Office for Nuclear Regulation

An agency of HSE

Generic Design Assessment – New Civil Reactor Build

GDA Close-out for the EDF and AREVA UK EPR™ Reactor

GDA Issue GI-UKEPR-CE-06 Rev 1 –

Seismic Analysis Methodology for the Design of the UK EPR™

Assessment Report: ONR-GDA-AR-12-002
Revision 0
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EXECUTIVE SUMMARY

The Office for Nuclear Regulation (ONR), an agency of the Health and Safety Executive (HSE), has carried out Generic Design Assessment (GDA) of the UK EPR^{TM} nuclear power plant. This report specifically addresses the GDA Issue **GI-UKEPR-CE-06 Rev 1** generated as a result of the GDA Step 4 Civil Engineering Assessment of the UK EPR^{TM}. The Step 4 assessment of the seismic design methodology found that there was not yet sufficient justification of the methodologies proposed for the seismic analysis of the UK EPR^{TM} and treatment of the design of the raft foundation. In response, EDF and AREVA submitted revised and additional safety case supporting documents towards the end of Step 4 of GDA. However, these were not reviewed at that time and therefore GDA Issue **GI-UKEPR-CE-06** was raised to allow a proper assessment of these documents to be carried out by the Regulator.

The objective of the GDA Issue was for EDF and AREVA to support assessment associated with the methodology for the seismic analysis of the raft foundation and nuclear island superstructures and provide adequate responses to any questions arising from the assessment by ONR of documents submitted during GDA Step 4 but not reviewed in detail at that time.

The resulting revisions of the methodology documents (ENGSGC100140 Rev C, ENGSDS100268 Rev B and ENGSDS100269 Rev B) adequately justify the seismic analysis methodology that EDF and AREVA propose to use for the UK EPR^{TM} in the context of GDA. The reference design used for GDA is for Flamanville in France and the details presented substantiate the methodology for that specific site. Sites in the UK will have different ground strata to Flamanville. However, I am satisfied that the checkpoints added to the documents, in response to comments raised by my assessment, will ensure that appropriate methods are applied in the UK site specific design.

I have therefore found EDF and AREVA's response to **GI-UKEPR-CE-06** to be satisfactory and recommend this issue is closed.

I have raised two assessment findings in order to ensure full substantiation is provided by the licensee for the seismic analysis of the site specific design during the site specific phase.

LIST OF ABBREVIATIONS

ABSC	ABS Consulting Ltd
ACI	American Concrete Institute
AF	Assessment Finding
AFCEN	Association Française pour les règles de conception et de construction des matériels des Chaudières ÉlectroNucléaires (French society for design, construction and in-service inspection rules for nuclear island components,)
ALARP	As low as is reasonably practicable
AREVA	AREVA NP SAS
ASCE	American Society of Civil Engineers
C1	Class 1 civil structures
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission)
CEEH	Civil Engineering and External Hazards
CW	Civil works
EC8	Eurocode 8 – BS EN 1998
EDF	Electricité de France SA
ETC-C	EPR Technical Code for Civil Works
EUR	European Utility Requirements
FA3	Flamanville 3 (new build nuclear power station in France)
FE	Finite element
FRS	Floor response spectra
GDA	Generic Design Assessment
HA and HF	Hard soil types
HSE	Health and Safety Executive
HOW2	ONR’s Business Management System
IC	Inner Containment
IAEA	International Atomic Energy Agency
MA, MB and MC	Medium soil types
N/A	Not applicable
NI	Nuclear island
ONR	Office for Nuclear Regulation (an agency of HSE)
PCSR	Pre-construction Safety Report
RO	Regulatory Observation
SA	Soft soil type

LIST OF ABBREVIATIONS

SAP	Safety Assessment Principle(s) (HSE)
SEI	Structural Engineering Institute, USA
SI	Site Investigation
SSI	Soil structure interaction
SSSI	Structure–soil-structure interaction
TAG	Technical Assessment Guide(s) (ONR)
TQ	Technical Query
TSC	Technical Support Contractor (for ONR)
UK CD	UK Companion Document (to the AFCEN ETC-C 2010 Edition)
UK EPR™	EDF and AREVA UK specific pressurised water reactor design
WENRA	Western European Nuclear Regulators' Association
Vs	Shear wave velocity
ZPA	Zero Period Acceleration

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1 INTRODUCTION

1.1 BACKGROUND

1 This report presents the close-out of the Office for Nuclear Regulation's (an agency of HSE) Generic Design Assessment (GDA) within the area of Civil Engineering and External Hazards. The report specifically addresses GDA Issue **GI-UKEPR-CE-06 Rev 1** (Ref. 1) and the associated GDA Issue Action generated as a result of the GDA Step 4 Civil Engineering Assessment of the UK EPR™ (Ref. 2). The assessment has focussed on the deliverables identified within the EDF and AREVA Resolution Plan (Ref. 3) published in response to the GDA Issue and on further assessment undertaken of those deliverables.

2 GDA followed a step-wise-approach in a claims-argument-evidence hierarchy. In Step 2 the claims made by the EDF and AREVA were examined and in Step 3 the arguments that underpin those claims were examined. The Step 4 assessment reviewed the safety aspects of the UK EPR™ reactor in greater detail, by examining the evidence, supporting the claims and arguments made in the safety documentation.

3 The EDF and AREVA safety case for the UK EPR™ design is contained within the Pre-construction Safety Report (PCSR) and its supporting documentation. The ONR Step 4 assessment was based on the March 2011 PCSR, known as the Step 4 Consolidated Pre-construction Safety Report (Ref. 4). Sub-chapter 3.3 which describes the design of safety classified civil structures has been updated in October 2012 (Ref. 5) to reflect the additional justification required by my assessment of the response to the civil engineering GDA issues.

4 The Step 4 Civil Engineering and External Hazards (CEEH) assessment identified six GDA Issues and 68 Assessment Findings as part of the assessment of the evidence associated with the UK EPR™ reactor design. GDA Issues are unresolved issues considered by regulators to be significant, but resolvable, and which require resolution before nuclear island safety related construction of such a reactor could be considered. Assessment findings are findings that are identified during the regulators' GDA assessment that are important to safety, but not considered critical to the decision to start nuclear island safety related construction of such a reactor.

5 The Step 4 assessment concluded that the UK EPR™ reactor was suitable for construction in the UK subject to resolution of the 31 GDA Issues resulting from all assessment technical topics. The purpose of this report is to provide the assessment which underpins the judgement made in closing GDA Issue **GI-UKEPR-CE-06** arising from the CEEH assessment.

1.2 SCOPE

6 This report presents only the assessment undertaken as part of the resolution of this GDA Issue and it is recommended that this report be read in conjunction with the Step 4 CEEH Assessment Report (Ref. 2) in order to appreciate the totality of the assessment of the evidence undertaken as part of the GDA process.

7 This assessment report is not intended to revisit aspects of assessment already undertaken and confirmed as being adequate during previous stages of the GDA. However, should evidence from the assessment of EDF and AREVA's responses to GDA Issues highlight shortfalls not previously identified during Step 4, there will be a need for these aspects of the assessment to be highlighted and addressed as part of the close-out phase or be identified as assessment findings to be taken forward to site licensing.

8 The possibility of further assessment findings being generated as a result of this assessment is not precluded given that resolution of the GDA Issues may leave aspects of the assessment requiring further detailed evidence when the information becomes available at a later stage.

1.3 METHODOLOGY

9 The methodology applied to this assessment is identical to the approach taken during Step 4 which followed the ONR business management system HOW2 document PI/FWD “Permissioning - Purpose and Scope of Permissioning”, Issue 3 (Ref. 6), in relation to mechanics of assessment within ONR.

10 This assessment has been focussed primarily on the submissions relating to resolution of the GDA Issue as well as any further requests for information or justification derived from assessment of those specific deliverables.

11 The assessment allows ONR to judge whether the submissions provided in response to the GDA Issue are sufficient to allow it be closed. Where requirements for more detailed evidence have been identified that are appropriate to be provided at the design, construction or commissioning phases of the project these can be carried forward as assessment findings.

12 The scope of this assessment is not to undertake further assessment of the PCSR nor is it intended to extend this assessment beyond the expectations stated within the GDA Issue Actions, however, should information be identified that has an affect on the claims made for other aspects of civil engineering structures such that the existing case is undermined, these have been addressed.

1.4 STRUCTURE OF THIS REPORT

13 This assessment report structure differs slightly from the structure adopted for the previous reports produced within GDA, most notably the Step 4 CEEH Assessment (Ref. 2). This report has been structured to reflect the assessment of the individual GDA Issue rather than a report detailing close-out of all GDA Issues associated with this technical area.

14 The reasoning behind adopting this report structure is to allow closure of GDA Issues as the work is completed rather than having to wait for the completion of all the GDA work in this technical area.

2 ONR'S ASSESSMENT STRATEGY FOR GDA CLOSE-OUT

2.1 CLOSE-OUT PLAN

15 The intended assessment strategy for GDA Close-out for the Civil Engineering and External Hazards topic area was set out in an assessment plan (Ref. 7) that identified the intended scope of the assessment and the standards and criteria that would be applied.

16 The assessment plan was based on:

- the EDF and AREVA resolutions plans for all six Civil Engineering GDA Issues;
- the project programmes contained in the resolution plans;
- the work scope for technical support contractors (TSC) commissioned by ONR to support the assessment; and
- internal ONR resources and interaction with other topic Inspectors.

17 The scope of work contained within the assessment plan comprised assessment of the following:

- technical submissions made to ONR in accordance with the resolution plans;
- whether an update was required to the March 2011 Pre-construction Safety Report (PCSR) which had been reviewed during the GDA (Ref. 4); and
- updates to the various documents supporting the PCSR.

2.2 THE APPROACH TO ASSESSMENT FOR GDA ISSUE CLOSE-OUT

18 The approach to the closure of GDA Issues for the UK EPR™ Project has involved the assessment of the submissions made by EDF and AREVA in response to the GDA Issues identified through the GDA process. These submissions are detailed within the EDF and AREVA Resolution Plan for the GDA Issue (refer to Section 3.2).

19 The deliverables listed in the Resolution Plan had been submitted towards the end of Step 4 and so had not been assessed at that time. During the GDA close-out phase, regular Level 4 technical meetings and workshops have been held to allow discussion and clarification with EDF and AREVA on its submission documents. EDF and AREVA supported ONR's assessment of these deliverables by continued dialogue of meetings and providing responses to questions arising.

20 New or updated documents were submitted in order to justify the seismic analysis methodology in response to ONR questions. Documents submitted therefore may have been revised two or three times until they met regulatory expectations. This process was iterated until convergence was reached on the relevant technical point.

2.3 STANDARDS AND CRITERIA

21 The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAP), internal ONR Technical Assessment Guides (TAG), relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites. The key SAPs and relevant TAGs have been detailed within this section. National and international standards and guidance have been referenced where appropriate within the assessment report. Relevant good practice, where applicable, has also been cited within the body of the assessment.

2.3.1 Safety Assessment Principles

22 The key SAPs applied within the assessment of GDA Issue **GI-UKEPR-CE-06** are included within Table 1 of this report. These are taken from Safety Assessment Principles for Nuclear Facilities.2006 Edition Rev 1 (Ref. 11).

2.3.2 Technical Assessment Guides

23 The following Technical Assessment Guides have been used as the major underpinning guides for this assessment (Ref. 12):

- T/AST/013 External Hazards
- T/AST/017 Structural Integrity: civil engineering aspects

24 Other TAGs have been consulted as appropriate. These include:

- T/AST/005 ONR guidance on the demonstration of ALARP (as low as reasonably practicable)
- T/AST/004 Fundamental Principles

2.3.3 National and International Standards and Guidance

25 The following international standards and guidance have been used as part of this assessment:

- International Atomic Energy Agency (IAEA) Safety Standard Series No.NS-R-1 (Ref. 13)
- Western European Nuclear Regulators' Association (WENRA) Reactor Reference Safety Levels (Ref. 14)
- American Society of Civil Engineers standard ASCE 4-98 "Seismic Analysis of Safety Related Nuclear Structures", Jan 2000 (Ref. 15)
- American Society of Civil Engineers draft standard ASCE 4-09, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary". Draft compiled for Santa Fe Meeting, 2011.(Ref. 16)
- American Society of Civil Engineers standard ASCE/SEI 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities". 2005 (Ref. 17).
- BS EN 1998, Eurocode 8, Design of Structures for Earthquake Resistance (Ref. 18).

2.4 USE OF TECHNICAL SUPPORT CONTRACTORS

26 Technical support to ONR in the area of seismic analysis has been provided by ABS Consulting Ltd. Ramboll (formerly Giffords) has also provided support on some aspects of finite element modelling.

2.5 OUT-OF-SCOPE ITEMS

27 There are no out of scope items. The entirety of GDA Issue **GI-UKEPR-CE-06 Rev 1** has been addressed. In addition, there are no changes to the scope of the GDA assessment detailed in the Step 4 report (Ref. 2).

3 GDA ISSUE

3.1 BACKGROUND TO THE GDA ISSUE

28 The methodology for seismic analysis of nuclear safety related structures was the subject of extensive discussions between ONR and EDF and AREVA during Step 4 of GDA. The civil structures in the reference design were designed using the EPR Technical Code for Civil Works (ETC-C), Rev B 2006 (Ref. 19). The current version of this code, AFCEN ETC-C 2010 (Ref. 20) (referred to as ETC-C 2010 hereafter) will be used for the UK EPR™, with an accompanying UK Companion Document (Ref. 21) which has been specifically written to adapt the ETC-C 2010 to UK standards, similar to a UK National Annexe to Eurocodes.

29 The ETC-C 2010 is a bespoke code, developed by EDF and AREVA for the EPR project. It is based upon Eurocodes, European Standards, French standards and other recognised guidance, but specifies additional criteria to be used for the EPR™. This reflects that some Eurocode rules should be amended and/or extended to apply to the specific demands placed on nuclear structures. These additional criteria have been developed within the French nuclear industry over the past decades.

30 One area which was raised as a Regulatory Observation (RO) in Step 4 of GDA (RO-UKEPR-037, Ref. 22) was the reliability of the ETC-C 2010 as a design code, in other words how confident can we be that structures designed to it will meet the safety demands placed upon them. The initial submissions made in response to RO-UKEPR-037 were found to fall short of regulatory expectations and this was communicated via ONR letter EPR70288R (Ref. 23). The majority of comments made in this letter were on the reliability of ETC-C 2010 and these have been resolved under GDA Issue **GI-UKEPR-CE-05** (Ref. 24). However, some aspects concerned the seismic methodology and associated design approach for the raft foundation and so this GDA Issue, **GI-UKEPR-CE-06**, was raised separately.

31 This issue centres on the seismic analysis and design of the common foundation raft, and its connection to the various Nuclear Island (NI) superstructures, which it supports. The NI of the UK EPR™ comprises buildings with a predominantly generic design. The design of the raft is therefore based on generic design loads but is also highly dependent on site specific aspects such as the strata below the foundation and its seismic characteristics.

32 The justification of the reference design presented for GDA relies heavily on the detailed design that had already been carried out for the Flamanville 3 (FA3) project in France. This design uses Flamanville site specific properties for hard ground (called HF), which comprises hard rock close to the surface, i.e. a fractured granite layer from 2m to 10m thick, underlain by a sound granite rock.

33 The main submission document for the seismic methodology was “Common Foundation Raft and Seismic Analysis – GDA Scope”, ENGSGC100140 Rev A (Ref. 25) which was received in June 2010. ONR comments during Step 4 were that this document was adequate on the design of the raft but was very weak on the analysis of the raft. It was also unclear which aspects of the design of this structure should be considered within the scope of GDA and which would need to be carried out during site specific phase.

34 ONR acknowledged during Step 4 (Ref. 2, paragraph 477) that “*in order to gain a complete understanding of the behaviour of the Nuclear Island structure, a representation of the founding material is required. At the generic stage of assessment, this is somewhat of a challenge, given the large potential range of soil conditions which may be encountered in the UK*.”

35 EDF and AREVA met with ONR at the Level 4 technical meeting in September 2010 and subsequent teleconferences to work through residual comments on the UK EPR™ seismic analysis methodology and raft foundation design approaches and considerations. These considerations were that:

- document ENGSGS 100140 Rev A focuses on design conditions and limits.
- no substantive discussion was included in the document on analysis methods/ objectives/inputs/outputs/ links to design process.
- there was a need for greater clarity and agreement between ONR and EDF and AREVA on the scope of the GDA seismic analysis and on that which would be done during site specific phase.

36 These discussions led to the update of engineering report ENGSGC100140 Rev A to Rev B (Ref. 26), and the development of two new engineering reports, ENGSDS100268 Rev A (Ref. 27) and ENGSDS100269 Rev A (Ref. 28). These were submitted towards the end of the Step 4 programme and so were not examined at that time. This GDA Issue **GI-UKEPR-CE-06** was raised to provide for the ongoing assessment of these three documents which form the seismic design methodology.

3.2 EDF AND AREVA RESOLUTION PLAN DELIVERABLES

37 The EDF and AREVA Resolution Plan (Ref. 3) was based on the three engineering reports which had already been submitted as described previously (Ref. 26, 27 and 28). These initial versions of the documents underwent several revisions during my assessment (as described later in this report) until regulatory expectations were satisfied.

38 An overview of each of the initial deliverables is provided within this section. It is important to note that this information is supplementary to the information provided within the March 2011 PCSR (Ref. 4) which has already been subject to assessment during earlier stages of GDA. In addition, it is important to note that the deliverables are not intended to provide the complete safety case for the Civil Engineering and External Hazards topic area. Rather they form further detailed arguments and evidence to supplement those already provided during earlier Steps within the GDA Process.

3.2.1 Document ENGSGC100140 Rev C

39 Document ENGSGC100140 Rev B (Ref. 26) is the identified deliverable in the Resolution Plan for consideration under **GI-UKEPR-CE-06.** Rev C of the document (Ref. 29) was the final revision under GDA which has been updated in order to provide an adequate response to the ONR assessment.

40 The title of ENGSGC100140 Rev C (Ref. 29) is “Common Foundation Raft and Seismic Analysis – GDA Scope”. The abstract states that “*the purpose of this document, produced for the UK EPR Generic Design Assessment project, is to provide a detailed list of requirements and principles applicable to the design of the common Foundation Raft and the seismic design of C1 classified structures of the Nuclear Island. The document proposes a boundary between the part of the foundation raft design that is within Generic Design Assessment and the part of the design which is site specific*.”

3.2.2 Document ENGSDS100268 Rev B

41 Document ENGSDS100268 Rev A (Ref. 27) is the initial submission of the deliverable identified in the Resolution Plan. Rev B of the document (Ref. 30) was the final revision under GDA which has been updated in order to provide an adequate response to the ONR assessment.

42 The title of document ENGSDS100268 Rev B is “UK EPR - Seismic Analysis of Foundation Raft”. The abstract states that “*the purpose of this document, produced for the UK EPR Generic Design Assessment project, is to provide a description of the use of soil impedances for soil springs determination in a soil structure interaction analysis. A second purpose is to define basemat uplift considerations for static and dynamic analyses. The final purpose of this report is to provide a list of functions available in Code Aster/ProMISS3D software, and define which function is used in the GDA.*”

3.2.3 Document ENGSDS100269 Rev B

43 Document ENGSDS100269 Rev A (Ref. 28) is the initial submission of the deliverable identified in the Resolution Plan. Rev B of the document (Ref. 31) was the final revision under GDA which has been updated in order to provide an adequate response to the ONR assessment.

44 The title of document ENGSDS100269 Rev B is “UK EPR - Methodology for Seismic Analysis of NI Buildings”. The abstract states that *“the purpose of this document, produced for the UK EPR Generic Design Assessment, is to describe the methodologies to be used and to clarify the methodology that will be applied in the seismic analysis of safety related C1 classified structures of the Nuclear Island (NI) in the Nuclear Site phase.”*

3.3 INTERFACE WITH OTHER UK EPR™ DOCUMENTS

3.3.1 March 2011 PCSR

45 The Resolution Plan (Ref. 3) states that “*no updates to the PCSR are expected since the documentation provided in response to RO-UKEPR-37 and ND Letter EPR70288N, along with the update to ENGSGC100140 and development of new reports ENGSDS100268 and ENGSDS100269 were incorporated into the PCSR (Sub-chapter 3.3) as part of the March 2011 PCSR submission. However, if any of these previously submitted documents require revision based on resolution of this GDA Issue, then the PCSR (Sub-chapter 3.3) may require update.”*

46 EDF and AREVA has identified during close-out of GDA Issues that resolution of **GI-UKEPR-CE-06** required the PCSR sub-chapter 3.3 to be updated. My assessment of these updated is discussed in Section 5.1.

3.3.2 ETC-C and UK Companion Document

47 The EPR Technical Code for Civil Works (ETC-C) was developed by EDF and AREVA for the design of the new fleet of EPR nuclear power plants, including Flamanville. It has now come under the auspices of AFCEN (French society for design, construction and in-service inspection rules for nuclear island components). AFCEN is a body set up in France to develop design and construction codes for nuclear power stations in light of current good practice and developments in R&D. It was founded by the French Atomic Energy Commission (CEA) and experts from the French nuclear industry. Therefore, the AFCEN 2010 version of the ETC-C (Ref. 20) is a stand alone document, and EDF and AREVA use a UK Companion Document (UKCD, Ref. 21) to specify any changes to the ETC-C that are required for the UK EPR™.

48 Information on the seismic design methods presented for GDA Step 4 was contained in the Appendix 1.A of ETC-C 2010 which gives methods and principles for seismic design values. It does not, however, give the justification behind those values. The Eurocode 8 standard, BS EN 1998 “Design of Structures for Earthquake Resistance” (Ref. 18) is also referenced.

49 The Resolution Plan did not state whether any modifications would be required to the ETC-C 2010 or its accompanying UK CD. However, EDF and AREVA identified changes that were required to the UK CD for resolution of **GI-UKEPR-CE-06**.

3.4 INTERFACE WITH OTHER GDA ISSUES

50 This GDA Issue has interfaces with deliverables for other GDA Issue resolution plans, as given in Table 2 below. This means that some of the commitments made by EDF and AREVA in order to resolve this GDA Issue are included in documents produced as deliverables for other GDA Issues. Where this is the case, details of the commitment are given in the appropriate section of this report.

Table 2: Interface of GI-UKEPR-CE-06 with other GI Deliverables

GDA Issue	Topic	Document Deliverables
GI-UKEPR-CE-01 (Ref. 32)	Hypothesis and Methodology Notes	EPR Nuclear Island Civil Engineering Design Process (Ref. 37)
GI-UKEPR-CE-02 (Ref. 33)	Use of the ETC-C	UK Companion Document (to the AFCEN ETC-C 2010) (Ref. 21)
GI-UKEPR-CE-03 (Ref. 34)	Beyond design basis behaviour of containment	N/A
GI-UKEPR-CE-04 (Ref. 35)	Containment analysis FE modelling	ENGSDS100269 Rev B (Ref. 31) Plus 4 other documents submitted for **RO-UKEPR-76**
GI-UKEPR-CE-05 (Ref. 36)	Reliability of the ETC-C	N/A

3.5 OVERVIEW OF UK EPR^{TM} SEISMIC ANALYSIS METHODOLOGY

51 The analysis of a structure for seismic loads can be carried out in a variety of ways. The choice of which method is appropriate lies with the designer. The key methodologies chosen by EDF and AREVA for the seismic analysis of the raft and the nuclear island are discussed in the following sections.

3.5.1 FE Models

52 The three methodology documents together describe the establishment of FE models, soil structure interaction, input motion, seismic calculation and processing of results. Checkpoints are used at key stages in the design to confirm that the seismic analysis for a particular site has adequately modelled the structural response.

53 The key points of the seismic analysis methodology were given in a table on page 4 of ENGSDS100269 Rev B (Ref. 31). Two separate FE models of the nuclear island (NI) are used:

- FRS Model – used for generation of the floor response spectra (FRS); and
- CW Model – used for the detailed design of the civil works (CW).

54 The table compares the two models. Both models are founded on soil springs with stiffnesses calculated from impedance functions (see Section 4.3.2). However, the impedance functions are based on different soil conditions for each model as described below.

55 The FRS model considers six different soils for the GDA design, as shown in Figure 1 below taken from ENGSGC100140 Rev C. The seismic design of the plant is thus generic for several potential sites and aims to envelope a "*large range of soils*". The six soil properties considered are: soft soil (SA), three medium soils (MA, MB and MC) and two hard soils (HA and HF). The HF soil is based on the actual stratigraphy of the Flamanville 3 site (FA3), which comprises two layers; fractured granite from 2m to 10m thick, underlain by sound granite. The other five soil properties are homogeneous ones, i.e. linear properties, and intended to cover a sufficient range of sites.

[redacted]

Figure 1: Range of Soils considered for FRS Model (Ref. 29 and PCSR Sub-Chapter 13.1)

56 Report ENGSDS100269 Rev B states that either, site specific soil conditions (lower bound, best estimate and upper bound) or multisite soil conditions (covering specific conditions of multiple sites) can be used in the FRS model during the site specific phase. The spectra produced using either method will be verified against the GDA spectra using a method to be defined at during detailed design for that specific site.

57 The reference design CW Model presented in GDA is based on the site specific soil conditions for FA3. The soil impedances (as discussed in Section 3.5.3) are calculated for the lower bound, best estimate and upper bound soil modulus for FA3. During detailed design, the CW model will be rebuilt with the actual site specific values, based on the site investigation carried out.

58 The analysis methods for the two models are stated as

- FRS Model – time history analysis with modal superposition; and
- CW Model – modal spectral analysis.

3.5.2 Seismic Input Motion

59 The seismic input motion is the same for the two models. The European Utility Requirements (EUR) for LWR Nuclear Power Plants (Ref. 38) provides standardised spectra for hard, medium and soft sites. The GDA earthquake is based on EUR spectra scaled at 0.25g in the horizontal direction with 5% damping. The vertical acceleration is taken as equal to 2/3 of the acceleration in the horizontal direction (Section 3, Ref. 29).

60 The EUR spectra are shown in Figure 2 below, repeated from Figure 1 of PCSR Sub-Chapter 13.1 (Ref. 4) and Section 6.3.1 of Ref. 29.

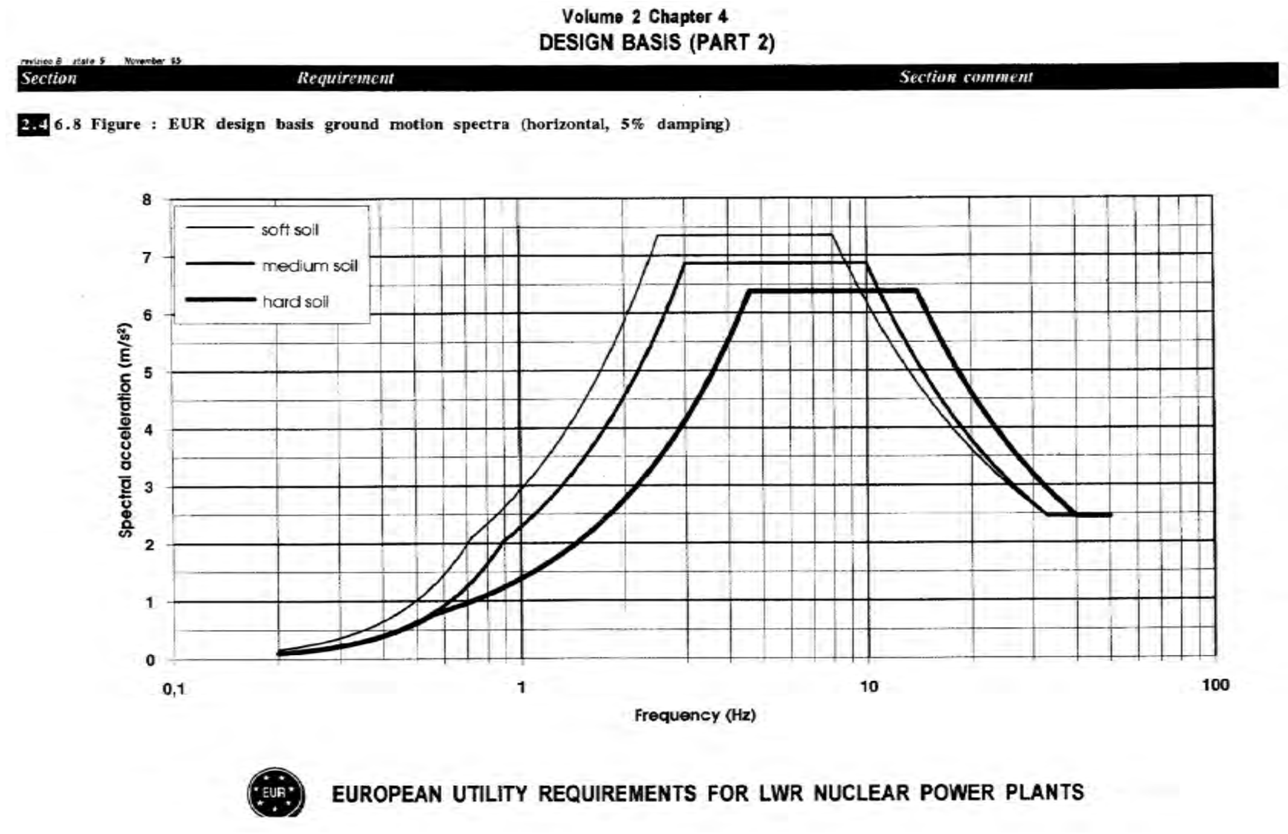

Figure 2: EUR Spectra (Ref. 29 and PCSR Sub-Chapter 13.1)

61 At site specific phase, one EUR spectra will be used for both models "*consistent with site conditions set at 0.25g pga provided the site specific spectrum is bounded by the EUR spectrum*."

3.5.3 Soil Structure Interaction

62 The UK EPR™ reference design presented in GDA uses the Impedance Function Method to model the ground beneath the common raft. Section 1.A.5 of the ETC-C 2010 describes two alterative methodologies and provides some limited guidance on each.

- The Direct Method – this uses finite elements to model the ground and these are normally in the same FE model as the foundation and the superstructure. Hence calculation of soil structure interaction is done in one step.

- The Impedance Function Method – this uses complex stiffness matrices (impedance functions) for each node common to the structure and the ground. The functions comprise two parts: spring stiffnesses and ground damping values. Both vary with frequency of the earthquake and have to be set relative to the overall frequencies of the ground-structure system. This soil structure interaction is normally calculated in a series of steps, requiring different software and interfaces.

63 The Direct Method using finite elements is a generally applicable method without any limitations. The Impedance Function Method has inherent simplifications of only being able to model the soil strata in an equivalent linear fashion and assumes the raft is a rigid foundation.

64 The Impedance Function Method of soil-structure interaction is still adopted in ENGSDS100268 Rev B and Section 6.1 gives the steps required to determine the values of the soil-springs. The document has been written to justify that the simplifications used with respect to soil non-linear effects (site stratifications, soil modulus degradation, basemat uplift) are satisfactory.

65 My assessment of the justification for using the Impedance Function Method relies on detailed technical points which are discussed in Section 4.3.2 below.

3.5.4 Use of Modal Superposition Method

66 The UK EPR^{TM} reference design presented in GDA uses the modal superposition time history analysis method for generating civil structure forces and displacement and for generating floor response spectra. This is an approximate method rather than a mathematically rigorous method such as the direct method which solves the dynamic equations directly. The approximation results from the treatment of damping in that different parts of the structure and soil will have different damping values yet the software iterates to one value for the whole soil/structure system.

67 The modal superposition time history analysis is still adopted in ENGSDS100268 Rev B and ENGSDS100269 Rev B and confirms the modal superposition time history analysis method will be used for both structural design and floor response spectra.

68 My assessment of the justification of the maximum levels of damping to be used for the site specific phase is discussed in Section 4.3.2 below.

3.5.5 Use of Equivalent Static Force Method

69 The reference design uses separate FE sub-models for the inner containment (IC) and its internal structures. These sub-models are refined compared with the two global NI models (the civil structural model and the floor response spectra model) and are needed for specific design of the pre-stressed containment. However, the two sub-models apply the seismic loads in different ways. The internal structures sub-model uses the accelerations applied at eleven different floor levels which are calculated from the civil structural global model. The IC sub-model uses a simplified method of applying the seismic loadcase which is called the equivalent static force method. The accelerations (ZPA: Zero Period Acceleration) at each level are taken from the floor response spectra model calculations (Ref. 39). Static forces, calculated by multiplying the mass at each level by the acceleration profile (F=ma), are then applied to the IC model.

70 Section 5.5.3 of ENGSDS100269 Rev B states that "*for buildings or parts of the buildings that require a more refined model for the design, the acceleration field is extracted from the seismic analysis of the global model and used in the detailed calculation for forces determination.*" Therefore, the equivalent static force method is still proposed to be used within the UK EPR^{TM} design for certain structures.

71 EDF and AREVA also submitted ENGSDS100269 Rev B in response to **GI-UKEPR-CE-04** which requested justification of the use of the equivalent static force method for the inner containment sub-model. My assessment of this is therefore given in my assessment report for **GI-UKEPR-CE-04** (Ref. 40). The comment made under this assessment the justification is given under Comment 10 for ENGSDS100269 Rev B in Section 4.3.3.

4 ONR ASSESSMENT

72 Further to the assessment work undertaken during Step 4 (Ref. 2), and the resulting GDA Issue **GI-UKEPR-CE-06** (Ref. 1), this assessment focuses on the seismic analysis methodology for the UK EPR. Identified deliverables intended to provide the requisite evidence were provided within the responses contained within the Resolution Plan (Ref. 3) provided by EDF and AREVA at the end of Step 4 of GDA.

73 This assessment has been carried out in accordance with the ONR business management system HOW2 document PI/FWD "Permissioning - Purpose and Scope of Permissioning", Issue 3 (Ref. 6).

4.1 SCOPE OF ASSESSMENT UNDERTAKEN

74 The scope of the assessment has been to consider the expectations detailed down within the GDA Issue, **GI-UKEPR-CE-06** (Ref. 1), and its single action. The issue is presented in Annex 2 of this report.

75 For each of the following areas further information was sought.

- Justification of the methodologies proposed for the seismic analysis of the raft foundation and nuclear island superstructures.
- Define the methods to be used to adequately confirm the mass participation of the individual structures supported on the common raft, and to appraise the dynamic behaviour that has been captured by the analysis modelling (Ref. 2, paragraph 504).
- Clarify how the acceleration profile is varied with height. This includes appraisal of the degree of rigid mass in the models and the use of "missing mass" corrections (Ref. 2, paragraph 512).
- Include clarifications presented by EDF and AREVA at CEEH Level 4 technical meetings as follows.
    1. The scope of the common raft analysis that was included in GDA and what remained in site specific phase.
    2. Use of computer software ProMISS3D and ASTER to include limitations/ assumptions used in the GDA reference design.
    3. An outline of how soil stiffnesses are calculated including soil modulus degradation etc. in the modelling that could be applied to UK.
    4. Statement of EDF and AREVA's intent to have acceptance in principle of "Equivalent Linear" methods from HSE GDA Step 4, with caveats where site specific justification will be required.
    5. Appendix containing route map to explain how impedance values and springs are used.

76 In summary, the purpose of the assessment was to judge whether the deliverables submitted in response to **GI-UKEPR-CE-06** provided sufficient justification of the methods proposed for the seismic analysis within the context of GDA.

4.2 PROGRESS OF THE ASSESSMENT

77 The three initial deliverables ENGSGC100140 Rev B (Ref. 26), ENGSDS100268 Rev A (Ref. 27) and ENGSDS100269 Rev A (Ref. 28) were assessed during the closure of GDA

issues phase of GDA. Comments on all three were issued to EDF and AREVA via letter EPR70353 (Ref. 41) in September 2011. The resolution of these comments was discussed with EDF and AREVA at the Level 4 technical meetings and developed further by comment resolution tables (Refs. 42, 43 and 44).

78 EDF and AREVA submitted draft updates of each report along with comment resolution tables for the comments on each report. The responses to comments either comprised additional justification to maintain the current methodology or revisions to the methodologies themselves. This was an iterative process and was progressed between September 2011 and March 2012. Resolution of the comments resulted in submission of ENGSGS100140 Rev C (Ref. 29) in December 2011, ENGSDS100268 Rev B (Ref. 30) in April 2012 and ENGSDS100269 Rev B (Ref. 31) in May 2012.

79 The ONR assessment was supported by ABS Consulting Ltd (ABSC) who carried out a review of the three initial deliverables against the two following items.

- Items identified during Step 4 where the seismic methodology used for UK EPR^{TM} needed further justification.
- Current good practice. ONR consider the standard ASCE 4-98 (Ref. 15) to represent relevant good practice in this area. ABSC carried out an appraisal of the seismic methodologies described in the deliverables with respect to the requirements of ASCE 4-98 (Ref. 15), its revised draft ASCE 4-09 Draft (Ref. 16) and ASCE 43-05 (Ref. 17).

80 The ABSC review is summarised in report 2120812-R-08, “Review of 3 Seismic Analysis Methodology Documents” (Ref. 45). Draft versions of this report were used to compile the list of ONR comments made within letter EPR70353 (Ref. 41), and to inform the assessment that followed.

81 The technical aspects of the items which required further justification are expanded in the following sections.

4.3 DETAILED TECHNICAL COMMENTS ON DELIVERABLES

82 The detailed technical comments raised after my assessment of the initial three deliverables were contained in letter EPR70353 (Ref. 41). These are described below for each report separately.

4.3.1 Document ENGSGC100140

4.3.1.1 Assessment

83 This section details my assessment of the initial deliverable ENGSGC100140 Rev B (Ref. 26). Generally, Rev B had not changed significantly from Rev A and remained focused on the design of the common raft. The additional information required by this GDA Issue is mainly contained in the two new reports (Refs. 27 and 28). However, three comments which needed further clarification were raised on report ENGSGC100140 Rev B as discussed below. The resolution of these comments was discussed with EDF and AREVA at the Level 4 technical meetings and developed further using the comments resolution table (Ref. 42).

84 EDF and AREVA submitted an updated version of the report, namely Rev C (Ref. 29) in December 2011 under cover of letter EPR01049N (Ref. 46). This revision included the following amendments which satisfactorily resolved the three comments.

1) Range of Soil Modulus

85 Section 3 of Rev. B (Ref. 26) describes the specific case of Flamanville 3 (FA3) where the lower and upper bounds of the soil modulus (E value) for each layer were calculated by applying factors of 2/3 and 3/2. This is the minimum range to consider when there is detailed site investigation (SI). A bigger range should be used if there is lower confidence in the SI.

86 My assessment queried the justification of using these values for all sites when they are specific to FA3 and are not generic. My view is that the approach to be adopted during the site specific stage needed to be made clear.

87 EDF and AREVA added the following sentence to Section 3 in Rev. C (Ref. 29).

"*Bounding conditions will be reviewed at* [site specific] *stage and will be set according to the results of the SI. Therefore, different bounding conditions may be adopted for* [the site specific stage]*".*

88 This sentence is satisfactory and confirms that the site specific design must calculate the lower bound, best estimate and upper bound values of the soil modulus.

2) Degradation of Soil Modulus

89 Section 6.1 of Ref. 26 gives the steps in the seismic analysis methodologies for the foundation raft. Under step 1, "Definition of soil hypothesis" it states that "*the equivalent linear method (degradation of soil modulus with shear strain) is the theoretical basis of the approach*". ASCE 4-98 Clause 3.3.1.4 requires that "*non-linear material behaviour induced in the soil due to the excitation alone….shall be considered in the SSI analysis*". Degradation of the soil modulus during an earthquake is a known effect particularly for softer sites. However, my assessment found no evidence to confirm degradation has been included in the reference design.

90 EDF and AREVA explained during the Level 4 technical meetings that the GDA reference design for the civil structures does not use soil modulus degradation since it is based on the FA3 rock site. For the GDA methodology, the variability of soil conditions at different sites was accounted for by considering 6 different soil conditions. However, each soil

condition was still based on a linear soil modulus and did not account for the soil modulus degrading during an earthquake.

91 EDF and AREVA added the following sentence in Rev C (Ref. 29).

"*For the Nuclear Site License, an appropriate assessment of the site soil variability and degradation will be performed*."

92 This is a commitment to include consideration of soil degradation in the site specific design, which is compliant with ASCE 4-98 Clause 3.3.1.4 and so is satisfactory. Further provision is also provided in ENGSDS100268 Rev B (refer to comment 3, Section 4.3.2).

3) Non-linear Behaviour

93 Section 6.2 of ENGSGC100140 Rev. B specifies the scope of the GDA for the seismic analysis of the raft. It is stated that "*where non-linear effects are judged to be significant, then appropriate site specific studies will be carried out during the* [site specific] *phase*." No definition is given of how the significance is to be judged.

94 EDF and AREVA explained during Level 4 technical meetings that when the site specific strata are outside the limits given in Section 6.2, it is considered non-linear effects are significant. The calculation of the three soil types best estimate, upper bound and lower bound carried out during site specific phase will consider variability of soils.

95 One of the limits given in Section 6.2 is a minimum shear wave velocity of the ground Vs30 > 300m/sec.This contradicts the site class SA (soft soil) which has a Vs30 = 280m/sec. EDF and AREVA's response was that limiting the GDA scope to sites with Vs30 > 300m/s is a covering approach towards the 280m/s value taken into account in SA soil. Rev C now includes additional clarification that parameters are for "*Soils with Vs30 > 300m/s (before allowing for degradation*)" and that "*specific studies should be conducted for sites with Vs30 lower than 300m/s"*. This is satisfactory.

4.3.1.2 Conclusion

96 The comments raised on this deliverable have been answered satisfactorily by the revised report ENGSGC100140 Rev C and I raise no assessment findings. The report also clarifies the scope of the foundation design within GDA and that which will need to be carried out at site specific stage.

97 The revised report satisfies Regulatory expectations and is in line with SAPs ECE.4 and ECE.5, i.e. that the site investigation data should be used to confirm the suitability of the natural site materials.

4.3.2 Document ENGSDS100268

4.3.2.1 Assessment

98 This section details my assessment of the initial deliverable ENGSDS100268 Rev A (Ref. 27). Ref. 27 was a new report submitted for **GI-UKEPR-CE-06** and provided further information on how the soil material properties and the soil-structure interaction had been modelled for the GDA design using the Impedance Function Method.

99 The technical assessment by ABSC (Ref. 45) notes that ASCE 4-98 Section 3.3.1 considers the Impedance Function Method as being one of two acceptable methods, the other being the Direct Method (refer to Section 3.5.3). However, the GDA Step 4 assessment questioned whether the Impedance Function Method would be suitable for UK sites, which are generally much softer than the FA3 site and may exhibit significant non-linear soil response.

100 The assessment of Ref. 27 raised seven technical comments which required further justification. The resolution of these comments was discussed with EDF and AREVA at the Level 4 technical meetings and developed using a comments resolution table (Ref. 43).

101 The formal update to the report, which will form part of the submission master list, is ENGSDS100268 Rev B (Ref. 30) and was submitted in April 2012 under cover of letter EPR01125R (Ref. 47). This revision included the amendments discussed below in response to each comment.

1) Local Spring Calculation

102 Section 3.2.4 describes how the springs representing the ground beneath the foundation can be weighted by a distribution factor 'f(op)' which depends on the distance 'op' of each spring to the centre of gravity of the raft. EDF and AREVA have used f(op) = 1.0 for all springs and this required further explanation. Further detail was also requested on how the local rotational stiffness is adjusted.

103 EDF and AREVA's response was that its design hypothesis for the GDA reference design was for the case of homogenous soil and hence the factor was set to 1.0. However, Section 3.2.4 was revised in Rev B (Ref. 30) to specify that the assumption of homogenous soil would be re-appraised for site specific designs. The calculation of local rotational springs applied at each node was also expanded in Section 3.2.4, and this is satisfactory.

2) Damping

104 Rev A states that the methodology uses the modal superposition time history analysis method for generating floor response spectra. This is only an approximate method since one level of damping is chosen for each mode and then used for both the soil and the structure. There is a concern that this can overdamp parts of the structure.

105 The maximum value of damping used in the UK EPR™ seismic methodology is given in PCSR Sub-chapter 13.1 Section 2.1.5.2 as "*the reduced modal damping value is limited at 30%*". I considered that this was high since ASCE 4-98 uses a maximum limit of 20% damping.

106 EDF and AREVA's response was to add specific requirements for modal superposition methods and damping in the next revision of the third deliverable, report ENGSDS100269 Rev B (Ref. 31). Two additional checkpoints (FRS 8 and CW 6) were added to this document to carry out additional studies for both the floor response model and the civil model for any mode which was damped between 20% and 30% in order to confirm that overdamping was not occurring.

107 This is acceptable and complies with ASCE 4-98.

3) Degradation of Soil Modulus

108 Degradation of the soil modulus during an earthquake had not been taken into account in the reference design, but could be significant for soft UK sites (see also comment 2 in Section 4.3.1 above).

109 A commitment was included in Section 4.4 of ENGSDS100268 Rev B (Ref. 30) that soil modulus degradation studies would be made for site specific design for soft sites and suggests the computer software Cyberquake as a suitable method. The verification of Cyberquake was queried by ONR in Technical Query TQ-EPR-979 (Ref. 48) during GDA Step 4. The response to TQ-EPR-979 stated that Cyberquake could be used to evaluate potential degradation of the soil modulus and the damping due to seismic distortions; however it would need to interface with ProMISS3D which is used to calculate the soil

impedances. Verification and validation of this interface between Cyberquake and ProMISS3D was not provided in GDA, since this is not required for the reference design. The use of ProMISS3D for sites other than those considered hard will require considerably more justification and this has been captured by Step 4 Assessment Finding **AF-UKEPR-CE-08** (Ref. 2, paragraph 324).

110 I therefore conclude that consideration of degradation of the soil modulus is a site specific issue and its justification for the detailed design is already captured by **AF-UKEPR-CE-08.**

4) Mesh Refinement

111 The mesh refinement of the FRS global NI model required further justification that the finite element mesh was sufficiently fine such that it could capture local modes of vibration of floors.

112 A commitment to carry out mesh refinement studies for site specific design was added to report ENGSDS100269 in Rev B, which is acceptable and satisfies my comment. This is appropriate because report ENGSDS100268 focuses on the calculation of ground springs where as ENGSDS100269 focuses on FE models.

5) Uplift of Foundation

113 ENGSDS100268 Rev A includes a check for uplift of the foundation in section 5.1.1. If a soil spring goes into tension its contribution to raft stability is ignored; this is standard practice. However, the methodology places a limit on the number of springs that can go into tension, i.e. a maximum of springs representing 30% of the foundation can go into tension. Above this value the linear approach needs further justification by comparison with an alternative approach. The ONR comments on this deliverable requested justification of the value of 30% tensile area.

114 EDF and AREVA added Appendix C to Rev B (Ref. 30) which comprises justification of the 30% uplift limit used. This includes calculations which compare linear and non-linear analyses of the same theoretical model. This shows that the linear analysis at the 30% limit is slightly more conservative than the non-linear and so is adequate justification of the limit adopted.

6) Decoupling of Rocking and Bouncing

115 Section 3.2.2 of ENGSDS100268 Rev A states that the six impedance curves produced for the three translational and the three rotational degrees of freedom do not include the matrix values for rocking and bouncing motions. Further clarification of the method used for decoupling of rocking and bouncing (also known as pumping) analyses was requested.

116 EDF and AREVA added an explanation of the de-correlation of the rocking and bouncing motions in Section 3.3.3 of ENGSDS100268 Rev B (Ref. 30). The approach of deriving just six impedances is a recognised simplification, which is valid when the foundation mat may be assumed to be rigid. Raft flexibility is discussed in Section 4.2 of Ref. 30 and confirms the raft is considered to be rigid during the soil impedance calculation. This adopted approach of ignoring raft flexibility is acceptable under ASCE 4-98 when establishing the seismic response (Ref. 45).

117 I conclude this explanation satisfactorily explains the methodology and is compliant with ASCE 4-98 requirements, provided the inherent simplifications of only being able to address non-linearities in an equivalent linear fashion and of being able to assume a rigid foundation remain valid (Ref. 45).

7) Structure-Soil-Structure Interaction

118 ENGSDS100268 Rev A or Rev B do not include the methodology for assessing structure-soil-structure interaction, i.e. effect of adjacent buildings on the soil beneath the common raft.

119 Since adjacent buildings were outside the scope of GDA, analysis of the structure-soil-structure interaction (SSSI) had not been presented in the reference design. Therefore, a commitment was included in Section 4.5 of ENGSDS100268 Rev B to carry out an SSSI analysis for site specific designs. (This had also been captured in the GDA Step 4 assessment report (Ref. 2) as Assessment Finding **AF-UKEPR-CE-20**.)

4.3.2.2 Conclusions

120 The revised report ENGSDS100268 Rev B has satisfactorily answered the comments raised on this deliverable, although responses to some comments are more appropriately dealt with in ENGSDS100269 Rev B (see Section 4.3.3). The document has provided sufficient additional justification for the calculation of soil impedances to determine soil springs in the soil structure interaction analyses in the context of GDA. These calculations will need to be repeated for the site specific design, but provided the checkpoints included in the methodology are adhered to and the design substantiated in accordance with them, these should satisfy the SAPs ECE.12, ECE.14 and ECE.15.

121 I am satisfied with the methodology. However, I have raised one assessment finding which is to ensure the checkpoints added to the methodology documents are carried out and any deviations justified by the licensee. This must be completed prior to first structural concrete, since the responses of adjacent buildings can affect the nuclear island.

> ***AF-UKEPR-CE-71**: The licensee shall justify that the final seismic analyses used for the detailed design of the UK EPR™ are adequate for the site specific conditions. Any deviations from the generic methodology documents, ENGSGC100140 Rev C, ENGSDS100268 Rev B and ENGSDS100269 Rev B shall be highlighted and adequate justification provided.*
>
> ***Required Timescale:** First structural concrete.*

4.3.3 Document ENGSDS100269

4.3.3.1 Assessment

122 This section details my assessment of the initial deliverable ENGSDS100269 Rev A (Ref. 28). Ref. 28 is a key document in describing the seismic analysis methodology. In the context of GDA, this document describes the methodologies that will be used for site-dependent issues. It therefore recognises that the reference design of FA3 was specific to a certain site and so did not fully demonstrate the methods to be used for the UK EPR™.

123 The following fourteen comments were raised in letter EPR70353N (Ref. 41) to request further justification for the methods presented in ENGSDS100269 Rev A (Ref. 28). The resolution of these comments was discussed with EDF and AREVA at the Level 4 technical meetings and developed further using a comments resolution table (Ref. 44).

124 The formal update to the report, which will form part of the submission master list, is ENGSDS100269 Rev B (Ref. 31) and was submitted in May 2012 under cover of letter EPR01145R (Ref. 49).

1) Validation of Computer Software

125 The validation or standards to be used for computer software was not included in Ref. 28.

126 EDF and AREVA's response was that since computer modelling is carried out for design other than for seismic analysis, the description of validation included in the "EPR Nuclear Island Civil Engineering Design Process Document (which is delivered under **GI-UKEPR-CE-01**) will cover this aspect. A statement to this effect is now included in Section 3 of Ref. 31, Validation of Codes.

2) Torsional Response

127 The UK EPR™ seismic methodology uses three synthetic input motions, one in each orthogonal direction x, y and z. ASCE 4-98 Clause 3.1.1 specifies an additional load to ensure torsional response of the structure is included which may result from non-vertically propagating waves. ONR requested justification of why this additional torsion had not been included in the UK EPR™ design.

128 Resolution of this comment required detailed discussions and further iteration and this is discussed in Section 4.3.4.

3) Comparison of FRS and CW Models

129 The FRS model is a simpler model than the CW model. ASCE 4-98 Clause 3.3.1.8 specifies that a comparison should be made between two such models to confirm that the simplified model gives equivalent results.

130 An additional checkpoint (FRS 7) was included in ENGSDS100269 Rev B for a comparison of the FRS and the CW models to be undertaken in accordance with ASCE 4-98. However, it is noted that EDF and AREVA's methodology also specified that local, more detailed modelling should be carried out for FRS calculations when the global FRS model is not sufficiently refined to capture that floor's vertical amplifications (see comment 7 below).

4) Time Histories

131 The seismic input motion is described in Section 4.5 of ENGSDS100269 Rev A. However, the description was unclear as to whether three time histories were used with three analyses or whether nine time histories were used.

132 Appendix 2 was added to Rev B (Ref. 31) which comprises flow charts for both the generic reference design and the detailed design and clarifies the process. For each of the six soil types, three time history accelerograms are used which are combined together into three analyses. The results of the three analyses are averaged and the maximum relative displacement for each node (in each direction) is taken as the maximum of the six soil types. For detailed design, two approaches can be used; either site specific soil properties are used; (lower bound, best estimate and upper bound soil modulus) or, a range of soils corresponding to multi site conditions may be used.

5) FRS Accelerations

133 To generate the floor response spectrum, the accelerations for nodes on the particular floor are averaged (Section 4.6.2 of Ref. 28). Further clarification was sought on how accelerations were averaged and how the resulting spectrum was peak broadened.

134 Appendix 3 was included in Ref. 31 which clarifies the process and comprises flow charts for both the generic reference design and the site specific detailed design. The same three combinations of the three time history accelerograms are used to analyse the structure for each of the six soil types. For each floor the spectra generated for selected nodes are enveloped for each combination, and then the combination spectra are averaged. The resulting six spectra, one for each soil type for that floor, are then enveloped.

135 For site specific design, where the FRS model is based on the site's actual soil conditions, a range of three soil modulii is used as before. The FRS generated for best estimate soil conditions is then broadened by +/-15% at the peaks and the final FRS at the selected node, is the envelope of that calculated using the three soils conditions (lower bound, best estimate broadened FRS and upper bound), which is compliant with ASCE 4-98. In the case of multisite calculations, provided a sufficient range of soils is considered, no additional spectral broadening is performed. This is an acceptable approach, since the spectra is already an envelope encompassing a range of events.

6) Interstorey Drift

136 More detail was required on how deflections between floors (interstorey drift) were calculated and how the additional moments resulting from these eccentricities (known as PΔ effects) were accounted for. The assessment by ABSC noted (Ref. 45) that the current approach was compliant with ASCE 4-98 but would not always satisfy ASCE/SEI 43-05 (Ref. 17).

137 A methodology for interstorey drift was added in Section 4.6.4 of ENGSDS100269 Rev B and a requirement, added to Section 4.6.3, that the minimal separation between two buildings should satisfy the requirements of ASCE/SEI 43-05 Clause 7.3. Checkpoints FRS 9 and CW 13 were added to ensure the PΔ effects were assessed.

7) Mesh Refinement

138 The checks on the mesh refinement for the global FRS model did not appear to be completely defined in the methodology. Therefore, it was unclear whether the global FRS model would adequately capture the local floor panel modes.

139 Section 4.4.1 of ENGSDS100269 Rev B now includes a review of the local floor response spectra if the global FRS model was not sufficiently refined to represent the local floor vertical amplifications.

8) Computing Limitations

140 Section 5.4.1 of Rev A made reference to the fact that choice of seismic analysis method could be limited by computing power. This seemed inappropriate as the method should be chosen on good practice, rather than what software was preferred by the designers.

141 The text was removed in Rev B. EDF and AREVA recognise that the computer software to be used for site specific detailed design may be different due to civil works designers' preference and that newer software may become available.

9) Combination of Modal Responses

142 A query was raised on the mathematical combination of modal responses. The method provided in Section 5.5.2.3 is the complete quadratic combination which is only applicable for dynamic response modes. A different method is normally needed for static response modes.

143 An additional checkpoint CW 10 was added to Section 5.5.2.3 for the case of a mode with a static response being significant.

10) Use of Equivalent Static Force Method

144 This comment queried the use of the simplified equivalent static force method (as described in Section 4.3.1) to calculate forces for a structure, using the accelerations resulting from the seismic analysis of the global model.

145 EDF and AREVA state that this method is conservative and have submitted evidence under **GI-UKEPR-CE-04** for the inner containment. My assessment of this (Ref. 40) has concluded that the method is indeed conservative for the inner containment. However, this may not be the case for all structures. Therefore, Section 5.5.3 of ENGSDS100269 Rev B (Ref. 31) now includes that "*a justification of the conservatism of this approach shall be given on a case by case basis. The consistency between the results obtained from the global and the detailed models shall be justified*."

11) Building Mass Participation

146 The methodology included a check that sufficient building mass was participating in the modes analysed for the whole of the nuclear island. However, there was no corresponding check on the individual buildings such that mass participation of a particular building may be less than required.

147 An additional checkpoint CW 8 was added to Section 5.4.3 of Rev B to include a check on mass participation for each individual building on the common raft.

12) Cut-off Frequency

148 This comment is linked to 11) above. This queried whether the cut-off frequency chosen by the designers i.e. the frequency at which to stop the modal analysis, would be chosen incorrectly if the mass participation was in fact an average of the whole NI rather than the individual buildings. A dominant mode for a particular building may not be included if its mass participation at the cut-off frequency was lower than required.

149 Checkpoint CW 8 added for Comment 11 ensures that the cut-off frequency would be chosen based on individual building responses.

13) CW Accelerations

150 Section 5.5.2.3 states that the modes will be combined using the complete quadratic combination method for dynamic response modes. This comment relates to 5) above and requested clarification on how accelerations for different modes were combined for the civil works design.

151 The use of CQC as a mode combination method is compliant with ASCE 4-98, but only for periodic modes. In response to this comment, EDF and AREVA added an additional checkpoint CW10 to Section 5.5.2.3 of ENGSDS100269 Rev B to allow for combination of other modes. This provides an acceptable range of combination of results.

14) Post-Processing

152 The description of the post-processing of results from FE analysis was not sufficiently detailed.

153 Additional details were added and reference was made to the EPR Nuclear Island Civil Engineering Design Process Note (Ref. 37) which is delivered under **GI-UKEPR-CE-01** and will include further details.

4.3.3.2 Conclusions

154 The revised text and additional checkpoints given in ENGSDS100269 Rev B (Ref. 31) has satisfactorily answered the comments raised on this deliverable. The document justifies the seismic analysis methodology proposed under GDA for the C1 classified structures of the nuclear island. The document also gives the additional measures proposed for the site specific design, and checkpoints that need to be included to substantiate the detailed design. These checkpoints should ensure the sensitivity of the analysis and the validity of results is in accordance with SAPs ECE.14 and ECE.15.

155 The assessment finding raised above **(AF-UKEPR-CE-71)** is to ensure that the licensee provides justification of the final design methods adopted relevant for this deliverable.

4.3.4 Accidental Torsion Loadcase

4.3.4.1 Background

156 The UK EPR™ seismic analysis uses three orthogonal time histories, in the X, Y and Z directions. The motion for each is a purely translational motion. Each motion is analysed separately and then the results combined afterwards.

157 The above method is commonly used in the design of buildings subject to seismic loads, for conventional buildings not just nuclear plants. The code ASCE 4-98 (Ref. 15) recognised that applying three separate translational motions to an FE model of a symmetrical building may not result in any torsional response being calculated. In reality, torsion may result from eccentricities in the building which the FE model does not include. Torsional behaviour can also be generated as a result of the incident seismic waves not being truly vertical or arriving at different times at different ends of the structure (incoherent waves).

158 Code ASCE 4-98 Clause 3.1.1 (e) requires that torsional moments caused by the following effects are considered (Ref. 46).

1. Accidental eccentricity with respect to the centre of rigidity.
2. Non-vertically incident or incoherent waves associated with seismic ground motion.

159 There are two distinct issues here, which are made clearer in ASCE 4-98 commentary clause c3.1.1 (e). Clause 3.1.1 provides an approach to cover both issues together; in case 1 it is robustness, in case 2 it is a seismic load effect. Also, in case 2 there are actually two different seismic effects;

a) non-verticality of incident waves which can introduce additive forces to those from purely translational motion;

b) Incoherent waves which can have a relieving effect for high frequency motion.

160 It is suggested in clause 3.1.1 that an acceptable way of dealing with all these torsional loads is to apply an additional torsional moment in the design. This additional moment comprises a horizontal force equal to the storey base shear in the x and y direction which is applied at a lever arm of 5% of the building plan dimension in the same direction. The storey shear force during ground motion is mainly due to the mass associated with the dead weight of the structure plus a proportion of live load.

161 Eurocode 8 (Ref. 18) provides guidance on accidental torsion to allow for uncertainties in the location of mass and in the spatial variation of the incoming seismic motion. It also suggests a 5% figure (Clause 4.3.2). Although Eurocode 8 does not directly apply to special structures such as nuclear power plants, I note that it agrees with ASCE 4-98.

4.3.4.2 UK EPR™ Approach

162 EDF and AREVA proposed an argument (Ref. 49) that the ASCE 4-98 accidental torsion load did not need to be added to the main FE analysis. The three effects were either already included in its FE models or were not significant. The justifications given against each effect are as follows.

163 Effect 1) – the FE model of the nuclear island is sufficiently detailed to model the true centres of mass and stiffness and so torsion evolving from the translational loadcases will be included in the analysis.

164 Effect 2a) – EDF and AREVA argue that in the case of Civil Works studies, Eurocode 8 also requires the designer to consider accidental eccentricity, in order to cover the torsional effects due to:

- the variability of live loads; and
- the yielding process that could occur more significantly in a certain zone of the building.

165 The UK EPR™ design considers that the effects of non-vertical waves on the NI are small because live loads are not significant, and the much larger dead loads are already included in the FE model. For the second Eurocode 8 consideration, the design of the UK EPR™ civil works is linear elastic and so no yielding process will occur at the design basis.

166 Effect 2b) – EDF and AREVA argue that ASCE 4-98 allows reduction factors to be used for incoherent waves, hence since UK EPR™ does not include consideration of incoherency it is conservative.

4.3.4.3 Assessment

167 I am satisfied with the arguments and justification put forward for effects 1) and 2b) above. However, I do not consider the justification for 2a), accidental torsion, to be demonstrably conservative in accordance with SAP ECE.13. This is discussed below.

168 The main reasons for introducing an additional accidental torsional load are

- the rotational component of ground motion about the vertical axis, and
- the difference between modelled and actual building stiffness and mass.

169 Structures with rigid foundations and plan dimensions considerably less than the wavelength of ground motion, tend to ride the wave and rotate about a vertical axis as well as translate. Ramboll reported (Ref. 50) that research by Newmark showed that for buildings with plan dimensions less than 150m, shear caused by torque could increase the shear force in walls caused by translation by the order of 5%.

170 Applying purely translational movement to a symmetric building model will theoretical result in no torsional load. The NI superstructure is asymmetric and is modelled accurately such that I am satisfied the torsional response from the dead load would be adequately modelled by applying the usual translational motion. However, eccentricity from live load would need to be considered. If the live load is symmetrically applied within the model then the additional torsion from non-vertical waves would not be generated by the model. The additional information supplied by EDF and AREVA in support of the live loads being a small percentage of the total is useful, but it is not directly evident what effect a variation in the live load would have as a percentage increase in the shear demands in the walls.

171 I am satisfied that accidental torsion due to non-vertical waves acting on the structure itself will be included in the current seismic analysis and detailed FE model. However, I consider the hypothesis that torsion resulting from live load is insignificant needs further justification. I therefore conclude that for the site specific phase a separate justification should be carried out to prove that the effect of live load variation is insignificant in terms of torsional response of the NI.

172 EDF and AREVA added the text below to report ENGSDS100269 in Rev B, to satisfy the above regulatory expectations.

"5.3.5 Accidental torsion effects

Accidental torsion effects may be neglected in the civil works analysis if the additional shear loads induced in walls are proved to be acceptably small with comparison to initial shear loads : a maximum deviation of +10% shall be respected.

This check shall be done on a simplified but representative case, using one of the following approaches:

Any method consistent with [EC8] (off-centered center of gravity) or with [ASCE 4-98] (additional torsional moment) or case-tests with pessimistic live loads repartition can be used for that demonstration. Only live loads should be off-centered, since accidental eccentricity due to representation of mass and rigidity centers is already covered by the detailed FE models."

173 I have raised one assessment finding to ensure the above justification, or its equivalent, is carried out for the site specific design to satisfy ECE.13. This must be completed prior to first structural concrete, to ensure the physical structure built fulfils the seismic response used in the design.

> ***AF-UKEPR-CE-72****: The licensee shall ensure that the torsional responses of the common raft and the Nuclear Island structures are adequately modelled such that torsional effects are included in the design values for the civil works and the floor response spectra. The licensee shall justify the method selected for the site specific design of the UK EPR™.*
>
> **Required Timescale:** *First structural concrete.*

5 INTERFACE OF GI-UKEPR-CE-06 WITH KEY DOCUMENTS

5.1 REVIEW OF THE PCSR

174 Information on the seismic design methods presented for GDA Step 4 was contained in the following sub-chapters of the March 2011 PCSR (Ref. 4):

- Sub-chapter 3.3 – Design of Category 1 Civil Structures. The sub-chapter is arranged on a structure by structure basis, such that the seismic design is spread throughout the sub-chapter. The ETC-C 2010 and reports ENGSGC100140 Rev B, ENGSDS100268 Rev A, ENGSDS100269 Rev A are referenced.
- Sub-chapter 13.1 – External Hazards Protection. Section 2 is titled "Protection Against Earthquakes".

175 Sub-chapter 3.3 has required minimal changes to reflect EDF and AREVA's response to **GI-UKEPR-CE-06**. This is because the detailed information is contained within the three finalised supporting documents (Refs. 29, 30 and 31). A new overarching document, the "EPR Nuclear Island Civil Engineering Design Process Note" (Ref. 37) has been introduced in response to **GI-UKEPR-CE-01** (Ref. 32), and this includes summary information on the seismic design methodology.

176 The updated PCSR Sub-chapter 3.3 (Ref. 5) was submitted at Issue 05 in October 2012. The changes required resulting from the resolution of **GI-UKEPR-CE-06** include the following:

- update of revisions for the three seismic methodology documents, and
- update of design rules for the common foundation raft (§6.3.1.1). SSSI will remain outside GDA scope due to its site dependency.

177 Sub-chapter 13.1 Section 2 has not required any modifications in response to **GI-UKEPR-CE-06**. This is acceptable because this sub-chapter gives a high level description of the seismic analysis methodologies and refers to sub-chapter 3.3 for the detail, which in turn refers to the three seismic methodology documents.

178 I am satisfied that the updates made to the PCSR are sufficient to describe the safety case for seismic analysis of civil structures, and to signpost the seismic methodology documents for the detailed design considerations.

5.2 REVIEW OF UK CD TO THE ETC-C 2010

179 The UK Companion Document Rev E (Ref. 21) comprises amended clauses from the ETC-C 2010 (Ref. 20) for use for the UK EPR™. The UK CD therefore takes precedence over the ETC-C 2010 for the civil engineering works design.

180 Appendix 1.A of the UK CD Rev E describes the seismic analysis methods to be used for the EPR and it references ENGSDS110268 and ENGSDS110269 as primary references for the seismic analysis of the foundation raft and the NI buildings respectively. This appendix modifies eight clauses, or parts of clauses, of the ETC-C 2010, in response to regulatory comments on the deliverables for **GI-UKEPR-CE-06**. The exact changes and the justification for each are given in "Assessment File of the UK Companion Document to AFCEN ETC-C 2010" (Ref. 51).

181 I am satisfied that the changes to the UK Companion Document adequately include the findings of my assessment of the response to **GI-UKEPR-CE-06**.

5.3 INTERFACE WITH OTHER GDA ISSUES

182 Resolution of this issue has required revisions to documents which are deliverables for other GDA Issues, as follows.

- EPR Nuclear Island Civil Engineering Design Process (Ref. 37) submitted under **GI-UKEPR-CE-01.**
- UK Companion Document (Ref. 21) submitted under **GI-UKEPR-CE-02.**
- ENGSDS100269 Rev B (Ref. 31) submitted under **GI-UKEPR-CE-04.**

183 The specifics of my assessment of these deliverables with respect to each GDA issue are given in the relevant ONR assessment report which should be read in conjunction with this report.

6 ASSESSMENT FINDINGS

6.1 ADDITIONAL ASSESSMENT FINDINGS

184 I conclude that the following assessment findings, also listed in Annex 1, should be taken forwards as normal regulatory business, in addition to those identified in the Step 4 Civil Engineering Assessment Report (Ref. 2).

> ***AF-UKEPR-CE-71**: The licensee shall justify that the final seismic analyses used for the detailed design of the UK EPR™ are adequate for the site specific conditions. Any deviations from the generic methodology documents, ENGSGC100140 Rev C, ENGSDS100268 Rev B and ENGSDS100269 Rev B shall be highlighted and adequate justification provided.*
>
> ***Required Timescale:** First structural concrete.*
>
> ***AF-UKEPR-CE-72**: The licensee shall ensure that the torsional responses of the common raft and the Nuclear Island structures are adequately modelled such that torsional effects are included in the design values for the civil works and the floor response spectra. The licensee shall justify the method selected for the site specific design of the UK EPR™.*
>
> ***Required Timescale:** First structural concrete*

6.2 IMPACTED STEP 4 ASSESSMENT FINDINGS

185 There are no impacted Step 4 assessment findings.

7 ASSESSMENT CONCLUSIONS

186 I am satisfied that the latest versions of the three deliverables for this GDA Issue, ENGSGC100140 Rev C, ENGSDS100268 Rev B and ENGSDS100269 Rev B (Refs. 29, 30 and 31) adequately justify the seismic methodologies that EDF and AREVA propose to use for the UK EPR^{TM} raft foundation and nuclear island superstructures in the context of GDA. I therefore conclude that **GI-UKEPR-CE-06** can be closed.

187 The reference design provided for GDA has substantiated the methods for the specific site of Flamanville in France, which is a very hard site. The deliverables include checkpoints to be used during the site specific detailed design with the emphasis on what may be required for a soft site, such as calculation of soil spring stiffnesses, non-homogeneous soils, soil modulus degradation and structure-soil-structure interaction.

188 There are various methods that can be used to carry out a seismic analysis as discussed in this report, and these are the choice of the designer. The methods proposed by EDF and AREVA are generally based on equivalent linear principles and reflect the fact that the design has been developed over the last decade. However, my assessment has compared them with current good practice and found that they are satisfactory provided that the simplifications used are more conservative than a detailed analysis. The licensee will therefore need to substantiate these simplifications for the site specific detailed design as part of the normal design process.

189 The methodology documents satisfactorily describe how the mass participation and the dynamic behaviour of the structure will be adequately captured by the analysis models. Clarification has been provided on how the analysis results for accelerations will be combined at each floor level to give input data for the subsequent equivalent static design for sub-structures.

190 Appendices and flowcharts have been added to ENGSDS100268 Rev B (Ref. 30) and ENGSDS100269 Rev B (Ref. 31) to clarify how ground springs are calculated from impedance functions and how the earthquake input motions are applied to the two models, FRS and CW.

191 The submission is considered sufficient for the purpose of Generic Design Assessment. Sufficient justification has been provided within reports ENGSGC100140 Rev C, ENGSDS100268 Rev B and ENGSDS100269 Rev B for the seismic analysis methodologies specified for the C1 common raft and the nuclear island structures it supports. Checkpoints have been added to the methodologies for the UK EPR^{TM} detailed design to ensure the simplified approaches are verified by the design substantiation. I have raised two assessment findings **(AF-UKEPR-CE-71** and **AF-UKEPR-CE-72)** to help insure compliance with the outcomes from **GI-UKEPR-CE-06 Rev 1**.

8 REFERENCES

Ref. Document

1 *GDA Issue GI-UKEPR-CE-06 Rev 1, Seismic Analysis Methodology.* ONR. July 2011. TRIM Ref. 2011/385293.

2 *Step 4 Civil Engineering and External Hazards Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-018 Rev 0. December 2011. TRIM Ref. 2010/581513.

3 *Resolution Plan for GI-UKEPR-CE-06.* EDF and AREVA. Rev 0. June 2011. TRIM Ref. 2011/345914.

4 *UK EPR GDA Step 4 Consolidated Pre-construction Safety Report – March 2011.* EDF and AREVA. Detailed in EDF and AREVA letter UN REG EPR00997N. 18 November 2011. TRIM Ref. 2011/552663.

5 *UK EPR PCSR – Sub-chapter 3.3 – Design of Safety Classified Civil Structures,* UKEPR-0002-035 Issue 05. October 2012. TRIM Ref. 2012/422397.

6 *ONR HOW2 document 'Permissioning - Purpose and Scope of Permissioning', PI/FWD Issue 3*. HSE. April 2010. www.hse.gov.uk/nuclear/operational/assessment/index.htm.

7 *Assessment Plan for Civil Engineering and External Hazards, Closure of GDA for the EPR*. ONR Assessment Plan ONR-GDA-AP-11-001 Rev 0. November 2011. TRIM Ref. 2011/650014.

8 *NOT USED*

9 *NOT USED*

10 *NOT USED*

11 *Safety Assessment Principles for Nuclear Facilities.* 2006 Edition Rev 1. HSE. January 2008. www.hse.gov.uk/nuclear/SAP/SAP2006.pdf.

12 ONR HOW2 Business Technical Assessment Guides
- *External Hazards.*T/AST/013 Issue 4.July 2011.
- *Structural Integrity Civil Engineering Aspects*.T/AST/017 Issue 2.HSE.March 2005
- *ONR guidance on the demonstration of ALARP (as low as reasonably practicable),* T/AST/005, Issue 4 Rev 1, Jan 2009.
- *Fundamental Principles*, T/AST/004, Issue 3, March 2010

www.hse.gov.uk/nuclear/operational/tech_asst_guides/index.htm.

13 *Safety of Nuclear Power Plants: Design Safety Requirements.* International Atomic Energy Agency (IAEA).Safety Standards Series No.NS-R-1. IAEA.Vienna.2000.www.iaea.org.

14 *Western European Nuclear Regulators' Association. Reactor Harmonization Group. WENRA Reactor Reference Safety Levels.* WENRA. January 2008. www.wenra.org.

15 *ASCE 4-98 Seismic Analysis of Safety Related Nuclear Structures,* American Society of Civil Engineers, January 2000, ISBN:078440433X.

Ref.	Document
16	*ASCE 4-09 Draft, Seismic Analysis of Safety-Related Nuclear Structures and Commentary.* American Society of Civil Engineers, Draft compiled for Santa Fe Meeting, 2011.
17	*ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities. American Society of Civil Engineers, 2005*. ISBN: 9780784407622:
18	*BS EN 1998, Eurocode 8, Design of Structures for Earthquake Resistance.* BSi British Standards Institution, CEN Comité Europeen de Normalisation. • *BS EN 1998-1:2004. Eurocode 8 Part 1. General Rules, seismic actions and rules for buildings.* 08/04/2005. • *UK National Annexe to BS EN 1998-1:2004. General Rules, seismic actions and rules for buildings.* 29/08/2008
19	*ETC-C, EPR Technical Code for Civil Works*. Rev B. 2006. TRIM Ref. 2010/404165.
20	*AFCEN ETC-C – 2010 Edition*: *ETC-C EPR Technical Code for Civil Works*. AFCEN. December 2010. TRIM Ref. 2011/430452.
21	*UK Companion Document to AFCEN ETC-C,* ENGSGC110015 Rev E, EDF and AREVA, September 2012. TRIM Ref. 2012/350151.
22	*EDF and AREVA UK EPR™ - Schedule of Regulatory Observations Raised during GDA Step 1 to Step 4.* HSE-ND. TRIM Ref. 2010/600727
23	*Response to RO-37 Step 2*.Letter from ONR to UK EPR Project Front Office. Unique Number EPR70288N. 21 January 2011. TRIM Ref. 2011/47921.
24	*GDA Close-out for the EDF and AREVA UK EPR™ Reactor* *GDA Issue GI- UKEPR-CE-05 Rev 1 – Reliability of the ETC-C*. ONR Assessment Report ONR-GDA-AR-12-001 Rev 0. March 2012. TRIM Ref. 2012/001.
25	*Common Foundation Raft and Seismic Analysis – GDA Scope.* ENGSGC100140 Rev A. EDF and AREVA. June 2010. TRIM Ref. 2011/92760.
26	*Common Foundation Raft and Seismic Analysis – GDA Scope.* ENGSGC100140 Rev B. EDF and AREVA. January 2011. TRIM Ref. 2011/85931.
27	*UK EPR - Seismic Analysis of Foundation Raft*. ENGSDS100268 Rev A. EDF and AREVA. February 2011. TRIM Ref. 2011/128837
28	*UK EPR - Methodology for Seismic Analysis of NI Buildings.* ENGSDS100269 Rev A. EDF and AREVA. February 2011. TRIM Ref. 2011/128975.
29	*Common Foundation Raft and Seismic Analysis – GDA Scope.* ENGSGC100140 Rev C. EDF and AREVA. December 2011. TRIM Ref. 2011/652047.
30	*UK EPR - Seismic Analysis of Foundation Raft*. ENGSDS100268 Rev B. EDF and AREVA. April 2012. TRIM Ref. 2012/154518.
31	*UK EPR - Methodology for Seismic Analysis of NI Buildings.* ENGSDS100269 Rev B. EDF and AREVA. May 2012. TRIM Ref. 2012/184476.

Ref.	Document
32	*GDA Issue GI-UKEPR-CE-01 Rev 1. Hypothesis and Methodology Notes for Class 1 Structures*. ONR. July 2011. TRIM Ref. 2011/385288.
33	*GDA Issue GI-UKEPR-CE-02 Rev 1. Use Of ETC-C For The Design And Construction of the UK EPR*. ONR. July 2011. TRIM Ref. 2011/385289.
34	*GDA Issue GI-UKEPR-CE-03 Rev 1. Beyond Design Basis Behaviour Of the Containment*. ONR. July 2011. TRIM Ref. 2011/385290.
35	*GDA Issue GI-UKEPR-CE-04 Rev 1. Containment Analysis.* ONR. July 2011. TRIM Ref. 2011/385291.
36	*GDA Issue GI-UKEPR-CE-05 Rev 1. Reliability Of The ETC-C.* ONR July 2011. TRIM Ref. 2011/385292.
37	*EPR Nuclear Island Civil Engineering Design Process*, ECEIG111110 Rev C, EDF and AREVA, September 2012, TRIM Ref. 2012/422394.
38	*EUR European Utility Requirements for LWR Nuclear Power Plants*, Vol. 2, Generic nuclear island requirements, Chapter 4, Design Basis (Part 2), Revision C, April 2001
39	*Design basis floor response spectra: EPR plant series*. ENGSDS050211 Rev A1, EDF SEPTEN, September 2005, TRIM Ref. 2011/155900.
40	*GDA Close-out for the EDF and AREVA UK EPR™ Reactor – GDA Issue GI-UKEPR-CE-03 Rev 1 - Beyond Design Basis Performance of the Inner Containment and GDA Issue UKEPR-CE-04 Rev 1 - Analysis of the Containment.* ONR assessment report ONR-GDA-AR-12-003 Rev 0. TRIM Ref. 2012/3.
41	*Seismic Analysis.* EPR70353N. Letter from ONR to UK EPR Project Front Office. 20 September 2011. TRIM Ref. 2011/486470.
42	*Response to ONR Comments on updates to ENGSGC100140*. EDF and AREVA. December 2011. TRIM Ref. 2011/627233.
43	*Response to ONR Comments on updates to ENGSDS100268*. EDF and AREVA. December 2011. TRIM Ref. 2011/627984.
44	*ONR Comments on updates to ENGSDS100269*. ONR. December 2011. TRIM Ref. 2011/628470.
45	*UK EPR External Hazard Assessment, Review of 3 Seismic Analysis Methodology Documents.* 2120812-R-08 Issue 1. ABS Consulting Ltd. March 2012. TRIM Ref. 2012/219499.
46	*Action1 – Seismic Design of C1 Classified Structures.* Letter from UK EPR Project Front Office to ONR. Unique Number EPR01049N. EDF and AREVA. 21 December 2011. TRIM Ref. 2011/652037.
47	*Action1 – Seismic Design of the Foundation Raft.* Letter from UK EPR Project Front Office to ONR. Unique Number EPR01125R. EDF and AREVA. 12 April 2012. TRIM Ref. 2012/154504.
48	*EDF and AREVA UK EPR™ - Schedule of Technical Queries Raised during GDA Step 1 to Step 4.* HSE-ND. TRIM Ref. 2010/600726.

Ref.	Document
49	*Action1 – Methodology for Seismic Analysis of Nuclear Island Buildings.* Letter from UK EPR Project Front Office to ONR. Unique Number EPR01145R. EDF and AREVA. 2 May 2012. TRIM Ref. 2012/184443.
50	*Additional Torsion Effects From Seismic Loading.* Report 19760/R02 Rev 1. Ramboll. May 2012. TRIM Ref. 2012/264653.
51	Assessment Files of the UK Companion Document to AFCEN ETC-C, • *Assessment File of the UK Companion Document to AFCEN ETC-C,* ENGSGC110033 Rev C. EDF SEPTEN. May 2012. • *Assessment File of the UK Companion Document to AFCEN ETC-C, (Section 2.2 to 2.5 of ENGSGC110015 D).* EDTGC120392 Rev A. EDF CEIDRE. May 2012.

Table 1: Relevant SAPs Considered for Close-out of GI-UKEPR-CE-06 Rev 1

SAP No.	SAP Title	Description
ECE.4	Engineering principles: civil engineering Investigations Natural site materials	Investigations should be carried out to determine the suitability of the natural site materials to support the foundation loadings specified for normal operation and fault conditions.
ECE.5	Engineering principles: civil engineering Investigations Geotechnical investigation	The design of foundations should utilise information derived from geotechnical site investigation.
ECE.12	Engineering principles: civil engineering Structural analysis and model testing	Structural analysis or model testing should be carried out to support the design and should demonstrate that the structure can fulfil its safety functional requirements over the lifetime of the facility.
ECE.13	Engineering principles: civil engineering structural analysis and model testing Use of data	The data used in any analysis should be such that the analysis is demonstrably conservative.
ECE.14	Engineering principles: civil engineering structural analysis and model testing Sensitivity studies	Studies should be carried out to determine the sensitivity of analytical results to the assumptions made, the data used, and the methods of calculation.
ECE.15	Engineering principles: civil engineering: structural analysis and model testing Validation of methods	Where analyses have been carried out on civil structures to derive static and dynamic structural loadings for the design, the methods used should be adequately validated.

Annex 1

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-CE-06 Rev 1

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-CE-71	*The licensee shall justify that the final seismic analysis methodology used for the site specific design of the UK EPR is adequate for the site specific conditions. Any deviations from the generic methodology documents, ENGSGC100140 Rev C, ENGSDS100268 Rev B and ENGSDS100269 Rev B shall be highlighted and adequate justification provided*	*First structural concrete*
AF-UKEPR-CE-72	*The licensee shall ensure that the torsional responses of the common raft and the Nuclear Island structures are adequately modelled such that torsional effects are included in the design values for the civil works and the floor response spectra. The licensee shall justify the method selected for the site specific design of the UK EPR™.*	*First structural concrete*

Note: It is the responsibility of the Licensees / Operators to have adequate arrangements to address the Assessment Findings. Future Licensees / Operators can adopt alternative means to those indicated in the findings which give an equivalent level of safety.

For Assessment Findings relevant to the operational phase of the reactor, the Licensees / Operators must adequately address the findings during the operational phase. For other Assessment Findings, it is the regulators' expectation that the findings are adequately addressed no later than the milestones indicated above.

Annex 2

EDF AND AREVA UK EPR™ GENERIC DESIGN ASSESSMENT

GDA ISSUE

SEISMIC ANALYSIS METHODOLOGY

GI-UKEPR-CE-06 REVISION 1

<table>
<tr><td>Technical Area</td><td colspan="3">CIVIL ENGINEERING</td></tr>
<tr><td>Related Technical Areas</td><td colspan="3">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-CE-06</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-06.A1</td></tr>
<tr><td>GDA Issue</td><td colspan="3">There is not yet sufficient justification of the methodologies proposed for the seismic analysis of the UK EPR™ and treatment of the design of the Raft foundation.</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Support assessment associated with the methodology for the seismic analysis of the raft foundation and nuclear island superstructures and provide adequate responses to any questions arising from the assessment by ONR of documents submitted during GDA Step 4 but not reviewed in detail at that time.

Based on my full assessment of the earlier reports and a limited, high level review of the reports recently received, I have sufficient confidence in the approach to conclude that it should be possible to provide a suitable demonstration of the suitability of the methodologies proposed.

With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>