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SEISMIC STUDIES AND DESIGN BASIS GROUND MOTION FOR NUCLEAR POWER PLANT SITES

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FOREWORD

Assurance of safety of public and occupational workers, and protection of the environment are important needs to be met in pursuance of activities of economic and social progress. These activities include the establishment and utilisation of nuclear facilities and use of radioactive sources which have to be carried out in accordance with relevant provisions in the Atomic Energy Act 1962 (33 of 62).

Since the inception of nuclear power development in the country, maintenance of high safety standards has been assigned primary importance. Recognising this aspect of nuclear power development, Government of India established the Atomic Energy Regulatory Board (AERB) in November 1983 vide standing order No. 4772 notified in Gazette of India dated 31.12.1983. AERB has been entrusted with the responsibility of laying down safety standards and frame rules and regulations in respect of Atomic Energy Act 1962. Under its programme of developing Codes and Safety Guides, AERB proposes to issue four codes of practice covering the following topics:

Safety in Nuclear Power Plant Siting

Safety in Nuclear Power Plant Design

Safety in Nuclear Power Plant Operation

Quality Assurance for Safety in Nuclear Power Plants

These Codes are intended to establish the objectives and to set the minimum requirements that shall be fulfilled to provided assurance that nuclear power plants will be sited, designed, constructed and operated without undue risk to the environment. The Codes will be followed by several Safety Guides. A provisional list of topics that would be covered by Safety Guides are given as Annexure to these Codes of Practice. The Safety Guides will contain the methods, guidelines, etc. of implementing specific parts of relevant Codes of practice, as acceptable to AERB. Methods and solutions varying from those set out in the Guides may be acceptable if they provide at least comparable assurance that Nuclear Power Plants can be operated without undue risk to the health and safety of the plant personnel, public and environment.

This document presents the safety guide on Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant sites. This guide will supplement the governing principles concerning earthquake and associated topics as stipulated in the Code of Practice on Safety in Nuclear Power Plant siting. This Safety Guide provides appropriate criteria, guidelines and outlines the procedure to be applied to derive the design basis ground motion of the site and to assess the suitability of the site against the hazards due to earthquakes. However, for other aspect not covered in this Guide, applicable and acceptable national and international Codes, Standards and Guides shall be followed.

Consistent with accepted practice for codes and guides, "shall" and "should" are used to distinguish for the potential. Appendices when included are a part of the document, whereas annexures, foot notes and bibliographies where included are only to provide information that might be helpful to the user. The Codes and Safety Guides will be subject to revision as and when necessary in the light of experience as well as the current state of the art in science and technology. The first revision of the Guide will be considered after a period of about three years.

This Safety Guide has been prepared by the staff of AERB and other professional drawn from various organisations. The Criteria adopted in the relevant International Atomic Energy Agency (IAEA) documents under the NUSS programme and similar documents from various leading countries, suitably adapted to Indian conditions have been utilised extensively in the preparation of this Code. It has been reviewed by experts both in the Government and outside before issue. AERB wishes to thank all individuals and organisations who have contributed in the preparation, review and finalisation of the code. List of persons who have participated in the Committee meetings and their organisations is included for information.

(A.K.DE)
Chairman, AERB

CONTENT

DEFINITIONS

Accident Conditions:

Substantial deviations from operational states which are expected to be infrequent and which could lead to release of unacceptable quantities of radioactive materials if the relevant engineered safety features did not function as per design intent.

Acceptable Limits:

Limits acceptable to Regulatory Body.

Active Crustal Volume:

A term used to characterise a three - dimensional portion of the earth crust for which a diffuse pattern of seismicity exists both spatially and temporally.

Active Fault:

See "Seismically Active Structure".

Applicant:

The organisation that applies for formal granting of a Licence to perform specified activities related to the Siting Construction, Commissioning, Operation and Decommissioning of a Nuclear Power Plant.

Authorisation:

The granting of written permission to perform specified activities.

Baserock (Basement):

A well consolidated geological formation which could be considered as homogeneous with respect to seismic wave transmission and response.

Bedrock:

The uppermost strongly consolidated and homogeneous geological formation, above the baserock and which exhibits contrast in mechanical properties to overlying deposits if any.

Bearing Stratum:

Soil or rock which has enough bearing capacity to support the contact pressure at the bottom of the structure of the Nuclear Power Plant under static or dynamic conditions.

Capable Faults:

A fault which has a significant potential for relative displacement at or near the ground surface.

Commissioning:

The process during which plant components and systems, having been constructed, are made operational and verified to be in accordance with design assumptions and to have met the performance criteria; it includes both non-nuclear and nuclear tests.

Construction:

The process of manufacturing and assembling the components of a Nuclear Power Plant, the erection of civil works and structures, the installation of components and equipment, and the performance of associated tests.

Decommissioning:

The process by which a Nuclear Power Plant is finally taken out of operation.

Design Basis Natural Events:

Natural events selected for deriving design basis.

Deterministic Method:

A method for which the parameters and their values are mathematically definable and may be explained by physical relationship.

Dynamic Amplification Factor (DAF)

Dynamic Amplification Factor is the pseudo absolute acceleration spectral value normalised with respect to peak ground acceleration.

Earthquake:

Vibration of earth caused by the passage of seismic waves rediating from the source of elastic energy.

Epicentre:

The geographical point on the surface of earth vertically above the focus of earthquake.

Free Field Ground Motion:

The motion which appears at a given point of the ground due to earthquake when vibratory characteristics are not affected by structures and facilities.

Fault:

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

Ground Motion Intensity:

A general expression charactersing the level of ground motion at a given point, it may refer to acceleration, velocity, displacement, macroseismic intensity or spectral intensity.

Hypocentre:

The location where the slip responsible for an earthquake commences, the focus of an earthquake.

Inspection:

Quality Control actions which by means of examination, observation or measurement determine the conformance of materials, parts, components, systems, structures, as well as processes and procedures, with predetermined quality requirements.

Intensity of Earthquake:

The intensity of an earthquake at a place is a measure of the effects of the earthquake and is indicated by a number according to the Modified Mercalli Scale of Seismic Intensities.

Intensity Scale Value:

Macroseismic intensity rating expressed in terms of the scale used.

Isoseismal:

Contour drawn to separate one level of seismic intensity from another.

Karstic Phenomena:

Formation of sinks or caverns in soluble rocks by the action of water.

Lens:

A geologic deposit that is thick in the middle and converges toward the edges, resembling a convex lens.

Local Magnitude of Earthquake (Richter)

The magnitude of an earthquake is the logarithum to the base 10 of the maximum trace amplitude, expressed in microns, with which the standard short period torsion seismometer (with a period of 0.8 second, magnification 2800 and damping nearly critical) would register the earthquake at an epicentral distance of 100 Km. The magnitude M is thus a number which is a measure of energy released in an earthquake.

Macroseismicity:

Seismicity of level such that it implies significant, coherent, substained tectonic activity. With respect to individual faults or faults zones, macroseismicity is seismicity of a level that implies a significant and constant tectonic driving mechanism.

Microearthquakes:

Microearthquakes have magnitudes less than 3.0, other earthquakes or macroearthquakes have magnitudes equal to or greater than 3.0.

Microtremor:

An ambient ground vibration with extremely small amplitude (of a few micrometers). This vibration can be producted by natural and/or artificial causes such as wind, sea-waves, and traffic disturbances.

Neotectonics:

For seismic regions, the tectonics of the Quaternary era.

Normal operation:

Operation of a Nuclear Power Plant within specific Operational limits and Conditions including shut-down, power operation, shutting down, starting up, maintenance, testing and refuelling.

Nuclear Power Plant:

A thermal neutron reactor or reactors together with all structures, systems, and components necessary for safety and for the production of power, i.e. heat or electricity.

Operation

All activities performed to achieve, in a safe manner, the purpose for which the plant was constructed, including maintenance, refuelling, in-service inspection and other associated activities.

Operating Basis Earthquake (OBE):

The "Operating Basis Earthquake" (OBE) is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produces the vibratary ground motion of which those features of Nuclear Power Plant (NPP) necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

Potential:

A possibility worthy of further consideration for Safety.

Quality Assurance:

Planned and systematic actions necessary to provide adequate confidence that an item or facility will perform satisfactorily in service.

Quality Control:

Quality Assurance actions which provide a means to control and measure the characteristics of item, process or facility in accordance with established requirements.

Quaternary Deposits:

The geological formations belonging to the second period of the Cenozoic geologic era, following the tertiary, and including the last 2-3 million years.

Records:

Documents which furnish objective evidence of the quality of item and of activities affecting quality.

Region:

A geographical area,, surrounding and including the Site, sufficiently large to contain all the features related to a phenomenon or to the effects of a particular event.

Regulatory Body:

Atomic Energy Regulatory Board which has legal authority for regulating the siting, Construction, Commissioning, Operation and Decommissioning of Nuclear Power Plants in the interest of Safety by licensing or other Authorisation Processes in India.

Reliability:

The probability that a device, system or facility will perform iits intended function satisfactorily for a specified time under stated operating conditions.

Response Spectrum

Response Spectrum is plot of the maximum absolute value response of a single degree freedom system with respect to its undamped natural frequency.

Safety:

Protection of all persons from undue radiological hazard.

Safe Shutdown Earthquake (SSE):

The "Safe Shutdown Earthquake" is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local sub-surface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems and components are designed to remain functional. These structures, systems, and components are those necessary to ensure:

1) The integrity of the reactor coolant pressure boundary.
2) The capability to shutdown the reactor and maintain it in a safe shutdown condition, or
3) The capability to prevent/mitigate the consequences of accidents which could result in potential off site exposure comparable to relevant AERB Guideline.

Safety Limits:

Limits upon process variable within which the operation of the Nuclear Power Plant has been shown to be safe.

Safety Report:

A document provided by the Applicant or License to the Regulatory Body containing information concerning the Nuclear Power Plant, its design, accident analysis and provisions to minimise the risk to the public and to the sit e personnel.

Seismically Active Stricture:

A structure or a fault which has slip in geologically recent period or seismic activity is called a seismically active structure.

Seismotectonic Province:

A geographic area characterised by similarity of geological structure and earthquake characteristics.

Site:

The area containing the plant, defined by boundary and under effective control of the Plant Management.

Site Area:

The immediate area of the site on which the structures of the Nuclear Power Plant are situated, and for which detailed geotechnical investigations are required.

Site Personnel:

All persons working on the Site, either permanently or temporarily.

Siting:

The process of selecting a suitable Site for a Nuclear Power Plant, including appropriate assessment and definition of the related design bases.

Specification:

A written statement of requirement to be satisfied by a product, a material or a process, indicating the procedure by means of which it may be determined whether the specified requirements are satisfied.

Surface Faulting:

The permanent offset or tearing of the ground surface by differential movement across a fault during an earthquake.

Tectonic structure:

A large scale structural feature resulting from deformation of the earth crust.

Tectonic province:

(refer seismotectonic province)

Tsunamis:

Long period seismic sea waves generated in a sea or ocean by an impulsive disturbance such as an abrupt bottom displacement caused by an earthquake, a volcanic eruption or a submarine landslide.

I. INTRODUCTION

1.1 GENERAL

This Safety Guide has been prepared as a part of the continuing effort of the Atomic Energy Regulatory Board (AERB) to establish Codes of Practice and Safety Guides relating to the engineering of Nuclear Power Plants.

In order to mitigate the hazards on account of an earthquake, appropriate engineering approach is required to be adopted. The Indian Standard Code, Criteria for Earthquake Resistant Design of Structures, IS 1893: 1984” stipulates the specification of aseimic design for buildings, industrial structures, etc. except for the Nuclear Power Plants (NPP). The requirements of aseismic design of NPP have to be relatively stringent. The "Code of Practice on safety in Nuclear Power Plant Siting" of AERB stipulates the governing principles concerning earthquakes and associated topics in relation to NPP siting. The present Guide supplements the stipulation of the code.

The safety related building and structures of a NPP should be designed in accordance with the provision of the Guide. Safety of the other structures outside the main plant area or site area whose performance has direct influence on the radiological hazard due to NPP, should also be evaluated in line with the recommendations of this Guide.

1.2 SAFETY DESIGN APPROACH

Investigations of the phenomena treated in this Guide should be performed for every NPP site. These investigations and studies should form the basis for engineering solution to mitigate the effects of the seismic hazard.

It is desirable to select the NPP site in areas falling in Zone I to IV of seismic zoning map, IS 1893: 1984.

The safety of NPP site should be evaluated with respect to seismic hazard that may arise out of the following:

1) Vibratory effects of the following:
2) Ground failure phenomena
   - Surface faulting
   - Liquefaction
   - Slope instability
   - Subsidence
   - Collapse
3) Seismically induced flood and water waves
   - Dam failure
   - Failure of reservoir
   - Tsunamis
   - Seiches

The vibratory effects of ground motion can be mitigated by engineering solutions. The main consideration for the design basis ground motion, defined in a subsequent section, is the protection of public and environment from radiological hazard.

If a site suffers from the potential of ground failure, it will be deemed unsuitable for siting NPP unless there are adequate and reliable engineering solutions.

Every site should be evaluated for the potential consequences arising from a seismically induced flood and water waves. If the evaluation shows that the consequences are not acceptable, appropriate engineering solution should be sought to mitigate their effects.

1.3 SCOPE

The present Guide deals with the approaches and methodology to be adopted in deriving the seismic design parameters and to check the suitability of the site for NPP.

The main emphases of the Guide are on the determination of the potential for seismically induced hazards affecting the acceptability of the site and on the evaluation of the design basis ground motion for the NPP. Investigations and studies which are required to be undertaken before selecting the site and to determine the seismic design input have been discussed. In addition, the Guide treats the aspects of mitigation of hazard due to seismically generated water waves and related flooding. The seismic instrumentation is also included in the Guided.

As there is no active volcanic province in India, the effects of volcanic activities is not included in this Guide.

The provision of the Guide is applicable to thermal Nuclear Power Plants. However, other Nuclear Installations failure of which may cause unacceptable radiological hazard in public domain may also find the approach presented in the guide useful. Non-nuclear structures, such as dams, whose failure may affect safety of NPP leading to unacceptable radiological risk should be assessed using the recommendation of this Guide.

This Guide is applicable for all future NPPs.

1.4 QUALITY ASSURANCE

A quality assurance (QA) programme should be established and implemented for all the activities covered under this Guide including data collection, data processing, field and laboratory tests and investigations etc. The QA programme should be developed on the basis of the philosophy adopted in the "Code of Practice on Quality Assurance for Safety in Nuclear Power Plants", No. AERB/SC/QA.

II. DESIGN BASIS GROUND MOTION

2.1 GENERAL

To mitigate the seismic hazard for protection of public and the environment, the NPP should be designed to withstand the effects of vibratory ground motion arising from strong earthquakes. The design basis ground motion for this purpose should be evaluated for each site.

2.2 LEVELS OF DESIGN BASIS GROUND MOTIONS

The design basis ground motion should be evaluated for two levels of severity. The severe earthquake level is termed is termed as S1 and that at the extreme level is designated as S2.

2.2.1 Specification of Design Basis Ground Motions

The S1 and S2 level ground motions should be specified for free field conditions through

1) The peak Ground Acceleration (PGA) or Zero period Acceleration (ZPA)
2) Response spectra
3) Acceleration Time History of the vibratory ground motion

2.2.2 S1 Level Earthquake

The S1 level is the level of ground motion which can be reasonably expected to be experienced at the site area once during the operating life of the plant.

In the design of Nuclear Power Plant the level of earthquake should be the Operating Basis Earthquake (OBE). If S1 level of ground motion is exceeded at the site, the plant should be shut down. It will then be inspected to determine if any damage had occurred. The plant will be restarted after it is certified fit for operation.

The peak ground acceleration of S1 level earthquake in horizontal direction should not be less than 0.05g.

The return period (mean recurrence interval) of the S1 level event should not be less than 100 years when it is determined by a probabilistic method.

2.2.3 S2 Level Earthquake

The S2 level is the level of ground motion that has a very low probability of being exceeded. It represents the maximum level of ground motion to be used for design of safety related structures, systems, components, and equipment of NPP.

In the design of Nuclear Power Plant the S2 level motion be referred to as the Safe Shutdown Earthquake (SSE). The S2 level ground motion is the maximum potential vibratory ground motion at the site based on the maximum earthquake potential of the (site) region.

The peak ground accleration of S2 level earthquake in horizontal direction should not be less than 0.1 g.

The S2 level motion will be fixed in accordance with the seismotectonic conditions in the region. A probabilistic evaluation may be carried out be demonstrate that the S2 level event has a return period of the order of 10,000 years.

2.3 DERIVATION OF PEAK GROUND ACCELERATION

Depending on the seismotectonic conditions, one or more than one earthquakes will be postulated in the region. In accordance with the available geological and seismological date base, three parameters of Design Basis Earthquake (DBE) should be defined to derive the Peak Ground Acceleration for each postulated earthquake event and they are:

1) Size of the earthquake (magnitude or epicentral intensity)
2) Depth of focus
3) Distance from the site

The peak ground acceleration for S2 level motion should be determined using a deterministic approach. Peak ground acceleration for the S1 level motion may be fixed using either a deterministic or a probabilistic approach based on seismotectonic considerations.

2.3.1 Presentation of Seismotectonic Information

For evaluation of the DBE, regional geological and seismological information should be compiled and scrutinized. All lineaments interpreted form different geodata (geological, geophysical, remote sensing, etc.) pertaining to the surface expressions of faults within 300 kms of the site, should be plotted on a map (1:1, 000,000/1:2,000,000). Geology of the area will be superimposed showing the age relationships of various geological units. Epicentres of all earthquakes ($M \geq 3.0$) should also be superimposed on the lineament map. Chapter-III deals in detail, with the requirement of geological and seismological investigations.

2.3.2 Analyses of Data

1) The regional area around the site should be sub-divided into tectonic provinces. A tectonic province is a contiguous geographical region characterised by relative consistency of geological structure and seismo-tectonic characteristics.

2) Significant tectonic features and lineaments (which could be considered or suspected to be the surface experessions of geological faults) should be identified.

3) All the seismogenic faults and tectonic structures should be identified.

4) As many earthquakes as possible will be associated with the seismogenic faults and tectonic structures.

5) Occurrence rates (in time and space) of earthquakes of different magnitudes associate with each tectonic structure and fault will be estimated.

6) A maximum earthquake potential will be assigned to each know fault and tectonic structure.

7) Earthquakes which cannot be associated with know fault and structures should be identified. These earthquakes will be know as "Floating Earthquakes or Diffuse Seismicity".

8) The area will be investigated through satellite imageries, aerial photographs, detailed geological maps and ground truth verification to determine additional tectonic structures, which could be considered the sources of the unidentified earthquakes. If found, their geological characteristics will be established.

9) The data will be analysed to determine if faults could be placed into one of the four catergories, namely,

Active
Potentially active
Activity unknown
Inactive

The shortcomings of the data, required for assessing the seismotectonic status of the region will be identified, and the steps which would be taken to fill the gaps in the information will be listed.

2.3.3 Evaluation of Earthquake Potential for S2 level

Evaluation of the S2 level PGA requires that the maximum earthquake potential associated with each tectonic unit/fault or tectonic province is estimated. To each tectonic unit a maximum earthquake potential should be assigend as the maximum credible earthquake magnitude on the basis of either the historical earthquake data or seismotectonic model. For each of these tectonic units an S2 level earthquake should be defined in the following manner.

The maximum earthquake potential associated with a tectonic unit should be moved to a point on the tectonic structure closest to the NPP site as follows:

1) For each active fault the maximum earthquake potential should be moved to a point on the fault closest to the site.

While doing so consideration may be given to the size and depth of the earthquake source.

2) For the tectonic province adjacement to that in which the site lies, the maximum earthquake potential should be moved to a point nearest to the site on the boundary of the tectonic province.

3) For the tectonic province in which the site lies, the maximum earthquake potential associated with this tectonic province should be assumed to occur at a certain distance from the NPP site, within which it has been demonstrated through detailed investigations that no active tectonic structure exists.

The floating earthquake potential of the region should also be separately moved to this point. It is desirable to demonstrate through actual earthquake monitoring that no earthquake was occurring within that distance.

4) Effect of induced Seismicity (IS)

An estimate should be made of the maximum earthquake potential due to possible effects of induced seismicity (IS) origination from impounding of reservoir (existing or proposed) or withdrawal of fluid or hydrocarbon (from existing or proposed facilities) associated with tectonic units, for which there exist the possibility of faults being reactivated. The Induced Seismicity (IS) potential will be placed on such structures at a point closest to the site.

2.3.3.1 Quantification of Maximum Earthquake Potential

The maximum earthquake potential may be fixed using following parameters depending on the available data base of

1) Historical earthquake observation
2) Paleoseismicity
3) Fault rupture length, Fault rupture area and Fault slip and slip rate.

Applicability of a particular parameter depends on the availability of reliable data base for the selected parameter.

Use of the maximum historic earthquake magnitude is based on the assumption that the maximum credible earthquake in a seismic zone has occurred in historical times and is well documented, and its recurrence interval can be estimated. This approach may be relied upon in regions where large magnitude earthquakes occur on faults with large slip rates, and reliable earthquake catalogues centuries are available.

If a reliable earthquake catalogue exists for the region and detailed information of earthquake sources is not available, the maximum earthquake potential may be assigned on the basis of the recorded historical and / or instrumental data. The maximum earthquake potential determined in this manner should bot be less than that obtained by adding an equivalent of at least one unit of MMI scale.

The paleoseismicity method calls for the application of photogeological and field techniques for mapping active faults to determine rupture lengths and maximum displacements during prehistoric earthquakes. Using empirical relations between earthquake mangitude, maximum surface displacement and the associated surface fault rupture length, the magnitudes of the paleoseismic events may be estimated. The method is applicable in areas where fault scarps are preserved and adequate stratigraphic studies have been carried out to map the faults.

The fault rupture method is based on the observation that surface faulting from strong earthquakes has a rupture length between one fifth and one half of the faults. Empirical relation between fault rupture length (L) and earthquake magnitude have been suggested by several investigators. These relations are more applicable to faults of length over 300 km, which have slip rates of several millimetres per year. In addition, similar relations for magnitude have been worked out with fault slip (D) and also with product like DL and with fault rupture area. On the same lines, magnitude is correlated with land deformation are, after shock area and stress drop. Also recurrence period of earthquake magnitude is correlated with long-term slip rate (S) of fault which may vary from small fraction of a centimetre to tens of centimetres per year depending on the tectonic environment and associated seismicity. However, according to current literature survey, estimate of earthquake magnitude from fault rupture length is only dependable and should thus be used for assessing maximum earthquake magnitude from maximum fault rupture length applicable to the area.

As many of the alternative approaches using above parameters as possible will be used to estimate the maximum Earthquake potential and the highest of these estimates should be taken for deriving the S2 level ground motion.

2.3.4 Determination of Ground Motion Level

An appropriate empirical relation may be used to determine the attenuation of the ground motion for each of the Design Basis Earthquakes (DBE) considered in the seismotectonic model. For any specified earthquake the PGA should not be less than the value predicated by attenuation formulae given in Table 2.1.

2.3.5 Peak Ground Motion for S1 level

The S1 level motion as far as possible should be derived on the basis of historical earthquakes that have affected the NPP site area.

The potential of induced seismicity should be considered in deriving S1 level motion when the site is located near to any artificial reservoir (existing or proposed) or place of extraction (existing or proposed) of fluid or hydrocarbon from the earth.

In absence of detailed information the S1 level motion may also the specified as half of the S2 level motion where the S2 level motion is fixed on the basis of application of seismotectonic approach.

Details of the proposed method for fixing the S1 level motion are left to the applicant.

TABLE 2.1: Suggested Attenuation Formulae

Site Type	Attenuation Formula	
	Far Field (Epicentral Distance > 10 km)	Near Field (Epicentral) Distance < 10 km)

2.4 RESPONSE SPECTRA

2.4.1 General

Response spectra may be specified in terms of displacement, velocity and acceleration. However, developing response spectra for acceleration is advantageous as it enables one to directly compute the structural response.

The spectra are generally normalised with respect to peak ground acceleration for which correlations exist to suit various conditions. The normalised spectrum is referred to as the spectral shape.

The spectral shape of the ground motion is influenced by seismogenic source characteristics and the attenuation characteristics of geological strata while transmitting the seismic waves from the hypocentres to the site area. The seismic waves are also modified by the subsurface geology.

2.4.2 Development of Response Spectra

Site Specific Spectra (SSS) shall be used in the design of NPP. Both the spectral graphs and digitised values of the design spectra shall be specified.

Due considerations should be given for size of the earthquake, source mechanism, stress drop, seismic moment, distance from the source, transmission path characteristics and site characteristics in developing the site specific response spectra.

Response spectral shape should preferably be derived from strong motion time histories at site. However, it is recognised that adequate number of records may not be available from the site in a reasonable period of time. The response spectral shape valid for places having similar seismic, geological and soil characteristics may be used in establishing the response spectral shape specific to the site.

Alternatively, site specific spectra may be developed using frequency dependent scaling of spectral values as function of magnitude, distance and local and subsurface [Lee (1987)].

Though the site specific spectra are recommended for the design, use of standard spectra may be helpful at the preliminary stage of the project. The standard response spectra are relatively smooth shaped and are generalised for application.
Typical site independent standard spectra were illustrated by Newmark, Blume and Kapur (1973) and Newmark and Hall (1978). Studies have shown significant variation of spectral shapes with local geology (rock/soil) and these are different from site dependent spectra [Hayashi et al (1971) and Kuribayashi et al (1972)].

The site dependent standard spectra may be developed from the work of seed et al (1976), and Mohraz (1976). Examples of such site dependent standard spectra are given in Annexure - I.

2.4.2.1 Site Specific Spectra Developed From Recorded Accelerograms

Due consideration should be given to different frequency characteristics of ground motions associated with different strain level. Hence, instead of choosing a single time history and the corresponding response spectra of a recorded accelerogram, design should be based on the response spectra derived from an ensemble of accelerograms recorded on similar sites and covering a broad range of source and transmission path characteristics. At least 25 accelerograms should be taken in developing the spectra. The magnitude and distance of these records should cover the corresponding ranges considered for S1 and S2 levels of earthquakes.

The method for treating the ensemble of response spectra consists of evaluating the mean and the standard deviation of the normalised spectra at each frequency and then adding one standard deviation to the mean to obtain the desired spectral shape. The method comprises the following steps.

1) Several strong motion accelerograms are collected from the site or from sites of similar geological and lithological features.
2) These accelerograms are suitably normalised.
3) Response spectra of these accelerograms are evaluated for different values of damping.
4) The spectra of individual events are combined to obtain the shapes of design spectra.
5) The shape of the normalised spectra may be modified taking into account the strain level in the subsurface caused by the ground motion.

2.4.2.2 Design Response Spectra

The response spectra should be computed at the frequency range points indicated in Table 2.2.

To derive the design spectra the site specific spectra developed using the methodology described in cl 2.4.2.1 should be smoothened to take care of the uncertainties in determining the spectral shape. Smoothening should be done using 5 points moving average scheme. No significant local peak should b missed during smoothening the response spectra.

2.5 TIME HISTORIES

The methodology for deriving the time histories described below is not applicable for structure having base isolation system for seismic protection.

(a) Time histories of vibratory ground motion should be developed considering all the prescribed ground motion parameters and should correspond to both S1 and S2 levels. Development of time history should be based on,

1) Computational method simulating earthquake ground motion [Scan-lan et (1974), Levy et al (1976), and Mohraz (1976)]

2) Strong motion record obtained in site vicinity or adequate modifications thereof, such as adjusting the peak acceleration, applying appropriate frequency filters, or combining records.

3) Strong motion records obtained at places having similar geological and lithological features.

(b) Time histories and the design response spectra.

Regardless of the procedure used, the time history generated response spectra (THRS) should be compatible with the specified design response spectra (SDRS) for the same values of damping i.e. THRS should not deviate significantly from the SDRS over the frequency range of interest. The matching should be attempted at as many points, as possible, where the SDRS has been specified. The baseline of the time history thus generated should be modified to ensure that the consequent ground velocity and displacement do decay realistically at the end of the duration.

(c) In addition to compatibility it is desirable that the time history satisfies the constraints on specified values of,

1) Peak ground acceleration
2) Peak velocity and displacement
3) Rise-time to peak acceleration
4) Duration of strong motion, and
5) Rate of zero crossing.

The above constraint parameters should be determined from the relevant data set.

(d) For the acceleration time histories of vibratory ground motion the duration should be defined by either of the following approaches.

1) The time interval (bracketed duration) between the first and the last peak of strong ground motion above a specified threshold value, generally, taken as 0.05 g.

2) Time between 95th and 5th percentiles of the integral of the mean square value of the acceleration.

2.6 DESIGN BASIS GROUND MOTION IN VERTICAL DIRECTION]

The peak ground acceleration, the response spectra and spectra compatible time history for vertical component ground motion, should be evaluated separately using the same procedures as for horizontal motion.

If sufficient data are not available, the motion in vertical direction may be defined by the ratio between peak accelerations in vertical and horizontal directions. The recommended value of the ratio is 2/3. The same spectral shape and normalised time histories developed for the horizontal motion may be used for vertical motion.

2.7 DESIGN BASIS GROUND MOTIONS IN TWO ORTHOGONAL HORIZOTAL DIRECTIONS

The peak accelerations of ground motion in two orthogonal horizontal directions are not same. The different may be quantified by ratio between the two orthogonal horizontal motions. If no specific information is available in this respect, the peak accelerations in the two orthogonal horizontal directions may be taken as same.

The spectral shape and normalised time history should be the same in both orthogonal horizontal directions.

In case of different values of PGA for the two orthogonal horizontal directions, the spectral shapes are scaled by the PGA for the corresponding direction.

2.8 RESPONSE SPECTRA AND TIME HISTORY FOR S1 LEVEL

The spectral shapes and the normalised time histories for S1 and S2 level ground motions are taken to be the same.

Table 2.2 - Suggested Frequencies for Calculation of Response spectra

Frequency Range (Hz)	Increment (Hz)
0.5 -3.0	0.10
3.0 -3.6	0.15
3.6 -5.0	0.20
5.0 -8.0	0.25
8.0 - 15.0	0.50
15.0 -180	1.0
18.0-22.0	2.0
22.0-34.0	3.0

III. GEOLOGICAL AND SEISMOLOGICAL INVESTIGATIONS

3.1 GENERAL

Evaluation of design basis ground motion should ensure that all the seismotectonic faults and structures, relevant to the site have been considered in the development of seismotectonic model. The seismotectonic model should be based on the coherent merging of the total data base. Another important consideration in this aspect is to associate the appropriate earthquake potential with seismogenic faults and tectonic structures. The success of rational derivation of design basis ground motion as dealt in chapter II significantly depends on the extent and accuracy of the data base.

3.2 DATA REQUIREMENT

In order to evaluate the seismotectonic model consisting of discrete set of seismogenic faults and/or structures, the seismological and geological data base should established and considered along with the current knowledge of neo-tectonics and crustal dynamics. And to assess the maximum earthquake potential that can be associated with either a seismogenic fault, structure or an active crustal volume, seismicity and geology should be investigated using,

1) Historical data on earthquakes,
2) Instrumental and recorded earthquake data,
3) Site specific instrumentation,
4) Information from regional geology,
5) Identification of lineaments, faults, active crustal volume and their detailed information.
6) Ground movement data,
7) Identification of inactive faults, and
8) Evidence of fault movement to evaluate potential for surface faulting.

3.3 INVESTIGATIONS ON SEISMICITY

Seismicity data should be collected throughout the region. The suggested sources of data relevant to India are given in Annexure II.

3.3.1 Historical Earthquake Data

The historical and/or instrumental earthquake data should be collected extending as far back in time as possible. Following information on earthquakes should be collected,

1) Data and time of earthquake
2) Location of epicentre
3) Intensity at the macroseismic epicentre or maximum intensity as appropriate
4) Intensity at the site
5) Isoseimal map
6) Estimated magnitude
7) Estimated depth of focus

Appendix - A gives the description of various seismic intensity scales and correlation between magnitude and maximum intensity. The quality and extent of information for each of the above parameters will be assessed for associated uncertainties.

3.3.2 Instrumental data on Earthquakes

Following information from all available earthquake instrumental recordings in the region should be collected.

1) Origin time
2) Location of the source
3) Magnitude
4) Dimensions and geometry of the aftershock zone
5) Macroseismic Intensity data including maximum intensity, isoseismal map, intensity at the site and the location of the macroseismic epicentre
6) Duration

Other information on earthquake such as focal mechanism, dimension of rupture, rupture velocity etc. should also be retrieved from the data as and when possible. The uncertainties associated with the estimation of above parameters should be assessed.

3.3.3 Site Specific Instrumentation

To obtain more accurate and confirmatory information on hypocentres and local crustal stress condition and other aspects of neotectonics, it is suggested to operate a network of microearthquake recording stations. The stations should be operative for a minimum period of three years and are required to obtain meaningful data for seismotectonic interpretation.

Microearthquake (MEQ) data should also be normally collected on a routine basis during the operating life of the NPP. However, if specially needed to assess the seismic status of any particular fault/lineament in the vicinity of the proposed site support from microseismic data may be essential. More details of microearthquake surverys are given in Appendix-D.

In addition, Strong Motion Instrumentation (SMI) is recommended for measurement of free field acceleration and component/equipment response of the NPP. The strong motion instrumentation is dealt in Appendix-E.

3.4 INVESTIGATIONS ON GEOLOGY

To assess the potential for various kinds of earthquake induced hazard and to develop the data base on geological and lithological aspects, following information should be collected from the existing sources an /or relevant investigations should be carried out wherever necessary.

1) Regional and local geology
2) Geology and engineering parameters of the strata beneath the site
3) Faults, lineaments, and other discontinuities
4) Ground truth data on lineaments with respect to fault activity
5) Dimensions of faults and fault zones, and information on their nature and degree of faulting
6) Identifying and defining the active crustal valumes
7) Any other information relevant to assess the earthquake potential of tectonic units

Appendices B and C deal with the relevant geological, geophysical and geodetic investigations.

3.4.1 Stages of Investigations

The investigations will be carried out in three stages,

1) Preliminary investigation stage
2) Detail investigation stage
3) Confirmatory investigation stages

3.4.1.1 Preliminary investigations

(a) The main objective of the preliminary stage of investigation is to study the following aspects in a qualitative format.

1) Identifying topographical features
2) Determining the geological and lithological properties.
3) Assessing the various kinds seismic hazard potential to the site.

(b) This stage also includes identification of any locations exhibiting potential geological hazards arising from mining, liquid extraction, impounding artificial reservoirs, etc. The latter two activities may generate induced seismicity (IS).

For assessment of maximum induced seismicity potential of a region, it is desirable to study seismic data of sufficiently long period of time before and after impoundment of resservoir. Neverthless, the design basis earthquake at S2 level [See Cl. 2.3.3 (4)] estimated independently is adequate in that the IS potential is unlikely to exceed the design basis earthquake magnitude.

(c) The data and information should be collected from the published literature, documents, and reports (national and international). The important outcome of preliminary investigations will lead to the identification of the seismic hazards which need to be considered for the site and to organise detailed investigations in the subsequent stages.

3.4.1.2 Detailed Investigations

In this stage detailed investigations are carried out in quantitative format for,

1) Evaluation of potential for earthquake induced ground failure
2) Evaluation of the seismotectonic status of the region
3) Specification of design basis ground motion
4) Quantifying the potential of seismically induced flooding

The information should be collected in detail from the existing and published source. Field investigations and laboratory tests as required will also be carried out. It is desirable to complete the investigations and studies in this phase to the extent possible.

3.4.1.3 Confirmatory Investigations

There are a few studies and investigations which are to be carried out for a longer period (2 to 3 year or more). These investigations are required to confirm certain presumptions made and items and identified during detailed investigation stage. This stage is generally involved with the study pertaining to the following aspects:

1) Neotectonics
2) Seismic activity of the site/region.

3.4.2 Detailed Investigation Regime

The investigations/studies should be carried out in four ranges;

1) Regional
2) Intermediate range
3) Local
4) Site area

3.4.2.1 Regional Investigations

(a) Objective of the investigation in regional scale is to provide the knowledge of the regional geological and tectonic framework and the understanding about its global setting. Another aim of this study is to identify further investigations of more detailed type which should be carried out during the intermediate range investigation.

(b) The radial extent of regional investigation is about 300 km. However, a lower value is acceptable if it is justified without doubt from the geological and tectonic setting of the region.

(c) The studies should be carried out using maps at scale of 1:250,000/1:100,000.

(d) The data will be obtained exhaustively from published and other existing sources and should be authentic. Where the existing data are deficient, it may be necessary to verify and complete the data base by acquiring new data.

3.4.2.2 Intermediate Range Investigations

(a) The intermediate range investigation should produce following in formation,

1) Characteristics of the ground (lithological information)
2) Structural geology
3) Tectonic features

(b) The intermediate range investigation should cover a radial distance of 50 km from the site. However, a lower values is acceptable if it is justified from the regional and tectonic setup.

(c) The study should be carried out using map at scale of 1:25,000/1:50,000 alongwith necessary detailed commentary.

(d) i) Exhaustive data should be collected from the published and existing documents. The subsurface information should be derived from,

1) Geological investigations
2) Geophysical investigations
3) Satellite imageries
4) Aerial photographs

ii) Following field investigations are suggested at locations where information on critical areas of unusual complexity is inadequate,

1) Boring
2) Trenching
3) Seismic (refraction and reflection) surveys

The information obtained from the above investigations will also help in interpreting the remote sensing data.

iii) Investigations should be carried out to obtain following information,

1) Style and type of fault-length, depth, strike and dip
2) Structural relationship among the faults
3) Age and movement history
4) Evaluation of latest displacement

Detailed neotectonic studies involving geomorphology, boring, trenching, geodetic and microearthquake surveys should be carried out when it is required.

3.4.2.3 Local investigations

(a) Objective of the local investigation is to define the following in greater detail.

1) Local geological structure
2) Local Tectonic history
3) Identification of sources of potential instability

(b) The local investigation area should cover a radial distance of 5 km.

(c) The study should be carried out at a geological map at scale 1:5,000/1:10,000 with necessary and detailed commentary.

(d) i) The investigations should be carried out to derive following information,

1) Detailed tectonic history including the ages of faults, dislocations based on trenching and age dating
2) Characterisation of stability of slopes, soil, and strata based on geomorphic, physiomorphic and hydrological data (eg. drainage, vegetation, water table, etc.)
3) The potential of ground collapse due to geological hazards such as differential erosion, karstic phenomena, fractures and unstable material.

ii) Additional studies will be required to obtain data base is more detailed than that developed in the regional and intermediate range studies. In order to provide these detailed and additional data, techniques such as bore holes, trenching and geological mapping are required.

3.4.2.4 Site Area Investigations

(a) The site area investigations aim at developing the data base from geological, geophysical and geotechnical studies using both in-situ field tests and laboratory testing. Emphasis is made on defining the engineering properties of the foundation medium both under static and dynamic earthquake loading conditions.
(b) The site area investigation should cover a minimum area of $1km^2$.
(c) Investigations at the site area extend and add more details to the data base developed in three investigational regimes described above. It should help in developing a geological map at a scale of 1:500/1:1000.
(d) Investigations which should be performed in this range are described below:

i) Geological and /Geotechincal investigations:

Investigations using bore holes or pit excavations (including in-situ testing), geophysical techniques and laboratory test should be conducted to develop data base for the sub surface layer of the site area. The information which should be collected from these tests are:

1) Stratigraphy and structure
2) Thickness, depth and dip of the subsurface layer
3) Engineering properties and index properties of subsurface medium like young's modulus, shear modulus, Poisson's ratio, consolidation and swelling characteristics, grain size distribution, N-value, density etc.

ii) Geophysical investigations:

1) Seismic refraction/reflection test
2) Cross hole test
3) Electrical resistivity tests

iii) Hydrological investigations:

Investigations using boreholes and other techniques should be conducted to define the physical properties (eg. thickness, porosity, physiochemical constituents), and steady state behaviour (recharge, transmissivity) of all aquifers in the site area, with emphasis on determining how they interact with the foundation.

iv) Ground response investigations:

1) The dynamic behaviour of the rock or soil columns at the site should be assessed using historical and instrumental data when available.
2) Determination of the predominant period of ground using 'microtremor' technique.

VI ACTIVE FAULTS AND ACTIVE CRUSTAL VOLUMES

4.1 GENERAL

This section contains guidelines for delineating the active fault and to identify the active crustal volumes in the vicinity. The scope of the investigations that are required to determine whether or not a fault is considered capable is given. The section also deals with the potential of surface faulting.

Where evidence shows that there may be capable fault in the site vicinity which is likely to induce surface faulting, it is recommended that an alternative site be considered.

4.2 CAPABLE FAULTS

On the basis of geological data, a fault or tectonic structure should be considered capable if,

1) It has shown movement, at or near the surface, within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
2) It has generated micro and macro-seismicity.
3) It has a structural relationship with a capable fault identified by criteria (1) and (2) above, such that movement on one fault can reasonably be expected to be accompanied by movement on the other.

It is inevitable that the periods necessary to identify capable faults are longest in less active areas. In such area, it is necessary to extend as far as possible the demonstrable period of non-movement on a fault, preferably to ages which predate the current tectonic regime.

4.3 IDENTIFICATION OF CAPABLIE FAULTS

(a) Faults of length more than 1 km which are identified within the range of local investigation as specified in Cl. 3.4.2.3 should be carefully examined.

(b) Sufficient surface and subsurface data should be obtained from the regional investigations, intermediate rang investigations, local investigations and the site area investigations,

   1) to show the absence of faulting at/or near the site,
   2) to show that the fault is not presently active,
   3) to describe the direction, extent and history of movement on the fault and to estimate reliably the age of the youngest movement, if such movements are inferred.

(c) If a fault is taken as capable fault, the history of displacements along the fault, the maximum Quaternary displacement and nature of fault will be evaluated. Following investigations/studies are suggested to evaluate a capable fault,

1) Dating of materials on either side of a fault plane.
2) Geomorphic features such as differentially raised terraces, incised meanders, curved drainage lines, intense gullying etc.
3) Changes in alluvium morphology observed on satellite imageries.
4) Space geodetic techniques such as baseline interferometry and satellite based laser tracking.

(d) Consideration should be given to the possibility that faults which have not demonstrated recent near-surface movement may be activated by induced seismicity due to impounding of reservoir or extraction of fluid.

(e) Use of more than one technique at a site for ascertaining the age of movement of faults is desirable for improving the reliability of the assessment.

(f) If it is not established that a fault is inactive, the same should be considered in the seismotectonic evaluation as active.

4.4 TREATMENT OF ACTIVE CRUSTAL VOLUMES:

The boundaries of active crustal volumes should enclose a contiguous area on the surface which experiences diffused seismicity of a consistent frequency and style.

Significant differences in rates of seismicity may suggest different tectonic conditions that can be used in defining active crustal volumes provided the length of time for which historical data are available is long enough to demostrate that conclusions based on these data are reasonable. However, significant differences in the depth of focus (eg. 10-30 km versus 200-400 km) may alone justify the differentiation.

4.4.1 Maximum Earthquake Potential Associated with Active Crustal Volumes.

The maximum earthquake potential not associated with seismogenic fault should be evaluated on the basis of historical data and of the seismotectonic characteristics of the region. Comparison with similar regions where extensive historical data exist may be very useful, but considerable judgement is needed for this evaluation.

V. POTENTIAL FOR GROUND FAILURE

5.1 GENERAL

This section deals with guidelines and procedures for assessing the potential for ground failure from,

1) Liquefaction
2) Slope instability
3) Subsidence
4) Collapse

5.2 LIQUEFACTION

(a) Evaluation of the liquefaction potential of soil at the site is an important part of the overall assessment of the seismic hazard. The physical parameters controlling the liquefaction phenomena are,

1) Lithology of the soil at the site
2) Ground water conditions and drainage pattern
3) Behaviour of the soil under dynamic earthquake loading, and
4) Duration and level of the vibratory ground motion.

(b) Data which are required to analyse liquefaction potential are,

1) Grain size distribution, density, relative density, static or dynamic undrained shear strength, stress history and age of sediments.
2) Groundwater conditions
3) Penetration resistance of the soil
4) Shear wave velocity of the soil
5) Evidence of past liquefaction at the site or in the site vicinity.

(c) Evaluation of liquefaction potential must always consider the latest information, especially that related to the bearing capacity and settlement of the foundation.

Sites having liquefaction potential are unacceptable.

5.3 SLOPE INSTABILITY

a) The following data are needed to analyse the potential of slop in stability:

1) The geometry, extent and distribution of soil layers (or rock formations) within, adjacent to, and beneath the slop.
2) For rock slopes, the details of form and features, such as zones of fracturing, the orientation of the strata and their localised weathering which might affect their stability.

3) Static and dynamic characteristics of the soil (or rock)
4) Ground water conditions.
5) Evidence of past slop failures.

(b) Sites having severe slop stability problems and limited alternatives for engineering solutions are unacceptable.

5.4 SUBSIDENCE

(a) Conditions such as the existence of a thick aquifer in the site vicinity, the extraction of fluids, or the existence of mining activities in the vicinity, may indicate potential for subsidence, particularly in case where contact zone between hard and soft rock exists.

In addition to the basic data acquired in the investigations (see section III) the following factors should be evaluated:

1) The total reduction of the groundwater level that could occur during the operating life of the nuclear power plant.
2) The differential change in groundwater level that could develop across the site.
3) The pertinent physical parameters of the aquifer, such as consolidation coefficient, degree of lateral homogeneity, etc.

(b) If the consequences of potential subsidence cannot be mitigated by engineering solutions, the site is unacceptable.

5.5 GROUND COLLAPSE

(a) Subsurface features associated with geological /geochemical process and/or human activities may create conditions for ground collapse which can adversely affect the safety of the site.

While acquiring the basic data during the various investigations in the region attention must be paid to,

i) Geologic/geochemical process

1) Existence of caverns or karstic networks in calcareous deposits
2) Potential for solution phenomena is salt formations
3) Joint and fracture patterns
4) Spatial extent and slop of strata, especially aquifers.

ii) Human activities (past and present)

1) Existence of tunnels
2) Existence of mine galleries or cavities in or out of operation
3) Mineral extraction (for instance by dissolution techniques)
4) Withdrawal of subsurface fluids.
5) Injection or ingress of fluids.

(b) At any site, the potential for each such phenomenon should be assessed and where appropriate, be incorporated in the overall design basis for the site to ensure safety.

If there exists potential of ground collapse hazard, the site will be deemed unacceptable when adequate and reliable engineering solutions are not available.

VI. SEISMICALLY GENERATED WATER WAVES AND FLOODS

6.1 GENERAL

Seismically induced events which give rise to hazardous effects of water waves and flood are,

1) Failure of dams
2) Failure of reservoirs (Natural and artificial)
3) Tsunamis
4) Seiches

After preliminary investigation, if a site shows potential of any such hazards, a detailed investigation should be undertaken for the evaluation of their magnitude and for appropriate engineering solution to be adopted.

6.2 SEISMICALLY INDUCED DAM FAILURE

In the contest of the safety of site a dam is said to have failed when it can no more retain sufficient volume of water that may cause undersirable effects on the NPP site. The loss of retention capacity can arise either from structural failure of the dam or due to overflow of water.

Any proposed site should be evaluated for potential consequences arising from the seismically induced failure of both upstream and downstream dams (existing and proposed).

If the evaluation shows that the consequence of failure is within the acceptable limit then no further action is required. Otherwise, potential for dam failure should be assessed against the design basis ground motion determined by the techniques established in Section - II.

The potential for failure of earthen dam should be assessed using the approach for slop failure as discussed in the Cl. 5.3.

6.3 FAILURE OF RESERVOIR

The earthquake may induce failure of reservoir sides due to landslide. Such a failure will cause surge and/or overflowing of the reservoir. If the reservoir is confined by dam, the safety of the dam should be assessed for the combined effect of the strong earthquake ground motion at the dam site as mentioned in Cl. 6.2 and the resulting surge. The potential of the flooding of site should be evaluated against the overflowing of reservoir as well as the effect of dam failure, if any.

6.4 TSUNAMIS

Tsunami is a sea or ocean wave or system of waves which is usually generated by crustal deformation on the sea bottom associated with seismic event, volcanic eruption, manmade underground explosions, landslides, etc.

The coastal region of India had been experiencing tsunamis since historical times. The available data base indicates that it is not of high mangnitude except at the coastal region of kutch.

The suggested design values of tsunami heights which could be used in engineering of coastal site are:

1) Western coast upto Karwar	: 3.0 m
2) South of karwar to Calcutta via Cape Comorin	: 2.5 m

6.5 SEICHES

(a) Seiche is an oscillatory movement of water in confined water bodies caused by earthquakes, landslides and other non-seismic events like underwater volcanic eruption, underground manmade explosion, meteorological disturbance such as storms, hurricanes, etc. Seiches produced only by earthquakes and landslides are considered here.

(b) In case a reservoir possesses potential for seiche and also has a dam at its periphery, the safety of the dam should be assessed for the combined effect of strong earthquake ground motion at the dam site and the resulting surge as mentioned in Cl. 6.3.

(c) i) The factors which largely govern the Seiche phenomena are,

1) Amplitude of earthquake long period waves and their duration.
2) Resonance effects due to matching of natural period of confined water body and the seismic wave.
3) The coincidence of surges caused by seismic events with those from other causes.
4) Topography and bathymetry of water body.

ii) In case of landslide induced surges, the additional important factors are:

1) Volume of water body.
2) Extent of landslide falling into the water.
3) Kinematics of landslides.

(d) Following aspects should be considered during the preliminary investigations:

1) Evaluation of historical records of past surges.
2) Evaluation o potential for large landslides.

However if such investigations indicate potential Seiche hazard due to earthquake and landslide, further investigations should be carried out.

APPENDIX - A

SEISMIC MEASUREMENT SCALES

A.1 MODIFIED MERCALLI INTENSITY (MMI) SCALE - 1956 VERSION [Richter (1968)]

a) Classification of masonry

Masonry A,B,C,D. To avoid ambiguity of language the quality of masonry, brick or otherwise is specified by the following lettering (which has no connection with the conventional Class A, B, C construction).

Masonry A. Good workmanship, mortar and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced not designed against horizontal forces.

Masonry D. Weak material, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

b) Intensity Value

I. Not felt. Marginal and long-period effects of large earthquakes.
II. Felt by persons at rest, on upper floors, or favourably placed.
III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognised as an earthquake.
IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation or a jolt like a heavy ball striking the walls. Standing cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frames creak.

V. Felt outdoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc. off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.

VII. Difficult to stand. Noticed by drivers. Hanging object quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets, and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slide and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Under ground pipes broken. Conspicuous cracks in ground. In alluviated areas, sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals rivers, lakes, etc. sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large masses displaced. Lines of sight and level distorted. Objects thrown into the air.

A.2 UNESCO INTENSITY SCALE (IS 1893: 1984)

a) Type of structures (Buildings)

Structure A. Buildings in field-stone, rural structures, unburnt brick houses, clay houses.
Structures N. Ordinary brick buildings, buldings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone.
Structure C. Reinforced buidlings, well built wooden structures.

b) Definition of Quantity

Single, few	About 5 per cent
Many	About 50 per cent
Most	About 75 per cent

c) Classification of Damage to Buildings

Grade 1	Slight damage	Fine cracks in plaster, fall of small pieces Of plaster
Grade 2	Moderate damage	Small cracks in walls; fall of fairly large Pieces of plaster, pantiles slip off; cracks in chimneys; parts of chimney fall down.
Grade 3	Heavy damage	Large and deep cracks in walls; fall of chimneys
Grade 4	Destruction	Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; and inner walls collapse.
Grade 5	Total damage	Total collapse of buildings

d) Intensity Scale

I. Not noticeable

The intensity of the vibration is below the limit of sensibility; the tremor is detected and recorded by seismographs only

II. Scarcely noticeable (very slight)

Vibration is felt only by individual people at rest in houses, especially on upper floors of buidlings

III. Weak, partially observed only

The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibration is like that due to the passing of light truck. Attentive observers notice a slight swinging of hanging objects, somewhat more heavily on upper floors.

IV. Largely observed

The earthquake is felt indoors by many people, outdoors by a few. Here and there people awake, but no one is frightened. The vibration is like that due to the passing of heavily loaded truck. Windows, doors and dishes rattle. Floors and walls crack. Furtniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor cars the shock is noticeable.

V. Awakening

a) The earthquake is felt indoors by all, outdoors by many. Many sleeping people awake. A few run outdoors. Animals become uneasy. Buildings tremble throughout. Hanging objects swing considerably. Pictures knock against walls or swing out of place. Occasionally pendulum clocks stop. Unstable objects may be overturned or shifted. Open doors and windows are thrust and slam back again. Liquids spill in small amounts from well-filled open containers. The sensation of vibration is like that due to heavy falling inside the buildings.

b) Slight damages in buildings of type A are possible.

c) Sometimes change in flow of springs

VI. Frightening

a) Felt by most indoors and outdoors. Many people in buildings are frightened and run outdoors. A few persons lose their balance. Domestic animals run out their stalls. In a few instances dishes and glassware many break, books fall down. Heavy furtniture may possible move and small steeple bells may ring.

b) Damage of Grade 1 is sustained in single buildings of Type B and in many of Type A. Damage in a few buildings of Type A is of Grade 2.

c) In few cases cracks up to widths of 1 cm possible in wet ground; in mountains occasional landslips; change inflow of springs and in level of well water are observed.

VII. Damage of buildings

a) Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motor cars. Large bells ring.

b) In many buildings of Type C damage of Grade 1 is caused; in many buildings of Type B damage is of Grade 2. Most buildings of Type A suffer damage of Grade 3 and a few of Grade 4. In single instance landslip on roadways on steep slopes; cracks in road; seams of pipelines damaged; cracks in stone walls.

VIII. Destruction of buildings

a) Fright and panic; also persons driving motor cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are damaged in parts.

b) Most building of Type C suffer damage of Grade 2 and a few of Grade 3. Most buildings of Type B suffer damage of Grade 4. Many buildings of Type C suffer damage of Grade 4. Occasional breaking of pipe seams. Memorials and monuments move twist. Tombstones overturn. Stone walls collapse.

c) Small landslips in hollows and on banked roads on steep slopes; cracks in ground up to width of several centimetres. Water in lakes becomes turbid. New reservoirs come into existence. Dry wells refill and existing wells become dry. In many cases change in flow and level of water is observed.

IX. General damage to buildings

a) General panic, considerable damage to fruniture. Animals run to and fro in confusion and cry.

b) Many buildings of Type C suffer damage of Grade 3 and a few of Grade 4. Many buildings of Type B show damage of Grade 4 and gew of Grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases railways lines are bent and roadways damaged.

c) On flat land overflow of water, sand and mud is often observed. Ground cracks to widths of upto 10 cm, on slopes and river banks more than 10 cm; furthermore a large number of slight cracks in ground; falls of rock, many landslides and earth flows; large waves in water. Dry wells renew their flow and existing wells dry up.

X. General destruction of buildings

a) Many building of Type C suffer damage of Grade 4 and a few of Grade 5. Many buildings of Type B show damage of Grade 5; most of type A have destruction of Grade 5; critical damage to dams and dykes and sever damage to bridges. Railway lines are bent slightly. Underground pipe are broken or bent. Road paving and asphalt show waves.

b) In ground cracks up to widths of several centimetres, sometimes upto 1 meter parallel to water courses occur broad fissures. Loose ground slides from steep slopes. From river banks and steep coasts, considerable landslides are possible. In coastal areas, displacement of sand and mud; change of water from canals, lakes, rivers, etc. thrown on land. New lakes occur.

XI. Destruction

a) Sever damage even to well built buildings, bridges, water dams and railway lines; highways become useless; underground pipe destroyed.

b) Ground considerably distorted by broad cracks and fissures, as well as by movement in horizontal and vertical directions,; numerous landslip and falls of rock. The intensity of the earthquake requires to the investigated specially.

XII. Landscape changes

a) Practically all structures above and below ground are greatly damaged or destroyed.

b) The surface of the ground is radically changed. Considerable ground cracks with extensive vertical and horizontal movements are observed. Falls of rock and slumping of river banks over wide areas, lakes are dammed; waterfalls appear, and rivers are deflected. The intensity of the earthquake requires to be investigated specially.

A.3 Relation Between Magnitude and Epicentral Intensity

Magnitude	2	3	4	5	6	7	8
Intensity Scale							
MMI	I-II	III	IV-V	VI-VII	VII-VIII	IX-X	XI
UNESCO	I-II	III	IV	V-VI	VII-VIII	VIII-X	X-XI

APPENDIX - B

GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS

B.1 INTRODUCTION

The geological and geophysical investigations are carried out to develop the data base on following aspects pertaining to seismic studies as discussed in the Guide;

i) Subsurface characteristics,
Stratigraphy and lithology
Depth of bed rock
Ground water
Shallow cavities, etc.

ii) Rock mass properties,
Shear and compressive wave velocities
Engineering properties of rock materials, etc.

iii) Geological features
Faults
Folds
Shear zones
Dykes
Buried channel, etc.

The geological and geophysical investigations when used judiciously can give detailed subsurface information within a very short span of time and are thus most effective in comparative studies of alternative locations at reconnaissance stage of explaoration. It is important and necessary to corroborate geophysical results from a few bore holes in the area and any discrepancies could be remedied through modified techniques.

B.2 SUGGESTED INVESTIGATIONS

Some of the suggested methods for the investigations are briefly described below. These methods could be used for both reconnaissance and intensive exploration purposes.

B.21 Investigations on Ground Water:

Investigations will be undertaken to ascertain the ground water conditions in local area (covering a radial distance of 10 km) surrounding the site. These should include well inventory and resistively surveys.

B.2.2 Bore Holes:

The lithology and structure of site area will be thoroughly evaluated on the basis of grid-drilling to a depth of at least 100 metres. After evaluating these borehole data it may be necessary to drill a few deeper drill holes (upto 200 m.). Lithologic logs be prepared and evaluated. Particular attention be directed to identifying possible fault gauge and/or clay horizons, etc. and karsts or other cavities, as these would require special attention while planning construction.

B.2.3 Seismic refraction method:

In cases of underlying shallow high velocity layer, the method gives depths to bed rock and seismic waves velocity from records of explosion or shock waves in a row of geophones arranged in a straight line. The various details such as length of seismic profile, position of explosion etc. depend on depth to bed rock and other geological factors.

B.2.4 Seismic reflection method:

Normally, reflection method could not be usefully employed for shallow exploration, but presently suitable systems are available and the same can be used for exploration purpose. Reflection method depth to different layers.

B.2.5 Electrical resistivity method:

This method can be effective for exploration of shallow geological strata having resistivity contrast. Water bearing strata of lower resistivity can be identified easily. Similary, thick overburden, crushed rock, shallow cavities, etc. are other features where the method can be usefully employed.

B.2.6 Magnetic method:

This method is normally used for exploration of magnetic rocks, dykes, etc.

B.2.7 Borehole logging method:

Various Physical properties of rock in borehole such as acoustic velocity, electrical resistivity, etc. can be directly measured for use in subsurface exploration. Nuclear logging is also used.

B.2.8 Cross-hole method:

Seismic velocities can be directly measured by cross hole technique which is more straight forward.

B.2.9 Gravity method:

Gravity method is rarely used for shallow exploration but, for exploration of faults, shear zone and other features of larger density contrast, this method may be used in special cases.

B.2.10 Microtremor method:

A very high gain system can be used to record 'microtremor' or very low ambient noise. Variation of predominant frequency in 'microtremor' is associated with foundation condition. Thus a rapid microtremor survey could serve as an efficient reconnaissance tool along with geophysical survey.

B.2.11 Radon Measurements:

In favourable condition, radon measurements may supplement information of considerable value in understanding geotectonics of the area and hence may be employed along with other geological and geophysical exploration methods.

Periodic radon observations during operation period of NPP may also be useful.

B.2.12 VLF (EM) Method:

VLF measurement can be used effectively for the mapping of wter filled fractures and shear zones. Similarly induced polarization method is useful for ground water exploration.

APPENDIX - C

GEODETIC MEASUREMENTS

C.1 INTRODUCTION

The geodetic measurements complement other geophysical studies by providing data on a continuous basis for ascertaining the seismic status of the site identifying anomalous precursory crustal movements, strain accumulation and gravity variations.

Geodetic investigations may be required to be carried out starting from pre-construction to both during and post construction period at the local and/or site area.

C.2 INVESTIGATION BEFORE CONSTRUCTION PERIOD

(a) Existing stale high precision survey control points and gravity stations are first located as close to the target area as possible. These control points would be in the form of at least two first order triangulation or traverse stations (for plan control), two high precision bench marks (for elevation control) and two order gravity stations.

(b) Although the target area is expected to be free of any geological faults or lineaments, the existence of these close to the target area, cannot be completely ruled out. Such features, if any, should be located on the ground by joint teams of geodesists and geologists.

(c) Sites for ground monuments are then suitable located and monuments erected by joint teams of geodesists and geologists. These monuments serve the roles of geodetic investigations both during and post construction periods.

Monuments, 200 to 300 metres apart, in a suitable pattern, inside the target area an astride the suspect lineament, would be adequate.

Depending on topography, the monuments for plan and elevation control may or may not be the same. However, the monuments for elevation control can also serve as the monuments for gravity survey.

The monuments should be in the form of suitable pillars founded on bed rock. The design of the pillar would depend largely on the depth of the bed rock. This is necessary to ensure that any movements subsequently detected are not attributed to loose overburden.

(d) The stage is now set for the first set of geodetic observations. After ascertaining the stability of the two existing plan control points near the target area (as envisaged in C.2 (a)) horizontal control survey (triangulation and/or Electromagnetic Distance Measurement (E.D.M.) traverse is carried out) to provide co-ordinates of the monuments with an accuracy of at least 1:40,000.

Similarly after ascertaining the stability of two existing bench marks near the target area, high precision levelling is carried out to provide heights of the monuments with an accuracy of $(1/k)^{-0.5}$ m.m. where, k is the length of the line in kilometre.

Similarly gravity values at the monuments are provided by microgravity surveys, to an accurancy of a few microgals.

(e) At least, Two more sets of repeat observations to the specifications given in C.2 (d) are then required to be carried out at intervals of 6 to 9 months.

(f) Analysis of data from the operations indicted in paras C.2 (a) and (b) will provide the following information:

1) Horizontal co-ordinates and heights of the monuments required for subsequent detailed topographical surveys if the target area is selected.

2) Horizontal and vertical movements at the monuments alongwith the trend of the movements. Strain parameters for the target area and their trend. Only those values are to be accepted which are subjected to appropriate statistical tests and found acceptable.

3) Gravity values, their variations and trend.

(g) Other geophysical studies such as those if geologists, geophysicist and seismologists, complement the above to ascertain the seismic status of the target area.

(h) If the site is assessed to be suitable, the above investigations will also help in arriving at the design parameter for the civil structures for the Nuclear Power Plants.

If the target area is finally selected, further geodetic investigations advised are indicated below:

C.3 INVESTIGATION DURING AND POST CONSTRUCTION PERIOD

(a) Detailed topographic surveys are required to be carried out for obtaining a map on scale 1:5,000 or larger for precise plant layout and erection.

(b) Repeat geodetic studies as given in paras C.2 (d) and C.2 (e) are carried out at intervals dictated by the trend observed in the earlier studies.

Such studies will help in monitoring the trend of horizontal and vertical movements, strain accumulation and gravity variations and identifying the anomalies in the trend which may be precursory in nature.

APPENDIX - D

MICROEARTHQUAKE SURVEY

D.1 INTROCUTION

Microearthquakes are generally referred to as small earthquakes of local magnitude not exceeding 3.0. Such weak tremors have very low intensity levels at which ground vibrations produced by them are normally not felt by human beings, nor is their strength adequate to cause nay damage to surface structures. They can only be detected instrumentally by using sensitive seismic devices.

D.2 ESTABLISHMENT OF A TYPICAL MICROEARTHQUAKE NETWORK

A regional group of 10-15 highly sensitive stations deployed in an area of approximately 30 km by 30 km constitutes a microearthquake network. The field seismic stations should be established at sites of low background microseismic noise to suppress the high frequency noise, installations of sensor at 50-100 m depth inside a suitably encased bore hole is suggested so as to achieve operational magnification in the rang 1-2 million at signal frequencies around 10 Hz.

Time signals (frequency modulated analog signals or 12/16 bit digital signals as the case may be) are continuously transmitted over UHF radio links to a Master Receiving Station (MRS). Signals corresponding to detected and recognised seismic events are recorded on digital magnetic tape that forms an integral part of a standardised data acquisition system placed in Central Recording Laboraty (CRL). Alongwith the seismic signals, coded time pulses derived from a crystal controlled stable (at least 1 part in 10^8), electronic clock are also written on the magtape. The CRL also has a multichannel data retrieval facility. A single or 2 channel helicorder is usually organised along the tape bypass route to monitor some of the working channels for visual inspection.

While all the field stations are battery powered, the MRS and CRL equipment are powered by a UPS of appropriate rating. Thus the radio telemetered seismic network monitors continuously seismicity of the selected region. In an upgraded system, the telenet is interfaced to a PC-XT/AT based data processing and archiving system.

D.3 USEFULNESS OF MICROEARTHQUAKE DATA

Microearthquake networks in general are recongnised as powerful tools for investigating earthquake generating processes in a given region. In particular, microearthquake data can be useful in the following ways:

(a) It provides confirmatory evidence of the presence (or the absence) of active geological faults which may not have perceptible surface expressions.

(b) It helps to study characteristics of zonal seismic sources which govern natural seismicity and seismotectonic status of the province under investigation.

(c) The relative strength of observed signals in microseimograms help to deduce seismic wave attenuation model which is useful for predicting intensity of ground motion at a site due to a local earthquake.

(d) It provides support to estimates of b-value (slop of the linear relation between magnitude and log of frequency of occurrence of earthquakes) obtained from mocroseismic data during early phases of site evaluation.

(e) It supplements seismological information available from historical records and regional catalogue of earthquakes.

(f) It help to keep vigil (seismic surveillance) on any abnormal seismic activity that may have some relation with a possible impending earthquake in the region.

(g) The problem of "floating earthquake" can be analysed by verifying through microearthquake survey as to whether there is any definite pattern of microearthquake activity in the neighborhood of the epicentre of the "floating earthquake".

Thus, collection of microearthquake data over an adequately large period of time is an important exercise which can provide valuable inputs in the estimation of seismic hazards in a given area.

D.4 SEQUENTIAL STEPS FOR MICROEARTHQUAKE SURVEY

The seismic monitoring should be started well before (3-5 years) the construction of a nuclear power plant and it is preferable to continue monitoring throughout the operating life of the plant.

With the help of detailed topo sheets, road maps and other relevant maps, a reconnaissance survey should be conducted to examine logistics before establishing a microearthquake net. This should be followed by,

(a) Instrumental survey to ensure line of sight between proposed MRS/CRL and each field station, and

(b) Actual measurement of background noise to ensure suitability (remoteness from sources of background high frequency noise that interferes with the detection of microearthquake signals).

(c) A radio telemetered seismic network should be established on the lines described above.

(d) The analog as well as digital seismic data collected should be subjected to detailed processing and analysis using standard techniques.

APPENDIX - E

STRONG MOTION SEISMIC INSTRUMENTATION

E.1 INTRODUCTION

It is necessary to provide strong motion seismic instrumentation at the NPP site to study response during earthquakes and to compare the same with that used as the design basis. Such comparison is essential for deciding amongst other things whether the NPP can continue to be operated safely and to permit such other timely action as may be appropriate. In addition, instrumentation would also provide basic information on the degree of applicability of the mathematical models used in the seismic analysis of NPP and equipment.

E.2 INSTRUMENTATION

The following instrumentation is recommended for the above purpose:

(a) Triaxial acceleration sensors or accelergraphs which records time history of acceleration during earthquakes. These may be self contained instruments (Accelerographs) or acceleration sensors wherein the data are transmitted to remote control recorders.

(b) Structural response recorders which record spectral accelerations at specified frequencies during earthquakes.

(c) Peak acelerographs which record peak acceleration.

(d) (1) Seismic Switch (SS) and (2) Response Spectrum Switch (RSS) which detect respectively ground acceleration and spectral acceleration. These devices are essentially needed to instantly assess if specified values of the earthquake design parameters have been exceeded when immediate administrative decision are called for to deal with the situation. In general, these instruments are comparatively cheap and thus can be deployed at number of locations for better assessment of structural behaviour during earthquakes.

E.3 SELECTION OF INSTRUMENTS

The choice of instruments of each category should be done by plant design engineer, seismologist and instrumentation specialist who should jointly select relevant and proper instrumentation with suitable dynamic range, trigger level, frequency band, damping, recording speed, etc. needed to specially assess acceleration time history, structural response etc. specific to seismic environment and structural features of the NPP. Following general recommendations are made for instrumentation at NPP:

(a) Preference for central recording
(b) Trigger level not to exceed 0.02g (corresponding free field acceleration). The actuation of any sensor should trigger all the sensors.
(c) Specified actuation level of acceleration for seismic switch for the purpose of alarm should not be more than 50 p.c. of expected peak ground acceleration (PGA) (S1 level) upto a maximum of 0.1 g at any site. The question of tripping the reactor automatically at any specified level of acceleration through the seismic switch involves several complex administrative and technical aspects and is thus left to the consideration of system design.
(d) Similarly, specified actuation level of RSS should not be more than 50 p.c. of design spectral value at the place of installation.
(e) Upon actuation of seismic switch or response spectrum switch, a remote indicator alarm in the control room, should be activated when immediate administrative measures are called for.

E.4 INSTALLATION OF INSTRUMENTS

The instrument stations should be firmly anchored and should be accessible for periodic servicing. Triaxial instruments in an instrument station should be oriented so that one horizontal axis component is parallel to the major horizontal axis assumed in the seismic analysis. The axes of other instruments in the instrumentation station should be parallel to the comparable axes of the triaxial instrument.

E.5 MAINTENANCE OF INSTRUMENTS

NPP should have continuing maintenance programme to assure that the instruments should perform as required. Technical and testing procedures should be defined and documented in advance and should be updated periodically. It should be ensured that maximum number of instruments are in service during plant operation and shutdown.

Maintenance procedures should be preplanned and performed in accordance with documented instructions or drawings appropriate to the instrument. The manufacturer's recommendations should be utilised to the fullest extent possible. Periodic channel checks, functional tests and calibration should be performed to provide data for evaluating instrumental status and effectiveness of the maintenance programme. Records of maintenance data should be established and maintained for each seismic instrument and should include calibration data, operational status, recommendations for follow up work and certification of person who performed the work.

Items that have specified life time and also that have been found to be defective should be immediately replaced.

Maintenance records and operational status of the instruments should be reviewed at the appropriate administrative level of the NPP periodically to maintain maximum effectiveness of the seismic instruments.

E.6 LOCATION AND NUMER OF SEISMIC INSTRUMENTS

Choice of locations and number of seismic instruments at NPP and their installations, should be done by the plant design engineer, seismologist and instrumentation specialist who should jointly select proper locations and install various instruments mentioned under E.2 so that maximum information about free field ground motion and response of the NPP are obtained through optimum installation. However, following recommendations for installations are made:

(a) One triaxial time history accelerogaph should be provided at each of the following locations:

1) Free-field
2) Containment foundation
3) Containment structure or Reactor building

(b) One triaxial response spectrum recorder should be provided at each of the following locations:

1) Containment foundation
2) A representative Reactor equipment support or piping support.
3) A representative equipment support or piping support outside containment structure.

(c) One triaxial peak accelerograph should be provided at each of the following locations:

1) A representative Reactor equipment item
2) A representative Reactor piping item
3) A representative equipment or piping item outside containment structure

(d) One triaxial seismic switch should be provided at the containment foundation.

(e) One triaxial response spectrum switch should be provided at the containment foundation.

(f) Instrumentation required at the multi-unit sites:

Instrumentation in addition to that installed for a single unit should not be required if essentially the same seismic response is expected at the other units based on seismic analysis. However, in case of separate control rooms, alarms should be provided in all control rooms.

(g) Additional installation should be made if considered necessary.

ANNEXURE - I

STANDARD RESPONSE SPECTRA

The standard response spectra shown in this Annexure are based on the work of Seep et al (1976) and are specified for two site conditions; rock and soil. The spectral shapes of these two site conditions, are given in Figs. An-1.1 and An-1.2. The expressions defining the dynamic amplification factors (DAF) for normalised pseudo absolute acceleration are given in Tables An-1.2.

Same spectral shape, as applicable, will be used in three cardinal directions (two orthogonal horizontal and vertical) for both S1 and S2 levels. The standard response spectrum will be scaled by the relevant site specific PGA value when it will be used in design.

The standard response spectra are specified for 0%, 1%, 2%, 3%, 5%, 7%,10%, and 20% of critical dampings. Interpolation technique will be used to calculate spectral ordinates for intermediate damping value (h_1 and h_2) may be done as long as the inequality $h_1 \le h \le h_2$ but $h_2 \le 2h_1$ is satisfied.

Table An-1.1

CONSTANTS FOR DAF VALUES OF NORMALISED PSEUDO ABSOLUTE ACCELERATION FOR ROCK SITES

TABLE An - 1.2

CONSTANTS FOR DAF OF NORMALISED PSEUDO ABSOLUTE ACCELERATION VALUES FOR SOIL SIES

ANNEXURE - II

DATA BASE

1. Geological, Geotectonic (1968) and Lithological Maps:

   These maps are publised by Geological Survey of India., Calcutta and are updated from time to time with the acquisition of new data. Latest smaller versions of these maps are appended in Indian Standard: Criteria for Earthquake Resistant Design of Structures (IS: 1893-1984)

2. Hydrogeological Map:

   Central Ground Water Board has Published consolidated hydrogeological map of India (1976) incorporating regional basic informations on ground water characteristics.

   Geological Survey of India has also published a similar map of India (1969) giving regional information.

3. Geophysical maps:

   3.1 Gravity maps (1974, 1975) published by National Geophysical Research Institute, Hyderabad incorporate various gravity data collected in the country.

   3.2 Boguer Gravity Anomaly Map of India, Boguer Gravity Anomaly Zone Map of India, Total Magnetic Intensity Anomaly Map of India, and Regionalised Residual Isostatic Map of Peninsular India are given by Qureshy M N, in photogrammetrica, 37, 161-184, 1982.

4. Tectonic map:

   4.1 Oil and Natural Gas Commission has published the consolidated tectonic map in 1968.

   4.2 Geological Survey of India has also published the tectonic map of India in 1963.

5. Earthquake data:

   "Catalogue of earthquakes in India and neighborhood from historical period upto 1979" published by Indian Society of Earthquake Technology in 1983, incorporates comprehensive data on earthquakes occurred in the area.

6. For more specific information on earthquakes, following publications may also be referred to:

6.1 A catalogue of Indian earthquakes from the earliest to the end of A.D. 1869 by Oldham T, Mem. Geol. Surv. Ind. 19 (pt.3), 1-53, 1883.

6.2 Earthquakes and other earth movements by Milne J, Kegan Paul Trench and Tribner Co. Ltd., London 1888.

6.3 International Seismological Summary (ISS) Publised by International Seismological Centre for the period 1917 - 1964.

6.4 Earthquakes in India by West W.D. Proc. Ind. Sc. Congress 24, 189-225, 1937.

6.5 Earthquakes in India and Neighborhood by Pendse C.G., Scientific Notes, Ind. Met Dept., New Delhi 10 (129), 177-220,1949.

6.6 Seismicity of the Earth and Associated Phenomena by Gutenberg B and Richter C F, Princeton Univ. Press, 1953.

6.7 Earthquakes in the Himalayan Region by Banerji S K, Indian Association for the Cultivation of Science, Calcutta 1957.

6.8 Preliminary Determination of Epicentres and Earthquake Data, Reports of U.S. Geological Survey (Department of Interior), U.S.A., 1964 onwards.

6.9 Seismicity of the Earth 1953-65 by Rothe JP, UNESCO, Paris, 1969.

6.9 Recent seismic disturbances in the Shivajisagar Lake Area of the Koyna Hydroelectric Project, Maharashtra, India by Guha SK, Gosavi PD, Varma MM, Agarwal SP, Padale JG and Marwadi SC, Central Water and Power Research Station, Poona, India 1970.

6.10 A preliminary report, The Dir, Iran Earthquake of April 10, 1972, Mc-Evilly, Thomas V and Reza Razani, Bull. Seism. Soc. Am., 63 (1), 339-354, 1973.

6.11 A preliminary report, The Dir, Iran Earthquake of April 10, 1972, Mc-Evilly, Thomas V and Razani, Bull. Seism. Soc. Am.,63(1), 339-354, 1973.

6.12 Earthquake Occurrence in India by Tandon A.NA. and Srivastava H.AN., Earthquake Engineering, Sarita Prakashan, Meerut, India 1974.

6.13 A catalogue of historical earthquakes in China from recent chinese Publications by Lee WHK, We FT and Jacobsen Cart, Bull, Seism. Soc. Am.66(6), 2003-2016, 1976.

6.14 New catalogue of earthquakes for Peninsular India during 1839-1900, Srivastava et al. (1985), Mausam, 36, 351-358.

6.15 Earthquake data from local seismic nets may also be utilised wherever possible.

6.16 Maps of India showing epicentres of earthquakes magnitudewise (Appendix A) and intensity distributions (Seismic Zoning map, Fig.1) incorporated in IS:1893-1984, obtained from the above earthquake data are also recommended for use.

ANNEXURE-III

FORMATS FOR THE REPORTS ONS EISMIC STUDIES AND DESIGN BASIS GROUND MOTION FOR NUCLEAR POWER PLANT SITES

An – 3.1 GENERAL

The reports on "Seismic Studies and Design Basis Ground Motion" should provide information regarding the seismic, tectonic and geologic characteristics of the site and the region surrounding the site. The "Code of Practice for Nuclear Power Plant Siting" outlines the general philosophy and the present guide describes the principal seismic and geologic considerations which should be followed in its evaluation of acceptability of the sites and seismic design bases.

The information on studies, investigations and other related work which need to be provided for the review by regulatory authority are categorised into four groups.

Group – I Preliminary Investigation

Group – II Detailed Investigation
Development of data base
Ground failure
Seismically induced water waves and flood
Dam failure

Group – III Design Basis Ground Motion

Group – IV Confirmatory Investigation
Geodetic Measurement
Microearthquake Survey

All the relevant information pertaining to each of the above subjects should be furnished in detail. Each report should be self contained and self explanatory.

Presentation of the above information may be structured in one report or in a number of reports as desired by the applicant.

An-3.2 FORMAT FOR THE DOCUMENTATION

Each report should have a title , document number, and should contain the name and signature of the persons preparing, reviewing and approving it.

1. The documentation of the report should be done chapterwise, and each chapter should be numbered.
2. A table of contents should be provided. When a document consists of several volumes, the complete table of contents should be included in each volume.
3. The chapters of the report should be planned according to the contents of the report. Each chapter of the document should cover a particular topic and be self-contained to the extent possible.

For systematic presentation, each chapter may be subdivided into a number of sections, sub-sections and so on. Article number and heading should be assigned for each division.

4. The first chapter of the report should be the introduction, which will contain objective of the report, scope of the report and the structure of the report.
5. The last chapter of the report should contain the summary and concluding remarks.
6. Abbreviations and symbols should be consistent with general usage and should be defined in each volume where they are used first.
7. All information presented in the drawings, maps, diagrams, sketches and chats should be numbered, should be legible and the symbols should be defined and the drawings should not be to a scale that necessitates the use of visual aids.
8. The information presented in the main body of the document should be supplemented as necessary by appendices.
9. A complete list of references should be included at the end of main body of the report.

If certain references are found important pertaining to the content of the report and is not commonly used, xerox copy of the relevant portion of those references or full should be attached to the report as annexures with numbering.

10. All pages should be numbered.

Equation number should be assigned to each equation or mathematical expression.

11. Outdated text and data should be removed and replaced by inserting revised pages issued with updated text and data. Removal and insertion of pages should be easy. Changes should be highlighted by a vertical line in the margin or some other effective indication. All pages submitted to update, revise or add information to the document should show the date of issue and a change or amended number.

An – 3.3 CONTENTS OF REPORT OF GROUP 1 INVESTIGATION

The report should include but not necessarily be limited to, the following information pertaining to preliminary investigation:

1. Objective, scope of the document and its limitation.
2. Brief description of the site
3. The sources and data base
4. Geological maps developed for 4 difference ranges of studies (cl.No.3.4.2) along with commentaries.
5. Identification of important issues which should be studied in detailed investigation stage.
6. Discussion on the acceptability and engineerability of the site.
7. Conclusion
8. Reference

An – 3.4 CONTENT OF DOCUMENT ON GROUP II INVESTIGATION

This document should include but not necessarily be limited to the information discussed below. It should contain all the information upon which the decision on the acceptability and engineerability of he site could be taken.

An – 3.4.1 Evaluation of Data Base

The data should be developed from the published reports, maps, private communication, other existing sources and the investigations carried out in four ranges. Four each range of studies, the report should contain:

1. Objective, scope and limitation
2. The geological map highlighting all deformation zones such a shears, joints, fractures, folds, faults, lineaments, tectonic structures, etc.
3. Commentary on the geological map.
4. Identification of new data require, and identification of investigations/studies to be carried out in down stream activity.
5. Information on the investigations and studies.
   a) Name of the investigation and the agency which carried out the investigation.
   b) Objectives of the investigation
   c) Description of the investigation
   d) Result: field data, test data
   e) Analysis of the result and data and their interpretation

6. Summary of the complete work:

a) Has evidence been looked for historical surface faulting? Yes/No.
b) Have studies been carried out to describe the potential of surface faulting? Yes/No.
c) Are all known faults in region listed? Yes/No.
d) Are dead faults identified? Yes/No.
e) Have the remaining faults been classified as capable faults? Yes/No.
f) Has information been collected to describe the degree of capability for the faults, which have been classified as capable? Yes/No.
g) Do the available earthquake data reasonably reflect the earthquake history of the region? Yes/No.
h) Were additional investigations undertaken and completed for improving the data base:

   a) examination of satellite imageries Yes/No
   b) examination of acrial photographs Yes/No
   c) ground check of lineaments Yes/No
   d) microearthquake studies Yes/No

i) Whatever investigations were considered necessary for arriving at optimum design basis have been completed? Yes/No
j) Are the basis of engineering and geological judgements and their limitations described in the report? Yes/No
k) Are additional investigations likely to alter the postulated earthquake design basis? Yes/No
l) If the answer to any of these questions is "yes", then the details of the investigations, the methodology used and the conclusions arrived at have been given? Yes/No
m) If the answer to any of the questions is 'no', the implications of the answer and the basis of the judgement applied and the associated limitation have been examined? Yes/No

7. Unresolved issues
8. Identification of investigations to be carried out
9. Conclusion
10. Reference

An – 3.4.2 Preliminary Estimation of Peak Ground Acceleration.

Determination of preliminary value of peak ground acceleration which will be used on evaluating the acceptability and engineerability of the site, should be addressed highlighting the following,

1. Seismic data
2. Development of seismotectonic map

3. Identification of inactive faults, structures and crustal volume
4. Establishment of seismotectonic model
5. Evaluation of maximum earthquake potential
6. Determination of PGA for S2 and S1 level
7. Identification of further investigations/studies
8. Unresolved issues
9. Reference

An – 3.4.3 Seismically Induced Ground Failure, Water Waves and Flood

The seismically induced water waves, flood, various types of ground failure specific to the safety of the site should be addressed highlighting the following,

1. Identification of type of the hazard and their location to be shown in the map developed during the investigation in regional range.
2. Data required and their acquisition.
3. Detailed description of the methodology adopted to evaluate the potential of the particular hazard.
4. Analysis of the data obtained from the investigation and interpretation of the result
5. Deviation from the recommendation of the Guide
6. Identification of further investigations
7. Unresolved issued
8. Conclusion
9. Reference

An – 3.5 CONTENCT OF DOCUMENT ON GROUP III INVESTIGATION

The document should include but not necessarily be limited to the information pertaining to determination of design basis ground motion discussed below.

1. Short description of site
2. Description of geological set up (cross reference may be made to the Group II document)
3. Discussion on preliminary estimation of peak ground acceleration (cross reference may be made to the Group II document highlighting those of Cl.An-2.4.2)
4. Finalisation of ,
    i) Seismic data
    ii) Seismotectonic map
    iii) Faults, tectonic structures and crustal volume to be considered in model
    iv) Seismotectonic model

v) Maximum earthquake potential

5. Determination of final peak ground acceleration of S1 and S2 levels.
6. Determination of site specific design response spectral shape.
7. Generation of design spectra compatible acceleration time history
8. Unresolved issues
9. Recommendations for design input
   Peak ground accelerations
   Design response spectral graphs
   Degitised values of design response spectra
   Design time history (in digitised form)
   The above parameters should be specified for all three directions (two orthogonal horizontal and vertical) for both S1 and S2 levels.
10. Reference

An –3.6 CONTENT OF DOCUMENT ON GROUP IV INVESTIGATION

The document should include but not necessarily be limited to the information discussed below:

An – 3.6.1 Confirmatory Investigation

1. Name of the investigation and the agency which carried out the investigation
2. Objective of the investigation
3. Description of investigation
4. Result: field and test data
5. Analysis of data and result and their interpretation
6. Detailed listing of reference
7. Unresolved issues
8. Conclusion
9. Reference

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November 27 & 28, 1989
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