Site Selection Criteria for Nuclear Power Plants and Evaluation of site Specific Design Basis Earthquake Parameters

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Introduction

The fundamental objective of any nuclear power plant operator is to protect people and the environment from the harmful effects of ionizing radiation due to any unforeseen incidents or accidents, leading to radiological consequences. The prevention of any such accident and release of radiation could be prevented by defence in depth in the design stage itself. Hence, adequate care is to be taken for site selection, good design and engineering safety features, which may in-turn provide safety margins, diversity and redundancy. Thus, site selection, characterisation and evaluation form an important part of establishing a Nuclear Power Programme (NPP) and can be significantly effected by cost and public acceptance. The role of geologists, geo-technologists is significant in this regard. Viewing these aspects, the present practices being followed for site selection and evaluation of design basis earthquake parameters for NPPs are discussed further.

Site Selection and Characterization

The purpose of characterisation of any particular area during the site selection stage is to determine the suitability of particular site for setting up a Nuclear Power Project (NPP). In this stage, geological, geo-morphological and geo-technical aspects are considered and regions or areas are usually identified that are excluded from further consideration. Subsurface information for this stage is usually obtained from current and historical documents, field reconnaissance, including geological surveys. In the recent past, remote sensing played great role in obtaining detailed and accurate information with minimum effort within least possible time frame.

For a nuclear power plant, site evaluation typically involves the following stages,

a. *Selection stage:* One or more preferred candidate sites are selected after investigation of a large region, rejection of unsuitable sites, and screening and comparison of the remaining sites.

b. *Characterization stage:* This stage is further subdivided into:

  - Verification, in which the suitability of the site to host a nuclear power plant is verified mainly according to predefined site exclusion criteria;
  - Confirmation, in which the characteristicsof the site necessary for the purposes of analysis and detailed design are determined.

c. *Pre-operational stage:* Studies and investigations from the previous stages are continued to refine the assessment of site characteristics. Data obtained from site allow a final assessment of simulation models used in the ultimate design of foundation and superstructure as well.

d. *Operational stage:* Selected investigations are pursued over the lifetime of the plant, to ensure that the variation of engineering properties are not

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varying significantly during the operating life of the plant.

Siting Aspects

The prime consideration in siting is availability of adequate plain land area and water, considering NPP and its township. Further, the site is first evaluated with respect to various acceptance / rejection criteria as given in AERB guide [1]. Once the site satisfies these criteria, further investigation are carried out.

Siting or evaluation of a candidate site for setting up a NPP is a stage in which, studies are undertaken, to demonstrate the suitability from various aspects, and in particular from the safety point of view. In evaluating the suitability of a site, following are the major aspects that need to be considered, and discussed in detail.

a) Effect of external events (natural and man-induced) on the plant.

b) Effect of plant on environment and population.

- Implementation of emergency procedures, particularly the protective counter-measures in the public domain.

Proposed candidate sites are examined with respect to the frequency and the severity of the possible external events and phenomena, which includes both natural and man-induced events, that could affect the safety of the plant. The design basis external events are determined for the combination of the proposed site and nuclear power plant.

General Environment

Following are the important desirable aspects for a favorable NPP site,

- Ground water table should be low to minimize uplift pressures on buildings.
- Future development plan around the area is minimal
- Industries handling toxic chemicals and waste are beyond 10km from the site,
- Railway sidings, and major road transport depots are beyond 10km from the site
- Availability of construction materials, are well identified.
- Basic infrastructural facilities are available to start pre-project activities
- Easier availability of construction materials and access to fetch them to site
- Access to site with respect to movement of persons and ODCs.
- Identified nearest highway, rail, sea and air links
- Rocky and leak tight founding media for solid waste management facilities.

Electrical System: Information is collected to identify the supply of construction power, start up power, and route of power evacuation. The peak construction power of the order of 10MWe is considered and nearby substation is located. The future plans of the CEA and State electricity board are studied within the time frame of the construction of power plant to identify the supply of the power. Start up power is taken from either nearby 220KV substation or an existing operating power plant. Power evacuation system is studied to identify the route of power evacuation. These studies are generally carried out by CEA.

External Natural Induced Events

Earthquake: Earthquake being one of the governing criteria for acceptance or rejection of a candidate site, the same is dealt in details, in the later part of discussion.

Flooding: Flooding is one of the important natural phenomenon for the selection of site. Hence, past history of the flooding at site is collected. The site should not have experienced any submergence. For the coastal site, safe grade level of site is estimated from the Highest high tide along with storm surge and wave run up due to tsunami, etc. The site should be preferably above this level. Else, the site Finished Ground Level (FGL) is made above this level and structures are built with Finished Floor Level (FFL) above FGL.

For inland sites, the estimation is made from the level of the nearest water body like canal, river, or reservoir, etc. Again at this stage, estimate is made by collecting historical data for the site with respect to flooding.

External Man-Induced Events

In order to safeguard the NPP from man-induced event, the sites are located away from the zone of human activity at a minimum distance, designated as Screening Distance Value (SDV). For most of the criteria, this SDVs considering both probability of occurrence of the concerned event and the impact on plant safety is evaluated. Accepting or rejecting a site is decided based on this evaluation.

- Any event having a very low probability of occurrence is not required to be considered for detailed design. A probability value of 10^{-7} per year may be considered low for this purpose. Hence, information concerning the frequency and severity of those important man-induced events are collected and analyzed for reliability, accuracy and completeness.
- In addition, industries handling toxic chemicals and waste, railway sidings, or road transport depots within 10km from the site are not allowed, to rule out of the possibility and severe events due to any unforeseen circumstances.

Out of the listed man-induced events, such as, Aircraft Crash, Chemical Explosions and Toxic Gas Releases, Oil Slick, blasting Operation, Mining, Drilling and Water Extraction form important man-induced events. Detailed deliberation of these events is beyond the scope of this paper, hence not covered further.

The general acceptance criteria [1], with respect to external events, which is considered for preliminary site selection process is indicated in Table-1 for ready reference. The desirable characteristics for locating a NPP are given in Table-2 and explained below.

Cooling Water Requirements

NPP need adequate quantities of assured supply of cooling water of acceptable quality, for condenser cooling and process water

Table 1: Acceptance criteria for site selection

No	Criteria	Acceptance Standard
1.	Seismicity *	Sites falling in Zones II to IV according to IS Classification [5]
2.	Distance from capable fault	More than 5 km. #
3.	Distance from small airfields	More than 5 km.
4.	Distance from major airports	More than 8 km.
5.	Distance from military airfields	More than 15 km.
6.	Distance from military installations storing ammunitions, etc.	More than 10 km.
7.	SDV for manufacture, storage and transhipment of toxic / inflammable explosive chemicals (minimum of 20000 ton of TNT equivalent)	More than 5km
8.	SDV for mining and blasting activity	More than 5km

* Sites falling in Zones II to IV to be evaluated in detail.

Detailed evaluation should be carried out for identifying the fault.

Table 2: Desirable Characteristics for Locating NPP

SNo	Characteristics	Desirability
1	Land Area	● Plain Ground of 2km x 1km (for 6 units 700/1000 MWe) ● Barren without much cultivation ● Govt. Land as much as possible ● No Forest Land ● Land for ancillary facilities (Specific for NPP type) ● Grade level above the design flood level ● At least 5 km away from facilities storing handling inflammable, toxic, corrosive or explosive materials and mining activities ● Away from International border ● Availability of more than two evacuation routes from site ● In sterilized zone of 5km radius from site natural growth is permitted but planned expansion of activities which will lead to an enhanced population growth are not allowed by administrative measure
2	Water for Condenser cooling and other uses	● Requirement: 12000 cu.m/hr for 1000 MWe with NDCT, 250000 cu.m/hr for 1000 MWe once through system ● Should not have much turbidity and carbonates ● Inland site water shall be from a reservoir ● Proximity of power station for start up power ● 500 cu.m/hr fresh water for the 1000 MWe plant ● 100 cu.m/hr fresh water for township
3	Environmental	● Avoid Forest land, Sanctuaries ● Avoid areas where large amount of fishing takes place ● Thermal pollution as per mandatory guidelines of Ministry ● The Radioactive effluent discharges shall be within ICRP limits ● No emission of Green house Gases, However discharge through air route of the radioactive element is defined and should be controlled in the limit
4	Electrical System	● Nearby availability of Start up Power ● Proximity of load centres for economic of Power transmission ● Appropriate power demand for life of plant. ● Power Purchase agreement with the major users
5	Meteorology	● Atmospheric dispersion shall be good ● Atmospheric inversion should not be there ● Avoid areas prone to Cyclones, hurricanes ● Preferable to have not much variation in temperature ● Preferable to have as less population and population centres in predominant wind direction ● Valleys with hills on either side at distance of 20 times the ridge height are acceptable. Bowl like structure need analysis at design stage on case by case basis.
6	Population	● The Population of district shall be 2/3rd of State Average Population ● As little population as possible in exclusion zone ● No population centres with population >10,000 in 5km radius ● No population centres with population >1,00,000 in 30km radius ● Total Population in sterilization zone < 20,000
7	Land Use	● Not much cultivation in the land within 10kms ● No Reserved forest
8	Water Use	● Avoid areas with large fishing activity ● Avoid areas using ground water substantially ● Avoid areas having shallow water table.
9	Subsoil Condition	● Preferable to have rock foundation ● Avoid areas having liquefaction, surface collapse, subsidence or uplift
10	Seismic	● Site should be in Zone-IV or below (preferred) ● No capable fault within 5km of site ● Detailed studies to determine the values of OBE and SSE
11	Flood Analysis	● For coastal site, maximum water level due to high tide, storm water surge, wave run up and tsunami shall be considered ● For the inland site, maximum water level due to precipitation, Dam Break shall be considered ● Flood potential for a return period of 1000 years ● Provision to avoid flooding of site due to the above causes.

12	Solid Waste Management	● Areas Preferred with rocky strata for foundations. ● Deep ground water table ● Availability of adequate land area ● Minimal irrigation around site
13	Radiological burden	● Radiological burden on the atmosphere due to all associated facilities shall be less than ICRP limits ● Dose apportionment of the area shall be done.
14	Access	● Site should be easily accessible by road and rail network ● Transportation of ODC should be possible ● Two independent emergency evacuation routes

cooling, and other safety related requirements. The available quantity of cooling water on long term basis, for the design life of the plant governs the cooling water system of the plant. The design and layout of intake and outfall structures, method of withdrawal, pumping head and type of cooling system, namely, once through or closed circuit depends solely on the availability of cooling water.

- For a coastal site, large volume of sea water can be utilized for once-through condenser cooling water systems. However, for an inland site, closed loop cooling water system is be suitable, considering the minimum requirement of water and least damage to ecological system and environment. Typical requirement of cooling water is indicated in Table-2.
- Loss of heat sink is one of the safety concern for the plant. Any breach / failure of downstream dam (due to an earthquakes or floods) may result in this condition and hence evaluated during initial stage itself. If the probability and consequences of this event cannot be reduced to acceptable levels, then such events shall be included in the design basis for the plant, and suitable alternate heat sink is established.

Availability of adequate quantity of water to maintain the reactor under safe shutdown state for at least thirty (30) days shall be ensured under all circumstances. *If the minimum water supply required for long term heat removal from the core cannot be ensured under all circumstances, the site shall be deemed unsuitable.* The minimum period of thirty days may have to be revised to a higher value depending on site characteristics.

Effect of Plant Environment and Population

The general principle in the siting of nuclear power plants is to have the facilities in a sparsely populated area and far away from large population centers. Lower population density in the region will help in achieving reduced population dose, and help in ensuring effective implementation of emergency measures and planning in case of an accident and easier to implement to a smaller population group.

The radiological consequences due to nuclear power plant on environment are to minimized to 'As Low As is Reasonably Achievable (ALARA)' taking into account the social and economical factors, both for normal and accidental conditions and within the stipulated criteria for radiological safety.

Hence, the impact of radiological consequences on the critical group as well as to the public as a whole due to the operation of nuclear power plant is evaluated during the siting stage. Population characteristics and its distribution in the region, including data on permanent residents, transient and seasonal population, present and future uses of land and water resources, cattle and livestock, agricultural produce, fish catches on annual basis, and other relevant particulars including any special characteristics which may influence the potential consequences of radiological releases to the environment are studied.

A nuclear power plant site extends to 1.5km all around from the centre of the facility (also called as exclusion zone). It is defined as an area where only power plant related activities are allowed as an administrative rule. This area is completely under control of the operator. The plant site is surrounded by a protective zone extending to about 5km from the facility (known as sterilization zone). Land use restrictions are in force within this zone. Natural Growth of Population is allowed in this zone, but inorganic growth (establishment of large industry) is not allowed.

The nuclear facility is to be surrounded by an emergency planning zone, extending to about 30 kilometers from the facility; the zone shall be covered by detailed rescue plans for public protection. In implementation, special attention shall be paid to the characteristics of the site's surroundings, such as recreational settlements.

Availability of transportation network, means of communication, etc. are of significance during any emergency condition, hence these aspects are reviewed. For this purpose, an area with in 15km from the plant may be considered and evaluated.

Population Distribution .

Desirable population characteristics in a plain terrain for setting a NPP are,

- Population centres greater than 10,000 should not be within 10 km of the plant.
- Population density within a radius of 10 km is less than 2/3 of the state average.
- No population centres more than 1,00,000 within 30 km from the plant.
- Total population in sterilised zone should be small, preferably less than 20,000.

Implementation of Emergency Procedures

Land and Water Use: In order to plan and implement emergency measures under accident conditions the characterisation of land use is carried out, considering the following,

- Extent of agriculture land, principal food products and their yields.
- Extent of dairy farming and yield.
- Extent of drinking water demand and its sources in the near vicinity of the plant.
- Extent of easy access for food supply from outside.
- Studies on all water bodies in the vicinity of the site and their outflow characteristics.
- Use of water for drinking, irrigation, fishing, agriculture, and industrial use.

Geotechnical Investigation Programme

The subsurface conditions at a site can be derived from the geological and geo-technical literature. A site may be classified as, a) a rock site, b) a soft rock, c) stiff soil site, d) a soft soil site, or a combination of these, and may be categorised accordingly.

The soil type is further divided into non-cohesive and cohesive soil. However, this rough classification may not apply for some sites. For instance, quaternary formations may present complex interfaces between rock and clay that are carefully investigated and monitored.

During preliminary and selection stage following are reviewed,

- Geotechnical properties of soil are evaluated by field measurements and lab tests.
- Bore holes (four to six in number, depending on site) are dug in the proposed area.
- Bore logging, SPT is carried out for alluvial substrata.
- Location of any underground aquifers are also identified.
- Alarming zones in the sub strata are identified.

- Evaluation of liquefaction potential, soil stability and other geological instability features
- Suitability of substrata should be suitable for carrying loads from the plant.
- Depth of ground water table from monsoon season to non-monsoon season.
- If substrata is rocky, then seismic refraction is also carried out.
- Information regarding heavy structures built in and around the region, bearing capacity considered for these structures.

Once, the candidate site is chosen for detailed studies, investigation of the subsurface conditions are taken up; because, investigation and characterisation are important at all stages of the site evaluation process. The purpose of this investigation is to provide information or basic data for decisions on the nature and suitability of the subsurface materials. At each stage of the site evaluation, the investigation programme provides the data necessary for an appropriate characterization of the subsurface. Detailed subsurface investigations are performed in later stages. However, the specific requirements with regard to the type of investigations will vary greatly from stage to stage.

In-situ Sub-surface Investigations

The programme of investigation differs in various stages of evaluation, as the data requirements vary greatly from one stage to another. Generally, the necessary data will yield geological and engineering related information for use in safety evaluations or engineering design and analyses. These data can be classified as:

- Geological information (stratigraphical and structural);
- Descriptions of the extent and nature of subsurface materials;
- Characterizations of soil and rock (in terms of properties);
- Information on groundwater (the groundwater regime, locations and characteristics of the hydrological units, physical chemistry of the water).

Hence, proposed site is thoroughly investigated and characterised to arrive at geo-technical parameters for design of structures. These investigations are normally carried out in two phases. The first phase include preliminary investigations, which will uncover most of the geological profiles of the site, and help in finalizing general layout of various important buildings and structures of the proposed project. This may include geophysical and geotechnical investigations, which depend on many direct and indirect exploration techniques.

In second phase, investigations are carried out in a detailed manner, keeping in view the general layout of various buildings and structures of the project. Finally, after excavating for foundation, confirmatory investigations are also carried out to ensure the engineering parameters considered for the preliminary design of buildings and structures are well with in the in-situ parameters, with adequate factor of safety, and design margins. Occasionally, these investigations may show some surprises, which may be limited to a very local zone under a small-isolated foundation, or may extend to various buildings covering major portion of the foundation rafts of important buildings. In such situations, the engineering parameters will be critically reviewed and any modifications in the final design of structures will be incorporated, if found necessary.

From the sub-surface investigations, a set of parameters are determined to perform the geotechnical evaluation necessary for the construction of a nuclear power plant.

The resulting set of parameters and data is called the profile. The profile may be defined as a geometrical and mechanical description of the subsurface materials. The definition may include the best estimates and ranges of variation for the characteristics of the foundation materials, (such as, E_d, E_s, G, V_s, u and r, etc), are determined and described in a way that is directly applicable to subsequent analyses. The sub-surface profiling may include,

- The geometrical description, such as subsurface stratigraphic descriptions, lateral and vertical extents, number of layers and layer thicknesses,
- The physical and chemical properties of soil and rock and values used for classification,
- 'S' and 'P' wave velocities (V_s and V_p), stress–strain relationships under small and large strains, static and dynamic strength properties, consolidation, permeability and other mechanical properties obtained by in situ and / or laboratory tests,
- Characteristics of the groundwater table, the design level of the water tables and the maximum water level due to the maximum probable flood and other conditions.

Though, conceptually the profile is unique to a particular site, various related design profiles for different purposes are adopted to allow for different hypotheses in the analysis and envelope the uncertainties involved in the evaluation process, and thus leading to a safer design (which may be occasionally conservative in some cases). Final design profiles are presented to assess the following:

- Site specific response spectrum;
- Liquefaction potential;
- Stresses in the foundation media;
- Foundation stability;
- Seismic Soil–structure interaction;
- Settlements and heaves;
- Stability in earth structures;
- Earth pressure and deformation in buried structures.

There are many geo-physical investigation methods being followed by engineers, to arrive at the underground profiling and stratification of founding media under consideration. These methods are capable of giving a detailed stratigraphy of the media (to certain extent), with variations related to any local pockets or surprises. The information thus obtained can be used to arrive at conclusions for foundation design. Typical methods adopted for important and safety related structures are indicated below.

- Cross-hole seismic survey
- Tomography studies
- Uphole and downhole seismic studies
- Acoustic Logging
- Seismic refraction
- Resistivity logging and
- Electrical Resistivity profiling and soundings.

However, some of these tests complement each other and thus give confidence for estimating an engineering property of founding medium, by different techniques. Discussion of detailed procedures and methodology for carrying these investigations is beyond the scope of this paper, and relevant literature may be referred to, for further information.

Acceptance or Rejection Criteria

The area and extent of investigations carried out need to be appropriate and in-line with the hazard under consideration. Geological hazards, such as, surface faulting, volcanic activity, landslides, permafrost, erosion processes, subsidence and collapse due to underground cavities (both natural and those deriving from human activities), or other causes are identified and evaluated. The information collected during initial stage is used with respect to candidate sites.

A site with geological conditions that could affect the safety of a nuclear power plant and that cannot be corrected by means of *geotechnical treatments or compensated for by constructive measures is unacceptable.*

Importance of Earthquakes as Natural Hazard

Out of all the external natural events and hazards, earthquake is of prime consideration for accepting or rejecting a particular candidate site. Hence, the seismic status of the region is evaluated in detail, to evaluate the capability for generating potential earthquakes.

Any site closer than 5km to a 'capable fault' shall be deemed unacceptable. The potential for soil liquefaction at the site shall be evaluated. If potential for liquefaction exists, the site shall be deemed unsuitable.

Consideration is given for Reservoir Induced Seismicity (RIS) due to impounding of dams (existing or sanctioned and being built) in the region, while evaluating site for seismic effects.

Codal Specifications for Seismic Aspects

Indian Nuclear Power Programme is under the regulatory purview of Atomic energy Regulatory Board (AERB), which publishes various codes, standards, guides for the siting, construction, operation and maintenance of NPPs. The siting code [1] indicates the following important issues for setting up a NPP, with respect to seismic aspects.

- The general seismic intensity expected in the region shall be carefully evaluated by considering the seismic history and its potential as well as geological characteristics of the region
- Historical data is collected relating to past earthquakes in the tectonic province covering an area of about 300km radius around the site in which the proposed nuclear power plant is to be located.
- If adequate earthquake data for the tectonic province is not available, data may be drawn from sites of similar tectonic characteristics.
- Faults in the region shall be investigated to determine their potential. A site closer than 5km to a capable fault shall be deemed unacceptable.

These aspects help to filter out sites, which are unacceptable, and help in finalising the most suitable candidates for detailed evaluation for setting up the plant.

Other international codes and standards [3,4] serve as guidelines for site selection and characterization, before accepting or rejecting a particular site.

Seismicity and Seismo-tectonic Evaluation

Earthquake occurrence in the Indian Peninsula Shield is believed to be associated with the rejuvenation of the precambrian fault zones of major uplift and subsidence, and the associated fracture zones. The maximum earthquake potential of the region around the site is arrived in accordance with the prescribed guidelines using historical records instrumented records, regional geology, tectonics and any other available evidence.

To start with, a lineament and seismo-tectonic map for the area within 300 km radius from the site is compiled based on the detailed investigations carried out by Expert National Institutions, (such as, Geological Survey of India or any other competent agency). The studies of lineament maps indicate tectonic characterisation of the site and thus, help in finalising the precise location of the project.

Any fault is considered capable, if,

- it shows evidence of movement at or near the surface, within the past half a million years,
- it has a demonstrated structural relationship to a known capable fault such that movement of the one may cause movement of the other at or near the surface.

- If detailed information regarding the fault is not easily available, an alternate approach would be by ground investigation / checking and identifying the association of epicentres of magnitude greater than 3.5 in Richter scale with the fault. If such an association is established, the fault shall be considered as a capable fault.

Data from Deep Seismic Sounding, if available, and geophysical data of the seismo-tectonic province in which the proposed site is situated should be examined to identify 'capable faults'. The investigation normally include,

- Examination for faulting around and fault-trends towards the site and any creep (movement of the ground).
- Thorough evaluation of the activity of each of the capable faults by the use of appropriate and accepted techniques and methods.
- The effect of secondary faults trending towards the site.

All the earthquake history in this region along with its epicentres are plotted on the map. Care is take that no capable fault should be within 5km of the site. An estimation of the PGA for the site is also undertaken. In addition to this, new tectonic activity for the area around the site for an area of 1500sq.km is also studied in detail during design stage. Thus, the study of lineaments and faults in the area will give a reasonable estimate of seismic potential of the site for generating major earthquakes.

Preliminary Estimation of Seismic Parameters

For the purpose of seismic response analyses, the following site categorisation is used,

o Type 1 sites: V_s > 1100 m/s

o Type 2 sites: 300 m/s < V_s < 1100 m/s

o Type 3 sites: V_s < 300m/s

Where, 'V_s' is the best estimate for the shear wave velocity of the foundation medium just below the foundation level of the structure in the natural condition (i.e. before any site work), for very small strains. The site categorisation is valid on the assumption that the shear wave velocity does not increase or decrease significantly with depth. However, if large variation is observed from the detailed geo-technical investigations, analyses will be carried out according to the best practices, to ascertain the effect of this variation on the design of superstructures.

A detailed and rigorous computation of site response under free field conditions is carried out for sites of Type-2 and Type-3. This computation is needed for the assessment of settlements, liquefaction, and detailed soil–structure interaction analyses.

The site response computation may also be required for developing 'Site Specific Response Spectra and Time History'. To carry out this computation, data on the following is gathered,

a. The input ground motion (derived by means of established procedures as per Ref.4),

b. Appropriate model of the site, based on,

   - The geometrical description of the soil layers;
   - The velocities of the S and P waves in each layer (Vs and Vp);
   - The relative density of the medium in each layer;
   - The G-g and h-g curves for each layer describe the apparent reduction of the shear modulus 'G' and the internal damping ratio 'h' of the soil with the shear strain 'g',

c. For those deep soil deposits in which wave velocities increase smoothly with depth, the change in the aforementioned parameters with respect to the depth of layers.

Depending on adopted engineering practice, the input ground motion may be estimated and specified either at the free field at the site or at a hard rock outcrop. For Type 3 sites, the input ground motion at a neighbouring hard outcrop (Type-1 site) is provided; or, if this is not possible, at a neighbouring stiff soil outcrop (Type-2 site); or, if this is also not possible, at an appropriate subsurface level.

Site Specific Design Basis Ground Motion

The regional geological, seismological and geotechnical studies around the site are carried out to arrive at site specific ground motion parameters for the proposed site. Agencies, such as, Geological Survey of India, Atomic Minerals Division, Central Water and Power Research Station play a significant role in these studies.

In the design of safety related structures / buildings of main plant, two levels of severity have been determined for specifying the ground motion for the seismic resistant design of NPPs. These are OBE and SSE levels of ground motions, which are similar to S1 and S2 levels of earthquake as per IAEA and International practice.

- **SSE level of ground motion** is that level of ground motion which has a very low probability of being exceeded. The SSE level ground motion is the maximum potential vibratory ground motion at the site based on the maximum earthquake potential of the (site) region. It represents the maximum level of ground motion to be used for design of safety-related structures, systems and Components (SSCs) of NPP. The PGA value of SSE level of ground motion in horizontal direction should not be less than 0.10g.
- **OBE level ground motion** corresponds to the maximum level of ground motion, which can reasonably be experienced at the site once during the operating life of Nuclear Power Plant. The return period (mean recurrence interval) of the OBE level event should not be less than 100 years when it is determined by a probabilistic method. The PGA value of OBE level of ground motion in horizontal direction should not be less than 0.05g. In absence of detailed analytical evaluation for OBE, the PGA for OBE is taken as half of the PGA for SSE.

For characterizing the earthquake in terms of design response spectra and time history of ground motion, the approaches adopted in general are,

i) To use actually recorded ground motion time history or simulated ground motion commensurate with the effective PGA predominant frequency range and duration of ground motion expected at site and then work out response spectra for the motion for adoption in design.

ii) To characterize the shape of the response spectra, keeping in view predominant frequency range of ground motion at the site and dynamic amplification for various levels of damping, with desired probability of exceedance or confidence level and then generate the compatible time history of the ground motion for the same.

iii) To generate Uniform Hazard Ground Response (UHGRS) for a probability of exceedance of 10^{-2} for OBE level ground motion and 10^{-4} for SSE level of ground motion for different damping values. However, this methodology is in developing stage and additional research is needed before implementation to future sites.

Evaluation of Pga and Other Parameters

The evaluation of S1 level of earthquake is either by probabilistic or a combined probabilistic and seismotectonic approach, taking into account the seismo-tectonics of the region.. The evaluation of S2 is based on the seismotectonic approach and on the history of earthquakes in the region. However, with the present state of art, adoption of deterministic approach is appropriate, till sufficient database is established to make probabilistic method more reliable, when compared to the former. Thus, the S1 and S2 level of ground motions are specified for free field conditions through,

- Peak Ground acceleration (PGA)
- Response Spectra
- Time History.

Derivation of Peak Ground Acceleration

The area around the site for a radius of 300 kms is investigated and all regional geological and seismological information are compiled. Geology of the area is also superimposed. Epicenters of all known earthquakes greater than M= 3.0 are superimposed on the same. The data is then analysed. Three parameters of Design Basis Earthquake are defined to derive the peak ground acceleration for each postu1ated earthquake:

- size of the earthquake (magnitude or intensity)
- depth of focus
- distance from the site.

Probabilistic approach

The objective of the probabilistic approach is to determine the level of ground motion that has an acceptably low probability of being exceeded during the operating life of the plant. This requires a basic data sample of the intensity of ground motion experienced in the region from historical earthquakes and also an acceptable probabilistic model. Because the data base is usually limited, a simple probabilistic approach can normally be used only in the determination of the S1. In the absence of detailed information, S1 level is also specified as half of S2 level, where S2 level is fixed on the basis of application of seismotectonic approach. Probabilistic considerations are usually used in the determination of the S2 only when, combined with seismotectonic consideration.

Probabilistic approach combining statistic and seismo-tectonic approach:

Design basis ground motions can also be determined by using the seismo-technoic approach combined with the available historical earthquake data; this combined approach is composed of steps such as the following.

a. A magnitude-frequency law is established and a maximum magnitude is sometimes assumed.

b. Seismic source models are selected (models of point sources, linear sources distributed superficially are available). This may require a substantial amount of seismotectonic studies.

c. Using an appropriate relationship (the dispersion of which may be taken into account) site ground motion intensity is evaluated.

d. The probability of exceeding selected ground motion parameters (acceleration, velocity, displacement) is determined for each source

e. The total probability that the selected ground motion parameters will be exceeded is obtained by summing the contribution from each source.

Seismotectonic technique:

- Identifying the region, the seismotectonic provinces, the seismically active structures and their maximum earthquake potential.
- Evaluating the design basis ground motions produced at the site by the occurrences of this maximum earthquake potential at the nearest point to the site on the seismically active structure or at the boarder of the seismotectonic provinces. If the seismically active structure is close to

the site the physical dimension of the source may, if possible, be taken into account.

a. The regional area around the site should be sub-divided into tectonic provinces.

b. Significant tectonic features and lineaments should be identified.

- All the seismo-genic faults and tectonic structures should be identified.
- As many earthquakes as possible are associated with the seismo-genic faults and tectonic structures.
- Occurrence rates (in time and space) of earthquakes of different magnitudes associated with each tectonic structure and faults are estimated.
- A maximum earthquake potential is assigned to each known fault and tectonic structures.
- Earthquakes not associated with known faults and structures should be identified. These earthquakes are known as floating earthquakes or diffuse seismicity.
- The area is investigated through satellite imageries, aerial photographs, detailed maps to determine additional tectonic structures, which could be considered the sources for unidentified earthquakes.
- An appropriate attenuation relation is used to determine the ground motion level due to these earthquakes at the site.

Estimation of Site Specific Response Spectra

The design response spectra is derived from strong motion time histories at site. In case of non-availability sufficient records, response spectral shapes for places having similar seismic, geological and soil characteristics are used. This method comprises of,

- Collection of several strong motion accelerograms from the site or sites of similar geological and lithological features
- Normalization of the above accelerograms suitably
- Response spectra of these accelerograms are evaluated for different values of damping
- Spectra of individual events are combined to obtain the shapes of design spectra
- Spectra so chosen is smoothened to account for the uncertainties in determining the spectral shape.

If the input ground motion is not provided in a form suitable for geotechnical studies, an adequate input ground motion should be determined. This input motion is chosen according to earthquake intensity, magnitude, epi-central distance, maximum acceleration, duration, frequency content and other parameters.

Estimation of Time History

Time history of vibratory ground motion is developed considering all the prescribed ground motion parameters, and should correspond to both SSE and OBE levels. Development of time histories should be based on,

- Computational methods simulating earthquake ground motion
- Strong motion records obtained in site vicinity or adequate modification there on
- Strong motion records obtained at places having similar geological and lithological features

It is desirable, that the time history satisfies the constraints on specified values of,

- Peak ground acceleration, velocity and displacement

- Rise time to peak acceleration
- Duration of strong motion
- Rate of zero crossing

It is also to be ensured that the time histories and the design response spectra should be compatible while finalizing the design parameters.

Design Basis Ground Motion in Vertical Direction

PGA in vertical direction, if not evaluated exclusively, is taken as 2/3 of the horizontal PGA, with same spectral shape and time histories as of horizontal direction, as a conservative measure. The ground motion in two horizontal orthogonal directions is taken as same, though they are evaluated independently.

Deconvolution

In the case of an input ground motion provided at surface level for design purpose, a deconvolution computations of the input motion in free field conditions may be carried out (during initial stages), for preliminary stage soil–structure interaction analysis for sites other than Type-1 sites. A high reduction in input ground motion due to deconvolution need to be carefully justified by means of parametric studies.

However, input ground motion specified for the surface may be used at the foundation level, instead of a deconvoluted input motion, and this is conservative practice in general, and hence, is acceptable for detailed design of structures to arrive at a safer alternative.

Conclusions

From the above discussion, it is evident that,

- Evaluation and characterization of a proposed site is of utmost importance, before accepting or rejecting a candidate site for constructing a Nuclear Power Plant and it's associated facilities.
- Seismic potential of the site plays a major role, in adopting a particular site and finalizing optimized layout of various buildings and structures, hence, in-depth site specific seismic studies are carried out to arrive at design basis ground motion parameters.

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