Office for Nuclear Regulation

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GROUND ENGINEERING, GEOTECHNICS AND UNDERGROUND STRUCTURE DESIGN			
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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
AGR	Advanced Graphite (moderated) Reactor
ALARP	As Low as Reasonably Practicable
ASCE	American Society of Civil Engineers
BDB	Beyond Design Basis
BGS	British Geological Survey
BIM	Building Information Modelling
BS	British Standards
BS EN	Eurocode Standards
BTS	British Tunnelling Society
CDM	Construction (Design and Management) Regulations 2015
CFS	Capable Faulting Study
CIRIA	Construction Industry Research and Information Association
CPT	Cone Penetration Test
DCO	Development Consent Order
EIMT	Examination, Inspection, Maintenance and Testing
ENSREG	European Nuclear Safety Regulators Group
GDA	Generic Design Assessment
GIS	Geographical Information System
HSE	Health & Safety Executive
IAEA	International Atomic Energy Agency
ICE	Institute for Civil Engineers
ISO	International Standards Organisation
LC	Licence Condition
ONR	Office for Nuclear Regulation
OPEX	Operating Experience
PSHA	Probabilistic Seismic Hazard Analysis
RAMS	Risk Assessments and Method Statements
RGP	Relevant Good Practice
SAP	Safety Assessment Principle(s)
SPT	Standard Penetration Test
SQEP	Suitably qualified and experienced person
SSC	Structure, System and Component
SSI	Soil Structure Interaction
SSSI	Structure Soil Structure Interaction
SuDS	Sustainable Drainage Systems
TAG	Technical Assessment Guide(s) (ONR)
TIG	Technical Inspection 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)
Capable fault	A fault that has a significant potential for displacement at or near the ground surface.	Derived
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
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
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
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	Derived

	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.	
	"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	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	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
Dynamic data / monitoring	Dynamic geotechnical data can be acquired through monitoring which can be achieved through surface and downhole instrumentation. Recorded seismic events can be used to inform the PSHA and site response analysis.	Derived
Fence Diagrams	A number of geological cross-sections and their intersections are used to build up a 3D understanding of the geological structure and stratigraphy of an area.	Derived
Geographical information system (GIS)	A system that is used to store, display, analyse and manage different types of geographical data.	Derived
Ground Investigation	A ground investigation is a process starting with initial documentation about the site and its environs followed by continuous exploration and interpretation, with the scope of the investigation requiring regular amendment in the light of the data being obtained. This includes desk studies, field reconnaissance and field and laboratory work within the broad geographical, geological, hydrogeological and environmental contexts. An objective of the ground investigation should be to obtain a clear understanding of the geomorphology, geology and hydrogeology of the site through appropriate desk study, site reconnaissance, mapping and intrusive field investigations.	BS5930:2015 +A1:2020, [2
Ground Model	Outline of the understanding of the disposition and character of soil, rock and groundwater under and around the site.	BS5930:2015 +A1:2020 [2]
Hydrogeology	The distribution of the movement of groundwater in the earth's crust (soil and rock).	Derived
Isopachytes	Lines that connect equal (true) thicknesses of a geological unit on a map. An isopach map can be used to show the true thickness trends of a geological unit across an area.	Derived
Nuclear Facility	Definition from WENRA Decommissioning Reference Levels: 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

Risk	The chance that someone or something is adversely affected in a particular manner by a hazard (R2P2).	SAPs definition
Safety Assessment	Definition from WENRA Decommissioning Reference Levels: 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	Definition from WENRA Decommissioning Reference Levels: 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.	WENRA DSRL
	'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.	SAPs definition
Safety function	IAEA Safety Glossary: A specific purpose that must be accomplished for safety	IAEA Safety Glossary
Serviceability failure	While some operational functionality may have been lost, the claimed safety functions are still satisfied (e.g. excessive deflection of a roof deck). These types of failure can have a negative effect upon the resilience of facilities to design basis or accident situations. These may also lead to an increase in ageing effects to the SSC. A serviceability failure is 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
Structure Soil Structure Interaction (SSSI)	During an earthquake the dynamic response of one structure can affect the response of a neighbouring structure, resulting in structure-soil-structure interaction.	Derived
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 (TAG17) provides guidance on the main aspects of civil engineering ground investigation and geotechnical engineering 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 ground investigations, geotechnical engineering and design of underground structures, including foundations. 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. Site characterisation studies inform site suitability assessments that predominantly focus on external hazards and civil engineering aspects, although in some cases, they may relate to the management of contaminated land or groundwater. A nuclear facility and every structure, system and component (SSC) on a site is ultimately supported by the ground. Therefore, the substantiation that the ground can provide the necessary support for SSCs is a vital part of the civil engineering safety case for the facility. The Inspector should note that ground investigation and geotechnical engineering is a key input to both civil engineering and external hazards analyses, therefore there is a strong interface to ONR-NS-TAST-GD-013 'External Hazards' regarding seismic hazards. An example of such analyses is the development of a dynamic ground model which is necessary for site response analysis that is usually conducted as part of a probabilistic seismic hazard analysis (PSHA). The Inspector may wish to consider how data gained from initial geotechnical investigations used to support PSHA, to derive and define the applicable seismic hazard, is of relevance to subsequent detailed analysis, substantiation and design of the civil engineering structures to withstand this hazard.

3. Geotechnical engineering, or geotechnics, embraces the fields of soil mechanics and rock mechanics, and many of the aspects of geology, geophysics and hydrology. Knowledge of the static and dynamic behaviour of soils and rock and the influence of groundwater is required. This involves collection of geological, geotechnical, geophysical, hydrological and hydrogeological data.

4. The design, implementation and interpretation of the site geotechnical investigation characterises the various parameters and models that will be used for design of SSCs. Therefore, the Inspector should note that this is a safety significant area. The Inspector should keep in mind that the geotechnical engineering analysis is often coupled to the structural characteristics of a facility or structure. An example is static and dynamic soil-structure interaction (SSI) analyses where changes to the stiffness or geometry of the structure can have an impact on the performance of the ground and vice versa.

5. Relevant good practice (RGP) for ground investigation and geotechnical engineering is largely non-prescriptive due to the site-specific nature of the materials to be characterised. Consequently, this Annex provides principles for the Inspector to consider whilst undertaking assessments. During Generic Design Assessment, the assessment of overly conservative bounding assumptions regarding the ground may initially appear reasonable but could result in unrealistic ranges of settlements or design loads that may excessively challenge the design or, necessitate alternative foundation designs.

1.1 Structure of this annex

6. This annex identifies the relevant and applicable principles for assessment of the process of sub-surface structure design.

7. The key phases within sub-surface structure design are:

- desk studies,
- site reconnaissance,
- ground investigation design,
- ground investigation supervision,
- analysis and reporting,
- foundation or structure design,
- confirmation of founding level / formation level / base of excavation,
- foundation and sub-surface structure construction.

8. This phased sequence forms the basis of 'geotechnical continuity', starting with the site investigation (bullets 1-5) followed by the foundation design and construction (bullets 6 to 8). BS 5930 [2] suggests such a phased approach through generating the parameters for use in design.

9. The annex is structured in a way that maps on to these phases:

- Section 2 for civil engineering principles regarding the first five (ground investigation, interpretation and reporting) phases,
- Section 3 for civil engineering principles regarding the numerical analysis (used to develop the proposed design solution),
- Section 4 for civil engineering principles regarding the last three (detailed design and construction phases,
- Section 5 for civil engineering relevant guidance,
- Section 6 for references made in this annex.

1.2 Applicable SAPs to this annex

10. It is key that ground engineering is informed by and meets the expectations of the SAPs; for this annex, the following SAPs are relevant:

- SAPs ECE.1 and ECE.5 and ECE.6 regarding upstream references to schedules and safety functional requirements,
- ECE.7 states the expectation that 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,
- ST.4 identifies the need for assessment of the suitability of a site to support safe nuclear operations, prior to a new site licence being granted,
- ECE.4 and ECE.5 identify the need to demonstrate stability of the soil and rock which provide support for the foundations and superstructure of a nuclear facility. To determine the suitability of these materials site investigations are undertaken,
- ECE.8 establishes the expectation that load bearing elements will be inspected and maintained,
- ECE.9 and ECE.10 confirm that earthworks and groundwater designs should be designed to be stable and not compromise safety,
- ECE.12, ECE.13 and ECE.14 refer to the expectations around the structural analysis and model testing to demonstrate the structure can meet the safety functional requirements (SFRs) over the full range of loading for the lifetime of the facility, with the appropriate use of data and sensitivity studies to demonstrate this,
- ECE.15 refers to the expectations around the validation of the methods used in the structural analysis and models used,
- ECE.16 suitability of materials used on site,
- ECE.18 refers to the considerations of inspection during construction,
- EHA.18 and EHA.7 explain beyond design basis events and 'cliff-edge' effects and how a small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences,

- ECE.20 sets the expectations regarding examination, inspection, maintenance and testing,
- ECE.24 refers to the expectations around the monitoring of settlement during and after construction, to check the validity of the design,
- ECE.25 states the expectation that designs for structures important to safety will be designed so that they can be constructed in accordance with established processes that ensure the required level of safety, considering adjacent SSCs,
- EHA.9 identifies the need for the evaluation of the seismology and geology of the area around the site and the geology and hydrogeology of the site in order to derive a design basis earthquake,
- EDR.1 refers to the expectation that designs will be designed to be inherently safe or to fail in a safe manner, identifying potential failure modes,
- ERL.1 refers to the expectations around reliability of civil engineering SSCs,
- EQU.1 states the expectations regarding processes for qualification to demonstrate SSCs will perform the intended function for the required duration,
- ECS.1 sets the expectation that SSCs will be categorised appropriately,
- ECS.3, ECS.4 and ECS.5 set the expectations of code use,
- SC.5, ERL.4 and EAD.2 sets the expectations regarding optimism, uncertainty and conservatism and the associated margins across the required life of the SSC,
- AV.1 and AV.2 state the expectations that theoretical models and the calculation methods will adequately represent the site and the physical processes that will take place,
- AV.3, AV.4 and AV.5 refers to the expectations around the use of data, the computer modes used to process the data and the documentation of the analysis,
- AV.6 refers to the expectations around sensitivity analysis,
- AV.7 and AV.8 refer to the expectations around the collation of data through the life of the facility to check and update the safety analysis, with analysis reviewed and updated where necessary and reviewed periodically,
- RL.5 and RL.8 are related to ground investigations associated with contamination,
- MS.2 outlines the expectation that there is adequate human resources and that the organisation has the capability to secure and maintain the safety of its undertakings,
- DC.6 states that documents and records that may be required for decommissioning purposes should be identified, prepares, updated, retained and owned so that they will be available when needed.

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

- TAG 17 Annex 1, ’Civil Engineering - Design’,
- TAG 17 Annex 4, ‘Civil Engineering - Construction Assurance’,
- TAG 17 Annex 6, ‘Civil Engineering - Post operation’.

12. The Inspector should be cognisant of the broad intent of the SAPs; namely that the important issue is not the level of conservatism assigned to one element of the civil engineering analysis and design process (in this case the geotechnical aspects), but the (overall) level of conservatism, applied to the process as a whole.

1.3 Exemptions

13. This annex refers to drainage pipework that is buried. This is not to be confused with pipework used in pressurised systems which are assessed by either structural integrity or mechanical engineering specialist inspectors.

14. Section 2 of this document is based primarily on guidance for the assessment of ground investigations for new build sites rather than existing sites, but similar principles apply to

existing sites. For the current operational or decommissioning sites in the UK, the consideration of geotechnical aspects was more limited at the time of their construction, but this should have been rectified to a degree during subsequent Periodic Reviews of Safety. Therefore, for new facilities on existing sites, the Inspector should appreciate that the geotechnical aspects should not be examined in isolation from the totality of the safety case. The Inspector may wish to seek assurance that the dutyholder has demonstrated the risks associated with the civil engineering works have been assessed in line with the ALARP principles.

15. For ONR guidance on ALARP see:

- ONR-NS-TAST-GD-005 Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable).

16. This annex does not cover sampling for contaminated land. For more information about land contamination, see section 5.7.1 of the TAG 17 head document.

2 GROUND INVESTIGATION, INTERPRETATION AND REPORTING

2.1 Purpose

17. The purpose of a ground investigation is to determine the ground conditions at a particular site. GI may be implemented in the siting phase, which should be in line with the expectations of SAP ST.4. Where the site specific ground conditions are considered in the licensing phase, the Inspector should note that these early ground investigations will likely provide the data to inform the various parameters, models and analyses used to design SSCs, including the foundations for all civil structures. There is also an interface with external hazards, as the early GI are sought as an input to the PSHA works (SAP EHA.9).

18. Ground investigations are also intended to identify and characterise any below ground contamination (radiological or conventional) present at the site. The ground investigation should provide sufficient data to allow appropriate protection or remediation measures to be developed. RL.5 and RL.8 capture the expectations of investigations of contaminated land for situations where contamination is anticipated or found in the ground.

19. Ground investigations can also be intended to identify and characterise any below ground services present at the site. When electrical services have been identified, the Inspector may wish to check the dutyholders' arrangements that are in place to provide protection to workers in line with the guidance as stated in:

- HSG47 'Avoiding danger from underground services' [3].

2.2 Desk studies

20. The purpose of a desk study is to develop an initial understanding of the site's geology and structure prior to the development of the programme of ground investigation. When assessing desk studies, the Inspector may wish to look to these two key outputs:

- an initial ground model,
- geotechnical risk register for the site.

21. The Inspector may wish to seek assurance that the dutyholder has identified the known ground conditions, risks and, as a key consideration, the uncertainties that can then be addressed via ground investigation. The Inspector may seek assurance that the preliminary ground model and geotechnical risk register develop in detail to capture the information that becomes available as the phases of the project progress.

22. The Inspector may assure themselves that the desk study has taken into account a range of data sources, making use of recent and historical information at regional, local and site-scales. Examples of such data sources are:

- recent and historical ground investigation data for the site,
- recent and historical data for the surrounding region,
- data for analogous geological deposits and/or terranes,
- published literature,
- geological maps and section,
- geophysical and remote sensing data,
- British Geological Survey (BGS) records.

23. When referring to such data sources, the Inspector may wish to consider the provenance, reliability and quality of data as well as the adequacy of data gathering techniques. The desk study should assist the dutyholder to specify the intrusive samples and tests to be undertaken, as well as aiding all involved parties with future interpretation and understanding of the site, providing context for the site and ground investigations.

24. The Inspector may wish to consider whether there are any imposed constraints on ground investigation activities including those attributable to topographical, archaeological, environmental and ecological considerations. Information collected during the desk study could include, but not be limited to:

- topographic features,
- surface water features,
- access routes,
- existing and historical land-use,
- gases within the ground,
- potential for voids,
- faults or other geological features,
- existing structures and developments,
- chemicals (e.g. non-aqueous phase liquids),
- radiation, hazardous and man-made materials (e.g. asbestos),
- potential for underground services or unexploded ordinance.

25. To expand upon the last four bullet points, the Inspector may wish to seek evidence that historic and current land use and utility records have been consulted during the desk study phase to identify any potential risks and constraints for the intrusive ground investigation. The Inspector should expect the dutyholder to consider the potential for buried structures, below ground services and/or contamination. It is expected that the dutyholder will hold the relevant information for privately owned services. If appropriate, an investigation into the risk of unexploded ordnance should be conducted by the dutyholder prior to intrusive ground works starting on site.

26. Where new or additional facilities are to be located on an existing site, the Inspector may seek assurance that suitable optioneering has been undertaken to arrive at the proposed location as part of broader ALARP considerations for the site as a whole. The Inspector may wish to check that such optioneering studies include relevant information about the ground investigation work that will be needed to inform the design of the new or additional facilities.

2.3 Site Reconnaissance

27. The Inspector may seek assurances that the dutyholder has conducted a site walkover before any intrusive works commence. In so doing, the Inspector may wish to seek a demonstration that the dutyholder has identified all the relevant health and safety risks, and seek assurance that there are adequate arrangements in place for these risks to be managed.

28. Site reconnaissance can be useful for appreciation of the adjacent facilities and working area, including identification of services that are not in accordance with drawings.

29. If the desk study identifies a risk of unexploded ordnance on the site, then the Inspector may seek assurance that appropriate measures are taken to mitigate the risk.

30. For both new build and existing sites, where below ground services are anticipated to be present, the Inspector should be aware that arrangements for locating services should not rely on drawings but be verified through site survey. It is not sufficient for a dutyholder to rely on records or drawings to identify the location of services alone, as the records may not be accurate. It is also not sufficient to assume that services run in straight lines between two identified points, as there may be variations in the line of services e.g. if a hard spot was encountered upon installation. The arrangements should place no reliance on the presence or otherwise of buried marker tapes or tracer wires, as these may not be correctly located. Such works around electrical services should be in line with HSE guidance.

2.4 Ground Investigation

31. The ONR expectation is for a ground investigation rationale document to be developed for new reactor sites or major nuclear developments. The purpose of the ground investigation rationale document is to:

- identify the need for the ground investigation including geotechnical risks to be addressed,
- outline the scope of the ground investigation,
- describe the ground investigation requirements,
- specify the data to be collected,
- justify the adequacy of the ground investigation to meet its requirements,
- review process once GI has been completed, to check if the ground conditions will meet the requirements proposed to be placed upon it, with further work undertaken as required.

32. The Inspector may wish to judge whether the rationale explicitly states the need for the ground investigation, as this will drive the scope, requirements and data to be collected. The need for a ground investigation can range from a holistic demonstration that a site is suitable for deployment of a nuclear facility, to underpinning a minor modification to an existing facility. The Inspector may wish to check that the scope and content of the rationale is proportionate to the risk and/or uncertainty at this early stage of the project.

33. The Inspector may wish to check whether the rationale outlines the ground investigation scope, including whether it identifies the various analysis streams that will require ground investigation data. The Inspector may seek assurance in the extant knowledge of the geology where the dutyholder identifies any gaps or uncertainties highlighted by the desk study and whether these are captured in the resultant ground model and geotechnical risk register. The requirements of each analysis stream should be developed, with input from the end users. End users may include but are not limited to:

- civil engineering,
- geotechnical engineering,
- hazard studies, including Probabilistic Seismic Hazard Analysis (PSHA) and Capable Faulting Study (CFS),
- Environmental Impact Assessments
- liabilities management, if there is residual or extant contamination to manage.

34. The Inspector should be aware of whether a specification has been developed for the ground investigation based on the requirements. The Inspector may wish to seek assurance as to the adequacy of the specification to identify intrusive or non-intrusive field investigations, laboratory testing, surveying, monitoring and additional desk studies,

including but not limited to: the location, number and type of boreholes, tests and measurements needed to satisfy the end user’s requirements and inform and validate the ground model.

2.4.1 Scope of ground investigations

35. The ground investigation scope should be proportionate to the project being undertaken, the risks identified and the complexity of the geology. The Inspector may wish to check whether the scope document includes all required aspects including geology, geotechnics, hydrology and hydrogeology. The Inspector should look to the dutyholder to justify the scope and adequacy of the ground investigation via the rationale document.

36. In determining the adequacy of the ground investigations, the Inspector may wish to consider RGP when assessing the developing scope of the ground investigation, such as Eurocode (EC) 7 [4] and [5] and British Standard (BS) 5930 [2]. RGP for ground investigation is generally non-prescriptive and developed for non-nuclear projects. Therefore, the RGP mentioned represents a starting point for the works, and the Inspector may wish to examine the dutyholders’ expert judgement used regarding developing the specification and the scope of the ground investigation. The Inspector should be aware that there is IAEA guidance that is nuclear specific for undertaking geotechnical work and ground investigations [6] and [7].

37. Regarding the limitations of codes and standards applied (e.g. applicability of Eurocodes to nuclear facilities); the Inspector may seek assurance regarding the dutyholders justification of their use, considering the limitations. The Inspector may wish to seek assurance that the scope and specification are appropriate for the requirements of the design, and that the investigation work and measures taken will be sufficient to demonstrate the requirements of the specification.

38. The Inspector may wish to seek assurance regarding the adequacy of whether the ground investigation is spatially comprehensive (both laterally and vertically) and, where appropriate, whether it adequately includes onshore and offshore ground investigation. During the assessment, the Inspector may seek assurance that the design of the ground investigation recognises the importance of characterising the parameters required for design with the goal of interpolation rather than extrapolation of test data. This may require large scale site tests, an example being to understand the consolidation characteristics of the ground. Ultimately, the Inspector may seek assurance that a suitable and sufficient ground investigation has been undertaken to enable analysis of the ground conditions, design of the structures and consideration of beyond design basis fault conditions to be evaluated.

39. For new build sites, the Inspector may wish to seek assurance in the adequacy of a proposed ground investigation when considering whether the dutyholder is using a plot plan to inform the decisions of where to locate each investigation site. A plot plan at this early stage would not necessarily be detailed but would provide the locations and footprints of the major civil structures and buildings on the proposed site, even if this is indicative at the time of undertaking the ground investigation. This information may be presented by superimposing the location of existing investigation sites over proposed locations for new data sites onto a plot plan. Should the plot plan evolve over the course of the project, further ground investigation may be required to provide understanding of the ground conditions beneath new or relocated facilities/buildings. The Inspector may consider whether the combination of any existing data (and its associated reliability) and the new ground investigation data sites would provide sufficient information to meet the requirements of the specification for the design.

40. In seeking further confidence on the adequacy of the ground investigation, the Inspector may consider whether there has been an appropriate level of independent technical review. Multi-disciplinary ground investigations require a wide range of skills, knowledge and experience, and benefit from a team approach. ONR expects there to be

independent peer review throughout the ground investigation in accordance with the expectations of SAP SC.1, as the data gained from the ground investigation informs the site safety case. This should include independent technical review of the development of the rationale and specification, during the ground investigation and reporting. The Inspector should expect this peer review to utilise either independent subject matter experts or alternative SQEP resource, proportionate to the scale and complexity of the project, and that the review may include end users. The Inspector may wish to seek assurance regarding the adequacy of this review, specifically the independence achieved to assess the adequacy of the ground investigation and its outputs for use in the subsequent design.

41. The Inspector should also give consideration as to whether or not the project programme allows for development of desk study, specification of ground investigation, implementation of phased ground investigations and subsequent reporting to inform the design process. Where the programme does not allow for this, the Inspector may wish to seek assurance that the dutyholder is aware of the risk that they carry when proceeding with any design work.

2.4.2 Ground model and geotechnical risk register

42. The ground model's purpose is to present the current understanding of the ground conditions at the site. The format of the ground model can vary but the Inspector may wish to seek assurance regarding the adequacy of the model, including whether it adequately includes the available geological, geotechnical, geophysical, hydrological and hydrogeological data. This can be presented having parameters relating to the ground conditions identified, along with their spatial distribution and any residual risks and uncertainty (including existing services, contamination etc.). The Inspector is reminded that SAPs AV.7 and AV.8 refer to the expectations in relation to the collation of data through the life of the facility to check and update the safety analysis, with analysis reviewed and updated where necessary and reviewed periodically.

43. The risks are usually summarised in a geotechnical risk register. The Highways England technical approval document CD 622 'Managing geotechnical risk' [8] outlines the requirements for a geotechnical risk register in Appendix B. Other sections of interest on the development of a geotechnical risk register are Sections 3 and 4 and Appendices C to G of this reference [8].

44. The ground model and geotechnical interpretation need to be consistent with the interpretation used for any design analysis in order for the safety case to be evidenced. Where applicable, geotechnical data from a range of sources should be used to demonstrate consistency of data and validate its interpretation. The Inspector may wish to seek assurance regarding the adequacy of the management of the model, including whether assumptions from the initial desk study have significantly changed and whether these changes have an impact on the design analysis.

45. As the initial ground model and geotechnical risk register are based on the desk study, the Inspector may seek assurance that there are arrangements in place for the dutyholder to update them as works progress. The Inspector may seek assurance that the arrangements will include refinement of the ground model and geotechnical risk register throughout the ground investigation and construction phases.

46. Whilst the ground model should provide an understanding of the 3D spatial variability of the site, this does not necessitate a 3D geological block model. The model may comprise a combination of all, or some of, the following: Data tables; 2D sections; geological maps; isopachytes; fence diagrams; geographical information system (GIS) models; 3D surfaces; 3D block models. Where appropriate, a 3D model could include completed earthworks, zones of fill material, groundwater levels allowed for in the design, etc.

47. Large, complex projects may necessitate the development of individual models (e.g. for geotechnical and hydrogeology properties).

48. If the dutyholder opts for a 3D model (or extracts information from a model such as surfaces) then the Inspector may consider whether it is appropriate for model information to be incorporated into project Building Information Modelling (BIM) to facilitate management of future ground risks and maintenance. For more information on BIM, see the Annex 2.

2.4.3 Ground investigation phasing and iterative review

49. The Inspector should expect a systematic, phased approach should be adopted for a ground investigation, which is proportionate to the project size. For large new build projects, generally a minimum of two ground investigation phases would be expected; preliminary investigations followed by detailed design investigations. For a new facility on an existing site, this may be disproportionate.

50. It may be necessary for the dutyholder to undertake additional investigations following the main ground investigation phases. This may be to provide more information relating to specific matters identified during previous ground investigation phases or the need for further information due to changes in the plot plan. The quantity and composition of investigations are likely to vary by investigation phase but should be driven by the project requirements for inputs to the design.

51. The Inspector may wish to encourage input from relevant end users whenever the ground model and geotechnical risk register are updated following each ground investigation phase and iterative review of the ground investigation scope. This approach enables follow-on investigations in the subsequent ground investigation phase to be scaled and specified appropriately in response to the obtained information and uncertainties in ground and groundwater conditions, as highlighted by the updated ground model.

52. The Inspector should focus on any changes to the ground investigation scope and the subsequent justification, particularly where the scope is reduced in terms of number and types of tests to be undertaken. The Inspector should be aware of reviews undertaken to understand the implications of design or layout changes, and whether additional data are required to substantiate the design changes.

53. In line with SAP MS.4, which states the need for lessons to be learned from internal sources, the Inspector may wish to confirm that the dutyholder has suitable arrangements to continue to collect and monitor ground conditions during the construction phase and that this information is fed into updates of both the ground model and risk register. The Inspector may wish to consider whether sufficient information has been collected to confirm that the assumptions made, or data used, in the design are appropriate. The Inspector may seek assurance that that the dutyholder is undertaking sufficient construction assurance during the construction period, reconciling the information gleaned from the construction with the design assumptions.

54. An updated ground model and geotechnical risk register are key outputs of a ground investigation. During construction, this model may be changed as a result of the formation levels and strata which are exposed in the excavation work. This information may validate the model, but where the exposed strata are not as anticipated, the model should be updated to record the actual site conditions. This is a key consideration because, once earthworks are complete, the information about the strata is buried.

55. The Inspector may request demonstration of the as-built ground model as part of the commissioning assessment, to seek evidence that the as-built records accurately capture the information that was made available during construction. This is in line with the expectations of Licence Condition 6 and SAP MS.2 which states that records

relevant to safety should be retrievable for the whole life of the facility, along with SAP DC.6 that sets the expectation that as-built records will inform decommissioning planning.

56. For more information, see:

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

2.4.4 Ground Investigation Supervision

57. In line with the requirements of Licence Condition (LC) 10 and SAP MS.2, the ONR expectation is for Suitably Qualified and Experienced Persons (SQEP) to be responsible for managing and specifying the ground investigation and its safety. Regarding the safety of the ground investigation, this is to mean the future safety of the nuclear site, should the ground investigation works be ill-conceived or executed.

58. Often the specification and scope of ground investigation works are undertaken by a specialist contractor, as is the ground investigation work itself and the subsequent analysis. Where this is the case, the Inspector may wish to seek assurance that the dutyholder has sufficient SQEP resource to fulfil the Intelligent Customer (IC) role through a Design Authority (DA) function. Regarding assessment of competence, see the principles in:

- ONR-NS-TAST-GD-027 ‘Training and Assuring Personnel Competence’,
- ONR-NS-TAST-GD-049 ‘Licensee Core Safety and Intelligent Customer Capabilities’,
- ONR-NS-TAST-GD-079 ‘Licensee Design Authority Capability’,
- ONR-NS-INSP-GD-010 ‘Licence Condition 10 – Training’.

2.4.5 Test techniques and parameters

59. Ground investigations are inherently site-specific; the selection and use of ground investigation techniques and parameters will be dependent upon many factors, a key one being the geology. The specific nature of the site’s geology, i.e. soil or rock, will determine the applicability and effectiveness of ground investigation techniques. There are some common techniques that are likely to be employed and some ground investigation parameters that are necessary to characterise any site. The number and type of tests should be proportionate to the purpose of the ground investigation which the Inspector may wish to seek assurance is clear in the rationale. Common ground investigation techniques include but are not limited to: Boreholes, sonic drilling or window sampling of soils, geophysical techniques both intrusive (i.e. down-hole techniques) and non-intrusive (e.g. surveying methods) including: Seismic reflection; down-hole; cross-hole; electrical resistivity tomography; and optical televiewer. In-situ testing techniques including standard penetration test (SPT); cone penetration test (CPT); and plate load tests. Laboratory testing and analysis is also common.

60. The Inspector should be aware that the in-situ tests should be cross-correlated and not considered solely independent of one another. The Inspector should consider whether the dutyholder has addressed both static and dynamic site characteristics. Both static and dynamic data are needed for different studies, for example, settlement and site response analysis respectively. The static values should be compatible with the dynamic values. For further detail on dynamic site characteristics, see:

- ONR-NS-TAST-GD-013 ‘External Hazards’ Annex 1 provides further detail on dynamic site characteristics.

61. The Inspector may wish to seek assurance that the ground investigations provide relevant groundwater information required for geotechnical design and construction. Groundwater parameters include but are not limited to: The extent and permeability of

water-bearing strata, including depth and thickness of the unit(s); joint systems and other interconnectivity within the rock; elevation of the groundwater surface and piezometric surface of aquifers including variation over time, high and low levels and the frequency of recurrence for these levels; pore-water pressure distribution; chemical composition and temperature of groundwater.

62. The Inspector should note the importance of groundwater presence as it can affect soil properties both statically and dynamically, and that this can make measuring these properties difficult. Compression waves measure the in-situ soil-water combination, which in soft soils is significantly different from drained properties. In such a case, shear waves should be used as water cannot transmit shear waves. Determining Poisson's ratio in such conditions is challenging. RGP for groundwater can been found in IAEA Safety Guide NS-G-3.6 [6] and IAEA NS-R-3 [7]. Buoyancy effects due to the presence of groundwater are discussed in Section 4.3.2 and 4.8 of this annex.

2.4.6 Ground variability and characterisation of uncertainty

63. Geological materials are often very variable in terms of their properties, reflecting the environments in which they were formed. Units can be relatively homogeneous in nature or display a large degree of heterogeneity, with isotropic or anisotropic behaviour. Therefore, it is a key consideration for the Inspector to seek assurance that suitable and sufficient attempts are made to understand this variability in the ground investigation, in line with the expectations of SAPs ECE.4 and ECE.5.

64. The Inspector should note that the scope of the ground investigation will be, in part, determined by the character and variability of the ground and groundwater, see SAP ECE.10. Typically, the desk study and / or preliminary investigations will establish a prior estimate of the character and variability of the ground that can then be refined by further ground investigation phases. The data specified and obtained in investigations need to be sufficient to enable the understanding of variability in geotechnical parameters. This, in turn, would then inform the design stages.

65. There will inevitably be uncertainties in ground investigation, these can arise for a number of reasons, including:

- quantity of data,
- data collection processes,
- environmental conditions,
- different techniques,
- data processing and analysis,
- laboratory analyses.

66. The use of multiple techniques in a location (e.g. the site, or within an individual borehole) can capture the variability and uncertainty for a specific geotechnical parameter and enable a more robust interpretation to be developed. Use of statistical methods to characterise the variability necessitates a minimum quantity of data. A phased ground investigation process enables review of whether additional data are required. Some uncertainty can be managed by the use of bounding values (see para. 81 of this annex).

67. The ONR expectations for the use of sensitivity studies are outlined in SAPs AV.6 and ECE.14, because sensitivity studies can assist in identifying the parameters or analysis aspects on which a design basis is dependent. Where these parameters or issues are also associated with a high degree of uncertainty, this can indicate where refined data collection, analysis, or even further research may be needed (see Section 3.5).

2.4.7 Monitoring and instrumentation

68. The Inspector should note the importance of the dutyholders arrangements to monitor a site throughout its lifecycle (i.e. pre-, during- and post-construction). The purpose of such monitoring is to provide inputs to the design analyses, substantiate the design and associated assumptions, and provide inputs to support longer-term Safety Case development (see Licence Condition 15). The Inspector may seek assurance that adequate arrangements are in place to monitor excavations and slope stability during construction and as required throughout the intended design life of the structures.

69. The assessment of the adequacy of the dutyholder's planned monitoring scheme should be justified as part of the ground investigation rationale; including the frequency at which monitoring is undertaken and duration of the programme. For example, the Inspector should expect an adequate justification to include:

- assurance that the monitoring programme is of sufficient duration to enable any variations that may impact on the design are identified and quantified (e.g. seasonal changes in groundwater level) to establish baselines,
- consideration given to long-term monitoring needs when developing and designing the scheme as there are some parameters that may need monitoring throughout the facility's lifetime (e.g. settlement),
- where appropriate, monitoring provided for key geotechnical, hydrological and hydrogeological parameters, including groundwater (levels and quality, see SAP ECE.10), and settlement,
- monitoring of beachfront topography or river alignment/ erosion, as well as bathymetry where particular claims are made around the impact of offshore geotechnical features on local wave effects, which should be managed by dutyholder arrangements under LC28 (see SAP ECE.12),
- consideration given to both static and dynamic geotechnical aspects, namely settlement (see SAP ECE.24) and PSHA / site response respectively.

70. Where ground conditions are particularly challenging, large-scale tests can be undertaken during the ground investigation phase to provide inputs to the design. The Inspector should encourage such an approach as the monitoring can inform the design with more information. When assessing the proposals, the Inspector may consider the applicability of the results to the subsequent design, as results may be impacted by weathering or other factors.

71. The Inspector may consider the adequacy of the monitoring scheme across the whole life of the site. An adequate scheme would have arrangements in place for the dutyholder to review the outputs on a periodic basis, especially when there are significant changes with respect to site activities. There is likely to be a need for additional monitoring and at shorter intervals (or continuous) during the construction phase with regards to slope and excavation stability.

2.5 Reporting

72. Licence Condition 6 refers to the requirements for arrangements to be in place for producing accurate records, in relation to civil engineering works, these include ground investigation data, results and interpretation. For geotechnical records, these may also be used by dutyholders to substantiate any contaminated land claims in line with the requirements of SAPs RL.2 and 5, should an area of contaminated land be identified.

73. For small projects, a single Ground Investigation Report may be produced that discusses all aspects of the ground investigation and provides an interpretation of the results. For larger projects, a logical hierarchy of reports may be needed. A basic reporting structure is provided below, but dutyholders may structure their reports differently.

74. The Inspector should consider whether the reporting of ground investigation information is conducted in accordance with RGP, e.g. BS5930 [2] and Eurocode 7 [4] and [5], including:

- Factual report(s): Presenting an account of all the ground investigation undertaken during a particular phase:
  - including raw data, measurements and observations directly from the ground investigation,
  - making reference to the methods and RGP that have been applied to collect the data.
- Interpretative report(s): Summarising the data, presenting an interpretation of the data and observations made during the ground investigation, including the range and distribution of physical properties (e.g. strength and deformation characteristics). This report evaluates the data, identifies any erroneous information or limitations and highlights any risks and/or uncertainties in the ground conditions (e.g. irregularities such as cavities or soluble materials). The report presents the resultant ground model(s) and geotechnical risk register.
- Design report(s): Defines the characteristic and design values to be used for geological materials, including the relevant and appropriate justification. The report may also provide assumptions, methods of calculation, and the codes and standards to be used. For small projects, the report could also provide the geotechnical design calculations and drawings with results verifying the safety and serviceability of the SSCs in the design. The report should provide clear statements of monitoring and site verification and/or testing requirements needed to validate the design assumptions.

75. With the reporting, the Inspector should note the importance of the potential for regular updates of the reports during and following construction. The Inspector may wish to seek assurance that these updates incorporate the encountered ground conditions and provide an as-built model as a reported item for demonstration. Sufficient information should be collected to confirm that the design parameter assumptions made, or data used in the design, align with the encountered site conditions; with a confirmation that assumptions either remain appropriate, or the design incorporates changes.

76. In line with Licence Condition 6 and SAPs MS.2 and DC.6, records of the ground investigation should be preserved; this includes the raw data and measurements, not only the interpretations. Records of design deviations should also be maintained, along with as-built drawings and records. The dutyholder may consider retaining geological core material from the ground investigation for use in subsequent construction and / or development on the site.

77. For more information on records management, see:

- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’.

3 GEOTECHNICAL NUMERICAL MODELLING AND ANALYSIS

78. The ground investigation data provides inputs to the various geotechnical numerical modelling and analyses that are required to gain understanding of:

- the conceptual foundation design,
- the construction methodology and sequencing,
- the design of temporary works,
- back calculation of the results from site tests for validation purposes,
- the static and dynamic soil-structure interaction,
- the structure-soil-structure Interaction effects,
- dynamic site response (This is usually carried out as part of PSHA, guidance on this is provided at ONR-NS-TAST-GD-013 ‘External Hazards’ and [2]).

79. The Inspector should note the use of the ground model to inform the development and validation of numerical models is a key aspect of the overall analysis process. The Inspector is reminded of SAPs ECE.12, ECE.13 and ECE.14 when considering structural analysis and modelling to demonstrate the structures can meet the Safety functional requirements (SFRs) for the required duration, with the appropriate use of data and sensitivity analysis as justification.

80. Key principles for the Inspector to note are included herein; in addition, civil engineering principles for assessment of modelling for civil engineering purposes are presented in:

- TAG 17 Annex 1, ‘Civil Engineering – Design’.

3.1 Use of deterministic bounding profiles

81. In order to simplify the design process and to reduce computational demand, it is common in geotechnical engineering to represent the variability and uncertainty characterised by the ground model deterministically. Often a factor is applied to the best-estimate properties to produce an upper and lower bound resulting in three profiles for the analysis and design. Some generic guidance is available regarding the factors that could be applied, examples being ASCE4-16 [9] and ETC-C [10]. However, these are site independent, therefore the Inspector may wish to seek assurance that these are appropriate for the site or facilities location, and consistent with the ground model. The Inspector should be aware that the intent of utilising upper and lower bound properties within the geotechnical analysis models is to obtain results that represent a bound on the overall potential response. It may not be appropriate for the analyses to set all inputs to individual upper or lower bound values as, in some instances, what appears to be a lower bound on an individual parameter could result in contradictory effects. The Inspector may wish to seek assurance that such potential effects have been investigated.

82. The Inspector should be aware that the choice of best estimate considers the reliability of the underlying data, its characterisation (i.e. its distribution) and expert judgement. Where data is limited, absent, or where the data is essentially uniformly distributed across a wide range of values, then the consideration of a spectrum of plausible best estimate values would be appropriate. The Inspector may wish to seek assurance that the appropriate type of ‘mean’ is being used for the data under consideration, for example, the use of the harmonic mean may be appropriate for shear wave velocities.

83. The uncertainty associated with the geotechnical parameters can often be large, typically represented by probability distributions with large standard variations. Therefore, it is often not practicable to bound these distributions fully within a deterministic design framework and aspiring to do so may result in excessive conservatism. The Inspector should note the expectations of SAP SC.5 and ERL.4 when considering conservatism in design.

84. The Inspector may wish to consider the selection of appropriate bounding distributions, specifically, the relative reliability of data sets. The Inspector may wish to consider whether the bounds proposed are sufficiently broad to encompass a suitable range of data points and whether additional sensitivity analyses may be appropriate.

3.2 Use of probabilistic approaches

85. For civil engineering design purposes, fully probabilistic analysis approaches are not yet widely implemented for dynamic or static soil-structure interaction (SSI). This is mainly due to the computational demand associated with running large and detailed models that make such approaches impracticable. However, the use of probabilistic approaches is widely applied in dynamic site response analysis, often within the framework of PSHA, see Figure 2 and further information in ONR-NS-TAST-GD-013 ‘External Hazards’.

3.3 Numerical modelling approaches

86. The modelling of the soil in structural analysis is a key consideration in order to capture the interaction between soil and structure. This is termed soil-structure interaction (SSI) and is relevant to both static and dynamic loading. SSI is generally neglected for flexible structures founded on stiff sites. SSI is significant for:

- stiff, heavy structures,
- long structures,
- embedded structures,
- very soft soil.

87. To account for SSI there are two main types of methodology for the Inspector to be aware of; the Direct Method and Sub structuring Method. Section 5 of ASCE 4-16 [9] provides further information on these methods for dynamic analyses, with the commentary therein also discussing advantages and disadvantages of some of the software packages available for these methods. Clauses 4.9 to 4.26 of [6] also provide guidance and general principles for SSI. Further information on this is provided in ONR-NS-TAST-GD-013 ‘External Hazards’ .

3.4 Validation and verification of numerical modelling in geotechnical engineering

88. The Inspector is reminded of the definitions of validation and verification from the SAPs [1]. Validation is 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. Verification is the process of confirming, e.g. by use of objective evidence, that an activity was carried out as intended, specified or stated.

89. SAP ECE.15, AV.1 and AV.2 set the expectations associated with the validation and verification of data, theoretical models and sensitivity analysis. AV.3, AV.4 and AV.5 refers to the expectations around the use of data, the computer modes used to process the data and the documentation of the analysis.

90. The Inspector should be aware that discrepancies between the behaviour of the numerical model and reality may have several causes that can be categorised into the following areas:

- simplifications made in the model such as geometry, boundaries, loads, materials (e.g. backfill type used), construction stages and sequencing, etc.,
- modelling errors related to numerical discretisation, methods, algorithms and solution procedures,
- simplifications made to the modelling of stratigraphy, anisotropy and spatial variation,
- modelling errors relating to the non-linear and time-dependent soil behaviour assumed in constitutive models. This can be the most significant source of discrepancies in geotechnical engineering applications,
- uncertainties related to variations in loads and model parameters,
- software and hardware issues related to bugs within operating systems and hardware configurations, in particular parallel processing. This requires thorough verification of the software,
- misinterpretation of results, such as the incorrect translation of model results into geotechnical design.

91. These sources of discrepancy necessitate confirmation that dutyholders are verifying computer software and validating their numerical models appropriately. The Inspector may wish to seek assurance that the validation methods involve the model as a whole, as well as individual components of the model. RGP in this area is discussed at length by the International Association for the Engineering Modelling, Analysis and Simulation

Community (referred to as NAFEMS) who produced [11], from which the key considerations can be summarised as:

- models and methods implemented in the software should, where practicable, be verified based on known solutions. The verification of these software packages is often carried out using standard routines supplied by the software developer,
- geometry needs to be validated against the reality,
- artificial model boundaries need to be validated against the results, considering variations in boundary type and position,
- selected material model and parameter values should be validated against test data from the ground model – see Section 2 above,
- finite element mesh should be validated against results considering mesh refinements,
- initial conditions (effective stresses, pore pressure distribution, pre-consolidation stress and other state parameters where applicable) should be validated against test data from the ground model – See Section 2 above,
- calculation phases should be validated against the construction stages that occur in reality,
- results from the analysis should be validated against the expected results informed from benchmarks, learning from case histories [11] other analysis methods, design charts (where appropriate) and practitioner knowledge and experience.

92. The above is illustrated by **Error! Reference source not found.**, a flow diagram highlighting the modelling process and validation.

93. Where iterative analysis software has been used, the Inspector may wish to seek assurance that the output has converged on a true solution, e.g. that static SSI analysis has enough iteration to converge on appropriate stiffness and settlements.

3.5 Sensitivity analyses

94. The Inspector should note the importance of 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. These analyses are particularly significant where there is poor quality or insufficient geotechnical data that cannot be improved upon, or where modelling decisions have to be based on extrapolation of the geotechnical data or known behaviour. These analyses can also indicate where refined data collection, analysis, or even further research is needed. The Inspector should expect sensitivity studies to be used appropriately with adequate verification and validation as necessary.

3.6 Other Geotechnical Considerations

95. Examples of other factors that need to be considered in modelling and analysis are: Made-ground, the (re-)use of site-won materials, backfill and man-made fill, compaction, mass concrete ground replacement, liquefaction, sloping soil profiles, and retained materials such as soil and water. Further detail is provided on some of these areas in the relevant guidance and codes [2] and [7].

4 FOUNDATIONS AND OTHER SUB-SURFACE STRUCTURES

96. 'The foundation is that part of a structure which serves exclusively to transmit the weight of the structure onto the natural ground' [12]. The foundation is designed on the basis of an expected ground response and the ground is assumed to respond in a particular way following an interpretation of the geotechnical data from a site investigation and excavation prior to construction.

4.1 Foundations and Sub-structure Design and Safety Case

97. The safety case for all foundations and sub-surface structures should be a coherent and organised presentation of the claims, arguments and evidence in place in line with the expectations of SAPs ECE.1, ECE.2, ECE.6 and ECS.1. Specifically, ECE.7 and ECE.9 apply to the assessment of earthworks. The expectations of these SAPs are for design information to be presented in an organised structure, at various stages of the design. The Inspector may wish to seek assurance that the documents include the criteria used (be it Generic Design Assessment (GDA), structure specific or site specific), the assumptions made, and limitations applied.

98. The design and safety case of the foundations could be developed through the different stages of design, e.g. for new build these would be GDA, Site Specific Assessment, through site licensing, and then into site construction with the use of the Pre-Construction Safety Reports and then Post-Commissioning Safety Reports once construction is complete. A substantiated foundation design that is demonstrably conservative would have a clear and explicit adequate margin that is substantiated with the consideration of modelling and analysis, geometry, settlements and stability, stiffness, strength, durability and constructability.

99. For more on safety considerations for foundation design, see:

- HSE RR319 - Safer foundations by design (buildability) [13].

4.1.1 Functional requirements

100. An increasing level of detail is required across the Pre-Construction and Post-Commissioning reports, and the Inspector should expect a clear, navigable link between the design outcomes and the safety functional requirements, e.g. for foundations these could include:

- settlement control: total and differential across the raft, local inclination and differential between adjacent structures, limits due to SSCs,
- local deformation (deflections for floor mounted SSCs),
- durability and clarity around the required design life,
- water tightness,
- strength (Ultimate Limit State),
- global (overall) stability,
- buildability and construction methodology (including principles of sequencing and construction joint strategy),
- control of ground gases (prevention and OPEX controls),
- monitoring systems,
- requirements for joints (between adjacent rafts and between supported structures),
- beyond design basis capability for the above.

4.1.2 Geometry

101. The Inspector may wish to seek confidence that the layout of the structures systems and components (SSCs) is both mature and stable, with considerations of relevant inputs from other disciplines. The Inspector may look for evidence of safety case inputs to civil engineering design and construction decisions, and this is to include upstream referencing of relevant Safety Functional Requirements or Engineering Schedules, to meet the expectations of the SAPs ECE.1 and ECE.5 and ECE.6. In such documentation, the Inspector should expect visibility of critical details, e.g. pits, sumps, changes in thickness and transitions and prestressing gallery interfaces. The Inspector should expect to see sufficient detail on drawings to check that the analytical representation is appropriate, and adequate detail to be used to assess any future (potentially site-specific) changes.

102. The Inspector may consider whether the spatial configuration and geometry are adequate, e.g. section sizes and transitions, in terms of their overall configuration and the local details. The Inspector should focus on complex areas which might include:

- zone of interaction with the gusset area,
- interface with and detailing of pre-stressing gallery,
- the transition from BRX to adjacent areas and associated location of any changes of thickness / stiffness,
- local details around any sumps, pits or any other discontinuities in the typical raft thickness,
- cast in services, utilities etc.

4.1.3 Geotechnical parameters and inputs

103. The Inspector may wish to seek assurance that inputs to design, including the geotechnical assumptions, are appropriately underpinned, reflecting the range of profiles forming the design. If geotechnical work uses envelopes (e.g. within Generic Design Assessment), the Inspector may seek evidence that the envelopes adequately reflect the range of profiles that form the envelope. The Inspector may wish to seek assurance that the static and dynamic properties are consistent with each other, and that the modelling and analysis adequately represents and envelopes all the profiles and assumptions. The Inspector is reminded of the interface with External Hazards discipline when assessing the early ground investigation information.

104. The Inspector may wish to seek assurance that the static SSI analysis has converged on an appropriate stiffness and settlement value, through sufficient iterations. The Inspector may wish to check the evidence of final differential settlements and inclinations as part of the construction phase, with confirmation that the predicted settlements are appropriate within tolerable limits.

105. The Inspector should be aware of the potential relatively high bearing pressures for reactor foundations, with focus of assessment on the soil stiffness non-linearity and the factor of safety on bearing pressure and the effect on soil stiffness, including consideration of the static and dynamic situations, including rocking.

106. The Inspector may wish to confirm there is a clear definition of conditions and site parameters used, which then transfer into the Basis of Design documentation which feed into the structural design reports and methodology reports.

107. Where waterproofing membranes are being used as part of the foundation or sub-surface structure design, the Inspector may wish to consider the compatibility of base friction assumptions with the use of a membrane, and the associated design life and maintenance requirements and subsequent safety case claims made on the membrane.

4.1.4 Loading

108. The Inspector may wish to seek assurance that all significant equipment loads and live loads that bear directly on to the raft are identified and quantified. The Inspector may wish to confirm that this includes clarity on scenarios where the lateral soil loads are considered. The Inspector should note the different seismic, static strength and stability models, and the influence of wall pressures on the results e.g. on the raft moment and shear profile. The Inspector may wish to seek assurance that there is clarity on the lateral loading assumed on any underground structures e.g. pre-stressing gallery walls.

4.1.5 Modelling and analysis

109. The Inspector may wish to confirm that there has been use of appropriately verified and validated software in line with the expectations of ECE.15, for soil representation, via both static and dynamic SSI. The Inspector may wish to confirm that the appropriate

meshing, application of loads, load combinations and boundary conditions and constraints have been applied to the models and analysis, including the model outputs, and how these are then used, alongside drawings and other documentation.

110. The Inspector may wish to seek assurance that there is clarity on the use of coarse and refined models and sub models, with key areas of interest for the modelling of reactor foundations including:

- highly reinforced areas of connection between the foundation and the inner containment,
- interface with any underground structures e.g. pre-stressing galleries, including the influence of the gallery on the foundation and design modelling and stiffness included in the gallery design,
- pits, sumps, or any other discontinuities in the foundation thickness and stiffness,
- sensitivity analyses where necessary to demonstrate that the assumptions made are adequately conservative.

4.1.6 Stability

111. The Inspector may wish to seek assurance that there is a clear methodology for the development of static forces from dynamic analysis, with code-based stability checks for sliding, overturning and floatation etc., as well as an appreciation of the influence of the pre-stressing gallery or underground structures on sliding.

4.1.7 Stiffness

112. The Inspector may wish to consider the appropriateness of any modification factors on concrete to determine the stiffness for:

- thermal loads (i.e. stresses from restraint of thermal strains),
- soil-structure interaction (i.e. the structure stiffness within the SSI),
- long term concrete modulus compatible with loading duration.

113. The Inspector should be aware of the deflection criteria and limits for serviceability and design basis, with certain SSC limitations (e.g. local inclinations etc.).

4.1.8 Strength

114. The Inspector may wish to seek assurance that checks have been undertaken for bending, in plane axial, shear and, where appropriate, torsion.

115. For reactor foundations, the Inspector may wish to seek assurance that there is a series of focused, auditable and traceable results for:

- gusset interface (specifically influence of gusset on reactor foundations),
- interface with any underground structures e.g. pre-stressing galleries, including the influence of the gallery on the foundation and gallery design,
- any changes in thickness of the raft from buildings to adjacent areas,
- local details around sumps, pits etc., where there is a greater margin expected for shear.

116. The Inspector may wish to seek assurance that the dutyholder has applied smoothing or averaging and enveloping where it is appropriate and justifiable. The Inspector may wish to seek assurance that there are sufficient margins on shear and flexure (see Beyond Design Basis section below).

117. The Inspector may wish to seek assurance that the results demonstrate a buildable structure, i.e. the maximum reinforcement percentages, consideration of general reinforcement congestion and consideration of practical detailing aspects.

4.1.9 Durability and Serviceability

118. The Inspector may wish to seek assurance that there is clarity on the potential for aggressive ground conditions and the management of this for the duration of the design life, with clarity around the safety functional requirements and claims made on membranes or other methods used to manage this. The Inspector should be aware that BRE Special Digest 1 ‘Concrete in aggressive ground’ [14] is recognised as Relevant Good Practice for considerations of concrete in aggressive ground. The Inspector is reminded of the SAP ECE.12 expectations around the structural analysis and model testing to demonstrate the structure can meet the SFRs over the full range of loading for the lifetime of the facility.

119. The Inspector may wish to seek assurance that there is clarity around the concrete grade, cover and durability classification, with specific focus on any water-tightness classifications and associated performance requirements. Where the design makes assumptions on or forward commitments related to a site-specific requirement, the Inspector may wish to seek assurance that these are clear and explicit, with a consideration for the way in which these will be addressed once design progresses.

120. For sub-surface structures, waterbars are often implemented to prevent liquid ingress or egress to surrounding ground. The Inspector may wish to seek assurance of the adequacy of durability of such design decisions in areas of aggressive ground conditions. The Inspector should be aware that there are considerations regarding buildability and confirmation of quality for waterbars and joints as part of their construction.

121. The Inspector should also note the durability considerations of organic materials incorporated into the water retaining construction (e.g. waterbars, sealants, joints and membranes). The Inspector is reminded of a Building Research Establishment (BRE) document “A review of materials used as waterbars and sealants in pond structures” [15] which considers the durability of organic based building materials.

4.1.10 Beyond Design Basis

122. The Inspector may wish to seek assurance that the foundation and other nuclear safety significant sub-surface structures have adequate demonstration of the avoidance of cliff edge failures under beyond design basis (BDB) considerations. The Inspector is reminded of the SAPs EHA.18 and EHA.7 which explain beyond design basis events and ‘cliff-edge’ effects and how a small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences. The civil engineering considerations of these for sub-surface structure design may include:

- avoidance of brittle failure,
- low sensitivity to soil variability,
- post crack ductility considerations,
- potential for ground conditions to be impacted e.g. fracturing or faulting, dynamic bearing capacity for beyond design basis scenarios,
- consideration of resilience against beyond design basis event shear failure.

123. For information on Beyond Design Basis, see:

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

4.1.11 Monitoring systems

124. The Inspector may wish to consider whether monitoring systems in the reactor foundations would be necessary to demonstrate satisfaction of the safety case, and therein if any safety case claims should be made on these systems. These could include

thermal and / or strain gauges under the reactor building. The Inspector should consider the justification provided if monitoring systems are not claimed in the safety case. The Inspector is reminded of the expectations as set out in ECE.24 around the monitoring of settlement during and after construction to validate the design. Also note the requirements for monitoring in line with the expectations of ECE.12 regarding coastal flooding.

4.1.12 Embedded items and lightning protection systems

125. The Inspector may wish to consider whether the lightning protection system utilises the foundation reinforcement as the ground conduction termination. If this is the case, the Inspector may wish to consider whether the connection to the reinforcement will be clamped or welded, and how will electrical continuity of reinforcement be adequately verified. The Inspector should refer to BS 6651 [16] for consideration. The Inspector should note that justification of any welding of reinforcement is likely to require focussed assessment, as the site controls for reinforcement welding of the reactor foundation require enhanced quality measures to be in place.

126. The Inspector may wish to consider the use of cast-ins items for equipment bases and cast-in services, with buildability considerations around the demonstration of accuracy of their placement and the tolerances applied to the construction. The same can be true for foundation or basement sumps with liners cast in. Mock-ups or trials may be necessary demonstration for quality assurance.

4.1.13 Site specific considerations

127. The Inspector should be aware that, when the design approaches site specific consideration, the forward actions or commitments should be addressed in a more developed or detailed design phase. Such site-specific aspects could include:

- water-tightness claims made on joints or membranes, waterstops or other ‘site specific’ or construction related design details,
- shrinkage and early age crack control on site,
- ground investigation results, including heave or uplift,
- settlement limits imposed by other disciplines,
- construction sequences to minimise edge restraint cracking,
- access requirements to facilitate construction stages and methodology.

4.1.14 Buildability

128. The Inspector may wish to use the Designers Risk Assessments produced in accordance with the Construction (Design and Management) Regulations to provide information on the risks that have been considered in the design and avoided / mitigated as a result of design. The Inspector may wish to consider whether these risk assessments are adequately developed and are consistent with the stage of design and design philosophy, and that the implications for site specific considerations have been sufficiently considered. The Inspector is reminded of the expectations of SAP ECE.25 and ECE.18 regarding constructability considerations and inspection during construction.

129. The areas of focus for the buildability consideration include highly congested reinforcement, changes in the foundation depth and local details around sumps or pits

130. Also, for sub-surface structures, the Inspector may wish to consider the buildability of connections to other buildings and overlying or interlaced structure, which might result in complex design details.

131. The Inspector should be aware that foundation selection and design for sub-surface structures is often based on many variable factors, and that there is a choice of forms of

construction that can be adopted to overcome particular issues encountered on site to achieve the same end.

132. Where suitable operational testing, inspection and surveillance procedures have been developed, the Inspector may wish to consider whether these activities and tasks are adequate, which may interface with ONR human factors and conventional health and safety inspectors. The Inspector may wish to consider whether the arrangements have been considered and validated as appropriate to the classification and been included in the Examination, Inspection, Maintenance and Testing (EIMT) schedule in compliance with Licence Condition (LC) 28 and in line with the expectations of SAP ECE.20.

4.2 Foundations and Sub-structure Construction

133. The following key sub sections present principles that apply to the majority of earthworks and construction activities for foundations and sub-surface structures.

4.2.1 Other regulatory interest in early construction and GI

134. The Inspector is reminded that early earthworks construction activities may be subject to restrictions, pending the approval of a Development Consent Order (DCO). There is the potential for interfaces with other regulators including the Planning Inspectorate (or equivalent), relevant environmental regulators including for activities that happen outside the plot plan of the licenced site, see Appendix G of the TAG17 head document. The Inspector may wish to consider what these DCO, planning permission and other environmental restrictions are, and if any of these has the potential to impact on early earthworks activities that have nuclear safety significance.

4.2.2 Construction Management

135. The Inspector may seek assurance that the site processes for earthworks are adequate, to gather confidence that these works are progressing in line with the requirements as stated in the works information and / or contract specification. The Inspector may seek assurance that the works information and contract specification(s) adequately meet the original design intent.

136. The Inspector may wish to seek assurance around the SQEP competence of who is responsible for the Structural Design Method Statements or similar documentation which outline the work description, risk assessment and work process. Detailed site construction method statements can be useful to the Inspector to gain confidence in the design philosophy and temporary works management and coordination, that it reflects the original design intent, and can be communicated to the construction teams.

137. The Inspector may seek assurance in the adequacy of the role of the dutyholder surveillance and supporting technical teams to undertake, manage and supervise the works undertaken by the supply chain. This should include who is undertaking the roles of Design Authority and Intelligent Customer function and who is accepting the works as adequately completed. The Inspector should be aware which parties are responsible for making design decisions regarding design changes, including providing justification that something is adequate and meets the original design intent. The Inspector may wish to seek assurance that the roles and responsibilities of all parties are clearly documented and understood consistently across all parties.

138. Operational experience (OPEX) in the field of earthworks and temporary works can inform the Inspector of events or near misses including OPEX from other industries outside the nuclear industry, the learning from which may apply to the construction phase of the project.

139. Expectations for the management and monitoring of earthworks and groundwater are established by SAPs ECE.8, ECE.10, ECE.18 and ECE.20.

140. For more detail on other key principles of construction management, see:

- TAG 17 Annex 4, 'Civil Engineering – Construction Assurance'.

4.3 Early works dutyholder oversight

141. The Inspector should expect the dutyholder to have arrangements in place to ensure checking, independent checking, oversight and validation of the works appropriate to its novelty and classification. These arrangements need to include oversight throughout the supply chain and include auditing appropriate to the structure classification and these should be applied through design, construction and operation of the facility.

142. The Inspector should be aware that the Design Authority and Intelligent Customer function have an key role to be involved in the specification of procedures to ensure that the original design intent, considerations and assumptions are met through the site processes, procedures and contract specifications and / or works information. At the early stages of earthworks, these persons may not be permanently located on site, so the Inspector should understand who takes the responsibility for the communication from the site to the relevant personnel in other departments.

143. The earthworks are often undertaken by specialist earthworks contractors, so the Inspector should be aware of the contractual arrangements regarding risk allocation, alongside understanding who is undertaking the Intelligent Customer function from the dutyholder regarding the contract, specification(s) and acceptance of works as complete.

144. As earthworks are the early construction activities, the site wide processes may be early versions that are being used for the first time during the earthworks activities. The Inspector may seek assurance that there are appropriate arrangements in place for the contractor to raise a query or question of the dutyholder regarding the design. The Inspector may seek assurance that all parties understand what process(es) the contractor(s) need to follow if it is not possible to achieve the requirements as set out in the works information or contract specification. Further to this, the Inspector may wish to seek assurance of the adequacy of the process(es) in place for the contractor to escalate site issues to the dutyholder, and how the dutyholder responds to these. The Inspector should be aware that any change requests that have the potential to impact nuclear safety should be formalised through a change control process with a categorisation based on safety of the situation prior to remediation, linking back to the original design intent and requirements of the contract specification or works information.

145. At the early earthworks stage, the processes and procedures for oversight may not be mature, but the Inspector should understand the levels of dutyholder oversight undertaken on the works that are nuclear safety significant. As the project progresses, the Inspector should be aware of developments to the site processes to understand how the dutyholder is managing oversight to positively influence the levels of quality achieved and maintained throughout the project. The Inspector should understand the levels of early oversight and how these align with the safety significance of the earthworks being undertaken. The Inspector should be aware that the dutyholder cannot rely on the supervision of the contractor, and has to provide their own level of oversight of the works. This is to be compliant with the requirements of Design Authority and Intelligent Customer. The Inspector should be aware that the level of oversight is commensurate to the level of hazard or nuclear safety significance of the work. The nuclear safety significance of earthworks may or may not be appreciated during the early phases of earthworks. There may be other reasons that the dutyholder will increase oversight of a contractors work, but the dutyholder should not reduce the levels of oversight without justification.

146. The Inspector should be aware that the dutyholder, through the Intelligent Customer function would also manage the competence of the contractors employed on the site to undertake these early works. The competence checks extend to qualifications, training

and experience, as well as consideration of the communication, understanding and the ability to make decisions and challenge. This is through means of checking work, written and verbal skills, use and understanding of drawings, bearing in mind the potential for different languages being spoken on a site. The Inspector may seek assurance that competence and communication are adequately managed by the dutyholder.

147. The Inspector may wish to become familiar with whether there are any clear, agreed process(es) for unexpected but foreseen events e.g. for earthworks; encountering hard or soft spots, which should explain how the earthworks contractor should respond when experiencing these on site. This can be a useful way to make the best use of the contractor's specialist experience, and requires less direct engagement from the dutyholder, albeit a level of dutyholder oversight should be maintained and specified in the procedure.

148. The inspector should also be aware of the interfaces between different contractors on site and understand the arrangements the dutyholder has in place to manage these. In some cases, it is useful for the inspector to understand the nature of the contractual arrangements as these can, if not well administered, drive perverse behaviours.

149. For more on the civil engineering principles for considerations of the Design Authority role and Intelligent Customer functions, see:

- TAG 17 Annex 4 'Civil Engineering – Construction Assurance',
- TAG 17 Annex 1 'Civil Engineering – Design'.

150. For more on the wider ONR guidance of the Design Authority role and Intelligent Customer functions, see:

- ONR-NS-TAST-GD-079 'Licensee Design Authority Capability',
- 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'.

4.3.1 Earthworks, excavations and slopes

151. Some earthworks on site have the potential to impact the future nuclear safety of the site and the construction. The Inspector should understand which activities with nuclear safety significance and may wish to seek assurance of the arrangements that are in place to manage the quality of these works. The Inspector may wish to seek assurance that the safety case associated with the site-specific attributes sets out the future activities that are safety related. When considering early construction works, the Inspector should understand where slope strengthening works, retaining works or other earthworks are key to nuclear safety, and should understand where these have a claim on them. The Inspector should be aware of where claims on construction activities are stated in the safety case e.g. whether a specified design life is required. The Inspector may wish to seek assurance that the claims are translated into the scope, the Works Information or other specification(s) for such work e.g. specific quality of materials. Where there is a claim made on slope stability for example, the Inspector may wish to seek assurance of the adequacy of the static monitoring system that measures the settlement and any movements of the slopes or excavation sides.

152. During early earthworks, trials and testing will be undertaken regarding the ground conditions and the interaction of machinery with the ground conditions. This is part of the demonstration of adequacy of construction equipment and the Inspector could become familiar with the trials being undertaken to gain confidence in the earthworks being undertaken will achieve the required level of quality stated in the works information or contract specification. When familiarising with these works, the Inspector may wish to

seek assurance that the acceptance criteria specified is adequate to achieve the required quality as part of the trials and tests.

153. During the earthworks phase, the Inspector may wish to seek assurance that the arrangements for groundwater and surface water control are adequate. The Inspector may seek assurance that the equipment and tools chosen for the works will be adequate for potential of pooling water and associated ground conditions. There may be an interface with the relevant environment regulators who issue discharge permits if water is being pumped off site.

154. Where the intention is for material to be stockpiled and reused, the Inspector should be aware of the potential future uses of the materials and consider whether there should be any specific requirements for storage. The Inspector should also be aware of the tests and acceptability criteria for the material, and what arrangements are in place should the material need to be conditioned prior to re-used for nuclear safety significant activities. The Inspector should be aware of the specific geotechnical parameters required for different types of backfill material, including compaction requirements, water content, particle size etc. as specified for re-use. The dutyholder may propose re-conditioning or other activities to bring the material up to specification. Where on site material has not been proven as acceptable for re-use, material may be imported to site. The Inspector should be aware of the acceptance process(es) that are in place that ensure imported material is in conformance to the requirements of the specification. The same is true for other imported materials e.g. the various constituents of concrete, from different suppliers.

155. The Inspector should understand the arrangements in place for achieving formation or founding levels, and the use of ground stabilisation techniques to achieve the requirements of the works information or contract specification. The inspector should be aware of the ground conditions that necessitate the use of ground anchors or soil nails and may wish to seek assurance that the use of these will not have a negative impact on the permanent structure.

156. The Inspector may wish to seek assurance that the arrangements in place for managing slope sides are appropriate and that the steepness of the slopes is as referred to in the Site Health and Safety Plan. Where the slopes provide a nuclear safety significant function, the Inspector may wish to seek assurance in the stability of the slopes, understanding whether slopes are matrix slopes or designed slopes, with a wet or dry design. The Inspector may wish to seek assurance that assumptions or requirements are placed on the slopes through the design are met during construction e.g. slope angles, lift heights of the excavation works, requirements for ground nailing or other ground anchoring works and slope monitoring.

157. The Inspector may wish to seek assurance of the adequacy of the arrangements in place for monitoring site slope movement. The Inspector may seek assurance that the dutyholder understands the cause of any significant movements that are recorded, and that the designers have been informed. The learning from earth movements can provide information to update and validate the ground model.

158. The Inspector should be aware that contaminated soils exposed during earthworks present potential handling and disposal problems, as referenced in the dutyholder’s Site Health and Safety Plan. The Inspector should expect the site to be engaged with radioactive materials specialist inspectors and / or the relevant environment regulator, as appropriate, following identification of contamination.

159. The Inspector may wish to seek assurance of the arrangements in place regarding material movement on site, which would identify any limitations or restrictions that may be placed on site. These could range from space restrictions for on-site storage or vehicle restrictions to and from site. For storage areas, the Inspector should expect the

dutyholder to understand the anticipated settlement rates and consolidation rates, and mitigate any risks associated with soil creep.

160. Some sites may require ground improvement works if the ground is soft or if unexpected ground conditions are encountered. The Inspector may wish to seek assurance of the adequacy of the arrangements in place for ground improvement activities, and whether there are any design life, maintenance or other future considerations that could have the potential to adversely impact on any nuclear safety significant activities for the duration of the site lifetime.

4.3.2 Ground water management

161. Ground water controlling measures are sometimes used for construction with deep excavations to ensure the stability of structures (buoyancy). These systems are typically passive in nature when they rely on vertical well tubes feeding into a collector system which discharges off the site, but still require adequate EIMT to check ongoing operation throughout the design life. The Inspector is reminded of SAP EDR.1 which refers to the requirements for reliability of civil engineering SSCs to be designed as inherently safe or to fail safe, and SAP ECE.10 which refers to the civil engineering considerations for groundwater management. For more information, see:

- CIRIA guide C750 [17] Groundwater control: design and practice (second edition).

162. These schemes require the dutyholder to have a way of measuring the ground water levels at a site and measures to monitor and review the way the ground water level varies to understand what factors impact the level over time, e.g. how quickly the ground water level responds to rainfall events.

163. The Inspector should be aware that water has a major influence on geotechnical behaviour of soils and rocks and should be carefully controlled (ground water and surface water). The Inspector should understand how the site design includes for temporary management of ground water to facilitate the construction and earthworks. Further to this, the Inspector may seek assurance of how the ground water is monitored throughout the construction phase, and how this information is used to validate the permanent ground water management scheme.

164. The Inspector should be aware of situations where ground water collects at the base of excavations. If it seeps through excavations, this can provide useful information to the ground water monitoring and trending, and could potentially inform an update of the ground water model. Where this water needs to be collected and removed, the Inspector should expect the dutyholder to be engaged with radioactive materials specialist inspectors and / or the relevant environment regulator, as appropriate, following identification of contamination. The Inspector should be aware of any nuclear safety significant construction activities that may be impacted by collation of groundwater. The Inspector should understand the robustness of dutyholders measures in place to remove and sufficiently relocate the water to prevent construction activities being interrupted.

4.3.3 Temporary Works

165. The Inspector may wish to seek assurance that site restrictions do not have the potential to adversely impact on the quality of nuclear safety significant works, specifically during earthworks and deep excavations where there are other site restrictions e.g. access, high risk areas and / or exclusion zones.

166. In the earthworks stage, the Inspector should expect the dutyholder to identify which areas have a nuclear safety function, and mitigate risks by sequencing the works accordingly to avoid interfaces that could impact quality.

167. For further consideration of temporary works, see:

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

4.3.4 Confirmation of Founding Level

168. The objective of the construction process is to create a foundation of a quality that fulfils the designer’s requirements, using safe construction techniques. This requires careful planning by the contractor, taking into account quality, health and safety and setting out requirements. For setting out, the Inspector should be aware of whether the ordnance datum has been used on the drawings or a local datum and any conversion factor has been applied. It is a key consideration for the Inspector to seek assurance in the methods the dutyholder and contractors are using to measure and check the formation levels and the level of the upper surface of the foundation.

169. The Inspector is reminded that the founding (or formation) level site design depends on a foundation that is in the correct founding medium and at the appropriate founding level. The designer selects the founding stratum on the basis of its strength and deformation characteristics and the Inspector may seek assurance that these design parameters have been verified on site. The Inspector should note that confirming the founding strata is also a key consideration to validate the ground model used in design. The Inspector may wish to seek assurance of the process(es) in place to manage significant anomalies; namely the design change process and processes to justify and accept changes to original design intent.

170. The Inspector may wish to consider the dutyholder arrangements in place to ascertain that a particular foundation is (to be) constructed in accordance with the drawings and specification. For such an assessment, the Inspector may consider checking aspects of the dutyholders arrangements that control the works associated with the:

- founding strata,
- founding level,
- foundation dimensions,
- construction materials,
- connections to the super structure,
- ground water levels.

4.3.5 Weathering of exposed ground

171. The Inspector may consider the acceptance criteria for the condition of the founding medium (often referred to as the formation level) prior to the contractor progressing on to the next phase of construction, which is most likely to be placing the protection blinding concrete. This process of excavation, exposure, acceptance and protection can involve a time restriction, as the strata previously at depth may become weathered once it has been exposed. The Inspector is reminded of the SAP ECE.16 relating to the suitability of materials used on site. The allowed timeframes are often demonstrated by site trials. The Inspector may wish to seek assurance that these timings are agreed by the designer and that there are proven processes in place that can meet the requirements, which are then subsequently adhered to by the contractor:

- Coarse grained soils (sands and gravels) are easily disturbed by excavation. Excavation of at least the last 150mm of soil above founding level is often made by hand and protected (usually with blinding concrete).
- Fine grained soils (e.g. silts and clays) can be softened by water and can be disturbed very easily so the surface protection (usually blinding concrete) follows after the founding elevation is exposed. The Inspector should note the local drain down points to keep ground water below excavated levels can be significant in these circumstances.

- Rock can break up under weathering and therefore a time restriction is often applied to prevent degradation of the rock after exposure. Often the last 0.5m of material is left prior to the final exposure of the formation level. The Inspector should note the surface of any rock excavation is ‘cleaned’ to dislodge loose material and highlight joint distribution, prior to inspection acceptance, and then covered up with a suitable material to protect from weathering (usually blinding concrete). The Inspector may wish to seek assurance as to how an acceptable level of ‘cleanliness’ of formation levels is demonstrated e.g. with photograph examples to promote consistency across the site.

172. The Inspector may wish to seek assurance that the arrangements in place for ground recording / testing record making, keeping and storage are adequate. This is a key aspect of the earthworks, as the evidence of quality is not available for a long period, and once the formation level is covered, it may not be possible to go back to collect the information retrospectively.

173. Once the founding strata has been exposed and the formation level reached, the information from surveys and acceptance of the formation level can feed into the site ground model. These records form part of the site as-built or as-constructed records, which become part of the safety case as they prove the quality required has been achieved. This is evidence provided to justify the design criteria has been met and the safety functional requirements of the items constructed have been and will continue to be met.

174. The Inspector should be aware of the processes in place to permit Intelligent Customer function to accept the works as complete to conclude the earthworks contract, per area.

175. For more information on IC acceptance and records, see:

- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’,
- ONR-NS-TAST-GD-049 ‘Licensee Core Safety and Intelligent Customer Capabilities’.

4.3.6 Handover between contractors

176. Once the earthworks contractors have completed their scope of works, there is a handover between contractors, for the earthworks contractor to prove their works are completed as required and for the structural/permanent works contractor to accept the area in order to begin their foundation or sub-surface structure construction. The Inspector should be aware that the handover requires dutyholder oversight and acceptance through the Intelligent Customer function to confirm the adequate quality has been achieved.

177. At the early stage in construction where different contractors are handing over areas, e.g. earthworks contractors handing over to permanent works contractors, the Inspector should be aware that the process for handover may be immature and may wish to seek assurance that learning is encouraged and adequately put into operation. The Inspector may wish to seek assurance that arrangements are kept updated to ensure developments are captured without delay, in order to prevent errors and to ensure the written arrangements adequately reflect the changing activities on the site at the early/ earthwork stages.

178. For more detail of the key civil engineering principles, see:

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

4.4 Concrete and reinforcement for sub-surface structures

179. As foundations and sub-surface structures are often the first to be constructed on a site, the Inspector should be aware of the 'first of a kind' nature of the works may validate the processes, procedures and methodology on first use. The Inspector may sample mock-ups and trials where these are used to verify the methodology and demonstrate achievable quality before the permanent construction. The Inspector may wish to seek assurance regarding the processes and arrangements used to make construction materials e.g. concrete and reinforcement steel. This may include seeking assurance of the adequacy of the receipt of the original raw materials or manufactured products e.g. aggregates, cement and steel, and whether the overarching management arrangements in place ensure quality is adequate prior to their use in nuclear safety construction.

180. For sub-surface construction, the Inspector should be aware of the potential impact of 'aggressive ground conditions' and other potential ground conditions that may require specific consideration in the design and execution of construction activities. Additional Protective Measures can be specified to protect the concrete from degradation due to chemicals present in the environment. The Inspector may wish to consider how such a requirement has been adequately captured in the safety case. The Inspector may wish to seek assurance that such protective measures are implemented on site adequately, if the design relies on these measures functioning adequately throughout the life of the site.

181. For more guidance on concrete and reinforcement, as well as general construction and site readiness reviews, see:

- TAG 17 Annex 4 'Civil Engineering – Construction Assurance',
- L153 'Managing health and safety in construction [18].

4.5 Earthworks, Foundations and Sub-surface Structure Construction Site Hazards

182. The Inspector should be aware that foundation or sub-surface structure construction is one of the most hazardous phases during the construction process on site. Typical hazards encountered in foundation construction may include:

- congested working areas in which different types of plant are manoeuvring,
- equipment / plant, that are difficult to guard at all times, especially when rotating at high speed,
- activities being carried out in poor light or limited visibility, often in muddy conditions on uneven ground,
- open excavations which often contain projecting reinforcement immediately adjacent to the working area,
- open trenches, some of which may be full of bentonite,
- partly constructed open basement or sump areas which could fill with water or harmful gases without sufficient pumping or ventilation,
- contaminated land and biological hazards such as leptospirosis,
- working with and handling chemicals and cement grouts,
- working at depth, including falling object risks,
- working near open water or partly flooded excavations,
- lifting and handling plant and materials,
- confined spaces,
- noise,
- dust.

183. The Inspector may wish to consider relevant work Risk Assessments and Method Statements (RAMS) for the works being undertaken.

184. When considering the works for construction activities, the Inspector is reminded of the interface with conventional health and safety inspectors, with whom it may be

appropriate to undertake a joint inspection. Further information is available on the ONR N19 training course 'ONR Personal Safety in Inspection'.

185. For more guidance on conventional health and safety, see:

- ONR-NS-INSP-GD-051 'The Regulation of Conventional Health and Safety on GB Nuclear Sites',

186. The Inspector should be aware of potential problems that may be encountered due to the nature of the ground, and may wish to seek assurance that trials, mock-ups or tests to be undertaken to demonstrate that methodologies in place are adequate to manage these potential health and safety considerations, including but not limited to:

Made ground:
- obstructions,
- sudden collapse of fills,
- chemical and organic contamination,
- variability in composition,
- site material re-use and on-site storage, spoil heap protection,
- restrictions on off-site disposal,
- on site processing sequencing,
- storage issues and weathering post processing,
- compaction difficulties and trials to demonstrate adequacy,

Soft clays, silts and loose sands:
- unstable cut slopes,
- plant and equipment not compatible with muddy conditions,
- lateral squeezing into unlined pile shafts,
- soft spots,
- 'boiling' in open excavations and shafts,
- liquefaction.

Stiff Clays, Silts and Weak Rock:
- boulders,
- indurated zones (hard layers),
- base heave,
- unstable joints and fissures,
- hard spots,
- swelling soils.

Rock Excavation:
- ability to excavate very hard rock,
- unstable joint orientation, faulting,
- vibration and noise,
- potential fly-rock from blasting or trimming activities.

4.5.1 Piled Foundations Design

187. SAP ECS.3 requires that SSCs important to safety are designed and constructed, tested and maintained etc. to appropriate standards.

188. Piles are normally used in poor soil conditions or for dock quays but can be used in many other ground construction solutions, such as for basement construction. For static loading, the interaction of the pile with the soil is reasonably well understood and it is relatively easy to test piles in-situ. However, in the case of dynamic loading, primarily seismic, it is not possible to conduct tests, so reliance is on analysis. Noting that piles are generally used in poor soil conditions, the dynamic response of the soil and the pile soil interaction is significant. This not only covers loading and stressing of the piles but also the potential for the reduced soil support leading to buckling of the pile.

189. The following is intended to be guidance on the regulatory expectations for the design and construction of piles. There may be special cases, not covered here, which require further consideration. The guidance is related to the classification of the structure being considered.

190. ECE.2 requires consideration of several related but independent arguments which applies to justify the use of piling. Of note is SAP paragraph 282 which gives a basis for the consideration and paragraph 284 which indicates that this is the basis of judgement for all levels of classification and that it is the stringency of application which will change according to the classification. Mechanical structures principles apply to the civil engineering design cases.

191. In addition, the Inspector should be aware that the margins to failure under progressive failure of the system should be determined in line with the expectations of SC.5, ERL.4 and EAD.2, where the design should take account of:

- individual unit loading,
- system loadings,
- margin determination should include structural limits for failure of several adjacent individual units,
- the level of redundancy in each situation should be appropriate to the Safety Classification of the system.

192. As inspection and testing in operation is not generally practicable, inspection and validation of the works during construction is significant as it is this aspect which will give confidence in the ageing and durability qualities of the system. The expectations for inspection and validation are addressed by SAP's ECE.8, ECE.18, ECE.20, EQU.1. The Inspector may wish to seek assurance that the design is based where practicable on relevant tests. For example, piles subject to Tension 'uplift tests', pile compression tests, laterally loaded piles tested to failure to determine lateral, rotational and ultimate performance of the design. The Inspector may wish to seek assurance that a conservative analysis and design is carried out with enhanced load factors where high safety significance, and / or low confidence in material properties exist. The Inspector may wish to seek assurance that the design is clear and explicit in terms of the margins available in the design under all loading conditions considered, in line with the expectations of ECS.5.

193. The Inspector should expect the quality arrangements applied to the design process to be carried forward to the construction phase where the standards of workmanship and degree of inspection, testing and validation during the construction phase should be proportionate to the classification, to meet the expectations of the ECS.5 and EQU.1.

4.5.2 Pile Construction and Testing

194. The Inspector should be aware of how significant the setting out, plan position and alignment of piles is to the efficacy of the constructed piles. The Inspector should be aware that the dutyholder should not accept the founding level of a driven pile solely on the basis of 'set'. The Inspector may wish to seek assurance that the dutyholder and contractor takes construction assurance steps to ensure piles are in the correct stratum.

195. Specific guidance is available for the design and lifting of slicing bands and the splicing of reinforcement cages for the use in piling [19].

196. The Inspector should be aware that testing rates for conventional structures (class 3) may be considered in terms of industry relevant good practice. For higher classifications it is expected that these rates are increased, see the expectations of ECS.4 and ECS.5. The rates may be significant where the safety requirements are onerous.

197. The Inspector may wish to use Table 1 as guidance when assessing dutyholders arrangements intended to demonstrate assurance of system attributes for each class of SSC:

Attribute	**Class 1 and Class 2**	**Class 3**
Load Factors	Nuclear Standard ACI 349 or equivalent	BS6399 / BSEN1991
Analysis	Nuclear Standard ASCE 4-16	Static Analysis
Margins	Normal and hazard loads. Progressive failure margin	Relevant good practice
Pile inspection in construction	Full inspection of ground at toe prior to placement. Inspection of reinforcement including cover Full monitoring of concrete quality.	Relevant Good Practice
Tests Inspection and checking	100% Independent testing and inspection during design and construction.	In house inspection and testing by SQEPs

Table 1: Basis of expectations of piling validation based on classification.

198. There are a great variety of proprietary piling systems with a choice of piling methods which all have advantages and disadvantages given the variety of factors to be considered. The dutyholder is likely to use a specialist piling contractor for the works, so the Inspector should be aware that the dutyholders choice of piling system may be influenced on factors other than quality of outcome. The Inspector should be aware that the decision for piling system may be related to ground conditions, ground water and other site specific and site-location specific factors.

4.5.3 Tension systems

199. Tension systems are not specifically covered within the civil engineering SAPs. During assessment of tension systems, the Inspector should be aware of the brittle failure modes and particular measures are required to ensure that this type of failure is precluded.

200. Where systems rely on anchorage in the ground (including rock), for example, ground or rock anchors, the Inspector may wish to focus assessment on the analysis and design and seek assurance that failure will not occur under seismic excitation or upwards forces due to overturning or floatation.

201. The Inspector should be aware that any loosening of the material around the anchorage area may lead to premature failure of the system at a load below the design load. The Inspector should also consider under-reaming or similar processes that could undermine the anchors.

202. For more detail on structural tension systems, see:

- ONR-NS-TAST-GD-020 ‘Civil Engineering Containments for Reactor Plants’.

4.5.4 Rock anchors

203. Because of the need to interpret ground conditions the preferable solution is to provide concrete foundations directly onto competent rock. The Inspector should acknowledge that this can be impractical, leading to large-scale excavation, large and uneconomic volumes of concrete and associated temporary works. Where there needs to be restraint

against uplift or sliding forces, rock anchors can be a suitable option where the use of alternatives are not appropriate.

204. Soil nailing and rock bolting are very similar to rock anchoring in terms of their construction and the same assessment principles apply, although their use is more likely to be related to stabilisation of ground in excavations rather than restraining structures.

205. SAP ECS.3 requires that SSCs important to safety are designed, constructed, tested and maintained to appropriate standards.

206. The following guidance applies to the design and construction of soil and rock anchors:

- BS 8081:2015+ A1:2017 +A2:2018 Code of Practice for Ground Anchorages [20],
- BS EN ISO 22477-5 Geotechnical Investigation and Testing – Testing of geotechnical structures – Part 5 Testing of Anchorages [21],
- BS EN 1537: 2000 Execution of special geotechnical work [22],
- EC7 EN 1997-1:2004+A1:2013 Section 8 Ground anchors (and UK national annex) – EC 7 verification of design is based on testing [4].

207. Generally these standards are not specific to the nuclear industry and should form the minimum applied standard suitable for construction forming Class 3 SSCs. For higher classifications, enhancements to these standards would be expected, see the expectations of ECS.4 and ECS.5.

208. The Safety Assessment Principles give broad expectations for the acceptability of civil engineering structures. The general principles of designing rock anchors for reliability apply, as with foundations and sub-surface structures. SAPs ECE.1 and ECE.19 apply to the design and construction of anchored foundations, with SAPs ECE.2, ECE.8, ECE.18 and ECE.20 highlighting aspects for further consideration.

209. When assessing existing nuclear facilities, the Inspector may find that the system will not meet current expectations. In this case, the system needs to be considered on its own merits, and consideration should be given to provision of reasonably practicable improvements.

210. The Inspector may wish to seek assurance of the adequacy of full-scale tests and mock-ups or trials. As part of the design validation, the Inspector should expect several test anchors to be pulled to failure as a conservative analysis of the design carried out with enhanced load factors where high safety significance, and / or low confidence in material properties exist. The Inspector may wish to seek assurance that the design is clear and explicit in terms of the margins available in the design under all loading conditions. In addition, the Inspector may wish to seek assurance that the margins to failure under progressive failure of the system are determined and that the test procedures are adequate (EQU.1).

211. The Inspector may wish to consider the design taking account of individual unit loading and system loadings and margins determination should include structural limits for failure of several adjacent individual units. The level of redundancy in each situation should be appropriate to the safety classification of the system in accordance with the expectations of ECS.2 and ERL.1.

212. Inspection and validation of the works during construction is of utmost importance and it is this aspect which will give confidence in the ageing and durability qualities of the system. Expected testing rates for conventional structures (class 3) may be set out in various standards. However, for higher classifications it is expected that these rates are increased. (SAPs paragraph 361) The rates may be significant where the safety requirements are onerous.

213. The guidance below in table 2 demonstrates the expectations for system attributes for each class of SSC.

Attribute	Class 1 and Class 2	Class 3
Load Factors	Nuclear Standards e.g. AC1 349	BSEN1991
Analysis	ASCE 4-16	BSEN1991
Margins	Normal and hazard loads. Progressive failure margin	BS Relevant good practice
Ground /rock anchor test at installation	In line with BS8081	In line with BS8081
Validation of Tests Inspection and checking	Proportionate independent testing and inspection during design and construction.	In house inspection and testing by SQEPs

Table 2: Rock anchor system expectations for systems of different classification

214. Often, anchor locations within existing facilities prohibit further access for EIMT during the working life. The Inspector may wish to seek assurance that the design has assessed risk and reduced the risk as part of the design, where stress losses due to creep and relaxation during operation would not be measurable. The Inspector should consider the reduction of risk in design and seek assurance that risks are reduced where possible e.g. new build construction, with alternative solutions to be adopted as appropriate.

4.6 Sub-surface (underground) Structures

215. The majority of the considerations for foundations apply also to structures that are constructed underground. The content herein applies specifically to structures that are buried. The scope of below ground structures in this context includes tunnels (bored and cut-and-cover), underground service galleries, shafts and significant underground basements. Buried structures also include waste vaults, and in some special containment cases such as the 'Gravel Gerties', surface founded concrete structures which are subsequently "buried" by mounding material around and on top of them (sometimes referred to as bunded structures).

216. Below ground structures on nuclear sites are those that are either fully buried or which have significant embedment into the ground, such as deep basements. They are likely to include structures connected with cooling water intakes and outfalls, debris vaults, deep basements to buildings and buried service galleries. In all cases, the degree of interaction with the surrounding ground will have a significant effect on the design of the structures.

217. There are well established methods for designing buried structures against static loading: however dynamic loading (primarily seismic, but occasionally blast) is a more complex area. The Inspector should be aware that one of the primary guidance documents for the design and assessment of nuclear safety significant buried structures is ASCE 4 [8] and [23]. This allows the use of simplified methods for nuclear safety significant buried structures provided the aspect ratio between the depth and width are limited to prescribed values. These criteria are readily applied to most nuclear island type structures. However, for completely enveloped structures such as service tunnels, this approach may not be applicable.

218. For the design of new structures, the Inspector should be aware it is considered relevant good practice to explicitly model not only the structure but also the adjacent soil. Analyses may use a decoupled approach such as that developed by Wong and Luco [24]. Alternatively, commercially available software can be used with the soil represented using springs or solid elements. In some instances (typically for wholly buried structures) kinematic approaches can be used where an applied displacement profile is applied to

the structure. The Inspector may wish to consider the validation and verification undertaken on such analyses by dutyholders. For more information, see:

- TAG 17 Annex 1 ‘Civil Engineering – Design’,
- ONR-NS-TAST-GD-013 ‘External Hazards’ Annex 1 ‘Seismic Hazards’.

219. When assessing sub-surface structures, the Inspector may wish to consider the following:

- the various tunnelling techniques (e.g. bored or cut-and-cover) and lining designs, including their appropriateness for different ground conditions and design requirements,
- the effects that groundwater has on buried structures, in particular its effect on construction, loading on the finished structure, degradation due to chemical attack or aggressive ground conditions, and design methods to prevent water seepage,
- the soil properties required for analysis and the sensitivity of the design to the properties assumed,
- relevant guidance with respect to the determination of seismic loading on buried structures,
- monitoring techniques for buried structures, both during and after construction,
- EIMT and potential repair of structures (to be included in design if new build),
- design life and claims placed on items that cannot be replaced or inspected e.g. membranes or waterstops.

220. It should be noted that, for underground construction, loads from groundwater often exceed those from soil. It is therefore a key consideration that the dutyholder demonstrates an adequate understanding of the groundwater regime and control of this risk in both the construction planning and design.

221. Historically, design issues with buried structures have not all been as a result of deficiencies in structural capacity, but rather in terms of their serviceability states. The Inspector should be aware that inspection of legacy defects in buried structures may not be practicable, and defects may manifest themselves once damage has already been incurred. The Inspector may wish to seek assurance that there is a clear line of sight from claims on the serviceability state to the construction methodology. The Inspector may wish to consider claims related to the long-term efficacy of waterproofing and / or sacrificial concrete, construction joints and movement joints, and the acceptability criteria associated with construction assurance activities.

222. For existing sub-surface structures on operational or post-operational sites, including vaults or near surface waste stores, these are designed to store waste for short periods of time. There are times where these existing facilities require repair or modification. For more information see:

- For existing structures, TAG 17 Annex 5: ‘Civil Engineering – Ageing Management and Damaged Structures’,
- For decommissioning such facilities, TAG 17 Annex 6: ‘Civil Engineering – Post Operations’.
- For ‘Upgrading of Near Surface Repositories for Radioactive Waste’ IAEA Technical report No. 433 [25]

4.7 Below ground drainage, tanks and ducts

223. The scope for this guidance is for the assessment of below ground drainage, tanks and ducts on nuclear sites (i.e. sewerage, surface water and active drainage systems). These systems should not to be confused with pipework used in pressurised systems, which are generally assessed by either Structural Integrity or Mechanical Engineering specialists. The Inspector is reminded of the interfaces between civil engineering

assessment and other disciplines. With pipework, this can be at the support provided by civil engineering SSCs, or where there are penetrations through structures to accommodate such services.

224. The Inspector should be aware that non-active drainage systems are not typically safety classified systems; principally due to difficulties in justifying their reliability. In the majority of cases they are non-classified systems and provide defence in depth to safety functions. The Inspector should appreciate whether the system is providing a nuclear containment safety function as this will dictate the level of assessment scrutiny.

225. The Inspector should appreciate how the design basis for the system is derived. Flow rates may be dictated by other areas of engineering outside the civil engineering scope, for example active and trade wastes, or external hazards deriving the precipitation hazard for storm drains. The Inspector should be able to determine realistic from unrealistic values derived from the volume and hazards or fault scenarios.

226. From a civil and structural engineering perspective, consideration should be given to the following items during assessment:

- hydraulic analysis for pipework sizing,
- materials used for existing pipework e.g. cast iron or plastic and associated expected design life and repair methods,
- backfilled materials around the pipework (potential for damage),
- geotechnical considerations, including excavation, backfilling, restoration and settlement,
- design and construction of pipelines, tunnels and ancillary works, including temporary works and formwork,
- operation, maintenance and testing of drainage systems,
- loading limits and exceptional loadings on the roads above pipework sections
- pipework renovation,
- tunnelling and shaft sinking construction and connections.

227. Outside the standard identified ONR Safety Assessment Principals in the Design Annex to TAG 17, the SAPs that are specifically relevant to drainage are:

- ELO.4, support services include water supplies, flood defence and drainage and essential services,
- ECV.1, ECV.2, ECV.3, ECV.4, ECV.7, related to active drains and transportation of nuclear waste,
- ECE.5, the results of the geotechnical investigation will inform design,
- ECE.22, structures should be tested for leak tightness prior to operation, and drainage systems should be used to confirm containment integrity, or to detect, locate, collect, quantify and where possible allow repair to leakages,
- ECE. 24, the arrangements to monitor civil structures to determine settlement and deformations of the ground due to the structure.

228. Drainage with a nuclear safety function is typically intended to route rainwater / floodwater away from SSCs claimed in a safety case or intended to contain contaminated (active) fluid and transport it from one location to another. These two different functions are considered below.

4.7.1 Rainwater / Stormwater Drains

229. The Inspector should be aware that rainwater drains on nuclear licensed sites are typically designed using normal civil engineering industrial standards [26]. The Inspector should also be aware that for nuclear sites, the derived hazards associated with intensity of rainfall may be much greater than that required for normal industrial facilities. The Inspector may wish to seek assurance that the design does not result in ponding of water which could enter the threshold of buildings with a nuclear safety role or is

sufficient to restrict movement around the site. Some allowance should be made for a reduction in the effectiveness of drains from partial blockages. The Inspector may wish to seek assurance that arrangements for LC28 inspections of drainage are aligned with the associated safety claims.

230. Where possible for new build designs, the Inspector should be aware that the roof drains should be external to the building envelope to reduce the possibility of internal flooding from rainfall. Where possible, the Inspector may seek assurance that overflow arrangements should be engineered rather than accidental; in other words, should a roof drain blockage occur, the route for water should be via known and engineered means.

231. The Inspector should be aware that recent developments in the control of groundwater runoff have led to legislative requirements and expectations around the use of sustainable drainage systems (SuDS). The Inspector should be aware the SuDS requirements are different in England, Scotland and Wales. The relevant environment agencies and the local planning authority are the enforcing authority for such matters. It is possible that there may be a conflict between such requirements and safety case requirements unless suitable planning is undertaken. For further information, see:

- CIRIA guide C753 ‘The Sustainable Drainage Systems Manual’ [27]. **Note:** many utility companies have their own standard technical specifications and designs which vary depending on region.

4.7.2 Active Drains

232. The Inspector should apply the ECV series of safety assessment principles to the assessment of active drains as these relate to confinement of any radioactive material. When assessing the designs, the Inspector may wish to seek assurance that these are designed to withstand design basis faults in accordance with ECV.4.

233. The Inspector may wish to apply particular focus to drains which are cast into the floor slab of buildings where future visual inspection is not practicable. For new designs, this approach should be avoided in accordance with the expectations of ECV.3. In these situations, the use of a double containment system is seen as relevant good practice, with appropriate monitoring arrangements for the interspace for leak detection, in accordance with the expectations of ECV.7.

234. Active sumps in floors are used in some plant designs to collect wastewater / spillages. These are typically lined with steel to provide a leak tight barrier. Particular attention should be paid to these, as there have been a number of examples where corrosion has damaged the liner (typically from Boric acid) in the wetting / drying zone.

235. The ONR Licence Condition 28: Examination, inspection, maintenance and testing, ONR Licence Condition 32 and ONR Licence Condition 34 specifically apply to active drainage pipework, tanks and leakage detection systems.

236. There may be overlapping vires with the environment agencies with regard to active drains, and clarity of regulatory scope should be sought at an early stage in the project.

4.7.3 Drains for Sea Defence Overtopping

237. Drains are used on some sites to control overtopping volumes around sea walls or other natural structures where the safety case requires the avoidance of the build-up of standing water. These are simple in nature and can be sized using volumes derived from RGP such as the overtopping manual [28].

238. The Inspector may wish to seek assurance that the design for sea defence overtopping drainage and associated storage or attenuation tanks includes for appropriate volumes

for the design life of the site in accordance with the guidance in ONR-NS-TAST-GD-013 'External Hazards', and in line with EHA.12, EKP.3 and paras 259 and 265 of the SAPs.

4.7.4 Conduits

239. Buried conduits are often used to house electrical cables and occasionally gas/ fuel line with the design usually based on manufacturers data. The Inspector may wish to examine in more detail the sealing arrangement, including where such services enter buildings, as these can act as inadvertent routes for groundwater ingress into a structure.

4.8 Ground water effects

240. Buoyancy due to the presence of ground water can have important effects in both static and dynamic case. In the former, it can affect the stability of foundations by producing uplift. In the latter, it can exacerbate the static effects by causing an increase in soil pressure and at the same time reducing the bearing capacity, in some situations leading to liquefaction.

241. The presence of water can affect the measurement of soil properties both statically and dynamically. A point often overlooked in design is that using compression waves in situ measures a soil water combination, which in soft soils is vastly different from drain properties, in such case shear waves should be used as water cannot transmit shear waves. The Inspector should be aware of limitations that may impact how the dutyholder might determine Poisson's ratio in such conditions.

242. The Inspector should particularly consider the partially constructed design case, where the Inspector may seek assurance that the design analysis includes for vulnerable temporary construction states and time periods. Where a potential for buoyancy is identified in this partially constructed state, the Inspector may seek assurance that the design includes a methodology providing means to prevent the buoyancy effects, in line with the expectations of ECE.25 and ECE.4 and ECE.5.

4.9 Tunnels

243. Tunnels on UK licenced sites are used for the collection, distribution and discharge of seawater used for cooling turbine condensers. They are typically in the region of 3-5m in diameter and range in length (up to several kilometres). They typically have reinforced concrete segmental liners which mate onto bespoke collection chambers (often called forebays), where the intake water is screened to remove debris prior to its use on site. The Inspector should be aware that the nuclear safety function of such tunnels does not typically require their full cross section to be available for flow of water.

244. There are established methods for the static design of tunnel linings (see British Tunnelling Society (BTS) guidance references in Section 5). The assessment of design of tunnels against seismic loading is a more complex consideration. The Inspector should be aware that the seismic design approaches adopted are most commonly kinematic where, the tunnel is assumed to deform with the ground as the result of passing seismic waves, and an estimation of the strain is made and the structure is designed to accommodate.

245. A key consideration for the Inspector is regarding the arrangements at the termination points of tunnels, as there is a sudden change in stiffness. The Inspector may seek assurance that the structural design engineered connections has sufficient rotational ductility to accommodate the imposed displacements.

246. When assessing intake and discharge/outfall tunnels, the Inspector may wish to seek assurance that the tunnel(s) are designed to withstand the effects of external hazards (e.g. seismic excitation). The Inspector may wish to consider the adequacy of any

assessment of the required cooling flows, with consideration of how the tunnels can become blocked or cleared, e.g. whether the tunnels are at risk of collapse or blockage due to other local failures near the mouth or near joints with other structures.

247. The Inspector is reminded of the interface with ONR conventional health and safety inspectors regarding the applicability of Construction (Design and Management) Regulations 2015 (CDM2015) when assessing the design of tunnels e.g. potential failure modes and EIMT considerations, see SAP ECE.25, where construction includes EIMT activities.

248. For more on CDM considerations, roles and duties, see:

- L153 'Managing health and safety in construction [18].

5 RELEVANT STANDARDS AND GOOD PRACTICE

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

250. 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.

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

- Civil Engineering TAG 17 other Annexes,
- ONR 'Licensing Nuclear Installations' [29],
- ONR-NS-TAST-GD-079 'Licensee Design Authority Capability',
- ONR-NS-TAST-GD-049 'Licensee Core Safety and Intelligent Customer Capabilities',
- ONR-NS-INSP-GD-035 'LC35 – Decommissioning',
- ONR-NS-INSP-GD-010 'LC10 – Training.

5.2 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).

5.3 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) [30].

5.4 Associated UK HSE Guidance (L Series and HSG Series)

Legal (L) Series

- L153 Managing Health and Safety in Construction Approved Code of practice for CDM 2015 [18],
- L101 Safe work in confined spaces. Confined Spaces Regulations 1997 Approved Code of Practice, Regulations and guidance,
- L140 Hand-arm vibration 2005, HSG170 Vibration solutions 1997 Practical ways to reduce hand-arm vibration.

Health and Safety Guide (HSG) Series

- HSG47 Avoiding danger from underground services [3],
- HSG85 Electricity at Work Safe Working Practices 2013,
- HSR25 the Electricity at Work Regulations 1989,
- HSG65 Managing for Health and Safety 2013,
- HSG 159 Managing Contractors,
- HSG268 The health and safety toolbox: how to control risks at work 2014.

Industry Guidance (INDG) Series

- INDG411 A quick guide for clients on CDM 2015.

Research Report (RR) Series

- HSE RR319 - Safer foundations by design (buildability) [13].

5.5 International Guidance (IAEA, WENRA and NUREG)

251. IAEA Safety Standards and Technical Documents including, but not limited to:

- Safety Requirements No. NS-R-3 (Rev. 1), Site Evaluations for Nuclear Installations [7],
- IAEA Safety Standards, Safety Guide No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants [6],
- IAEA Safety Standards, Specific Safety Guide No. SSG-35, Site Survey and Site Selection for Nuclear Installations [31].

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

- Regulatory Guide 4.7, General Site Suitability Criteria for Nuclear Power Plants,
- Regulatory Guide 1.132, Site Investigations for Foundations of Nuclear Power Plants,
- Regulatory Guide 1.138, Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants,
- NUREG-0800 [32].

5.6 Design Standards and industrial guidance

5.6.1 Ground Engineering

- ASCE 4-16 [9],
- ETC-C code [10],
- Eurocode 7 (BS EN 1997-1 and 1997-2 plus National Annexes) [4], [5],
- BS 5930:2015+A1:2020, Code of Practice for Ground Investigations [2],
- Highways England DMRB CD 622 Managing geotechnical risk [8],
- BS 1377:1990 Methods of test for soils for engineering purposes, parts 1 to 9,
- BS 8004:2015+A1:2020: Code of practice for foundations,
- BS 8002:2015: Code of practice for earth retaining structures.

253. Additional normative references to the above, including but not limited to:

- ICE manual of geotechnical engineering 2012: Volume I ISBN: 9780727757081 ICE manual of geotechnical engineering 2012: Volume II SBN: 9780727757104,
- BS EN ISO 14688-1:2018 Geotechnical investigation and testing - identification and classification of soil. Identification and description,
- BS EN ISO 14688-2:2018 Geotechnical investigation and testing - identification and classification of soil. Principles for a classification.

254. Technical guidance for specific site and ground investigation needs including, but not limited to:

- hydrology and hydrogeology (e.g. BS EN ISO 5667, 22282 and 22475 series),
- contaminated land (e.g. BS 10175:2011+A2:2017, Investigation of potentially contaminated sites – Code of practice),
- underground services (e.g. HSE HSG47 - Avoiding danger from underground services [3]),
- CIRIA Geophysics in engineering investigations (C562),
- CIRIA Eurocode 7 - implications for UK practice (C641).

255. Technical guidance for specific testing methods including, but not limited to:

- ASTM D4428/4428-M – 14 Standard Test Methods for Crosshole Seismic Testing,
- ASTM D7400 – 17 Standard Test Methods for Downhole Seismic Testing,
- BS EN ISO 22476-3 Geotechnical investigation and testing – Field testing – Part 3: Standard Penetration Test,
- CIRIA Report R 143 The standard penetration test (SPT): methods and use, 1995,
- Stroud M A. (1989) The Standard Penetration Test - Its Application and Interpretation. Penetration testing in the UK, Thomas Telford, London, pp. 29-49,
- CIRIA Cone penetration testing: methods and interpretation (B2).

256. Sources for further information including, but not limited to:

- ICE UK Specification for Ground Investigation, Second edition: 2012,
- ICE manual of geotechnical engineering: Volume I ISBN: 9780727757081,
- ICE manual of geotechnical engineering: Volume II SBN: 9780727757104,
- CIRIA Unexploded ordnance (UXO) risk management guide for land-based projects (C785),
- CIRIA Unexploded ordnance (UXO) A guide for the construction industry (C681),
- CIRIA Brownfield and contaminated land development book set,
- CIRIA Contaminated sediments: a guide for risk assessment and management (C781),
- CIRIA The Volatile Organic Compounds (VOCs) Handbook. Investigating, assessing and managing risks from inhalation of VOCs at land affected by contamination (C682),
- CIRIA Asbestos in soil and made ground: a guide to understanding and managing risks (C733),
- CIRIA Asbestos in soil and made ground good practice site guide (C765),
- CIRIA Groundwater control: design and practice (second edition) (C750),
- CIRIA Grouting for ground engineering (C514).

5.6.2 Geotechnical numerical analysis SSI

257. RGP for static SSI is not well covered by standard codes or practice (e.g. Eurocode 7). However, some guidance is provided in:

- ETC-C code,

- NUREG-0800,
- IAEA guidance NS-G-3.6,
- NAFEMS,
- Wong, H.L., Luco, J. E., “Soil-Structure Interaction: A Linear Continuum Mechanical Approach (CLASSI),” Report CE, Department of Civil Engineering, University of Southern California, Los Angeles, CA, 1980 [24].

5.6.3 Foundation and sub-surface structure design

Design and Construction of foundations

258. The following minimum standards apply to the design and construction of foundations and sub-surface structures:

- ACI349 Code Requirements for Nuclear Safety Related Concrete structures and commentary (ACI 349-13),
- EN1992-1-1 and EN1992-2, Eurocode 2: Design of concrete structures,
- EN206, Concrete. Specification, performance, production and conformity,
- BS 8500-1:2015+A2:2019 , Concrete. Method of specifying and guidance for the specifier,
- CIRIA C766, ‘Control of cracking caused by restrained deformation in concrete’
- HSE RR319 – ‘Safer foundations by design (buildability)’,
- ‘IStructE manual on detailing reinforcement’,
- The Concrete Society ‘Concrete Advice 25 – Large volume concrete pours’.

Reinforcement

- BS 4449:2005 +A3:2016 - Steel for the reinforcement of concrete - Weldable reinforcing steel - Bar, coil and decoiled product – Specification,
- BS 7973–1:2001 - Spacers and chairs for steel reinforcement and their specification. Part 1 - Product performance requirements. Part 2 - Fixing and application of spacers and chairs and tying of reinforcement,
- BS8000-2.2 - workmanship on building sites – in-situ and pre-cast concrete,
- BS8666:2005 - Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete – Specification,
- BS EN ISO 17660:2006 Welding of Reinforcing Steel : Part 1- Load-bearing welded joints; Part 2 - Non load-bearing welded joints,
- CIRIA SP118 (1995) - Steel Reinforcement – a handbook for young construction professionals ISBN 978-0-86017-418-9,
- Concrete Society - Concrete on site 2 – Reinforcement [33] ,
- IStructE - Standard method of detailing structural concrete (Third Edition) June 2006 and associated Technical Guidance Notes.

5.6.4 Piled Foundations

259. The following minimum standards apply to the design and construction of piles:

- Eurocode BSEN 1997-1 and BSEN 1992-1,
- ICE Specification for piling and retaining walls,
- Thomas Telford ISBN 9780 7277 33580.

260. Generally these standards are not specific to the nuclear industry and should form the minimum applied. In general, these are suitable for construction forming Class 3 SSCs. For higher classifications enhancements to these standards are expected.

5.6.5 Underground structures

261. International and British design standards relating to underground structures:

- Eurocodes:
  - BS EN 1991 - Actions on structures,
  - BS EN 1992 - Design of concrete structures,
  - BS EN 1997-1: 2004: Eurocode 7 – Geotechnical design. General rules.
- CIRIA C750D, Groundwater control – design and practice, 2016,
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FIGURE 1 – GENERAL FRAMEWORK FOR THE SELECTION OF DERIVED GEOTECHNICAL PROPERTIES, TAKEN FROM ONR-NS-TAST-GD-013 'EXTERNAL HAZARDS' ANNEX 1

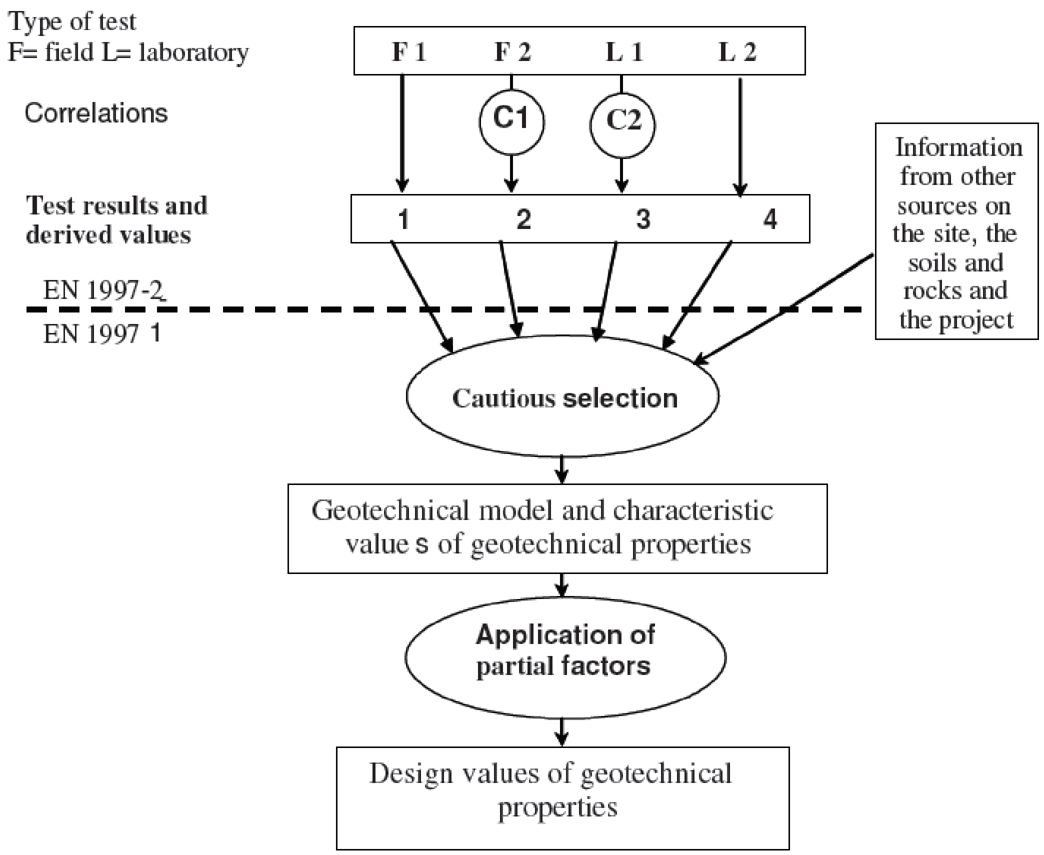

FIGURE 2 – SEISMIC HAZARD & STRUCTURAL ANALYSIS (PROCESS OVERVIEW FOR STRONG GROUND MOTION HAZARD)

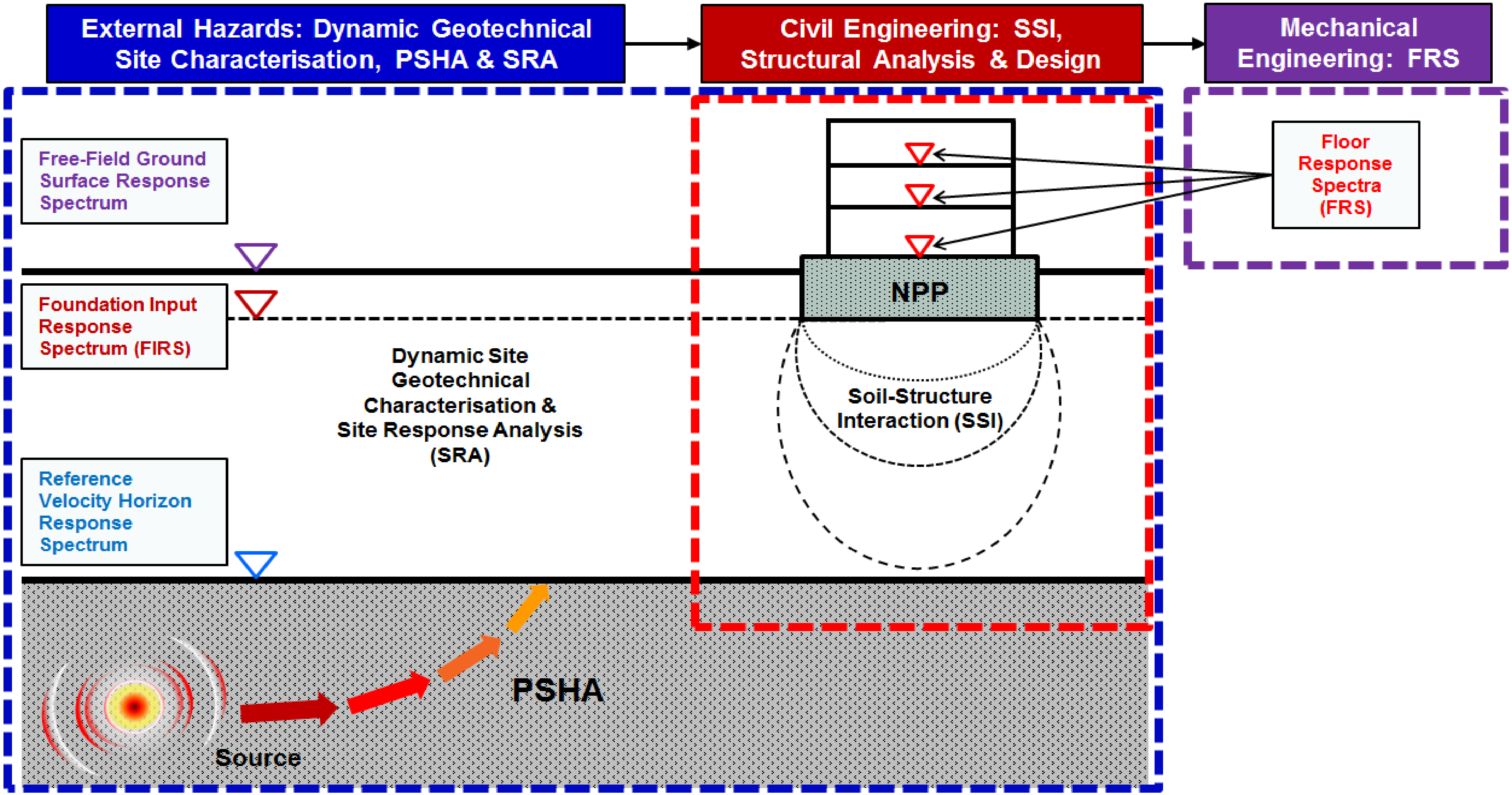

FIGURE 3 – A FLOW DIAGRAM HIGHLIGHTING THE MODELLING PROCESS AND VALIDATION.