AERB SAFETY STANDARD NO. AERB/SS/CSE

CIVIL ENGINEERING STRUCTURES IMPORTANT TO SAFETY OF NUCLEAR FACILITIES

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FOREWORD

Safety of public, occupational workers and the protection of environment should be assured while activities for economic and social progress are pursued. These activities include the establishment and utilisation of nuclear facilities and use of radioactive sources. They have to be carried out in accordance with relevant provisions in the Atomic Energy Act 1962 (33 of 1962).

Assuring high safety standards has been of prime importance since the inception of the nuclear power programme in the country. Recognising this aspect, the Government of India constituted the Atomic Energy Regulatory Board (AERB) in November 1983 vide standing order No. 4772 notified in Gazette of India dated 31.12.1983. The Board has been entrusted with the responsibility of laying down safety standards and to frame rules and regulations in respect of regulatory and safety functions envisaged under the Atomic Energy Act of 1962. Under its programme of developing safety codes and guides, AERB has issued four codes of practice covering the following topics:

Safety in Nuclear Power Plant Siting

Safety in Nuclear Power Plant Design

Safety in Nuclear Power Plant Operation

Quality Assurance for Safety in Nuclear Power Plants.

Civil engineering structures in nuclear installations form an important feature having implications to safety performance of these installations. This safety standard is written to specify the objective and minimum requirements for the design of civil engineering buildings/structures that are to be fulfilled to provide adequate assurance for safety of nuclear installations (PHWR & related systems) in India.

This standard may be revised as and when necessary in the light of experience as well as developments in the field. The appendix included in the document is considered to be an integral part of the document, whereas the annexure, footnotes, and bibliography are to provide information that might be helpful to the user.

The emphasis in the codes, standards and guides is on protection of site personnel and public from undue radiological hazard. However, for aspects not covered in these documents, applicable and acceptable national and international codes and standards shall be followed. Industrial safety shall be assured through good engineering practices and by complying with the Factories Act, 1948 as amended in 1987 and the Atomic Energy (Factories) Rules, 1996.

This safety standard on Civil and Structural Engineering (CSE) has been prepared by the staff of AERB, BARC, NPC, DCL, TCE and BIS. In drafting this standard, they have used extensively the relevant National and International documents (mentioned in the "Bibliography" section of this guide).

This safety standard has been reviewed by experts and vetted by the AERB Advisory Committees before issue. AERB wishes to thank all individuals and organisations who have contributed in the preparation, review and finalisation of the safety standard. The list of persons who have participated in the committee meetings, alongwith their affiliations, is included for information.

-Sd
(P. Rama Rao)
Chairman, AERB

DEFINITIONS

Acceptable Limits
Limits acceptable to Regulatory Body.

Accident conditions
Substantial deviations from operational states which could lead to release of unacceptable quantities of radioactive materials. They are more severe than anticipated operational occurrences and include design basis accidents and severe accidents.

Active Component
A component whose functioning depends on an external input, such as actuation, mechanical movement, or supply of power, and which therefore influences system process in an active manner. Examples of active components are pumps, fans, relays and transistor. It is emphasised that this definition is necessarily general in nature as in the corresponding definition of passive components. Certain components, such as rupture discs, check valves, injectors and some solid state electronic devices, have characteristics which require special consideration before designation as an active or passive Component.

Ageing Management or Life Extension
The engineering, operations and maintenance actions to control, within acceptable limits of ageing,, degradation and wear out of systems, structures or components.

Anticipated Operational Occurrences
All operational processes deviating from normal operation which may occur during the operating life of the plant and which, in view of appropriate design provisions, neither cause any significant damage to items important to safety nor lead to accident conditions.

Approval
A formal consent issued by the Regulatory Body to a proposal.

Atomic Energy Regulatory Board (AERB)
National authority designated by Government of India, having the legal authority for issuing the regulatory consents for various activities related to a facility and to perform safety and regulatory functions including enforcement for the protection of the public and operating personnel against radiation.

Audit
A documented activity performed to determine by investigation, examination and evaluation of objective evidence the adequacy of, and adherence to Codes, Standards, Specifications established procedures, instructions, administrative or operational programmes and other applicable documents, and the effectiveness of implementation.

Authorisation
See `Regulatory Consent'.

Commissioning
The process during which structures, systems and components of a facility, having been constructed, are made operational and verified to be in accordance with design specifications and to have met the performance criteria.

Common Cause Failure
The failure of a number of devices or components to perform their functions as a result of a single specific event or cause.

Competent Authority
Any officer or authority appointed or approved by Atomic Energy Regulatory Board (AERB).

Construction
The process of manufacturing and assembling the components of a facility, the erection of civil works and structures and installation of components and equipment.

Contamination
The presence of radioactive substances in or on a material or in the human body or other place in excess of quantities specified by the competent authority.

Decommissioning
The Process by which a facility is finally taken out of operation in a manner that provides adequate protection to the health and safety of the workers, the public and of the environment.

Decontamination
The removal or reduction of contamination by physical or chemical process.

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

Design Basis Accident (DBA)

Design basis accidents are a set of hypothesised accidents which are analysed to arrive at conservative limits on pressure, temperature and other parameters which are then used to set specifications that must be met by plant structures, systems and components, and fission product barriers.

Design Basis Ground Motion

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.

Design Inputs

Those criteria, parameters, bases or other requirements upon which detailed final design is based.

Design outputs

Documents, such as drawings and specifications, that define technical requirements necessary for manufacture, installation and operation of structures, systems and components.

Diversity

The existence of redundant components or systems to perform an identified function, where such components or systems collectively incorporate one or more different attributes.

Documentation

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

Earthquake

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

Embedded Part (EP)

Any structural shape, plate, bolts, etc. attached to concrete through direct bond or other anchors.

Emergency situation

A situation which endangers or is likely to endanger safety of the NPP, the site personnel or the environment and the public.

Examination
An element of inspection consisting of investigation of materials, components, supplies, or services to determine conformance with those specified requirements which can be determined by such investigation.

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

Items Important to Safety
The items which comprise:

(1) those structures, systems, and components whose malfunction or failure could lead to undue radiation consequences at plant or outside plant.

(2) those structures, systems and components which prevent Anticipated Operational Occurrences from leading to Accident Conditions;

(3) those features which are provided to mitigate the consequences of malfunction or failure of structures, systems or components.

Main Structural Members
The structural members which are primarily responsible to withstand, carry and distribute the applied load.

Maintenance
Organised activities covering all preventive and remedial measures, both administrative and technical necessary to ensure that all structures, systems and components are capable of performing as intended for safe operation of plant.

Normal Operation
Operation of a plant or equipment within specified operational limits and conditions. In case of Nuclear Power Plant this includes start-up, power operation, shutting down, shutdown state, maintenance, testing and refuelling.

Nuclear Power Plant (NPP)
A thermal neutron reactor or reactors together with all structures, systems and components necessary for safety and for production of power i.e. electricity.

Nuclear Facility
A facility and its associated land, buildings and equipment in which radioactive material is produced, processed, used, handled, stored or disposed of (for example repository) on such a scale that consideration of safety is required.

Objective Evidence
Term used in context of Quality Assurance, qualitative or quantitative information, record or statement of fact pertaining to the quality of an item or service, which is based on observation, measurement or test and which can be verified.

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

Operating Organisation
The organisation so designated by Responsible Organisation (RO) and authorised by Regulatory Body to operate the facility.

Operating Personnel
Those members of Site Personnel who are involved in the operation of the NPP.

Operation
All activities following commissioning and before decommissioning performed to achieve, in a safe manner, the purpose for which an installation was constructed, including maintenance.

Operational Limits and Conditions (OLCs)
A set of rules which set forth parameter limits, the functional capability and the performance level of equipment and personnel approved by Regulatory Body for safe operation of the facility.

Operational Records
Documents, such as instrument charts, certificates, log books, computer print-outs and magnetic tapes, made to keep objective history of the NPP operation.

Operational States
The states defined under Normal Operation and Anticipated Operational Occurrences.

Passive Component
A component which has no moving part, and, for example, only experiences a change in pressure, in temperature, or in fluid flow in performing its functions. In

addition, certain components, which function with very high reliability, based on irreversible action or change, may be assigned to this category. Examples of passive Components are heat exchangers, pipes, vessels, electrical cables and structures. It is emphasized that this definition is necessarily general in nature as is the corresponding definition of Active Components. Certain components, such as rupture discs, check valves, injectors and some solid-state electronic devices, have characteristics which require special consideration before designation as an active or passive components.

Physical Separation
A means of ensuring independence of an equipment through separation by geometry (distance, orientation, etc), appropriate barriers or a combination of both.

Plant Management
The members of site personnel who have been officially delegated responsibility and authority by the operating organization for directing the operations of the plant.

Postulated Initiating Events (PIEs)
It is a hypothetical event that could lead to anticipated operational occurrences and accidental conditions, their credible failure effects and their credible combinations.

Prescribed Limits
Limits established or accepted by Regulatory Body for specific activities or circumstances that must not be exceeded.

Qualified Person
A person who, having complied with specific requirements and met certain conditions, has been officially designated to discharge specific duties and responsibilities. [For example, Reactor Physicist, Station Chemist and Maintenance Persons of Nuclear Power Plants are qualified persons].

Quality
The totality of features and characteristics of a product or service that bear on its ability to satisfy a defined requirement.

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

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

Realistic Parameters
The realistic parameter or result being estimated or determined should fall within an expected or anticipated range characteristic of mean or median values and not represent an upper and lower bound which distort the quantity.

Records
Documents which furnish objective Evidence of Quality of items or activities affecting quality. It also includes logging of events and other measurements.

Regulatory Consent
It is a written permission issued by the Regulatory Body to perform the specified activities related to the facility. The types of consent are 'Licence', `Authorisation', 'Registration', and `Approval' and will apply depending upon the category of the facility, the particular activity and radiation sources involved.

Reliability
It is the probability that a structure, system, component or facility will perform its intended (specified) function satisfactorily for a specified period under specified conditions.

Responsible Organization (RO)
The organization having overall responsibility for siting, design, construction, commissioning, operation and decommissioning of a facility.

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

(1) The integrity of the reactor coolant pressure boundary.

(2) The capability to shutdown the reactor and maintain it in a safe shutdown condition, or

(3) The capability to prevent the accident or to mitigate the consequences of accidents which could result in potential off-site exposure higher than the limits specified by the Regulatory Body.

Safety
Protection of all persons from undue hazard.

Safety Limits
Limits upon process variables within which the operation of the facility has been shown to be safe.

Safety Report
A document provided by the applicant or licensee to Regulatory Body containing information concerning the facility, its design, accident analysis and provisions to minimise the risk to the public and to the site personnel.

Safety System (Safety Critical System)
Systems important to safety, provided to assure, under anticipated operational occurrences and accident conditions, the safe shutdown of the reactor (Shutdown System) and the heat removal from the core (ECCS), and containment of any released radioactivity (Containment Isolation System).
Services The performance by a supplier of activities such as design, fabrication, installation, inspection, non-destructive examination, repair and/or maintenance.

Single Failure
A random failure which results in the loss of capability of a component to perform its intended safety functions. Consequential failures resulting from a single random occurrence are considered to be part of the single failure.

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

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

Surveillance
All planned activities namely monitoring, verifying, checking including in-service inspection, functional testing, calibration and performance testing performed to ensure compliance with specifications established in a facility.

Technical Specification for Operation
A document submitted on behalf of or by the responsible organisation covering operational limits and conditions, surveillance and administrative control requirements for the safe operation of the facility and approved by Regulatory Body.

Testing
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, process, services or documents conform to specified requirements.

CONTENTS

l. INTRODUCTION

1.1 General

1.1.1 Safe generation of electricity is the requirement of Nuclear Power Plant (NPP). Any industrial activity induces certain risks to human beings and the environment and requires an endeavour to keep the risk low. The additional risk associated with nuclear installations like NPP is the potential hazard of radiation. The goal of nuclear safety, important also for safe design, is therefore, to protect site personnel, the public and the environment by establishing and maintaining effective safety requirements against radiological hazard.

1.1.2 The "Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants", No. AERB/SC/D describes the design approaches and design requirements for structures, systems and components that shall be met for safe operation in order to prevent or mitigate the consequences of Postulated Initiating Events (PIEs) which could jeopardise safety. The general safety objectives have also been described in the above Code. All safety related civil engineering structures and their components shall he designed to achieve these safety objectives. This standard has been written for specific needs of Pressurised Heavy Water Reactor (PHWR) and related systems. However, this standard may be used for other nuclear facilities.

1.1.3 The present Standard provides the safety principles and design criteria of civil engineering structures of NPP. The provisions of this Standard aim at defining essential requirements related to civil engineering activities to ensure safety of NPP. The Standards, Safety Guides and Manuals listed in this Standard should be used in implementing this Standard.

1.2 Safety Criteria

1.2.1 To achieve adequate safety it is essential to take safety into consideration as an element of the overall design process. The purpose of the safety approach presented in this Standard is to design the civil engineering structures so as to ensure maintaining the plant in a normal operating state, to ensure appropriate response immediately following a PIE, and to facilitate the management of the plant following accident conditions.

1.2.2 The safety criteria for design, construction and operation of civil engineering structures shall be derived from the following:

(1) The radiation exposure of the public and plant personnel is kept within appropriate prescribed limits under all operational

states and within acceptable limits under all postulated accident conditions. The concept of as low as reasonably achievable (ALARA) should be applied.

(2) The design process shall incorporate measures which shall be part of the defence in depth in an integrated manner.

(3) To ensure safety, the following general design requirements shall be met:

(a) Means shall be provided to safely shutdown the reactor and maintain it in the safe shutdown condition in operational states and during and after accident conditions.

(b) Means shall be provided to remove residual heat from the core after reactor shutdown, including accident conditions.

(c) Means shall be provided to reduce the potential for the release of radioactive materials and to ensure that any releases are below prescribed limits during operational states and below acceptable limits during accident conditions.

(4) PIEs include many factors which singly or in combination may affect safety and which may;

- be connected with the site of the NPP and its environment.
- be caused by human action
- originate in the operation of NPP itself.

Consequences of PIEs are to be used in determining the design basis of the NPP.

1.3 Scope

1.3.1 This Standard describes the design requirements and design approaches of all civil engineering structures important to safety and their components in order to achieve safe operation of plant and to protect plant personnel, public, and environment from radiological hazards by mitigation of the consequences of accident conditions.

This Standard is applicable to the PHWR based Nuclear Power Plant. However, for other nuclear facilities the provisions of this Standard are applicable from nuclear safety considerations.

Safety assessment of the other structures outside the plant area or site area, such as dams, terrain slopes, etc. whose performance has influence on safety of the NPP, shall be carried out following the requirements of this Standard.

1.3.2 This Standard covers the following aspects related to civil engineering structures of NPP.

(1) Safety approach related to the civil engineering activities of the NPP.

(2) Civil engineering aspects pertaining to plant layout and conceptual development of buildings and structures.

(3) Design and construction of containment and other concrete and steel structures important to safety.

(4) Design and construction of Embedded Parts (EPs) and penetrations required for structures, systems and components important to safety.

(5) Seismic analysis of civil engineering structures important to safety. The extent to which the analysis, methodology and approach to seismic qualification is dealt in this Standard, is also applicable for other structures, systems and components.

(6) Geotechnical aspects.

(7) Commissioning.

(8) Operation

(9) Decommissioning.

(10) Retrofitting.

(11) Quality Assurance Programme (QAP) including in-service inspection, surveillance and monitoring.

1.3.3 The Standards, Safety Guides and Manuals listed in this Standard and other related AERB Safety Guides and Manuals should be used in implementing this Standard. The provisions of other related AERB Safety Codes/Standards/ Guides shall be implemented wherever applicable.

1.4 Structure of the Document

1.4.1 This Standard comprises 9 Chapters, 1 Appendix and 1 Annexure. Each Chapter is divided into a number of Sections which are further divided into a number of paragraphs or clauses.

1.4.2 The safety design approach of civil engineering structures of NPP has been delineated in Chapter-2. The design requirements are described in Chapter-3 which is followed by the aspects of construction given in Chapter-4. Chapters-5,6,7 contain the requirements pertinent to structures for commissioning, operation and decommissioning of the plants respectively. Stipulations for retrofitting are given in Chapter-8. Chapter-9 provides the requirements of quality assurance programme (QAP).

1.4.3 Appendix-A defines, describes, and categorises the various individual loads to be considered in the design of civil engineering structures of NPP.

2. SAFETY DESIGN APPROACH

2.1 General

2.1.1 Civil engineering structures are engineered to meet their safety requirements in the following stages :

(1) Planning

(2) Design

(3) Construction

(4) Pre-commissioning Tests

(5) Monitoring, in-service inspection, surveillance and. maintenance during operation

The decommissioning aspects of the civil engineering structures need to be addressed during planning, design, construction and commissioning stages.

2.2 Safety Design Bases

2.2.1 Safety design bases (SDB) developed on safety based concept shall be adopted in all the stages of engineering of safety related civil engineering structures.

2.2.2 In the safety based concept possible design and operational events (both for normal and abnormal conditions) are first postulated. The engineering is then carried out to ensure that the structural system is reliable and is competent to withstand or mitigate the consequences of these postulated conditions.

2.2.3 For the purpose of application of safety design bases in the design of civil engineering structures the safety functions of the structures are first identified. The structures are classified based on these functions. The design bases of the structures are derived from their classifications.

2.2.4 The PIEs which would result in accident condition shall be identified and the consequences of resulting accident shall be analysed to specify the design constraints of the structures.

2.3 Safety Functions of Civil Engineering Structures

2.3.1 The consideration of safety functions is an approach for systematically meeting the safety requirements. The safety functions in the context of civil engineering structures and their components shall include all functions that they may perform to ensure plant safety in operational states, and in the state during and post accident conditions. AERB Safety Guide No.AERB/SG/D-1 describes these safety functions and their applicability.

2.3.2 Civil engineering structures important to safety are required to perform safety functions during entire operating life of the plant and some of them are required to be serviceable depending upon the stage of decommissioning or part of the plant even after decommissioning plant. Ageing degradation, often caused or accelerated by factors related to exposure to hostile environment or inadequate measures for quality assurance or deficiency in engineering or their combination, could impair their safety functions and thus the possible risk to public health and safety. Measures against ageing degradation should be considered in the design and construction of the structures. In addition, effective ageing management of these structures shall be planned and implemented to ensure their fitness-for-service throughout the service life.

2.4 Classifications

Safety Classification

2.4.1 The safety classification of all civil engineering structures shall comply with their safety functions and shall be in accordance with the criteria given in AERB/SG/D1.

Seismic Classification

2.4.2 All the plant buildings and structures, and other non plant structures are classified into three. seismic categories in terms of their importance to safety in the event of an earthquake.

2.4.3 Seismic category-1 shall include .

(I) Items whose failure could directly or indirectly cause accident conditions.

(2) Items required for shutting down the reactor, monitoring critical parameters, maintaining the reactor in a safe shutdown condition and residual heat for a long term.

(3) Items that are required to prevent radioactive releases or to maintain release below limits established by AERB for accident conditions (e.g. containment system).

2.4.4 As a conservative measure, it is recommended to include in category-I those items which are designed to mitigate the consequences of design basis accident, which may be postulated to occur in the primary pressure boundary despite the fact that the primary pressure boundary is designed against earthquake loads.

2.4.5 Seismic category-2 shall include

(1) Items, not covered in category-1, required to prevent the escape of radioactivity beyond limits prescribed for normal operation.

(2) Items not covered in category-1, required to mitigate those accident conditions which may last for such long periods that there is a reasonable likelihood that an earthquake of the defined severity may occur during this period.

2.4.6 Seismic category-3 shall include all items not important to safety and not covered in category-1 or 2.

Special Consideration of Seismic Classification

2.4.7 When, as the result of an earthquake, the collapse, falling, dislodgement or any other spatial response of an item is expected on the basis of analysis, test or experience to occur and could jeopardize the functioning of items in a higher category;

(1) Such items shall be classified in the same category as the endangered items;

(2) Under the reference ground motion, the absence of collapse, etc., or loss of function, of the lower category items, shall be demonstrated;

or

(3) The endangered items shall be suitably protected, so that they are not jeopardized.

Since only the structural integrity of items reclassified because of their potential to jeopardize higher category items need to be assured, less rigorous seismic evaluation criteria may be used.

2.4.8 The inclusion of an item in seismic category 1 or 2 shall be based on a clear understanding of the functional requirements which shall be assured for safety following an earthquake or those safety functions after an accident condition not caused by an earthquake. According to their different function, parts of the same system may belong to more than one category. Maximum load or stress, structural integrity or stability, degree design of leak tightness, degree of damage (fatigue, wear and tear, etc.), mechanical or electrical function capability, maximum displacement, degree of permanent distortion, and preservation of geometrical dimensions are examples of aspects which shall be considered.

Quality Classification

2.4.9 The civil engineering structures which are of safety class and which fall under seismic categories 1 and 2 shall meet the quality requirements as stated in Chapter 9 of this standard.

Design Classification

2.4.10 The civil engineering structures are categorised into four design classes depending on the design approach, requirements, and criteria.

(1) DC1 : Pressurized Concrete Reactor Vessels(PCRVs)*

(2) DC2 : Containment Structures.

(3) DC3 : Internal structures of Reactor Building, auxiliary and safety related balance of plant buildings and structures of an NPP; and civil engineering structures of other nuclear facilities.

(4) DC4 : Non Safety Class Structures.

2.5 Design Basis

2.5.1 The design basis of civil engineering structures important to safety shall specify the necessary capabilities of the plant structures to cope with specified range of operational states and accident conditions within the specified/acceptable radiological limits. The design bases of civil engineering structures shall be developed considering their safety, seismic, and design classifications as well as their quality assurance requirements. Table 2.1 contains the summary of classifications of civil engineering structures and the corresponding design conditions with load combinations to be adopted in the design. The design basis includes the specifications for functional requirements, loading effect for normal operation and conditions created by PIEs, important assumptions, and in some cases, the particular method of analysis.

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* Note: PCRVs are in use in Advanced Gas Cooled Reactors.

2.6 Approach to PIEs

2.6.1 The civil engineering design of NPP caters to the following:

(1) The designed facilities shall withstand the consequences of PIEs and credible sequences of events following the PIEs.

(2) Mitigation of the consequences of certain PIEs (e.g. seismic, wind, flood, etc.) such that further detrimental effects on the safety of plants, systems, etc. supported by the buildings/structures are minimised.

2.7 Design Approach

2.7.1 The designed capability of structure shall be adequate to satisfy the design criteria derived from the design bases of Cl. 2.5.1.

2.7.2 The various structural systems under the scope of this Standard shall be designed satisfying the requirements of this Standard and other AERB Safety Codes and Guides. If design is carried out satisfying different criteria and requirements, the acceptability of the design need to be justified suitably. Probabilistic approach (ref. Annexure-I) may be found useful for this purpose.

2.8 Industrial Safety

2.8.1 Civil engineering design shall satisfy the stipulations and requirements of the latest revision of "Atomic Energy (Factories) Rules".

2.7.1 The designed capability of structure shall be adequate to satisfy the design criteria derived from the design bases of Cl. 2..5.1.

TABLE 2.1

SUMMARY OF CLASSIFICATIONS, DESIGN CONDITIONS AND LOAD COMBINATIONS FOR CIVIL ENGINEERING STRUCTURES

Sl. No.	Design Class	Safety Class	Seismic Category	Quality Requirement	Design[1,7] Conditions	Load [2] Combination
1.	DC 1	1	1	Refer Chapter 9	Normal Abnormal	LC1, LC2 LC3, LC4 LC5, LC6
2.	DC 2	2	1	Refer Chapter 9	Normal Abnormal	LC1, LC2 LC3, LC4 LC5, LC6
3.	DC 3	2 ,3	1	Refer Chapter 9	Normal Abnormal	LC1, LC2 LC3, LC4 LC5, LC6
		3[4]	2	Refer Chapter 9	Normal Abnormal	LC1, LC2 LC3, LC4 LC5, LC6
		4[5]	2	Refer Chapter 9	Normal Abnormal	LC1, LC2 LC4
4	DC 4	NNS[6]				

Note :

(1) Ref . Cl . 3.2.2.

(2) Ref . Cl . 3.5.5

(3) This load combination is applicable only for Internal Structures of Reactor Building.

(4) Structures which do not perform the safety functions associated with supporting the core cooling systems related to safe shutdown of reactor or prevent/mitigate the consequences of accident which could result in potential off-site exposure comparable to relevant AERB guidelines. This class also includes structures of nuclear facilities with limited radioactive inventory whose functioning shall be maintained in the event of the design basis ground motion.

(5) Structures of nuclear facilities with limited radioactive inventory whose loss of function may be permitted but should be designed against collapse in the event of design basis ground motion. Lower safety level for load combination LC2 and LC4 (smaller load factors for limit safe design or plastic design and higher allowable stresses in allowable stress design method) is allowed for this structure.

(6) Non-nuclear services not important to safety should meet the design requirements as per relevant national standard engineering practices.

(7) Design requirements should be as per the relevant AERB Guides (ref. Section 3.5 of this standard.)

3. DESIGN CRITERIA

3.1 General

3.1.1 Civil and structural engineering design of NPP shall be carried out using safety based design concept of Chapter 2.

3.1.2 The structural system shall be so designed that it serves the purpose of safety in two ways. It supports or houses the systems and components important to safety such that no fault can occur due to the effects of certain PIEs which might otherwise have caused release of activity. Secondly, given a condition, the release of activity beyond the structural boundary of the building is within permissible limit.

3.1.3 Consideration shall be given at design stage such that adequate provision exists for conducting tests as required during commissioning, operation and in-service inspection.

3.2 Design Requirements

3.2.1 The design target of the structures shall be derived from the relevant safety functions as specified in C1.2.3.1 for which the buildings and structures shall be designed. These design targets are transformed to the following design requirements or their combinations;

(1) Radiological protection

(2) Serviceability

(3) Strength

(4) Stability

Design Conditions

3.2.2 Depending upon the load combinations to be considered in the design, two types of design conditions are specified.

(1) Normal Design Conditions include the Load Combinations LC1 and LC2, i.e., Normal and Severe Environmental load combinations respectively as defined in Cl. 3.5.5.

(2) Abnormal Design Conditions include the Load Combinations LC3, LC4, LC5 and LC6, i.e. Extreme Environmental, Abnormal, Abnormal - Severe environmental and Abnormal - Extreme environmental load combinations respectively as defined in Cl. 3.5.5.

Radiological Protection Provided by Structures

3.2.3 Structural members having shielding requirements shall satisfy the following:

(1) Required shielding properties.

(2) In determining the cross sectional dimensions of a structural element both structural strength and shielding requirements are to be satisfied.

(3) To prevent radiation streaming through gaps following measures are taken:

- No linear through crack across the thickness
- Movement joints, construction joints, expansion joints etc. are to be staggered/stepped.

For establishing adequacy of shielding and streaming, refer to Clause 5.1.5.

Serviceability

3.2.4 All serviceability requirements such as deflection, crack width, etc. shall be determined from the safety as well as functional requirements of structures, systems and components. Structures shall be designed for all to the these serviceability requirements.

3.2.5 In the absence of system specification on the above parameters, the provision of relevant AERB Standards and Safety Guides listed in this Standard, should be satisfied. The design for serviceability shall be carried out following the requirements of Section 3.5.

Strength

3.2.6 The design for strength is influenced by plant layout, structural configuration, and the assignment of stiffness to the structural elements. The plant layout and structural layout shall be in accordance with design, Clause 3.4.2 and 3.4.3 respectively. The design shall be carried out following stipulations of Section 3.5. .

Stability

3.2.7 Structures shall be designed to satisfy the following stability requirements, as applicable:

(1) Elastic stability

(2) Foundation stability against overturning, sliding and floatation

(3) Stability against aerodynamic effects

The requirement of AERB Safety Guide "Geotechnical Aspects for Buildings and Structures important to safety of "Nuclear Facilities" No. AERB/SG/CSE-2 shall be satisfied to ensure overall stability of structures.

3.3 Design for Natural and Man-Induced Events

Minimum Requirements

3.3.1 Following events and credible combinations thereof shall be considered as minimum requirements unless otherwise their probability of occurrence being less than the value acceptable to regulatory body, is demonstrated.

(1) Natural Events:

Earthquake, wind, flood, snow, solar radiation.

(2) Man-Induced Events:

- Internal Events:

  Fire and explosions, internal missiles, failure of pressure parts, pipe whip and jet impingement, blast effects and compartment pressurisation, internal flood, heating and condensation, dropped load, explosive gases, impact during construction, effect of corrosive and toxic materials.

- External Events:

  Missiles due to turbine disintegration and other sources, explosions, effect of corrosive and toxic materials, aircraft crash.

Measures Against Natural and Man-Induced Events

3.3.2 The following approaches and/or their combinations are adopted to handle the above events in the design,

(1) Provide measures to avoid the occurrence of man-induced events

(2) Provide protection measures

(3) Design the structural systems to withstand the consequences of these events.

3.3.3 The events due to chemical and toxic gas release and other man-induced hazards shall be avoided by selecting the site at a safe distance by satisfying screening distance value (SDV) stipulated in "Code of Practice on Safety in Nuclear Power Plant Siting", No. AERB/SC/S.

3.3.4 Aircraft crash shall be avoided by satisfying screening distance value of AERB/SC/S.

3.3.5 Impact during construction and drop load events shall he avoided by appropriate measures.

3.3.6 The operating islands and roads around shall be protected from the design basis flood (including seismically induced flooding) either by selecting grade level higher than that of probable maximum flood level or by providing dyke wall.

3.3.7 The buildings and structures important to safety or part of them shall be protected from events like missiles due to turbine disintegration by suitable plant layout and structural layout.

3.3.8 Structural systems shall be designed for strength and serviceability to withstand the consequences of all events listed in 3.3.1 other than those covered in 3.3.3 and 3.3.4.

3.4 Layout Considerations

3.4.1 Effort shall be made to minimise uncertainties in design at the conceptual stage. The conceptual development should be carried out considering the following principles.

(1) The plant layout and configuration planning of individual buildings and structures shall be made in such a manner that well established methodology can be applied in analysis and with established assumptions.

(2) Conceptual development should be made such that the design problem could be solved with the help of present state of art.

(3) Relevant requirements of industrial safety (ref. 2.8) are satisfied.

Plant Layout

3.4.2 Following principles shall be taken into consideration in developing the plant layout.

(1) The requirements arising out of system performance and safety functions are satisfied.

(2) Requirement of radiation zoning is fulfilled.

(3) Proper segregation of plant areas are achieved and are consistent with plant safety requirements.

(4) Buildings and roads are so laid out that unobstructed access is always available.

(5) Proper turning radii at road curves and gradients are provided for the movement of heavy crane and other vehicles.

(6) Provision is made for space around buildings for erection facility, cranes, etc. during construction.

(7) Buildings and structures important to safety should be placed outside the area prone to low trajectory turbine missiles.

(8) Sufficient gap for seismic isolation or shake space between adjacent structural parts or buildings is provided.

(9) Requirements arising from other site specific conditions are accounted for.

(10) Proper access control measures are to be provided.

Structural Layout

3.4.3 The structural configuration should be developed with following considerations.

(1) Plant and system safety requirements are satisfied.

(2) All emergency requirements arising out of industrial and nuclear safety are satisfied.

(3) The safety related systems and components of similar safety class/ seismic category are located and placed suitably in buildings/ structures of appropriate classification as far as possible.

(4) Structural connections between different safety class structures and seismic category structures are avoided as far as possible.

(5) The structural system of individual building is as simple, symmetrical and regular as possible.

(6) Avoiding protruding sections (lack of symmetry) as far as practicable.

(7) Locating the centre of gravity of structure as low as possible.

(8) Making the centre of rigidity at various elevations as close to the centre of mass at that elevation as practical.

(9) Internal arrangement of structures should be such that less important structural elements would protect the more important ones to a good extent.

(10) Materials should be so selected that the safety of the building is enhanced.

(11) Avoiding use of different grade of concrete for primary structural elements of the same structure as far as practicable.

(12) Direct and easy emergency escape routes with reliable lighting and other building services for the use of the plant personnel are provided.

(13) Access planning to ensure effective control of personnel movement for preventing spread of radioactivity within the plant and outside to be made. For this purpose, adequate monitoring, washing and change facilities are provided with clear demarcation or barricades between the various radiation zones.

(14) Personnel and equipment accesses to the reactor building through air locks should ensure that separation of the containment environment from the outside environment is achieved at all times.

(15) Provision of fire protection.

(16) Placement of foundation of all adjacent buildings and structures to be done in order to reduce differential settlement between the adjacent buildings and structures as much as practicable.

(17) Overlapping of foundation of different structures should be avoided as far as possible.

(18) Easy maintenance and surveillance.

3.5 Design for Strength and Serviceability

Analysis

3.5.1 (1) The safety related structures shall be designed for strength and serviceability following appropriate detailed analysis to determine the responses for various load combinations. The detailed analysis comprises static as well as dynamic analysis.

(2) The static analysis shall be carried out for all types of static loadings. Objective of dynamic analysis of structures is to determine structural response under seismic or other design basis dynamic loadings.

(3) Linear structural analysis shall be used to evaluate structural response for the design of new plants. However, nonlinear analysis may be required in certain cases like raft lift-off analysis due to seismic excitation.

3.5.2 Both Classical method and Finite Element Method (FEM) for structural analysis are acceptable. The methodology and the software shall be validated in accordance with Cl. 9.2.3 and 9.2.4.

Loads and Load Combinations

3.5.3 Individual Load

Unless otherwise specified individual loads which shall be considered in the design are described in Appendix-A.

3.5.4 Magnitude of Load

(1) Magnitude of live load, load due to systems, and components, etc. shall be determined from the functional, operational and maintenance considerations.

(2) Magnitude of accidental/abnormal loading shall include an appropriate dynamic load factor when these loads are considered as equivalent static loads. Otherwise appropriate dynamic analysis is to be carried out to determine structural response.

(3) The wind load should be determined from site specific data using criteria given in Code AERB/SC/S and for appropriate life period for which plant is to be designed. Otherwise wind load may be determined from relevant part of IS 875, using criteria given in AERB/SC/S.

(4) The design basis ground motion shall be determined in accordance with AERB Safety Guide "Seismic Studies and Design Basis Ground Motions for Nuclear Power Plant Sites", No. AERB/SG/S-11.

(5) The design basis flood shall be determined in accordance with AERB Siting Code AERB/SC/S.

3.5.5 Load combinations

Following load combinations shall be considered in the design unless stated otherwise:

LC1 : Normal Load combinations
The normal load combinations involve only normal loads.

LC2 : Severe Environmental Load Combinations
These load combinations include normal and severe environmental loads.

LC3 : Extreme environmental load combinations
Normal and extreme environmental loadings are .included in these load combinations.

LC4 : Abnormal Load combinations
These load combinations include normal and abnormal loads.

LCS : Abnormal-Severe Environmental Load Combination
These load combinations include normal, severe environmental and abnormal loads.

LC6 : Abnormal-Extreme Environmental Load Combinations
These load combinations include normal, abnormal and extreme environmental loads.

Materials

3.5.6 All materials to be used in construction and maintenance of civil engineering structures shall conform to AERB Safety Guide "Materials of construction for Civil Engineering Structures important to safety of Nuclear Facilities", No. AERB/SG/CSE-4.

3.5.7 Stability of the materials under the radiation field shall be ensured and built-up of induced activities should not be there.

Design for Stiffness of Structural Elements

3.5.8 Effects of various loadings or load combinations are of following types :

(1) Primary stresses

(2) Secondary stresses

(3) Stress concentration/Peak stresses

The structures shall be designed for strength and serviceability due to loading effects as stated above both at early life and late life conditions depending on design requirements.

Design consideration shall also include functional requirements subsequent to the operational life of the plant.

3.5.9 (1) Concrete structures

All design class DC3 concrete structures important to safety shall be designed in accordance with the provision of AERB Standard on "Design of Concrete Structures important to safety of Nuclear Facilities", No. AERB/S/CSE-I.

(2) Steel structures

All design class DC3 steel structures important to safety shall be designed in accordance with the provision of AERB Standard on "Design, Fabrication and Erection of Steel Structures important to safety of Nuclear Facilities", No.AERB/S/CSE-2.

(3) Containment Structures

The design of containment structures (which is classified as design class DC2) and testing shall be done in accordance with AERB Standard "Design of Nuclear Power Plant Containment Structures", No.AERB/S/CSE-3.

(4) Embedded parts and penetrations

All embedded parts and penetrations important to safety shall be designed in accordance with AERB Standard on "Design, Fabrication and Erection of Embedded Parts and Penetrations Important to Safety of Nuclear Facilities", No.AERB/S/CSE-4.

3.5.10 The design class DC3 structures may be of different safety classifications. Unless specified otherwise same level of safety (load factors and strength factors, or factor of safety) is provided for safety class 2 and 3 structures (Ref. Table 2.1). Variable level of safety in design of the other DC3 structures; depending on their safety and seismic classifications, is acceptable as per Table 2.1.

3.6 Aseismic Design

General Requirements

3.6.1 The NPP shall be designed to be safe against earthquake in accordance with AERB Safety Guides AERB/SG/S-11 and AERB/SG/CSE-1.

3.6.2 The aim of aseismic design including seismic qualification of structures, systems, equipment and components is to demonstrate that the item important to safety is able to perform its safety function during and following the time it is subjected to the effects resulting from the earthquakes.

Earthquake Level

3.6.3 Two earthquake levels shall be considered for safety design.

(1) S 1 level earthquake

(2) S2 level earthquake

3.6.4 The S 1 level is the level of ground motion which can be reasonably expected to be experienced at the site area once during the operating life of the plant. In the design, the S 1 level earthquake is referred to as the Operating Basis Earthquake (OBE).

3.6.5 The S2 level is the level of ground motion that has a very low probability of being exceeded. It represents the maximum level of ground motion to be used for design of safety related structures, systems and components, of NPP. In the design, the S2 level ground motion is referred to as the Safe Shutdown Earthquake (SSE).

Design Input

3.6.6 The design ground motion or seismic design input for buildings and structures for both levels of earthquake shall be specified for free field condition through the following parameters:

(1) The Peak Ground Acceleration (PGA)

(2) Response Spectra

(3) Acceleration Time History

The above seismic design input parameters shall be determined in accordance with the AERB Safety Guide on "Seismic Studies and Design Basis Ground Motion of Nuclear Power Plant Sites", No. AERB/SG/S-11.

3.6.7 If design specification requires other parameters like duration of seismic excitation, time period at which the ground acceleration achieves PGA value, then these parameters shall also be specified.

3.6.8 When standardised seismic design input (i.e. PGA, spectral shape/time histories) are used in the design of NPPs at number of sites, the standard seismic design input shall be qualified for the site specific design ground motion.

Design Criteria

3.6.9 (1) All seismic category-I structures, systems and components shall be designed for OBE and SSE.

(2) Whenever it is required to consider the fatigue effect , the design /qualification shall be done for occurrences of atleast five (5) OBE and one (1)SSE. The number of cycles per earthquake should be obtained from the synthetic time history (with a minimum duration of 10 seconds) used for the system analysis, or a minimum of 10 maximum stress cycles per earthquake may be assumed.

3.6.10 All seismic category-2 structures, systems and components shall have the capability to withstand the effect of OBE.

Design Methods

3.6.11 Seismic analysis and qualification of all seismic category-1 and 2 structures shall be performed in accordance with the AERB Safety Guide, "Seismic Analysis and Qualification of Structures, Systems, Equipment and Components important to safety of Nuclear Facilities", No. AERB/ SG/CSE-1.

3.6.12 All items under seismic category-3 may be designed or qualified for earthquake resistance according to the practice for non-nuclear application. The civil engineering structures may be designed in accordance with Indian Standard, "Criteria for Earthquake Resistant Design of Structures", No. IS 1893.

3.6.13 The structural response due to seismic excitation shall be determined using appropriate structural analysis. If structural response is determined by dynamic analysis, the structures may be designed considering this as a static effect.

3.7 Design Requirements Related to Geotechnical Aspects

3.7.1 The safety of NPP related to Geotechnical aspects shall be assessed for the following.

(1) Safety of site against ground failure.

(2) Safety of foundation system.

3.7.2 Safety of site shall be assessed against ground failure like slope and embankment failure, local instability, liquefaction, soil erosion, etc.

3.7.3 The safe design of foundation system shall be evolved through the study of interaction between the structure and foundation materials for both static and dynamic class of loading. This requires appropriate analysis and geotechnical investigations. The design shall consider all possible scenario leading to malfunctioning of structures, systems and components due to undesirable behaviour of foundation systems.

3.7.4 The safe design of foundation system and safety assessment of site against ground failure shall be done in accordance with AERB Safety Guide, "Geotechnical Aspects for Buildings and Structures important to safety of Nuclear Facilities", No. AERB/SG/CSE-2 and AERB/SG/S-11.

3.8 Special Requirements

3.8.1 When acceptable analytical design methods for fulfilling a particular design criterion (e.g. leak tightness criterion of containment structure) are not available, the structure shall be tested for compliance. Adequate measures shall be taken to rectify defects, if any.

Requirements Against Fire

3.8.2 Protection against fire hazard consists of two measures; direct measures as well as the passive or in-built provisions. The direct measures i.e. detection, and fire fighting arrangement shall be developed in line with the AERB stipulations of AERB Safety Code AERB/SC/D. The provision of passive measures such as choice of fire resistant materials, provision of barriers, etc. in construction of building structures shall be taken in addition to the direct measures.

3.8.3 Unless justified otherwise, the fire rating shall be as given below:

(1) The fire rating of roof and external cladding of all buildings important to safety shall be 3 hours.

(2) The fire rating of internal walls, slabs and any fire barrier of buildings important to safety shall be not less than 3 hours.

(3) No load (imposed) bearing structural component of any buildings important to safety shall be designed for fire rating less than 2 hours.

(4) When a structural element of a building or structure passes through more than one compartment or room, the design fire rating of the element shall be taken as the highest value of the fire rating of the rooms or compartments through which it is passing.

3.8.4 Design of Structural Elements Against Fire Hazard

If expansion joints are provided to cater for the movement due to fire or expansion and where joints are provided for other reason but are subjected to the potential of fire hazard, the minimum width of the joint shall be as follows:

0010d, for fire resistance of one hour

0.0015d, for fire resistance of longer duration. against

where, d is the spacing of joints given in mm.

3.8.5 The design and detailing of concrete and steel structures shall conform to the relevant provisions of AERB Standards AERB/S/CSE-1 and AERB/S/CSE-2 respectively.

Requirements for Decommissioning

3.8.6 (1) Identification of buildings/structures which are to be kept under surveillance for a long time.

(2) Development of suitable design criteria of these buildings.

(3) Suitable structural layout of the building to provide facilities to access and remove structures, systems and components prior to dismantling of the building.

(4) Design the structure such that it would facilitate dismantling.

(5) Suitable measures, such as appropriate surface finish, surface hardness, painting, for easy decontamination. 'The painting shall withstand requisite radiation field.

(6) Providing necessary protection and safeguard capability and sufficient strength against the possible hazard and accident during decommissioning.

(7) Limiting the consequences of degraded structural elements of buildings.

Other Considerations

3.8.7 Design or qualification of the structures outside main plant area, which are not directly associated with systems and components important to safety but as a result of whose failure undue radiological consequences may arise, shall be performed as follows:

(1) When dyke wall or any other structure is used as protective device for the safety of site against design basis flood, or any other hazard originated outside the plant area it shall be designed as design class DC3 and seismic category-1 structure.

(2) Qualification of existing structures shall be done in accordance with the provision of retrofitting given in Chapter-8 if the structures are in operation for full service condition for atleast 3 years otherwise requirement of 3.5 shall be satisfied.

Structural Instrumentation

3.8.8 Provision, wherever necessary, should be made for adequate instrumentation to collect data on parameters, such as temperature, strain, deformation, settlement, vibration, deterioration, leakage, for assessment of structural behaviour, monitoring and ageing management as well as for life extension studies. For strong motion seismic instrumentation, reference should be made to AERB Safety Guide "Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites", No. AERB/SG/S-11.

4. CONSTRUCTION

4.1 General Requirements

4.1.1 The construction methodology shall be so adopted that the design intents of the buildings/structures are satisfied.

4.1.2 The sequence of construction shall be such that the construction activities of any building do not jeopardise the safety of the adjacent or nearby buildings/structures or part of it which has already been constructed.

4.1.3 Requirements of industrial safety as per Atomic Energy (Factories) Rules be satisfied.

4.1.4 The construction methodology and sequences should have due considerations of decommissioning.

4.1.5 AERB Safety Manual "Construction Methodology for Civil Engineering Structures important to safety of Nuclear Facilities", AERB/SM/CSE-3 contains the guidelines on construction.

4.1.6 Adequate experiments shall be made by way of mock-up simulation or by way of laboratory experiments whenever difficult construction is foreseen or new equipment and methods are employed.

5. COMMISSIONING

5.1 General Requirements

5.1.1 Prior to commissioning of the plant, tests on some civil engineering structures are required to be performed. The objective of the test is to establish that the design requirements are met, and also to validate the analytical design, if necessary.

5.1.2 The containment testing shall be done in accordance with the provision of AERB/S/CSE-3.

5.1.3 The testing procedure of spent fuel pool and water retaining structures shall follow the procedure laid down in AERB/S/CSE-l.

5.1.4 Testing of chimney shall be carried out for specified leakage control. as per design requirements.

5.1.5 Adequacy of shield of civil engineering structures/components shall be established including streaming aspects.

5.1.6 If any structure or structural component is required to be tested for any particular reason, the technical specification of test shall be developed prior to undertaking the testing. The technical specification shall contain the objectives of test, detailed test criteria and procedure which shall be formulated in line with the safety functions of the structures.

6. OPERATION

6.1 General Requirements

6.1.1 During operation of the plant, main activities pertaining to civil engineering structures are maintenance, in-service inspection and monitoring. All these activities shall be carried out satisfying the requirements of "Code of Practice on Safety in Nuclear Power Plant Operation", AERB/SC/O.

6.1.2 Monitoring the performance of the structures and their components important to safety shall be carried out so as to verify their capability to perform the required safety functions.

6.2 Maintenance

6.2.1 The maintenance programme of NPP shall be planned on the basis of periodic inspection. The periodic inspection will be carried out during planned shutdown of the NPP. Inspection should typically include detection of physical damages, spilling, cracks, rusting phenomena, loosening of EPs, joints of structural framework, leak detection of fluids and leak detection of containment. A periodic inspection time table shall be fixed for any station.

6.2.2 Maintenance in areas having radiation field shall be carried out only with work permit.

6.2.3 Action plan for maintenance shall be written and shall be approved by appropriate authority. Action plan shall include the following.

(1) Planning of methods of repair/maintenance, including tooling. In areas of high radiation field remote handling devices will be used.

(2) Use of materials which are unstable in area subjected to radiation shall be avoided.

6.2.4 Special attention shall be paid to methods of maintenance while dealing with penetration in containments, biological shields and restoration of surfaces which have undergone vigorous decontamination process.

6.2.5 All maintenance activities should be carried out in line with the procedures outlined in AERB Safety Manual on "Maintenance of Civil Engineering Structures of Nuclear Power Plants", AERB/SM/SCE-l.

6.3 Testing

6.3.1 During operation period, containments are required to be tested periodically. The tests shall be carried out as per AERB/S/CSE-3.

6.3.2 If tests for any other structures or its members are required to be conducted, the requirement of Cl. 5.1.6 should be complied with.

7. DECOMMISSIONING

7.1 General Requirements

7.1.1 Decommissioning of a nuclear facility are the actions taken at the end of its operating life to retire it from service in a manner that provides adequate protection for health and safety of workers and the general public and the protection of the environment. Decision regarding decommissioning should be taken following the requirements of "Code of Practice on Safety in Nuclear Power Plant Operation", AERB/SC/O.

7.1.2 Principal objectives of decommissioning of civil engineering structures are to decontaminate and dismantle, to the extent necessary, structures for cleaning up the site to the levels acceptable for limited use by an organisation authorised by AERB or unrestricted use by public. However, all structures of a decommissioned nuclear facility could not be released for public use. These structures should be maintained in appropriate stable and sealed condition. The strategy and procedure of decommissioning of civil engineering structures of a nuclear facility should satisfy the requirements of AERB Safety Manual on "Decommissioning of Nuclear Facilities", No. AERB/SM/DECOM-1.

7.1.3 Scheme for decontamination and dismantling, to the extent necessary, of civil engineering structures should be developed considering their existing layout and design features.

7.1.4 Decommissioning of the civil engineering structures, which are to be kept in "stable condition" for a long period, should be carried out systematically through the following major steps :

(1) Assessment of the time period for which they should be maintained in "stable condition".

(2) Identification of the safety demand and functional requirements during assessed period of "stable condition".

(3) Evaluation of their structural adequacy to meet the safety demand and satisfy the functional requirements during the entire period of "stable condition".

(4) Remedial measures for rectification of the inadequacies, if any, observed from evaluation.

8. RETROFITTING

8.1 General

8.1.1 The exercise of retrofitting may arise during the construction or during the service life of the structure. The circumstances due to which such an exercise becomes necessary are as under:

(1) Upgrading of a component or a portion of building or structure due to change in state of art.

(2) Modifications required due to installation of additional equipment.

(3) Additions and alterations required for use of the building or structure for purpose other than originally contemplated.

(4) Changes required on account of incidences taking place, which are not considered in the design.

8.1.2 Retrofitting of buildings and structures of existing plants shall be done in accordance with the provision laid down in this document. For retrofitting, it should be ensured that the design requirements and safety functions are achieved. To establish this, more rigorous design analysis as well as tests/ experiments may be carried out.

The special provision of retrofitting (described in Cl. 8.3.2 to 8.3.7) of this Standard shall be applicable to the civil engineering structures of those plants which have completed atleast three planned shutdown after attaining full power operation.

8.2 Condition Survey

8.2.1 Before undertaking the review for retrofitting, the inspection of the existing components or members is called for. This inspection will include the following:

(1) Collection of data on condition and behaviour of the structural member during its service life.

(2) Information collection as regards, whether the member is subjected to loads for which it has not been designed.

(3) Inspection of the member, which among other, should address the following:

— condition of concrete and steel structures.

— apparent cracking.

— condition of the reinforcing bars of concrete structures, if exposed.

— inspection by non-destructive testing.

— load test, if warranted.

8.3 Procedure

8.3.1 Following steps shall be taken when retrofitting is undertaken,

(1) Check back the old design input data

(2) Evaluation of the strength and serviceability.

(3) Recomputation with additional loads and serviceability condition due to change in regulations, change in design conditions such as heat, load, environmental effects and additional equipment or other loads.

8.3.2 The structural analysis for retrofitting should be carried out in accordance with Section 3.5 of Chapter 3 to determine structural response. Non-linear structural analysis is also acceptable when safety assessment of concrete structures is carried out for limit state of strength and that of steel structures by plastic design method. When non-linear methodology is adopted the effect of axial or inplane forces should be included in the analysis.

Seismic Analysis and Qualification

8.3.3 Seismic analysis and qualification of buildings, structures and components shall be carried out in accordance with AERB Safety Guide on Seismic Analysis AERB/SG/CSE-5 along with the following provisions.

8.3.4 The seismic studies to evaluate design basis ground motion shall be carried out in accordance with AERB Safety Guide AERB/SG/S-11. Deconvolution of spectra and associated seismic input is acceptable for seismic analysis and qualification related to retrofitting. The free field ground motion may be deconvoluted down through the foundation medium to a suitable bottom boundary using well established method and state-of-the-art.

8.3.5 When non-linear analysis methodology in accordance with Cl. 8.3.2 of this Standard is adopted, the effect of other normal loading shall be considered simultaneously in the seismic analysis.

8.3.6 In non-linear seismic analysis, appropriate procedure shall be adopted to calculate stiffness parameters of the structural elements.

8.3.7 The increased values of material damping may be used in retrofitting. These alternative material damping values are given in AERB/SG/CSE-5. No increase in soil damping values (both material and radiation) is allowed for retrofitting.

8.4 Strength Assessment of Existing Structures

8.4.1 The strength of existing concrete and steel structures shall be assessed in accordance with the provision of AERB Standard AERB/S/CSE-1 and AERB/S/CSE-2 respectively.

8.4.2 In strength assessment of the existing structures, the change in material properties due to ageing may be considered.

9. QUALITY ASSURANCE

9.1 General Requirements

9.1.1 An overall Quality Assurance Programme (QAP) in respect of civil engineering structures covering all phases of a Nuclear Power Plant viz. design, construction, commissioning, operation and decommissioning shall be developed and implemented in each phase so as to achieve adequate assurance on quality and safety. The detailed QAP for each constituent phase shall form part of this overall QAP. The Responsible Organisation (RO) shall ensure that both overall QAP and the relevant detailed QAP for constituent phase meet the requirements of "Code of Practice on QA for Safety in Nuclear Power Plants", AERB/SC/QA and other applicable Codes and Guides. The programme requires comprehensive planning, organisation, implementation (task performance), verification and certifications appropriate to task necessary to assure the requisite quality.

9.1.2 The QAP shall contain details in respect of the following :

- Policy
- Management
- Performance functions
- Quality control which broadly includes verification and corrective functions
- Documentation.
- Audit.

9.1.3 A written policy statement committing the management to implement and maintain QAP shall be made.

9.1.4 The programme shall ensure that primary responsibility for achieving quality rests with those assigned the task(s) and not those seeking to confirm the achievement of quality by means of control. Functional responsibility shall be defined distinguishing task performance from task verification and shall be delineated formally.

9.1.5 The programme shall be reviewed at appropriate intervals by management of organisations participating in the programme. The review shall be conducted on the status and adequacy of the programme.

Corrective actions shall be taken when programme deficiencies are discovered.

9.1.6 Manual for quality assurance programme shall be prepared for each project. The Manual shall contain all the planned and systematic activities which are required for achieving the intended quality in design and construction, and verification that each task has been satisfactorily performed and the corrective actions have been implemented as necessary.

9.1.7 Systematic and documented internal and external audit shall be carried out to verify compliance with, and to determine the effectiveness of the various elements of QAP.

9.1.8 Adequate QA documents shall be prepared and maintained in a systematic manner for easy retrieval to provide objective evidence of quality to meet the requirements of applicable Standards, Codes, Guides and Specifications and shall include the results of all activities in the programme.

9.2 Quality Assurance Programme in Design

9.2.1 The QA programme in design shall be developed in accordance with Section 4.2 of AERB/SC/QA and satisfying the general requirements given in Section 9.1 of this Standard.

9.2.2 QAP for retrofitting shall be developed on the basis of principles and guidelines adopted in the QAP for design.

Validation

9.2.3 If validation of a design is required following approaches should be adopted:

— Validation and/or comparison with the results of tests to confirm that the physical representation assumed is reasonably correct.

— Comparison of design using alternative methods. **-**

— Parametric studies.

— Verification of the applicability of the methods.

9.2.4 Important computer programmes which will be used in the design or analysis shall be validated with test problems.

9.3 Quality Assurance Programme in Construction

9.3.1 The QA programme in construction of buildings and structures shall developed in accordance with the AERB Safety Guide on "Quality Assurance for Construction of Civil Engineering Structures important to safety of Nuclear Facilities", No.AERB/SG/CSE-37 and satisfying the general requirements given in Section 9.1.

9.4 Quality Assurance Programme in Commissioning

9.4.1 QAP in commissioning stage for civil engineering structures shall be developed in accordance with general requirements of Section 9.1 and applicable Guides.

9.5 Quality Assurance Programme in Operation

9.5.1 The QAP pertaining to civil engineering structures during plant operation deals with in-service inspection and surveillance, monitoring, and testing (as required). The procedure of in-service inspection, monitoring and testing as required shall be so developed that all the necessary and prudent actions are ensured for the continued integrity, safety and reliability of the structures throughout its operational life.

In-service Inspection and Surveillance

9.5.2 Structures important to safety shall be designed and constructed so that they can be tested, maintained, inspected and monitored for functional capability during the life of the plant commensurate with applicable Standards.

9.5.3 Requirements of in-service inspection, monitoring, surveillance, testing and maintenance emanates from the following:

(1) Good engineering practices derived from the experience of existing plants. Such experience is reflected in the selection of features of structures and their components so that. adequate monitoring, testing, inspection and maintenance is possible.

(2) Statutory requirements related to general industrial safety, insurance practice or specific regulatory requirements.

(3) Where a particular structure is to perform safety related function, the steps to ensure achievement of specified level of reliability shall be followed.

(4) When analysis indicate that a particular structure or its arrangement is subject to heavy duty, the designer may call for more stringent and frequent inspection procedure than would normally be required.

9.5.4 Minimum items of safety related buildings and structures which shall be subjected to periodic in-service inspection are as follows:

(1) Pre-stressing systems of structures whenever required.

(2) Main structural members of safety class structures at the floor levels.

(3) Monitoring of performance of spent fuel storage bays.

(4) Basement areas for ingress/egress of ground water.

(5) Water removal arrangements from roof, floors and galleries.

(6) Structural finishes to detect any distress or signs of failure.

(7) Performance of biological shields from radiological considerations.

(8) Corrosion, erosion and general deterioration of structural members.

9.5.5 Appropriate QAP shall be developed for periodic leak testing of containment for both local as well as integrated leakage rate tests.

Monitoring Associated with Earthquake

9.5.6 Monitoring associated with earthquake and necessary instrumentation shall be provided in accordance with AERB/SG/S-I 1.

Monitoring Associated with Geotechnical Engineering

9.5.7 Geotechnical monitoring when required shall be performed in accordance with AERB/SG/CSE-2.

9.6 Quality Assurance Programme in Decommissioning

9.6.1 A comprehensive QAP shall be developed in accordance with requirements given under Section 9.1 and applicable Codes and Guides. This shall be implemented in a manner so as to ensure that civil engineering structures are decontaminated, dismantled and disposed of as per the final plan of decommissioning without any hazard either radiological or industrial to the site personnel or the public.

APPENDIX-A

LOADS

A.1 General

A.1.l This Appendix defines and characterises the individual loadings which are be considered for the design of buildings/structures unless specified otherwise.

A.2 Load Description

A.2.1 If any load/loading effect is not explicitly described below, the same shall be combined appropriately with the following:

(1) Dead Load : Self weight of all permanent constructions and installations including the self weight of walls, partitions, floors, roofs, false ceilings, equipment, etc. Loading effect due to hydrostatic pressure, settlement, volume change of concrete and prestressing shall also be included under the effect of this loading.

(2) **Live Load** : Load produced by the intended use of occupancy including distributed, concentrated, impact, vibration and snow load. The loading effect due to storage of materials, movable equipment, operational loads from equipment, pressure difference during normal operation, soil pressure and temporary loads applied during construction, erection, testing and maintenance shall also be included under the effect of this load.

(3) **Environmental Load :** Loading effects resulting from wind, rain, flood, seismic and other environmental events which are related to a particular site.

(4) **Thermal Load** : Load effect generated by temperature variations, including the steady state and transient state during operational and accident conditions, variation in ambient temperature and solar radiation.

(5) **Design Pressure** :

(a) For containment structures : The differential pressure acting across the containment elements, equivalent to the calculated peak value of overpressure due to design basis accident;

(b) For Reactor Building Internal Structures : The maximum differential pressure across various floors and walls of Reactor Building Internal Structure that would develop during design basis accident. (This is also known as Surge Pressure).

(6) **Test Pressure** : The pressure that will be applied during the pressure testing.

(7) **Load due to pipe rupture** : Load effect due to pipe rupture, jet impingement, pipe whip and pipe reaction as a result of pipe rupture.

(8) **Missile** : Load effect resulting from the impact of missiles generated by tornado, pipe rupture, turbine and other rotary machinery disintegration, land-water-air transport, aircraft impact, etc.

A.3 Load Categories

A.3.1 Normal Loads

Normal loads are the individual load effects which are encountered during construction, testing and all operational states. These include :

DL - Dead Load

F - Loads resulting from the application of prestress.

LL - Live Load

P_t - Test pressure

P_v - Pressure loads resulting during normal operational condition. ,.

R_o - Pipe and equipment reactions during normal operation excluding dead load and earthquake reactions.

T_t – Thermal effects and loads during the test.

T_o – Thermal effects and loads during normal operation, solar radiation effects and effects during construction.

A.3.2 Severe Environmental Loads

Severe environmental loads are those load effects which are generated due to natural phenomena and would be infrequently encountered during the plant life. These include

E_o - Load effects due to the Operating Basis Earthquake, including responses of supported components, piping and equipment, hydrodynamic effects and dynamic effects of surrounding soil.

W_c - Load effects due to the severe wind specified for the plant.

FF - Design basis flood

A.3.3 Extreme Environmental Loads

Extreme environmental loads are load effects due to postulated natural phenomena but whose probability of occurrence is very low. These include :

E_{ss} - Load effects due to Safe Shutdown Earthquake, including SS responses of supported components, piping and equipment, hydrodynamic effects, and dynamic effects of surrounding soil.

W_t - The loading effect due to wind induced missiles generated by extreme wind specific to site.

A.3.4 Abnormal Loads

Abnormal loads are those load effects generated by design basis accident (DBA) due to both external and internal events. These include :

F_2 - Hydrostatic load due to internal flooding.

MA - Load and other effects of aircraft impact.

ME - Missiles due to external events other than those related to wind or tornado, explosions in transportation systems, disintegration of turbine and other components.

MI - Loading due to internal missiles.

MT - Missiles, wind and overpressure generated from explosions in transportation systems, on land, water or in air.

Mt - Load and other impactive effects of turbine missile.

P_a - Design accident pressure

R_a - Pipe and equipment reaction under thermal conditions generated by a postulated pipe break and including R_o

T_a - Design accident temperature

Y_j - Jet impingement load on a structure generated by a design basis accident.

Y_m - Missile impact load on a structure, such as pipe whip generated by design basis accident.

Y_r - Loads on the structure generated by the reaction of the broken high-energy pipe during design basis accident.

A.4 Load Class

A.4.1 Dynamic class of loading

(1) Impactive Loads

These loads are time dependent loads due to collision of solid which are associated with finite amount of kinetic energy. Unless otherwise specified impactive loading of following types shall be considered :

- Missiles
- Pipe whips
- Drop loads

(2) Impulsive Load

Impulsive loads are time dependent loads which are not associated with collision of solid masses. Unless specified otherwise impulsive load of following types shall be considered :

- Earthquakes
- Wind
- Pressure
- Jet impingement
- Pipe whip restraint reactions

A.4.2 Static Class of Loading

Loading which could be assumed as time independent.

A.5 Characterisation of Individual Loading

A.5.1 Table A.1 contains all possible individual loads along with corresponding categorisation with respect to classification and category. However there may be some individual loading relevant to a particular site condition which are not included in the Table A.1 shall also be considered in the design.

TABLE A .1

CHARACTERISATION OF INDIVIDUAL LOADING

INDIVIDUAL LOAD		CLASS	CATEGORY
NAME	SYMBOL		
Dead Load[(1)]	DL	Static	Normal
Presenting Force	F	Static	Normal
Lateral Earth Pressure	H	Static	Normal
Loading effect due to support settlement	SST	Static	Normal
Equipment Load(numbered)	EQ	Static	Normal
Live Load [(2)]	LL	Static	Normal
Hydrostatic load	HS	Static	Normal
Test Pressure	P_1	Impulsive[(3)]	Normal
Pressure load resulting from pressure variation either inside or outside the containment.	P_v	Impulsive	Normal
Operating Temperature	T_o	Static	Normal
Thermal load during pressure testing	T_t	Static	Normal
Loading effect due to the solar radiation	SR	Static	Severe environment
Reaction due to pipe, etc.,	R_o	Static	Normal
Operation basis earthquake (OBE)	E_o	Impulsive[(3)]	Severe environment
Loading effect due to external flooding (design basis flood)	FF	Impulsive[(3)]	Severe environment
Severe wind load	W_c	Impulsive[(3)]	Severe environment
Maximum differential pressure generated from postulated accident used as design basis accident	P_a	Impulsive$_{(3)}$	Abnormal
Pipe and equipment reactions generated by postulated accident used as design basis and including R_o.	R_a	Impulsive$_{(3)}$	Abnormal

INDIVIDUAL LOAD		CLASS	CATEGORY
NAME	SYMBOL		
Hydro-dynamic loading — Due to OBE — Due to SSE — Due to Design Basis Accident	HM	 Impulsive(3) Impulsive(3) Impulsive(3)	 Serve environment Extreme environment Abnormal
Maximum attainable temperature due to postulated accident used as design basis	T_a	Impulsive(3)	Abnormal
Loading effect due to internal flooding	F_2	Impulsive(3)	Abnormal
Missiles			
- Due to land ,water and air transport	MT	Impactive	Abnormal
- Missiles due to external events like turbine and other rotary machinery disintegration	ME	Impactive	Abnormal
— _Internal missiles	MI	Impactive	Abnormal
Loading effect due to aircraft impact	MA	Impactive	Abnormal
Drop loading	LD	Impactive	Abnormal
Safe shutdown earthquake	ESS	Impulsive(3)	Extreme environment
Extreme wind load (wind induced missiles only)	Wt	Impactive	Extreme environment

Note:

(1) Effect due to shrinkage , heat of hydration etc., pertaining to concrete structure will fall into category of dead load.

(2) For convenience live load may be subdivided into Live load during normal condition (LLn) and Liveload during shutdown conditions (LLs).

(3) The element sections could be designed for these loading considering the effect as static type though the structural response may be determined by dynamic analysis.

ANNEXURE-I

GENERAL SAFETY EQUATION FOR DESIGN

Safety Equation

I.1 The safety equation which represents mathematically the safety based concept described in this Standard is,

$P_f = P_{f \cdot allowable}$

where, $P_f = Pr(A)\ n\ Pr(B)$

Pr(A) = Probability of failure of structure/components for design constraints defined by event B.

Pr(B)= Probability of occurrence of event B.

The event B as described in the above safety equation should be postulated from the design and operational (both normal and abnormal) conditions and it shall be credible. The $P_{f \cdot allowable}$ is the allowable value of probability of failure of the structural systems.

I.1.1 The credible sequence of events that lead to radioactivity release following PIE includes an extreme/severe environmental event or system failure, its consequences on structures and its components (i.e. loading, etc.), failure of structures and components leading to external release. The $P_{f \cdot allowable}$ should be determined following this logical sequence and from f. allowable the overall safety requirement that the probability of radioactivity release exceeding the limit specified by AERB beyond the exclusion zone is less than the acceptable value.

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PROVISIONAL LIST OF STANDARDS, SAFETY GUIDES AND MANUALS UNDER CIVIL ENGINEERING SAFETY STANDARD

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