GUIDE NO. AERB/NPP/SG/CSE-2

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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

GEOTECHNICAL ASPECTS AND SAFETY OF FOUNDATION FOR BUILDINGS AND STRUCTURES IMPORTANT TO SAFETY OF NUCLEAR POWER PLANTS

ATOMIC ENERGY REGULATORY BOARD

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GEOTECHNICAL ASPECTS AND SAFETY OF FOUNDATION FOR BUILDINGS AND STRUCTURES IMPORTANT TO SAFETY OF NUCLEAR POWER PLANTS

Atomic Energy Regulatory Board
Mumbai-400 094
India

February 2008

Price

Orders for this guide should be addressed to:

The Administrative Officer
Atomic Energy Regulatory Board
Niyamak Bhavan
Anushaktinagar
Mumbai-400 094
India

FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers, as well as protection of environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, safety codes and related guides and manuals for the purpose. While some of these documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulatory aspects of these facilities.

Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities. Safety codes establish the safety objectives and set requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

Civil engineering structures in nuclear installations form an important feature having implications on safety. This safety guide is written to specify the guidance on geo-technical aspects and safety of foundation for buildings and structures that is to be fulfilled to provide adequate assurance for safety of nuclear power plants in India.

Consistent with the accepted practice, ‘shall’ and ‘should’ are used in the guide to distinguish between a firm requirement and a desirable option respectively. Appendices are integral part of the document, whereas footnotes and references/bibliography are included to provide further information on the subject that might be helpful to the user. Approaches for implementation different to those set out in the guide may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public, and protection of the environment.

This guide applies only for facilities built after the issue of the document. However during periodic safety review, a review for applicability of current standards for existing facilities would be performed.

For aspects not covered in this guide, applicable national and international standards, codes and guides acceptable to AERB should be followed. Non-radiological aspects, such as industrial safety and environmental protection, are not explicitly considered. Industrial safety is to be ensured through compliance with the applicable provisions of the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996.

Specialists in the field drawn from the Atomic Energy Regulatory Board, the Bhabha Atomic Research Centre and the Nuclear Power Corporation of India Limited and other consultants have prepared this guide. It has been reviewed by experts and relevant AERB Advisory Committee on Codes and Guides and the Advisory Committee on Nuclear Safety.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

(S.K. Sharma)
Chairman, AERB

DEFINITIONS

Atomic Energy Regulatory Board (AERB)

A national authority designated by the Government of India having the legal authority for issuing regulatory consent for various activities related to the nuclear and radiation facility and to perform safety and regulatory functions, including their enforcement for the protection of site personnel, the public and the environment against undue radiation hezards.

Construction

The process of manufacturing, testing and assembling the components of a nuclear or radiation facility, the erection of civil works and structures, the installation of components and equipment and the performance of associated tests.

Design

The process and the results of developing the concept, detailed plans, supporting calculations and specifications for a nuclear or radiation facility.

Design Basis Ground Motion (DBGM)

The ground motion parameters of a given level of earthquake severity, which are used in the design of a facility. Examples of these parameters are peak ground acceleration (PGA), response spectrum, acceleration time history of the ground motion, etc. Examples of severity levels of earthquakes are safe shutdown earthquake (SSE) and operating basis earthquake (OBE) used in the design of nuclear power plants.

Documentation

Recorded or pictorial information describing, defining, specifying, reporting or certifying activities, requirements, procedures or results.

Item

A general term covering structures, systems, components, parts or materials.

Items Important to Safety (IIS)

The items which comprise:

- those structures, systems, equipment and components whose malfunction or failure could lead to undue radiological consequences at plant site or off-site;
- those structures, systems, equipment and components which prevent anticipated operational occurrences from leading to accident conditions;

- those features which are provided to mitigate the consequences of malfunction or failure of structures, systems, equipment or components.

Nuclear Facility

All nuclear fuel cycle and associated installations encompassing the activities from the front end to the back end of nuclear fuel cycle processes and also the associated industrial facilities such as heavy water plants, beryllium extraction plants, zirconium plants, etc.

Nuclear Power Plant (NPP)

A nuclear reactor or a group of reactors together with all the associated structures, systems, equipment and components necessary for safe generation of electricity.

Nuclear Safety

The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of site personnel, the public and the environment from undue radiation hazards.

Operation

All activities following and prior to commissioning performed to achieve, in a safe manner, the purpose for which a nuclear/radiation facility is constructed, including maintenance.

Quality

The totality of features and characteristics of an item or service that have the ability to satisfy stated or implied needs.

Quality Assurance (QA)

Planned and systematic actions necessary to provide the confidence that an item or service will satisfy given requirement for quality.

Safety

(See 'Nuclear Safety')

Site

The area containing the facility defined by a boundary and under effective control of facility management.

Siting

The process of selecting a suitable site for a facility including appropriate assessment and definition of the related design bases.

Specification

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

Structure

The assembly of elements which supports/houses the plants, equipment and systems.

Testing (QA)

The determination or verification of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental or operational conditions.

Verification

The act of reviewing, inspecting, testing, checking, auditing, or otherwise determining and documenting whether items, processes, services or documents conform to specified requirements.

SPECIAL DEFINITIONS
(Specific for the present guide)

Boring

An exploratory hole in soil or rock, or both, made by removal of materials.

Disturbed sample

A sample whose density and moisture content have changed to such extent that it does not reasonably approximate that of the material in situ. Such a sample may bear a resemblance to an undisturbed sample in having preserved the gross shape given to it by a sampling device.

Geotechnical

Pertaining to the earth sciences (geology, rocks, soils, seismology, and groundwater hydrology) and that part of civil engineering that deals with the interrelationship between the geologic environment and the works of man.

In situ soil structure

A complex physical- mechanical property, defined by the sizes, shapes, and arrangements of the constituent grains and intergranular matter and the bonding and capillary forces acting among the constituents.

In situ test

A test performed on in-place soil or rock for the purpose of determining some physical property. As used in this Guide, it includes geophysical measurements.

Liquefaction

Loss of shear strength of soil, due to instantaneous increase in pore pressure under cyclic loading.

Observation well

An open or bored well that permits measuring the level or elevation of the ground water table.

Piezometer

A device or instrument used for measuring pore pressure or hydraulic potential at a level or point below the ground surface.

Representative sample

A sample that (1) contains approximately the same mineral constituents of the stratum from which it is taken, in the same proportions, and with the same grain-size distribution and (2) is uncontaminated by foreign materials or chemical alteration.

Rock Quality Designation (RQD)

An indirect assessment of the degree of fractures and joints present in the rock mass and hence a parameter useful for estimating rock quality. It is calculated by summing the lengths of all hardall hard and sound pieces of recovered core longer than 4 inches (10 cm) and dividing the sum by the total length of core run and multiplying the result by 100.

Sounding

An exploratory non destructive or noninvasive technique/methodology used to determine the subsurface charactersticscharacteristics.

Undisturbed sample

A sample obtained and handled in such a way that disturbance of its original structure is minimal so that the sample is suitable for laboratory tests of material properties that depend on in situ soil structure.

CONTENTS

1. INTRODUCTION

1. 1 General

The objective of the design of a nuclear power plant (NPP) is to assure that the plant can be operated without undue radiological risk to the plant personnel, the public and the environment. The performance of NPP foundation system plays an important role to achieve this goal.

NPP structures generally impose heavy loads on the foundation systems. Safe design of foundation aims at providing sound foundation systems for NPP buildings and structures so that they can fulfill their functional requirements and towards the objective of nuclear safety.

Two major tasks for ensuring safety of foundation for NPP structures are:

(a) assessing the suitability of site against ground failure, and

(b) safe design of foundation systems.

Suitability of site is required to be assessed against various ground failure modes like slope and embankment failure, local instability, subsidence and soil erosion. Safe design of foundation is completed in two stages. Identification of foundation type and proportioning of founding area from stability and settlement considerations is done in first stage. In second stage, structural design of foundation is performed.

The foundation system of a NPP consists of three important components:

(a) Foundation structures

(b) Engineered foundation supports

(c) Foundation materials as founding media.

Foundation structures may be isolated or combined footings, raft, pile, well foundation etc. For example, foundation of reactor building is the base raft. It may be shallow or deep foundation depending on the site sub-strata condition. Engineered foundation supports are backfill, lean concrete, improved and stabilised founding media etc. Foundation materials are basic materials of founding media, which could be either soil type or rock type. The consideration should be made on the vertical depth and lateral extent of the soil beyond which the properties of the foundation materials can no longer affect the plant safety. Suitability of foundation materials for NPP structures is assessed by conducting detailed and systematic subsurface investigations. The scope of subsurface investigation covers geotechnical, geophysical and geological investigations.

1. 2. Objective

The purpose of this document is to provide guidance on dealing with geotechnical and geological investigations and other engineering considerations that are important to safety of foundations for NPP structures.

This safety guide describes the methods for evaluating safety of site against ground failure and safety of foundation systems. The guide also describes methods for conducting field investigations to acquire data on geological and geotechnical characteristics of site.

1. 3 Scope

This guide identifies the various foundation design parameters and describes geotechnical investigations to be conducted both in the field and at laboratory to determine the design values of the geotechnical parameters required for engineering of foundation system of NPP structures. The guide provides recommendations for developing site specific investigation programs and for conducting the geotechnical investigations. The safety guide 'Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites', AERB/SG/S-11[1], establishes the requirements for conducting site investigations to provide information needed for determining seismic design parameters and to permit site evaluation against ground failures.

The methods and procedures for assessment of safety of foundation for nuclear facilities are covered in this guide. The guidelines on design of shallow and deep foundations, design of rock anchors for foundations, requirements of monitoring the actual field behaviour of structure during construction as well as plant operating phase are given to enable assessment of performance of foundation systems. Detailed requirements of geotechnical instrumentation are also outlined.

The guide discusses the geotechnical engineering aspects of the subsurface conditions and relevant geological aspects that directly affect the foundation systems. It provides the details of investigations that should be carried out in order to obtain an appropriate understanding of the subsurface conditions as required for concluding that these are suitable for building of an NPP.

It also provides a description of the geotechnical profiles and the parameters suitable for performing safety analysis of foundation of NPP structures.

The guide addresses the influence of geotechnical design parameters on foundation structures and construction requirements. It also deals with safety of earth structures and stability of slopes under design basis environmental conditions.

Safety of other structures outside the main plant area or site area such as dams, slopes, hills etc. whose performance could have direct influence on the safety of NPP should also be evaluated in line with the recommendations of this guide.

2. GEOTECHNICAL AND GEOLOGICAL INVESTIGATIONS

2.1 General

The purpose of geotechnical and geological investigations is to provide information or basic data needed to design NPP foundation for safety and performance. The investigation program should provide the basic data required for detailed characterisation of the subsurface and to identify potential geological hazards that may exist at the site. The investigation program should cater to all stages of the site evaluation process.

2.2 Stages of Geotechnical and Geological Investigations

2.2.1 The investigations are generally carried out in three stages:

(a) Preliminary investigations during site survey or selection stage

(b) Detailed investigations prior to foundation design

(c) Confirmatory investigations after excavation of foundation pits.

Depending on the characteristics of the subsurface at site, confirmatory investigations may continue during construction stage and operating phase of plant also.

2.2.2 The information available in various stages of investigations can be classified as:

(a) Geological information (stratigraphical, structural, and seismic)

(b) Description of extent and nature of subsurface materials

(c) Soil and rock characterisation (properties)

(d) Ground water information (regime, location, extent etc).

2.3 Requirements of Geotechnical and Geological Investigations

2.3.1 Preliminary Investigations

The main purpose of preliminary investigation, which is generally conducted during site survey stage, is to assess the engineering aspects of a particular site from geotechnical and geological considerations, and also to acquire sufficient information for preliminary design of foundation systems.

During this stage, information on general geology, characteristics of subsurface materials, seismicity, tectonic activities, potential for geological hazard, foundation conditions etc. are collected from the available literature, documents and other sources of information as well as by conducting investigation. ‘Code of Practice on Safety in Nuclear Power Plant Siting’, AERB/SC/S [2], provides the basic guidelines for consideration of important site related parameters. The information should be collected at this stage to enable to develop database for taking up preliminary safety analysis of following aspects:

(a) Determine preliminary values of seismic design parameters,

(b) Ground water level variation,

(c) Slope and embankment stability,

(d) Liquefaction,

(e) Soil erosion and contamination,

(f) Preliminary foundation design parameters and

(g) Stability of coastal regime.

The extent of investigation in this stage should be so selected that sufficient information could be obtained to conduct the safety analysis, as described above, with adequate margin. Geophysical methods such as seismic refraction survey should be employed in initial stage of investigations. Geomorphological studies should also be carried out. The investigation requires the understanding of geology of the area of interest and sufficient database on subsurface characteristics. This can be obtained by field reconnaissance and a review of available current/historical reference documents. Limited direct and indirect investigations along with both field and laboratory tests need to be carried out to determine the foundation design parameters.

One of the major outcomes expected out of preliminary investigation is to identify the areas of geotechnical and geological investigations on which special emphasis is to be made in the detailed investigation stage.

2.3.2 Detailed Investigations

The investigations at this stage are carried out after the plant layout along with the locations of major plant structures have been finalised and the building loads have been established. The purpose of the detailed investigation is to obtain the database to conduct all the relevant safety analysis pertinent to the site. The results obtained in the preliminary stage are used to work out the programme of detailed investigations. These results are also verified in this stage.

Direct and indirect method of subsurface investigations along with both in situ and laboratory tests should be conducted in detail to evaluate geotechnical parameters for foundation design. The selection of the methods for different investigations should have the relevance to site characteristics.

The location and depths of borings and measurements should be chosen such that the geology and foundation conditions are sufficiently defined in lateral extent and depth to permit designing all structures and excavations.

General guidelines for spacing and depths of boring are given in Table-1. The outcome of seismic refraction studies or other geophysical methods conducted during preliminary investigation would be helpful in finalising the location and depth of boreholes.

The investigation which will be carried out during confirmatory stage should be identified at this stage.

2.3.3 Confirmatory Investigations

These are certain investigations and studies, which are to be carried out after ground breaking or excavation of foundation pit/trench. Investigations at this stage are required to confirm the outcome of detailed investigation.

There may be some situations where certain investigations may be undertaken during confirmation stage if some unexpected or significant phenomena are observed after excavation.

In order to confirm the various values adopted for analysis and design of foundation of the structures, final excavated surfaces for safety related structures and other excavations important to the verification of subsurface conditions should be geologically mapped, logged and further tests conducted, if required. The mapping should be performed after the foundation pit has been cleaned to excavated level and before the placement of mudmat concrete or backfill. The time gap between mapping and placement of mudmat concrete should not be so large that the exposed surface gets deteriorated due to exposure to environment after mapping. These maps should be prepared to record geological details in the foundation pit. Any treatment required to be carried out to improve, modify or control geological conditions should be indicated. Examples of such improvements are deep compaction, pre-loading, rock reinforcing systems, consolidation grouting, installation of permanent dewatering systems or any other special treatment. Photographic or videographic records of foundation mapping should be available. Records of improvement carried out should also be available.

2.4 Specifications of Geotechnical and Geological Investigations

Geotechnical investigations are required to determine different parameters for performing various safety analyses depending on postulated failure mode of foundation systems. Table-2 lists out failure modes and associated items and parameters of safety analysis.

Safety analysis parameters to be studied for different site conditions (rocky type/soil type site) are given in Table-3. Geotechnical, field and laboratory investigations for determining safety analysis parameters are listed in Table-4, for both rocky site as well as soil site.

All the geotechnical and geological investigations shall be carried out in accordance with relevant Indian Standards (IS). Table-5 and 6 summarise the specifications of field and laboratory tests for various investigations. The results of investigations shall be interpreted in accordance with the approach given in the relevant specifications, codes and references. However, separate approaches can be used whenever it is found necessary and justified.

2.4.1 To allow rational decisions to be made regarding the nature and suitability of the subsurface the required data are generated from the following sources and investigations:

(a) Historical and current documents

(b) Indirect exploration

(c) Direct exploration

(d) Field tests

(e) Laboratory tests.

2.4.1.1 Historical and Current Documents

Authentic historical and/or current documents should be used in collecting information to build up database. AERB/SG/S-11 titled 'Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites' describes guidelines for conducting geological and geotechnical investigations for determining the parameters associated with seismicity and related phenomina. Further guidelines are provided in Appendix-A.

2.4.1.2 Indirect Exploration

Indirect explorations are usually conducted by geophysical methods. In this method, properties, data or information are inferred or calculated from indirect tests. These methods generally cover large areas and provide geological and related geotechnical information needed for developing site characteristics. Examples of such geophysical methods are seismic refraction survey and electrical resistivity survey. The predictions of indirect explorations should be verified with direct investigations such as test bore holes/trenches. Further guidelines are provided in Appendix-A.

2.4.1.3 Direct Exploration

Direct explorations provide good access for in situ testing and sampling for almost all subsurface conditions. Further guidelines are provided in Appendix -A.

2.4.1.4 Field Tests

Field tests or investigations like boring/drilling and sampling shall be carried out in accordance with the provisions contained in the references given in Table-5.

2.4.1.5 Laboratory Tests

Laboratory tests should be carried out on retrieved samples and the results should be interpreted in accordance with the provisions contained in the references given in Table-6.

2.4.1.6 Preservation and Retention of Samples, Cores and Records

The indexing and storage of soil samples or drill cores should be as per IS:4078 [3]. The core boxes should be labeled on both the outside and inside of the hinged lid of the box. For handling and labeling of samples, the provision of Appendix-E of IS:1892 [4] should be followed. As a prudent measure, it is suggested to preserve colour photographs of the cores in each box along with the lables as well.

Samples, drill cores and records pertaining to investigations should be retained at least till such time all matters relating to the interpretation of subsurface condition at the site have been resolved. The need to retain samples, cores and records beyond this time is a matter of judgement and should be decided on case by case basis. Core boxes and record storage facilities should be protected against possible damage or destruction by insects, rodents or adverse environmental conditions.

2.5 Identification, Determination and Evaluation of Foundation Design Parameters

Single value for all subsurface parameters cannot always be determined. The best estimates and range of variation of these parameters should be established from the estimates or range using the following guidelines.

(a) Determine the estimates or range of parameters from more than one investigation. For this purpose the geotechnical programme should be so developed that for each subsurface parameter both field and laboratory tests are carried out with preferably using alternative methods for each category, wherever possible. Number of investigations may be increased for a particular parameter depending on its significance on the overall safety.

(b) Select the design value of the parameter as the best estimate, using engineering judgment, from the estimates or range of the parameters determined from various investigations such that:

- the design value is compatible to the site condition,
- conservative results are obtained from safety analysis using this value,

- adequate safety margins are provided, and
- the design value of one parameter does not contradict with the design values selected for other related parameters.

The results of the investigations should be interpreted as per the specifications given in codes and references listed in this guide. However, a different approach may be adopted if that is found to be more rational than those given in the codes and references referred in this guide.

3. SAFETY OF FOUNDATION

3.1 General

The safety of foundation system of NPP depends on

(a) stability of foundation alongwith subsurface materials,

(b) movement of foundation, and

(c) the integrity and stability of ground in surrounding bedding of site.

Safe design of NPP foundation shall be performed considering above three aspects and ensuring adequate margin of safety. The margin of safety is the level of conservatism to be provided in the design to take care of the design uncertainties. These uncertainties are generally the non-quantifiable factors affecting adversely the behaviour of foundation systems.

3.2 Approach to Foundation Safety

The foundation system shall be designed for the failure modes which shall be postulated considering all the possible scenarios that can affect the environment, the safety of the plant, personnel and public, and functional requirement of the structure foundation.

The items of safety analysis are identified from the failure modes. Safety analysis includes those phenomena or behaviour of the foundation system and the surrounding locality which need to be studied and investigated for the safety of site and safe design of foundation systems. Several foundation safety analysis items needs to be analysed to evaluate each failure mode.

Safety analysis requires the determination of certain characteristics of foundation materials or subsurface parameters. These parameters are determined from geotechnical investigations.

3.3 Failure Modes

Following failure modes shall be considered for the safety of NPP foundation:

(a) Ground failure

The foundation material may lose its integrity due to excessive ground motion which could cause collapse of plant structures. This type of failure is ground failure.

(b) Foundation stability

Foundation may fail due to imposition of excessive load, sliding, overturning, flotation, etc.. These failure modes are considered in foundation stability analysis.

(c) Foundation movement

Foundation movement failure mode concerns with movement of foundation due to settlement, heaving and tilting which may cause excessive deformation leading to overstressing of structures and malfunctioning of operation equipment.

In addition to the above, another scenario could be envisaged which is not exactly associated with the failure of foundation system but may lead to the failure of plant structures, systems and components. This is due to the transmission of vibratory ground motion which exceeds specified design limits. Example of such a phenomenon is vibratory ground motion caused by blasting during rock excavation.

3.4 Foundation Safety Aspects

In order to ensure that the foundations of NPP buildings are capable of fulfilling its safety related function and integrity requirements, following safety aspects should be considered:

(a) The applied bearing pressure should not exceed the safe bearing capacity of the sub-grade material upon which the foundation is constructed.

(b) The foundation design should ensure that total and differential settlement due to compression of the underlying sub-grade are within acceptable limits, both for structure as well as the process system housed in it.

(c) The sub-grade below and adjacent to the foundation should not be subjected to liquefaction, due to the effect of ground shaking.

(d) The foundation design should ensure that all the loads coming from superstructure, are transmitted to the sub-grade with appropriate safety margins and that structural integrity of foundation is maintained, under all specified load combinations. The foundation design should ensure compliance with specified minimum factors of safety against sliding, overturning, uplift and flotation under all worst load combinations.

(e) The foundation layout should ensure provision of adequate vibration isolation gaps to avoid transmission of vibration between the buildings, if required.

(f) Overlapping of the foundations of the adjacent structure should be avoided, as far as possible.

(g) One single type of foundation should be used per structure and its foundations should preferably rest at same elevation.

3.5 Geotechnical Parameters

Numerical approach is generally adopted for the foundation safety analysis. The analysis models are described by a number of geometrical and physical parameters. The geometrical parameters are related with size and shape of the foundation and to the lateral and in-depth extent of the foundation materials. The physical parameters are related to the constitutive laws of materials i.e. load-deformation-time relationships and also to their strength characteristics.

3.6 Foundation Safety Analysis

Assessment of safety of the foundation system for the failure modes given in section 3.3 shall be carried out by analysing all the postulated safety analysis items. The safety analysis items for various failure modes are given in Table-2. Depending on site condition, the items for safety analysis should be selected from Table-3. The summary of these items is given below:

(a) Design acceleration level and seismic response

(b) Ground water

(c) Stresses in founding materials

(d) Local instability

(e) Liquefaction

(f) Soil erosion

(g) Bearing capacity

(h) Sliding, overturning and flotation

(i) Settlement and heave

(j) Slope and embankment instability.

The evaluation of the various safety items is discussed below:

3.6.1 Design Acceleration Level and Seismic Response:

Design acceleration level and seismic response shall be evaluated following the provision and methodology given in AERB safety guide AERB/SG/S-11 titled ‘Seismic Studies and Design Basis Ground Motion for Nuclear power Plant Sites’.

3.6.2 Ground Water

Ground water regime has very significant influence on the safety for all failure modes including vibratory ground motion. Safety analysis should be made to evaluate influence of ground water regime with conservative approach. As the ground water table could be different after the completion of the project, the design ground water table should be assessed conservatively. The analysis should include the following points:

(a) Groundwater conditions relative to the stability of the safety related buildings and structures

(b) Design criteria for control of ground water levels or collection and control of seepage

(c) Requirements of dewatering during construction and methods of dewatering

(d) Record of field and laboratory permeability tests, ground water quality

(e) History of ground water fluctuations, including those due to flooding, and projected variances in the ground water levels during the life of the plant

(f) Description and interpretation of actual ground water conditions experienced during construction (Confirmatory stage).

3.6.3 Stresses in Founding Materials

It is necessary to study the stress field which may affect the ground failure, (slope and embankment failure) foundation movement and foundation stability as a result of initial and superimposed load conditions arising from static and dynamic loading effects.

The initial stress conditions due to gravity forces are described by distribution of stresses in the earth masses. The derivation of initial stress condition may be performed by assuming the earth mass as linear elastic medium with appropriate boundary conditions.

The effect of superimposed load on the contact pressure distribution for both static and dynamic load may be determined by soil structure interaction (SSI) analysis. Two methods are used for SSI analysis-direct method (using finite element model for foundation material) and impedance function method (by means of series of springs whose stiffness is determined from the foundation material characteristics for static loading). The SSI analysis for dynamic loading could be carried out using similar approach.

Various subsurface parameters which are required to evaluate stresses in foundation materials are given in Table-2.

3.6.4 Local Instability

This phenomenon of ground failure occurs due to various geological features of the surrounding locality like heterogeneity of subsurface materials, surface faulting and other geological weakness like subsurface cavities and karstic phenomenon, etc.. The methodology described in the AERB safety guide AERB/SG/S-11 titled ‘Seismic Studies and Design Basis Ground Motion for

Nuclear power Plant Sites'[1] shall be adopted to analyse these phenomena.

Various parameters to be used in this safety analysis are listed in Table-2 and in AERB safety guide AERB/SG/S-11.

3.6.5 Liquefaction

Appendix-B provides the guidelines for the safety analysis required in case of liquefaction hazard. Various safety analysis parameters to be determined for this purpose are given in Table-2.

3.6.6 Soil Erosion

Guidelines for the assessment of soil erosion are described in Appendix-C.

3.6.7 Bearing Capacity

To assess the safety of foundation system against failure of bearing capacity, two important aspects should be considered. These are determination of the stresses imposed on the foundation materials and evaluation of safe bearing capacity of the foundation materials.

Calculation of the stresses imposed on the foundation material shall consider both the static and dynamic loading. The seismic effect on the foundation material imposed by structures is generally calculated from the dynamic analysis of structures considering soil structure interaction (See 3.6.3). The seismic loads thus calculated are assumed as static load in the final safety assessment.

Various safety parameters to be determined for this analysis are given in Table-2. The design value of bearing capacity shall be evaluated using the approach described in IS:12070 [5], IS :6403 [6] and IS:1904 [7].

If the calculated bearing capacity is such that adequate margin of safety can not be achieved, improvement of foundation materials should be undertaken. Section 4.7 describes the relevant methodology for this purpose. Otherwise, different foundation system should be identified.

3.6.8 Sliding, Overturning and Flotation

Sliding of foundation structures should be carefully investigated on the basis of the existing faults, weathered zone, fractured zone, clay zones, etc. in subsurface medium. Various safety analysis parameters to be determined for this analysis of sliding and overturning are given in Table-2.

Under certain combinations of ground motion, groundwater level and geometrical configuration of the building, conventional computing procedures may give rise to a potential uplift. This does not mean that the foundation would necessarily lift up but rather that conventional procedures to compute the structural response may not be applicable under these circumstances.

In the event that the estimated surface area of the uplift of the foundation is larger than 30% of the total surface of the foundation, a more sophisticated method may be used in the analysis of the dynamic soil-structure interaction for examining the possibility in reduction of the uplift value. The estimated uplift of the foundation should, however, be limited to 30% of the total area of foundation.

3.6.9 Settlement and Heave

The assessment of settlement and heave is important for the safety of foundation. The differential settlement of different parts of a building causes tilting. The approach for safety assessment for settlement and heave is described in Appendix-D.

Various safety analysis parameters for this analysis of settlement and heave are given in Table-2. IS:8009 [8] can be used to evaluate settlement of foundations.

3.6.10 Slope and Embankment Stability

Safety assessment of slope and embankment stability should be established as per approach given in Appendix-E.

3.7 Stages of Safety Analysis

The entire safety analysis may be completed in the following three stages:

(a) Site Evaluation Stage

The objective of this stage of safety analysis is to assess acceptability of site from ground failure consideration and to acquire sufficient information for the preliminary design of foundation system. The information is collected using current and historical documents and supported by limited direct exploration. Determination of the requirement of other two stage work is also suggested at this stage.

(b) Detailed Analysis and Design Stage

The detailed analysis of all postulated safety items are performed at this stage along with the design of foundation system. The information for this stage is collected through detailed subsurface investigations. The results obtained in site evaluation stage are also confirmed at this stage.

The work to be undertaken in confirmatory stage including the monitoring work is specified in this stage.

(c) Confirmatory Stage

The results obtained at detailed analysis and design stage and site evaluation stage are confirmed at this stage. This stage also undertakes the work which is found necessary after excavation of foundation pit.

4. DESIGN OF FOUNDATION SYSTEM

4.1 General

Shallow foundations are, in general, adopted for nuclear safety related buildings and structures. Deep foundations are employed when the quality of founding materials is not adequate to support foundation structure, even after improving or replacing the weak founding materials. The deep foundations consist of intermediate structures like piles, caissons, which transfer the load from foundation mat to deep load bearing strata.

Design of foundation structure has basically two steps:

(a) Geometrical design

The type and geometrical dimensions of the foundation are decided from geotechnical safety consideration.

(b) Structural design

The strength design of the foundation structural element is carried out from structural safety consideration.

4.2 Foundation Stability

The allowable bearing capacity of the foundation material shall be determined in accordance with subsection 3.6.7. No decrease in factor of safety in calculating allowable bearing capacity from the computed maximum/ultimate bearing capacity is allowed under seismic effect. Similar provision is applicable for deep foundation.

The design of foundation system is acceptable if the minimum factors of safety for foundation stability against sliding and overturning are 1.5 for load cases with operating basis earthquake (OBE) and 1.1 for load cases with safe shut down earthquake (SSE). The factor of safety for flotation should not be less than 1.1.

There may be a momentary loss of contact of the foundation with its subbase under the action of time dependent loading effect such as that due to seismic excitation. This loss of contact should be restricted to 30% of area of foundation.

4.3 Foundation Structures

4.3.1 Shallow Foundation

Isolated footing, strip and spread foundation, raft or mat are commonly used shallow foundations for NPP structures. In selecting the geometry of the foundation, proper attention should be given to the following :

(a) Effect of foundation dimension on bearing capacity or other foundation design parameters

(b) Rigidity of super structure, foundation structures and foundation materials

(c) Combined effect of super structure and foundation structure rigidity on the foundation materials

(d) Effect of new foundation on existing foundation and vice versa during and after construction.

State of the art method shall be used in the stability analysis. IS:2950 (Part-I) [9] and IS:1080 [10] are suitable for the stability analysis and geometrical design of raft and spread foundation respectively.

The structural design of the foundation shall be carried out in accordance with AERB Safety Standard 'Design of Concrete Structures Important to Safety of Nuclear Facilities', AERB/SS/CSE-1 [11].

4.3.2 Deep Foundations

Piles and caissons are example of deep foundations. Depending on soil conditions, pile or caissons foundations may be used in Nuclear Power Plant.

The design and testing of pile foundations shall be carried out as per IS:2911 [12] subject to the following:

(a) The seismic effect on pile foundation should be taken as static class of loading unless special pile design under dynamic load is considered

(b) Minimum factor of safety to determine pile capacity by static formula shall be 3. No decrease in factor of safety under seismic event is acceptable

(c) When pile foundation is adopted at a site which has potential to the liquefaction, following steps should be taken:

- The pile should be taken upto a depth of soil strata which does not have liquefaction potential
- At least one third of the length shall be penetrated through the soil strata free from liquefaction potential
- The effective skin friction shall be taken only for the 75% of the pile length penetrated to the soil which has no liquefaction potential
- In case the lateral resistance of vertical piles can not be mobilised, raker piles should be used to resist the horizontal force

(d) The structural design of pile and pile cap shall be carried out in accordance with the provision of [11].

4.4 Foundation Supports

Engineered foundation supports are required where the existing ground level is lower than the design foundation level or to replace weaker subsurface materials by able supporting materials which can withstand the loading of building/structures, transmitted through foundation structures.

Following guidelines should be followed:

(a) To design engineered foundation supports, characteristics of both the in situ soil and borrowed soils should be considered.

(b) In case of existing ground being lower than the design foundation level, the level of existing ground level is brought to the required level by filling with the help of good soil materials or lean concrete,

(c) If the original soil material needs to be replaced by superior materials, following precautionary measures should be taken:

- The stability of the whole excavation must be maintained during excavation
- The backfill material, generally granular in nature must be of good quality and properly compacted.

(d) If there is over cutting during excavation of foundation pit, it should be made good by filling up with concrete of appropriate grade.

(e) For ground improvement refer subsection 4.7.

4.5 Founding Materials

It should be ensured through adequate subsurface investigations that the founding material is competent for transferring the design loads through the foundation. Founding materials may be soil or rock. Soil may be cohesionless soil or cohesive soil. Rock may be hard rock or soft/weathered rock. If the founding materials are soils or soft rock, a knowledge of the stress history of the subsurface materials should be obtained to predict settlements and heaves and the possibility of gross foundation (shear) failure.

When the founding material is not capable of carrying the building loads on shallow foundations within acceptable deformation, ground improvement should be carried out as described in subsection 4.7.

4.6 Rock Anchors

4.6.1 In order to keep the loss of contact between foundation raft and supporting strata within allowable limits or to achieve adequate factor of safety against over turning or flotation of raft, it may be necessary to stitch the foundation raft to the supporting foundation material by rock anchors. The rock anchors are of two types:

Type-A Passive anchors using high yield strength reinforcing bars. Such type of anchors may be suitable for low capacity say upto the order of 500 KN.

Type-B Active anchors using pre-stressing cable. This class of anchors can be used where higher anchorage force is required.

4.6.2 The uplift resistance of anchorage is given by lesser of the following :

(a) The tensile strength of the anchor bars (reinforcing bars) or cables (pre-stressing strands)

(b) The anchorage strength of the bars or cables (i.e bond strength between steel and concrete/grout)

(c) The bond strength between the concrete or grout and surrounding rock

(d) The dead weight (or submerged weight if the anchorage is below water level) of a cone of rock which must be lifted by the anchor or group of anchors, if failure does not occur by (a), (b) or (c).

4.6.3 Guidelines given in IS:10270 [13] should be used for the design and construction of pre-stressed rock anchors.

4.6.4 The capacity of rock anchor should be determined by calculation based on known properties of steel, concrete or grout and should be verified by testing under realistic field condition. At least three prototype anchors should be tested to evaluate an anchor in a given set of rock and installation condition. The tests are destructive and should not be in general made on stitch anchors that form part of the actual foundation rock stitching system. Two percent of anchors should be proof tested for their design strength.

4.6.5 The corrosion protection of the anchor bar or pre-stressing cable is an important aspect. Required corrosion protection measures should be adopted in the anchorage detailing. In case of active anchors (with pre-stressing cables), it is necessary to monitor the residual stress in the cable periodically as also to monitor corrosion potential. Necessary provisions should be made at the initial installation stage itself for its long term monitoring. Care should be taken in detailing the anchor and its connection to raft to ensure that an anchor does not form passage for ingress of ground water into the raft or basement.

4.7 Ground Improvement

4.7.1 Cohesionless Soil

For cohesionless soil, the method consists of improving the soil quality by increasing its density, thus increasing its bearing capacity and reducing settlement and liquefaction potential. These objectives are obtained by:

(a) Compaction or tamping in subsurface : This involves compacting the soil with the appropriate compaction equipment such as vibratory roller etc..

(b) Vibroflotation in deeper conditions : This is a process of densification of granular soil by vibration at depth using a device similar to the type used for the vibratory compaction of mass concrete. There is temporary liquefaction of the soil with resultant closer packing of the particles through gravity effects. Vibroflotation involves the reduction of the void ratio since the voids are filled by overlaying material during the densification process. As compaction is carried out from the bottom upwards, the reduction in the void ratio is shown by settlement of the surface.

(c) Dewatering : Withdrawal of water from a cohesionless material reduces the liquefaction potential and produces an effect similar to compaction. This process can be useful during excavation. This is further described in section-5.

(d) Grouting and soil cement stabilisation.

4.7.2. Cohesive Soils

In cohesive soils, the aim is the improvement of the drainability of the medium in order to increase the consolidation rate of the material and improve shear strength. This can be obtained by:

(a) Geodrains : These are very simple drill holes used with geo-synthetic material that maintains an open hole and makes dewatering easier. In the sand drain process the hole drilled by auger is filled by sand. The installation of geodrains should be followed by preload as described in (c) below. Guidelines given in IS:15284 (Part 2) [14] should be used for design and construction of vertical drains.

(b) Stone Columns : This process uses materials similar to those in vibroflotation. The hole advanced in cohesive soil remains open and is then filled with densely compacted granular material. The stone columns also provide bearing points capable of carrying additional small loads. Guidelines given in IS:15284 (Part I) [15] should be used for design and construction of stone columns.

(c) Preloading : Temporary surcharge loads are used to eliminate settlements that would otherwise occur after structure is completed. The pre-load surcharge should be greater than the estimated load of the proposed structure. The pre-loading is more effective in improving the shear strength of soft soil when preceded by geodrain installation. Also it is necessary to ensure that the pre-load is placed in stages to prevent shear failure of soft soil, under the very weight of the surcharge.

(d) Grouting : It is a technique of injecting kind of stabilising agent into the soil mass under pressure. Grout may be mixture of cement and water, chemicals or lime, flyash, cement, etc.

4.7.3. Rocky Conditions

In rocky conditions where voids are present in hard layers, filling of the cavities is done by:

(a) Grouting : This process carried out under pressure not only fills in the cavities but also the main joints which are present.

(b) Concreting : This is done where the cavities are large and located near the ground surface. Prior excavation and cleaning may be necessary.

4.7.4. Use of Geosynthetics

A number of synthetic materials, commonly made of polyester, nylon, polyethylene, and polypropylene are used to improve the soil properties, for soil protection or as reinforcement in earth walls or embankments for control of erosion.

4.7.5. The ground improvement methods suggested in section 4.7.2 are long duration activities for effective improvement and may not be suitable for projects where such a long time is not available. In such circumstances, suitable alternative measures may be adopted.

5. DEWATERING

5.1 General

Ground water is usually regarded as one of the most difficult problems in excavation work and during construction of substructure. However, from the general knowledge of the soil, ground water conditions and an understanding of the laws of hydraulic flow, it is possible to adopt methods of dewatering which will ensure safe and economical construction scheme in any condition. It is important to obtain all the necessary information before commencing work and this aspect should not be neglected at the site investigation stage.

5.2 Requirement of Dewatering

5.2.1 Temporary Dewatering

Dewatering is controlling the ground water level during the excavation for foundation. Temporary dewatering is required to facilitate construction operations, by achieving dry conditions for working, till such time the construction reaches above the ground water level. Dewatering is necessary to control the seepage of water into excavation pit. It may be also necessary to avoid flotation of a partly constructed structure due to buoyancy effect, till such time sufficient gravity load is available to counteract the buoyancy.

5.2.2 Permanent Dewatering

Wherever the quality of ground water is harmful to the structure from durability point of view and/or control of ground water ingress is to be effected through ground water lowering, permanent dewatering system may be installed, as additional measure to minimize ingress into the structure, basement and around.

The implementation of a credible dewatering scheme to withstand all kinds of ground water situations is required. For the unqualified success of the dewatering scheme, proper assessment of the permeability of the subsurface strata with its seepage potential is also necessary. If the pumps used are electrically driven it is desirable to have the standby power supply where safety function is associated.

5.3 Dewatering Systems

The following methods can be used for dewatering:

(a) Pumping from open sumps

(b) Pumping from well points

(c) Pumping from bored wells

(d) Pumping through infiltration galleries

Reduction of ground water ingress may be made by forming impervious barriers such as sheet piling, R.C diaphragm wall, grouting with cement or clay suspension etc.

5.4 Dewatering System Design

The dewatering system design should take into account the ground water flow rates, stability of excavation slopes under various ground water table levels and progress of excavation, soil erosion under flow, provision of instrumentation for monitoring ground water levels etc.

6. MONITORING

6.1 General

The subsurface exploration, in situ testing and laboratory testing should provide parameters and site characteristics suitable for predicting the performance of foundation systems under various loading conditions. The use of these parameters allows foundation design criteria to be established for the performance of the foundation materials and structures under anticipated loading. The preferred method of verifying foundation performance is to monitor the actual field behavior during and after construction.

6.2 Monitoring during Construction

During the construction phase, following parameters should be monitored:

(a) Heave and settlement of ground

(b) Stability of slopes

(c) Ground water level

(d) Transmission of vibrations

(e) Pore water pressure wherever required.

6.3 Monitoring during Operation

The following parameters should be monitored during operation of the plant:

(a) Settlement of foundations

(b) Ground water quality

(c) Ground water movement and level

(d) Pore water pressure wherever required

(e) Vibration measurement wherever required.

6.4 Geotechnical Instrumentation

The following monitoring devices may be used to observe the behaviour of the foundation and related materials (refer Appendix-F):

(a) Piezometers

(b) Settlement monuments

(c) In situ settlement plates

(d) Load and pressure cells

(e) Inclinometers

(f) Seismometers.

7. QUALITY ASSURANCE

7.1. General

A Quality Assurance (QA) programme should be established and implemented for all the activities covered in this guide. The QA programme should be developed on the basis of following documents to the extent applicable:

(a) Code of Practice on Quality Assurance for Safety in Nuclear Power Plants, AERB/SC/QA

(b) Quality Assurance in Siting of Nuclear Power Plants, AERB/SG/S-10

(c) Quality Assurance during Site Construction of Nuclear Power Plants, AERB/SG/QA-4.

(d) Civil Engineering Structures Important to Safety of Nuclear Facilities, AERB/SS/CSE.

7.2. Quality Assurance Requirements

The quality assurance programme should include the following elements as a minimum requirement:

(a)	Programme plan	:	Planning and design, documentation
(b)	Organisation structure	:	Staffing and personnel qualification, responsibility and interfaces
(c)	Document preparation	:	Review and approval, issue and distribution, change/revision control
(d)	Performance function	:	Field tests, lab tests, calibration and accuracy of equipment used for testing, storage and retrieval of test results and samples
(e)	Audit/review method	:	Frequency, reporting
(f)	Non-conformance control	:	Identification, review, disposal and documentation
(g)	Corrective and preventive actions	:	Trend analysis, corrective and preventive steps
(h)	Reporting and records	:	Procedures, proforma for reporting of test results/calculations, interpretation of results

APPENDIX-A

GUIDELINES ON GEOTECHNICAL AND GEOLOGICAL INVESTIGATION

A.1 General

Geological and geotechnical investigations are required to provide the information and data needed to define local foundation and ground water conditions as well as geotechnical parameters required for safety analysis, design and engineering of foundation and earth structures.

The investigations are also expected to provide the information and data required to define site geology. The entire work of investigations should be assessed and critically reviewed jointly by the independent geotechnical consultant, project representative and engineering consultant, as the investigation progresses. This is to ensure that best practices of boring, sampling and testing are being followed at all times, such that the requirements of the investigation can be fulfilled. The sources for generation of information and data, for this purpose, are generally the following;

- Historical and current documents
- Indirect exploration
- Direct exploration
- Tests and checking

A.2 Historical and Current Documents

The investigation requires an understanding of the general geology of the area of interest. A major portion of information required for such understanding can be obtained from available historical and current documents, like:

- Topographic maps
- Geological and engineering geological maps
- Soil maps
- Geological reports and other geological literature
- Geophysical maps
- Earth satellite imagery; aerial photographs
- Geotechnical reports and other geotechnical literature
- Water well reports and water supply reports
- Oil and gas well records

- Hydrogeologic maps, hydrologic and tidal data, flood records, climate and rainfall records
- Mining history, old mine plans and subsidence records
- Seismic data and historical earthquake records
- Newspaper accounts of landslides, floods, earthquakes, subsidence and other geological events of significance
- Records of performance of structures in the vicinity
- Data from internet.

Other possible sources of information are individuals, geology and engineering departments of colleges and universities, geological survey of India and other governmental engineering departments such aslike PWD, Irrigation etc.

Field reconnaissance survey is suggested to confirm the information from the above documents, if felt necessary.

A.3 Indirect Exploration

Indirect exploration is generally geophysical technique and is based on substance model involving homogeneous elastic horizontal layers. Appropriate measures should be taken so that it represents actual condition rationally and yields results with desired level of confidence. Recommended surveys include seismic refraction, seismic reflection, electrical resistivity, nuclear logging and ground penetrating radar and remote sensing. The investigations which are listed in Table-4 should be conducted as per specifications for field and laboratory tests given for rock/soil in Table-5 and Table-6 respectively.

A.4 Direct Exploration

Direct exploration methods are those where data or information are obtained from samples, from direct observations, or from in situ investigations. Generally, they require drilling of boreholes with or without extraction of a core, or the excavation of a trench for observation and testing. Access for sampling, testing or observation is provided in general by:

- Pits and trenches
- Borings and drillings
- Samplings
- Existing quarries/wells in the vicinity
- Any other works in progress near by.

Table-1 gives guidelines for spacing and depth of boreholes. Table-4 summarises the geotechnical investigation programmes for specific foundation materials such as rocks/soils. The pit and trenching, should be done in accordance with IS:1892 Ref [4] and IS:4453 [16].

A.5 Tests and Checking

- Field check
- Field tests
- Laboratory tests.

During field checks, undesirable surface characteristics such as cavity zones, swelling rocks and shales, zones of weakness or discontinuties in rocks, potential slide planes etc. are identified. Field checks are also to be done after the excavation of foundation pits and trenches for any geological treatment.

Field tests are carried out to measure mechanical properties of foundation materials. It should also include various in situ loading tests, field permeability and piezometric measurements of ground water. Table-5 gives the list of field tests along with the applicable code/reference for testing.

Laboratory testing is conducted on samples obtained by direct exploration methods. The purpose is to supplement and confirm the in situ test data in order to fully and correctly characterise the soil and rock at the site. The testing programme identifies and classifies soil and rock samples. Their physical and engineering properties are obtained from published data or by measurement. Details of laboratory testing methods are given in Table-6. These laboratory tests should be directed towards the following:

- Soil index and classification
- Soil moisture-density relationships
- Consolidation and permeability characteristics for soils
- Physical and chemical properties of soils
- Shear strength and deformability of soil
- Engineering properties of rock
- Dynamic characteristics of the soil
- Chemical analysis of ground water.

Site characterisation parameters for use in the design profile are derived from the tests as well as from the direct and indirect exploration results.

A.6 Report Preparation

The results of the investigation at a particular stage should be combined with basic data obtained from the preceding phases into a detailed geotechnical report. The report should include the following items:

- Geological maps and profiles

- Description of geological factors and site geology
- Exploration programme and basis thereof
- Location plans of boring, field tests
- Boring logs and test pit logs
- Results of in situ testing
- Results of laboratory testing
- Results of geophysical surveys
- Description and results of analyses
- Detailed description of ground water regime and physiochemical properties
- Recommendations of safety analysis parameters.

APPENDIX-B

LIQUEFACTION AND GROUND FAILURE

B.1 Introduction

Liquefaction and consequent ground failure resulting from earthquakes have been the cause of significant or catastrophic damage of buildings.

Soils susceptible to liquefaction are normally cohesionless soils such as sand and gravel containing a small portion of silts and clays and in a loosely deposited condition below the water table.

Both laboratory investigations and observations of field performance have shown that the liquefaction potential of a soil deposit depends on the characteristics of the soil, the initial stresses acting on the soil and the characteristics of the earthquake. The significant factors include:

- Soil type
- Relative density
- Initial confining pressure
- Magnitude of Earthquake
- Intensity and duration of ground shaking
- Ground water regime.

The soil type can be characterised by the grain size distribution. Generally uniformly graded materials are more susceptible to liquefaction than well-graded materials. Fine sands tend to liquefy more easily than coarse sands. The susceptibility to liquefaction of cohesionless soil with low relative density is more than that of same material in a denser condition. Increase in silt content reduces the susceptibility to liquefaction.

It has also been observed that for a given initial density the stress required to initiate liquefaction under cyclic load conditions increases with the initial confining pressure.

The vulnerability of soil deposit to liquefaction during an earthquake depends on the magnitude of the stresses or strains induced in it by an earthquake; these in turn are related to the intensity of ground shaking. The duration of ground shaking is a significant factor in determining liquefaction potential because of significant stress or strain cycles to which soil is subjected.

B.2 Date Requirement

The following information or data need to be collected for assessment of liquefaction potential:

- The thickness and the variation of the subsurface layer at the site
- The average relative density for each layer determined from standard penetration test (SPT) blow counts or static cone penetration tests (SCPT)
- The ground water level
- Grain size distribution, permeability, liquid limit, and natural moisture content in soil at various layers
- Undrained cyclic shear strength of subsurface material, established from cyclic triaxial tests, in laboratory on undistributed or remolded samples of soil
- The number of equivalent uniform cycles considered representative of the reference ground motion at the site
- Data on liquefaction, which has occurred at the site or in the site vicinity in the past.

B. 3 Methods of Assessment

The liquefaction potential at a site can be assessed by using either an empirical approach or analytical approach coupled with appropriate laboratory tests and field tests [17]

B.3.1 Empirical Approach

An empirical approach is based on the observations from past earthquake and readily evaluated from SPT or SCPT data, by using the charts which have been empirically established. These charts correlate the stress ratio with SPT or SCPT penetration resistance, earthquake magnitude and fine content of soil.

B.3.2 Analytical Approach

Analytical approach comprises of the following steps:

- Calculation of the stresses induced by the design earthquake. These stress histories are transformed into numbers of equivalent uniform cycles of shear stress
- Establishment of the cyclic strength characteristics of the soil at each layer, using ‘N’ values from SPT or cone penetration resistance. Wherever appropriate, cyclic testing programme on soil samples should be conducted
- Comparison of the available cyclic strength data with the induced stresses
- A factor of safety against the occurrence of liquefaction is computed

as the ratio of the available cyclic strength to the induced stress. Acceptable factor of safety should be specified on a case by case basis.

For sites of relatively low seismicity, the empirical approach is generally sufficient. For sites in high seismic regions, both the analytical and as a check empirical approach be used.

APPENDIX-C

SOIL EROSION

C.1 Internal Erosion

Erosion in sandy soil occurs mainly due to water seepage. Internal erosion can result from ground water seeping into underground streams carrying with it fine soil particles. The consequence loss of ground from beneath foundations may lead to distress of structure. Internal erosion can also occur as a result of careless technique in deep excavation below the water table when soil particles are carried in to the excavation by flowing water. Ground subsidence may occur due to solution of minerals from the ground as a result of water seepage.

C.2 Surface Erosion

Soil surface erosion may take place as a result of loss of material due to strong winds. Fine sand, silts and dry peat are liable to erosion by wind. The possibility of undermining of foundations in such cases can be prevented by providing sufficient embedment for foundation. Alternately the erodible soil may be blanketed by gravel, crushed rock or clay or growing vegetation, turf etc. over the soil. Erosion by rain water in certain loose dispersive soil can also take place.

C.2.1 Erosion Along River Course/Shoreline

Surface erosion may also occur due to heavy flood water flows. This could be severe if structures are located at the bottom of valleys or near river banks. The required depth of such foundations should be obtained by hydraulic calculations and local observation. The undermining of foundations may also be prevented by attention to the siting of structures, adequate drainage and paving or other forms of surface protection, of paths taken by periodical discharge of flood waters. In case of coastal sites, since shoreline erosion could affect items important to safety, an investigation should be undertaken to determine whether a potential for shore instability exists. Sequential satellite data obtained from the previous years may be used in assessing the changes in the shoreline / river valleys. Similarly, considerations should also be given for possible erosion of river banks or change of river course in case of inland sites or sites on river banks.

APPENDIX-D

SETTLEMENT AND HEAVE

D.1 General

Settlements or heaves are important in connection with foundation deformation which could lead to overstressing of building and interference with the operation of machinery such as pumps and turbines. Differential settlement and heaves between two buildings have significant influence on the performance of nuclear power plant because of presence of pipes, conduits, tunnels, etc. that provides connection between buildings and structures.

D.2 Component of Settlement and Heave

The settlement and heave have two components:

- Elastic
- Time dependent.

The elastic component may occur during construction and most of it occurs before operational life of the plant. They are not usually of safety significance so far as their magnitude is within the acceptable limit. The time dependent settlements occuring during operational life of the plant and their safety on overall plant shall be assessed. Stage wise long-term settlement calculations also may have to be carried out considering the sequence of construction.

D.3 Evaluation of Time Dependent Settlement and Heave

The design of foundations for buildings, interconnecting structures between adjacent buildings and foundations for machinery require a rational assessment of differential and total settlement. Time dependent settlement may be computed by classical theory of consolidation and other sophisticated nonlinear analyses. A number of numerical techniques can be found in literature on the subject. Following steps are necessary to evaluate time dependent settlement:

- The anticipated loading history shall be specified (excavation sequence, dewatering process, backfilling, construction process)
- The design value of the coefficient of consolidation, initial modulus, tangent modulus, Poisson's ratio, and other relevant parameters which define particular constitutive law shall be properly evaluated from subsurface investigations as described in section-2
- Data resulting from laboratory testing and in situ testing values and their variation for defined layers of the subsurface materials is obtained for numerical modeling

- These values shall be determined for entire profile of interests
- The settlement and heaves are evaluated for static class of loading. Seismic effects once determined by dynamic analysis of structures should be considered as static loading for the evaluation of settlement and heaves.

D.4 Engineering of Settlement and Heave

- The evaluation of settlement should be performed
- The level and extent of instrumentation for settlement and ground water measurements shall be appropriately related to the soil characteristics (Section-6)
- From settlement and heave measurements taken during excavation, dewatering, backfilling and construction, the displacement versus load relationships can be developed and assessed
- The numerical models used to predict settlements and heaves should be corrected by comparison of their predictions with the actual behaviour so that any necessary adjustment can be introduced into the design
- It is advisable to defer construction of connections between buildings or structures subjected to differential movement till the predicted settlement behaviour is verified by measurements.
- In cases where safety related piping is required, flexible connections may have to be used to reduce stressing resulting from differential movement.
- In some circumstances, measurements and numerical computation of movements are specified as operational requirements of a nuclear power plant. Hence, a well-defined measurement programme for upgrading the design profile and improving the reliability of the numerical models is essential.

APPENDIX-E

SAFETY OF EARTH STRUCTURES

E.1 General

Various earth structures in and around NPP comprise of dykes, dams, hills, embankments, cuts, sea walls, water retaining structure etc. Depending on their safety classification and seismic category classification, their design should be consistent with design of NPP structures., In particular, the safety evaluation against natural hazards (earthquake, flood, rainfall), thunder storm, cyclone, tsunami and their return period should be consistent with design of similar class structures.

E.2 Slope Stability

Appropriate field and laboratory investigations are required to determine:

- The extent and distribution of soil layers (or rock formation for rock slopes) within, adjacent and beneath the slope. For rock slopes, information on orientation of joints, localised weathering should also be gathered.
- The geometry of the slope.
- The static and dynamic characteristic of the soils (rock).
- The water levels and fluctuations of the water table.

E.2.1 Depending on the distance of earth structure from safety related structure of NPP, slope angle, height, geology, water content and geotechnical properties of earth structure, potentially hazardous earth structure should be identified and their safety should be evaluated. Effects of external events such as earthquake and severe precipitation should be independently considered in assessing the potential hazard of natural slope.

E.3 Methods of Evaluation of Slope Stability

The seismic stability of slopes is normally evaluated by either the pseudo-static method or the dynamic method of analysis.

E.3.1. Pseudo-static Method

In the pseudo-static method the stability of the slope is assessed by computing a factor of safety against sliding. A conventional method of slices may be used. The driving forces consist of gravity, surcharge and earthquake loads. The earthquake load is represented by seismic coefficient and is assumed to act at the centroid of the potential sliding mass. Determination of the resisting forces is based on the static strength of the soils computed along the potential sliding surfaces.

E.3.2 Dynamic Method

- Dynamic method is based on the use of dynamic response analysis incorporating soil strength characteristics determined by laboratory cyclic tests. The dynamic response analysis is done by using the two-dimensional method. A model of the slope and its foundation stratum is constructed using the finite element method. The input to this model is a time history of motion, compatible with the specific ground motion at the plant site, and having either its horizontal component or its horizontal plus vertical components simultaneously applied at the base of the model. The results of the response evaluation provide the time histories of induced stresses throughout the model.

- These induced stresses are to be compared with the cyclic test results. Because cyclic strength depends on the initial stresses, the static stresses within the slope and its foundation stratum (i.e. stresses existing before the earthquake) must be computed; this computation is done using static finite element procedures.

- The local factor of safety is defined as the ratio of the cyclic strength stress limit to the induced stress and is computed at various locations throughout the model. The stability of the slope is then assessed by examining the range and variations of the values of this local factor of safety. The factor of safety should be equal or larger than 1.5, unless a lower value is justified by sophisticated analysis.

Procedures also exist for computing the amount of potential deformation of the slope using the results of these dynamic analyses.

E. 4 Stability of Dykes and Dams

During geophysical and geotechnical investigations and before construction of these structures, special attention should be paid to permeability of the site close to the areas of the foundations. This permeability should be controlled throughout the plant operation.

In addition to usual failure modes, design should also consider all the possible failure modes which are dependant on the following two parameters:

- Pore pressure inside the embankment and
- The internal erosion caused by water flows inside the embankment.

In-service inspection, monitoring of dams and dykes and maintenance work should be performed during operation stage to prevent them from possible damage due to internal erosion.

E.5 Stability of Seawalls, Break Waters, Revetments

These structures are required to protect important facilities of NPP against wave action of sea or lake waters, during storms, flood and tsunami. These structures should be properly designed so that they can prevent soil erosion, floods and structural failures which may undermine the safety of important facilities. Dynamic effects of waves should be evaluated taking into account the maximum still water level derived from flood hazard evaluations.

The stability of these structures should be assessed keeping in view their functional requirement as well as their effects in case of failure.

If effects of failure are likely to endanger safety of other important items, appropriate engineering solutions should be provided or the plot plan should be rearranged.

The methods similar to those described in section E-3 should be used to assess their stability. If these structures are resting on sandy soils, its liquefaction potential should also be examined.

APPENDIX-F

GUIDELINES ON GEOTECHNICAL INSTRUMENTATION

F.1 Introduction

This appendix deals with geotechnical instrumentation for monitoring the time dependent soil behaviour, particularly during construction and under loads imposed by the building.

Prior to construction, instrumentation helps in determining the original soil characteristics and behaviour; during and after construction it provides information concerning behaviour during excavation, construction and after the application of building loads.

F. 2 Relevant Parameters

The principal parameters to be investigated with the aid of the geotechnical instrumentation are:

- The soil behaviour during excavation (e.g. elastic rebound and swelling) and during backfilling (e.g. elastic and consolidation settlements)
- The stress distribution at the building - soil interface and at depth under loading conditions during and after construction
- The time dependent building movements due to settlement induced by soil heterogeneities and the non-uniform load distribution at the ground surface. The differential settlements between two buildings and their tilting are important
- The mat deformation due to soil-structure interaction
- The behaviour of the water table level and its regime.

F.3 Instrumentation

F.3.1 Soil Behaviour

The behaviour of the soil is measured by:

- Pressure cells, located at the soil-mat interface. The number must be such that they take into account the soil heterogeneities and non-uniform loading conditions
- Deep settlement meters located in boreholes. These permit monitoring

of the behaviour of different soil layers. If possible, they should be installed before excavation is begun.

F.3.2 Building Behaviour

The behaviour of building is checked by:

- A set of topographic measurements or settlement pins, firmly fixed to the building mat. A sufficient number must be installed to permit proper estimation of building tilt
- Pendulums which measure the building deviations from vertical and provide mat tilting estimates.

F.3.3 Mat Deformation

The deformation (bending) of the mat itself is monitored by:

- Hydraulic devices using the principle of liquid level equilibrium (e.g. U-tube manometer). Their location and number must be such as to permit a good estimate of the deformation of the mat over its total area
- Strain-stress gauges placed in the mat concrete and suitably protected.

F.3.4 Water Table Behaviour

The behaviour of the water table is monitored by piezometers which may or may not be self-recording. Some of the piezometers must permit sampling of the ground water for analysis. Their number and locations are site dependent.

F.3.5 Slope Behaviour

The stability of excavated and natural slopes near the foundation of the buildings of the nuclear power plant should be monitored during excavation, construction and operation by means of tilting meters or rock deform meters (inclinometers).

F.3.6 Seismic Behaviour

The seismic behaviour of foundation and subsurface material should be monitored by means of seismometers. The need for instrumentation to monitor in situ pore water pressure should also be considered.

TABLE-1

REQUIREMENTS OF SPACING AND DEPTH OF BOREHOLES

Type of Structure	Spacing of Boring	Minimum Depth of Penetration
Safety related structures/ buildings.	At least one boring beneath every safety related structure. For larger and heavier structures such as Reactor bldg., Turbine bldg. one boring per maximum area of 900 m^2 (maximum 30 m spacing). Additional boreholes, at corners and along periphery as necessary. Where conditions are found to be non-uniform, closer bore hole spacing should be chosen to obtain a clear definition of changes in soil and rock properties.	(1) Boring shall extend to a depth equal to the width of foundation or 20 m below the lowest part of the planned foundation, which ever is greater. (2) Boring shall be deep enough to define and evaluate the deep stability problem, if any. This may require one bore hole of 100m depth below each unit. (3) Where soils are very thick, the maximum depth may be taken as that at which the change in vertical stress due to loads is less than 10% of the effective overburden stress.
Linear structures like trenches, tunnels, dams, dykes etc.	One boring per 30 m length. For larger cross section (>30m width), additional borehole.	5 times the tunnel or pipe diameter below its invert elevation.
Dams, dykes	- do -	In addition to criteria (1), (2), (3)above, depth of penetration should be sufficient to define all aquifers and zones of under seepage that could affect the performance of structures

TABLE-2

FAILURE MODE, ITEMS AND ASSOCIATED PARAMETERS FOR SAFETY ANALYSIS

S.No.	Failure Mode	Safety Analysis Item	Safety Analysis Parameters
1.	Ground failure	(a) Seismic response and design acceleration level	1. Stress history including strain assessment 2. Shear and compression wave velocity variation with depth 3. Dynamic moduli, Poisson's ratio and damping 4. Pore water pressure
		(b) Ground water	1. Chemical and physical characteristics of ground water 2. Soil permeability 3. Ground water level and its variation
		(c) Slope and embankment instability	1. Stratigraphy 2. Unit weight 3. Compressibility/consolidation 4. Cohesion 5. Angle of internal friction 6. Elastic moduli 7. Dynamic moduli, Poisson's ratio and damping 8. Shear strength 9. Permeability
		(d) Local instability, subsidence and surface faulting	1. Heterogenity of subsurface materials 2. Existing subsurface faulting or other weaknesses in the foundation locality. 3. Subsurface cavity and karstic formation.
		(e) Liquefaction	1. Grain size distribution 2. Relative density 3. Pore water pressure 4. Dynamic shear strength 5. SPT value. 6. Shear strength parameters 7. Magnitude of earthquake
2.	Foundation Stability	(a) Bearing capacity	1. Shear Strength 2. Elastic Moduli 3. Density 4. Modulus of subgrade reaction 5. Cohesion

TABLE-2 (CONTD.)

FAILURE MODE, ITEMS AND ASSOCIATED PARAMETERS FOR SAFETY ANALYSIS

S.No.	Failure Mode	Safety Analysis Item	Safety Analysis Parameters
			6. Angle of internal friction 7. Triaxial/Uniaxial strength 8. Relative density 9. Rock mass classification 10. Load settlement characteristics
		(b) Sliding and overturning	1. Degree of discontinuity 2. Rock quality designation including rock mass characteristics 3. Pore water pressure 4. Shear strength 5. Shear moduli 6. Over consolidation ratio
		(c) Stress in foundation materials	1. Stratigraphy 2. Density 3. Compressibility/consolidation 4. Angle of internal friction 5. Elastic moduli 6. Dynamic Moduli, Possion's ratio
		(d) Seismic response and design acceleration level	Same as 1 (a)
		(e) Ground water	Same as 1 (b)
3.	Foundation Movements	(a) Settlement and Heave	1. Elastic moduli 2. Dynamic moduli and Possion's ratio 3. Creep 4. Compressibility/consolidation 5. Over-consolidation ratio 6. Loading history of foundation material 7. Behaviour under repeated dynamic deformation 8. Degree of discontinuity and presence of fracture zones 9. Shear and compression wave velocity variation with depth
		(b) Seismic response and design acceleration level	Same as 1 (a)
		(c) Ground water	Same as 1 (b)

TABLE-3

SAFETY ANALYSIS PARAMETERS TO BE DETERMINED FOR DIFFERENT SITE CONDITIONS

S.No.	Safety Analysis Parameters	Site Condition		
		Rocky Site	Soil Site	
			Cohesive Soil	Sandy Soil
1.	Grain size distribution	-	Y	Y
2.	Unit weight	Y	-	-
3.	Bulk density	-	Y	Y
4.	Relative density	-	-	Y
5.	Chemical and physical characteristic of ground water/soil	Y	Y	Y
6.	Ground water level and its variation	Y	Y	Y
7.	Permeability	Y	Y	Y
8.	Pore water pressure	-	Y	Y
9.	Elastic moduli (Static)	Y	Y	Y
10.	Shear moduli	Y	Y	Y
11.	Dynamic moduli, Poisson's ratio and damping	Y	Y	Y
12.	Shear and compression wave velocity	Y	Y	Y
13.	Cohesion, angle of internal friction	-	Y	Y
14.	Atterberg limits	-	Y	Y
15.	Uniaxial compressive strength	Y	-	-
16.	Shear strength	-	Y	Y
17.	Dynamic shear strength	-	Y	Y
18.	Modulus of subgrade reaction	Y	Y	Y
19.	Compressibility/consolidation	-	Y	Y
20.	Over consolidation ratio	-	Y	-
21.	Stratigraphy	Y	Y	Y
22.	Heterogeneity of subsurface materials	Y	Y	Y
23.	Existing subsurface faulting or other weaknesses in the foundation locality	Y	-	-
24.	Degree of discontinuity and presence of fracture zones	Y	-	-

TABLE-3 (CONTD.)

SAFETY ANALYSIS PARAMETERS TO BE DETERMINED FOR DIFFERENT SITE CONDITIONS

S.No.	Safety Analysis Parameters	Site Condition		
		Rocky Site	Soil Site	
			Cohesive Soil	Sandy Soil
25.	Rock quality designation and rock mass rating	Y	-	-
26.	Creep, stress history and strain assessment	Y	-	-
27.	Subsurface cavity and karstic formation	Y	Y	Y
28.	Electrical resistivity	Y	Y	Y

Note : 'Y' indicates parameter to be determined.

TABLE-4

SAFETY ANALYSIS PARAMETERS AND ASSOCIATED GEOTECHNICAL INVESTIGATIONS

S. No.	Safety Analysis Parameters	Geotechnical Investigations			
		Rocky Site		Soil Site	
		Field Test	Laboratory Test	Field Test	Laboratory Test
1.	Grain size distribution	-	-	-	Gradation analysis, percent fines, soil classification
2.	Unit weight	Gamma-Gamma log	Bulk density	Standard penetration test (SPT) split spoon sampler	Bulk density test.
3.	Relative Density	-	-	SPT, Static cone penetration test (SCPT)	Relative density
4.	Chemical and physical characteristics of ground water/soil	-	Chemical test, Organic content, Soluble salts	-	Chemical test, Organic content, Soluble salts
5.	Ground water level and their variation	Observation of water level in borehole, Electric resistivity test	-	Observation of water level in borehole, Electric resistivity test	-
6.	Permeability	Field pumping test, borehole field ermeability test	Permeability	Field pumping test	Permeability
7.	Pore water pressure	-	-	Piezometer	-
8.	Elastic Moduli (static)	Borehole jack test, Pressure meter test, Plate bearing test and Plate jacking test, Radial	Unconfined compression test, Triaxial compression test (undrained)	Plate bearing test, Pressure meter test	Direct shear test, Resonant column test, Triaxial compression test

TABLE-4 (CONTD.)

SAFETY ANALYSIS PARAMETERS AND ASSOCIATED GEOTECHNICAL INVESTIGATIONS

S. No.	Safety Analysis Parameters	Geotechnical Investigations			
		Rocky Site		Soil Site	
		Field Test	Laboratory Test	Field Test	Laboratory Test
		jacking test, Goedman jack test.			
9.	Shear moduli (static)	Static shear test	Sonic velocity test.	Vane shear test	Direct shear test
10.	Dynamic modulus, poison's ratio. damping	Cross hole seismic test, uphole/down hole seismic test, 3-D velocity log, wave propagation test	Resonant column test	Cross hole seismic test up hole / down hole seismic test, 3-D velocity logging, SASW test	-
11.	Shear and compression wave velocity variations with depth	Cross hole seismic test, uphole/down hole seismic test, 3-D velocity log	Sonic velocity	Cross hole seismic test up hole / down hole seismic test, 3-D velocity logging, SASW test	Reasonant column test
12.	Cohesion and angle of internal friction (shear strength)	-	Triaxial compression (undrained)	-	Direct shear test (consolidated drained), triaxial compression Test
13.	Atterberg limits	-	-	-	Plastic limit, liquid limit
14.	Compressive strength	Plate bearing test, Plate jacking test, pressure meter test	Direct tensile strength, modulus of rupture, unconfined	SPT, Dutch cone penetrometer, Plate bearing test, Pressure	Unconfined compressive test, triaxial compression (unconsolidated,

TABLE-4 (CONTD.)

SAFETY ANALYSIS PARAMETERS AND ASSOCIATED GEOTECHNICAL INVESTIGATIONS

S. No.	Safety Analysis Parameters	Geotechnical Investigations			
		Rocky Site		Soil Site	
		Field Test	Laboratory Test	Field Test	Laboratory Test
			compression, triaxial compression (undrained)	meter test	undrained) test, triaxial compression (consolidated, undrained test, triaxial compression (consolidated, drained).
15.	Shear strength	Direct shear test, use of torsional shear test concrete rock interface test	-	SPT, Dutch cone penetrometer, pressure meter test, field vane shear test.	-
16.	Dynamic shear strength	-	-	Wave propagation test	Resonant column test
17.	Modulus of subgrade reaction	Plate bearing test, In situ deformation test.	-	Plate bearing test	-
18.	Compressi-bility / Consolidation	Plate Bearing Test, Pressure meter test	-	Plate bearing test, Dutch cone penetrometer, pressure meter test	-
19.	Overconsoli-dation ratio	-	-	-	Consolida tion test, e log p curve
20.	Stratigraphy	Borehole, Borehole camera, seismic	-	Borehole, borehole camera,	-

TABLE-4 (CONTD.)

SAFETY ANALYSIS PARAMETERS AND ASSOCIATED GEOTECHNICAL INVESTIGATIONS

S. No.	Safety Analysis Parameters	Geotechnical Investigations			
		Rocky Site		Soil Site	
		Field Test	Laboratory Test	Field Test	Laboratory Test
		reflection and refraction survey	-	seismic reflection and refraction survey	-
21*.	Heterogeneity of subsurface materials	Geotechnical/ Geological/ Geophysical logging/ Neutron log.	-	Geotechnical/ Geological/ Geophysical boring SCPT	-
22*.	Existing surface faulting or other weakness in the foundation locality	Geological and geophysical investigations, bore hole cameras	Slaked durability	-	-
23*.	Degree of discontinuity	Borehole cameras, 3-D velocity log, visual testing of core collected from boreholes.	-	-	-
24.	Rock quality designation (RQD) and Rock mass rating	Boreholes and taking core in the appropriate core taking tubes.	Pertro-graphic examination	-	-
25.	Creep, stress history and strain assessment	Boreholes defor-mation meter, In-clusion stress meter, borehole strain, radial jack test, strain measurement by over coring me-thod. Hydraulic fracturing test.	-	-	-

* At NPP sites, where presence of complex subsurface conditions or subsurface cavities are anticipated, geophysical methods that can be used as high resolution survey techniques include seismic reflection, continuous seismic refraction, cross hole seismic tomography, microgravimetry, electrical resistivity imaging , acoustic resonance with a subsurface source, ground probing radar etc. in addition to conventional methods such as electrical resistivity sounding and profiling.

TABLE-5

SPECIFICATIONS OF FIELD TESTS ON ROCK/SOILS

Sr. No.	Name of Tests/Investigations	Relevant IS Codes/Reference
1.	Boring	
	I. Rock	
	a. Percussion Drilling	IS:1892 [4]
	b. Rotary drilling	
	(i) Core drilling	IS:1892, IS:6926 [18], IS:5313 [19]
	(ii) Shot drilling	IS:6926, IS:5313, IS:1892
	II. Soil	
	a. Hand auger	IS:1892
	b. Shell and auger	IS:1892
	c. Wash boring	IS:1892
	d. Percussion drilling	IS:1892
	e. Rotary drilling	
	(i) Mud rotary drilling	IS:1892
	(ii) Mud rotary drilling	IS:1892
2.	Sampling	
A.	Exploratory Sampling	
	I. Rock	
	a. Double tube core barrel	IS:1892, IS:6926
	II. Soil	
	a. Open tube sampler	IS:1892, IS:2132 [20]
	b. Split spoon sampler	IS:1892, IS:2131 [21]
	c. Double tube core barrel	IS:1892
B.	Undisturbed Sampling	
	I. Rock	
	a. Open cuts and trenches	IS:1892
	b. Rotary drill fitted with coring bit with core retainer	IS:1892
	II. Soil	
	a. Thin walled tubes 50 to 125 mm	IS:1892, IS:2132, IS:10108 [22]
		IS:8763 [23]
	b. Piston tube sampler	IS:1892
	c. Sampler with special core retainer	IS:1892, IS:8763
	d. Sand sampler	IS:1892

TABLE-5 (CONTD.)

SPECIFICATIONS OF FIELD TESTS ON ROCK/SOILS

Sr. No.	Name of Tests/Investigations	Relevant IS Codes/Reference
3.	Gamma-Gamma log Neutron log.	[24]
4.	Observation of water table in borehole	IS:1892, IS:6935 [25]
5.	Electrical resistivity test	IS:1892, IS:15736 [26]
6.	Field permeability test	IS:5529 (Part I and II) [27]
7.	Borehole field permeability test	[28]
Field test on Rock		
8.	Field pumping test	IS:5529 (Part I and II)
9.	Borehole jack test	ASTM: D4506 [29]
10.	Pressuremeter test	IS:1892
11.	Plate bearing test	IS:12070, IS:1888 [30], IS:2950 (Part-I) [9]
12.	Plate jacking test	IS:7317 [31]
13.	Radial jacking test	ASTM: D4506
14.	Goedman jack test	[32]
15.	Cross hole seismic test	ASTM:D4428 [33]
16.	Up hole/down hole seismic test	[34]
17.	3-D velocity log (optional)	[35]
18.	Simple shear testing (using uniaxial jack)	IS:7746 [36]
19.	Direct shear test	ASTM:D4554 [37]
20.	In situ deformation test	ASTM:D4555 [38]
21.	Use of torsional shear test	[32]
22.	Borehole camera	IS:11315 [39]
23.	Geotechnical/Geological/ Geophysical logging	IS:4464 [40], IS:1892
24.	Geological and geophysical investigation.(Seismic refraction survey)	IS:1892, IS:11315, IS:15681 [41]
25.	Visual testing of core collected from bore holes.	IS:11315
26.	Boreholes and taking core in the appropriate core taking tubes	IS:11315 (Part-II)

TABLE-5 (CONTD.)

SPECIFICATIONS OF FIELD TESTS ON ROCK/SOILS

Sr. No.	Name of Tests/Investigations	Relevant IS Codes/Reference
27.	Borehole deformation meter	ASTM:D4623 [42]
28.	Inclusion stress meter	[42]
29.	Borehole strain gauge	[42]
30.	Radial jacking test	ASTM:D4506
31.	Strain measurement by overcoring method	ASTM:D4623 [42]
32.	Hydraulic fracturing test	[32]
Field test on Soil		
33.	Standard penetration tests	IS:2131
34.	Static cone penetration test	IS:4968 (Part-III) [43]
35.	Cyclic plate load test	IS:5249 [44]
36.	Wave propagation test	IS:5249
37.	Dutch cone penetrometer	ASTM:D3441 [45]
38.	Field vane shear test	IS:4434 [46]
39.	Subsurface sounding : dynamic method using cone and bentonite slurry	IS:4968 (Part-II), IS:10589 [47]
40.	Subsurface sounding : dynamic method using 50 mm cone and without bentonite slurry	IS:4968 (Part-I), IS:10589
41.	Dry density : sand replacement method	IS:2720 (Part- 28) [48]
42.	Dry density : core cutter method	IS:2720 (Part-29)
43.	CBR test	IS:2720 (Part 31)
44.	Density in place by ring and water replacement method.	IS:2720 (Part 33)
45.	Density in place by rubber balloon method	IS:2720 (Part 34)
46.	In situ direct shear test for soil containing gravel	IS:2720 (Part 39, Section 2)
47.	Plate bearing test for modulus of subgrade reaction	IS:9214 [49]
48.	Vibratory wire type equipment for pore pressure measurement	[50]

TABLE-6

SPECIFICATIONS OF LABORATORY TESTS ON ROCK/SOILS

Sr. No.	Name of Tests/Investigations	Relevant IS Codes/Reference
Lab. Test on Rock		
1.	Petrographic examination of rock	ASTM:C295 [51]
2.	Porosity	[32]
3.	Permeability	[32]
4.	Unconfined compression test	IS:9143 [52], IS:9221 [53]
5.	Triaxial compression test (undrained)	ASTM:D2664 [54]
6.	Resonant column test	[32] and [55]
7.	Sonic velocity (high frequency ultrasonic pulse technique)	ASTM:D2845 [56] / [32]
8.	a. Direct tensile strength	ASTM:D2936 [57]
	b. Point load strength	IS :8764 [58]
9.	Modulus of rupture	[32]
10.	Slake durability	IS:10050 [59]
Laboratory Test on Soils		
11.	Gradation Analysis	IS:2720(Part-4) [47]
12.	Percent fines	IS:2720 (Part-4)
13.	Soil Classification	IS:1498 [60]
14.	Bulk density test	IS:2720 Part 7 and 8
15.	Relative density	IS:2720 (Part-14)
16.	Chemical test	IS:2720 (Part 23,24,25 and 27)
17.	Organic content	IS:2720 (Part- 22)
18.	Soluble salts	IS:2720 (Part-21)
19.	Permeability	IS:2720 (Part- 17, 36)
20.	Direct shear test (consolidated drained)	IS:2720 (Part- 13), IS:11229 [61]
21.	Triaxial compression (unconsolidated undrained)	IS:2720 (Part- 11)
22.	Triaxial compression (consolidated undrained)	IS:2720 (Part- 12)
23.	Triaxial compression (consolidated drained)	[62]
24.	Direct shear test (shear box)	IS:2720 (Part- 39, Section I and section II)
25.	Unconfined compressive strength	IS:2720 (Part- 10)

TABLE-6 (CONTD.)

SPECIFICATIONS OF LABORATORY TESTS ON ROCK/SOILS

Sr. No.	Name of Tests/Investigations	Relevant IS Codes/Reference
26.	Consolidation test	IS:2720 (Part- 15)
27.	e-log P curve	IS:2720 (Part- 15), IS:8009 (Part-I)
28.	Water content	IS:2720 (Part- 2)
29.	Specific gravity	IS:2720 (Part- 3)
30.	Liquid limit and plastic limit	IS:2720 (Part- 5), IS:9259 [63]
31.	Shrinkage test	IS:2720 (Part- 6)
32.	Maximum dry density by light compaction method	IS:2720 (Part- 7)
33.	Maximum dry density by heavy compaction method	IS:2720 (Part- 8)
34.	Dry density-moisture content relationship (constant mass)	IS:2720 (Part- 9)
35.	CBR test	IS:2720 (Part- 16)
36.	Linear shrinkage	IS:2720 (Part- 20)
37.	pH value	IS:2720 (Part- 26)
38.	Vane shear test	IS:2720 (Part- 30)
39.	Swelling pressure	IS:2720 (Part- 41)
40.	Free swell index	IS:2720 (Part- 40)
41.	Sand equivalent of soil and fine aggregate	IS:2720 (Part- 37)
42.	Field moisture equivalent	IS:2720 (Part- 18)
43.	Centrifuge moisture equivalent	IS:2720 (Part- 19)
44.	Resonant column test	[55]

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LIST OF PARTICIPANTS

ADVISORY COMMITTEE FOR REGULATORY DOCUMENTS ON CIVIL AND STRUCTURAL ENGINEERING (ACRDCSE)

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Shri S.M. Palekar	:	TCE, Mumbai
Shri R.B. Gunde	:	TCE (Former), Mumbai
Smt. Shylamoni P. (Member-Secretary)	:	AERB

* Author of the draft of this guide

ADVISORY COMMITTEE ON NUCLEAR SAFETY (ACNS)

Date of meeting	:	June 15, 2007

Members and Invitees of ACNS:

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Published by : Atomic Energy Regulatory Board
Niyamak Bhavan, Anushaktinagar
Mumbai - 400 094
INDIA.

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