STANDARD NO. AERB/NF/SS/CSE (Rev. 1)

GOVERNMENT OF INDIA

AERB SAFETY STANDARD

CIVIL ENGINEERING STRUCTURES IMPORTANT TO SAFETY OF NUCLEAR FACILITIES

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY STANDARD NO. AERB/NF/SS/CSE (Rev.1)

CIVIL ENGINEERING STRUCTURES IMPORTANT TO SAFETY OF NUCLEAR FACILITIES

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FOREWORD

Activities concerning establishment and utilization 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, therefore, has undertaken a programme of developing safety codes, safety standards, related safety guides and safety manuals for the purpose. While some of these regulatory safety documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, others cover regulatory aspects of these facilities.

AERB 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 and safety standards establish the objectives and set the minimum 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 regulatory safety documents are prepared by experts in the relevant fields and are reviewed by advisory committee of the board before publication. The documents are revised when necessary, in light of experience and feedback from users as well as new developments in the field.

Civil engineering structures form an important feature of nuclear facilities having implications on their safety performance. This safety standard on Civil and Structural Engineering (CSE) specifies the objective and the minimum requirements for the design of civil engineering buildings/structures that are to be fulfilled to provide adequate assurance for safety of nuclear facilities in India. This safety standard supersedes the earlier version published in the year 1998. The standard has been revised by expanding its scope to all nuclear facilities and brings out the graded approach to be followed while applying the provisions. In addition, it provides guidance on margin assessment of structures, ageing management and structural health assessment taking into account the prevailing international practices. Feedback from use of earlier version of this standard has also been accounted for during revision.

Appendix is an integral part of the standard, whereas references and bibliography are to provide information that might be helpful to the user. For aspects not covered in this standard, 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 has been drafted by in-house working group. The draft was further reviewed by a task force with specialists drawn from technical support organisations and institutions, and other consultants. Comments have been obtained from all major stake holders and they have been suitably incorporated. The safety standard has been vetted by the AERB Advisory Committee on Nuclear and Radiation Safety (ACNRS). AERB wishes to thank all individuals and organizations who have contributed in the preparation, review and finalization of the safety standard.

D. Shukla.

(D. K. Shukla)
Chairman, AERB

DEFINITIONS

Accident conditions

Deviations from normal operation which are less frequent and more severe than anticipated operational occurrences, and which include design basis accidents and design extension conditions.

Ageing Management

The engineering, operations and maintenance actions to control ageing degradation of systems, structures or components within acceptable limits.

Anticipated Operational Occurrences

An operational process deviating from normal operation, which is expected to occur during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety, nor lead to accident conditions.

Approval

A type of Regulatory instrument issued by the regulatory body to perform specified activities relating to particular 'sources' and 'practices' specified in Rule 3 of Atomic Energy (Radiation Protection) Rules, 2004

Atomic Energy Regulatory Board

National authority designated by the Government of India, having the legal authority for issuing regulatory consents 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 hazards.

Commissioning

The process by means of which systems and components of nuclear and radiation facilities, having been constructed, are made operational and verified to be in accordance with the design intent and to have met the required performance criteria.

Condition Assessment

Act of verifying the adequacy of primary structural system to the extent possible, through thorough review of design and records of construction, inspection, maintenance as well as in light of data received through condition survey and in-situ or laboratory testing.

Condition Survey

An act of identifying cause, source & extent of distress in the structure through visual inspection and/or in-situ and laboratory testing methods, and planning effective, implementable and applicable repair methods.

Construction

The process of manufacturing 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.

Decommissioning
The process by which the use of radiation equipment or installation is discontinued on a permanent basis, with or without dismantling the equipment, including removal or containment of radioactive materials.

Decontamination
The complete or partial removal of contamination by a deliberate physical, chemical or biological process.

Design extension conditions
Accident conditions, beyond design basis, but that are considered in the design process of the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits.

Design Basis Accidents
A set of postulated accidents leading to accident conditions for which a facility is designed in accordance with established design criteria and conservative methodology, and for which releases of radioactive material are kept within acceptable limits.

Design Basis Ground Motion
The ground motion parameter values associated with postulated earthquake considered for the purpose of the design of a facility from safety consideration.

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

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

Embedded Part (EP)
Any structural member, plate, angle, channel, pipe sleeve, penetrations or other section anchored to a concrete structure through a direct bond or other anchors. (See "Embedment")

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 (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.

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

Margin assessment
The assessment of available margin beyond design capacity

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

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

Operating Basis Earthquake
An 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. The features of a nuclear power plant necessary for continued safe operation are designed to remain functional, during and after the vibratory ground motion caused by the earthquake.

Operation
All activities following commissioning (after initial fuel loading) performed to achieve, in a safe manner, the purpose for which a nuclear/radiation facility is constructed. For nuclear power plants, this includes maintenance, refueling, in-service inspection and other associated activities performed during initial operation, regular operation or long term operation.

Operational States
The states defined under “normal operation” and “anticipated operational occurrences”.

Postulated Initiating Events
A postulated event identified in design as capable of leading to anticipated operational occurrences or accident conditions.

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

Quality Assurance
The function of a management system that provides confidence that specified requirements will be fulfilled

Records
Documents which furnish objective evidence of the quality of items and activities affecting quality. It also includes logging of events and other measurements.

Reliability
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
An organisation having overall responsibility for siting, design, construction, commissioning, operation and decommissioning of a facility.

Safe Shutdown Earthquake
The earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology, seismology and specific characteristics of the 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 which are necessary to assure:

- the integrity of the reactor coolant pressure boundary; or
- the capability to shutdown the reactor and maintain it in a safe shutdown condition; or
- the capability to prevent the accident or to mitigate the consequences of accidents which could result in potential off-site exposures higher than the limits specified by the regulatory body; or
- the capacity to remove residual heat.

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 risks.

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.

Site
The area defined by a boundary, containing facility or source and are under effective control of the management of the facility or activity

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, Systems and Components (SSCs)
A general term encompassing all of the elements (items) of a facility or activity which contribute to protection and safety, except human factors. Structures are the passive elements: buildings, vessels, shielding, etc. A system comprises several components, assembled in such a way as to perform a specific (active) function. A component is a discrete element of a system. Examples of components are wires, transistors, integrated circuits, motors, relays, solenoids, pipes, fittings, pumps, tanks and valves.

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

Technical Specification for Operation
A document approved by the regulatory body, covering the operational limits and conditions, surveillance and administrative control requirements for safe operation of the nuclear or radiation facility. It is also called as ‘operational limits and conditions.

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.

Time limited Aging Analysis
Time limited ageing analyses (TLAAs) are plant calculations and analyses that consider the effects of ageing, involve time–limited assumptions defined by the current operating term and generate conclusions or provide the basis for conclusions related to the capability of a structure or component to perform its intended function.

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

ABBREVIATIONS

AERB	Atomic Energy Regulatory Board
ALARA	As Low As Reasonably Achievable
AOO	Anticipated Operational Occurrences
ASCE	American Society of Civil Engineers
BARC	Bhabha Atomic Research Centre
BDBE	Beyond Design Basis Event
BDBFL	Beyond Design Basis Flood Level
BIS	Bureau of Indian Standard
CSE	Civil and Structural Engineering
DBA	Design Basis Accidents
DBE	Design Basis Earthquake
DBGM	Design Basis Ground Motion
DC	Design Class
DCL	Development Consultants Limited
DEC	Design Extension Conditions
FEM	Finite Element Method
FSI	Fluid Structure Interaction
IS	Indian Standard
ISI	In-Service Inspection
LC	Load Combination
LOCA	Loss Of Coolant Accident
LTTM	Low Trajectory Turbine Missile
MCE	Maximum Credible Earthquake
NF	Nuclear Facility
NLTHA	Nonlinear Time History Analysis
NPC	Nuclear Power Corporation
NO	Normal Operation
NPP	Nuclear Power Plant
OBE	Operating Basis Earthquake
PIEs	Postulated Initiating Events
QAP	Quality Assurance Programme
RO	Responsible Organisation
SC	Safety Code
SDB	Safety Design Bases
SDV	Screening Distance Value
SG	Safety Guide
SMRF	Special Moment Resisting Frame
SS	Safety Standard
SSE	Safe Shutdown Earthquake
TLAA	Time Limited Ageing Analyses

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1. INTRODUCTION

1.1. General

1.1.1. AERB Safety Codes on Design of Nuclear Power Plants [2, 3] stipulate the design requirements for structures, systems and components to prevent or mitigate the consequences of Postulated Initiating Events (PIEs) which could otherwise jeopardise safety. AERB Safety Codes also specify general safety objectives required to be met. All safety related civil engineering structures and their components are designed to achieve these safety objectives.

1.1.2. This Safety Standard prescribes requirements related to civil engineering structures to ensure safety of Nuclear Power Plants (NPPs) and other Nuclear Facilities (NFs). The Safety Standards, Safety Guides and Safety Manuals listed in this Standard provide further requirements and guidance to implement this standard.

1.1.3. This standard supersedes the earlier version of the standard published in 1998. The revised standard brings out additional requirements for ensuring basic safety functions under extreme external events (beyond design basis) and severe accident conditions; and considerations for concurrent and/or sequential hazards. The revision also addresses requirements related to nuclear facilities other than NPPs and brings out the graded approach to be followed while applying the provisions.

1.2. Objective

This Standard specifies the analysis and design requirements of civil engineering structures important to safety in order to achieve safe operation of NFs and to protect personnel, public, and environment from radiological, industrial and fire hazards. It also sets out requirements to be fulfilled during construction, commissioning, operation decommissioning as well as margin assessment of civil engineering structures.

1.3. Scope

1.3.1. The provisions of this standard are applicable to civil engineering structures of NFs. In some instances, the requirements are specified for NPPs, however they may be applied to other NFs suitably, using a graded approach based upon the potential for radiological impact.

1.3.2. Licensee shall carryout safety assessment of other structures/ topographical features outside the plant/site, such as dams, terrain slopes etc. whose performance has an influence on safety of the NFs, following the requirements of this Standard. If such assessment is not undertaken, failure of these structures shall be postulated and safety of structures in the NFs shall be demonstrated.

1.3.3. The provisions of other related AERB Safety Codes / Standards / Guides shall be implemented, wherever applicable

1.4. Structure

1.4.1. This Standard comprises 9 chapters and 1 appendix. The principal design requirements of civil engineering structures of NFs have been delineated in chapter 2. The design criteria/ requirements are described in chapter 3 which is followed by the aspects of construction given in chapter 4. Chapters 5, 6 and 7 contain the requirements pertinent to structures for commissioning, operation and decommissioning of the plants respectively. Stipulations for margin assessment, ageing management, health assessment and retrofitting are given in chapter 8. Chapter 9 provides the requirements of quality assurance programme.

1.4.2. Appendix A describes various individual loads to be considered in the design of civil engineering structures of NFs.

2. PRINCIPAL DESIGN REQUIREMENTS

2.1. General

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

(1) Planning & Design
(2) Construction
(3) Commissioning
(4) Operation

2.1.2. Decommissioning aspects of the civil engineering structures need to be addressed during all the above stages.

2.2. Implementation of safety in design of civil engineering structures

2.2.1. Design basis developed on 'safety based concept' shall be adopted at all stages of engineering of civil structures important to safety of nuclear facilities. In the safety based concept, possible transients/ events for various plant states encompassing Normal Operation (NO), Anticipated Operational Occurrences (AOOs), Design Basis Accidents (DBAs) and Design Extension Conditions (DECs) are first postulated. Engineering is then carried out to ensure that the structural system is reliable and competent to withstand the consequences of these postulated scenarios.

2.2.2. For application of safety based concept in the design of civil engineering structures, first the safety functions of structures are identified. The structures are then classified based on these functions. Design bases of the structures are derived from their classifications. The PIEs, which would result in accident condition are identified and the consequences of resulting accident are analyzed to specify the engineering design requirements of the structures.

2.2.3. The requirements for establishment of design bases with respect to external events are specified in AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1) [4].

2.3. Safety Functions

2.3.1. 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 under all plant states. AERB Safety Guide 'Safety classification and seismic categorisation for structures, systems and components of pressurised heavy water reactors', AERB/NPP-PHWR/SG/D-1 [5] 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 even after decommissioning of the plant. In NPPs, the identified civil engineering structures intended to meet basic safety functions, (i.e., immediate and long term (guaranteed) shutdown, decay heat removal from core and spent fuel, and containment) shall remain functional under extreme external events and design extension conditions. For Hazard-1 category facilities, those structures identified for post-accident management shall remain functional under extreme external events and design extension conditions.

2.3.3. These civil engineering structures shall be identified and checked for the assessment design conditions (refer section 3.2), in addition to design for normal and abnormal design conditions.

2.4. Safety, Seismic and Design Classifications

2.4.1. To derive the design requirements for NPPs, all structures shall be identified and their safety, seismic and design classifications shall be undertaken as per the criteria given in AERB Safety Guide 'Safety classification and seismic categorisation for structures, systems and components of pressurised heavy water reactors', AERB/NPP-PHWR/SG/D-1[5]. With regard to NFs other than NPPs, the approach for arriving at the design requirements shall be as per section 2.8.

Special Consideration for Classification

2.4.2. When, as a result of an earthquake, wind or any other external events, the collapse, falling, dislodgement or any other spatial response of an item is expected to occur (e.g. on the basis of analysis, test or experience) and which could jeopardize the functioning of items in a higher category, then:

(1) Such items shall be classified in the same category as that of the endangered items; and under the reference magnitude of the external hazard, the preclusion of collapse, etc. or functionality of the reclassified category items, shall be demonstrated; or

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

2.4.3. For item 1 above, since only the structural integrity of reclassified category items (because of their potential to jeopardize higher category items) need to be assured, criteria suggested in Chapter 8 may be used for margin assessment, with structural performance limits corresponding to collapse prevention.

2.5. Design Basis

2.5.1. The design bases for civil engineering structures important to safety shall specify their necessary capability, reliability and functionality for the relevant operational states, accident conditions and conditions arising from internal and external hazards, to meet the specific acceptance criteria over the lifetime of the NFs. Design bases of civil engineering structures shall be developed considering their safety, seismic, and design classifications as well as their quality assurance requirements.

2.5.2. For all NFs, external hazard shall be defined as per AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1) [4] and associated safety guides. Internal hazards shall be considered as per the applicable design requirements. For each hazard, loads emanating from hazard and correlated phenomena shall be evaluated and used in design. In addition, loads envisaged to act on the structure during construction and commissioning phases of the facility shall be appropriately accounted for.

2.5.3. For the structures required to be functional to ensure basic safety functions and post-accident recovery of Hazard Category 1 facilities, margin shall be assessed for load combinations corresponding to assessment design conditions as per Chapter 8. Design basis shall account for concurrent and sequential hazards through credible combination of internal and external events. The design shall address the performance of the structures during design extension conditions.

2.5.4. Classification of Civil Engineering Structures of NPPs and the corresponding design conditions with load combinations to be adopted in the design is presented in Table 2.1. Classification of the Civil Engineering Structures of other NFs taking into account hazard categorization of facilities as per AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1) [4] is presented in Table 2.2.

2.5.5. Based on the classification of NFs (other than NPPs), the design basis, design requirements including design codes and load combinations of major natural external events (such as earthquake, wind, and flood) are presented in Table 2.3 for various Civil Engineering Structures. The design of NPPs shall also satisfy the requirements specified in Table 2.3 (with respect to national standards) for Class A structures.

2.6. Approach for identification of Postulated Initiating Events

2.6.1. A systematic approach shall be adopted during the design of NFs to identify a comprehensive set of Postulated Initiating Events, such that all foreseeable events with a significant frequency of occurrence and all foreseeable events with the potential for significant consequences due to radiation exposure are anticipated and considered in the design basis or in the design extension conditions.

2.6.2. The structural design of NFs shall cater 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 and flood) shall be such that further detrimental effects on the safety of plants, systems, etc. supported by the buildings/structures are minimized.

2.7. Design Approach

2.7.1. A set of accident conditions that are to be considered in the design shall be derived from the PIEs for establishing the bounding conditions for design of the structure. The designed capability of structure shall be adequate to satisfy the design criteria derived from the design bases (Section 2.5). The various structural systems under the scope of this Standard shall be designed to satisfy the requirements of this Standard and other relevant AERB Safety Codes and Guides. If design is carried out satisfying criteria and requirements different from the above, acceptability of the design shall be justified.

2.7.2. Design of structures shall be carried out for normal and abnormal design conditions as specified in Section 3.2. A set of design extension conditions shall be derived on the basis of engineering judgment, deterministic and probabilistic assessments for the purpose of further improving the safety of the facility. These design extension conditions shall be used to identify additional accident scenarios to be addressed in design of structures. To ensure the availability of basic safety functions during beyond design basis events, margin assessment for assessment design conditions shall be carried out as per Section 3.2. Structures identified to carry out these basic safety functions shall be demonstrated to be functional under loads arising from extreme external events and severe accident conditions.

2.7.3. Unless specified otherwise, linear analysis shall be carried out to estimate the design forces due to design basis external and internal events under all plant states including design extension conditions.

2.8. Graded Approach for NFs other than NPPs

2.8.1. In case of NFs other than NPPs, the design requirements of each civil engineering structure shall be based on classification as given in Table 2.2. Based on this classification, the structures shall be designed as per the requirements given in Table 2.3. If failure of a lower class structure can influence the safety of higher class structure, then the lower class structure shall be assessed for the loads applicable to design of higher class structure. It shall be demonstrated that under this condition, the lower class structure does not affect the behavior of the higher class structure in any manner.

2.8.2. Hazards from external events, such as earthquake, wind and flood, shall be transformed into equivalent loads as per section 3.1.

TABLE 2.1

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

S.No	Design Class	Safety Class	Seismic Category	Design[1,6] Conditions	Load Combinations[2]
1	DC1	1	1	Normal	LC1, LC2
				Abnormal	LC3, LC4, LC5, LC6
				Assessment	LC7[8], LC8[7,8]
2	DC2	2	1	Normal	LC1, LC2
				Abnormal	LC3, LC4, LC5, LC6
				Assessment	LC7[8], LC8[7,8]
3	DC3	2,3	1	Normal	LC1, LC2
				Abnormal	LC3, LC4, LC5, LC6[3]
				Assessment	LC7[8],
		3[4]	2	Normal	LC1, LC2
				Abnormal	LC4, LC5
		4	2	Normal	LC1, LC2
				Abnormal	LC4
4	DC4	NNS[5]	3		

Note:

(1) Refer section 3.2

(2) Refer section 3.5.2

(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 and other systems related to shutdown of reactor or prevent/mitigate the consequences of accident which could result in potential off-site exposure according to relevant AERB guidelines.

(5) Non-nuclear structures not important to safety should meet the design requirements as per relevant national codes and standard engineering practices.

(6) Design requirements should be as per the relevant AERB Guides (Refer section 3.3)

(7) This load combination is applicable for only containment structures.

(8) These load combinations are used for assessing the margin/ capacity against assessment design conditions.

TABLE 2.2

CLASSIFICATION OF CIVIL ENGINEERING STRUCTURES OF NFs OTHER THAN NPPs

Class	Description
A	Buildings and structures whose failure can initiate events leading to offsite[1] radiological hazard[2]
B	Buildings and structures whose failure can initiate events leading to onsite[3] radiological hazard
C	Buildings and structures whose failure can initiate events leading to: (1) Radiological hazard within plant[4] boundary and offsite chemical hazard or, (2) Offsite chemical hazard
D	Buildings and structures whose failure can initiate events leading to: (1) Radiological hazard within plant boundary (2) Radiological hazard within plant boundary and onsite chemical hazard or, (3) Onsite chemical hazard
E	Other industrial buildings

[1] Area beyond the site boundary (public domain)

[2] Hazard categorisation of the facility follows the principle of 'unmitigated consequence of an accident'. Towards categorizing a facility for the purpose of adopting graded approach, a conservative screening process should be applied assuming that the entire radioactive inventory of the facility is released by any external event initiated accident. If the conservative screening process shows that the potential consequences of such releases from the facility would result in off-site, on-site or within plant boundary radiological impact, it should be categorized as Hazard Category I, II or III facility, respectively, as per AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/SC/S Rev.1. Radiological hazard shall be estimated based on unmitigated release of entire radioactive inventory or total structural collapse

[3] The area containing the facility defined by a boundary and under effective control of management

[4] The facility under consideration

TABLE 2.3
EXTERNAL EVENT DESIGN PARAMETERS FOR CIVIL ENGINEERING STRUCTURES OF NFs OTHER THAN NPPs[5]

Parameters	Events	Class A	Class B	Class C	Class D	Class E
Design Basis	Seismic	E_{ss} : Return period of 10,000 years E_O : Specified by plant	E_O : Return period of 2,500 years	Requirements of Category-1 structures of IS 1893 Part IV [26] [Use R = 0.67 times the response reduction factor (R) specified in IS 1893 part IV[26] for structures without special provisions for ductile seismic resistance]	Requirements of IS 1893 part IV[26] with applicable structure categorization as per IS 1893 Part IV [26] [Use R = 0.67 times the response reduction factor (R) specified in IS 1893 part IV [26] for structures without special provisions for ductile seismic resistance]	Requirements of IS 1893 part IV with applicable categorization [26] [Use R = 0.67 times the response reduction factor (R) specified in IS 1893 part IV [26]
	Wind	Wt: Load effects due to wind with return period of 10000 years (Site specific data) W_C : Load effects due to wind with Return period of 500 years (Site specific data)	W_C : Load effects due to wind with Return period of 500 years (Site specific data)	W_Z: Load effects due to wind with Return period of 100 years as per IS 875 [27]	W_Z : Load effects due to wind with Return period of 100 years as per IS 875 [27]	W_Z : Load effects due to wind with Return period of 50 years as per IS875 [27]
	Flood	FF: Return period of 10000 years	FF: Return period of 1000 years	F_{IS}: Return period of 100 years	F_{IS}: Return period of 100 years	F_{IS}: Return period of 100 years
	Requirements with respect to National standards					
	Seismic	Seismic effects to be estimated as per the requirements of IS1893 part IV [26] Category-1 structures [I/R=1]. OR,	Seismic effects to be estimated as per the requirements of IS1893 part IV [26] Category-1 structures [I/R=1]. OR,	-	-	-

[5] Any building that does not fall under these classes (A to E) shall be designed as per the provisions of appropriate BIS standards

Parameters	Events	Class A	Class B	Class C	Class D	Class E
		The site specific spectra (E_{ss}) shall envelop the IS Spectra corresponding to A_h = Z*Sa/g and (I/R=1) at 5% damping.	The site specific spectra (Eo) shall envelop the IS Spectra corresponding to A_h = Z*Sa/g and (I/R=1) at 5% damping.			
	Wind	Structures shall be designed for load effects due to wind speed corresponding to 10000 years return period based on IS875 [27].	Structures shall be designed for load effects due to wind speed corresponding to 500 years return period based on IS875 [27].	-	-	-
	Flood	Based on relevant national standards, if available	Based on relevant national standards, if available	Based on relevant national standards, if available	Based on relevant national standards, if available	Based on relevant national standards, if available
Applicable Code		Concrete#: AERB/SS/CSE-1 [7] Steel: AERB/SS/CSE-2 [8] Embedded Parts: AERB/SS/CSE-4 [9] Seismic Qualification: AERB/SG/D-23 [10]	Concrete#: AERB/SS/CSE-1 [7] Steel: AERB/SS/CSE-2 [8] Embedded Parts: AERB/SS/CSE-4 [9] Seismic Qualification: AERB/SG/D-23 [10]	Concrete: IS 456 [24] Steel: IS 800 [25] Others: National Standards	Concrete: IS 456 [24] Steel: IS 800 [25] Others: National Standards	Concrete: IS 456 [24] Steel: IS 800 [25] Others: National Standards
Load Combinations [See also Section 3.5.2]		Normal Design Conditions: LC1, LC2 Abnormal Design Conditions: LC3, LC4, LC5, LC6 Assessment Design Conditions: [6]LC7, LC8	Normal Design Conditions: LC1, LC2* Abnormal Design Conditions: LC4, LC5 [*For seismic design, in LC2, use Partial Safety Factor of load for E_O as 1.0]	Seismic: All Combinations as per IS 1893 Part IV [26] for category 1 structures Wind and Flood: All Combinations as per IS 456 [24] and IS 800 [25].	Seismic: All Combinations as per IS 1893 Part IV with applicable structure categorization as per IS 1893 Part IV[26] Wind and Flood: All Combinations as per IS 456 [24] and IS 800 [25]..	Seismic: All Combinations as per IS 1893 [26] with applicable structure categorization as per IS 1893 Part IV. Wind and Flood: All Combinations as per IS 456 [24] and IS 800 [25]..

[6] LC7&LC8 load combinations are applicable for all identified structures, including that required to fulfil key safety functions as applicable, as well as , accident management in an extreme event

Note:

i) E_{ss} : Safe Shutdown Earthquake (SSE)

ii) E_O :

  a. For NPPs: Operating Basis Earthquake (OBE) / S1 Level Earthquake

  b. For Hazard Category-1 NFs other than NPP: Specified by plant

  c. For Hazard Category-2 NFs: Design level earthquake (2500 years return period)

iii) FF : Loading due to design basis flood (Severe environmental load category)

iv) F_{IS} : Loading due to design basis flood evaluated using relevant national standard (if any)

v) W_t: Load effects due to wind corresponding to 10000 years return period

vi) W_C : Load effects due to wind (corresponding to applicable return period for the structure class)

vii) V_Z : Design wind speed corresponding applicable return period taking into account appropriate modification factors as per relevant national standard [27]

viii) Wz : Load effects due to V_Z

ix) Z : Zone factor as per IS 1893 Part IV

3. DESIGN CRITERIA

3.1. General

3.1.1. Structural design of NFs shall be carried out based on 'safety based design' concept (refer section 2.2). Methods to ensure a robust design shall be applied and proven engineering measures shall be adhered to in the design of NF. 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 Conditions

3.2.1. Structural design of NFs shall be carried out for design basis internal and external events adopting applicable safety criteria and sound engineering practices. Depending upon the load combinations to be considered in the design, following design conditions shall be considered in the design basis of NF:

(1) Normal Design Conditions, which include the Load Combinations LC1 and LC2, i.e., Normal and Severe Environmental load combinations, respectively, (as defined in Section 3.5.6) and

(2) Abnormal Design Conditions, which 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 Section 3.5.6).

Assessment Design Conditions

3.2.2. In case of NPPs, structures required to ensure the availability of basic safety functions (i.e., immediate and long term (guaranteed) shutdown, decay heat removal from core and spent fuel, and containment) as well as those structures identified for post-accident management shall be assessed for the Assessment Design Conditions (ADC), which include the load combinations LC7 and LC8, i.e., environmental load combinations for ADC and abnormal load combinations for ADC as defined in Section 3.5.6. For nuclear facilities, class A structures that are required to fulfil key safety functions as applicable, as well as, accident management in an extreme event shall be assessed for the Assessment Design Conditions (ADC), which include the load combinations LC7 and LC8, i.e., assessment environmental load combinations for ADC and assessment abnormal load combinations for ADC as defined in Section 3.5.6. This assessment shall demonstrate that structures are able to function under extreme external events and severe accident conditions. The assumptions and methods for these assessments shall be realistic.

3.3. Design Requirements

3.3.1. Structures shall be designed/ assessed to meet strength, serviceability and stability requirements for specified load combinations due to loads arising out of normal operation, anticipated operational occurrences, DBAs and DECs including severe accident conditions as well as from external hazards and their credible combination with plant states.

3.3.2. The design target strength, stiffness and ductility of the structures shall be derived from the relevant safety functions as specified in section 2.3 for which the buildings and structures shall be designed. These design targets shall be transformed to the following design requirements or their combinations;

(1) Radiological protection
(2) Stability
(3) Serviceability
(4) Strength

Radiological Protection provided by Structures

3.3.3. Structural members having shielding requirements shall satisfy the following:

(1) Required shielding properties
(2) Structural strength, durability and shielding requirements in determining the cross sectional dimensions of structural elements
(3) Meet the following criteria to prevent radiation streaming/ leakage through gaps:
   a) No linear through crack across the thickness
   b) Movement joints, expansion joints, etc. shall be staggered/ stepped. This should be implemented for construction joints to the extent practicable.
(4) Induced radioactivity and irradiation damage

Stability

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

(1) Elastic stability
(2) Foundation stability against overturning, sliding and floatation as well as collapse of strata supporting foundation
(3) Stability against aerodynamic effects

3.3.5. The guidance provided by AERB Safety Guide ‘Geotechnical aspects and safety of foundation for buildings and structures important to safety of nuclear power plants’, AERB/NPP/SG/CSE-2 [11] shall be followed to ensure stability of structures including founding strata.

Serviceability

3.3.6. All serviceability requirements such as deflection, foundation settlement, crack width and vibration amplitude shall be determined from the safety as well as functional requirements of structures, systems and components. Structures shall be designed to meet all these requirements. As a minimum, the provisions of relevant AERB Standards and Safety Guides should be satisfied. The design for serviceability shall be carried out following the requirements of Section 3.5.

Strength

3.3.7. The design for strength is influenced by plant layout, structural configuration, and the assignment of stiffness to the structural elements. The design of structures shall be carried out as per Section 3.5. The plant layout and structural layout shall be as per Section 3.4.2 and Section 3.4.3, respectively.

3.4. Layout Considerations

3.4.1. Uncertainties in design shall be minimised at the conceptual stage. The conceptual development of layout shall 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 shall be made such that the design problem could be solved with the help of state of art

(3) Relevant requirements of Atomic Energy Factories Rules (AEFR) [6] and National building code are satisfied

Plant Layout

3.4.2. The following 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 is achieved and is 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 and cul-de-sac at dead ends, if any, are provided for movement of heavy crane and other vehicles during construction as well as operation of facility. Road of appropriate width shall be provided all around safety related buildings/ structures from fire-fighting considerations and shall not terminate in dead ends

(6) Provision is made for space around buildings for erection facility, cranes, etc. during construction as well as for laying of various safety related utility services during operation

(7) Buildings and structures important to safety are placed outside the area prone to externally and internally generated missiles and low trajectory turbine missiles as far as practicable

(8) Sufficient gap is provided for seismic isolation (shake space) between adjacent

structural parts or buildings

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

(10) Proper access control measures are provided

Structural/ building Layout

3.4.3. The following shall be taken into consideration in developing the Structural/ building layout:

(1) Plant and system safety requirements are satisfied

(2) Emergency requirements arising out of industrial and nuclear safety are satisfied

(3) Safety related systems and components of similar (if not higher) safety class/ seismic category are located and placed suitably in buildings/ structures of appropriate classification, as far as possible

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

(5) Structural system of individual building is as simple, symmetrical and regular as possible. Protruding sections and lack of symmetry are avoided as far as practicable. The center of gravity of structure are located as low as possible. The center of resistance at various elevations is made as close to the center of mass at that elevation as practicable

(6) Internal arrangement of structures are such that less important structural elements would protect the more important ones to a good extent

(7) Materials are so selected that the safety of the building is enhanced

(8) Materials and grade of concrete as well as dimensions of applicable structural members are selected commensurating with radiation shielding requirements

(9) Different grades of concrete for primary structural elements of the same structure are avoided as far as practicable

(10) Placement of foundation of all adjacent buildings and structures is done in order to reduce differential settlement as much as practicable

(11) Overlapping of foundation of different structures is avoided as far as possible

(12) Dimensions of structural elements are selected so as to minimise congestion of reinforcement and ensure proper placement of concrete

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

(14) 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

(15) Personnel and equipment accesses to the reactor building through air locks, is such that separation of the containment environment from the outside environment is achieved at all times

(16) Provision of fire protection

(17) Easy maintenance and surveillance

3.5. Design for Strength, Serviceability and Stability

3.5.1. Structures shall be designed/ assessed to meet the serviceability, strength and stability requirements for all possible load combinations due to loads arising from various plant states viz NO, AOO, DBA and DEC including severe accident conditions, as well as from external hazards and their credible combinations. In addition, loads envisaged to act on the structure (such as loads from differential settlement of foundation, loads encountered during construction, commissioning phases as well as during maintenance activities of the plant) shall be accounted for.

3.5.2. Design shall account for constructability aspects and feedback from construction experience.

3.5.3. **Analysis Considerations**

(1) Safety related structures shall be designed for the responses for various load combinations determined from static as well as dynamic analysis.

(2) For structural configurations that are not amenable to routine analysis procedures or, in case of first of a kind structural configuration, the analysis shall be supported by adequate testing.

(3) Static analysis shall be carried out to determine structural responses under static and equivalent static loadings, and dynamic analysis additionally under seismic and other design basis dynamic loadings.

(4) Both, Classical Method and Finite Element Method (FEM) of structural analysis are acceptable. Applicability of the methodology shall be demonstrated and the software validated.

(5) Linear structural analysis shall be used to evaluate structural response for the design. Nonlinear/ equivalent linear analysis for design purpose may be required in certain cases, like direct approach for soil-structure interaction and raft lift-off analysis due to seismic excitation, which may be appropriately justified.

(6) For load combinations LC1 to LC6, adequacy of the design of the structures shall be demonstrated through compliance of the provisions of the relevant design codes, and not through "design by analysis approach".

(7) The mathematical model for the analysis shall include, as a minimum, all the structural components and elements that form the primary load-resisting systems.

(8) The types of finite elements used to model the structural system shall depend on the type of structure and the response parameters of interest.

(9) Finite elements susceptible to shear locking shall not be used unless this phenomenon is demonstrated not to be present in the analysis results.

(10) The Finite Element (FE) Model shall produce response parameters of interest pertaining to design objective, and not be significantly affected by further refinement in element mesh size and shape.

(11) Requirements related to mesh refinement of FE Model to be used in the analysis shall be state-of-the-art on the subject carrying out the mesh convergence study.

(12) The model for seismic analysis shall appropriately represent the location of mass and stiffness, thus accounting for moment and torsional effects caused by the eccentricity. Actual and accidental torsion shall be considered in the design of structure and its members. Forces due to accidental torsion shall only be used to increase the member forces.

(13) Soil-structure interaction effects shall be considered in the analysis of structures for both static and dynamic analysis unless the fixed base analysis is justified.

(14) Analysis considering nonlinear material models can be adopted for margin assessment, specifically for events having magnitude beyond the design basis.

(15) For structures situated in soft soil, design shall consider detailed numerical modeling for soil structure interaction, soil nonlinearity and applicable soil strain states (static as well as dynamic conditions corresponding to OBE and SSE).

Loads and load combinations

3.5.4. Unless otherwise specified, the following individual loads shall be considered in the design. The details of the loads (class, category, etc.) are described in Appendix A.

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

E_o : Load effects due to 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 severe wind specific for the plant

FF : Design basis flood

E_{ss} : Load effects due to safe shutdown earthquake including 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 the site

F_h	:	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 impact 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 Ro
Yj	:	Jet impingement load on a structure generated by a design basis accident
Yt	:	Loads on the structure generated by the reaction of the broken high energy pipe during design basis accident
Ym	:	Missile impact load on a structure, such as pipe whip generated by design basis accident
E_{LE}	:	Loads due to Extreme earthquake (EE) including responses of supported components, piping and equipment, hydrodynamic effects and dynamic effects of surrounding soil
P_{LE}	:	Loads beyond design accident pressure to estimate the ultimate load bearing capacity

3.5.5. Magnitude of different loads shall be estimated based on the following:

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

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

(3) The Design Basis Ground Motion (DBGM) shall be determined in accordance with the stipulations of AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1) [4] following the methodology described in AERB Safety Guide, AERB/SG/S-11 [12].

(4) The design basis flood shall be determined in accordance with AERB/NF/SC/S (Rev-1) [4] following the methodology described in AERB/SG/S-6A [13], AERB/SG/S-6B [14] and AERB/SG/S-11[12], as applicable.

(5) The wind load should be determined from site specific data using criteria given in AERB/NF/SC/S (Rev-1) [4] and for appropriate life period for which facility is to be designed. In the absence of site specific data, wind load may be

determined from IS 875 (Part 3) [27], using criteria given in AERB/NF/SC/S (Rev-1) [4] and AERB/NF/SG/S-3 [15]. In any case, the loads obtained using IS 875 (Part 3) [27] shall be taken as minimum.

(6) If applicable, assessment of structures against aircraft impact and its consequences shall be carried out using realistic analytical model and realistic assumptions about the size and velocity of the aircraft.

3.5.6. The following load combinations shall be considered for design/ assessment of NFs:

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
These load combinations include Normal and extreme environmental loadings.

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

LC5 : 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.

LC7: Environmental Load Combinations for ADC
These load combinations include normal loads and loads due to rare/ extreme external events. For this purpose, only one rare/ extreme event (and correlated events, if applicable) shall be considered at a time.

LC8: Abnormal Load Combinations for ADC
These load combinations include normal loads and loads arising out of severe accidents/ beyond design basis internal events. For this purpose, only one severe accidents/ beyond design basis internal events (and correlated events, if applicable) shall be considered at a time.

Materials

3.5.7. Materials used for construction of civil structures shall conform to acceptable level of durability, strength and stability requirements (under the radiation field). AERB Safety Guide on 'Materials of construction for civil engineering structures important to safety of nuclear facilities', AERB/NF/SG/CSE-4 [16], provides guidance on the Materials to be used in construction of civil structures.

3.5.8. Stability of the materials under the radiation field shall be ensured and build-up of induced activity shall be minimized.

Design of structural elements

3.5.9. The structure shall be designed for strength and serviceability due to loading effects throughout the lifetime depending on design requirements. Design considerations shall include functional requirements subsequent to operational life of the facility.

3.5.10. 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 (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.

3.5.11. Design considerations for different types of structures shall be as given below. Graded approach (Section 2.8) shall be followed while addressing these considerations.

(1) Concrete structures

Design Class DC3 concrete structures important to safety shall be designed in accordance with the provision of AERB Standard AERB/SS/CSE-1 [7].

(2) Steel structures

Design Class DC3 steel structures important to safety shall be designed in accordance with the provision of AERB Standard AERB/SS/CSE-2 [8].

(3) Containment Structures

3.5.12. The strength of the containment structure, including locally stressing elements, such as, buttresses, ring beam; and appurtenances such as access openings, penetrations, isolation valves, etc. shall be estimated based on the internal pressures and temperatures and dynamic effects such as missiles and reaction forces resulting from the design basis accidents, design extension conditions, impact of external events and appropriate combinations of internal and external events.

3.5.13. The design/ assessment shall consider containment response for pressure and temperature buildup and for effects associated with thermal conditions and dynamic loads. Design provision shall be made to prevent loss of the containment structural integrity in all plant states.

3.5.14. An assessment shall be made of ultimate load bearing capacity of the primary containment structure. The layout of the containment shall be such that sufficient testing, and repair, if necessary, can be conducted at any time during the life of the plant.

3.5.15. The containment structure and internal systems shall be designed and constructed in such a way that it is possible to perform a pressure test at a specified pressure to demonstrate its functional and structural integrity. The pressure tests and the structural integrity tests shall be in accordance with AERB Safety Guide 'Proof and leakage rate testing of reactor containments', AERB/SG/O-15 [17].

3.5.16. The number of penetrations through the containment shall be optimized and all penetrations shall meet the same design requirements as that of containment structure

3.5.17. The reactor containment structures irrespective of reactor types are classified based on the magnitudes of their LOCA pressure[7] as below:

i. Class L:
Containment for which LOCA pressure is less than or equal to 0.035 MPa.

ii. Class M
Containment for which LOCA pressure is greater than 0.035 MPa and less than or equal to 0.20 MPa.

iii. Class H
Containment for which LOCA pressure is greater than 0.20 MPa.

3.5.18. The concrete containment structures shall be classified as design class DC2. Class L containment structures shall be designed and constructed in accordance with the requirements of safety standard AERB/SS/CSE-1. Class M and Class H containment structures shall be designed following the requirements of specialized containment standards[8].

3.5.19. Embedded parts and penetrations important to safety shall be designed to meet the strength, serviceability, stability and radiation shielding requirements, as applicable. The design shall be in accordance with the AERB Safety Standard on 'Design, fabrication and erection of embedded parts and penetrations important to safety of nuclear facilities', AERB/NF/SS/CSE-4 [9].

3.5.20. Structures outside the nuclear facility, like dams and embankments, which may influence the safety of facility, shall be analyzed and designed/assessed for the loads and load combinations similar to affected structure of the facility as per relevant national standards. In absence of feasibility to design / assess those structures for the anticipated loads, the consequences of their failure shall be considered in design of the NF.

3.6. Design for internal events

3.6.1. The design shall take due account of internal hazards, such as fire, explosion, flooding, missile generation, collapse of structures and falling objects, pipe whip, jet impact and release of fluid from failed systems or from other installations on the site. The events may include failures or mal-operation of equipment. Appropriate features for prevention and mitigation shall be provided to ensure that safety is not compromised.

3.6.2. Some external events may initiate internal fires or floods and may also cause the generation of missiles. Such interaction of external and internal events shall also be

7 For FBR, equivalent pressure due to appropriate accident condition may be considered in place of LOCA pressure

8 In absence of AERB standards, ASME (Section-III, Div. 2) and ETC-C are acceptable standards for design of containment structures considered in the design, wherever appropriate.

3.6.3. SSC important to safety shall be designed and located in a manner that minimizes the probability of occurrence and effects of fires and explosions caused by internal events.

3.6.4. Design adequacy of identified structures under DEC shall be ensured following the requirements of Chapter 8.

3.7. Design for external events

3.7.1. The safety of NF structures under external events shall be achieved through:

(1) Locating the facility as per the requirements specified in AERB safety code for site evaluation of NFs [4].

(2) Designing the nuclear facility against the loads arising out of the potential external events at the site

(3) Monitoring the potential hazards around the site continuously and assessing the safety of structures of NFs against these change in hazards periodically, and implementing compensatory measures (retrofitting) of the facility when maximum intensity level of impacts, as accepted in the design bases, is exceeded.

(4) Where site is located near airforce stations or it falls in their test flying range, consideration for possible vibrations of the structures caused by “sonic boom” (due to ultrasonic fighter planes, especially at the time of landing) shall be given.

3.7.2. The design shall consider those natural and human induced external events (i.e. events of origin external to the plant) that have been identified through adequate conservatism in the site evaluation process. Applicable natural external hazards include events, such as earthquakes, tsunami, floods and winds, and meteorological conditions. Human induced external events include those that are identified in the site evaluation, such as potential aircraft crashes, ship collisions, large area fire and air-shock wave due to explosions in nearby transport corridors and nearby hazardous industries. Loss of Ultimate Heat Sink from conditions arising out of external hazards shall be addressed.

3.7.3. The design of the plant shall provide for a sufficient safety margin to protect against site specific external events (earthquake, flood, extreme wind, and temperature) and to avoid cliff edge effects. While evaluating margins, acceptance criteria with respect to functionality and collapse prevention are prescribed in Table 8.3 in terms of allowable storey drifts.

3.7.4. Where the results of engineering judgment, deterministic safety assessments and probabilistic safety assessments indicate that combinations of events could lead to AOOs or to accident conditions, such combinations of events shall be considered to be DBAs, or shall be included as part of DECs, depending mainly on their likelihood of occurrence. Certain events might be consequences of other events, such as a flood following an earthquake, fires (electrical, chemical, etc.) following an earthquake, debris and sediments accumulation due to tsunami, and explosion and fire due to aircraft impact. Such consequential effects shall be considered to be part of the original postulated initiating event.

3.7.5. For multi-facility sites, hazards used for design should be arrived by considering the site as a whole to account for the interactions between the facilities.

Earthquake

3.7.6. The NFs shall be designed to be safe against earthquake determined considering the annual probability of exceedance stipulated in AERB safety code for site evaluation of NFs [4]. The earthquake levels and design input shall be determined in accordance with AERB Safety guide, 'Seismic studies and design basis ground motion for nuclear facility sites', AERB/NF/SG/S-11 [12]. The structural response due to seismic excitation shall be determined using appropriate structural analysis.

3.7.7. For Civil Engineering Structures of NPPs:

(1) Seismic Category 1 SSCs shall be designed for S1 (OBE) and S2 (SSE);

(2) Seismic Category 2 SSCs shall have the capability to withstand the effect of S1 (OBE);

(3) Seismic Category 3 SSCs shall meet the requirements of national standards;

(4) Structures identified to perform basic safety functions and those structures identified for post-accident management shall remain functional under specified (extreme) earthquake levels beyond S2 (SSE) as defined in AERB/SG/S-11.

3.7.8. For civil engineering structures of NFs other than NPPs, seismic design requirements are given in Table 2.3.

3.7.9. Seismic analysis and qualification of all Class A and B Structures (Table 2.2) of Hazard Category 1 NFs and also Class B Structures of Hazard Category 2 NFs[9] shall be performed in accordance with the AERB safety guide, AERB/NPP-PHWR/SG/D-23 [10]. Class A structures of NFs other than NPPs which are identified to perform basic safety functions, shall remain functional under specified (extreme) earthquake levels beyond S2 (SSE) as defined in AERB. Whenever it is required to consider the fatigue effect, the design/ qualification shall be done as per AERB/NPP-PHWR/SG/D-23 [10].

3.7.10. Ductile detailing shall be carried out, as per applicable code of practices used for design of structure, to enhance seismic performance. Credit for ductile detailing may be taken only for displacement based margin assessment.

3.7.11. All Structures of Hazard Category 3 and lower shall be designed/ qualified for earthquake resistance as per the requirements specified in Table 2.3.

[9] By definition, there are no Class A structures in Category 2 NFs

Wind

3.7.12. The plant structures shall be designed with sufficient margin to prevent structural damage during the maximum potential wind loadings appropriate for the site, determined considering the annual probability of exceedance stipulated in AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1) [4].

3.7.13. The method specified in IS 875 (Part 3) [27] shall be used to transform the design basis wind speed into an equivalent pressure on structures and to select pressure coefficients corresponding to the structure's geometry and physical configuration.

3.7.14. Atmospheric pressure change effects shall be transformed into design loads for open and enclosed structures. The missile effects from wind loadings shall be appropriately transformed into equivalent static loads on structures.

3.7.15. Dynamic effects of the wind shall be considered for structures whose natural period of vibration is greater than 1 second. Special structures (such as chimneys and transmission towers) shall be designed following the specific requirements in the respective national standards in conjunction with the provisions of IS 875 (Part 3) [27].

Flood

3.7.16. The site shall be designed as a "dry site". If the dry site is not feasible, measures such as landfills, dykes and sea walls shall be resorted to protect against external flooding. Under such cases, these mitigation structures shall be classified as safety related structures and designed accordingly.

3.7.17. Site drainage shall be designed for discharging flood water resulting from value of precipitation corresponding to 10^{-2} annual frequency of exceedance for overall site. In addition, the safety related structures, systems and components, waste storage/ management areas and escape routes or entrance/ exit roads to safety related areas shall not be flooded due to flood with mean annual frequency of exceedance specified in AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev 1) [4]. The external openings below grade level shall be minimized and all such openings including tunnels and trenches shall be engineered to protect against entry of water into the below grade elevations of safety related structures.

3.7.18. The structures of NFs shall be capable to withstand the static and dynamic effects including debris impact of the highest flood and loading from ground water levels with sufficient margin to prevent structural damage for the most severe flood and groundwater levels for the site. The design basis shall consider the following aspects:

(1) The most severe flood as per the return period corresponding to the category in AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S with an appropriate margin

(2) Appropriate combination of the effects of normal and abnormal conditions with the effect of the natural phenomena

(3) The importance of the safety functions to be performed

3.7.19. At sites where available margins are less (Refer Chapter 8), emergency power equipment and cooling pumps to cater to basic safety functions shall be installed in dedicated, bunkered and well maintained watertight buildings and compartments.

3.7.20. Unless the hydrostatic head associated with the highest flood and ground water levels is relieved by utilizing a drainage or a pumping system around the foundations of structures, hydrostatic pressure has to be considered as a structural load on basement walls and the foundation slab of a structure.

3.7.21. For consideration of uplifting or floating of a structure, total buoyancy force may be based on the water table considered at the finished grade elevation excluding the wave action. If load combinations include S2 (SSE) level of earthquake, the water table may be considered at existing ground level of site while calculating the total buoyancy force. However, the wave action shall be included in the calculation for lateral and overturning moments of a structure. The dynamic loads of wave action shall be considered, if the flood level is above the finished grade level.

3.7.22. Propagation of flood waves onto or around the site could result in several correlated phenomena, apart from flooding. If applicable, the design of the facility should address such phenomena. These phenomena along with possible design measures for site protection during flood [30] are enumerated below:

(1) Flooding

The protection from flooding effects of flood waves can be provided either by locating SSCs important to safety above the design basis flood level or adequate flooding protection can be provided to ensure that the function is not compromised. Landfilling necessary to raise the plant above the level of the flood conditions for the design basis flood, should be considered as an item important to safety and should be designed and maintained.

(2) Scouring

Flood waves and in particular tsunami currents may potentially result in scouring and damaging the foundations. If applicable, all safety related structures and in particular intake structure, should be assessed and designed to resist the scouring.

(3) Deposition

If applicable, all items important to safety should be located and designed such that they are not affected by the deposition of debris and sediment from flood waves and currents.

(4) Hydrostatic and hydrodynamic forces

Items important to safety that are exposed to various phenomena associated with flood wave passage that induce force loading, e.g. hydrostatic force, buoyant force, hydrodynamic force, surge force, impact force, and breaking-wave forces, should be adequately designed.

(5) Debris and projectiles

Design criteria should be employed for identified SSCs important to safety exposed to impacts from water-borne debris and projectiles due to tsunami wave propagation. An alternative is to locate SSCs such that they will not be exposed to water-borne debris and projectiles.

(6) Dry intakes during drawdown

NPPs that have safety related cooling water supply from onshore/ offshore intake structures should ensure that the maximum extent of recession and the accompanying lowering of the water level near the intake location do not result in dry intakes during tsunamis. To address the same, the intakes may be located beyond the estimated recession point or provision of adequate dead storage may have to be provided. Else, alternate provisions for safety-related water supply should be made available from a source/ storage which is not affected by tsunami waves.

Temperature

3.7.23. Thermal loading of buildings/ structures due to climatic and operational temperature changes shall be considered in the design of the buildings where there is a possibility of ultimate or serviceability limit states being exceeded due to thermal movement and/or stresses.

3.7.24. Thermal loads shall be determined for each relevant design situations. The elements of load bearing structures shall be checked to ensure that thermal movement shall not cause overstressing of the structure, either by provision of joints or by including the effects in the design.

3.7.25. Temperature load on buildings due to climatic and operational temperature changes shall be determined accounting for regional data and experience. The climatic effect shall be determined by considering the variation of shade air temperature and solar radiation.

3.7.26. Thermal loads on structure shall be specified using uniform temperature component, linearly varying temperature component and temperature difference between different parts of the structure. While calculating the thermal loads the initial temperature (stress-free temperature) shall be taken as the temperature of the structural element at the relevant stage of its completion. If it is not predictable, average temperature during the construction period shall be taken.

3.7.27. The range of temperature due to solar radiation varies for different regions and under different diurnal and seasonal conditions in the country. The absolute maximum and minimum atmospheric temperature (in shade), which may be expected in different localities in the country, are provided in IS 875 (Part 5) [28] and shall be considered as the minimum requirement in this regard including its applicability. Depending upon the structural configuration, type of construction material, etc., actual temperature profile experienced by the various structural members could differ. This shall be appropriately accounted for in the analysis and design. The structural analysis shall account for the following:

(1) Change of the mean temperature through section with respect to the initial temperature

(2) Temperature gradient through the section.

Aircraft Impact

3.7.28. Requirements for design or assessment of structures against aircraft impact shall be determined as per applicable AERB Design codes. For design of the structures against aircraft impact hazard, conservatively derived analytical model and realistic assumptions about the size and velocity of aircraft shall be considered. Global and local effects due to aircraft impact shall include impact due to hard and soft missiles, vibration effects, shockwave and fire due to fuel.

3.7.29. Design of identified structures for the load arising out of these effects shall be carried out as per AERB Safety Standard on 'Design of concrete structures important to safety of nuclear facilities', AERB/SS/CSE-1 [7] and AERB/SS/CSE-2 [8] for safety related concrete and steel structures, respectively.

3.7.30. For assessment of structures against the impact of an aircraft, requirements specified in Section 8.2.13shall be used for computational model and assumptions about the size of the aircraft, its velocity and other impact related parameters. The assessment shall consider global and local effects of aircraft impact hazard.

3.7.31. **Other Natural and Human Induced External Events**

(1) The events due to chemical and toxic gas release and other human-induced hazards shall be avoided by selecting the site at a safe distance by satisfying screening distance value (SDV) stipulated in AERB Safety Code on 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1) [4]. Else their effects shall be assessed (as per AERB/SG/S-7) and accounted for in design.

(2) If applicable, drop loads during operation of cranes shall be accounted for in design.

(3) The buildings and structures important to safety or part of them shall be protected from events, like missiles due to turbine disintegration; Low Trajectory Turbine Missile (LTTM), by suitable plant layout and structural layout, else it shall be accounted in the structural design.

(4) Loads due to shrinkage shall be considered in the design of structures. Shrinkage depends on relative humidity, volume to surface area ratio of structural element,

composition of concrete like cement type, cement content, fine aggregate to total aggregate ratio, presence of silica flume in the concrete, air content etc., property of concrete like workability, characteristic strength, etc. Relative humidity has to be estimated based on data obtained from the meteorological station at site or based on data from a station that represents the site under consideration.

3.8. Design Requirements related to Geotechnical Aspects

3.8.1. The safety of NFs related to geotechnical aspects shall be assessed for the following:

(1) Safety of site against ground failure

(2) Safety of foundation system

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

3.8.3. 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 the possible scenarios leading to malfunctioning of structures, systems and components due to undesirable behavior of foundation systems. In case of soil sites, effects due to combined interaction between adjacent structures and soil shall also be considered in the analysis.

3.8.4. For Hazard Category-1 & 2 facilities, geotechnical investigation and characterization shall be performed as per AERB Safety Guide, ‘Geotechnical aspects and safety of foundation for buildings and structures important to safety of nuclear power plants’. AERB/NPP/SG/CSE-2 [11]. The safe design of foundation system and safety assessment of site against ground failure shall be performed as per AERB Safety Guides AERB/NPP/SG/CSE-2 [11] and AERB/SG/S-11 [12].

3.8.5. Tailings dams and the earthen embankments that confine them shall be designed using information on tailings characteristics, available construction materials and site specific factors (such as topography, geology, hydrology and seismicity). The design and construction of embankment system for the storage of tailings slurry should meet the safety criteria of relevant standards with respect to long term stability, particularly against erosion, heavy rain, flood and seismic events. Stability analysis for embankments shall be carried out under both static and dynamic loading conditions at various cross-sections of dams at every stage of construction. The design of Tailings Management Facilities shall be performed as per AERB Safety Guide, ‘Radiological safety in uranium mining and milling’, AERB AERB/FE-FCF/SG-2 [19] and AERB Safety Guide ‘Siting, Design, Construction, Commissioning, Operation, Closure and Monitoring of Tailing Management Facilities for Uranium Ore processing’, AERB/FE-FCF/SG-4 [33].

3.8.6. Need for monitoring of soil foundation system shall be assessed. In case of foundations of identified safety related structures in soils and safety related earthen structures (e.g., tailings dam), necessary instrumentation shall be provided to monitor the relevant structural responses/ geotechnical parameters.

3.9. Special Requirements

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

Requirements against Fire

3.9.2. Approach to fire safety needs to be consciously incorporated in planning, layout, design and construction stages. Protection against fire hazard consists of two measures, namely: (i) direct measures, and (ii) passive or in-built measures. The direct measures i.e. detection, and firefighting arrangement, shall be developed in line with AERB stipulations, and the passive measures such as choice of fire resistant materials, provision of barriers, etc. in construction of building structures shall be in line with relevant AERB codes/standards. Adequate care shall be taken for fire due to dry grass in open areas, especially during summer months.

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

(1) The fire rating of roof and external cladding, internal walls, slabs and any fire barrier in buildings important to safety shall not be less than 3 hours

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

(3) 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 passes.

Design of Structural Elements against Fire Hazard

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

(1) 0.0010d, for fire resistance of one hour

(2) 0.0015d, for fire resistance of longer duration

in which, “d” is the “spacing between expansion joints” in mm.

3.9.5. The design and detailing of concrete and steel structures shall conform to AERB Safety Standard on ‘Design of concrete structures important to safety of nuclear facilities’, AERB/SS/CSE-1 [7] and AERB/SS/CSE-2 [8] respectively. The design shall also satisfy provisions of national standards.

3.9.6. Ability to prevent spread of fire and to protect the building occupants are not adequate to assure fire safety. Although this standard provides design requirements for fire resistance of building structures based on prescriptive approach, performance based design addressing structural response to different fire scenarios may be necessary for robust and effective design of the buildings. In this regard, state of the art concepts are helpful in identifying performance objectives, conducting risk analysis, selecting design fire scenarios and fire exposure curves for the fire-resistant design of concrete and steel structures.

Requirements for Decommissioning

3.9.7. For decommissioning activities of the facility, requirements for buildings/ structures are as follows:

(1) Identify buildings/ structures that are kept to be under surveillance for a long time
(2) Develop suitable design criteria of these buildings
(3) Plan a 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 easy dismantling
(5) Undertake suitable measures, such as appropriate surface finish, surface hardness, painting, for easy decontamination. The painting shall withstand requisite radiation field
(6) Provide necessary protection and safeguard capability and sufficient strength against the possible hazard and accident during decommissioning
(7) Limit consequences of degraded structural elements of buildings.

Other Considerations

3.9.8. 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 below:

(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 for NPPs or design requirements corresponding to highest class of structure of NF as per Table 2.1.
(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 at least 3 years, otherwise requirement of Section 3.5 shall be satisfied.
(3) The intake structures identified to serve as ultimate heat sink even during the design extension conditions shall be qualified for rare extension conditions so that the basic safety functions are met.

Structural Instrumentation

3.9.9. For assessment of structural behaviour, monitoring and ageing management as well as for life extension studies, periodic health monitoring shall be carried out for all safety related structures.

3.9.10. Structural instrumentation capable of collecting data on structural parameters, like rebar stress/strain, concrete stress/strain, prestress loss, rebar and prestress cable corrosion, temperature, deformation, vibration, deterioration and leakage, shall be provided for identified structures and in particular, containment structure. For strong motion seismic instrumentation, AERB Safety Guide, AERB/SG/S-11 [12] should be referred.

3.10. Margin/Capacity Assessment

3.10.1. Margin/Capacity assessment of structures to demonstrate its functionality beyond its design basis shall be undertaken using realistic assumptions regarding material, loads, and acceptance criteria.

3.10.2. Age related deterioration of structures, if applicable, shall be captured. For structures identified to perform the basic safety functions as well as those structures identified for post-accident management under DEC and extreme external events exceeding design basis, margin assessment shall be carried out for load combinations LC7 & LC8 under assessment design conditions.

3.10.3. Margin/Capacity assessment can be carried out as a part of periodic assessment/ re-evaluation during the operating life of the facility.

3.10.4. In margin assessment, nonlinear analysis should be carried out for calculating the responses of the structures considering realistic/actual properties of the materials without consideration of partial safety factor for load and material. When simplified approaches (for seismic reevaluation purpose only) wherein nonlinearity and over strength are accounted indirectly through response reduction factors and inelastic energy absorption factors, the material safety factors and load factors shall be same as that for abnormal design conditions. Chapter 8 provides detailed requirements for margin assessment for different events.

4. CONSTRUCTION

4.1. General requirements

4.1.1. Construction activities shall be planned, scheduled and sequenced. Necessary interface between construction and design organizations shall be established during planning and design stages to ensure that the resulting structural design is amenable for construction. Feedback from previous construction experiences involving difficulties in construction, inspection and maintenance, shall be appropriately addressed in the design stage itself.

4.1.2. The sequencing of construction activities shall ensure that prior construction work shall not be adversely affected by later construction works. The sequence of construction shall be such that the construction activities of a building do not jeopardize the safety of the adjacent or nearby buildings/ structures or part of it, which has already been constructed. Requirements of industrial safety as per Atomic Energy (Factories) Rules [6] shall be satisfied.

4.1.3. The construction methodology shall be so adopted that the design intents of the buildings/ structures are satisfied. The construction methodology for safety related structures shall be prepared and sequences given due considerations of decommissioning. Regulatory review of construction methodology, quality assurance programs for construction, mix designs and other relevant documents, shall be completed prior to start of construction.

4.1.4. The development and qualification of well-defined methods of construction, inspection or testing that are relevant to safety, shall be completed before commencement of the construction activities, especially for the application of first-of-a-kind technology. 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.

4.1.5. The licensee and the construction organization shall ensure that sufficient qualified and experienced personnel are available for the construction project as per requirement. Processes shall be put in place to ensure initial qualification and continuous qualification of personnel.

4.1.6. Safety culture shall be developed in all individuals of the participating organizations, viz. licensee, contractor etc., with account taken of their roles in terms of safety significance. The construction methodology shall be developed and implemented in such a way as to help all interested parties involved in the construction project to strengthen safety culture, particularly in organizations less familiar with nuclear safety requirements. A system shall be established for training of personnel, who have been transferred to projects for the construction of a nuclear facility from other industries, to make them aware of the additional issues associated with nuclear safety.

4.1.7. Design changes that could have an impact on safety shall be minimized after construction starts and recorded by means of a well-defined process. Design changes shall be implemented at site only after due approval of the designers. Any major change in the design shall be approved by the regulatory body prior to its implementation.

4.1.8. All construction joints shall be made in strict compliance with the approved construction drawings. Any changes in the location of construction joints shall have the approval of designers.

4.1.9. During construction, comparison shall be carried out between the as built plant and its design parameters. Comprehensive photographic records and, where appropriate, video records and computer simulations, shall be collected and compiled, particularly for first of a kind activities and/or areas that will later be inaccessible for subsequent inspections. Such visual records of as built conditions made during construction shall show identification marks and should be comprehensively catalogued with descriptive captions.

4.1.10. A system shall be established for collecting all identified non-conformances and recording and processing them accordingly. Non-conformances of safety significance shall be treated as events, and shall be resolved by means of a corrective and preventive action program in a graded manner. A process should be put in place for obtaining regulatory approval of safety significant non-conformances, corrective and preventive actions.

4.1.11. Experience in construction and examples of good practices, not only from the present nuclear facilities, but also from the construction of other nuclear and non-nuclear facilities, shall be taken into account by the licensee, and lessons learnt be disseminated for enhancement of quality and safety within the industry.

4.1.12. Necessary fire protection measures shall be made available at the construction site, until the fire detection, protection and suppression systems for the installation are operational.

5. COMMISSIONING

5.1. General requirements

5.1.1. Prior to commissioning of the plant, tests on certain civil engineering structures shall be performed. Such tests shall be identified during the design stage itself and necessary provisions be made for the same. The objective of the test is to establish that the design requirements are met, and to validate the analytical design, if necessary.

5.1.2. The containment testing shall be done in accordance with the provision of AERB Safety Guide ‘Proof and leakage rate testing of reactor containments’, AERB/NPP/SG/O-15 [17]. The testing procedure of spent fuel pool and water retaining structures having potential radioactivity shall follow the procedure laid down in AERB/SS/CSE-l [7]. As per design requirements, testing of chimneys shall be carried out for specified leakage control.

5.1.3. Adequacy of shielding of civil engineering structures/ components shall be established including streaming aspects.

5.1.4. If any structure or structural component is required to be tested for any particular reason, the specification of test shall be developed prior to undertaking the testing. The 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. These activities shall also be carried out for tailings dam, check dams and cutoff drains etc. All these activities shall be carried out satisfying the requirements AERB/SC/O [20]. 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. Effective maintenance of Civil Engineering Structures important to safety is essential for safe operation of NFs. A maintenance program for Civil Engineering Structures important to safety shall be prepared covering preventive and remedial measures, of both administrative and technical nature, necessary to perform maintenance activities satisfactorily. The range of activities shall include inspection (including in-service inspection), repair and replacement of parts and painting, as appropriate and testing. It may include modifications to structures.

6.2.2. The maintenance program shall cope with plant structures that are in operation, and plant structures that are already constructed but awaiting operation. The maintenance program of NFs shall be planned on the basis of periodic inspection. Inspection shall typically include detection of physical damages, spalling, cracking, damage due to corrosion phenomena, loosening of EPs, joints of structural framework and leak detection of fluids. The maintenance group shall periodically monitor data as well as review maintenance records for evidence of incipient or recurring failures.

6.2.3. Preventive maintenance entails pre-planned routine inspection, repairing and testing of Civil Engineering Structures. Its purpose is to detect incipient failures and to ensure continuing capability of the structure to perform its intended functions. These pre-planned activities shall be specified in a preventive maintenance schedule. The need for remedial maintenance may arise when deficiencies or failures are noticed during plant operation.

6.2.4. To observe and check the behavior of safety-related Civil Engineering Structures of NPPs, strains in structural elements, prestressing force in cables, settlement of structure, crack width, and creep of concrete shall be monitored during the life period. To collect these data, necessary instrumentation shall be provided during construction stage itself. Similar instrumentation and data requirements, including that of seismic instrumentation, for NFs other than NPPs shall be identified at design stage. Requirements for collection and analysis of data, protection and maintenance of instrumentation shall be included in the technical specification and/or maintenance manual of the NFs.

6.3. In-Service Inspection

6.3.1. In-service inspection shall be undertaken to evaluate the status of the structure with respect to continued safe performance following established criteria. The criteria used for maintenance are pertinent only with respect to the maintenance aspect. Inspection for maintenance is a regular feature and shall be carried out at higher frequency, while in-service inspection, being more thorough, may be carried out at a lower frequency and after occurrence of any abnormal event.

6.3.2. The extent and stringency of in-service inspection requirements are related to safety significance of the structures to be inspected and tested. The acceptance standards for inspections, tests and corrective actions, such as repair of structures, if ascertained to be unsatisfactory, shall be chosen accordingly. Safety classes assigned to the structures in the design of the plant may be taken into consideration for in-service inspection classification.

6.3.3. The Civil Engineering Structures subjected to in-service inspection shall be inspected by visual method as a general rule and by surface and volumetric methods, wherever necessary on the basis of findings of visual method. In addition, in-service testing to ascertain possible leakage shall check the integrity of the pressure-retaining structures.

6.3.4. Pre-service inspection shall be performed before the commencement of operation to provide data on initial conditions supplementing manufacturing and construction data as a basis for comparison with subsequent inspections. This inspection shall be similar in method, technique and use of equipment as those planned to be used later during ISI, as far as practicable. The pre-service inspection shall be extended to cover all structures or structural parts, which are subject to in-service inspection. When any structural part is repaired or replaced, a pre-service inspection shall be performed on that part prior to its commissioning.

6.3.5. Frequency at which ISI is conducted shall be defined within the inspection procedure. Frequency shall take into consideration the aggressiveness of environmental conditions. The established frequency shall assure that any age-related degradation is detected at an early stage and appropriate mitigation actions can be implemented.

6.3.6. The findings during visual inspection shall be reviewed to judge whether the inspection is adequate or further evaluation is needed, using enhanced visual inspection (magnification, etc.), testing or other analytical technique. Any inspection giving indications of distress/deterioration exceeding the acceptance criteria shall be supplemented by other non-destructive inspection methods and techniques, to establish the character of the defect (i.e. size, shape and orientation) and thus determine the suitability of the structure for further operation. It shall be ensured, while choosing supplementary techniques and methods, that the conditions affecting the structure are thoroughly investigated.

6.3.7. When the evaluation indicates that the structure is unacceptable for continued operation, then the structure shall be repaired/strengthened or rebuilt. Structures after repair shall be restored to their desired strength, durability and serviceability. The structures shall be repaired in accordance with the codes and standards that were applied at the time when the structure was constructed and in accordance with the quality assurance program in effect at the time of repair. Confirmatory investigations shall be carried out after major repairs and this data shall form the future baseline for monitoring of the structure.

6.4. Ageing Management Program

6.4.1. 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 pose risk to public health and safety. Measures against ageing degradation shall 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.

6.4.2. Environment effects and various types of phenomenon can cause ageing of structures of NFs. To ensure safety of the facility over the lifetime, ageing management program shall be implemented for all civil engineering structures associated with NFs following a graded approach. Periodic maintenance of structures is the first step towards ageing management program. Maintenance shall include inspection, repair and replacement of parts, as appropriate, periodic testing and modification to structures. Effective maintenance ensures effectiveness of structures for its safe operation as per design intent. Maintenance of safety structures pertaining to NFs shall be based on AERB/SM/CSE-1 [21].

6.4.3. In-service inspection of safety structures is an important and mandatory arm of ageing management program. In-service inspection comprises of detailed condition assessment of structures and is different from the routine maintenance. In-service inspection of structures shall be carried out periodically to ensure their efficacy and acceptability for continued safe operation of the plant. In-service inspection of structures pertaining to safety shall be conducted as per AERB/NPP/SM/CSE-2 [22].

6.4.4. Overall ageing management program of safety related structures of the plant shall identify:

(1) Effective and appropriate actions and practices to provide for timely detection and mitigation of ageing effects in the structure

(2) Indicators of the effectiveness of the program.

6.4.5. Ageing management of SSCs shall be implemented proactively (with foresight and anticipation) throughout the plant's lifetime, i.e., in design, fabrication/construction, commissioning, operation and decommissioning.

6.5. Health Assessment

6.5.1. Health assessment of Civil Engineering Structures can be prompted by one or more of the following reasons:

(1) Suspected structural damage,

(2) Change in intended use of structure,

(3) ISI as a part of ageing management, and

(4) Extension of structure design life.

6.5.2. Health assessment of plant buildings covers condition evaluation of a structure, determination of its structural adequacy for actual or proposed loads, or assessment of extent of damage and remedial measures. Assessment methodology shall depend on building configuration and physical constraints. Assessment techniques may range from a visual inspection through non-destructive techniques, to partially destructive sampling and testing. Condition evaluation may include time limited ageing analysis, condition survey followed by condition assessment and retrofitting, if necessary.

Time Limited Ageing Analysis

6.5.3. Time limited ageing of SSCs, such as loss of force in prestressing tendon, penetration pressurization cycles and fatigue analysis for the containment liner plate shall be monitored periodically and actions taken, including safety analysis, based on time dependent recorded data.

6.5.4. Time limited ageing analysis (TLAA) shall include SSCs, which are in operation for long term, and defined time related assumptions. It shall include effects of degradation and safety determination shall be as per regulatory requirement.

6.5.5. TLAA shall be included in periodic safety review as well as in ageing management program to assess the capability of structure to perform its intended function. TLAA need to be evaluated to ensure the following:

(1) The analysis remains valid for the intended period of operation.

(2) TLAA has been projected to the end of the intended period of operation.

(3) The effects of ageing on the intended function(s) of the structure or component will be adequately managed for the intended period of operation.

Condition Survey

6.5.6. Condition survey of existing buildings shall be objective and comprehensive. It shall include:

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

(2) Information collected 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

a) Condition of concrete and steel structure,
b) Apparent cracking,
c) Corrosion of the reinforcing bars of concrete structure, if exposed,
d) Inspection by non-destructive testing, and other techniques including coring, as appropriate, and
e) Load test, if warranted.

Condition Assessment

6.5.7. Condition assessment shall be carried out to estimate the extent of deterioration of durability, strength and stiffness with respect to the design requirements or its intent. The condition assessment shall be done using the data obtained from condition survey.

6.5.8. The classification regarding the type of up-gradation of the deteriorated structure or its component to be adopted, and whether a structure or its component is to be repaired/strengthened or replaced/rebuilt, shall be based on the following items as per design requirements or its intent:

(1) Functional requirements of the structural elements,
(2) Durability, design strength, and stiffness requirements,
(3) Affected strength and modulus of elasticity of the concrete, and
(4) Ductility and elastic limit of steel reinforcements.

6.5.9. Assessment of structures or component shall be based on the extent of damage vis-à-vis design requirements. In view of this, structures may be categorised on the basis of condition assessment and expected performance after repair and/or strengthening, as follows:

Type I: Structures/components that satisfy all design requirements fulfilling the stipulations of present regulatory documents.

Type II: Structures/components that fall below design requirements as per present regulatory documents but satisfy similar stipulations of regulatory documents prevailing during the time of construction of the plant.

Type III: Structures/components that do not satisfy the safety and design requirements prevailing during the time of construction.

6.5.10. During assessment of adequacy of structure, additional realistic considerations such as: characteristic as-built material strength of taking into account the time related degradation and extent of available data from construction period as well as realistic superimposed loads may be utilised. Analysis methodology and design criteria (including partial safety factors for load and material strength) as per applicable regulatory document shall be adopted. For loads/ load combinations covering external events as well as accident conditions, if justified, corresponding methodology as indicated in chapter 8 may also be followed.

Approach for Repair and Retrofitting

Based on condition assessment, decision regarding repair/strengthening, rebuilding/ replacement shall be taken based on the guidelines given below:

6.5.11. Repair methods shall be developed on the basis of results of condition survey, and condition assessment. Appropriate confirmatory studies shall be undertaken for the repaired structures/ components to ascertain their fitness with respect to structural integrity and serviceability.

Type I structures/components are safe and could be used after minor repairs, if required.

Type II structures/components are repairable. After rehabilitation, these structures shall satisfy the requirements of current day codes/standards. If the rehabilitated Type II structures are not able to meet the requirements of current day codes/standards, a detailed assessment of the behaviour of the structure considering applicable loading conditions shall be conducted taking into account functional and structural acceptance criteria. The operation of such structures for the identified duration shall be (i) under stringent periodic evaluation and monitoring or (ii) permitted to operate under de-rated capacity with periodic monitoring.

Type III structures/components are deteriorated. Any of the following approaches may be adopted for repairing/ strengthening and replacement/ rebuilding.

(1) If Type III structures are repaired to satisfy the design requirements fulfilling the stipulation as stated for Type I above, they may be used without any special provision after repair.

(2) Structures/components that cannot be repaired following the approaches mentioned in (i), the design requirements for these structures/ components shall be satisfied by strengthening so as to meet the condition of restricted/derated operation as specified for Type II structures.

(3) Structures/components that cannot be upgraded (repaired/ strengthened) using any of the approaches given in (i) or (ii) above, shall be replaced/rebuilt.

Type II and III structures after up-gradation shall undergo the confirmatory study.

6.6. Testing

6.6.1. During operation period, containments are required to be tested periodically. The tests shall be carried out as per AERB Safety Guide 'Proof and leakage rate testing of reactor containments', AERB/SG/O-15 [17]. If tests for any other structures or its members are required to be conducted, the requirements given in Chapter 5 shall be complied with.

7. DECOMMISSIONING

7.1. General requirements

7.1.1. Decommissioning of a nuclear facility is the process by which a nuclear 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 the environment.

7.1.2. Decision regarding decommissioning shall be taken following the requirements of AERB/SC/O [20].

7.1.3. 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 organization authorized by AERB or unrestricted use by public. All structures of a decommissioned NF cannot be released for public use. These structures shall be maintained in appropriate stable and sealed condition. The strategy and procedure of decommissioning of Civil Engineering Structures of NFs is provided in AERB/SM/DECOM-1 [34].

7.1.4. Scheme for decontamination and dismantling, to the extent necessary, of Civil Engineering Structures shall be developed considering their existing radiological conditions, layout and design features. Decommissioning of the Civil Engineering Structures, that are to be kept in "stable condition" for a long period, shall be carried out systematically employing following major steps:

(1) Assess the duration for which they should be maintained in "stable condition".

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

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

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

8. SAFETY ASSESSMENT OF STRUCTURES

8.1. General

8.1.1. Safety assessment of structures may comprise of capacity/margin assessment for demonstrating functionality under assessment design conditions or for revised design basis, assessment of structural health for continued operation and ageing management considering specific degradation mechanisms. The latter part is covered in Chapter 6.

8.1.2. Assessment of safety of NFs may be prompted based on the following:

(1) Evidence or perception of a greater hazard at the site than expected before owing to:

i. New/ additional data, like occurrence of external events of higher magnitude than envisaged earlier, and evidence of new features or change in characteristics of features that can alter/influence the considered hazard potential

ii. New hazard revaluation methods

iii. New information on relevant climatic change that may necessitate revision of design loads

(2) Revision of relevant codes/ standards and/or regulatory requirements.

(3) Requirement to ensure that the facility has adequate margins beyond the design loads.

(4) Expansion of the facility that may have an impact on the existing structure.

(5) Requirement of a periodic safety review.

8.1.3. Safety assessment of the structure shall be done in accordance with the provisions laid down in this document. If existing structure does not qualify for conditions described above, appropriate retrofitting shall be done.

8.2. Capacity/ Margin Assessment

8.2.1. The design of NFs shall have adequate margin to protect items important to safety against all external and internal hazards considered in design basis to avoid cliff edge effects. The margins available need to be assessed to demonstrate safety under different scenarios discussed in Section 8.1 above. Realistic assessment can be adopted to evaluate the consequences of the event.

8.2.2. Margin assessment against important external and internal events shall comply with requirements given in clauses here under. The design of NFs shall provide adequate margin to protect items ultimately necessary to prevent an early radioactive release or a large radioactive release in the event of levels of natural hazards exceeding those considered for design.

Assessment for Earthquake

8.2.3. For assessing capacity[10] against seismic motion, ground motion parameters shall be specified in line with AERB Safety Guide, 'Seismic studies and design basis ground motion for nuclear facility sites' AERB/SG/S-11 [12]. The evaluation process for seismic capacity deals with post-elastic behavior of structure and the numerical model shall be capable of simulating the phenomenon. Nonlinear response history analysis (NRHA) or nonlinear static procedures (such as Pushover Analysis (POA)) shall be used for seismic margin/capacity assessment.

8.2.4. Constitutive model of materials shall consider no material safety factors. The constitutive model shall be capable enough to capture inelastic behavior of materials in compression as well as in tension. In case of NRHA, material model shall be able to capture the cyclic behavior of material. Higher damping than that considered in design can be used with technical justification. But, for structures which are to perform additional functions that require limitations in cracking, the damping used shall be commensurate with the state of deformation corresponding to the functional requirement.

8.2.5. Simplified methods adopting design code based approach is permissible for seismic re-evaluation purpose, wherein nonlinearity and overstrength are accounted for margin assessment through the use of higher structural damping values and energy absorption factors listed in Table 8.1 and Table 8.2, respectively. This method is inherently conservative compared to nonlinear analysis based methods, because of the use of material safety factors and load factors as per the relevant design standards, as given in Table 2.3.

8.2.6. For structures identified to carry out basic safety functions under Extreme Earthquake (Section 2.7), capacity assessment shall be carried out and functionality of these structures for the intended purpose shall be demonstrated. Acceptance criteria corresponding to functional failure as given in Table 8.3, shall be used for this purpose. In addition, aspects like available seismic isolation gap, and other system requirements shall be considered while finalizing the acceptance criteria.

8.2.7. For capacity assessment, carried out for seismic re-evaluation, the acceptance criteria shall be defined in terms of functionality or collapse based on requirement, which shall be justified. Structural performance limits for collapse are given in Table 8.3. In cases, where such assessments are not able to demonstrate conformances with respect to structural response limits prescribed in Table 8.3, retrofitting shall be carried out.

[10] Capacity can be in terms of force, displacement, rotation, strain as applicable for the desired performance criteria

Assessment for Flood

8.2.8. Margin assessment of plant or structures against flooding shall be done for possible events that can flood the site/ structures. For inland site, extreme rainfall, seiches, canal/ river breach, dam break and for coastal site; extreme of individual tidal wave, wave run-up, storm surge, tsunami and their respective combination (as per design) shall be considered.

8.2.9. In case of dry sites, margin assessment against extreme external event involves demonstrating the validity of this assumption under the estimated beyond design basis flood level (BDBFL) for identified safety related structures. If 'dry site' is not envisaged for BDBFL, margin assessment against flooding shall be such that structures performing basic safety functions of the plant are functional under the consequences of the considered flooding event. If required, flood routing analysis using validated methods shall be carried out inside buildings to assess the impact of flooding on various SSCs.

8.2.10. Assessment of structures shall be carried out for hydrostatic load, hydrodynamic load and wave loads using empirical relations or fluid structure interaction (FSI). Wherever applicable, assessment shall consider effect of drawdown, debris impact, sediment and debris deposition and scouring, wind effects and precipitation.

Assessment for Wind

8.2.11. Margin assessment against extreme wind shall be carried out considering possible effects such as cross wind and gust effect in addition to regular wind speed. In case of structures where wind effects are expected to influence the safety, detailed analysis considering nonlinear material behavior shall be used for margin assessment. Methodology similar to pushover analysis adopted to assess the seismic margin can be used.

8.2.12. Effect of wind induced missile on structure, if applicable, shall be assessed by empirical approaches or by analysis using methodology similar to that for aircraft impact assessment.

Assessment for Aircraft Impact

8.2.13. Assessment against aircraft impact involves nonlinear analysis to estimate the structural response to the relevant global effect such as vibration and local effect such as spalling, scabbing, penetration and perforation. The assessment shall consider realistic size, mass and velocity of aircraft. Locations of aircraft impact on the structure shall be specified on the basis of realistic considerations with technical justifications.

8.2.14. The computational model shall be developed using coupled aircraft-structure interaction analysis or force-time history method.

8.2.15. The constitutive model of concrete shall be capable of capturing the nonlinear behavior at high strain rates and high confining pressure. The material model shall incorporate the compaction damage (pore crushing), compression damage, tensile damage, and post-cracking shear performance in the form of shear strength degradation. The constitutive model of the reinforcing steel shall include the effect of material yielding, strain hardening, strain rate hardening, temperature softening and damage. The fracture model of reinforcing steel shall include the effect of stress-triaxiality, strain rate and adiabatic effects. Dynamic strength properties and strain based failure criteria for the steel and concrete materials considered shall be justified.

8.2.16. For coupled aircraft-structure interaction analysis, the constitutive behaviour of the aircraft fuselage, wings and engines shall be modelled appropriately using the commercial finite element codes. The constitutive model of the different components of the aircraft shall also be suitably incorporated. The constitutive model shall include the effect of material yielding, strain hardening, strain rate hardening, temperature softening and damage. The fracture model shall include the effect of stress-triaxiality, strain rate and adiabatic effects. The computational model and the constitutive models of aircraft shall be appropriately validated before carrying out the full scale simulations. Empirical/ Semi-empirical formulations, if available, validated by tests/experiments can also be adopted case by case basis.

8.2.17. Adequacy of geometric modelling and mesh sensitivity analysis along with consistent numerical schemes shall be justified for the simulation. Numerical model of impact analysis shall have the capability to capture sufficient frequency range including high frequency structural responses.

8.2.18. The resulting fires due to aircraft impacts may cause damage to systems needed to maintain fuel cooling and the spent fuel pool as well. If the aircraft perforates the containment structure, an internal fire will result, both from burning jet fuel and the ignition of secondary combustibles. The fire damage caused by an aircraft impact can extend well beyond the physically damaged area due to the overpressure effects from the initial fireball and the spread of fuel through open pathways within the structure.

8.2.19. The post impact fire analysis shall include heat transfer and thermal degradation in a step by step manner to evaluate the resultant damage due to crash induced fire. Margin assessment for aircraft impact shall include the effects of fire due to fuel spillage. If there is no containment breach, then fire related damage or physical damage need not be considered from aircraft impacts on systems inside containment except damage due to shock loading. Additionally, the assessment of fire effect induced by aircraft impact on the outer containment and surrounding buildings needs to be performed under the external event category [31].

Assessment for Other Natural Hazards

8.2.20. Safety margin against hazards, other than seismic, flood and wind, considered in design, shall be assessed considering severity of hazards higher than those considered in design. Assessment should demonstrate functionality of structures to ensure that basic safety functions are not jeopardized.

Assessment for Other Human induced External Hazards

8.2.21. To ensure the safety of the plant/facility, assessment shall be carried out for effects of applicable human induced external hazards, (e.g. blast, fires, gas clouds and toxic gas releases), with due consideration of possible higher intensity of hazards. For each identified hazard, the parameters of interest shall be derived following methodology specified in AERB Safety Guide on 'Human-induced events and establishment of design basis', AERB/NPP/SG/S-7 [18]. Possibility of ingress of gases/liquids inside the structures and associated hazards arising out of the same shall be considered.

8.2.22. For determining higher intensity of hazards, probable increase in population/traffic in and around the areas shall be considered. For blast/explosions loading, propagation of shock wave through air along with overpressure shall be considered. If shock wave reaches plant structures, structures shall be assessed for overpressure and trailing negative (suction) pressure loading.

Assessment for internal hazards

8.2.23. Assessment of safety margin of structures for internal hazards generally shall include determination of ultimate load carrying capacity of containment structures. The purpose of this assessment is to determine the pressure capacity of the containment at which the structural integrity is retained, and a failure leading to a significant release of fission products does not occur. A complete evaluation of the internal pressure capacity shall address major containment penetrations, such as the equipment hatches, airlocks, and major piping penetrations; as well as stiffening elements such as buttresses, ring beam, etc. Large penetrations and stiffening elements shall be included in the finite element model. In case the margin for local failure around large penetrations and that for general sections are very close, smaller penetrations and penetration closure components in the critical areas shall be analyzed using a separate finite element model, test data, or both. If closed-form solutions or semi empirical methods are used to estimate the pressure capacity in lieu of nonlinear analysis, technical justification shall be provided.

8.2.24. In the analysis for estimating the ultimate load capacity, and in the interpretation and evaluation of results, the following aspects shall be accounted:

(1) The ultimate load carrying capacity assessment shall account for the effects of embedded features of the structure like the reinforcement and prestressing arrangement and liner configuration realistically. The effect of accident temperature on the ultimate load bearing capacity shall be accounted for.

(2) Calibration of nonlinear finite element model shall be done with responses obtained for design pressure and temperature to ensure linear elastic response of the nonlinear model. The initial condition for the nonlinear analysis of the

containment structure shall include dead load, prestressing load, and operating temperature. In addition to ultimate load capacity, the analysis shall estimate the pressure(s) corresponding to concrete cracking initiation and through thickness cracking, initial yielding of the steel members, such as liner, reinforcing steel, prestressing tendon (if applicable), and pressure bearing steel components not backed by concrete (e.g., closure head, hatch).

(3) The nonlinear stress-strain curve for steel materials (e.g., steel liner, reinforcing steel, prestressing tendons, steel components, steel shell etc) shall be based on the minimum specified yield strength for the specific grade of steel and a stress-strain relationship beyond yield that is representative of the steel. The effect of temperature on the stress-strain curve for steel, if any, shall be appropriately accounted in the analysis.

(4) Concrete constitutive models shall include tensile cracking (normally treated as occurring in the principal stress directions at the integration points), post cracking shear retention, concrete crushing and strain softening. Overly "strong" tension-stiffening curves shall be avoided. Consistent fracture energy (Gf) of concrete shall be used supported with site tested data or equivalent mesh independent tension-stiffening model of concrete. Analysis shall include nonlinear stress-strain curve, including softening portion/crushing energy (Gc), in compression. The effect of temperature on the stress-strain curve for concrete, if any, shall be accounted in the analysis.

(5) For cylindrical reinforced concrete containments, the ultimate capacity analysis shall be based on attaining a maximum global membrane strain away from discontinuities (i.e., the hoop membrane strain in a cylinder) of 1 percent.

(6) For cylindrical prestressed concrete containments, the ultimate capacity shall be estimated based on satisfying both of the following strain limits: (1) a total tensile average strain in tendons away from discontinuities (e.g., hoop tendons in a cylinder) of 0.8 percent, which includes the strain in the tendons before pressurisation, and (2) a global free-field strain for the other materials that contribute to resist the internal pressure (i.e., liner, if considered, and rebars) of 0.4 percent.

(7) The analysis shall consider additional failure modes, such as concrete shear and concrete crushing which may occur near discontinuities, tendon/reinforcement failure strain to allow the determination of the controlling containment failure mode.

(8) The internal pressure capacity of major containment appurtenances such as equipment hatches, airlocks, dish heads and major piping penetration bellows shall be assessed. Necessary modifications shall be carried out to ensure that the ultimate capacity of appurtenances are higher than the ultimate load capacity estimated for the containment structure.

(9) The evaluation shall consider the potential for containment leakage at pressure levels below the calculated structural capacity. Analyses shall demonstrate that leakage from containment components, such as penetrations, bolted connections, seals, hatches, or bellows, is sufficiently small for the calculated

pressure and temperature capacity conditions. Otherwise, the pressure capacity should be based on a defined total leakage limit from these components.

(10) ULBC assessment shall be carried out considering incremental rise in pressure and credit shall not be given to Containment Filtered Venting System (CFVS). Ultimate load capacity of any type of containment structure shall not be less than:

(a) the maximum peak pressure calculated for potential severe accidents or,

(b) twice the design pressure; whichever is higher.

(11) Containment shall be designed to ensure that the functional failure does not take place up to twice the peak pressure identified during the accident with potential for release of radio nuclides in to the primary containment atmosphere

(12) Functional failure for steel lined prestressed concrete containment shall be based on maximum principal tensile strain in general area of steel liner reaching 0.2% using a global numerical model (full containment structure with associated features).

OR

Functional failure shall be based on fracture energy release rate of liner material (in terms of *J*-integral[11]) exceeding its critical value J_{cr} (obtained from material test data with statistical variations) using a numerical model capable of evaluating phenomena under such scales.

If pressure corresponding to an accident with potential for release of radio nuclides is less than or equal to half the design pressure of containment the assessment of containment for functional failure may be waived off provided the liner is designed considering maximum pressure and associated other conditions.

(13) Functional failure of unlined RCC and unlined PCC containment shall be based on limiting tensile stress across any section less than the direct tensile strength of concrete to avoid through and through crack.

[11] Estimation of functional failure using *J*-integral approach needs local analysis of liner with as-built configuration of backing members and flaw in weld at junction.

TABLE 8.1

TYPICAL DAMPING VALUES (% OF CRITICAL DAMPING) TO BE USED FOR SEISMIC RE-EVALUATION OF EXISTING NPPs [29]

Items	With stress levels < Yield	With stress levels > Yield
Structures		
Reinforced concrete structures*	7	10
Welded steel structures	5	7
Bolted or riveted steel structures	7	10
Reinforced masonry walls	7	10
Systems and components (Except the following)	5	5
Tank, Liquid sloshing modes	0.5	0.5
Cable raceway	10	15
HVAC duct	7	7
Vertical pumps	3	3
Instrument racks	3	3

Note:
Values in the left column apply for SSCs that are not permitted to or does not undergo stress levels beyond the elastic limit under seismic loads
*For RCC structures, higher value of damping in the extreme right column can be used only if demand (calculated with inelastic absorption factor, $F_\mu = 1$)in more than 50% of the major lateral load resisting members is higher than the code capacity.

TABLE 8.2

TYPICAL ENERGY ABSORPTION VALUES ($F\mu$) TO BE USED FOR SEISMIC EVALUATION OF EXISTING NPPs [29]

Items	F_{μ}
Concrete columns where flexure dominates	1.25-1.50
Concrete columns where shear dominates	1.00-1.25
Concrete beams where flexure dominates	1.50-1.75
Concrete beams where shear dominates	1.25-1.50
Concrete connections	1.00
Concrete shear walls	1.50-1.75
Steel columns where flexure dominates	1.25-1.50
Steel columns where shear dominates	1.00-1.25
Steel beams where flexure dominates	1.50-2.00
Steel beams where shear dominates	1.25-1.50
Steel connections	1.00
Welded steel pipes	1.50-2.00

Note: A range of values is proposed because choice of appropriate value should be consistent with the practices adopted (e.g., design practice, quality of construction, and severity of control, etc) as may be applicable for NFs of different categories.

TABLE 8.3

STRUCTURAL PERFORMANCE LIMITS FOR FUNCTIONALITY AND COLLAPSE IN TERMS OF ALLOWABLE LIMITS FOR INTER STOREY DRIFT [32]

S. No	**Structure**	**Allowable drift limits (Radians)**	
		Functional	*Collapse prevention*
1.	Reinforced Concrete SMRF	0.010	0.015
2.	Bending controlled walls	0.004	0.006
3.	Shear controlled walls	0.004	0.006
4.	Steel SMRF	0.010	0.025
5.	Steel braced frames		
	• Concentric	0.005	0.013
	• Eccentric	0.005	0.017

S. No	**Structure**	**Allowable Rotation limits (radians)**	
		Functional	*Collapse prevention*
1.	Reinforced concrete SMRF		
	a) Beam	0.005	0.010
	b) Columns	0.003	0
2.	Steel SMRF		
	a) Beams and columns, $P<0.2P_y$	0.004	0.017
	b) Columns, $P= 0.3P_y$	0.004	0.012
	c) Columns, $P=0.4P_y$	0.004	0.009
	d) Columns, $P = 0.5P_y$	0.004	0.005
	e) Columns, $P>0.5P_y$	0	0
3.	Slab/wall, moment frames	0.005	0.006

9. QUALITY ASSURANCE

9.1.1. An overall Quality Assurance Programme (QAP) in respect of Civil Engineering Structures covering all phases of a NFs 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 AERB Safety Code 'QA for Safety in Nuclear Power Plants', AERB/NPP/SC/QA (Rev. 1) [23] and other applicable Codes and Guides. The program requires comprehensive planning, organisation, implementation (task performance), verification and certifications appropriate to task necessary to assure the requisite quality.

APPENDIX A

LOADS CONSIDERED IN DESIGN OF CIVIL ENGINEERING STRUCTURES OF NUCLEAR FACILITIES

1. Loads

1.1. General

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

1.2. Load Description

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 walls, partitions, floors, roofs, false ceilings, fixed equipment, etc. Loading effects due to hydrostatic pressure, settlement.

(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 be included under the effect of this load.

(3) **Load due to Pre-stress:** Load resulting from application of pre-stress shall be included under the effect of this loading.

(4) **Load due to volume change:** Loading effects due to volume change of concrete shall be included either as an imposed equivalent thermal/initial load or part of Dead Load. Appropriate reduction factor may be considered to account for the loss of rigidity due to cracking.

(5) **Environmental Load:** Loading effects resulting from Earthquake, Wind, Rain, Flood and other environmental events, which are related to a particular site.

(6) **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.

(7) **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).

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

(9) **Operating temperature:** The temperatures as obtained in various locations inside the nuclear power plant under normal operating condition and shutdown

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

(11) **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.

1.3. Load Categories

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

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 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 severe wind specific for the plant

FF : Design basis flood

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 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 the site

Abnormal Loads

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

F_h : 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 impact 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 Ro

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

Y_t : Loads on the structure generated by the reaction of the broken high energy pipe during design basis accident

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

Loads for Assessment Design condition

E_{LE} : Loads due to Extreme earthquake (EE) including responses of supported components, piping and equipment, hydrodynamic effects and dynamic effects of surrounding soil

P_{LE} : Loads beyond design accident pressure to estimate the ultimate load bearing capacity

1.4. Load class

Dynamic class of loading

Loads which are time dependent. Following are the further categorization of dynamic class of loadings:

(1) Impact Loads

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

a) Missiles
b) Pipe whips
c) 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:

a) Earthquakes
b) Wind
c) Pressure
d) Jet impingement
e) Pipe whip restraint reactions

Static Class of Loading

Loads which could be assumed as time independent.

1.5. Characterization of individual loads

Table A.1 lists out all possible individual loads along with corresponding categorization 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

CHARACTERIZATION OF INDIVIDUAL LOADING

INDIVIDUAL LOAD		CLASS	CATEGORY
NAME	**SYMBOL**		
Dead Load[1]	DL	Static	Normal
Prestressing 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_t	Impulsive	Normal
Pressure load resulting from pressure variation either inside or outside from 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	Normal
Reaction due to pipe, etc.,	R_o	Static	Normal
Operating basis earthquake (OBE)	E_o	Impulsive[3]	Severe environmental
Loading effect due to external Flooding (design basis flood)	FF	Impulsive[3]	Severe environmental
Severe wind load	W_c	Impulsive[3]	Severe environmental
Maximum differential pressure generated from postulated accident used as design basis accident	P_a	Impulsive[3]	Abnormal

INDIVIDUAL LOAD		CLASS	CATEGORY
NAME	SYMBOL		
Pipe and equipment reactions generated by postulated accident used as design basis and including Ro	R_a	Impulsive(3)	Abnormal
Hydro-dynamic loading a) Due to S1 (OBE)	HM	Impulsive(3)	Severe environmental
b) Due to S2 (SSE) c) Due to Design basis Accident		Impulsive(3) Impulsive(3)	Extreme environmental abnormal
Maximum attainable temperature due to postulated accident used as design basis	T_a	Impulsive(3)	Abnormal
Loading effect due to internal flooding	F_H	Impulsive(3)	Abnormal
Loading effect due to pipe rupture, jet impingement pipe whip and pressure transient a) Jet impingement b) Pipe whip c) Reaction due to pipe whip	Y_j Y_m Y_r	Impulsive Impulsive Impulsive	Abnormal Abnormal Abnormal
Missiles a) Due to Land, water and air transport b) Missiles due to external events like turbine and other rotary machinery disintegration c) Internal missiles	MT ME MI	Impact Impact Impact	Abnormal Abnormal Abnormal

INDIVIDUAL LOAD		CLASS	CATEGORY
NAME	SYMBOL		
Loading effect due to aircraft impact	MA	Impact	Abnormal
Drop loading	LD	Impact	Abnormal
Safe shutdown earthquake	E_{ss}	Impulsive	Extreme environmental
Extreme wind load (wind induced missiles)	W_t	Impact	Extreme environmental
Extreme Earthquake	E_{EE}	Impact	Assessment design conditions
Ultimate load capacity of containment	P_{bdba}	Impact	Assessment design conditions

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

(2) For convenience, Live load may be subdivided into Live load during normal condition (LLn) and Live Load during shutdown condition (LLs)

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

REFERENCES

1. ATOMIC ENERGY REGULATORY BOARD, Glossary of terms for nuclear and radiation safety guide AERB/SG/GLO, AERB, Mumbai, (2022).
2. ATOMIC ENERGY REGULATORY BOARD, 'Design of pressurised heavy water reactor based nuclear power plants', AERB/NPP-PHWR/SC/D, AERB, Mumbai, (2009).
3. ATOMIC ENERGY REGULATORY BOARD, 'Design of light water reactor based nuclear power plants', AERB/NPP-LWR/SC/D, Mumbai, (2014).
4. ATOMIC ENERGY REGULATORY BOARD, 'Site evaluation of nuclear facilities', AERB/NF/SC/S (Rev-1), AERB, Mumbai, (2014).
5. ATOMIC ENERGY REGULATORY BOARD, 'Safety classification and seismic categorisation for structures, systems and components of pressurised heavy water reactors', AERB/NPP-PHWR/SG/D-1, AERB, Mumbai, (2003).
6. ATOMIC ENERGY REGULATORY BOARD, 'Atomic Energy (Factories) Rules', AERB, Mumbai, (1996).
7. ATOMIC ENERGY REGULATORY BOARD, 'Design of concrete structures important to safety of nuclear facilities', AERB/SS/CSE-1, AERB, Mumbai, (2001).
8. ATOMIC ENERGY REGULATORY BOARD, 'Design, fabrication and erection of steel structures important to safety of nuclear facilities', AERB/SS/CSE-2, AERB, Mumbai, (2001).
9. ATOMIC ENERGY REGULATORY BOARD, 'Design, fabrication and erection of embedded parts and penetrations important to safety of nuclear facilities', AERB/NF/SS/CSE-4, AERB, Mumbai, (2003).
10. ATOMIC ENERGY REGULATORY BOARD, 'Seismic qualification of structures, systems and components of pressurised heavy water reactors', AERB/NPP-PHWR/SG/D-23, AERB, Mumbai, (2009).
11. ATOMIC ENERGY REGULATORY BOARD, 'Geotechnical aspects and safety of foundation for buildings and structures important to safety of nuclear power plants'. AERB/NPP/SG/CSE-2, AERB, Mumbai, (2008).
12. ATOMIC ENERGY REGULATORY BOARD, 'Seismic studies and design basis ground motion for nuclear facility sites', AERB/NF/SG/S-11, AERB, Mumbai, (2022).

13. ATOMIC ENERGY REGULATORY BOARD, ‘Safety guide on design basis floods for inland sites’, AERB/SG/S-6A, AERB, Mumbai, (2000).
14. ATOMIC ENERGY REGULATORY BOARD, ‘Safety guide on design basis floods for coastal sites’, AERB/SG/S-6B, AERB, Mumbai, (2001).
15. ATOMIC ENERGY REGULATORY BOARD, ‘Extreme values of meteorological parameters, AERB/NF/SG/S-3’, AERB, Mumbai, (2008).
16. ATOMIC ENERGY REGULATORY BOARD, ‘Materials of construction for civil engineering structures important to safety of nuclear facilities", AERB/NF/SG/CSE-4, AERB, Mumbai, (2011).
17. ATOMIC ENERGY REGULATORY BOARD, ‘Proof and leakage rate testing of reactor containments’, AERB/NPP/SG/O-15, AERB, Mumbai, (2004).
18. ATOMIC ENERGY REGULATORY BOARD, ‘Human-induced events and establishment of design basis’, AERB/NPP/SG/S-7, AERB, Mumbai, (2005).
19. ATOMIC ENERGY REGULATORY BOARD, ‘Radiological safety in uranium mining and milling, AERB/FE-FCF/SG-2, AERB, Mumbai, (2007).
20. ATOMIC ENERGY REGULATORY BOARD, ‘Nuclear power plant operation’, AERB/NPP/SC/O, AERB, Mumbai, (2008).
21. ATOMIC ENERGY REGULATORY BOARD, ‘Maintenance of civil engineering structures important to safety of Nuclear Power plant operation’. AERB/SM/CSE-1, AERB, Mumbai, (2002).
22. ATOMIC ENERGY REGULATORY BOARD, ‘In-service inspection of civil engineering structures important to safety of nuclear power plants’, AERB/NPP/SM/CSE-2, AERB, Mumbai, (2004).
23. ATOMIC ENERGY REGULATORY BOARD, ‘Quality assurance in nuclear power plants’, AERB/NPP/SC/QA (Rev-1), AERB, Mumbai, (2009).
24. BUREAU OF INDIAN STANDARDS, ‘Plain and reinforced concrete - Code of practice’, IS 456, New Delhi, (2000).
25. BUREAU OF INDIAN STANDARDS, ‘General construction in steel - Code of practice, IS 800, New Delhi, (2007).
26. BUREAU OF INDIAN STANDARDS, ‘Criteria for earthquake resistant design of structures’, IS 1893 (Part 4), New Delhi, (2015).
27. BUREAU OF INDIAN STANDARDS, ‘Code of practice for design loads (Other than EQ): Wind loads’, IS 875 (Part 3), New Delhi, (2015).

28. BUREAU OF INDIAN STANDARDS, ‘Code of practice for design loads (Other than EQ): Special loads & combinations’, IS 875 (Part 5), New Delhi, (2003).
29. INTERNATIONAL ATOMIC ENERGY AGENCY, ‘Seismic evaluation of existing nuclear power plants’, Safety report series-28, IAEA, Vienna (2003).
30. UNITED STATES NUCLEAR REGULATORY COMMISSION, ‘Tsunami hazard assessment at nuclear power plant sites in the United States of America’, NUREG/CR-6966, USNRC, USA, (2009).
31. UNITED STATES NUCLEAR REGULATORY COMMISSION, ‘Methodology for performing aircraft impact assessments for new plant designs, NEI 07-13, USNRC, (2013).
32. AMERICAN SOCIETY OF CIVIL ENGINEERS, ‘Seismic design criteria for structures, systems and components in nuclear facilities’, ASCE 43-05.
33. ATOMIC ENERGY REGULATORY BOARD, Siting, Design, Construction, Commissioning, Operation, Closure and Monitoring of Tailing Management Facilities for Uranium Ore processing, AERB/FE-FCF/SG-4, AERB, Mumbai, (2013)
34. ATOMIC ENERGY REGULATORY BOARD, ‘Decommissioning of Nuclear facilities, AERB/SM/DECOM-1, AERB, Mumbai, (1998)

BIBLIOGRAPHY

NPP Design and Construction: Safety Aspects

1. INTERNATIONAL ATOMIC ENERGY AGENCY, 'Safety aspects of nuclear power plants in human induced external events: General considerations', Safety report series-86, IAEA, Vienna, (2017).
2. INTERNATIONAL ATOMIC ENERGY AGENCY, 'Safety of nuclear power plants: Design', IAEA SSR-2/1 (Rev. 1)', IAEA, Vienna, (2012).
3. INTERNATIONAL ATOMIC ENERGY AGENCY, 'Construction for nuclear installations', IAEA SSG-38, IAEA, Vienna, (2015).
4. UNITED STATES NUCLEAR REGULATORY COMMISSION, 'Standard review plan for the review of safety analysis reports for Nuclear power plants: LWR edition', NUREG 800, USNRC.
5. UNITED STATES NUCLEAR REGULATORY COMMISSION, 'Containment structural integrity evaluation for internal pressure loadings above design basis pressure', NUREG 1.216/R0 (2016).
6. UNITED STATES NUCLEAR REGULATORY COMMISSION, 'Containment integrity research at sandia national laboratories: An overview', NUREG/CR-6906SAND2006-2274P (2006).

NPP Ageing management

1. INTERNATIONAL ATOMIC ENERGY AGENCY, 'Ageing management for nuclear power plants: International generic aging lessons learned (IGALL)', Safety report series--82, IAEA, Vienna, (2015).

NPP Margin Assessment

2. INTERNATIONAL ATOMIC ENERGY AGENCY, 'Safety aspects of nuclear power plants in human induced external events: Margin Assessment', Safety report series-88, IAEA, Vienna, (2017).

Reactor Containment Integrity

3. UNITED STATES NUCLEAR REGULATORY COMMISSION, 'Containment integrity research at sandia national laboratories', NUREG/CR-6906, USNRC, (2006).

4. UNITED STATES NUCLEAR REGULATORY COMMISSION, ‘Containment structure integrity evaluation for internal pressure loadings above design-basis pressure’, RG 1.216, USNRC, (2010).

Impact Analysis

5. UNITED STATES NUCLEAR REGULATORY COMMISSION, ‘Methodology for performing Aircraft impact assessments for new plant designs, NEI 07-13, USNRC, (2009).
6. UNITED STATES NUCLEAR REGULATORY COMMISSION, ‘Guidance for the assessment for beyond design basis impacts’, RG 1.217, USNRC, (2011).

Seismic Analysis & Design

7. AMERICAN SOCIETY OF CIVIL ENGINEERS, ‘Seismic analysis of safety-related nuclear structures’, ASCE 4-16, (2016).

Structural Engineering

8. AMERICAN SOCIETY OF CIVIL ENGINEERS, ‘Minimum design loads and associated criteria for buildings and other structures’, ASCE 7-16, (2016).

Temperature/Solar Radiation

9. ASHRAE Handbook Fundamentals, ‘American Society of Heating, Refrigerating and Air-Conditioning Engineers’, (2005).

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Shri Moloy Chakrovorthy, NPSD	:	Member
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Dates of Meeting
May 2018 to November 10, 2021

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Date of Meeting:
March 31, 2019, November 18, 2021

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