.16g α_h for DBE = 0.224 α_v for DBE = 0.149	23 rd - 20.11.2012
83	Kutehr HEP	Himachal Pradesh	Ravi	Barrage	27	32° 20' 52" N/ 76° 31' 58" E	V	JSW Energy Ltd.	PGA (h) for DBE = 0.16g α_h for DBE = 0.232 α_v for DBE = 0.155	23 rd - 20.11.2012

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
84	Bajoli Holi HEP	Himachal Pradesh	Ravi	Concrete Dam	66	32° 16' 46"N/ 76° 40' 36"E	V	GMR Hydro Power Pvt. Ltd.	PGA (h) for DBE = 0.16g α_h for DBE = 0.213 α_v for DBE = 0.142	23 rd - 20.11.2012
85	Nyamjang Chhu HEP	Arunachal Pradesh	Nyamjang Chhu	Barrage	11.2	27° 43' 06"N/ 91° 43' 37"E	V	Bhilwara Energy Ltd	PGA (h) for DBE = 0.18g α_h for DBE = 0.288 α_v for DBE = 0.192	23 rd - 20.11.2012
86	Sissiri HEP	Arunachal Pradesh	Sissiri	Roller Compacted Conc. dam	145.5	28° 16' 10"N/ 95° 33' 10"E	V	SSH Pvt. Ltd.	PGA (h) for DBE = 0.18g α_h for DBE = 0.27 α_v for DBE = 0.18	23 rd - 20.11.2012
87	Hirong HEP	Arunachal Pradesh	Siyom	Concrete Dam	133.5	28° 37' 36.8"N/ 94° 22' 53"E	V	Jaypee Arunachal Power Ltd	PGA (h) for DBE = 0.18g α_h for DBE = 0.229 α_v for DBE = 0.153	23 rd - 20.11.2012
88	Kiru HEP	J&K	Chenab	Concrete Dam	140	33° 20' 37"N/ 75° 57' 34"E	IV	NHPC	PGA (h) for DBE = 0.16g α_h for DBE = 0.26 α_v for DBE = 0.17	23 rd - 20.11.2012
89	Demwe Lower HEP	Arunachal Pradesh	Lohit	Concrete Dam	163.02	27° 52' 48"N/ 96° 22' 39"E	V	Athena Demwe Power L.td.	PGA (h) for MCE = 0.38g PGA (h) for DBE = 0.19g PGA (v) = 2/3 rd of PGA (h) α_h for DBE = 0.28 α_v for DBE = 0.18	23 rd - 20.11.2012
90	Bowala Nand Prayag HEP	Uttarakhand	Alaknanda	Barrage	12	30° 24.4' N/ 79° 22.8' E	IV	UJVNL Limited	PGA (h) for MCE = 0.36g PGA (h) for DBE = 0.18g PGA (v) = 2/3 rd of PGA (h) α_h for DBE = 0.18 α_v for DBE = 0.12	23 rd - 20.11.2012
91	Par-Tapi-Narmada Link project (7 dams)	Gujarat & Maharashtra					II	NWDA	-	23 rd - 20.11.2012
(i)	Jheri Dam	Maharashtra	Par	Composite	36.5 (C) 76 (E)	20° 22' 25"N/ 73° 25' 51"E	II	"	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.15g <u>DBE Cond:</u> PGA (h) = 0.09g; PGA (v) = 0.08g α_h for Conc = 0.09 α_h for Earthen = 0.02 α_v for Conc = 0.09 α_v for Earthen = 0.01	23 rd - 20.11.2012

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
(ii)	Mohankav chali dam	Gujarat	Par	Composite	70.6 (Conc) 70.0 (Earthen)	20° 22'48"N/ 73° 19' 20"E	II	"	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.15g <u>DBE Cond:</u> PGA (h) = 0.09g; PGA (v) = 0.08g α_h for Conc = 0.09 α_h for Earthen = 0.02g α_v for Conc = 0.09 α_v for Earthen = 0.01	23 rd - 20.11.2012
(iii)	Paikhed dam	Gujarat	Par	Composite	90.9 (Conc) 57.4 (Earthen)	20° 27'42"N/ 73° 23'37"E	II	NWDA	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.15g <u>DBE Cond:</u> PGA (h) = 0.09g; PGA (v) = 0.08g α_h for Conc = 0.09 α_h for Earthen = 0.02 α_v for Conc = 0.08 α_v for Earthen = 0.02	23 rd - 20.11.2012
(iv)	Chasmandava dam	Gujarat	Tan	Composite	35.4 (Conc) 51.0 (Earthen)	20° 37'02 N/ 73° 22' 36"E	II	"	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.14g <u>DBE Cond:</u> PGA (h) = 0.08g; PGA (v) = 0.07g α_h for Conc = 0.09 α_h for Earthen = 0.03 α_v for Conc = 0.08 α_v for Earthen = 0.02	23 rd - 20.11.2012
(v)	Chikkar dam	Gujarat	Ambica	Composite	29.90 (Conc) 60.0 (Earthen)	20° 42' 00 N/ 73° 30' 50"E	II	"	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.14g <u>DBE Cond:</u> PGA (h) = 0.08g; PGA (v) = 0.07g α_h for Conc = 0.08 α_h for Earthen = 0.02 α_v for Conc = 0.08 α_v for Earthen = 0.02	23 rd - 20.11.2012

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
(vi)	Dabdar dam	Gujarat	Kapari	Composite	62.40 (Conc) 51.4 (Earthen)	20° 48' 58 N/ 73° 32' 05"E	II	"	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.14g <u>DBE Cond:</u> PGA (h) = 0.08g; PGA (v) = 0.07g α_h for Conc = 0.10 α_h for Earthen = 0.03 α_v for Conc = 0.09 α_v for Earthen = 0.02	23 rd - 20.11.2012
(vii)	Kelwan dam	Gujarat	Purna	Composite	62.40 (Conc) 50.1 (Earthen)	20° 55' 30 N/ 73° 32' 00"E	II	NWDA	<u>MCE Cond:</u> PGA (h) = 0.17g; PGA (v) = 0.14g <u>DBE Cond:</u> PGA (h) = 0.08g; PGA (v) = 0.07g α_h for Conc = 0.10 α_h for Earthen = 0.03 α_v for Conc = 0.09 α_v for Earthen = 0.02	23 rd - 20.11.2012
92	Damangan ga-Pinjal link Project	Gujarat & Maharashtra					III	NWDA		23 rd - 20.11.2012
(i)	Bhugad Dam	Gujarat & Maharashtra	Damanganga	Composite	68.63 (Conc.) 68.63 (Earthen)	20°12'48"N/ 73°17' 37"E	III	"	<u>MCE Cond:</u> PGA (h) = 0.18g; PGA (v) = 0.16g <u>DBE Cond:</u> PGA (h) = 0.08g; PGA (v) = 0.07g α_h for Conc = 0.09 α_h for Earthen = 0.02 α_v for Conc = 0.09 α_v for Earthen = 0.02	23 rd - 20.11.2012
(ii)	Khargihill dam	Maharashtra	Vagh	Composite	75.62 (Conc) 75.62 (Earthen)	20° 05'24 "N/ 76°16' 57"E	III	"	<u>MCE Cond:</u> PGA (h) = 0.18g; PGA (v) = 0.16g <u>DBE Cond:</u> PGA (h) = 0.08g; PGA (v) = 0.07g α_h for Conc = 0.18 α_h for Earthen = 0.04 α_v for Conc = 0.17 α_v for Earthen = 0.03	23 rd - 20.11.2012

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
93	Tato-II HEP	Arunachal Pradesh	Siyom	Concrete Dam	155	28° 32' 4.5"N / 94° 23' 57.2"E	V	Tato Hydro Power Ltd	<u>MCE Cond:</u> PGA (h) = 0.44g PGA (v) = 0.36g <u>DBE Cond:</u> PGA (h) = 0.21g PGA (v) = 0.17g $\alpha_h = 0.26$ $\alpha_v = 0.21$	23 rd - 20.11.2012
94	Lower Orr Dam Project	Madhya Pradesh	Orr	Composite	41.84 (Conc) 32.085 (Earthen)	24° 50' 50"N / 78° 05' 55"E	II	NWDA	<u>MCE Cond:</u> PGA (h) = 0.11g; PGA (v) = 0.09g <u>DBE Cond:</u> PGA (h) = 0.05g; PGA (v) = 0.04g α_h for Conc = 0.06 α_h for Earthen = 0.03 α_v for Conc = 0.05 α_v for Earthen = 0.02	23 rd - 20.11.2012
95	Dagmara HEP	Bihar	Kosi	Barrage	11	26° 20' N / 86° 44' 9.1"E	IV	Bihar State Hydro-electricity Power Corp.	<u>MCE Cond:</u> PGA (h) = 0.39g PGA (v) = 0.25g <u>DBE Cond:</u> PGA (h) = 0.20g PGA (v) = 0.12g α_h for conc. portion = 0.11 α_v for conc. portion = 0.07 α_h for Earthen dam = 0.16 α_v for Earthen dam = 0.11	23 rd - 20.11.2012
96	Tiuni-Plasu HEP	Uttarakhand	Tons	Barrage	36.30	30° 57' 02"N / 77° 51' 20"E	IV	Irrigation Deptt., Govt. of Uttarakhand	<u>MCE Cond:</u> PGA (h) = 0.47g PGA (v) = 0.35g <u>DBE Cond:</u> PGA (h) = 0.27g PGA (v) = 0.20g $\alpha_h = 0.27$ $\alpha_v = 0.20$	23 rd - 20.11.2012
97	Halon Project	Madhya Pradesh	Halon	Composite	35	22° 22' 30"N / 80° 47' 30"E	III	NVDA	$\alpha_h = 0.12$ $\alpha_v = 0.08$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
98	Rupsia-bagar Khasiabara H.E. Project	Uttarakhand	Gori-ganga	Concrete Dam	62	30°9'56.45"N/80°15'11.2"E	IV	N.T.P.C. Limited	$\alpha_h = 0.16$ $\alpha_v = 0.11$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
99	Dikhu H.E. Project	Nagaland	Dikhu	Rockfilled	112	26°39'34"N/94°47'00"E	V	Manu Energy Systems (P) Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
100	Rongnichu HE Project	Sikkim	Rongnichu	Barrage	15.5	27°16' 6.86"N/88°35'20.06"E	IV	Madhya Bharat Power Corp. Ltd.	$\alpha_h = 0.21$ $\alpha_v = 0.14$	25 th 28.06.2013 & 08.07.2013
101	Gongri HE Project	Arunachal Pradesh	Gongri	Barrage	29	27°20'22"N/ 92°19'13"E	V	Dirang Energy Pvt. Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
102	Rattle HE Project	Jammu & Kashmir	Chenab	Concrete Dam	133	33°10' 43"N/ 75°48'26"E	IV	GVK Rattle HEP Pvt. Ltd.	$\alpha_h = 0.16$ $\alpha_v = 0.11$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
103	Rangit-II H.E. Project	Sikkim	Rimbi	Concrete Dam	40	27°18' 47.44"N/ 88°10'27.77"E	IV	Sikkim Hydro Power Ventures limited	$\alpha_h = 0.16$ $\alpha_v = 0.11$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
104	Thana Plaun HEP	Himachal Pradesh	Beas	Concrete Dam	106.7	33°49' 49"N/ 76°47'31"E	V	HPPCL	$\alpha_h = 0.24$ $\alpha_v = 0.16$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
105	Shongtong -Karcham HEP	Himachal Pradesh	Satluj	Barrage	22	31°32' 30"N/ 78°16'50"E	IV	HPPCL	$\alpha_h = 0.21$ $\alpha_v = 0.14$	25 th 28.06.2013 & 08.07.2013
106	Miyar HEP	Himachal Pradesh	MiyarN alla	Barrage	27	32°46' 08"N/ 76°42'27"E	IV	Miyar Hydro Electric Power Company Limited	$\alpha_h = 0.16$ $\alpha_v = 0.11$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013
107	Nyukcharong Chu HEP	Arunachal Pradesh	Nyukcharong Chu	Barrage	22	27°38' 21.3"N/ 92°0' 20.9"E	V	SEW Nyukcharong Chu Power Corporation Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	25 th 28.06.2013 & 08.07.2013 And 26 th 11.12.2013

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
108	Dhaulasidh HE Project	Himachal Pradesh	Beas	Concrete Dam	70.75	31°48'23.1"N/ 76°26'30"E	V	SJVN Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	26 th 11.12.2013
109	Chamkarchu (stage-I) HE Project	Bhutan	Chamkar chhu	Concrete Dam	108	27°10' 20.87"N/ 90°56'24.89"E	-	NHPC Limited.	$\alpha_h = 0.24$ $\alpha_v = 0.16$	26 th 11.12.2013
110	Seli H.E. Project,	Himachal Pradesh	Chenab	Concrete Dam	123	32°45'36"N/ 76°35'25"E	IV	Seli HEP limited	$\alpha_h = 0.17$ $\alpha_v = 0.11$	26 th 11.12.2013
111	Kynshi-I HE Project,	Meghalaya	Kynshi	Concrete Dam	58.10	25°26' 46.808"N/ 91°12'44.832"E	V	Athena Kynshi Power Pvt. Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	26 th 11.12.2013
112	Devsari HE Project,	Uttarakhand	Pinder	Concrete Dam	65	30°2' 35"N-30°7' 30"N / 79°34'17"E-79°35'00"E	V	SJVN Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	26 th 11.12.2013
113	Sach Khas HE Project,	Himachal Pradesh	Chenab	Concrete Dam	90	32.967°N / 76.424°E	IV	L&T Himachal Hydropower Limited	$\alpha_h = 0.16$ $\alpha_v = 0.11$	26 th 11.12.2013
114	Mohanpura major multi purpose project	Madhya Pradesh	Newaj	Composite	35.71m (Earthen) 47.9m (Conc.).	23°57' 54"N/ 76°46'37"E	II	Water Resources Department Madhya Pradesh	$\alpha_h = 0.06$ $\alpha_v = 0.04$	27 th 23.06.2014
115	Reoli Dugli HEP	Himachal Pradesh	Chenab	Concrete Dam	79m	32.803°N/ 76.424°E	IV	L&T Himachal Hydropower Ltd.	$\alpha_h = 0.16$ $\alpha_v = 0.11$	27 th 23.06.2014
116	Dugar HEP	Himachal Pradesh	Chenab	Concrete Dam	128m	33°07' 12.89"N/ 76°21'13.77"E	IV	Dugar Hydro Power Ltd.	$\alpha_h = 0.17$ $\alpha_v = 0.11$	27 th 23.06.2014
117	Attunli HEP	Arunachal Pradesh	Dibang	Concrete dam	85m	28°40'01"N/ 96°07'01"E V	V	Attunli HEP Company Ltd.	$\alpha_h = 0.24$ $\alpha_v = 0.16$	27 th 23.06.2014
118	Lower Kopili HEP	Assam	Kopili	Concrete dam	70.13 m	25°40'N / 92°47'E	V	Assam Power GC Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
119	Etalin HEP	Arunachal Pradesh	Dri and Tangon	Concrete dam	101.5 (Dri) 80.0 (Tangon)	28°42'24"N /95°51' 52"E (Dri Dam Site) 28°39'18"N /96°00'07"E (Tangon Dam)	V	Etalin HEPCL	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
120	Naying HEP	Arunachal Pradesh	Siyom	Concrete dam	138m	28°31'10"N /94°30' 25"E	V	Naying DSC Power Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
121	P V Narasimha Rao Kanthana pally Sujala Sravanthi Project	Telangana State	Godavari	Barrage (with Left & right earth dam)	28.2 m - Barrage 15.5 m – Earth dam	18°27'40.22"N / 80°24' 35.24"E	III	SEW-Rithwik Joint Venture	$\alpha_h = 0.12$ (for both concrete and earthen portion) $\alpha_v = 0.08$ (for both concrete and earthen portion)	28 th 09.01.2015
122	Mawphu HE Project (Stage-II)	Meghalaya	Umiew	Concrete dam	51m	25°19'27"N /91°38' 08"E	V	NEEPCO Ltd.	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
123	Arun-3 HEP	Nepal	Arun	Concrete dam	70m	27°30'00"N /87°12'00"E	V	SJVN Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
124	Wangchu HEP	Bhutan	Wangchu	Concrete dam	134m	26°48'52"N /89°37' 57"E	V	SJVN Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
125	Luhri HE Project	Himachal Pradesh	Satluj	Concrete dam	86m	31°19'00"N /77°22' 00"E	V	SJVN Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
126	Kalai-II HEP	Arunachal Pradesh	Lohit	Concrete dam	198m	27°54'20"N /96°48' 16"E	V	Kalai Power Pvt Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
127	Heo HE Project	Arunachal Pradesh	Yarjep	Barrage	16m	28°32'20"N /94°16' 31"E	V	Heo Hydro Power Pvt. Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
128	Pauk HE Project	Arunachal Pradesh	Yarjep	Concrete dam	105m	28°33'37.58"N / 94°13' 56.25"E	V	Pauk Hydro Power Pvt. Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
129	Kamala (Subansiri Middle) HEP	Arunachal Pradesh	Kamla	Concrete dam	216m	27°46'18"N /93°59' 19"E	V	Kamala HEPCL	$\alpha_h = 0.24$ $\alpha_v = 0.16$	28 th 09.01.2015
130	Tawang-Stage-I HEP	Arunachal Pradesh	Tawang Chu	Barrage	26m	27°35' 20"N /91°59' 3"E	V	NHPC Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
131	Tawang-Stage-II HEP	Arunachal Pradesh	Tawang Chu	Barrage	28m	27°32' 48"N /91°49' 57"E	V	NHPC Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015
132	Loktak Down Stream HEP	Manipur	Liemat ak	Concrete Dam	30m	24° 43'52.61"N / 93°35' 7.62"E	V	NHPC Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015
133	Sawalkot HEP	J&K	Chenab	Roller Compact ed Concrete Dam	193m	33°11' N / 75°06' E	IV	JKSPDCL	$\alpha_h = 0.16$ $\alpha_v = 0.11$	30 th 15.09.2015
134	Lakhwar Multi-Purpose Project	Uttarakhand	Yamuna	Concrete Dam	204m	30°31'03"N /77°56' 58"E	IV	UJVN Limited	$\alpha_h = 0.16$ $\alpha_v = 0.11$	30 th 15.09.2015
135	Turga Pumped Storage Project	West Bengal	Turga Nala	Upper dam – Rockfill Lower Dam - Concrete Dam	Upper dam – 59.5 m Lower dam – 59 m	23°11'50.5"N /86°03' 50.7"E	III	WAPCOS Limited	$\alpha_h = 0.12$ $\alpha_v = 0.08$	30 th 15.09.2015
136	Chango Yangthang HEP	Himachal Pradesh	Spiti	Concrete Dam	47m	31°55'35"N /78° 35'50"E	IV	Chango Yangthang Hydro Power Limited	$\alpha_h = 0.16$ $\alpha_v = 0.11$	30 th 15.09.2015
137	Tagurshit HEP	Arunachal Pradesh	Tagurshit	Concrete Dam	50.5m	28°29'49.75"N /94°24'53.85"E	V	L&T Arunachal Hydropower Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015
138	Kholongchhu HEP	Bhutan	Kholongchhu	Concrete Dam	95m	27° 30'32"N /91°31'10"E	V	SJVN Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015
139	Punatsangchhu-I HE Project	Bhutan	Punatsangchhu	Concrete Dam	130m	27°24'21"N /89° 54'45"E	V	WAPCOS Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015
140	Punatsangchhu-II HE Project	Bhutan	Punatsangchhu	Concrete Dam	86m	27° 18'44.11"N /89° 57'13.8"E	V	WAPCOS Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	30 th 15.09.2015
141	Phanchung HEP	Arunachal Pradesh	Pachi	Barrage	18.3m	27° 30' 55.7"N /93°04' 6.9"E	V	PACHI Hydro Power Project Limited	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
142	Morand Dam Project	Madhya Pradesh	Morand	Main Earthen dam and a composite saddle dam with spillway	Main dam (Earth en dam) – ht 47.03 m; Saddle dam (Earth en dam – ht 21.51 m	22°19' 23.02"N / 77°28' 43.30"E	III	Narmada Valley Development Authority	$\alpha_h = 0.12$ $\alpha_v = 0.08$	31 st 23.06.2016
143	Ganjal Dam Project	Madhya Pradesh	Ganjal	Composite dam with concrete spillway	42.567 m	22°13' 47.27"N / 77°19' 50.58"E	III	Narmada Valley Development Authority	$\alpha_h = 0.12$ $\alpha_v = 0.08$	31 st 23.06.2016
142	Kwar HEP	J&K	Chenab	Concrete dam	109m	33°21'01"N / 75°53' 39" E	IV	Chenab Valley Power Projects Pvt. Ltd.	$\alpha_h = 0.16$ $\alpha_v = 0.11$	31 st 23.06.2016
143	New Ganderbal HEP	J&K	Sind	Barrage	11.5m	34°16' 21.89"N / 74°52' 27.23"E	V	JKSPDC	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016
144	Kirthai HEP (Stage-I)	J&K	Chenab	Combined Roller Compact ed Concrete	165m	33°15'33"N / 76°10' 10" E	IV	JKSPDC	$\alpha_h = 0.18$ $\alpha_v = 0.12$	31 st 23.06.2016
145	Hiramandalam Reservoir of B.R.R. Vamsadhara Project, Phase-II of Stg-II	Andhra Pradesh	Vamsadhara	Earthen Dam	42.74 m	18°40'00"N / 83°57'00"E	II	Water Resources Deptt,	$\alpha_h = 0.06$ $\alpha_v = 0.04$	31 st 23.06.2016
146	Nand Prayag Langasu HEP	Uttarakhand	Alaknanda	Barrage	14.6m (river bed)	30°19'43"N / 79°18' 28"E	V	UJVNL	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
147	Luhri HEP (Stage-I)	Himachal Pradesh	Satluj	Concrete Dam	80m	31° 19'00"N / 77° 22'00"E	V	SJVNL	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016
148	Bunakha HEP	Bhutan	Wangchu	Concrete Dam	188m	27° 08'00"N / 89° 32'33"E	V	THDC Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016
149	Sankosh HEP	Bhutan	Sankosh	Roller Compacted Concrete (RCC) Dam	235m	26° 46'41"N / 89° 55'55"E	V	THDC Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016
150	Umngot HEP	Meghalaya	Umngot	Concrete Dam	111m	25° 21'38"N / 92° 06'45"E	V	MePGCL	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016
151	Pancheshwar Multi-purpose Project	India-Nepal	Mahakali	Rock-fill dam	315m	29°25'N / 80° 14'E	V	WAPCOS Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	31 st 23.06.2016
152	Tamanthi HEP	Myanmar	Chindwin	Earthfill dam	74m	25° 07' 30"N / 95° 02' 30"E	V	NHPC Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
153	Goriganga -III A HEP	Uttarakhand	Goriganga	Barrage	30.1m	30° 02'44"N / 80°18'25"E	V	NHPC Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
154	Bursar Project	J&K	Marusudar	Concrete dam	289m	33°30'38"N / 75°47' 06" E	IV	NHPC Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
155	Naitwar Mori HEP	Uttarakhand	Tons	Barrage	30.5m	31°03'35" N / 78°05'43"E	IV	SJVNL Ltd	$\alpha_h = 0.22$ $\alpha_v = 0.15$	32 nd 12.07.2017
156	Nafra HEP	Arunachal Pradesh	Bichom	Rockfill Dam /conc. spillway	40m	27° 21' 15.71"N / 92° 33' 56.66"E	V	SEW Nafra Power Corporation Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
157	Kulsi Multi-purpose Project	Assam	Kulsi	Concrete Dam	62m	25° 50' 19"N / 91°21' 20"E	V	Brahmaputra Board	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
158	Chhatru HEP	Himachal Pradesh	Chandra	Weir	10m	32°18'18.3"N / 77° 25'18.3"E	IV	DCM Sriram Infrastructure Ltd	$\alpha_h = 0.18$ $\alpha_v = 0.12$	32 nd 12.07.2017

Sl. No	Name of Project	State	River	Dam Type	Dam Height (m)	Latitude/ Longitude (Approx.)	Seismic Zone	Project Authority	Recommended Seismic design parameters	NCSDP meeting reference (No. & Date)
159	Parnai HEP	J&K	Suran	Barrage	11m	33° 36' 42.8" N / 74° 21' 17.73"E	IV	JKSPDC Ltd	$\alpha_h = 0.21$ $\alpha_v = 0.14$	32 nd 12.07.2017
160	Rupaligad Re-regulating Dam	India-Nepal	Mahakali	Concrete dam	95m	29° 16' 55" N / 80° 18' 20" E	V	WAPCOS Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
161	Lower Kalnai HEP	J&K	Kalnai Nallah	Concrete dam	49m	33° 08' 06" N / 75° 45' 30" E	IV	JKSDDC Ltd	$\alpha_h = 0.16$ $\alpha_v = 0.11$	32 nd 12.07.2017
162	Mago Chu HEP	Arunachal Pradesh	Mago Chu	Barrage	20.5m	27° 37' 43.62" N / 92° 02' 17.55" E	V	SEW Mago Chu Power Corporation Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
163	New Melling HEP	Arunachal Pradesh	Mago Chu	Barrage	22m	27° 38' 25.9" N / 92° 04' 29.7" E	V	SEW New Melling Power Corporation Ltd	$\alpha_h = 0.24$ $\alpha_v = 0.16$	32 nd 12.07.2017
164	Nakthan HEP	Himachal Pradesh	Parbati & Tosh	Barrage	15 m (Parbati Barrage) 17 m (Tosh Barrage)	31.993° N / 77.530° E - (Parbati) 32.048° N / 77.493° E - (Tosh)	IV	HPPCL	$\alpha_h = 0.23$ $\alpha_v = 0.15$	32 nd 12.07.2017

Abbreviation used

MCE	-	Maximum Credible Earthquake;
DBE	-	Design Basis Earthquake;
PGA (h)	-	Peak Ground Acceleration (horizontal component);
PGA (v)	-	Peak Ground Acceleration (vertical component)
α_h	-	Horizontal Seismic Design Co-efficient ;
α_v	-	Vertical Seismic Design Co-efficient

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