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CIVIL ENGINEERING - DESIGN			
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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
BDB	Beyond Design Basis
BS	British Standards
BS EN	Eurocode Standards
CAD	Computer Aided Design
CDM2015	Construction (Design and Management) Regulations 2015
DB	Design Basis
DEC	Design Extension Conditions (beyond design basis)
EIMT	Examination, Inspection, Maintenance and Testing
ENSREG	European Nuclear Safety Regulators Group
FE	Finite Element
FEA	Finite Element Analysis
FEm	Finite Element model
FRS	Floor Response Spectra
GMPEs	Ground motion prediction equations
HSE	Health & Safety Executive
IAEA	International Atomic Energy Agency
ISO	International Standards Organisation
ITA	Independent Technical Assessment
LC	Licence Condition
LOCA	Loss of Cooling Accident
LLOCA	Large Loss of Cooling Accident
ONR	Office for Nuclear Regulation
PCPV	Pre-stressed Concrete Pressure Vessel
pga	Peak ground acceleration
RGP	Relevant Good Practice
SAP(s)	Safety Assessment Principle(s)
SQEP	Suitably qualified and experienced person
SSC	Structure, System and Component
SSI	Soil Structure Interaction
TAG	Technical Assessment Guide(s) (ONR)
WENRA	Western European Nuclear Regulators' Association

GLOSSARY

Term	Description	
Ageing	General process in which characteristics of a structure, system or component gradually change with time or use.	Definition from WENRA Decommissioning Reference Levels (DSRL)
Ageing Management	Engineering, operations and maintenance actions to control within acceptable limits the ageing degradation of structures, systems or components.	WENRA DSRL
Care and Maintenance	A phase within the decommissioning stage of a facility, for which the deferral of further decommissioning has been substantiated, and for which safety is maintained by passively safe means and an appropriate examination, inspection, maintenance and testing programme.	Derived
Construction	“construction work” means the carrying out of any building, civil engineering or engineering construction work and includes— (a) the construction, alteration, conversion, fitting out, commissioning, renovation, repair, upkeep, redecoration or other maintenance (including cleaning which involves the use of water or an abrasive at high pressure, or the use of corrosive or toxic substances), de-commissioning, demolition or dismantling of a structure; (b) the preparation for an intended structure, including site clearance, exploration, investigation (but not site survey) and excavation (but not pre-construction archaeological investigations), and the clearance or preparation of the site or structure for use or occupation at its conclusion; (c) the assembly on site of prefabricated elements to form a structure or the disassembly on site of the prefabricated elements which, immediately before such disassembly, formed a structure; (d) the removal of a structure, or of any product or waste resulting from demolition or dismantling of a structure, or from disassembly of prefabricated elements which immediately before such disassembly formed such a structure; (e) the installation, commissioning, maintenance, repair or removal of mechanical, electrical, gas, compressed air, hydraulic, telecommunications, computer or similar services which are normally fixed within or to a structure, but does not include the exploration for, or extraction of, mineral resources, or preparatory activities carried out at a place where such exploration or extraction is carried out	CDM2015
	The activities related to installation or building, modifying, testing, remediating, repairing, renovating, repurposing, alteration, refurbishment, replacement, maintaining, decommissioning, decontamination, dismantling or demolishing a civil engineering structure, system or component. ‘Construction’ can happen at any stage in the lifecycle of the site, including earthworks, site preparation, enabling works, ground investigations, geotechnical or ground engineering, foundations and superstructure construction works, mock-ups and trials, and temporary works to support the same. Construction may also include civil engineering works associated with examination, inspection, testing and maintenance.	For the purposes of this TAG and the associated annexes
Containment / Confinement	IAEA guidance refer to confinement (rather than containment) of nuclear material. IAEA define the containment as the physical structure that confines the nuclear material. Methods or physical structures designed to prevent the dispersion of radioactive material	IAEA Safety Glossary
Contractors	All references to 'contractors' include proportionate consideration of the whole contracting and supply chain, whether for the provision of goods and services to the licensee or on the licensed site. This includes designers, vendors, suppliers, manufacturers etc. as appropriate.	SAPs definition
Decommissioning	Administrative and physical actions taken to allow removal of some or all of the regulatory controls from a nuclear facility.	SAPs definition

Decontamination	The complete or partial removal of contamination by a deliberate physical, chemical or biological process.	WENRA DSRL
Demolition	Removal of the buildings, structures and plant and disposal of the arising materials.	Derived
Design	The definition of design for this civil engineering annex applies equally across all stages of a nuclear facility's lifecycle, including generic and/or concept design, licensing, site identification, site specific design, construction and installation, operation, modifications, post-operation, decommissioning and demolition, 'care and maintenance' phase etc. 'Design' can also include, the safety case documentation, supporting references, justification and substantiation of claims, modelling or other analysis tools, the process(es) and records of design decision making, and independent reviews of the above. It should be recognised, within the life cycle of 'civil engineering works', that the assumptions made by the designer and incorporated within the justification of the design within a safety case, must be properly carried through the construction stage and through to modifications, demolition and site clearance. All associated construction activities throughout the life cycle are much a part of the safety case as the design.	For the purposes of this annex
	"design" includes drawings, design details, specifications and bills of quantities (including specification of articles or substances) relating to a structure, and calculations prepared for the purpose of a design;	CDM2015
Design Life	IAEA Safety Glossary: The period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced.	IAEA Safety Glossary
Design intent	SAPs definition: The fundamental criteria and characteristics (including reliability levels) that need to be realised in a facility, plant or SSC in order that it achieves its operational and safety functional requirements.	SAPs definition
Dutyholder	For the purpose of this annex, the dutyholder is any organisation or person that holds duties under legislation that ONR regulates. 'Dutyholder' includes Licensees, Requesting Parties, Potential Future Licensees, Operational Licence Dutyholders, Decommissioning Site Licensees, New Build Site Licensees, budget holders, vendors and supply chain members.	For the purpose of this annex
Management system	A set of interrelated or interacting elements (system) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner. The management system integrates all elements of an organization into one coherent system to enable all of the organization's objectives to be achieved. These elements include the organizational structure, resources and processes. Personnel, equipment and organizational culture as well as the documented policies and processes are parts of the management system. The organization's processes have to address the totality of the requirements on the organization as established in, for example, IAEA safety standards and other international codes and standards.	WENRA DSRL
Nuclear Facility	A facility and its associated land, buildings and equipment in which nuclear materials are produced, processed, used, handled, stored or disposed of on such a scale that consideration of safety is required.	WENRA DSRL
Nuclear Safety	The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers the public and the environment from undue radiation hazards	WENRA DSRL
Operation	All activities performed to achieve the purpose for which an authorized facility was constructed.	WENRA DSRL
Progressive collapse	A failure of a primary load bearing element which results in immediate or rapid failure of adjacent elements, possibly, but not necessarily, leading to collapse of the entire loadbearing structure.	Derived
Quality Management	SAPs definition: Co-ordinated activities to direct and control an organisation with regard to quality (i.e. ensuring that requirements are fulfilled). Direction and control with regard to quality generally includes quality policy, quality objectives, quality planning, quality control, quality assurance and	SAPs definition

	quality improvement. Licence Condition 17 requires adequate quality management arrangements in respect of all matters which may affect safety. Such matters include those derived from the safety case, facility design and licence conditions.	
Quality Management System	Quality management system A management system to direct a unit and control an organisation with regard to quality; a combination of resources and means with which quality is realised (ISO 9000).	SAPs definition
Risk	The chance that someone or something is adversely affected in a particular manner by a hazard (R2P2).	SAPs definition
Safety Assessment	Assessment of all aspects of the site, design, operation and decommissioning of an authorized facility that are relevant to protection and safety.	WENRA DSRL
Safety Case	A collection of arguments and evidence in support of the safety of a facility or activity. This will normally include the findings of a safety assessment and a statement of confidence in these findings. SAPs definition: 'safety case' refers to the totality of a licensee's (or dutyholder's) documentation to demonstrate safety, and any sub-set of this documentation that is submitted to ONR. Note: Licence Condition 1 defines 'safety case' as the document or documents produced by the licensee in accordance with Licence Condition 14.	WENRA DSRL
Safety function	A specific purpose that must be accomplished for safety	IAEA Safety Glossary
Serviceability failure	A single or group of related SSC fail to perform some of their non-safety functions or fail to meet some of their specified parameters, but do not collapse.	Derived
Soil Structure Interaction (SSI)	The process in which the response of the soil influences the motion of the structure and vice versa.	Derived
Static monitoring	Settlement monitoring may include but not be limited to total stations, light detection and ranging (LiDAR), extensometers and embedded levelling devices to measure deflection	Derived
Structure	"structure" means— (a) any building, timber, masonry, metal or reinforced concrete structure, railway line or siding, tramway line, dock, harbour, inland navigation, tunnel, shaft, bridge, viaduct, waterworks, reservoir, pipe or pipeline, cable, aqueduct, sewer, sewage works, gasholder, road, airfield, sea defence works, river works, drainage works, earthworks, lagoon, dam, wall, caisson, mast, tower, pylon, underground tank, earth retaining structure or structure designed to preserve or alter any natural feature and fixed plant; (b) any structure similar to anything specified in paragraph (a); (c) any formwork, falsework, scaffold or other structure designed or used to provide support or means of access during construction work, and any reference to a structure includes part of a structure;	CDM2015
Structures Systems and Components (SSCs)	Definition from WENRA Decommissioning Reference Levels: 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**.	WENRA DSRL

1 INTRODUCTION

1. This annex to Technical Assessment Guide 17 (TAG 17) provides guidance on the main aspects of civil engineering design considered relevant to nuclear safety on nuclear licensed and authorised sites. It includes general guidance and advice to ONR inspectors on aspects of civil engineering design, design management and related assurance. This TAG annex is not intended to provide detailed guidance on the design process: its main purpose is to highlight certain salient areas for inspectors to consider as part of their regulatory assessment. It aims to highlight the application of the Safety Assessment Principles (SAPs) [1] to aid the assessment of civil engineering works and structures (see Appendix 1 of TAG 17), for activities during the design phases.

2. This annex is not to explain how to undertake design of a nuclear facility. ECS.3 states the expectation that the civil engineering structures systems and components (SSCs) will be designed to the appropriate codes and standards.

3. The guidance in this annex applies to all aspects of civil engineering design for nuclear safety significant SSCs. The guidance applies across different phases of the lifetime of the site. Where the guidance only applies to a certain phase of the design, this is stated.

1.1 Structure of this annex

4. This Annex identifies the most relevant SAPs applicable to civil engineering design. The key phases within civil engineering design are:

Section 3 – for civil engineering principles regarding safety case claims and hazard derivation:

- Safety Case, 'golden thread' and safety case claims
- Design Authority Competency & Intelligent Customer.
- Hazard Identification,
- Design Basis and Beyond Design Basis,
- Fundamental safety functions
- Safety Functional Requirements (SFRs) and safety measures,
- Schedules
- Categorisation and Classification ('Cat and Class')
- Arguments and passive safety
- Safety Case Documents

Section 4 – for civil engineering principles regarding design assessment as an activity that is undertaken, independent of the construction:

- Design philosophy
- Design codes and standards
- Reliability and conservatism
- Intelligent Customer function
- Independent checks
- Concept design and design optioneering stages
- Layout
- ALARP optioneering
- Novel, innovative and un-proven designs
- Loading,
- Finite Element Modelling and numerical analysis
- Pre-stressed designs
- Investigation and Data Collection (not ground investigation),
- Design Verification and Validation (including Quality Assurance, Independent checks),
- Designing for hazard combinations,
- Designing for emergencies

- Designing for construction
- Design for Operation and Examination, Inspection, Maintenance and Testing (EIMT),
- Design for Decommissioning,
- Learning from previous experience,
- Information Control and Document Management,
- Interfaces between Design Disciplines,
- Interface with Procurement,
- Interface with Construction/Installation / commissioning,
- Safety Case Production and Interface,
- Design Substantiation Reports
- Post Design Review,
- Design process and maturity

Section 5 – for specific civil engineering principles to consider in addition to the above where design activities are in parallel to construction or site works.:

- Design handover
- Design maturity
- Design authority
- Intelligent Customer
- Interfaces between construction site and design team
- Design assurance
- Information Management
- Design change control
- Safety case production and interface
- Interface with procurement and design
- Asset management and safety case
- Inferface with equipment installation
- Post design review
- Design Verification and Validation (including Quality Assurance, Independent checks),
- Design changes related to defects or non-conformances
- Operational experience (OPEX).

1.2 Applicable SAPs to this annex

5. It is expected that design meets the expectations of the SAPs. In particular for this annex, the relevant SAPs are noted in Table 4, appended to this annex.

6. Further SAPs are referenced in the following Annexes of TAG 17 when considering the wider civil engineering considerations of design, construction and decommissioning:

- Construction, in Annex 4 ‘Civil Engineering - Construction Assurance’,
- EIMT, in Annex 5 ‘Civil Engineering – Ageing Management and Damaged Structures’,
- Decommissioning, in Annex 6, ‘Civil Engineering - Post operation’.

7. The Inspector should be cognisant of the broad intent of the SAPs, namely that it is not the level of conservatism assigned to one element of the civil engineering analysis and design process, but the (overall) level of conservatism, applied to the design process as a whole, in line with the sample that is being assessed.

1.3 Relevant Guidance and Licence Conditions

8. Civil engineering design requirements arise generally for the following reasons, with the associated guidance and licence conditions as follows:

Scenario	**Licence conditions that are specifically applicable to this scenario**	**Guidance Document Reference(s)**
The requesting party wishes to undertake a Generic Design Assessment (GDA)	Not applicable	"New Nuclear Power Plants: Generic Design Assessment Guidance to Requesting Parties" ONR-GDA-GD-006 [2] Civil engineering specific guidance is in section 3.2 of "New Nuclear Power Plants: Generic Design Assessment Technical Guidance" ONR-GDA-GD-007 [3] "A guide to the Regulatory Process" [4] All these documents are available on http://www.onr.org.uk/new-reactors/guidance-assessment.htm
Site licensing	Not applicable	'Licensing Nuclear Installations' [5] [3]
The dutyholder wishes to design, construct, install and commission a facility on a new site, or within an existing site.	Licence condition 19	ONR-NS-INSP-GD-019 'Construction and Installation of New Plant'
	Licence condition 20	ONR-NS-INSP-GD-020 'Modification to Design of Plant under Construction'
	Licence condition 21	ONR-NS-INSP-GD-021 'Commissioning'
The dutyholder wishes to undertake a modification to an existing facility.	Licence condition 22	ONR-NS-INSP-GD-022 'Modification or Experiment on Existing Plant'
The dutyholder is conducting an assessment of structures, systems and components for a periodic safety review.	Licence condition 15	ONR-NS-INSP-GD-015 'Periodic Review'
The dutyholder wishes to decommission a facility.	Licence condition 35	ONR-NS-INSP-GD-035 'Decommissioning'

Table 1 – Licence Conditions relevant to particular lifecycle stages of a site

1.4 Exclusions

9. This annex focusses on the assessment principles for inspectors to use when assessing designs. However, it assumes code compliance in design and therefore does not intent to state the specifics for design. Some aspects of design are discussed outside this annex. For further guidance regarding geotechnical design information, and foundation and other sub-surface structure design, see:

- TAG 17 Annex 3 'Civil Engineering –Ground Investigations, Geotechnics and Sub-surface structure design'.

10. The Inspector is reminded of the stages of design in the Royal Institute of British Architects (RIBA) guidance known as the RIBA Plan of Work 2020, which has been updated in 2020 [6] but these stages are not considered specifically within this annex.

2 CIVIL ENGINEERING DESIGN PHASES

11. The phases of civil engineering design explained in this section of the annex are:

- Generic Design Assessment, (where applicable)
- Siting / site selection,
- Site Licensing (if not on an extant Licensed Site),
- Detailed Design,
- Detailed Design (alongside construction activities in parallel),
- Design and Commissioning,
- Design During Operation and Post-operation.

2.1 Generic Design Assessment (GDA)

12. The guidance in Sections 3 and 4 states the key assessment principles and considerations for civil engineering assessment of safety case and design. There can be limited civil engineering design and safety case information available at the early stages of design during the GDA phase. The GDA phase identifies areas that are to be considered at the site-specific phase, where more information is available. This section aims to focus the Inspector at aspects of particular importance at the GDA phase.

13. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment of the civil engineering structures cannot therefore be carried out in isolation, as there are often safety issues of a multi-topic (or multidisciplinary) nature.

14. The overarching guidance for civil engineering and other disciplines throughout GDA is to seek assurance that the ‘golden thread’ of the safety case is well understood and clearly presented through documentation, linking design codes with safety functions, with a clear use of cross-referencing within documents. The Inspector is reminded of the expectations in SAPs SC.4, ECS.2, ECS.4, EKP.4, ERL.1 and ERL.4.

15. The guidance for Generic Design Assessment has been revised. Overall guidance can be found in [2] and the civil engineering specific guidance is in section 3.2 of [3]. [3] is to be used for GDAs that commenced after May 2019, when this guidance document was issued. For GDA assessment that commenced before May 2019, the previous guidance document [2] still stands.

16. The GDA process progresses through steps, and as progress is made, there is a shifting focus. The guidance advises on the progress over time from establishing the Claims through to Arguments and Evidence. As the design develops and as more design details are available for assessment, the Inspector is guided to consider whether the appropriate design decisions are made at the appropriate stages.

17. The intent of the GDA process is to achieve a Design Acceptance Confirmation (DAC). From a civil engineering perspective, to achieve a DAC, the following should have been achieved:

- The evidence of the design substantiation is in place to confirm that the claims and arguments made in the design and safety case are met.
- There are adequate examples of the ‘golden thread’ (section 0 of this annex).
- There are adequate examples that the design information is adequate for to demonstrate the design can be safely constructed e.g. drawings and schedules.
- The site-specific considerations are correctly identified and clearly understood, with a forward commitment to be undertaken at the site-specific phase.

18. GDA assessment can be either before or run in parallel with Site Licensing activities. There may be areas of overlap between the site licensing work and the GDA, in which case the Inspector is encouraged to liaise with those undertaking other related works to understand the scope of the GDA and licencing works, to gain a shared understanding of which site specific topics may also need to be included as part of the site licensing assessment, as the GDA progresses.

2.2 Siting / Site selection

19. The guidance in Sections 3 and 4 of this document states the considerations for civil engineering assessment of safety case and design. There is very limited civil engineering design or safety case information available at the early stages of site selection. This section aims to focus the Inspector at aspects of particular importance at the site selection phase.

20. ONR does not have a direct role in selecting locations for sites for future new build. ONR grants a Licence to a new facility and it supports requests from the planning inspectorate as part of its review activities, ahead of granting a development consent order.

- ST.1 re-iterates the need for ONR's position to be consistent with the prevailing government siting criteria.
- ST.4 is clear that the site should be "suitable". In simple terms this means that it is capable of hosting the proposed development from a civil engineering perspective and that the external hazards which potentially threaten the facility are not so extreme that a suitable safety case cannot be constructed, both for current conditions and for the projected lifetime of the facility. Some examples of considerations are given below.

21. The principal civil engineering assessment requirements regarding siting location are:

- the presence of a capable fault across the site plot plan is generally seen as excluding the site from further consideration,
- threats from accidental aircraft crash can be calculated, and should not in most cases act as exclusionary. The Inspector may wish to seek assurance that siting considerations are in line with the ALARP principles,
- for new build coastal sites, the protection hierarchy would drive towards a "dry site" concept, i.e. the platform height for safety critical facilities is above the design basis flood level. For a number of UK coastal sites, this may not be reasonably practicable, with the first line of defence being some form of shoreline protective engineered structure. The Inspector may wish to sample the arguments, especially considering the effort to raise platforms, the potential for a cliff edge escalation of risk, and the longevity of installations on a site (circa 120+years from construction start to decommissioning end, with potentially longer durations when considering on site waste storage or plant life extension). This may be assessed alongside the engagement of external hazards specialist inspectors to seek assurance that appropriate predicted water levels are used in the assessment. The Inspector should expect the design to allow for managed adaptive approaches, where potential future modification may be required in response to uncertainties in developments in climate change predictions,
- whether a site investigation has been carried out, to provide information on the ground conditions, which therefore demonstrates that the site is suitable when considering the external hazard assessments, particularly for determining the relevant parameters required for the seismic hazard at the site,
- consideration of the interface with the decisions made by the Infrastructure Planning Commission, see [7],
- consideration of the location of external facilities or transport routes which potentially threaten any new build. It is considered unlikely that these would be exclusionary; nonetheless they need to be understood in terms of their impact on nuclear facility design.

22. The siting of new or additional facilities on existing licensed sites is not a specific matter for ONR in terms of specific 'approval' of the physical location. As part of broader ALARP considerations for the site as a whole, this should be borne in mind, and the Inspector may wish to be satisfied that suitable optioneering has been undertaken to select the proposed location.

23. Prior to the appointment of a licensee for a new build project, it may be a vendor who is responsible for design development and control. Under these circumstances, the vendor's design management process may still be subject to regulatory review, and a regulatory strategy should be developed for this which should take cognisance of the guidance provided in this document.

24. For the purposes of this document, the term 'dutyholder' is used as an all-compassing term for anyone who engages with the ONR regarding activities that are proposed to be undertaken on a licensed site.

25. For further guidance see:

- 'Licensing Nuclear Installations' [5] 'Site Selection' paragraphs 63-70,
- 'UK National Policy for siting of nuclear power facilities' National Policy Statement for Nuclear Power Generation (EN-6) [7],
- ONR-NS-LUP-GD-001 'Land Use Planning and the Siting of Nuclear Installations' [8],
- ONR-NS-LUP-GD-003 'Job Guide for Processing of Planning Applications' [9],
- ONR-NS-LUP-IN-002 'Population Density Assessment around Proposed Nuclear Power Station Sites' [10].

2.3 Pre-licensing

26. Early engagement (pre-licensing phase) de-risks the Nuclear Site Licence Application (NSLA) phase as it is an opportunity for ONR to ask relevant questions and gain confidence in the approaches taken to the works that support NSLA.

27. Pre-Licensing engagements can occur in the period of time before NSLA. This can be either after or run in parallel with Generic Design Assessment (GDA). There may be areas of overlap between the Nuclear Site Licence Application work and the GDA, in which case the Inspector is encouraged to liaise with those undertaking other GDA related works to understand the scope of the GDA.

2.4 Site Licensing

28. This section focusses on the civil engineering assessment after the Nuclear Site Licence Application (NSLA) has been submitted. The focus of this assessment is whether the site is suitable to support safe nuclear operations for the full lifetime of the station.

29. Key Safety Assessment Principles to be considered during civil engineering consideration of the site licencing submission include;

- ECE.4 and ECE.5 to demonstrate suitability of the soil and rock which provide support for the foundations and substructure and superstructure of the nuclear facility, using information from site investigations,
- ECE.7, ECE.9 and ECE.10 as the foundation design should meet the safety functional requirements placed upon them, with consideration of other earthworks activities and groundwater conditions,
- ECE.11 and RL.2 to establish the ground conditions and contamination or other concerns relating to ground conditions,
- ECE.16 and ECE.25 to demonstrate the constructability of the design,
- ST.4 to demonstrate the suitability of a site to support safe nuclear operations, prior to a new site licence being granted.

30. As a minimum, civil engineering assessment must consider whether:

- the ground is suitable for the proposed structures upon / within it for the full lifetime of the site,
- the cooling structures are feasible to provide adequate means of cooling,
- plot plan layout and size including consideration of potential constructability concerns e.g. GDA may consider a single unit, site licence application may be for more than one unit, with a construction sequence of a unit operating whilst an adjacent unit is still being constructed,
- sufficient information has been collected to confirm that the assumptions made, or data used, in the design are appropriate e.g. site specific geotechnical civil engineering design parameters,
- the capability of the dutyholder's organisation is adequate, regarding civil engineering design and intelligent customer oversight

31. The Inspector should be aware that the interfaces with other disciplines will develop over the period of licensing. The key interface will be with External hazards Inspector, to ensure appropriate design bases are developed as part of the external hazards assessment, the full scope of which is expected to be agreed before Nuclear Site Licence Application (NSLA) and developed in full before Nuclear Site Licence grant. The hazard design bases derive the loadings that will be applied to the civil engineering design. At the licensing phase, the External hazards Inspector will lead on the site characterisation work in line with ONR-NS-TAST-GD-013 'External Hazards', with support provided as necessary in the area of civil engineering. The civil engineering Inspector will lead on the ground investigation work, with support from external hazards discipline. For more information regarding early engagement regarding ground investigations, see:

- TAG 17 Annex 3 'Civil Engineering – Ground Investigation, Geotechnics and Underground Structure Design.

32. From the site investigations, the Inspector may wish to consider:

- whether material properties have been derived from the site investigations adequately, with sufficient data from the proposed plot plan, with adequate understanding of the site ground conditions across the site,
- the impact of groundwater changes and how these are applied to the design e.g. on man-made embankments or excavations proposed,
- identification of any ground contamination (including all hazardous materials, as well as radiological),

33. A key consideration for the Inspector is around how the site characterisation information is used for the approach to foundation design and how the design parameters have been applied, including consideration of settlements, bearing pressures, heave etc.

34. The Inspector is reminded that site design life has an influence on the ALARP considerations for site elevation / platform height as well as wider civil engineering SSC design. If a protected site is considered, the Inspector may wish to gain assurance in the approach to flood defences, including protection of long-term waste storage on site.

35. Generally, at the licensing phase there is a potential overlap with the work of relevant national and local planning authorities related to the Development Consent Order (DCO) for the proposed site. ONR are not the competent authority for planning decisions or authorising the construction of a nuclear facility in a particular location, which falls to the relevant national and local planning authorities. The Inspector is reminded that there may be an interface where the Inspector is requested to provide DCO with assurance in some of the aspects of their assessment.

36. The Inspector may wish to verify that decommissioning activities considered in the civil engineering design are captured in the funded decommissioning programme.

37. Wider guidance on licensing of new sites is provided in:

- ‘Licensing Nuclear Installations’ [5], specifically “The point of Licencing” paragraphs 74-136,
- The Energy Act 2008 “Funded Decommissioning Programme Guidance for New Nuclear Power Stations” [11],
- ONR-NS-PER-IN-004 – “The Processing of Licence Applications for New Nuclear Sites”.
- ‘UK National Policy for siting of nuclear power plants’, National Policy Statement for Nuclear Power Generation (EN-6) [7].

2.5 Detailed Design (before construction)

38. The Inspector’s choice of sampling is key to ensuring an adequate assessment of the information available during detailed design. The key assessment principles for civil engineering design for consideration at this stage are presented in Section 4 of this document. Section 3 of this document covers safety case assessment. The Inspector is reminded that the assessment of design includes the underpinning claims made in the safety case, the associated justification and evidence of the design to meet these claims.

39. When assessing detailed design, the Inspector should consider the regulatory hold points that the ONR has agreed, both under primary and derived powers, with the dutyholder, and plan for which information will be available for regulatory hold points.

40. The Inspector may wish to seek assurance in the adequacy of the processes in place to effect design change, alongside the roles of different designers and the authority held regarding making design decisions.

2.6 Detailed Design (during construction)

41. The key assessment principles for the consideration of civil engineering design when construction of the design is occurring in parallel to design works are presented in Section 5 of this annex, to be read alongside the guidance of:

- TAG 17 Annex 4 ‘Civil Engineering – Construction Assurance’.

42. For further information, see:

- ‘Licensing Nuclear Installations’ [5] ‘Regulation under the licence – Construction / Installation’ paragraphs 137-145.

2.7 Design and Commissioning

43. The commissioning of a civil engineering structure occurs as the construction continues, and as such falls somewhat outside the standard commissioning guidance. It is expected that a high standard of record keeping will be maintained throughout the construction phase, to provide supporting evidence for construction inspection, quality assurance and commissioning (EQU.1). The amount of design and construction information available develops over time. The Inspector may wish to consider whether the dutyholder arrangements ensure that :

- during design, the design intent is met, that during construction, the intent is met,
- derogations, defects and NCR’s are suitably considered and dealt with,
- any ongoing LC28 requirements ahead of commissioning are adequate,
- that any testing (leak tightness, usually) is complete and adequate,
- the dutyholder has presented this as part of formal commissioning documentation.

44. Some elements of civil engineering may require testing and mock-ups to demonstrate the adequacy for design, the testing of which could fall under the definition of ‘commissioning’.

45. The Inspector may wish to verify that such tests have appropriate supervision and surveillance and are arranged in a way to reflect the reality of the permanent construction.

46. When assessing commissioning, the Inspector may consider the:

- potential for aggregation of minor issues over time,
- defect resolution or management processes in place,
- site culture of tolerability to defects,
- acceptance criteria for tolerances in line with the requirements specified in contract documentation and safety cases.

47. For more guidance on commissioning and record keeping, see:

- Section 5 of this document for design considerations during construction,
- TAG 17 Annex 4, ‘Civil Engineering – Construction Assurance’,
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’.
- ‘Licensing Nuclear Installations’ [5] “Regulation under the licence – Commissioning” Paragraphs 146-152.

2.8 Design During Operation and Post Operation

48. Ageing effects and structural degradation can occur before, during and post operation. Designs of modifications / alterations should be cognisant of these effects and the existing condition of the structure under modification.

49. If the start of operations is delayed post- or part-way through construction, these effects could undermine the safety functions provided by civil engineering SSC and should be considered during the design.

50. The Inspector should be aware of the Licence Condition 22 considerations for modifications or experiment on existing facility. The Inspector should appreciate the potential impact of any civil engineering modification works on any nuclear safety SSCs that are contained within that structure, e.g. the impact on controlled internal environments when weatherproofing materials are removed.

51. For more information on design during operations, see:

- TAG 17 Annex 5 ‘Civil Engineering – Ageing management and damaged structures’,
- TAG 17 Annex 6 “Civil Engineering – Post Operation”,
- ‘Licensing Nuclear Installations’ [5] ‘Regulation under the licence – Operation’ paragraphs 153-170,
- ‘Licensing Nuclear Installations [5] ’Section 4 - Delicensing’ paragraphs 171-189.

3 KEY ASSESSMENT PRINCIPLES FOR CIVIL ENGINEERING SAFETY CASE

3.1 Civil Engineering Safety Case

52. The civil engineering safety case should be integral with the overall safety case. It should be accurate, objective and demonstrably complete for its intended purpose, in line with the expectations of SAP SC.4, and Requirement 3 of IAEA guidance SSR 2/1 [12].

53. The Inspector should expect a civil engineering safety case to include:

- identification of its inter-relationship with other parts of the safety case,
- identification, specific references and full traceability of “upstream” activities to civil engineering,
- identification of the safety claims and functional requirements placed on civil engineering works,
- categorisation and classification of the civil engineering works, dependent upon the safety functional requirements placed upon them,
- identification of the substantiation of the civil engineering design to meet the requirements placed upon it.

54. “Upstream” activities are those undertaken to determine the safety case demands which may be placed upon the civil engineering elements and the conditions to which they will be exposed throughout all stages of their life. The Inspector should be aware that such considerations should include temporary conditions during construction and test sequences ahead of operation, and examination, inspection maintenance and testing (EIMT) during the operational phase itself. These may be defined by fault studies, internal and external hazards and PSA, and include activities that derive:

- analysis of fault sequences,
- internal and external hazard identification and quantification,
- hazard combinations / coincident hazards / consequential hazards,
- beyond design basis (design extension) considerations,
- safety functions, safety measures and safety functional requirements,
- plant layout.

55. The Inspector may wish to seek evidence of a clear demonstration that the structures, systems or components (SSCs) within the scope of the civil engineering works have been designed and can be constructed, commissioned and maintained in such a way as to enable it to fulfil its safety functions for its projected lifetime. In line with the expectations of ECE.12, ECS.3 and SC.4, the Inspector should expect this to be achieved through a clearly presented structure of documents supporting the civil engineering safety case, most likely to be organised and presented in terms of claims, argument and evidence.

56. For information about the ONR assessment of Safety cases, see:

- ONR-NS-TAST-GD-051 ‘The Purpose, Scope and Content of Safety Cases’.

3.2 ‘Golden Thread’

57. SAP FA.5 states the expectation that the safety case should list all initiating faults that are included within the design basis analysis of the facility. SAP ECE.1 states the expectation that the required safety functions and structural performance of the civil engineering structures under normal operating, fault and accident conditions should be specified.

58. When assessing the safety case, the Inspector should have a clear appreciation of the documentation the dutyholder presents which represents the ‘golden thread’ of the safety case. The golden thread is a clear line of information from the original hazard derivation through to the claim made on the civil engineering structure, which continues on to the presentation of how the structure will meet the claims made upon it.

59. The Inspector should be aware of the upstream activities that derive the hazard loading and seek assurance that this is translated appropriately into the civil engineering design. This forms part of the golden thread. For example, the identification numbers associated with faults, hazards and/or events that are considered in the design could be referred to in the civil engineering safety case documentation.

60. Fundamental to the assessment of civil engineering activities is to have a clear understanding of what is often termed the “golden thread” of safety which passes through the various levels of safety documentation and design. The concept of claims, argument and evidence is briefly explained in paras 79-81 of the SAPs. Some safety cases will articulate clearly the basis of the case in the specific terms of claims, arguments and evidence. Where this is not done, it is useful for the Inspector to identify from the case what the key claims are; usually a direct result of the Safety Functional Requirements (SFRs). For existing nuclear facilities, it is common to find that there are so-called “multi-legged” safety cases. These rely on the multiple elements to act holistically, with weaknesses from one part supplemented by strengths from others, for example, one part of a structure may not be inspectable, but any degradation is detectable reliably and simply via alternative means.

3.3 Civil Engineering Safety Case Claims

61. SAP ERL.1 states the expectation that claims made will take into account the context of the structure, including the novelty of the design, the environment etc. The Inspector should expect the safety functional requirements (SFRs) of a structure, system or component (SSC) to be explicitly stated in the safety case documentation to demonstrate how nuclear safety is met via design.

62. SAP ERL.1 also states that the reliability claimed for any structure should be demonstrated by suitable analysis and data, or where data is unavailable, a combination of:

- comprehensive examination of the issues,
- a review of precedents,
- an independent third-party assessment where necessary,
- a periodic review of further developments in technical information precedent and relevant good practice.

63. Claims are usually set at a high level, and should be clear, unqualified and unambiguous in nature. For example: The structure will maintain its functional capability during and after all design basis loading. The performance expectation is clear, and the demand placed upon it equally so. For new build structures this can be straightforward, for existing structures it can be less so. A claim may be convoluted such as; the structure will remain stable under all design basis loading, with local damage that may occur, albeit insufficient to compromise the SFRs. A more comprehensive suite of arguments and evidence will be required to support a claim of this nature.

64. While the SAPs predominantly deal with nuclear safety, it should be recognised that civil engineering structures have the potential for conflicting requirements between nuclear safety, security, safeguards, fire and conventional safety.

65. The Inspector may wish to take into account that design or construction measures adopted reduce the risks in line with the ALARP principles, seeking assurance that these do not undermine any SFRs required of the civil engineering SSC.

3.4 Design Authority

66. Design and the links to safety case are managed by the dutyholder, with specific roles associated with the responsibility for civil engineering works to reflect these links. The Design Authority (DA) is a role that is responsible for ensuring the claims, arguments and evidence presented in the safety case are appropriate and are never undermined by decisions or changes made as the design develops and construction works progress. This role encompasses outputs of dutyholder designers, consultants, contractors and the supply chain.

67. The Design Authority function should also act as Intelligent Customer when activities are not undertaken by the dutyholder organisation directly, but where the civil engineering activities that are procured (civil engineering contractor works or consultative services) are related to nuclear safety. This is discussed in the next section.

- SC.8 states ownership of the safety case should reside within the dutyholder organisation with direct responsibility for safety.
- MS.2 states the responsibilities associated with the dutyholder understanding of the safety of the facilities and their design, operation and safety cases. For civil engineering this responsibility is related to SAPs ECE.1 and ECE.2 regarding the functional performance and use of independent argument in the safety case. This responsibility also relates to SAPs ECS.1 and ECS.2 regarding the appropriate identification of safety functions through hazard and fault analysis, with appropriate categorisation and classification of civil engineering works and structures.

68. The key civil engineering principles for the assessment of the DA function are to establish:

- that the role of DA includes ensuring that the safety case requirements are met by the design intent,
- whether the design intent is consistent with the safety function and performance requirements,
- whether the dutyholder has appropriate person(s) in place to undertake the role of DA,
- that the hazard identification, fault analysis and subsequent categorisation and classification processes are duly followed and presented in the safety case and safety schedules,
- the overall point of responsibility to make decisions,
- if the design uses several standards, whether they are compatible with each other to adequately support the safety case claims, arguments and evidence required to provide a robust safety case, and where optional parts of the codes are used, whether their use is appropriate and has this been justified in the safety documentation,
- whether a subsequent specification has been produced (construction or otherwise) for civil engineering works, and whether the DA function has had involvement in its production to ensure compliance with the safety case,
- whether there are procedures in place (involving the DA) to ensure that design changes and modifications are assigned safety significance based on their potential impact on the safety case,
- whether dutyholders understand the scope and limitations of their authority for decision making regarding changes to design and their potential impact on the safety case and design intent, with an appropriate protocol around escalating issues,
- whether the procedures for design changes are implemented correctly, including consideration of examination, inspection, maintenance, testing, modification, decommissioning and demolition to ensure design intent is consistently met throughout the lifecycle of the site,
- whether the design changes or modifications are adequately incorporated into the safety case with the output accurately reflected in the as-built records.

69. Further guidance is available:

- ONR-NS-TAST-GD-079 ‘Licensee Design Authority Capability’,
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’,
- TAG 17 Annex 2, ’Civil Engineering – Building Information Modelling’ sets out the Design Authority requirements for procurement of services to collect data.

3.5 Design Basis Considerations

70. The design basis for civil engineering systems, structures and components (SSC) should be defined for normal operational and fault/abnormal situations. Depending upon the purpose of the facility, the design basis might include a range of demands, resulting in different outcomes for the same civil engineering SSC.

71. The Inspector should expect recovery risks to be reduced so far as is reasonably practicable, with any adjacent ongoing operational risks adequately managed.

3.5.1 Inputs to Civil Engineering Design Basis

72. Typically, fault studies derive the fault scenarios which produce the civil engineering design requirements and civil engineering safety functional requirements (SFR) that need to be satisfied (see Section 3.7 and 3.8 of this document). The Inspector may wish to seek assurance on how the design requirements and hazard loadings have informed the civil engineering design.

73. Civil engineering structures may not be limited to those that are located within the nuclear licenced site. Those that are outside the site, but which nevertheless are determined to be necessary to ensure adequate safety or incident response (including during beyond design basis fault conditions), require proportionate consideration.

74. As part of ensuring there are the appropriate inputs to the civil engineering design basis, the Inspector should have a clear view of the expected output of these, specifically related to those structures requiring the highest levels of reliability. SAP ECE.2 establishes the expectation that, for civil engineering structures requiring the highest levels of reliability, civil engineering SSCs resilience should be quantified and specified in the safety case.

3.5.2 Analysis of fault sequences

75. The output of the fault analysis may be a suite of SFRs and other functional requirements (e.g. serviceability) for the civil engineering SSC. The range of design basis demands should be derived from the fault analysis (SAPs FA.1 to 25) and a thorough, systematic consideration of the internal and external hazards (SAPs EHA.1 to 19). Security and safeguard requirements can also place demands on civil engineering SSC. This systematic approach may have been assessed by security, fault studies and internal hazards inspectors.

76. The Inspector should expect the civil engineering design to have applied the outputs of a systematic approach to identifying a comprehensive set of postulated initiating events. In line with requirement 16 of IAEA guidance SSR 2/1 [12], the Inspector may wish to seek assurance that the output of the analysis is adequately considered in the civil engineering design, including all foreseeable events with the potential for serious consequence and significant frequency of occurrence.

77. The Inspector should be aware that the analysis of the following will form an input to the civil engineering safety case:

- the postulated initiating events for the plant,
- those protective measures that are necessary to ensure that the required safety functions will be performed.

78. The Inspector may wish to seek assurance regarding the adequacy of the way in which the dutyholder manages the design basis events (SAP FA.4) with frequent faults, infrequent faults and beyond design basis events (design extension conditions) and how these are input to the civil engineering structures design, and whether these inputs are clearly differentiated.

79. It is expected that the fault studies discipline will assess the postulated initiating events, fault sequences and consequences, identification of fault barriers for fault sequence termination and fault protection schedules. The focus of the civil engineering assessment is on the visibility of faults with a resulting civil engineering design implication and how the civil engineering design satisfies the demand.

80. The Inspector should be aware that all operating states of the facility need to be considered, including anticipated inspection and maintenance activities, and the need to include post-fault conditions and recovery.

81. For more guidance on fault studies, see:

- ONR-NS-TAST-GD-006 ‘Design Basis Analysis’,
- Annex 2 of the SAPs, in conjunction with SAP NT.1 and NT.2

3.5.3 Probabilistic Safety Analysis

82. For a major project, the Inspector should expect that a Probabilistic Safety Analysis (PSA) should be presented. This comprises a systematic analysis to identify all key fault sequences which can lead to radiological consequences, used to evaluated their contribution to the level of risk represented by the facility. The Inspector should be aware that this may lead to some adjustment of the civil engineering design. The Inspector may wish to check that the Design Basis Event (DBE) is derived on deterministic principles with the balance of risk checked by the PSA. The Inspector is reminded that the scope of DBE extends beyond earthquakes and external hazards. The Inspector should expect a proportionate approach that demonstrates adequate safety of the individual facility subject to a range of challenges. The Inspector may wish to seek assurance that the output of the analysis informs the civil engineering design as appropriate.

83. For more guidance on PSA, see:

- ONR-NS-TAST-GD-030 ‘Probabilistic Safety Analysis’,
- SAPs paras 239, 628 & 629.

3.5.4 Internal and external hazard identification and quantification

84. The Inspector should expect that all foreseeable internal and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the facility, have been identified and their effects evaluated. This is in line with the requirement 17 of the IAEA guidance SSR 2/1 [12].

85. For civil engineering assessment, these analyses will generate loadings and shielding and containment requirements for use in the design of civil engineering SSCs. As with the fault sequences, the Inspector may wish to consider how adequately the design basis events and beyond design basis (design extension) events for the civil engineering structures have been differentiated, articulated and substantiated.

86. It is expected that the internal and external hazards disciplines will assess the hazard screening [SAP EHA.19]. Hazards can be screened out based on a probabilistic basis or by virtue of their low impact. When assessing a design at this hazard screening phase, the Inspector should appreciate hazards that are screened out because they can only be addressed once site specific information is available, as the Inspector may wish to consider the impact hazard screening can have on civil engineering, both before and during site specific assessment.

87. The Inspector may wish to seek assurance of the adequacy of the data collected regarding hazards during screening, specifically around any uncertainties associated with assumed loadings, structural analysis methods or structural capability and the properties of material potentially affected by degradation.

88. The Inspector may wish to check that any assumptions are appropriately checked, reviewed or carried forward into civil engineering design at the appropriate time in the design (SAP ECE.13).

89. The Inspector should be aware that the civil engineering structure provides SFRs e.g. where the structure acts as a barrier to protect the SSCs and/or personnel from internal and external hazards. It is expected that the hazard definition and shielding protection or other barrier requirements will be assessed by other disciplines. The Inspector may need visibility of the hazard schedules to understand how hazards are being communicated through the analysis and how the subsequent loading is derived for the civil engineering design. The principal civil engineering assessment requirements regarding hazard identification and fault analysis are to make a judgement as to whether:

- all consequences of faults and subsequent accidental loads on structures are considered, e.g. internal flooding pressure on walls to withstand horizontal water pressure,
- the justification for the screening out of external hazards or proposed changes to the expectations of SAP EHA.4 regarding the annual frequency of exceedance of non-discrete hazards are understood and have been appropriately justified and applied to the civil engineering design
- the loading output is understood, i.e. conservatisms and optimisms are stated,
- the loading output is adequately catered for in design,
- the design is fit for purpose and provides adequate protection against hazards,
- the design considers risk management by ‘designing out’ interfaces related to layout or workspace that could cause avoidable consequences e.g. an accident or fault scenario, including layout of adjacent structures/ personnel walkways,
- the design of the site against flooding should consider the climate change predictions and the design should allow for managed adaptable solutions, e.g. potential future modification in response to uncertainties in the design phase,
- all foreseeable events have been included, (or knowingly omitted),

90. Where no claims are made on all or part of a structure when subject to external hazards loading, the safety case should give consideration to the potential consequences of significant parts of the structure collapsing, including potentially significant impact loads on SSCs and the need for post-event recovery. The Inspector may wish to check how the dutyholder has considered the need for suitably qualified escape routes for workers who may become trapped due to failure of non-qualified structures, specifically where the routes are required for Licence Condition 7 emergency arrangements.

91. For more guidance on internal and external hazards, see:

- ONR-NS-TAST-GD-013 ‘External Hazards’,
- ONR-NS-TAST-GD-014 ‘Internal Hazards’.

3.5.5 Hazard combinations

92. EHA.6 establishes the expectation that the analysis of the effects of internal and external hazards should take into account hazard combinations, simultaneous effects, common cause failures and consequential effects. The Inspector should expect that such combinations of events are considered to be design basis accidents or are included as part of beyond design basis (design extension) conditions, depending mainly on their likelihood of occurrence (SAP EHA.6). This is also identified in Requirement 20 of the IAEA guidance SSR 2/1 [12].

3.5.6 Severe Accident Analysis (SAA)

93. For a major project, a Severe Accident Analysis (SAA) should be used in the development of further risk-reducing measures, including informing the beyond design basis considerations.

94. The Inspector may wish to seek assurance that the output of the SAA has been appropriately included in the civil engineering design, including effects such as elevated temperatures.

95. For more guidance on SAA, see:

- ONR-NS-TAST-GD-007 ‘Severe Accident Analysis’.

3.5.7 Beyond Design Basis / Design Extension Considerations

96. The expectations for the Inspector to consider potential events beyond (more severe than) the design basis are established in the following:

- Requirement 12 of the IAEA guidance SSR 2/1 [12] states the design of the facility shall provide for an adequate margin to protect items important to safety against levels of external hazards to be considered for design, derived from the hazard evaluation for the site, and to avoid cliff edge effects
- WENRA guidance for Design Extension Conditions (DEC), Issue F of Safety Reference Levels for Existing Reactors [13].

97. SAP EHA.18 explains the expectations for beyond design basis. SAPs ECE.1 and ECE.12 establish the expectation that design margins should be such that civil engineering structures continue to provide their residual safety function following the application of beyond design basis loads. This should be achieved by either having sufficient design margins, or by failing in a manner that suitably limits the radiological consequences.

98. EHA.7 establishes the expectation that the design of the facility shall provide an adequate margin to protect items important to safety, such that a small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences. These are sometimes referred to as ‘cliff edge’ effects. In line with the expectations of ECE.6, the predicted failure modes should fail to safety (EDR.1) be gradual, ductile and, for slowly developing loads, detectable. The loadings assumed should take account of uncertainty in the underlying fault or hazard specification.

99. At the GDA phase, candidate site hazard values are unlikely to be defined and any inherent margin between values adopted for design and the site-specific values cannot be claimed, but cliff edge considerations are still expected to be addressed. A generic site envelope is used to describe hazards considered at GDA. The Inspector could refer to the GDA case when considering any site-specific cases.

100. When assessing the design and considering design basis events, it may become clear that a particular hazard drives the design and can be seen as ‘bounding’ the demand on a structure. Should the dutyholder extend this logic into the beyond design basis area, the Inspector is to be aware that hazard magnitudes do not develop at the same rate, for example against an annual probability of exceedance of 10^{-5}, the bounding hazard may be different than at a probability of 10^{-4}. This can become more complex when comparing hazards with a continuum vs discrete form. In addition, if best estimate approaches are used, the balance of epistemic and aleatory uncertainties needs to be appreciated by the Inspector. The Inspector may wish to seek assurance that any claimed bounding case is fully bounding for all the scenarios being considered for the civil engineering safety case.

101. The potential for a beyond design basis (BDB) demand should be considered for all design basis events which could be exceeded. For example, a seismic event is considered in the design basis, then the beyond design basis demand is a more severe seismic event which could result in structural collapse or loss of containment. Where a flooding event is considered in the design basis, a more severe flood leading to

overtopping of a flood defence or inundation of an emergency electrical supply would form the beyond design basis demand. The Inspector should be aware that no single type of demand or hazard should make a disproportionate contribution to overall facility risk (SAP paragraph 749). If it does, then further actions are likely to be required to further mitigate against the consequences of the demand or event. Where the design basis combines other events with an external hazard loading e.g. loss of cooling accident (LOCA) combined with seismic loading, the Inspector should expect a cliff edge analysis to ensure the LOCA and seismic (plus cliff edge) does not have a disproportionate effect on the structure.

102. Residual safety function(s) (e.g. to resist collapse) following the application of beyond design basis loads could be demonstrated by either having sufficient design margins, or by failing in a manner that suitably limits the radiological consequences.

103. For assessing beyond design basis analysis, in addition to those considerations highlighted in the design basis analysis, the Inspector may wish to seek assurance that:

- the cliff edge effects are sufficiently unlikely to occur (SAP EHA.7), such that a small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences,
- the civil engineering SSC are suitably robust (by consideration of factors such as design margins, redundancy, alternate load-paths, post-yield ductile failure, prevention of disproportionate or progressive collapse, compliance with ductile detailing rules and high confidence in the predicted failure mode),
- a suitable margin assessment has been undertaken. Some dutyholders have historically applied a fixed margin to their design basis loading. The Inspector should be aware that this approach may result in overly conservative designs, or in the case of high uncertainties in loading or behaviour, it may be non-conservative,
- the safety performance of civil engineering structures that are required for managing and controlling actions in response to an accident, including plant control rooms, on-site emergency control centres and off-site emergency centres, are defined,
- the schedule of load combinations has been used for design, and the beyond design basis loadings have been considered, including the considerations of cliff edge effects and margins to failure,
- appropriate consideration of whether the uncertainties in estimating the effects of faults or hazards have been adequately adopted in the design,
- the behaviour under beyond design basis loadings have been considered before the plant design is fixed, with consideration given to the behaviours of the structures (e.g. elastic, ductile or brittle). Progressive and disproportionate collapse must be avoided in design (SAPs ECE.2, ECE.6, EMC.11),
- the safety functional requirements on the structures for beyond design basis are established, and a set of established serviceability or performance limits and conditions are met by the design,
- residual safety function(s) (e.g. to resist collapse) following the application of beyond design basis loads could be demonstrated by either having sufficient margins, or failing in a manner that suitably limits radiological consequences.

104. When assessing the dutyholders approaches to demonstrate consideration of beyond design basis, the Inspector may expect demonstration that:

- high strain (e.g. deflection) and overstress effects (e.g. cracking, delamination, spalling) are tolerable;
- leak or radiological release acceptance criteria are appropriate,
- residual safety functional requirements (e.g. to avoid collapse) are satisfied,
- localised plastic deformation absorbs the input energy, but a collapse mechanism has not been formed,

- a number/diversity of lines of defence which are not vulnerable to common cause failure are provided,
- ductile failure modes precede brittle failure modes,
- the structure is suitably robust, possibly using non-codified design methods such as yield line or push over analysis.

105. The Inspector should be aware that a simplistic approach to code compliance, such as referring to partial safety factors is unlikely to be appropriate for beyond design basis assessments. Partial safety factors allow for multiple considerations such as the variability of materials and construction quality and the uncertainty in defining applied loads or structural response. The Inspector may find it acceptable if the dutyholder considers a best estimate of structural performance in line with the expectations of SAP FA.16 and SAP paras 246-334. In such an approach, partial material and load factors may be set to unity if it can be demonstrated that worst credible loading has been considered (e.g. load created when a wall is overtopped by flooding).

106. Confidence in the prediction of physical behaviour of materials and structures under beyond design basis loadings may be insufficient, especially for complex and novel construction methods. In this situation, the Inspector may consider the applicability of verification activities (e.g. physical scale models or extrapolation from in-situ test results) to improve confidence in the predictions, and/or research aimed at confirming the modelling assumptions.

107. The output of the beyond design basis consideration can be used to inform the severe accident analysis (SAA) response plans (SAP FA.15, FA.16 and FA.25). Some degree of iteration between the BDB consideration and SAA may be acceptable to achieve a cost effective, practicable position, where overall risks are reduced so far as is reasonably practicable.

108. The Inspector may request development of a strategy of how the Beyond Design Basis considerations are to be included in the civil engineering design, to understand the scenarios considered for each case. For more guidance on beyond design basis, see:

- ONR-NS-TAST-GD-006 ‘Design Basis Analysis’.

3.6 Fundamental Safety Functions

109. In line with Requirement 4 of IAEA guidance SSR 2/1 [12], the expectation is that the wider safety case for the facility should be driven by fulfilment of the following fundamental safety functions:

- control of reactivity,
- removal of heat from the reactor and from the fuel store,
- confinement of radioactive material, shielding against radiation and limitation of accidental radioactive releases.

110. Safety functions cascading down into civil engineering would be expected to be derived from these fundamental safety functions, and the ‘golden thread’ should allow the detailed requirements to be traced back to these fundamental safety functions. The Inspector may wish to consider whether the civil engineering SSC may be required to provide shielding, in which case the Inspector may wish to seek assurance that the appropriate elements provide this function.

3.7 Safety functions

111. The following SAPs are particularly applicable to the assessment of safety functions:

- SC.8 highlights that the responsibility for defining the nuclear safety functions of a structure will reside with appropriately qualified persons within the dutyholder

organisation, and the ownership of the safety case should reside with those who have direct responsibility for safety,
- EKP.2 and EKP.3 sets the expectations around fault tolerance and defence in depth to prevent fault progression with independent barriers,
- ERL.1 and ERl.2 sets the expectations that a claim of reliability of SSCs will be made, and that these are stated,
- ERL.4 sets the expectations that there will be margins of conservatism to allow for uncertainties,
- EKP.4 establishes the expectation that the safety function(s) to be delivered within the facility should be identified by means of a structured analysis, where the identification of safety functions is based on an analysis of normal operation and all significant fault sequences arising from possible initiating faults determined by fault analysis,
- EKP.5 states that the measures will be identified by which the safety function is delivered, with a hierarchy around safety provision.

3.8 Safety functional requirements

112. Safety cases should specifically articulate safety functional requirement (SFRs) for civil engineering SSCs. Each SSC might have a number of different design basis demands, reflecting the fact that it may need to perform more than one SFR.

113. Generally, the civil engineering SFRs might include:

- structural support (to structures, systems or components),
- containment and / or confinement (including leak prevention and detection),
- radiological shielding,
- protection from hazards (including external and internal hazards),
- provision of a required internal environment (HVAC/weatherproofing etc.),
- for future decommissioning requirements, including waste management.

114. Civil Engineering SSCs with a safety role will need to meet one or more SFRs. The Inspector may wish to consider the degree to which the protection hierarchy has been applied to civil SSCs. This can be related to protection from hazards (including leaks) and can be provided by protection and mitigation, for example by:

- Arranging the layout so that a hazard is separated from people,
- providing a civil engineering element (cover, shell or liner) that resists the hazard (internal, external or impact hazards) to prevent impact or leakage,
- designing the civil engineering SSC itself to inherently resist the hazard, without requirement of additional elements, to protect nuclear safety SSCs,
- mitigating the consequences from the impact of hazards.

115. Where the civil engineering SSCs are required to meet SFRs, the Inspector may wish to consider how the civil engineering design substantiation considers the strength, stability, durability, serviceability and / or water / air tightness as demonstration that applicable SFRs are met.

116. When assessing beyond design basis considerations, the Inspector should be aware that a civil engineering SSC may be required to perform elastically under certain loading, when otherwise this duty is not called upon in normal operations.

117. When assessing sites with extended time frames associated with extension of life, or extended structural performance required after a site has ceased operation, or change of use beyond original design intent, demonstration of adequate longevity for the various structural elements or materials may become bounding. The Inspector may wish to consider the arrangements (and any changes to arrangements) that will be required for EIMT, specifically repairs and replacements, that will ensure the SFRs are met for the

required lifetime. TAG17 Annex 5 and Annex 6 discuss the expectations of ageing management and post-operation considerations (including SAP DC.1) in greater detail.

118. When reviewing SFRs, the Inspector may wish to:

- determine that the result of the design basis demands being placed upon the SSC is proportionate to the probability (frequency) of the event leading to the demands,
- seek assurance that all fault conditions and internal / external hazards which could challenge safety functional requirements have been considered,
- consider if reasonably practicable measures to minimise the potential safety consequences of the design basis demand being placed upon the SSC have been implemented,
- establish that the potential safety consequences are based upon conservative assumptions regarding the frequency of the event and the performance of the civil engineering SSC,
- seek assurance that there is a link from fundamental safety functions to SFRs, alongside the justification as to which safety functions and SFRs have been screened as not applicable to civil engineering SSCs.

3.9 Safety measures

119. EKP.5 sets out the expectations for assessment of safety measures. The Inspector should be aware where safety measures are identified to deliver the required safety function(s). Safety measures may constitute active systems, but the vast majority of civil engineering SSC providing a safety function are passive safety measures.

120. Non-passive civil engineering elements that may be classed as a safety measure could include doors, gates or windows that withstand fire, blast, impact or flooding, or blow-out panels (or similar) to relieve internal pressures. These safety measures are usually installed to mitigate radiological or other consequences of a fault sequence or event, so are often considered in design basis analysis and/or beyond design basis analysis.

3.9.1 Schedules

121. Engineering schedules are frequently used to identify items important to safety and the safety functional requirements placed upon them. Ideally, these should include the Safety Functional Requirement (SFR) placed upon each SSC, and the plant operational states when these could occur.

122. SAP ECE.6 establishes the expectation that a schedule of load combinations, together with their frequencies, should be used as the basis for structural design. Loadings during normal operating, testing, design basis fault and accident conditions should be included. The Inspector may wish to seek assurance that the loading schedule and the schedule that declares the safety functional requirement placed upon the SSC are in alignment. When the loading input to design meets the SFR, the design should be substantiated through correct use of civil engineering codes.

123. The Inspector should expect a systematic approach to have been taken to identifying those elements important to safety that are necessary to fulfil the fundamental safety functions and the safety functional requirements placed upon the SSCs.

124. From the assessment, the Inspector should be able to identify the inherent features that are contributing to fulfilling, or that are affecting, the fundamental safety functions for all plant states. The Inspector may wish to judge whether the dutyholder’s approach has full traceability.

3.10 Categorisation and Classification

125. The following provides a brief overview of the expectations regarding SSC classification relating to civil engineering:

- Class 1 – the design will be undertaken using nuclear specific standards, or standards which can be shown to deliver an equivalent reliability. Structures are typically expected to remain elastic under design basis loads. Detailing of the structures should be such that beyond design basis behaviour is ductile and predictable,
- Class 2 – the design will be undertaken using standards which deliver the reliability commensurate with the safety claims made,
- Class 3 – the design will be undertaken using normal industrial standards.

126. The Inspector may wish to seek assurance that safety functional requirements are used to define the Category and Class for the civil SSC (SAPs EKP.4, ECS.1 and ECS.2, and paragraphs 158-168). A civil engineering SSC might have different classification for different categories associated with the different safety functional requirements placed on the SSC.

127. The Inspector should be aware of the limitations when a dutyholder links design standards to classification, as specific rules do not exist within design standards.

128. If the Inspector’s expectations regarding the Category and Class of the civil engineering SSC are not satisfied, it may be permissible to accept an overall facility justification if sufficient alternative lines of defence are provided, independent of the civil SSC (SAP EKP.3). This is covered in more detail in the Defence in Depth section of this document.

129. For more guidance on categorisation and classification, see:

- ONR-NS-TAST-GD-094 – ‘Categorisation of safety functions and Classification of structures, systems and components’.

3.10.1 Seismic Performance Classification

130. For civil engineering structures with nuclear safety significance, it is common to supplement the safety classification with a performance-based classification scheme, especially for seismic hazard withstand, where it is common to have a dual classification for key structures, indicating not only their safety classification but also their seismic classification. Seismic classification is typically of three types:

- Seismic class 1 – remains fully functional during and after a design basis event,
- Seismic class 2 – does not collapse during a design basis event and retains limited functionality following an event,
- Seismic class 3 – no specific seismic design.

131. Seismic classification schemes can also include containment functions relating to water tightness and/or air tightness during and following an earthquake. Seismic safety functions applicable to civil engineering structures may be generated by other disciplines.

132. It is common to find mixed classifications for structures. For example, the overall enclosure may be class 1, seismic class 1, with sub-structures in the main structure that may be classified at lower levels. The Inspector should appreciate the scrutiny required to seek assurance that the potentially dissimilar behaviour of connected items is catered for in the design and reflected in the safety case claims. The Inspector should be aware of the interfaces between civil engineering SSCs and the expectation as set out in SAP ECS.2, where the failure of an item of lower classification will not propagate to an item of a higher classification (SAPs paragraph 167).

133. The Inspector should note that some dutyholders will use the prefix ‘S’ on some classifications (sSSC) to differentiate from the SSC class.

134. The Inspector should expect that all items important to safety be identified and classified on the basis of their function and their safety significance. Seismic classification in terms of the hazard level (annual probability of exceedance) to be withstood by each structure, along with its performance level, is also expected. This includes those structures which may not contain a nuclear hazard but whose performance could prejudice the integrity of adjoining structures. This is in line with Requirement 22 of IAEA guidance SSR 2/1 [12].

3.11 Arguments and passive safety

- ECE.1 establishes the expectation that the required safety functions and structural performance of a structure should be quantified and specified,
- ECE.2 establishes the expectation that for structures requiring the highest levels of reliability, multiple independent and diverse arguments should be provided in the safety case,
- EKP.3 establishes the requirement for defence in depth against potentially significant faults.

135. In civil engineering, structures are often considered to provide their safety function in a passive way, i.e. they do not rely on control systems, active safety systems or human intervention to act as a defence or barrier. That does not mean to say that the structure itself is not considered a safety measure in its own right (SAP EKP.5). Safety should be secured by passive measures where possible, and priority should be given to providing reliable and effective barriers (inherent design features) so that later barriers, though in place, need not be called upon. Further, safety and security measures should be designed and implemented in such a manner that they do not compromise each other. The Inspector should be aware that inspection and maintenance of such passive safety measures is important to ensure that SSCs do act in a way that is anticipated under fault conditions.

136. SAP EKP.3 establishes the expectation that defence in depth against significant faults or failures is achieved by the provision of multiple independent barriers to fault progression. As part of the multiple independent barriers in place, one or more of these barriers may be provided by civil engineering SSC, often acting in a passive mode. This safety function is confirmed in the IAEA Safety Requirements SSR2/1 [12]; a Level 1 barrier acts as a prevention of abnormal operation and failures by design. Such barriers are should be conservatively designed, constructed and maintained, applying suitable engineering practices and quality levels.

137. Where civil engineering SSCs provide a barrier function, ECE.2 states the expectation for the required robustness and resilience of civil engineering structures to be quantified and specified. Multiple, independent and diverse arguments should provide a robust, multi-layered justification, in which weaknesses in individual lines of defence are offset by strengths in others. The Inspector may wish to consider where civil engineering SSCs are providing the only effective barrier, if multiple barriers are not possible, that commensurate reliability and appropriate justification are demonstrated. The Inspector may wish to consider the single failure criteria in this scenario. The typical arguments that can be adopted are presented in SAPs paragraph 337.

138. In the event that a civil engineering SSC is called upon to provide a function with the highest reliability, particular arguments would need to be invoked in a manner consistent with the approach of structural integrity or for pre-stressed concrete pressure vessels.

139. For structures providing a significant containment safety function (e.g. spent fuel ponds and active waste stores), multiple barriers or layers of protection are expected. For the containment of liquids, leak detection measures should be incorporated in the design.

140. For structure types that are inherently less ductile, a sufficiently high margin may be provided by demonstrating that failures are extremely unlikely to occur for credible initiating events.

141. The Inspector may wish to consider where there are conservatisms or margins, and whether these margins are accounted for in normal operations, design basis events or accidents, and whether the margins are eroded by multiple unrelated sources that have the potential to occur concurrently. The same is true for the considerations of cliff edge effects, where margin is required to be demonstrated in line with SAP ERL.4.

3.11.1 Defence in depth

142. SAP EKP.3 states the expectations around defence in depth and the use of multiple independent barriers to fault progression. SAP SC.5 states the expectation that safety cases should identify areas of optimism and uncertainty, together with their significance, in addition to any claimed conservatism. The Inspector may wish to consider whether the contribution that the civil engineering SSC makes to control of plant conditions in the design basis and / or beyond the design basis event is clearly identified, and whether this has sufficient margin of conservatism to allow for uncertainties in line with the expectations of SAPs ECE.1 and ERL.4.

143. Where a civil engineering SSC important to safety cannot be designed to be capable of EIMT in the future, e.g. buried structures, additional measures may be needed to ensure the SSC achieves the SFRs for the duration of the intended design life. This may place an SFR on the additional measure(s). The Inspector should expect that a robust technical justification will be provided to demonstrate the safe working life of the structure important to safety have been evaluated, defined and substantiated at the design stage, in line with the expectation of Requirement 29 of IAEA guidance SSR 2/1 [12] and SAP EAD.1.

3.12 Safety Case Documents

144. Having established the pre-requisites for the civil engineering safety case, the expectation is that a clear document structure be presented to explain the flow of information into civil engineering and its development into a fully compliant design. The safety case documentation, alongside the design documentation and any design substantiation documentation, should provide the Inspector with a full picture of the design and safety case. For civil engineering assessment, the Inspector should consider the golden thread from the hazard derivation through to the design substantiation (See section 0 of this annex).

145. During the assessment, the Inspector should consider any decisions that cannot be made at a particular stage due to lack of information, and whether decisions are made which foreclose options in the future. The level of safety case documentation available depends on the stage of the design process.

146. For more information on expectations regarding safety case documentation, see:

- ONR-NS-TAST-GD-051 ‘The Purpose, Scope and Content of Safety Cases’.

4 KEY ASSESSMENT PRINCIPLES FOR CIVIL ENGINEERING DESIGN

147. The Inspector should expect the approach to design to be proportionate to the nuclear safety significance, including the need for independent assessments and reviews, as well as Design Authority and Intelligent Customer overview. The adequacy of the plant design, including design tools and design inputs and outputs, shall be verified and validated by individuals or groups separate from those who originally performed the design work. This is in line with the IAEA guidance 2/1 [12] requirements 2 and 18.

148. SAP ECE.12 establishes the expectation that structural analysis and / or model testing should be undertaken to support the design and should demonstrate that the structure can fulfil its safety functional requirements over the full range of potential loading for the lifetime of the facility allowing for degradation.

4.1 Design philosophy

149. The Inspector should expect to see a written explanation of the design philosophy for all designs of civil engineering SSCs. The Inspector may wish to seek assurance that an appropriate design approach has been applied and adhered to. The Inspector may wish to seek assurance that a design philosophy document is being produced during early engagement.

150. The Inspector should expect a clear and concise written design philosophy will be maintained throughout all stages of a facility, to include (where applicable) but not be limited to:

- function of the structure (including functions subject to accident conditions), for the lifetime of the structure,
- key materials to be adopted,
- form of structure (including method of ensuring lateral stability),
- key assumptions,
- design codes to be applied,
- design tools and processes to be adopted,
- design verification processes to be applied,
- construction sequence,
- commissioning activities.

4.2 Design codes and standards

151. ERL.1 establishes the expectation that the reliability claimed for any structure should take into account its novelty, experience relevant to its proposed environment, and uncertainties in operating and fault conditions, physical data and design methods. This can be partially addressed by ensuring the suitability of codes and standards and establishing that they will produce a design with adequate reliability. Wherever possible, for the design of civil engineering SSCs assigned as Class 1 and 2, the Inspector should expect designs to be undertaken in accordance with an applicable design code or recognised design guidance. This is in line with Requirement 9 of the IAEA guidance SSR 2/1 [12] and the expectations of SAPs ECS.1 and ECS.2. This is covered in more detail in the Categorisation and Classification section of this document.

152. The structural design of almost all civil engineering structures should be based on a recognised codified approach. The breadth of structural materials, structural types and codes available mean that providing detailed guidance is beyond the scope of this guide. The basic principles to be applied and an indication of what is seen as RGP are provided in SAP ECS.3.

153. The principal civil engineering assessment requirements regarding use of codes and standards are:

- if the design uses several standards, the Inspector may wish to consider whether the codes are compatible with each other to adequately support the safety case claims, arguments and evidence required to provide a robust safety case. The Inspector should be aware of the combination of guidance from different codes to demonstrate the design remains conservative,
- where optional parts of the codes are used, the Inspector may wish to consider whether the design decisions to use or exclude optional parts of the code are appropriate and have been justified in the safety documentation,
- whether the structural concept lies within the boundaries of code assumptions,

- when using non-UK codes and guidance, to demonstrate that material standards and material availability in the UK do not undermine confidence in the application of the code,
- whether the design makes use of relevant good practice and appropriate data, considering that design codes used historically do not necessarily reflect current thinking or knowledge. The Inspector should expect justification for particular use of data which may be valid even if it is not contemporary,
- where use, if made, of withdrawn codes (for example British Standards that have been withdrawn and replaced by structural Eurocodes) the Inspector should be satisfied that this has been justified and that the codes used are not undermined by more recent relevant good practice,
- whether the most up to date version of a design code is being adopted, unless the use of an older code can be demonstrated to be relevant good practice.

4.3 Reliability

154. Reliability is commonly defined as "the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered". There are four elements to the definition that the Inspector may wish to consider:

- Probability refers to the likelihood that a device or structural component will work properly.
- The second element refers to adequate performance. In order to determine whether a component has performed adequately, a standard is needed to define what is meant by adequate performance (i.e. ULS, SLS).
- The third element is the intended period of time. This is the mission endurance or lifetime of the structure under consideration.
- The final element of the definition is the operating conditions.

155. These terms imply acceptance of some degree of uncertainty. Until recently, structural reliability was not routinely analysed or quantified in the design process. Reliability was accounted for tacitly by the factor-of-safety approach to design and the structural designer/analyst does not perform a formal risk analysis on newly designed structures.

156. In some cases, for example where code compliance cannot be readily demonstrated or where explicit claims are made over the reliability of a structure a formal reliability analysis may be used by dutyholders. In such cases, the Inspector may wish to establish in the first instance why a standard/code based approach cannot be used, as a sound deterministic design is well-known to provide robust outcomes. The Inspector may judge that detailed reliability evaluations are a viable approach. The Inspector may wish to consider the use of First/second-order reliability method (FORM / SORM), whilst these are established methods, they are not the province of the generalist. The Inspector may wish to examine at a high level the last 3 points above as until clarity is received over those elements, progress with the details of the analysis cannot be made.

4.4 Conservatism in Design

157. Conservatism is used throughout the stages of civil engineering lifecycle, from siting and licensing (where ground investigation data is interpreted into design parameters), design analysis (predicting dynamic behaviour and use of codes), construction and / or modification to asset management of ageing facilities (defects and margins and factors of safety) and ultimately decommissioning and demolition. The Inspector may wish to check where there are conservatisms made and consider what impact such conservatisms may have on the civil engineering design. Demonstration of an appropriate level of conservatism for dynamic analysis may require the consideration of both upper and lower bound values for parameters affecting actions and load resisting capacities in order to ensure the overall design is conservative. The use of sensitivity studies can assist in understanding such effects. The Inspector should consider SAPs SC.5 and ERL.4 when considering such conservatism in design.

158. The SAPs identify that data used in structural analysis should be selected or applied so that the analysis is demonstrably conservative. It is recognised that an overly conservative approach could lead to the comparative importance of potential safety issues becoming obscured. Statistical methods and techniques can supplement the design process, by providing an improved understanding of failure modes, margin and sensitivity to input parameters and assumptions. This can be of particular value in supporting beyond design basis assessments and supporting demonstration of an ALARP position. The Inspector should be mindful of the extent of reliance on such methods, and that they are not a substitute for designing against deterministic engineering rules and presenting a demonstrably conservative design. It may be appropriate for the Inspector to consider the adequacy of the approaches to such statistical methods, along with any verification and validation exercises undertaken.

159. SAP SC.5 establishes the need for clarity around the areas of optimism and uncertainties in:

- the design of facilities, including material properties, defects or dynamic behaviour;
- the basis of safety case, including the analytical methods and codes, underlying assumptions and data with margins and factors of safety.

160. As such, the Inspector may wish to consider whether safety case is clear about optimism, uncertainty and conservatism, so that the risks are understood and can be managed appropriately throughout the life of the facility. With clear identification of safety significance of the claims being made and the uncertainty around them, the Inspector can make an assessment of the aggregation of issues against how much margin remains.

4.5 The Intelligent Customer function

161. The Inspector is reminded that some dutyholders contract out significant portions of the design of civil engineering works. The role of Intelligent Customer (IC) is to ensure the dutyholder undertakes checks regarding whether the specifications are appropriate and will meet the design intent. The IC checks that third party output(s) are in line with the original specification, that they meet the design intent and are of suitable quality. This role covers the outputs of designers, consultants, contractors and supply chain, and can cover dutyholder outputs, dependent on the dutyholder designer contract arrangements. The following SAPs are particularly significant when assessing the IC function:

- ECE.18 establishes the expectation that inspection and testing during construction is undertaken to demonstrate quality,
- ECS.3 establishes the expectation that civil engineering works should be completed to the appropriate codes and standards,
- MS.2 regarding the expectations around a capable organisation, specifically IC function described in SAPs paragraph 66,
- ECS.4 and ECS.5 establishes the expectation that if there are no appropriate codes or standards, an appropriate alternative approach is adopted, with the use of experience, tests or analysis applied as necessary,
- EQU.1 establishes the expectation that there will be qualification procedures to demonstrate the required quality has been achieved.

162. The key areas to consider when assessing a dutyholders IC function related to civil engineering are:

- whether the dutyholder has appropriate person(s) in place to undertake the role of Intelligent Customer function, understanding what constitutes relevant good practice,
- whether the IC function has been involved with design and assessment undertaken by organisations and persons who have demonstrable capability in

undertaking such designs, and whether the IC function has assessed whether they are engaged at an appropriate stage and have sufficient capacity so that the design can be completed prior to execution of the works,
- whether IC function has had involvement in ensuring that sufficient time is included in the design programme to allow appropriate consideration of the design substantiation, including activities undertaken by regulatory organisations,
- whether the IC function has been involved to ensure that organisations undertaking or procuring design or assessments apply appropriate quality verification processes to all substantiation, and whether verification processes will be sufficiently independent of the originator to ensure impartiality of consideration,
- whether performance requirements have been produced and are consistent with the design intent, and whether the IC function has been involved in the production of the performance requirements documents,
- whether a subsequent specification has been produced (construction or otherwise) for civil engineering works, and whether the IC function has had involvement in its production to ensure compliance with the stipulated performance requirements,
- whether the IC has had involvement in the compilation of the tender pack produced, whether there is sufficient information for planning and pricing of the design works or construction phase, with adequate specification and requirements, and whether the consultants, contractors or manufacturers arrangements include provision of clear lines of responsibility and authority. Clear reporting protocols and clear routes for escalation of issues into the dutyholder should be apparent,
- whether the IC function is involved in surveillance arrangements of the outputs once contracts have been awarded, to demonstrate that the appropriate quality and standards of deliverables have been achieved.

163. For more guidance on aspects of IC throughout the other civil engineering phases, which link back to design decisions, see:

- TAG 17 Annex 2, “Civil Engineering – Building Information Modelling” sets out the IC requirements for procurement of services to collect data,
- TAG 17 head Document.

164. Further guidance is available in:

- ONR-NS-TAST-GD-049 ‘Licensee Core Safety and Intelligent Customer Capabilities’,
- ONR-NS-TAST-GD-077 ‘Supply Chain Management Arrangements for the Procurement of Nuclear Safety Related Items or Services’,
- ONR-NS-TAST-GD-079 ‘Licensee Design Authority Capability’.

4.6 Independent checks

165. There is a need for independent review of design, supplementary to the numerical checks, validation and verification activities. This is to ensure that the codes have been applied appropriately and that safety case claims are met. This is often undertaken by Independent Technical Assessment (ITA), Independent Nuclear Safety Assessment (INSA) or Independent Peer Review (IPR). The Inspector should expect the arrangements for these checks to be independent of the Design Authority (DA) and Intelligent Customer (IC) functions as the DA and IC are not independent and are performing different roles, even though they may identify the same issues.

166. Where possible independent checks should use diverse methods or analytical models (SAPs paragraph 683). Where the independent check has utilised the same analysis model as the designer this should be justified and sufficient evidence provided that the model has been independently validated. Single discipline design reviews that are

arranged at various stages as the design develops and attended by experienced civil engineers independent of the project are also considered good practice in terms of demonstrating that designs have had adequate independent oversight.

167. The Inspector should appreciate the other aspect of ‘independent checks’ associated with temporary works or loading activities. Independent checking of temporary works or lifting operations are specific activities, e.g. to check the physical installation of temporary works prior to loading with concrete, or to check lifting equipment in line with legal requirements. The rigour of such checks is dependent on the classification of the work activities, which is not a nuclear specific classification, but which is explained in the guidance:

For more information, see:

- BS 5975:2019 ‘Code of Practice for temporary works procedures’ [14],
- L113 ‘Lifting Operations and Lifting Equipment Regulations HSE guidance Approved Code of Practice and guidance’ [15].

The Inspector may wish to consider the potential impact of temporary works or lifting on the permanent construction as part of the design phase with early contractor Involvement (ECI).

Information on temporary works may not be available at the design stage, as some temporary works are designed by the contracted supply chain during construction. The Inspector may wish to seek assurance that the verification processes are sufficiently independent of the originator to ensure impartiality of consideration.

4.7 Concept design and design optioneering stages

168. At the early stages of any civil engineering design, decisions are made on the design concept and choices are made around the design. The Inspector may wish to seek assurance in the adequacy of decisions made, to gain visibility of the process to choose one type of design over another. This is usually undertaken with an optioneering process, where advantages and disadvantages of decisions are weighed up and the concluding decision presented as the design chosen.

169. The Inspector may wish to seek such confidence in the process through early engagement during optioneering and concept design decisions, without becoming part of the design process themselves.

170. The Inspector should be aware that the civil engineering design is often undertaken to accommodate a range of layout requirements. Layout requirements are diverse and varied, covering many disciplines. The inputs can be from considerations of human factors or radiological or conventional health and safety, or protection from internal or external hazards or faults.

171. The Inspector may wish to consider the logic used to make layout decisions, especially if the design decision provides a complication for the civil engineering design that could be avoided with further consideration e.g. heavily congested reinforcement, or prevention of access for future civil engineering EIMT activities.

4.8 Layout

172. The layout and orientation of features on the site or within a facility should minimise risks to nuclear safety. This is an area for multidisciplinary inspection, applying a cross-cutting method, with consideration from civil engineering alongside inspectors from the internal and external hazards, human factors, mechanical, control and instrumentation, conventional health and safety disciplines.

173. The key SAPs that for consideration when assessing layout decisions are:

- EL0.1 establishes the expectation that the design and layout should facilitate access without compromising security,
- ELO.4 establishes the expectation that the design and layout should minimise the effects of faults and accidents,
- EMC.8 establishes the expectation that the geometry and access arrangements should have regard for the need for EIMT activities,
- EHF.6 establishes the expectation that the workspaces should be designed to support task performance.

174. The Inspector should be aware that layout, designs and construction should be such that dismantling can be undertaken using proven and safe working practices (ECE.26 and DC.1, see Section 4.20 of this annex).

4.8.1 Site Layout

175. The Inspector should expect the safety case to include or make specific reference to the associated parts of the overall safety case that have determined the plant layout.

176. IAEA guidance SSR 2/1 [12] places requirements on the regulation of the decisions regarding civil engineering. The Inspector should expect evidence of consideration of the following aspects in relation to the site layout:

- shielding barriers (requirement 5),
- internal and external hazards (requirement 17),
- physical separation of safety systems (requirement 21),
- plant layout for facilitating activities associated with calibration, testing, maintenance, repair or replacement, inspection and monitoring (requirement 29),
- plant layout for optimal operator performance (requirement 32),
- fire protection barriers (requirement 17 and 74),
- features to facilitate the movement, transport and handling of radioactive waste (requirement 78).
- proximity to facilities off the licenced site and out of the control of the dutyholder.

177. The key civil engineering assessment principles regarding site layout design are:

- the layout of features must also consider security, nuclear safeguarding and other requirements of the facility,
- site access to buildings in emergency situation, e.g. proximity of emergency response facilities to the potential causes of accidents,
- the positioning of embankments, natural and excavated slopes, river levees and sea defences close to the facility must not jeopardise the safety of the facility,
- the potential for interactions during seismic events or accident conditions (such as reflected pressure waves) between adjacent structures must be considered.

178. In line with the Construction (Design and Management) (CDM2015) Regulations, there is a requirement for the design layout to include for the ability to construct, decommission and demolish structures without causing undue hazards e.g. sequencing of construction. This is a particular consideration for the site licensing phase (see section 2.3 of this document),but should be considered at all phases as the design develops. Considerations for site layout include:

- collapse radius of temporary features, such as construction cranes, or permanent features e.g. stacks and towers,
- proximity of construction activities to existing high hazard or vulnerable facilities or activities, including construction planned to occur adjacent to an operating unit,
- provision of temporary openings in structures to allow installation of plant and equipment, etc.

4.8.2 Layout of buildings

179. The Inspector may wish to review the civil engineering layout, with consideration for the size of rooms concordant with proposed activities therein, and whether inputs to architectural design have been adequately considered and interpreted.

180. The key safety assessment principles are regarding building or facility layout are:

- EHF.1 establishes an expectation for a systematic approach to be in place for integrating human factors within the design,
- EHF.5 establishes an expectation for proportionate analysis of tasks important to safety,
- EHF.6 establishes an expectation that workspaces should be designed to support task performance,
- EHA.17 establishes an expectation for the consideration of the materials used and their contribution to fire loading in the facility.

181. The key civil engineering assessment considerations for the civil engineering layout of buildings are:

- a robust, clearly demonstrable load path, with appropriate degrees of redundancy and resistance to disproportionate collapse,
- protection of high hazard materials and activities from aircraft impact or missiles,
- segregation of high hazard materials and activities from potential sources of fire or explosion,
- the overall resilience to flooding, applying appropriate safety classification to the structures, employing suitable redundancy and diversity and avoiding single barriers where possible (SAP EHA.12),
- the potential fire loading on a structure and the protection provided by barriers and partitions,
- over-pressurisation of compartments, following a failure of plant e.g. high energy pipe break, and how the compartments will react to the initial, instant pressures and subsequent pressure loadings,
- means of access for emergency responders and egress for persons at risk within the facility,
- the potential for the ingress of naturally occurring gases and vapours for the design of underground structures (see TAG 17 annex 3 “Civil Engineering – Ground investigations, Geotechnics and Underground Structure Design”,
- provision to complete adequate EIMT for the entirety of the required lifetime.

182. The Inspector should note that the IAEA guidance SSR 2/1 [12] makes specific mentions of the following for civil engineering design decisions regarding layout. The Inspector should expect evidence of consideration of the following aspects:

- safeguards against unauthorised entry of persons and goods (requirement 38),
- sufficient flow routes between separate compartments inside the containment for pressure equalization considerations during accident conditions (requirement 17),
- Control Room and Supplementary Control Room designed with consideration of suitable barriers to the external environment (requirement 65 and 66),
- control of containment conditions (requirement 58, see ONR-NS-TAST-GD-020).

183. For more information on layout and workplace spaces, see:

- ONR-NS-TAST-GD-062 ‘Layout and Workplace spaces’.

184. For wider guidance, see:

- L24 “Workplace health safety and welfare associated with the Workplace (Health Safety and Welfare) Regulations Approved Code of Practice [16]

4.8.3 Plant Layout and structural symmetry

185. Eccentric layouts of heavy plant and asymmetry/irregularity in building structure layout (stiffness, load paths or geometry) can lead to an increase in the magnitude and complexity of the response of a structure to a seismic event. The Inspector may wish to seek assurance that appropriate consideration of these effects has been undertaken when determining the layout of new facilities.

4.8.4 Shielding

186. The Inspector may wish to look ‘upstream’ to the internal hazard and radiological protection evaluation which is expected to identify shielding requirements for civil engineering SSC. The evaluation is intended to prevent or reduced exposure to radiation as part of design. The IAEA guidance SSR 2/1 [12] Requirements 5 and 81 makes specific mention of design considerations for radiation protection, as does SAP RP.6, including:

- the design of a nuclear facility shall be such as to ensure that radiation doses to workers at the facility and to members of the public do not exceed the dose limits, that they are kept as low as reasonably achievable in operational states for the entire lifetime of the facility, and that they remain below acceptable limits and as low as reasonably achievable in, and following, accident conditions,
- shielding shall be provided so that radiation exposure is prevented or reduced,
- materials used in the manufacture of structures, systems and components shall be selected to minimize activation of the material as far as is reasonably practicable.

187. For more information on layout and workplace spaces, see:

- ONR-NS-TAST-GD-002 ‘Radiological shielding’.

4.9 ALARP Optioneering

188. SAP SC.4 establishes the expectation that a safety case should: (a) explicitly set out the argument for why risks are ALARP; and (b) link the information necessary to show that risks are ALARP, and what will be needed to ensure that this can be maintained over the period for which the safety case is valid.

189. The ALARP principle applies at a high level in terms of radiological consequences. For civil engineering assessment, ALARP principles also relate to reducing all other hazards and risks as low as is reasonably practicable.

190. The ECE safety assessment principles provided in the SAPs should be considered when judging whether risks have been reduced to a level that can be considered as ALARP. The Inspector should consider whether the dutyholder has achieved an overall balance of safety, rather than satisfying each individual principle, when making an ALARP judgement. The principles themselves should be met so far as is reasonably practicable, but there is no specific hierarchy in the civil engineering SAPs.

191. During an ALARP optioneering exercise, the Inspector may wish to consider whether the designer has a clear appreciation of the concept they are trying to achieve. This could be articulated through a design philosophy or basis of design document. For the Inspector to have confidence in the process of optioneering, the optioneering documentation should identify the following:

- principal Safety Functional Requirements,
- design lifetime,
- performance specification (loading, reliability, durability),
- resilience and robustness requirements,

- design codes,
- analysis methods,
- operational constraints,
- commissioning acceptance requirements,
- EIMT strategy,
- decommissioning approach,
- quality requirements,
- interfaces,
- legislative requirements.

192. For some structures, or modifications to structures, it may not be immediately obvious that the solution adopted is ALARP. In such cases, it is expected that some form of formalised optioneering or equivalent process has been undertaken to give confidence in the design choice. The selected approach / design / option, sometimes referred to as ‘the ALARP decision’, should be supported by an adequate justification and suitably underpinned by evidence.

193. The Inspector should be aware that there is a risk that ALARP justifications have been written with a predetermined outcome in mind. Where the Inspector suspects this could be the case, the Inspector should consider the full implications of the choices made, including:

- weightings applied appropriately to the scoring,
- scorings are underpinned by substantiation,
- costs (time, trouble and financial) are applied appropriately,
- arguments presented consider all the relevant and applicable factors,
- options are all equally adequate to meet the needs of the original design intent,
- Undue conservatism is not applied to particular options to artificially inflate the cost,
- Undue optimism is not applied to lower cost options to ensure they emerge as the preferred option.

194. The ALARP principle can also be used when assessing time at risk and the Inspector is reminded also of SAP paragraph 759ff. and NT.2 which explain the expectations regarding time at risk considerations.

4.10 Novel, innovative and un-proven designs

195. The expectation is that items important to safety shall be of a design that has previously been proven in equivalent applications. If not, items shall be of high quality and of a technology that has been qualified and tested with appropriate qualification procedures (EQU.1). This is in line with Requirement 9 of the IAEA guidance SSR 2/1 [12] and ERL.1. This can mean that design decisions are not fully substantiated at the early design stages, with a reliance on site specific information, mock-ups or trials. In these situations, the Inspector may have expectations for future works, and to identify commitments the dutyholder has made to fulfil these in the future.

4.11 Loading

196. SAP ECE.6 establishes the expectation that load development and a schedule of load combinations, together with their frequencies, should be used as the basis for structural design. Loadings during normal operating, testing, design basis fault and accident conditions should be included.

197. The Inspector may wish to seek assurance in the adequacy of the derivation of the loading applied to the structures. As a result of the identified hazard combinations arising from fault and hazard studies, the Inspector should expect that values of loading be developed and defined, along with their associated load factors. The Inspector should expect this to be presented in an appropriate succinct form, be that a schedule or

drawings, in line with the expectations of SAPs ECE.2 and ECE.6. See section 3.9.1 for guidance on links between the hazard, loading and SFR or engineering schedules. This also applies to the loading applied to models. The Inspector may wish to seek assurance that load paths are clearly understood, with justification for any discontinuities in load-path.

198. Following the hazard identification and fault analysis, the loading functions for structures should be defined in terms which can be readily applied in the design process, with an auditable trail to their derivation provided.

199. The key civil engineering principles for assessment of loading in design include:

- whether the potentially large number of loading combinations leads to a rationalisation to a smaller subset of loads which govern the design. The Inspector may wish to seek assurance that loads are correctly identified and applied. Where global loads govern the overall stability of a building, other loads which will govern the design of local features should not be overlooked. For example, wind loading may not govern overall building stability, but may govern the local design of doors and/or cladding,
- where claims of withstand capability are made on structures, the Inspector should expect the design to capture all internal and external hazard loadings and demonstrate that the loads from hazards are within the bounds of civil engineering design substantiation. A schedule of load combinations that includes construction, normal, accidental and test conditions should be derived and applied to all relevant civil engineering elements,
- ensuring that the focus is not entirely on the beyond design basis loads. For example, when considering wind loading, it is possible that the 1 in 50 year wind load (with load factors consistent with standard Eurocode design) may envelope the 1 in 10,000 year event (with no load factors), due to the saturation of the hazard with frequency,
- horizontal loadings, especially from all fault scenarios, including internal flooding through the total flood paths,
- whether dynamic actions are likely and have been adequately demonstrated,
- whether the loading design is robust i.e. direct load paths where possible, as direct load paths lead to robust structures,
- whether all foreseeable events have been included, (or knowingly omitted), including sampling the inputs, understanding the golden thread and where the loading inputs have been derived from,
- all possible load combinations, including appropriate load factors. These should be considered to ensure they reflect the probability of exceedance of the contributory loads and that the load factor adopted takes account of uncertainty in the underlying fault or hazard derivation.

200. The design basis event for civil engineering structures is defined as the event which will not result in loss of the safety function. The Inspector may wish to also consider the durability and serviceability limit state of the structures, and whether some structural distress following exposure to the design basis event may be tolerated for structures. The Inspector should expect the extent and severity of the distress to be highlighted. The Inspector may wish to consider the aggregation of structural damage resulting from loading applied following a design basis event.

201. To preclude cliff edge effects, margins to failure should extend beyond the design basis fault (or hazard) load by an amount consistent with assumptions in the severe accident analysis. Beyond design basis load considerations should be included before the structural design is finalised. The Inspector may consider such load cases when assessing existing structures not designed in accordance with current standards or codes, taking into account any damage or ageing mechanisms (see ‘operational and ageing sites’ annex).

202. The Inspector may wish to seek assurance that the derivations of loads are demonstrably conservative. Where site specific data is incorporated into the schedule of loads (e.g. measurements of actual imposed load), partial load factors may be reduced, but the Inspector may wish to seek assurance that the source of the information is identified.

4.11.1 Wind Loading

203. When assessing civil engineering design wind loading are, the Inspector may wish to consider:

- dynamic augmentation factors and damping in structures,
- long wind (pressures on surfaces) and vortex shedding (transverse dynamic) effects,
- vortex shedding protection measures such as strakes,
- localised pressure effects at corners and parapets acting upon components and net wind loads acting upon structural systems,
- internal wind induced pressures and the effects of dominant openings,
- wind drag effects on large or irregular structures,
- permeability effects, included open sided and canopy structures,
- potential for changes in the local environment due to the long operational life of nuclear facilities, resulting in changes in wind speeds, this could include considerations for the future demolition of adjacent buildings that might be assumed to provide shelter at the design stage,
- wind acting in combination with other external events (snow, rain, low temperature, etc.),
- tornado effects (localised damage, depressurisation challenges to containment, wind created missiles),
- increased vulnerability due to non-standard operational configurations of plant or temporary alterations,
- threats to safety created by a rapid succession of wind events, leading to degraded structural or operational states,
- pedestrian, vehicle or deployable equipment environment when considering emergency response,
- derivation of a ‘sheltering operational condition’ wind speed,
- safe control and management of outdoor lifting operations.

204. For more guidance on wind loading, see:

- ONR-NS-TAST-GD-013 ‘External hazards’, for tornadoes and hazard combinations,
- guidance and periodical publications produced by the UK Wind Engineering Society (WES) [17],
- BS 6399 UK National Annex [18].

4.12 Finite Element Modelling and Numerical Analysis

205. Finite Element Analysis (FEA) is a way of simulating one or more specific behaviours of a physical body by a series of mathematical models. In the case of civil engineering structures, the body may be a localised structure or component, or an entire building with soil interaction. Its representation forms the FE model (FEm).

206. A FEm combines a model of the body’s geometrical form with models of the materials and the loadings. The body is discretised into a mesh of elements that need to be anchored in space and these anchoring conditions form the boundaries of the FEm, allowing the FEm to be analysed in isolation. The loading can take the form of any physical action that causes a reaction of the material; forces, pressures, temperature gradients, impulses and accelerations are common. Across these, the definition and application of loads will fall into one of two categories: static or dynamic.

207. The purpose of FEA is usually to gain confidence in the performance of the body under the applicable load scenario(s), either by predicting the accurate response or, in cases when this is impractical, by demonstrating a conservative response. Ensuring the mathematical formulation is functioning appropriately requires verification and, as the FEm is used to represent an actual physical entity, validation to confirm the behaviour is representative and ensure limitations are understood. Sensitivity studies can be used to evaluate the modelling assumptions and overcome uncertainty in defining parameters of the model (e.g. the geometry, loading, material strength or stiffness). The Inspector may wish to seek assurance that key aspects, such as the boundary conditions and the connections between elements and components, have been appropriately defined and validated.

208. For further guidance on Finite Element Analysis, see:

- NAFEMs provides a large collection of publications on FEA [19].

4.12.1 FEA Modelling strategy

209. The Inspector may wish to seek assurance that the modelling strategy is appropriate for the structure, the loads and the purpose of the analysis. As computation power continues to increase, the use of large three-dimensional (3-D) FEm's to reflect entire buildings or facilities is becoming more prevalent. These models are often able to estimate the structural response with greater certainty than other more approximate forms of modelling (an example could be lumped mass models using elastic beams).

210. Nonetheless, there remain practical limitations on what can be represented within one model. There is also a place for the use of different modelling techniques for validation purposes e.g. to understand global behaviour. The purpose of the model is of particular importance, and the Inspector should be clear on the overall modelling strategy being adopted for design, validation, verification and sensitivity.

211. In assessing the model strategy, the Inspector should give due consideration to:

- the family of Safety Functional Requirements and Engineering Requirements against which the structure(s) is/are being evaluated,
- the nature and complexity of the structure(s) being evaluated and, in the case of a large, complicated structure such as a building, the nature of the individual constituent structural components that make up the whole,
- the main load paths (vertical and lateral) of the structure, and how these tie in with the proposed modelling strategy. Where concrete is being used to provide biological shielding, this may result in structural elements that are notably thicker than would otherwise be required, and this may influence the load path in the local vicinity.

212. Each Engineering Requirement, as it applies to the constituent structural components, should be suitably represented by a model to enable the evaluation of the structural performance. A diverse combination of requirements, and / or a varied structure will require a more expansive modelling strategy comprising multiple FEm's and non-FEA models, (e.g. plastic behaviour models including strut and tie, yield line analysis and soil slip plane analysis).

213. For each model, the Inspector may wish to consider:

- the purpose of the model and the alignment of this to the Engineering Requirements,
- the desired outputs from the model and how these will be used in the design justification or substantiation,
- the boundary conditions including, where relevant, the representation of the soil.
- the geometrical fidelity,

- the material models,
- the meshing (density and shape) and element types,
- the use of non-linear constraint equations between node-points,
- the nature and application of the loads, and the combination of loads,
- the approach to capturing imperfections in the construction,
- the data handling and post-processing,
- the interface with other electronic representations of the structure,
- the statistical variability of the load and material and approach to achieving reliability (e.g. use of codified partial safety factors or strength reduction factors).

214. The Inspector should have an appreciation of how models used within civil engineering interact with those used by other disciplines. This includes:

- thermal and structural analysis of equipment, such as large vessels,
- internal and external hazard loads,
- fire loading,
- pressure and thermal loading associated with steam line ruptures.

215. For the civil engineering analysis, it is common for different models to be used for:

- soil-structure interaction,
- seismic analysis,
- global stability,
- structural stress analysis,
- analysis of prestress,
- analysis of thermal behaviour,
- assessment of structural behaviour at significant discontinuities,
- analysis of beyond design basis scenarios,
- other dynamic actions including aircraft impact, pipe failure, or equipment vibration.

216. The interfaces between models, including convergence of behaviours (e.g. soil springs) and data transferring (e.g. seismic response) should be a point of focus for the Inspector.

217. Reinforced concrete (RC) structures are the most common structural form found in the nuclear sector. The use of unreinforced concrete is rare for superstructures, as for civil structures modern codes and standards typically require a minimum level of reinforcing steel to be provided to control crack formation. RC is an inherently nonlinear material, and there are a number of features for reinforced concrete the Inspector may wish to consider in the modelling approach being adopted. These include (not restricted to):

- consideration of the multi-axial stress state of the concrete, including the non-linear effect of cracking under tension and the confining effect of compression. How this is considered in both the analysis, and any subsequent processing of FEm results to inform the structural design,
- consideration of creep in assessing the structural performance,
- some structures may include post-tensioning. Particular attention should be paid to the influence of the construction and load sequences on locked in strains and stresses and age-dependent material properties,
- squat elements with short spans, sensitive to the modelling of connections (e.g. the ‘overlap’ regions at slab-wall joints), typically subject to shear deformations where plane sections do not remain plane,
- slender elements may be more sensitive to second order effects,
- the nature of the load, whether it applies a through-thickness tension (e.g. a suspended load) or through-thickness compression (e.g. a bearing or pressure),
- for thermal loads, whether there is any self-relief of the loading due to concrete cracking.

218. Within any model, loads are conventionally applied as accelerations, displacements or forces. It is critical that the manner in which individual loads are applied is compatible with one another when multiple loads are combined. For example, in most software a displacement must not be applied coincidently with a force. Superposition of results from different load cases can also only be used when the models are linear.

219. The inspector may wish to consider whether the substantiation covers the following SAPs appropriately:

- assumptions and simplifications used in the development of the model (ECE.12),
- conservatisms expected from the model (ECE.13),
- suitable means for verification (ECE.14),
- suitable methods to verify and validate the model and demonstrate that it accurately represents the behaviour of the structure (ECE.15),
- a description of the proposed modelling methodology; including how they are applied to design (EKP.3, EKP.4, EKP.5).

4.12.2 Verification

220. The SAPs define verification as “The process of confirming, e.g. by use of objective evidence, that an activity was carried out as intended, specified or stated”.

221. The Inspector should expect appropriate verification of the FEm to be demonstrated in line with SAP ECE.15 and the AV series of SAPs. For the FEA this requires checking that the mathematics and processes underpinning the FEm are functioning correctly. The Inspector may wish to seek clarity on the verification activities that have been undertaken for the following:

- construction of the model including basic characteristics of the model including geometry, applied loads, masses, element types, element connectivity, boundary conditions and restraints etc.,
- the FEm input parameters,
- the FEm outputs, particularly the force balance, the displacements, the reactions, the connectivity, and the resultants,
- the process for ensuring consistent boundary conditions when using sub-models derived from the main FEm or separate local FEm’s,
- modelling errors related to numerical discretisations, methods, algorithms and solution procedures,
- software and hardware Issues related to bugs within operating system and hardware configurations, in particular parallel processing. This requires thorough verification of the software,
- the process of transferring and post-processing results from the FEm to the pre- and post-processing software (the Inspector should pay particular attention to the verification of proprietary in-house software).

222. The Inspector should note that numerical checks can be made using a different FEA programme or by using a simpler model to verify gross results. Most major FEA software packages have standard routines supplied by the software developer that should be run to verify that the software is functioning correctly. The Inspector should be aware that it is reasonable to expect general FEA programmes that have been extensively used for a long time to have been confirmed to be adequate, at least for the more common element mixes. There are a number of specialised programmes that will not have undergone examination to the same extent. These programmes, and rarely used elements in general programmes, should be demonstrated to behave as intended. The easiest way to carry out such demonstrations is to benchmark a series of models against analytical models known to behave as expected and/or against relevant pre-existing physical test data. If neither of these approaches is feasible, it may be necessary to carry out some physical tests.

4.12.3 Validation

223. The SAPs define validation as “The process of confirming, e.g. by use of objective evidence, that the outputs from an activity will meet the objectives and requirements set for that activity.

224. The Inspector should expect appropriate validation of the FEm to be demonstrated in line with SAP ECE.15 and the AV series of SAPs. Generally, the validation methods involve the model as a whole, as well as individual components of the model. The validation required for the FEm is dependent on the modelling strategy adopted along with the objective of the analysis.

225. Validation is often bespoke to the FEm and determined by expert judgement and practitioner knowledge and experience informed by results from the FEm. For large and/or complex analysis projects the inspector should expect a verification and validation plan to be produced by the dutyholder at the outset. The Inspector should bear in mind that the use of simple models to provide validation will often be preferable.

226. The Inspector should note that most software packages have validation examples consisting of problems using analytical models that have an analytical solution. These are usually presented to demonstrate the validity of a specific element type. Where a model contains a mixture of elements further validation will be required.

227. In some cases, it may be necessary to refer to test results, which if not available, may require specific tests to be conducted.

228. The Inspector may wish to consider the following themes when assessing the validation of a FEm:

- the overall modelling methodology may need to be validated against alternative methods or assumptions, for example this could be the validation of a sub-structuring SSI approach with a direct SSI approach, the use of averaging or other simplifications, or the use of a non-linear model for exploring claims regarding beyond design basis response etc.,
- the geometry of the model needs to be validated against the reality. This may require further analysis of the FEm should, for example, as built dimensions or reinforcement details differ. For older structures where reinforcement and/or concrete details are uncertain, site surveys and in some instances intrusive testing may be appropriate to validate parameters,
- the boundary conditions need to be validated using results that consider variations in boundary type and position along with impact of adjacent structures. Satisfactory iteration and convergence in developing boundary conditions for SSI should also be demonstrated,
- the selected material model and parameter values should be validated against model results to ensure consistency with modelling approach, test data if available may also be used for validation of more complex non-linear models,
- simplifications of details may require separate validation using refined or local models,
- the finite element mesh should be validated against results considering mesh refinements and where applicable results from local models. This should involve checking that model assumptions are not violated e.g. damping levels and stiffness is appropriate for the model stress resultants. If an elastic material model is used in conjunction with the principle of superposition then the results should be checked to ensure the model is responding elastically,
- the initial conditions should be validated against test data where appropriate. This particularly applies to geotechnical analysis – see TAG 17 Annex 3 – ‘Ground Investigations, Geotechnics and Underground Structure Design’,
- the derivation of inputs e.g. time histories or other load functions should be validated against design code requirements,

- the calculation phases should be validated against the construction loading sequence that occurs in reality,
- the results from the analysis should be validated against the expected results informed from benchmarks, learning from case histories, other analysis methods, design charts (where appropriate) and practitioner knowledge and experience.

229. For complex, very large FEm's, such as PCPV's validation thorough testing of such large structures clearly cannot be carried out. In such cases, a combination of testing small sections that are representative and the use of a different software package for comparison should be considered.

230. The Inspector should be aware that the geotechnical aspects of the model are of particular importance with respect to validation; further information on this is provided in:

- TAG 17 Annex 3 'Civil Engineering – Ground Investigation, Geotechnics and Underground Structure Design.

4.12.4 Sensitivity Analysis

231. The Inspector should note the importance of founding judgements based on interpolation of analysis results rather than extrapolation. Sensitivity analyses are a key exploration tool for supporting this aim (SAPs ECE.14 and AV.6 apply) that complement, but are separate to, the validation of the model.

232. The Inspector should be clear that the primary purpose of sensitivity studies is to explore the impact of uncertainties and assumptions associated with the FEm parameters or analysis approach to understand if changes produce disproportionate changes to the results that could undermine design basis intent.

233. The Inspector may wish to establish what sensitivity studies are in place and how these marry with the modelling and analysis strategy. These studies can be undertaken using appropriate models that may be separate, or alternatively they can use copies of the main FEm. In some cases, simple models can be used to ensure computational efficiency.

234. Sensitivity studies should ordinarily investigate individual parameters in order to gain understanding of the influence the parameter has. The Inspector may wish to consider the adequacy of the parameters investigated. Whilst all parameters could be considered for sensitivity studies, this is usually not practical.

235. Where the analysis results are particularly sensitive to the variability of more than one parameter, the inspector should consider whether it is reasonable for the analysis to consider combinations of parameters, for example where one parameter is set at its 'upper bound' value and another is simultaneously at its 'lower bound' value. Consideration of such combinations will depend on the level of uncertainty in the parameters being varied and the degree of confidence required in the analysis results.

236. Disproportionate sensitivity may be an artefact of the modelling (e.g. mesh size) or an indicator of the true behaviour. The latter may be true when changing a parameter leads to an abrupt change in failure mode (e.g. from a ductile flexural mode to a brittle shear mode).

237. The Inspector should note that sensitivity studies are of particular importance when understanding SSI analysis where modelling is reliant on multiple input parameters which are subject to varying levels of uncertainty. Multiple parallel sensitivity studies may be required to investigate the input parameters in turn.

4.12.5 Static Analysis

238. The vast majority of safety critical civil structures are formed from reinforced concrete (RC). Despite RC's non-linear and composite behaviour, a common assumption in an FEA is to treat the RC as a linear elastic isotropic material. In these cases, the FEA will be straightforward. In some cases, in order to justify a structure, some parts may be treated in a quasi-nonlinear manner. In such cases, the Inspector may wish to seek assurance that the FEA programme correctly represents the underlying behaviour. To this end, the Inspector is reminded of the variation in mathematical formulations adopted by different software packages.

239. FEA is often undertaken for analysing the effect of Static SSI in order to determine bearing pressures and deflection/consolidation for large and complex shaped foundations. This is usually undertaken using specialist software. The Inspector should be aware that if the analysis is based on an assumption of elastic behaviour the edge bearing stresses are usually much higher than the average. Under symmetric loading an assumption of redistribution might be a reasonable assumption. For unsymmetrical loading, particularly due to overturning such as on sea walls and retaining walls, it may be necessary to undertake a nonlinear analysis to justify against bearing failure.

240. Most of the general FEA programmes have facilities for undertaking analysis of structures which undergo material nonlinear response to the applied loading. This essentially means that the material from which the structure is formed exceeds its elastic limit. For materials such as steel the nonlinear behaviour is well understood and should be relatively straightforward.

241. Modern FEA programmes have at least two means of accounting for material nonlinearity, one is using elastic-plastic elements that are stress dependent and allow the nonlinear behaviour to occur where the stress dictates. Another is where the user assigns elements that permit large rotations, usually termed plastic hinges, at specific locations in the structure where the nonlinear behaviour is predicted to occur. Whilst the latter approach is more economical in terms of runtime it relies on the experience of the analyst to choose the appropriate locations. An approach that improves identifying the location of plasticity is to perform an elastic analysis to determine potential locations. The Inspector is reminded, when dealing with steel structures, which are usually relatively slender compared to RC structures, is a check on the overall stability, this can be significant when nonlinear effects are likely; most FEA programmes have that capability.

242. The Inspector should be aware of other specialist applications that may require detailed consideration including:

- the use of piles may need special consideration because of the strong interaction with the soil usually through a combination of friction and end bearing. Under seismic loading it is likely that the piles will undergo bending, developing reduced and in some cases zero, contact intermittently near the surface (post holing), (see paragraph 234 of this document),
- for the analysis of retaining walls traditionally utilises failure surfaces to determine the load applied by the retained material, usually soil. Standard FEA programmes do not incorporate elements to model failure surfaces and resort has to be made to forming a surface from general slip elements. For some cases, the use of recognised specialised geotechnical FEA packages is recommended,
- water retaining structures are usually designed to be elastic under load so as to minimise crack openings. Where these contain water bars, dependent on the detail, it may be necessary to consider explicitly modelling them.

243. The Inspector should be cognisant of the following special conditions:

- Fracture mechanics is more commonly associated with structural integrity, but it is also relevant to some civil engineering components some examples are diagrids, pipe supports, structural connections subjected to fatigue inducing loading. Some FEA programmes have the facility to model the growth of cracks and are useful when the component does not conform to the standard solutions.
- Fire can lead to a rapid degradation in the strength capacity of structures particularly on unprotected steelwork structures. Treatment of fire requires specialist software, otherwise an approach using a standard FEA programme with lower bound conditions could be considered.
- The effects of radiation, including embrittlement, may be a consideration for the civil engineering parts of the internals of a reactor pressure vessel and any tendons passing near to the inner surface, so variations in the material properties due to irradiation needs to be taken into consideration in any FEA of those parts.

4.12.6 Dynamic Analysis

244. For static analysis, the dynamic response of the structure is not explicitly taken into consideration. For dynamic analysis, this is taken into consideration. As for static analysis, both linear and nonlinear material properties can be implemented.

245. In general, all nuclear safety related structures will be designed to some level of seismic input motion, this means that they need to be subject to a dynamic analysis, from at least one perspective. Examples of other causes of dynamic loading are wind, blast, impact, sea loading, and machine vibration. A key point to note is that these dynamic loads are applied to the structure as forcing functions whilst the seismic motion causes the base of the structure to undergo motion that then acts on the masses in the structure. The Inspector may wish to seek assurance that the analysis is setup for either applied loading or base input; these are classic differences in dynamic responses.

246. The Inspector should be aware of the following applicability and limitations of the use of modelling for dynamic (seismic) analysis (Table 2). It is recognised that other model types exist and depending on the analysis method chosen, a variety of model combinations are possible. Hence, this table is for guidance only and the Inspector may need to obtain specialist advice during the assessment.

247. Note for Table 2: Classes 1,2 & 3 are based on the Safety functions and Safety Classification of SSCs as defined in the SAPs ECS.1 and ECS.2.

248. The Inspector should be aware that for seismic analysis there are two fundamental ways of analysing structures, either as a fixed base analysis assuming a rigid soil, or as an SSI model in which the compliance of the soil is taken into consideration. Fixed base analysis is the simplest to apply and is an accurate representation for a rock site. For softer sites the accuracy diminishes as the mass of the structure increases relative to the stiffness of the soil system. A key consideration for softer sites is that the structure will undergo rotational as well as translational motion, which for tall structures with a centre of mass near the base, can result in high accelerations from the rotational effects. Consideration of softer sites brings in the need to represent the soil system in the FEA by some means, for which there are a number of options that will be discussed below.

249. The other forms of dynamic loading are generally easier to model and analyse. They are usually represented as a force time history that is applied to the appropriate part of the structure. In simple terms wind and sea loading will need a reasonably long-time history to check whether the structure could be tuned to the loading frequency. Vibrating machinery is normally periodic so a periodic forcing function should be used. In the case of blast and impact loads, these are very short duration loading and should be applied using a very small time step in order to capture the rapid change in the forcing function and hence correctly model the energy input, as a check, most FEA programmes can

output the energy input. There are a number of different solution methods that can be used for dynamic analysis, each with its own merits. There are also a number of different ways in which the response of the structure can be analysed. In addition, the analysis can be sub-divided into a number of stages, which can involve the use of different FEA programmes for each stage. A key consideration is that whilst all these various approaches can be used for linear analysis, it is not the case for nonlinear analysis. The Inspector may wish to seek assurance that the analysis approach is suitably matched to the problem to be analysed.

Model Type	Suitability	General Applicability			Limitations
		Class 1	Class 2	Class 3	
Single lumped mass model	Validation purposes on simple structures designed using equivalent static methods	Not suitable	Not suitable	V&V Only	Inaccurate prediction of high frequency responses - inaccuracies amplified in the presence of soft soil. Unable to model shear walls/frames. Can lead to excessively conservative results in the vertical direction. Unable to predict localised effects
Beam model / one dimensional finite element model with soil springs	Validation purposes Frame type structures Simple symmetrical structures Benchmarking and sensitivity studies	V&V Only	Suitable	Suitable	Inaccuracies in predictions of high frequency responses - inaccuracies amplified in the presence of soft soil. Unable to represent local effects (e.g. roof bending, basemat flexibility) Unable to predict out-of-plane responses of floors and walls. Structures with shear walls need to be modelled with shell elements and are subject to wide variations in results. Torsional effects from eccentricity between the centre of mass and centre of rigidity require special consideration.
Three-dimensional finite element model	Suitable for modelling of all safety related nuclear structures Expected for modelling of structures in new nuclear facilities Large asymmetric complex structures on soil sites SSI analysis	Suitable	Suitable	Suitable	Requires greater amounts of computing power, simulations can take long periods of time to undertake each run, can take longer to produce the model. Simulation results produce large amounts of data. Technically complex requiring more robust V&V and SQEP resources.

Table 2: General acceptability of some commonly used structural models for dynamic analysis

250. Further guidance on SSI is provided in:

- ONR-NS-TAST-GD-013 ‘External Hazards’, Annex 1 ‘Seismic Hazard’.
- ASCE 4-16 Seismic analysis of safety-related nuclear structures [20]

251. The Inspector is reminded of the following areas that often require consideration:

- Damping can have a very significant effect on the results from FEA. The structural damping applied should be compatible with the stress-state of the structure and the safety functional requirements. The material and radiation damping from the soil also should be included in the analysis and demonstrated to be appropriate. Where appropriate, degradation of soil properties may need to be allowed for in the modelling, possibly by undertaking a sensitivity analysis,

- The input motion should be derived and applied in a manner consistent with the analysis methodology.
- The FEm mesh needs to be capable of accurately predicting the required parameters across the entire frequency range of interest and adequately validated.
- Assumptions regarding the stiffness (or extent of cracking) of the structure should be clear and compatible with the stress state of the structure and the safety functional requirements.
- The derivation of hydrodynamic effects from, for example, sloshing fluids in tanks or spent fuel ponds. This can potentially generate cyclic loadings with low levels of associated damping.
- If the overturning force generated is sufficient to produce uplift of the foundation, then what otherwise would be a linear dynamic analysis becomes a nonlinear dynamic analysis. The contact area of the base will change and with it along with the response or compliances of the soil, both due to changes in contact shape and potentially soil properties. This can increase the potential for a bearing failure through several alternative failure scenarios. Although such conditions are unlikely at the Design Basis, they may occur under Beyond Design Basis input levels and introduce a cliff edge.
- If sliding cannot be excluded it should be noted that this is a nonlinear response involving consideration of friction and the opening and closing of gaps where tension develops at the side of foundations when sliding occurs. It is often assumed it is conservative to ignore the action on the side of the foundations; doing so means that the changes in the response frequencies are not captured. In practice sliding under dynamic will be of limited displacement but, in most cases, it will be in combination with overturning leading to a complex nonlinear dynamic analysis.
- The assumptions in the seismic input, where vertical input is assumed to be compression waves means that the input is affected by the presence of a water table if one exists. Depending on the soil type, the soil-water matrix will behave differently to either of the two components and should be considered. Water tables tend to vary in level either seasonally or over longer periods so maximum and minimum levels should be accounted for.
- There are often many hidden assumptions within analyses. This could include , but is not limited to the way mass and stiffness proportional damping is applied, the cut off for participating mass, the treatment of missing mass, timesteps used in time history analysis, the solution algorithm itself (in some codes for example, acceleration time histories are converted to displacement time histories for application to the model).

252. The Inspector should be aware that two structure types that are particularly challenging from a dynamic analysis perspective are piles and graphite cores (the latter are covered by structural integrity graphite specialists but are supported by and interface with the civil structure).

- For all but end-bearing piles, piles rely on the surrounding soil to provide both vertical resistance along their length through contact friction and stability against buckling failure. Under seismic loading it is likely that the piles will undergo bending, developing reduced and in some cases, zero contact intermittently near the surface (post holing). The inspector may wish to seek assurance that the stability of the pile is checked for the case where the pile (or pile system) suffers the maximum soil contact loss. It is recommended that as piles tend to be used in poor soil conditions, a check is made to see whether the soil degrades sufficiently to indicate the possibility of liquefaction or cyclic mobility, which could lead to need to check the stability elsewhere.

- Graphite cores are constructed from layers of discrete blocks that form an approximate circular disc on plan. The blocks are interlocked with vertical keys that sit in vertical slots in each brick on each of the faces. For further guidance on this topic, see ONR-NS-TAST-GD-029 ‘Graphite Reactor Cores’.

4.12.7 Empirical methods of analysis

253. For a number of common design situations, often involving dynamic loading, there is a sufficient body of research to support the use of simplified analysis and assessment methods without the need for recourse to more complex and time-consuming finite element analysis. In many cases these simplified methods will provide an adequately conservative upper bound approach, and recourse to more complex analysis may only be required where the use of simplified methods results in calculated load effects that cannot readily be accommodated.

254. Typical design situations where there is extensive use of empirical methods are:

- Missiles
- Dropped loads
- Blast
- Pipe whip

255. The inspector should seek evidence that empirical methods have a track record of use in the nuclear or other high hazard industries or are recognised as suitable for use within national or international codes and standards. Where more novel methods of analysis are proposed, the reason for their use should be justified and the inspector should seek evidence of appropriate peer review, verification and validation.

256. A frequently used nuclear industry procedure for the assessment of dynamic loads and structural response on steel and concrete structures is the R3 Impact Assessment Procedure [21], as further described in [22]. The methods used in R3 are mostly based on an accepted interpretation of experimental data, supported in part by theoretical and numerical studies. For blast effects, a widely used approach is that provided in UFC-3-340-02 [23], which provides design methods based on the results of small-scale and full-scale tests using a range of materials.

257. The inspector should confirm that the scope and limitations of the adopted methods are understood and that the analysis parameters are not outside the range for which the method has been validated. The methods adopted should be capable of producing a design with adequate reliability, as further described in Section 4.3.

258. The key feature of impact, shock or blast loadings is that they occur over a very short time period, particularly in the case of impacts, and in most cases cause nonlinear behaviour.

4.12.8 Impact loading

259. Impact loading can be divided into two types that are generally called hard and soft impacts, the defining feature being that hard impacts tend to rebound, whereas soft impacts tend not to rebound. This difference is significant for the time step used for the FEA, with the hard impact occurring in a much shorter time. The time over which the impact takes place, along with mass, is the parameter that determines the force generated. The shorter the time of impact, the higher the force. A typical example of a hard impact is that from the corner of a dropped fuel flask hitting the floor and a typical example of a soft impact is a plane’s fuselage crashing into a shielded building.

260. The Inspector may wish to consider the following key aspects of hard and soft impacts:

- Hard impacts occur when both the impacting body, termed the impactor, and the impacted body termed the target, are stiff and non-crushable. A typical example is solid steel on steel impact. In such cases the deformation is highly localised, as consequence the FEm needs to have a very fine mesh in the contact region. This is required to allow the deformation to occur progressively, rather than instantaneously. Associated with the refined mesh is the need for very small time-steps to allow the deformation to occur in short stages. This usually means that the solution will be undertaken using an explicit solver because they are able to solve the large number of time steps much faster than implicit solvers.
- Apart from very low velocity impacts, the contacting materials will locally undergo both material and geometric nonlinearity. It is likely that an adaptive mesh approach will be used, which is where the mesh is adjusted to the shape of the deformed body rather than remain fixed in space.
- Under these types of impact the strain hardening properties of the material becomes significant because it acts to stiffen the material and reduce its deformation and hence increase the force, which in turn increases the deformation, hence creating an additional nonlinearity. Because impact involves two contacting surfaces friction is a major factor and requires contact surfaces and a value for the friction coefficient, which due to the localised heat generated is different from standard material friction values and needs to be determined. Consideration of friction of course introduces another source of nonlinearity. Whilst the friction will produce Coulomb damping the time interval of impacts is so short, that damping has negligible effect.
- Sensitivity studies would be expected to be presented for the strain hardening and the friction and bounding approaches may be appropriate.
- Soft impacts occur either as a result of the presence of soft materials or crushable structures such as those with thin walls. An example of soft material is the use of an impact mat below a flask lift area to protect the structure below from a flask drop. A crushable object encounter in nuclear civil engineering is an impacting aircraft where the fuselage progressively crushes upon impact. A feature of these types of impacts is that they occur over a longer time period than hard impacts. The forces that are developed during the impact result from large deformation of large parts of the structures rather than from a highly localised area. This means that adaptable meshes are likely to be used in what is a highly nonlinear analysis.
- It is unlikely that there will be just one configuration of crush and will be dependent on the orientation. It is therefore likely that a number of analyses will be required in order to be able to consider a range of outcomes. In some cases, the impacting body may be represented by a force time function which represents the crush mode with time. This is often the approach used for impacting aircraft and avoids the need to explicitly model the aircraft thus making the analysis much simpler and it becomes effectively a shock loading problem.
- In the case of structures such as impact mats, they may be either specially designed or propriety manufactured. In the former case the properties will need to be determined, which would normally be by conducting tests allowing the modelling to reflect the test results including the larger geometric deformations, this is difficult problem and it might be preferable to carry out some tests so that gross behaviour can be modelled rather than the detailed behaviour of individual components. This same gross behaviour would be expected to be part of the information provided by a propriety manufactured item.

4.12.9 Blast loading

261. Blast loading is usually associated with blasts from the rapid expansion of a chemical reaction such as an explosive. The Inspector should note that the key feature of blast loading is that it normally acts over a relatively large area. Blast loadings usually occur

over longer time periods than impact loadings, the exception being an explosion next to part of a structure, which is more akin to a shock loading.

262. As the load is applied over a relatively long time the FEm can be expected to be meshed in similar refinement to that used for a seismic analysis or possibly a static analysis. The pressure pulse derived from the CFD, or other calculations, will need to be applied to each of the elements that see the loading. Most FEA packages have the capability to generate loading patterns across elements. A check on the accuracy can be made by checking the total applied load, this is a useful check particularly if the loading is not uniform. As with other dynamic analyse, the mesh size needs to be commensurate the time-step.

263. Blast loading can become highly complex especially with congested geometries of structures. In addition, the failure of elements of structures (by design or accident) causes additional complexity as loading may then apply on inner and outer surfaces of structures. In such circumstances, the Inspector should seek specialist support.

264. Loads due to sea wave loading and jetting from a Loss of Coolant Accident (LOCA) may be considered as a form of blast loading. This type of loading may act on different parts of the structure and require a Computational Fluid Dynamic analysis using FEA to determine the loadings, although there are specialised computer programmes that can deliver similar loading information. This will provide time histories of loadings at various locations of the structure, a key consideration if different parts of the structure respond with slight time delays.

4.12.10 Shock loading

265. Shock is a sudden acceleration or deceleration caused by an impact or a blast loading. An example of a shock loading is an instantaneously applied load, which is where a load with no associated velocity is suddenly applied to a structure. A typical example is a passive restraint system which is in contact with the body it is restraining in the event of failure of that body. Another example is where a body is rolled onto a beam or plate structure. Typically, the sudden application of load produces a dynamic amplification of two times the load if it where statically applied. This provides a check if a dynamic FEm is used. The Inspector may wish to verify whether strain rate effects need to be accounted for. Examples of such a situation are steam pipework head restraints and boiler closure unit restraints fitted to a number of operating AGR stations.

266. In some cases the shock loading may be defined in the form of a shock spectra, which has similarities with the approach used for seismic response spectra, giving the response of a single degree of freedom system to a particular loading pulse and can therefore be treated in a similar way. The Inspector may wish to seek assurance that a check is made that the component to which the shock is applied remains linear; else a nonlinear analysis will be required.

4.13 Pre-stressed designs

267. There are three time-dependent components which will reduce the pre-stressing load in a structure, which continue to occur decades after the initial losses during construction. These are:

- concrete shrinkage,
- concrete creep,
- pre-stressing tendon creep (relaxation of the pre-stressing steel).

268. The Inspector should be aware there are multiple influencing factors to the concrete shrinkage and creep, and they are difficult to predict reliably, whereas tendon creep is generally characterised much more accurately.

269. ONR-NS-TAST-GD-020 ‘Civil Engineering Containments for Reactor Plants’ states the expectation that the design should assess how the dutyholder has considered tendon failure in the design. The Inspector may wish to seek assurance that the approach implemented fulfils the full lifetime design hazard loadings, that design assumptions are valid, and ensuring the substantiation for tendon breaks are captured in the appropriate safety case reports.

270. For more information on pre-stressed design and regulation see:

- ONR-NS-TAST-GD-020 ‘Civil Engineering Containments for Reactor Plants’,
- USNREG Regulatory guide 1.35.1 [24],
- CIRIA guide C660 was the non-contradictory complimentary guidance in the UK to EC2 [25]. This has been replaced by CIRIA guide C766 [26].

4.14 Investigation and data collection (not ground investigation)

271. SAP ECE.13 establishes the expectation that data used in the structural analysis should be selected or applied so that the analysis is demonstrably conservative. The Inspector should challenge choices around codified ‘options’ if they do not provide a conservative result.

272. Where there is limited information regarding the design and construction of a structure, non-intrusive or invasive inspection and testing techniques may be required. Data which might add to the understanding of an existing structures includes, material properties (compressive strength, tensile strength, modulus, cement content), geometry (dimensions, verticality, member sizes), condition investigation (corrosion, cover-meter, carbonation, petrographic inspection), location of cast-in or embedded items (rebar survey, exposure survey), performance verification (deflection monitoring, pull out tests) etc.

273. The Inspector must be cognisant of the number and physical distribution of data points when determining how much confidence can be attributed to the results. It is unlikely that the sample size / distribution will be sufficient to allow a statistical analysis to be undertaken. Hence, design decisions made on the basis of collected data should be demonstrably conservative.

4.15 Design verification and validation (including quality assurance, independent checks)

274. The Inspector may wish to seek assurance that documents provided to substantiate a safety functional claim have undergone an appropriate quality assurance process (EQU.1), where a reviewer and approver have signed the documents if required.

275. Independent checks are discussed in Section 4.6 of this annex.

276. For further information on documentation quality checks, see:

- ONR-NS-INSP-GD-006 ‘LC6 – Documents, Records, Authorities and Certificates’,
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’.

277. For more information regarding construction quality assurance (to demonstrate that the design intent has been satisfied), see:

- TAG 17 Annex 4 ‘Civil Engineering – Construction Assurance’.

4.16 Designing for hazard combinations

278. The Inspector should be aware of the combined simultaneous demands on a civil engineering SSC (coincident loading, multiple demands developing as a result of an internal / external hazard), and should have confidence that the appropriate combination factors have been applied, reflecting the probability of the combination. The Inspector may wish to seek assurance that the design analysis covers the hazard combinations in the loading schedule accurately, and reflects the hazard combinations that have been identified in the fault studies and other hazard schedules.

279. For further information on hazard combinations, see Sections 3.5.1-5 of this document.

4.17 Designing for emergencies

280. The adequacy of off-site civil engineering SSC supporting an emergency response should be considered if the site cannot be demonstrated to be self-sufficient to all design basis demands (e.g. highway bridges, road embankments).

281. The anticipated performance of civil engineering SSC during normal operating, fault and accident condition should be highlighted, especially when the performance requirement differs when subject to different actions (e.g. containment during operation, resistance to collapse during accident conditions).

282. The safety functional performance of civil engineering SSC required for mitigation, managing and controlling responses to an accident should be defined. These structures include control rooms and on-site and off-site emergency control centres. Consideration should be given to ensuring their safety function following the event that led to the accident. This is in line with the requirements 65 and 66 of IAEA guidance SSR 2/1 for the control room and supplementary control room.

283. For further information on site requirements for emergency events, see:

- ONR-NS-TAST-GD-103 ‘Emergency Power Generation’,
- ONR-NS-TAST-GD-082 ‘The Technical Assessment of REPPIR Submissions and the Determination of Detailed Emergency Planning Zones (DEPZ)’.

4.18 Designing for construction

284. Whilst it is captured in the CDM2015 designer duties, SAP ECE.25 also establishes the expectation that items important to safety should be designed so that they can be manufactured, constructed, assembled, installed and erected in accordance with established processes that ensure the achievement of the design specifications and safety functional requirement. The effects of construction hazards on any nearby safety related SSCs is a key consideration for inspectors.

285. The Inspector may wish to seek assurance that the design takes these factors into account, including the actions that the dutyholder is taking to ensure that the required safety function of the civil engineering structure will be achieved. The Inspector may wish to consider the:

- design actions taken to mitigate against risks resulting from construction activities and details of residual risks (preferably by the use of Designers Risk Assessments (DRAs), or similar documentation),
- accessibility for construction, considering already constructed elements of the project or existing facilities,
- availability of off-site manufactured items, their delivery, storage and installation (SAPs EMC.13 and EMC.14),
- installation of large items, after construction of civil engineering SSCs, including for any planned modularisation and prefabrication, lifting and jacking,

- management of temporary or permanent confined spaces (limited ventilation, egress restrictions, naturally occurring and man-made gases, flooding etc.) (SAPs ECE.11 and EHA.1),
- EIMT expectations specified by the designer. These must be clearly identified in the records provided by the designer, e.g. settlement monitoring,
- early contractor involvement (ECI) to understand construction task analysis e.g. how reinforcement will be installed and inspected in deep foundations,
- temporary construction scenarios, e.g. dominant openings may result in a temporary increase in internal wind pressures, temporary structural stability or incomplete load paths, through propping restrictions or wind loading on temporary works for short duration activities.

286. If the design includes novel or unusual materials, components and construction methods, sufficient evidence (e.g. mock-ups or demonstrations) shall be provided to demonstrate confidence in the buildability of the design.

287. For further information on guidance for designers for construction considerations, see:

- L153 ‘Managing health and safety in construction’ [27],
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’,
- TAG 17 Annex 4 ‘Construction Assurance’.

4.19 Designing for operation and EIMT

288. The design should consider ageing and degradation effects which may reduce the ability of the SSC to satisfy its safety functional requirement. Designs, including material specifications, should endeavour to minimise predicable effects, and to take a conservative approach to account for known degradation mechanisms. This should, as far is as reasonably practicable, provide resilience against degradation mechanisms that are unknown at the time of design.

289. The Inspector should consider whether the designer has adequately anticipated the possibility that the SSC may have a safety functional requirement beyond the originally specified design life. The Inspector may wish to seek assurance that these factors are appreciated by the designer and have been explicitly considered in the design.

290. The requirements and claims on long term inspection of structures arising from the safety case should be clearly identified. If an item important to safety cannot be designed to be capable of being tested, inspected or monitored to the extent desirable, the Inspector should judge whether a robust technical justification has been provided to demonstrate that it will continue to provide this safety function throughout its operational life, in line with the Requirement 29 from IAEA guidance SSR 2/1 [12]. This might include:

- designing in additional safety margins,
- providing additional lines of protection,
- demonstrating that the system would be tolerant of any potential ageing or degradation effects,
- the use of reference items exposed to similar environments for testing (coupons).

291. SAPs EMT.1 and SC.6 paragraph 106(c) establish the expectation that the safety case should justify how the EIMT requirements identified within it will be implemented effectively. The means of implementation considered should include the required examination, inspection, maintenance and testing regimes specified in or assumed by the safety case.

292. SAP EMT.2 establishes the expectation that structures will receive regular and systematic EIMT as defined by the safety case.

293. The key civil engineering principles for the Inspector to consider when assessing design decisions that impact operations and EIMT are:

- provision for the safe operation of the facility. SAPs ECE.8 and ECE.20 establish the expectation that provision will be made for examination, inspection, maintenance and testing of the civil engineering key load bearing elements and other elements that perform safety functions, both during normal operations and following a design basis event, to demonstrate that the structure continues to meet its safety functional requirements,
- potential hindrances to inspection such as radiation, burial and access difficulties,
- loads applied by access equipment required for inspection and maintenance. Load restrictions should be clearly identified in the designers' record documentation provided for the operational stage,
- whether appropriate consideration has been made to reduce risks during future maintenance and repair or replacement activities, e.g. harness systems, access and egress, edge protection, brittle finishes, unprotected openings, lighting, ventilation, etc.,
- whether an improvement to the proposed material specification or detail could reduce the future maintenance demand, e.g. robust waterproofing measures, minimised movement joints, improved concrete cover in aggressive ground conditions, a higher specification corrosion protection system etc.,
- whether consideration has been given to the provision of cast-in corrosion monitoring, strain monitoring and similar devices (SAP ENC.2) The Inspector could consider whether instrumentation is required to undertake inspection and if the equipment is sufficient to undertake the task, with installation at construction phase or after defects appear. The inspector may wish to consider whether any installed instrumentation is appropriately safety classified and whether there is the facility to replace it should it become defective.
- measures to minimise activation or penetration of potential future contamination, contain spills and inadvertent releases (e.g. bunds and sumps) and attenuate contaminant transportation. If drainage pipework has to be embedded into a concrete structure, then a leakage detection system should be provided,
- whether details avoid potential traps, voids or non-accessible areas where unmonitored nuclear material or contamination could accumulate.

294. The Inspector may wish to consider whether there are sufficiently redundant and diverse inspection techniques proposed for safety critical SSC, and whether EIMT procedures should be validated before they are incorporation into the design.

295. SAPs ECE.21 and ECE.22 establish the expectation that the satisfactory performance of a containment structures should be demonstrated. This activity may need to be repeated during the operational stage of a facility. This corresponds with Requirement 55 of IAEA guidance SSR 2/1 [12] regarding the control of radioactive releases from containment. The Inspector may wish to seek assurance confidence that the design makes appropriate provision for proof pressure tests and leak tightness tests, including any loads created during testing.

296. The Inspector may wish to seek assurance by assessing how the design proposes to identify any failures in containment during operation e.g. by the provision of leak collection pathways and sumps, monitoring and sampling points etc.

297. SAP EMC.11 establishes the expectation that the predicted failure mechanisms of SSCs should be gradual and predictable. SAP ECE.2 and SAPs paragraph 337 establish the expectations for the justification of design and safety cases of civil engineering SSCs.

298. The Inspector may wish to seek assurance that the design ensures that deterioration, distress or any other evidence of a reduced margin against failure should be detectable during EIMT activities. The Inspector may choose to assess whether there is sufficient

time between the identifying an issue (e.g. degradation) to allow suitable remedial or mitigation actions to be taken.

299. For more on design considerations relating to operation and EIMT, see:

- ONR-NS-TAST-GD-020 ‘Civil Engineering Containments for Reactor Plants’,
- TAG17 Annex 5 ‘Civil Engineering – Ageing Management and Damaged Structures’.

4.20 Design for decommissioning

300. SAPs ECE.26 and DC.1 establish the expectation for special consideration at the design stages to consider waste management and future decommissioning and dismantling of the civil engineering SSCs. This is in line with Requirement 12 of the IAEA guidance SSR 2/1 [12].

301. The Inspector may wish to seek assurance that the design has made due consideration of decommissioning and demolition and how this information is recorded.

302. The Inspector may wish to consider:

- whether there are arrangements in place for making accurate records of the as-built status of the structure, including any design changes. It is imperative that load paths, particularly those resisting lateral loads, are clearly identified. Limitations of the structure to support demolition equipment and arising should also be clearly recorded,
- limitations on the order and method of dismantling. This must be clearly identified in the records provided by the designer e.g. sequence of destressing,
- methods to minimise activation of civil engineering materials,
- measures to aid post operation clean out and decontamination (e.g. surface finishes and treatments to prevent embedded contamination or activation),
- whether the design facilitates the radioactive waste management (including removal),
- whether materials and construction methods have been selected which can be dismantled and disposed of in a safe manner,
- whether any specific health and safety control measures have been identified and documented in the health and safety file for use at the decommissioning and dismantling phase,

303. For more information on design for decommissioning and demolition, see:

- TAG 17 Annex 6, ‘Civil Engineering – Post operations’,
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’,
- The Energy Act 2008 “Funded Decommissioning Programme Guidance for New Nuclear Power Stations” [11],
- ONR-NS-TAST-GD-026 ‘Decommissioning’,
- ONR-NS-INSP-GD-035 ‘Decommissioning’.

4.21 Learning from previous experience

304. SAP MS.4 refers to learning from experience to improve arrangements. The Inspector may wish to seek assurance that the designer has taken due account of relevant experience that has been gained in the construction, operation and decommissioning of similar facilities, including international experience and experience outside the nuclear industry.

305. Where relevant good practice from other relevant industries is adopted, the Inspector may wish to seek assurance that such practices are adopted appropriately to the specific application. This is in line with the Requirement 11 from IAEA guidance SSR 2/1 [12].

306. The Inspector is reminded of previous experience from the wider civil engineering industry that may be applicable to the sample of their assessment:

- structures have been designed so that the mode of failure is ductile and sufficient warning signs would be evident to allow action to be taken to prevent failure (e.g. single members in tension should avoided),
- changes undertaken after completion of the initial design are considered for their potential structural implications (e.g. changes should be subject to a multi-disciplinary design review),
- sufficient care has been taken to ensure that movement joints are suitably detailed and positioned to avoid creation of a potential collapse mechanism.

307. Further guidance is available in:

- “Practical guide to structural robustness and disproportionate collapse in buildings” [28], but nuclear safety related structures may require more details and specific consideration on a case by case basis,
- HSE guidance RR834 ‘Preventing catastrophic events in construction’ [29],
- Standing committee on structural safety (SCOSS) [30],
- ACI 307-08: Code “Requirements for Reinforced Concrete Chimneys” [31].

4.22 Information control and document management

308. The Inspector may wish to seek assurance of the adequacy of process(es) in place to manage information and document revisions, and that these are suitable for the phase of the design being considered. This can be significant when considering the use of model and drawing revision numbers, or the use of 3D automated computer tool outputs during design development. For more information, see:

- TAG 17 annex 4, ’Civil Engineering – Construction Assurance’,
- TAG 17 Annex 2, ‘Building Information Modelling’.

309. There is a risk that designers may be using superseded or uncoordinated information. The Inspector may wish to seek assurance that the most up to date and coordinated information gets issued throughout the supply chain, including to sub-contractors. This can be a particular issue where there are several layers of contractors beneath the designer.

310. The Inspector should be aware of the information storage tools that the designer has access to and whether there are any limitations this computer tool imposes on the designer’s access to information.

4.23 Change control

311. The Inspector should be aware of changes to the design as the design progresses. The Inspector may wish to seek assurance that adequate dutyholder arrangements are in place to ensure that design changes do not compromise the design intent or undermine any claims made in the safety case.

312. The Inspector may wish to seek assurance that the process for the decision making around design changes fully considers the impact of the change on the design, and that each change is given due consideration, according to the categorisation and classification of the element being changed.

313. Where there are many design changes, the Inspector should be aware these may be collated and presented to a decision committee. The Inspector may wish to seek assurance that the decision-making meetings/committees are undertaken with adequate scrutiny and challenge with the appropriate and suitably qualified and experienced personnel (SQEP) actively involved in the meetings.

314. For more information regarding challenge in decision making meetings, see:

- ONR-NS-TAST-GD-080 ‘Challenge Culture Capability (including an Internal Regulation function), and the provision of Nuclear Safety Advice’.

4.24 Interfaces between design disciplines

315. There is an interface between civil engineering design and mechanical, electrical, and HVAC (heating, ventilation and air conditioning) (MEH) installation, as well as embedment and control and instrumentation design. This is both to consider the equipment that is to be installed within the structure, and how the performance of the structure (including seismic and settlement) are managed by the design.

316. The Inspector may wish to seek evidence from appropriate multi-disciplinary design reviews (including inputs from independent representatives) that demonstrate the designs have been reviewed and challenged, and that interfaces between engineering disciplines have been addressed.

317. The Inspector may wish to seek assurance that tolerances for supporting equipment that is embedded into the civil engineering design are adequately managed, and whether such tolerances are achievable during construction. This may need demonstration through mock-ups or other trials to prove the design can be constructed.

4.25 Interface with procurement

318. The Inspector should be aware of the contractual arrangements between those working on the design and the dutyholder, as the commercial arrangements may have an impact on the deliverables, communication or quality of the design (EQU.1). For example, contractual requirements may demand the design is delivered out of sequence, with a civil engineering design being delivered before the designs of systems which interface with the civil engineering are sufficiently developed.

4.26 Safety case production and interface

319. As the design progresses, the safety case production will also be developing. The Inspector may wish to seek assurance that the design and the safety case interface is being managed, that the teams are interacting and how developments across the teams are communicated.

4.27 Design substantiation reports

320. The aim of the design substantiation reports (DSR), also referred to as design justification reports (DJR), are to provide a clear narrative for each Safety Functional Requirement provided in the Basis of Safety Case (or similar) and the Basis of Design (or similar).

321. A clear narrative explained in the DSR/DJRs (or similar documents) can make reference to Engineering or SFR Schedules to demonstrate the golden thread.

322. The levels of maturity of these reports (DSR/DJR or similar) should be appropriate for the design phase being assessed.

323. The Inspector may wish to seek assurance that these documents are referenced clearly to signpost the full suite of documents that form the safety case.

324. The Inspector is reminded that the DSR/DJR or similar reports would be expected to include design information (or reference out to separate reports) regarding the following topics:

- assumptions and conservatisms that ensure the civil engineering designs are robust, including sensitivity studies and consideration of BDB and cliff edge effects,
- evidence to support the claims and arguments made in the higher-level documents,
- demonstration of adequate validation and verification activities,
- substantiation of any commitments made during earlier design stages,
- evaluation of topics of interest e.g. lifetime or maintenance requirements on elements providing key safety functions,
- relevant information on construction, EIMT and decommissioning,
- visibility of design elements that are not completed and will be undertaken at a later phase, e.g. site-specific considerations,
- the extent of the civil engineering scope e.g. crane support structures but not the crane substantiation.

4.28 Post design review

325. SAP MS.2 establishes the expectation that organisations continuously learn from experience. The Inspector may engage with lessons learnt exercises to understand the review of the design, although the participants must feel free to share their real experiences.

4.29 Design process

326. The Inspector may wish to seek assurance in the design processes that are in place to manage design decisions, and seek assurance that the Design Authority is appropriately involved in the decisions where nuclear safety is considered, with appropriate consideration of the categorisation and classification and potential consequences.

327. The design may be at an early or immature phase when the Inspector begins the assessment. The context of the process maturity, the learning from experience and continuous improvements should form part of the assessment. The Inspector should be aware of this context when assessing processes that are adopted. As processes develop over time, this can demonstrate how an organisation embraces learning from experience and a ‘challenge culture’. For more information, see:

- ONR-NS-TAST-GD-080 ‘Challenge Culture Capability (including an Internal Regulation function), and the provision of Nuclear Safety Advice’.

4.29.1 Design maturity

328. The design may not be complete at the time of an assessment. The Inspector may wish to seek assurance that the project has sufficient resources and time to complete the work that is required, and that a design process in place to support design completion, with sufficient time downstream of the design for construction activities thereafter.

5 KEY ASSESSMENT PRINCIPLES FOR CIVIL ENGINEERING DESIGN UNDERTAKEN IN PARALLEL WITH CONSTRUCTION ACTIVITIES

329. This section is intended to cover the areas of interface that the Inspector assessing design should consider in addition to section 4, when construction of a project has started, and design activities are ongoing in parallel. The introduction of construction activities alongside design work on a project can introduce new areas of consideration for the Inspector.

5.1 Design handover

330. It is expected that design will be completed as far as reasonably possible before the date that construction activities start on site and that there is a handover process of full packages of design information to the site.

331. The dutyholder arrangements for the handover process should allow sufficient time for the site to accept and understand the site information in order to adequately prepare the site for the construction to begin. This is an area of interface between the Inspector assessing design, and the Inspector assessing construction assurance. The scope of assessment should cover this handover, whichever Inspector undertakes the assessment.

5.2 Design maturity

332. For major projects, such as construction of a new facility, it is likely that some aspects of design will be undertaken in parallel with the construction activities. This section focuses on considerations for the Inspector who is assessing the design in this scenario, in addition to those presented in section 4 of this annex.

333. The design activities prior to construction usually achieve a level of maturity that is sufficient for a design to be ‘fit for construction’ (or similar) or ‘frozen’ prior to the date for construction start. There are several possible scenarios the Inspector may encounter, including (but not limited to):

- A standard project, where only the construction detailing and addressing late design changes remains outstanding at the start of construction, post design freeze.
- A project where the design programme has been compressed or when construction is being incrementally awarded, resulting in different aspects of the structure being at a different level of design development, ranging from fully designed to designed in outline only.
- A major project such as a nuclear new build, where significant design elements are likely to remain outstanding and only design principles have been established at the start of the site construction.

334. As construction progresses, the Inspector(s) assessing the ongoing design are encouraged to liaise with those undertaking other regulatory activities on the construction site, to understand the potential changes that the site construction activities can impose on the design, and to avoid potential gaps in the regulation of construction.

335. For the scope of the civil engineering regulatory activities undertaken for construction assurance on the construction site, please see:

- TAG 17 annex 4 “Civil Engineering – Construction Assurance”.

5.3 Design Authority (DA)

336. The guidance provided in section 3.4 of this document applies also to situations where design and construction is undertaken in parallel, but the Inspector may wish to consider the following additional factors:

- Defects and non-conformances relating to construction of structures with nuclear safety significance, and the role of DA in the decision of the categorisation and classification of such quality issues on the original design intent,
- DA review and approval of Methodologies, works information or other contractual specifications to ensure that the desired output will meet the design intent,

- DA review and approval of dutyholder processes and procedures (EQU.1) that allow the dutyholder to have confidence in the construction activities, including surveillance of site activities,
- Delegation of DA authority, including to those permanently featured on a construction site,
- Communication links to those who are in different locations, including communication routes and channels even if the offices are local to the site,
- The efficacy of DA presence on site.

5.4 Intelligent Customer (IC)

337. The guidance provided in section 4.5 of this document also applies to situations where design and construction is undertaken in parallel, but the Inspector may wish to consider the following additional factors:

- The IC function will need to change to provide oversight of design and construction activities simultaneously, resulting in additional demands on the IC function. The IC function may require different processes or site-specific arrangements that were not necessary for the design work before the construction activities began.
- Contractual arrangements for site construction works may create additional barriers between the constructor and the IC, and if so, there is a risk that these may reduce the effectiveness of the IC role.
- Construction programme and cost factors have the potential to result in the supply chain not involving the IC in decisions which could undermine the ability of the SSC to satisfy the intended safety function with the intended safety margins.

338. For further information on the importance of IC in construction, see:

- TAG 17 annex 4 “Civil Engineering – Construction Assurance” section 2.

5.5 Interfaces between construction site and design team

339. The Inspector is reminded that there may be changes to well-established design processes once the construction commences, to ensure the processes are fit for purpose to meet the demands of site as well as the design organisations. The Inspector may wish to seek assurance that any changes to the process do not have a detrimental impact on the quality of the design deliverables (EQU.1).

340. The Inspector may wish to seek assurance of the adequacy of the process used to communicate design information to the construction site. A potentially significant consideration for assessment is to consider how information from site flows back to the designers. The processes for this communication will potentially develop over time between the site construction team and the design delivery team. The Inspector is reminded that there may be several parallel informal and formal routes for information to be communicated. The Inspector may wish to seek assurance that the maturity of these communication paths is appropriate for their function, as this may impact on the efficacy of information sharing, with a potential impact on quality control.

341. The substantiation in the design reports should have provided the Inspector with sufficient information about the design safety case claims and any safety functional requirements placed upon civil engineering SSCs. The Inspector may then consider how this information is communicated to the site construction team as a key part of construction achieving adequate quality, for the SSC to meet the original design intent.

342. The Inspector should be aware that the interface with the construction team is a key but often highly pressurised position, as this communication facilitates processes to start on the construction site where there are many interfaces to manage. The Inspector may wish to seek assurance that information that is being adequately communicated to the

design team from the construction team, and how the efficacy of this communication could impact design decisions made.

343. During design, the documentation provided for ONR assessment can be updated or revised as the design progresses. The Inspector may wish to seek assurance that the revision of the documents they are using is the same as the current revision of documents used in both the design offices and on site.

5.6 Design assurance

344. The Inspector may wish to seek assurance that the assumptions made in design and data used in the design are appropriate when compared to the reality of the site. Where reality unveils a situation that contradicts a design assumption, there should be arrangements in place to amend and update any design data or modelling to reflect reality.

345. When assessing design assurance for design assumptions in the absence of site specific information, e.g. ground conditions, the Inspector may wish to seek assurance that information gleaned from the actual construction is reconciled with the interpretive site data used in the design, for more information, see:

- TAG 17 Annex 3 ‘Civil Engineering – Ground Investigation, Geotechnics and Underground Structure Design.

346. When considering design assumptions that are made in the absence of site specific information, e.g. material specification, the Inspector may wish to seek assurance that information gained from site mock-ups, trials or other site tests are reconciled with the design ‘works information’ or ‘technical specification’ (or similar construction design documentation). The Inspector is reminded that the Intelligent Customer function is expected to be involved in this process. For more information, see:

- TAG 17 Annex 4 ‘Civil Engineering – Construction Assurance’,
- ONR-NS-TAST-GD-077 ‘Supply Chain Management Arrangements for the Procurement of Nuclear Safety Related Items or Services’,
- ONR-NS-TAST-GD-049 ‘Licensee Core Safety and Intelligent Customer Capabilities’.

5.7 Information management

347. The Inspector should be aware of the management of information on site, especially related to design changes and how information is communicated. In the UK there are computer tools are used to varying degrees across the supply chain, and as such there can be a combination of 3D models and 2D drawings used on site for the same area of construction. The Inspector may wish to seek assurance that constructability information used in design will be effectively communicated to site, e.g. Early Contractor Involvement (ECI) diagrams of methodology. For more information on this, see:

- TAG 17 Annex 4 ‘Civil Engineering – Construction Assurance’,
- TAG 17 Annex 2 ‘Building Information Modelling’.

5.8 Design change control

348. SAP ECE.19 establishes the expectation that where a defect or non-conformity is identified and is judged to have a significant detrimental effect on integrity, remedial measures are to be applied to ensure original design intent is met. The Inspector should therefore be aware of the changes due to non-conformances or defects that could impact on design due to their being captured in the process. Where this is the case, the Design Authority (and perhaps Intelligent Customer) function is key to own the safety

case associated with the item being constructed and ensure that design intent is still met.

349. SAP ECE.17 establishes the expectation that sufficient construction materials and techniques, including the control arrangements and management system (supervision and surveillance) is in place to minimise and prevent defects. Proven techniques can come in the form of mock-ups or trials on site. The Inspector should be aware of where a design decision is reliant on the output of mock-ups or trials and may seek assurance as to what the resultant effect on the design is.

350. Information about trending of quality issues and other constructability considerations may be communicated to the design team to make changes that are not necessarily recorded in the non-conformance process (EQU.1).

351. The Inspector should expect the dutyholder to use a process to capture these changes. The Inspector may wish to seek assurance that the arrangements in place do not allow decisions to be made to change the design (e.g. methodology) that may adversely impact construction quality.

352. The Inspector may wish to seek assurance that the arrangements in place do not allow decisions to be made to change the design to accommodate inadequate quality that could adversely impact the original design intent.

353. The Inspector may wish to seek assurance in the adequacy of the processes in place that manage the design changes decision making. The Inspector should be aware that during construction, it is likely that several changes will be combined into one design change form for discussion in a single meeting. The Inspector may wish to seek assurance that the safety function and categorisation and classification of civil engineering SSCs are appropriately considered in such a meeting.

354. Some processes that are used in the design phase may be adequate for that phase, but may be changed during the construction phase to also suit the works on site. The Inspector should be aware of any changes to processes that manage design during the construction phase e.g. design change management. The Inspector may wish to examine the degree that aggregation of design changes are addressed by the dutyholder.

5.9 Safety case production and interface

355. The Inspector should be aware that the site may have a design team located on the site which has Design Authority responsibility. The Inspector may wish to seek assurance that the role of the designer on site is understood, and how site contractors and site-based designers communicate to the safety case and design team in the design offices, and how authority is delegated to make design changes. The Inspector may wish to seek assurance that the safety case team are involved appropriately in design change decisions.

5.10 Interface with procurement and design

356. The Inspector should be aware of construction supply chain changes that may impact on the design intent. A design change may be requested because of a change to the supply chain. The Inspector should appreciate where the design could be compromised as a result of changes to the supply chain.

357. The Inspector should be aware that commercial contracts between designers and construction contractors may cause some issues with communication or delivery of full scope of work which may impact the quality of documentation or design delivery.

358. The function of Intelligent Customer (IC) is a key consideration for the dutyholder when procuring services. For more information on procurement and Intelligent Customer function, see:

- TAG 17 Annex 4, 'Construction Assurance',
- ONR-NS-TAST-GD-077 'Supply Chain Management Arrangements for the Procurement of Nuclear Safety Related Items or Services',
- ONR-NS-TAST-GD-049 'Licensee Core Safety and Intelligent Customer Capabilities'.

5.11 Asset management and safety case

359. Once structures are constructed on site, there will be an associated asset management requirement on the structures. The civil engineering asset may be exposed to a more aggressive environment for an extended period prior to completion of the weatherproof envelope. The Inspector may wish to consider how the asset management requirements are decided for the construction phase and how these requirements are communicated to the site. The Inspector should expect there to be adequate arrangements in place for managing the ongoing asset EIMT in compliance with Licence Condition (LC) 28, with requirements usually stated in the safety case and managed on site with the use of LC28 Maintenance Schedules. For more information, see :

- TAG 17 Annex 5 'Civil Engineering – Ageing management and damaged structures'.

5.12 Interface with equipment installation

360. The construction sequence of a structure may impact the way in which equipment is installed, but this may not be confirmed before construction has commenced. Once a civil engineering asset is completed, there may be interactions with other equipment to either be installed or for temporary openings to be made for maintenance or outages. The design should consider the way in which equipment will be installed and maintained, including large temporary openings with a clear view of how the opening will be closed. Such decisions may not have been made during design and may only be revealed on site as the construction sequence or other site-specific issues may not have been decided earlier on in the process. In this instance, the Inspector should be aware of the impacts of decisions around temporary openings, including the use of couplers or changes to the standard use of shuttering, and how such decisions may impact quality (EQU.1).

361. During construction, there may be embedment plates or other items that are constructed that relate to the support to other nuclear safety significant equipment. The Inspector should be aware of the impact that any changes to installed or proposed equipment design may have on the durability or serviceability of the civil engineering structure that has already been constructed.

5.13 Post design review

362. During construction, the team may be required to undertake design as well as manage the design changes and other information from the construction site. This may impact the availability of staff or create challenging timescales which may put the design delivery teams under pressure. The Inspector may wish to seek assurance that the design team is provided with sufficient time and resources to undertake the design activities, considering the duties that the Designer and the Client have under CDM 2015.

363. The Inspector should expect post-design reviews to capture any learning, including feedback from other disciplines where civil engineering design has caused a problem for downstream installation. Such an exercise is intended to avoid similar problems in similar circumstances in the future.

5.14 Design verification and validation (including quality assurance and independent checks)

364. For assessing design when construction activities are occurring in parallel, seeking assurance that method statements, drawings and other documentation are stamped as ‘approved’ for use or ‘fit for construction’ is critical. This is likely to occur after the design substantiation / justification reports (DSR or DJR) are completed, as part of a handover of design information to the construction site. This information can be communicated in the form of ‘works information’ and ‘technical specification’ in addition to drawings or other design calculations and substantiation documents. It is a key consideration for the inspectors who are regulating site construction assurance and those regulating design to agree the scope of the work to ensure the handover of design information is regulated. This can be significant regarding independent checks and quality assurance (EQU.1) if the design team are under pressure to deliver to timescales, or if there is insufficient resourcing to allow adequate checking activities once the design is ready to be issued to the site.

365. The Inspector may wish to engage with the on-site dutyholder internal regulator to seek assurance that there are independent reviews and checks of quality assurance with both physical work activities, as well as processes and procedures that control the works (EQU.1).

5.15 Design changes related to defects or non-conformances

366. There is an interface with the site construction when defects or non-conformances result in a significant compromise to nuclear safety design intent. There are several SAPs related to defects. The Inspector should expect the defects and non-conformances that arise to be recorded appropriately and communicated to the design team to make a decision about whether the defect requires remediation, with reference to the following SAPs:

- SAP ECE.3 establishes the expectation that the civil engineering structures are sufficiently free of defects so that their safety functions are not compromised,
- SAP ECE.18 establishes the expectation that there will be inspection and testing during construction to demonstrated workmanship standards etc. are appropriate,
- SAP MS.3 establishes the expectation that decisions made at all levels in the organisation affecting safety are informed, rational, objective, transparent and prudent.

367. The Inspector may wish to consider the extent of design decisions that are made on site. This includes meetings about decisions around whether to remove and replace defective items where the decision to leave ‘as built’ could compromise the design intent. Where the decision for accepting a defect or design change are significant, these decisions may be taken away from the construction site teams and communicated to the wider design team. The Inspector may wish to check that decisions about changes to design intent or acceptance of defects are in line with the correct categorisation and classification in accordance with SAP ECS.2. The Inspector should be aware that there may be a series of previous design decisions regarding derogations, where aggregation of the design changes may impact the overall structural performance.

5.16 Operational Experience (OPEX)

368. Requirement 11 of the IAEA guidance SSR 2/1 [12] states “in the provision for construction and operation, due account shall be taken of relevant experience that has been gained in the construction of other similar plants”.

369. Section 4 of this document discussed learning from experience of international sites (of the same or different design) being constructed in parallel with the design of a UK based

facility. This also applies to the construction on a UK site that is still being designed in parallel to the construction activities. Changes of construction methods and sequencing may occur if the initial construction method could be improved. The Inspector may wish to be made aware of such changes and the potential impact this could have on design intent and construction quality assurance.

6 RELEVANT STANDARDS AND GOOD PRACTICE

370. This section provides a summary of the relevant guidance for inspectors to be aware of, along with sources for further information that provide useful background.

371. The Inspector is advised to check whether these guides are the most up to date, given the review period of the TAG.

372. Note the lists provided are not full and comprehensive lists. The Inspector should only use the guidance that is relevant to the scenario being assessed and seek other appropriate guidance to suit the circumstances.

6.1 ONR Technical Assessment Guides (TAGs) and Technical Inspection Guides (TIGs)

- ONR-NS-TAST-GD-006 ‘Design Basis Analysis’.
- ONR-NS-TAST-GD-009 ‘Examination, Inspection, Maintenance and Testing of Items Important to Safety’.
- ONR-NS-TAST-GD-013 ‘External Hazards’.
- ONR-NS-TAST-GD-014 ‘Internal Hazards’.
- ONR-NS-TAST-GD-016 ‘Integrity of Metal Structures, Systems and Components’.
- ONR-NS-TAST-GD-020 ‘Civil Engineering Containments for Reactor Plants’.
- ONR-NS-TAST-GD-026 ‘Decommissioning’.
- ONR-NS-TAST-GD-027 ‘Training and Assuring Personnel Competence’.
- ONR-NS-TAST-GD-030 ‘Probabilistic Safety Analysis’.
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’.
- ONR-NS-TAST-GD-034 ‘Transient Analysis for DBA in Nuclear Reactors’.
- ONR-NS-TAST-GD-036 ‘Diversity Redundancy Segregation and Layout of Mechanical Plant’.
- ONR-NS-TAST-GD-042 ‘Validation of Computer Codes and Calculation Methods’.
- ONR-NS-TAST-GD-043 ‘Severe Accident Analysis’.
- ONR-NS-TAST-GD-045 ‘Radiological analysis for Fault Conditions’.
- ONR-NS-TAST-GD-048 ‘Organisational Change’.
- ONR-NS-TAST-GD-049 ‘Licensee Core Safety and Intelligent Customer Capabilities’.
- ONR-NS-TAST-GD-050 ‘Periodic Safety Reviews (PSR)’.
- ONR-NS-TAST-GD-051 ‘The Purpose, Scope and Content of Safety Cases’.
- ONR-NS-TAST-GD-056 ‘Nuclear Lifting Operations’.
- ONR-NS-TAST-GD-057 ‘Design Safety Assurance’.
- ONR-NS-TAST-GD-058 ‘Human Factors Integration’.
- ONR-NS-TAST-GD-059 ‘Human Machine Interface’.
- ONR-NS-TAST-GD-060 ‘Procedure Design and Administration Controls’.
- ONR-NS-TAST-GD-061 ‘Staffing Levels and Task Organisation’.
- ONR-NS-TAST-GD-062 ‘Workplaces and Work Environment’.
- ONR-NS-TAST-GD-064 ‘Allocation of Function Between Human and Engineered Systems’.
- ONR-NS-TAST-GD-065 ‘Function and Content of the Nuclear Baseline’.
- ONR-NS-TAST-GD-067 ‘Pressure Systems Safety’.
- ONR-NS-TAST-GD-075 ‘Safety Aspects Specific to Nuclear Fuel in Power Reactors’.

- ONR-NS-TAST-GD-077 ‘Supply Chain Management Arrangements for the Procurement of Nuclear Safety Related Items or Services’.
- ONR-NS-TAST-GD-079 ‘Licensee Design Authority Capability’.
- ONR-NS-TAST-GD-080 ‘Challenge Culture Capability (including an Internal Regulation function), and the provision of Nuclear Safety Advice’.
- ONR-NS-TAST-GD-081 ‘Safety Aspects Specific to Storage of Spent Nuclear Fuel’.
- ONR-NS-TAST-GD-083 ‘Land Quality Management’.
- ONR-NS-TAST-GD-094 ‘Categorisation of Safety Functions and Classification of Structures Systems and Components (SSCs)’.
- ONR-NS-TAST-GD-098 ‘Asset Management’.
- ONR-NS-INSP-GD-035 ‘LC35 – Decommissioning’.
- ONR-NS-INSP-GD-011 ‘LC10 – Training’.
- ONR-NS-INSP-GD-019 ‘Construction and Installation of New Plant’.
- ONR-NS-INSP-GD-020 ‘Modification to Design of Plant Under Construction’.
- ONR-NS-INSP-GD-021 ‘Commissioning’.
- ONR-NS-INSP-GD-022 ‘Modification or Experiment on Existing Plant’.

6.2 UK Regulations

- Construction (Design and Management) Regulations 2015 (CDM2015).
- Section 34 of the Environmental Protection Act 1990.
- UK Building Act 1984 and Building Regulations 2010.
- The Electricity at Work Regulations 1989.
- Control of Substances Hazardous to Health Regulations (as amended) (COSHH 2002).
- Working at Height Regulations 2005.
- The Confined Spaces Regulations 1997.
- The Waste (England and Wales) Regulations 2011 (as amended), the Hazardous Waste Regulations 2005 and the Controlled Waste Regulations 2012 and the Special Waste Regulations 1996 (for Scotland, SEPA).

6.3 UK Policy

- UK National Policy for siting of nuclear power plants e.g. Department of Energy and Climate Change, National Policy Statement for Nuclear Power Generation (EN-6) [7].

6.4 Industry Guidance (INDG) Series

- INDG411 A quick guide for clients on CDM 2015.

6.5 International Guidance (IAEA, WENRA and USNRC)

IAEA guidance including, but not limited to:

- SSR 2/1 Design of Nuclear Power Plants [12].

373. United States Nuclear Regulatory Commission guidance including, but not limited to:

- Regulatory Guide 4.7, General Site Suitability Criteria for Nuclear Power Plants [32].
- NUREG-0800 Review of Safety Analysis Reports for Nuclear Power plants [33].

6.6 Linear finite element analysis and modelling

374. The key RGP that inspectors should be aware of are:

- ONR-NS-TAST-GD-013 (External Hazards).

- ONR-NS-TAST-GD-020 (Civil Engineering Containments for Reactor Plants).
- American Concrete Institute, ACI-349 and ACI-318.
- American Society of Civil Engineers: ASCE 4-16 & ASCE 43-05.
- ASME Boiler & Pressure Vessel Code, Section III, Code for containments.
- NAFEMs provides a large collection of publications on FEA [19]

375. There are also a large number of books covering FEA, with two classic references:

- Bathe, K-J., (1982), Finite Element Procedures in Engineering Analysis, Prentice-Hall Inc. [34]
- Cook R. D., (1981), Concepts and Applications of Finite Element Analysis, John Wiley and Sons [35]

6.7 Seismic design

376. Applicable codes and standards are:

- American Society of Civil Engineers, Seismic Analysis of Safety- Related Nuclear Structures and Commentary, ASCE 4-16, 2017.
- American Society of Civil Engineers, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE 43-05, 2005.
- AFCEN ETC-C: EPR, Technical Code for Civil Works, 2010

377. The key guidance that inspectors should be aware of are:

- IAEA, External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Standards Series, Safety Guide NS-G-1.5, 2003.
- IAEA, Seismic Design and Qualification for Nuclear Power Plants, Safety Standards Series, Safety Guide NS-G-1.6, 2003.
- U.S.NRC, US Regulatory Lessons Learned from New Nuclear Power Plant Applications on Evaluating SSI (presentation), October 2010.
- Nuclear Energy Agency, Proceedings of the CSNI Workshop on Soil Structure Interaction (SSI) Knowledge and Effects on the Seismic Assessment of NPP's Structures and Components, NEA/CSNI/(2011)6, October 2011.
- KTA 2201.1 (2011-11), Design of Nuclear Power Plants against Seismic Events; Part 1: Principles, Nuclear Safety Standards Commission, November 2011.
- KTA 2201.3 (2013-11), Design of Nuclear Power Plants against Seismic Events; Part 3: Building Structures, Nuclear Safety Standards Commission, November 2012.
- KTA 2201.4 (2012-11), Design of Nuclear Power Plants against Seismic Events; Part 4: Components, Nuclear Safety Standards Commission, November 2012.
- N289.1-08 (R2013) - General requirements for seismic design and qualification of CANDU nuclear power plants.
- N289.3-10 (R2015) - Design procedures for seismic qualification of nuclear power plants.
- ASN RFS V.2.g: Règles générales concernant plusieurs systèmes, structures ou équipements, 1985.
- ASN/Guide/2/01: prise en compte du risqué sismique a la conception des ouvrages de génie civil d'installations nucléaires de base à l'exception des stockages à long terme des déchets radioactifs, 1985.
- U.S.NRC, Review of Safety Analysis Reports for Nuclear Power Plants, Section 3.7.2 Seismic System Analysis, Rev 4, September 2013.
- A methodology for assessment of nuclear power plant seismic margin, NP-6041-SL Rev 1, Aug 1991.

6.8 Blast and impact loading and response

378. Applicable codes and standards are:

- ASCE, Design of blast resistant buildings in Petrochemical Facilities.
- UFC 3-340-02 Structures to resist the effects of accidental explosions, (which supersedes TM 5-1300, Structures to resist the effects of accidental explosion, Technical manual).
- ACI 318M, Building code requirements for structural concrete.
- ACI 349, code requirements for nuclear safety related concrete structures, special provision for impulsive and impactive effects.
- UFC-023-03, Design of buildings to resist progressive collapse.
- ASCE manual 42, Design of structures to resist nuclear weapons effect.
- TM-855-1 Fundamentals of protective design for conventional weapons (Design and analysis of hardened structures to conventional weapons effects).
- Eurocodes.

7 REFERENCES

1. ONR, "Safety Assessment Principles for Nuclear Facilities, 2014 Edition, Rev 0," November 2014, www.onr.org.uk/saps/saps2014.pdf.

2. ONR "New Nuclear Power Plants: Generic Design Assessment Guidance to Requesting Parties" ONR-GDA-GD-006 Rev 0 October 2019 http://www.onr.org.uk/new-reactors/guidance-assessment.htm (last accessed November 2020).

3. ONR Civil engineering specific guidance is in section 3.2 of "New Nuclear Power Plants: Generic Design Assessment Technical Guidance" ONR-GDA-GD-007 Rev 0 May 2019 http://www.onr.org.uk/new-reactors/guidance-assessment.htm (last accessed November 2020).

4. ONR "A guide to the Regulatory Process" NGN01 Rev 0 September 2013 http://www.onr.org.uk/new-reactors/guidance-assessment.htm (last accessed November 2020).

5. ONR 'Licensing Nuclear Installations' http://www.onr.org.uk/licensing-nuclear-installations.pdf (last accessed November 2020).

6. RIBA Plan of Work 2020 https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work.

7. Department of Energy and Climate Change (DECC) National Planning policy statement (PPS) for Nuclear Power Generation (EN-6) Volume 1 & 2 Planning for new energy infrastructure 2011 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47859/2009-nps-for-nuclear-volumeI.pdf (last accessed November 2020).

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8. ONR-NS-LUP-GD-001 'Land Use Planning and the Siting of Nuclear Installations'.

9. ONR-NS-LUP-GD-003 'Job Guide for the Processing of Planning Applications'.

10. ONR-NS-LUP-IN-002 'Population Density Assessment around Proposed Nuclear Power Station Sites'.

11. The Energy Act 2008 "Funded Decommissioning Programme Guidance for New Nuclear Power Stations" https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/42628/3797-guidance-funded-decommissioning-programme-consult.pdf (last accessed November 2020).

12. IAEA guidance SSR 2/1 'Safety for Nuclear Power Plant (NPP) Design' Rev 1. www.iaea.org (last accessed November 2020).

13. WENRA Guidance document Issue F: Design Extension of Exiting reactors – WENRA Safety Reference Levels for Existing Reactors (following update from lessons learned

TRIM Ref: 2019/XXXXXX

from the TEPCO Fukushima Dai-Ichi accident) www.wenra.org (last accessed November 2020).

14. BS 5975:2019 Code of Practice for temporary works procedures.

15. HSE Guidance L113 Lifting Operations and Lifting Equipment Regulations HSE guidance Approved Code of Practice and guidance www.hse.gov.uk (last accessed November 2020).

16. HSE Guidance L24 "Workplace health safety and welfare associated with the Workplace (Health Safety and Welfare) Regulations Approved Code of Practice 1992. www.hse.gov.uk (last accessed November 2020).

17. guidance and periodical publications produced by the UK Wind Engineering Society (WES) www.windengineering.org.uk (last accessed November 2020).

18. BS 6399-1:1996 Loading for Buidlings – Code of practice for dead and imposed loads - UK National Annex (withdrawn – superseded by BS EN 1991-1-7:2006+A1: 2014).

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20. ASCE 4-16 Seismic analysis of safety-related nuclear structures.

21. R3 Impact Assessment Procedure, EDF Energy and Magnox Ltd, 2009.

22. Impact assessment in the UK nuclear power industry: An overview of the R3 impact assessment procedure, A.R.R. Telford, International Journal of Pressure Vessels and Piping, 2010. https://www.sciencedirect.com/science/article/pii/S0308016110001109 (last accessed November 2020).

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24. USNREG Regulatory guide 1.35.1 'Determining prestressing forces for inspection of prestressed concrete containments' https://www.nrc.gov/docs/ML0037/ML003740040.pdf, (last accessed November 2020).

25. CIRIA guide C660 'Early age thermal cracking in concrete' (non contradictory complimentary guidance in the UK to EC2).

26. CIRIA guide C766 'Control of cracking caused by Restrained deformation in concrete'.

27. HSE guidance L153 'Managing health and Safety in Construction www.hse.gov.uk (last accessed November 2020).

28. IStructE publication "Practical guide to structural robustness and disproportionate collapse in buildings" October 2010, https://www.thenbs.com/PublicationIndex/documents/details?Pub=IStructE&DocID=296414 (last accessed November 2020).

29. HSE Research Report RR834 'Preventing catastrophic events in construction' http://www.hse.gov.uk (last accessed November 2020).

30. Standing committee on structural safety (SCOSS) www.structural-safety.org (last accessed November 2020).

31. ACI 307-08: Code "Requirements for Reinforced Concrete Chimneys".

32. USNREG Regulatory guide 4.7, ‘General Site Suitability Criteria for Nuclear Power Plants’. https://www.nrc.gov/docs/ML1218/ML12188A053.pdf (last accessed November 2020).

33. USNRC, “NUREG-0800 Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” 2017. https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0800/ch3/ (last accessed November 2020).

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TABLE 1 – SAPS APPLICABLE TO CIVIL ENGINEERING DESIGN

Safety Assessment Principles for Civil Engineering			
Safety case area	**Subject**	**Identity**	**Wording**
Engineering principles: civil engineering	Functional performance	ECE.1	The required safety functions and structural performance of the civil engineering structures under normal operating, fault and accident conditions should be specified.
	Independent arguments	ECE.2	For structures requiring the highest levels of reliability, multiple independent and diverse arguments should be provided in the safety case.
	Defects	ECE.3	It should be demonstrated that structures important to safety are sufficiently free of defects so that their safety functions are not compromised, that identified defects can be tolerated, and that the existence of defects that could compromise safety functions can be established through their lifecycle.
Engineering principles: civil engineering: investigations	Loadings	ECE.6	Load development and a schedule of load combinations, together with their frequencies, should be used as the basis for structural design. Loadings during normal operating, testing design basis fault and accident conditions should be included.
Engineering principles: civil engineering: design	Foundations	ECE.7	The foundations and sub-surface structures should be designed to meet their safety functional requirements specified for normal operation and fault conditions with an absence of cliff edge effects beyond the design basis.
	Inspectability	ECE.8	Designs should allow key load-bearing elements to be inspected and, where necessary, maintained.
	Earthworks	ECE.9	The design of embankments, natural and excavated slopes, river levees and sea defences close to the facility should not jeopardise the safety of the facility.
	Groundwater	ECE.10	The design should be such that the facility remains stable against possible changes in the groundwater conditions.
	Naturally occurring gases	ECE.11	The design should take account of the possible presence of naturally occurring explosive, asphyxiant or toxic gases or vapours in underground structures such as tunnels, trenches and basements.
	Structural analysis and model testing	ECE.12	Structural analysis and/or model testing should be carried out to support the design and should demonstrate that the structure can fulfil its safety functional requirements over the full range of loading for the lifetime of the facility.
	Use of data	ECE.13	The data used in structural analysis should be selected or applied so that the analysis is demonstrably conservative.
Engineering principles: civil engineering: structural analysis and model testing	Sensitivity studies	ECE.14	Studies should be carried out to determine the sensitivity of analytical results to the assumptions made, the data used, and the methods of calculation.
	Validation of methods	ECE.15	Where analyses have been carried out on civil structures to derive static and dynamic structural loadings for the design, the methods used should be adequately validated and the data verified.
	Materials	ECE.16	The construction materials used should comply with the design methodologies employed, and be shown to be suitable for enabling the design to be constructed and then operated, inspected and maintained throughout the life of the facility.
	Prevention of defects	ECE.17	The construction should use appropriate materials, proven techniques and a quality management system to minimise defects that might affect the required integrity of structures
Engineering principles: civil engineering: construction	Inspection during construction	ECE.18	Provision should be made for inspection and testing during construction to demonstrate that appropriate standards of workmanship etc. have been achieved.
	Non-conformities	ECE.19	Where construction non-conformities or identified defects are judged to have a significant detrimental effect on integrity, remedial measures should be applied to ensure the original design intent is still achieved.
	In-service inspection and testing	ECE.20	Provision should be made for inspection, testing and monitoring during normal operations aimed at demonstrating that the structure continues to meet its safety functional requirements. Due account should be taken of the periodicity of the activities.

	Proof pressure tests	ECE.21	Pre-stressed concrete pressure vessels and containment structures should be subjected to a proof pressure test, which may be repeated during the life of the facility.
Engineering principles: civil engineering: in-service inspection and testing	Settlement	ECE.24	There should be arrangements to monitor civil engineering structures during and after construction to check the validity of predictions of performance made during the design and for feedback into design reviews.
	Provision for construction	ECE.25	Items important to safety should be designed so that they can be manufactured, constructed, assembled, installed and erected in accordance with established processes that ensure the achievement of the design specifications and the required level of safety. The effects of construction hazards on any nearby safety related SSCs should be taken into account.
	Provision for decommissioning	ECE.26	Special consideration should be given at the design stage to the incorporation of features to facilitate radioactive waste management and the future decommissioning and dismantling of the facility.

CITATION OF OTHER RELEVANT SAPS USED IN THIS TAG ANNEX

Safety Assessment Principles applicable to Civil Engineering outside ECE. suite			
Safety case area	**Subject**	**Identity**	**Wording**
Leadership and management for safety	Capable organisation	MS.2	The organisation should have the capability to secure and maintain the safety of its undertakings
	Decision making	MS.3	Decisions made at all levels in the organisation affecting safety should be informed, rational, objective, transparent and prudent.
	Learning	MS.4	Lessons should be learned from internal and external sources to continually improve leadership, organisational capability, the management system, safety decision making and safety performance.
The regulatory assessment of safety cases	Safety case characteristics	SC.4	A safety case should be accurate, objective and demonstrably complete for its intended purpose.
	Optimism, uncertainty and conservatism	SC.5	Safety cases should identify areas of optimism and uncertainty, together with their significance, in addition to strengths and any claimed conservatism.
	Safety case content and implementation	SC.6	The safety case for a facility or site should identify the important aspects of operation and management required for maintaining safety and how these will be implemented.
	Safety case ownership	SC.8	Ownership of the safety case should reside within the dutyholder's organisation with those who have direct responsibility for safety.
Siting	Development control planning advice	ST.1	Development control planning advice provided by ONR should align with siting criteria set by Government policy.
	Suitability of the site	ST.4	The suitability of the site to support safe nuclear operations should be assessed prior to granting a new site licence
Engineering principles: key principles	Fault tolerance	EKP.2	The sensitivity of the facility to potential faults should be minimised.
	Defence in depth	EKP.3	Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.
	Safety function	EKP.4	The safety function(s) to be delivered within the facility should be identified by a structured analysis

	Safety Measures	EKP.5	Safety measures should be identified to deliver the required safety function(s).
Engineering principles: safety classification and standards	Safety Categorisation	ECS.1	The safety functions to be delivered within the facility, both during normal operation and in the event of a fault or accident, should be identified and then categorised based on their significance with regard to safety.
	Safety classification of structures, systems and components	ECS.2	Structures, systems and components that have to deliver safety functions should be identified and classified on the basis of those functions and their significance to safety.
	Codes and standards	ECS.3	Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate codes and standards.
	Absence of established codes and standards	ECS.4	Where there are no appropriate established codes or standards, an approach derived from existing codes or standards for similar equipment, in applications with similar safety significance, should be adopted.
	Use of experience, tests or analysis	ECS.5	In the absence of applicable or relevant codes and standards, the results of experience, tests, analysis, or a combination thereof, should be applied to demonstrate that the structure, system or component will perform its safety function(s) to a level commensurate with its classification.
Engineering principles: equipment qualification	Qualification procedures	EQU.1	Qualification procedures should be applied to confirm that structures, systems and components will perform their allocated safety function(s) in all normal operational, fault and accident conditions identified in the safety case and for the duration of their operational lives.
Engineering principles: design for reliability	Failure to safety	EDR.1	Due account should be taken of the need for structures, systems and components to be designed to be inherently safe, or to fail in a safe manner, and potential failure modes should be identified, using a formal analysis where appropriate.
Engineering principles: reliability claims	Form of claims	ERL.1	The reliability claimed for any structure, system or component should take into account its novelty, experience relevant to its proposed environment, and uncertainties in operating and fault conditions, physical data and design methods
	Measures to achieve reliability	ERL.2	The measures whereby the claimed reliability of systems and components will be achieved in practice should be stated.
Engineering principles: reliability claims	Margins of conservatism	ERL.4	Where safety-related systems and/or other means are claimed to reduce the frequency of a fault sequence, the safety case should include a margin of conservatism to allow for uncertainties.
Engineering principles: maintenance, inspection and testing	Identification of requirements	EMT.1	Safety requirements for in-service testing, inspection and other maintenance procedures and frequencies should be identified in the safety case.
Engineering principles: maintenance, inspection and testing	Frequency	EMT.2	Structures, systems and components should receive regular and systematic examination, inspection, maintenance and testing as defined in the safety case.
Engineering principles: maintenance, inspection and testing	Reliability claims	EMT.6	Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components (including portable equipment) in service or at intervals throughout their life, commensurate with the reliability required of each item.
Engineering principles: integrity of non-metallic components and structures	Examination through life	ENC.2	The design of non-metallic components or structures should include the ability to examine the item through life for signs of degradation.

Engineering principles: ageing and degradation	Safe working life	EAD.1	The safe working life of structures, systems and components that are important to safety should be evaluated and defined at the design stage.
	Lifetime margins	EAD.2	Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components.
	Periodic measurement of material properties	EAD.3	Where material properties could change with time and affect safety, provision should be made for periodic measurement of the properties.
	Periodic measurement of parameters	EAD.4	Where parameters relevant to the design of plant could change with time and affect safety, provision should be made for their periodic measurement.
	Obsolescence	EAD.5	A process for reviewing the obsolescence of structures, systems and components important to safety should be in place.
Engineering principles: layout	Access	ELO.1	The design and layout should facilitate access for necessary activities and minimise adverse interactions while not compromising security aspects.
	Minimisation of the effects of incidents	ELO.4	The design and layout of the site, its facilities (including enclosed plant), support facilities and services should be such that the effects of faults and accidents are minimised.
Engineering principles: external and internal hazards	Identification and characterisation	EHA.1	An effective process should be applied to identify and characterise all external and internal hazards that could affect the safety of the facility.
	Design basis events	EHA.3	For each internal or external hazard which cannot be excluded on the basis of either; low frequency or insignificant consequence (see Principle EHA.19), a design basis event should be derived.
	Frequency of initiating event	EHA.4	For natural external hazards, characterised by frequency of exceedance hazard curves and internal hazards, the design basis event for an internal or external hazard should be derived to have a predicted frequency of exceedance that accords with Fault Analysis Principle FA.5. The thresholds set in Principle FA.5 for design basis events are 1 in 10 000 years for external hazards and 1 in 100 000 years for man-made external hazards and all internal hazards (see also paragraph 629).
	Design basis event operating states	EHA.5	Analysis of design basis events should assume the event occurs simultaneously with the facility’s most adverse permitted operating state (see paragraph 631 c) and d)).
	Analysis	EHA.6	The effects of internal and external hazards that could affect the safety of the facility should be analysed. The analysis should take into account hazard combinations, simultaneous effects, common cause failures, defence in depth and consequential effects.
	‘Cliff-edge’ effects	EHA.7	A small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences.
	Aircraft crash	EHA.8	The total predicted frequency of aircraft crash, including helicopters and other airborne vehicles, on or near any facility housing structures, systems and components should be determined.
	Earthquakes	EHA.9	The seismology and geology of the area around the site and the geology and hydrogeology of the site should be evaluated to derive a design basis earthquake (DBE).
	Electromagnetic interference	EHA.10	The facility design should include preventative and/or protective measures against the effects of electromagnetic interference.
	Weather conditions	EHA.11	Facilities should be shown to withstand weather conditions that meet design basis event criteria. Weather conditions beyond the design basis that have the potential to lead to a severe accident should also be analysed.

	Flooding	EHA.12	Facilities should be shown to withstand flooding conditions up to and including the design basis event. Severe accidents involving flooding should also be analysed.
	Use, storage and generation of hazardous materials	EHA.13	The on-site use, storage or generation of hazardous materials should be minimised, controlled and located, taking due account of potential faults
	Fire, explosion, missiles, toxic gases etc. – sources of harm	EHA.14	Sources that could give rise to fire, explosion, missiles, toxic gas release, collapsing or falling loads, pipe failure effects, or internal and external flooding should be identified, quantified and analysed within the safety case.
	Hazards due to water	EHA.15	The design of the facility should prevent water from adversely affecting structures, systems and components
	Fire detection and fighting	EHA.16	Fire detection and fire-fighting systems of a capacity and capability commensurate with the worst-case design basis scenarios should be provided.
	Appropriate materials in case of fires	EHA.17	Non-combustible or fire-retardant and heat-resistant materials should be used throughout the facility (see Principle EKP.1).
	Beyond design basis events	EHA.18	Fault sequences initiated by internal and external hazards beyond the design basis should be analysed applying an appropriate combination of engineering, deterministic and probabilistic assessments.
	Screening	EHA.19	Hazards whose associated faults make no significant contribution to overall risks from the facility should be excluded from the fault analysis
Engineering principles: human factors	Integration within design, assessment and management	EHF.1	A systematic approach to integrating human factors within the design, assessment and management of systems and processes should be applied throughout the facility's lifecycle.
	Task analysis	EHF.5	Proportionate analysis should be carried out of all tasks important to safety and used to justify the effective delivery of the safety functions to which they contribute.
	Workspace design	EHF.6	Workspaces in which operations (including maintenance activities) are conducted should be designed to support reliable task performance. The design should take account of the physical and psychological characteristics of the intended users and the impact of environmental factors.
Engineering principles: containment and ventilation: containment design	Prevention of leakage	ECV.1	Radioactive material should be contained and the generation of radioactive waste through the spread of contamination by leakage should be prevented.
	Minimisation of releases	ECV.2	Containment and associated systems should be designed to minimise radioactive releases to the environment in normal operation, fault and accident conditions.
	Means of confinement	ECV.3	The primary means of confining radioactive materials should be through the provision of passive sealed containment systems and intrinsic safety features, in preference to the use of active dynamic systems and components.
	Leakage monitoring	ECV.7	Appropriate sampling and monitoring systems should be provided outside the containment to detect, locate, quantify and monitor for leakages or escapes of radioactive material from the containment boundaries.
Fault Analysis	Fault tolerance	FA.4	DBA should be carried out to provide a robust demonstration of the fault tolerance of the engineering design and the effectiveness of the safety measures.
	Initiating faults	FA.5	The safety case should list all initiating faults that are included within the design basis analysis of the facility.

	Consequences	FA.7	Analysis of design basis fault sequences should use appropriate tools and techniques, and be performed on a conservative basis to demonstrate that consequences are ALARP.
Numerical targets and legal limits	Assessment against targets	NT.1	Safety cases should be assessed against the SAPs numerical targets for normal operational, design basis fault and radiological accident risks to people on and off the site.
	Time at Risk	NT.2	There should be sufficient control of radiological hazards at all times.
Decommissioning	Design and operation	DC.1	Facilities should be designed and operated so that they can be safely decommissioned.
Land quality management	Identifying radioactively contaminated land	RL.2	Steps should be undertaken to identify any areas of radioactively contaminated land on or adjacent to the site.