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Current Practices in Defining Seismic Input for Nuclear Facilities

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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;
– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Within the OECD framework, the NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety amongst the NEA member countries. The CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The clear priority of the committee is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs the committee provides a forum for improving safety related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA's Committee on Nuclear Regulatory Activities (CNRA) which is responsible for the programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with the other NEA's Standing Committees as well as with key international organizations (e.g., the IAEA) on matters of common interest.

FOREWORD

This report has been written in the framework of the Working Group on Integrity and Ageing of Components and Structures (IAGE WG) of NEA, and more precisely with an active participation of members of the Seismic sub-group. This activity is fully consistent with the OECD/NEA-medium-term strategies for IAGE working group (2006) and the mandate of the working group.

The OECD/NEA CSNI Working Group on Integrity and Ageing of Components and Structures (WGIAGE) activity (CAPS) on seismic input definition and its control point was approved by the CSNI in June 2011. The main objective of the CAPS was to clarify current practices in Member States on the seismic input definition from far and near field sources and its control point.

OECD/NEA thanks every participant to the work and specifically the pilot of this CAPS activity Maria Jose Crespo from Principia.

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EXECUTIVE SUMMARY

This report has been written in the framework of seismic subgroup of the OECD/NEA CSNI Working Group on Integrity and Ageing of Components and Structures (WGIAGE) to provide a brief review of current practices regarding the definition of the seismic input for design and reevaluation of nuclear power plants.

It is taken for granted that, prior to conducting the seismic design of a nuclear facility, a seismic hazard analysis (SHA) has been conducted for the site where the facility is located. This provides some reference motions for defining those that will later be used as input for the dynamic analyses of the facility.

The objective of the report is to clarify the current practices in various OECD Member States for defining the seismic input to be used in the dynamic calculations of NPPs, once the SHA results are already at hand. Current practices have been summarized for Canada, Czech Republic, Finland, France, Germany, Japan, Slovenia, South Korea, Spain, Sweden, The Netherlands, United Kingdom and United States.

The main findings of the report are:

a) The approaches followed by the regulatory bodies of OECD Member States differ substantially, certainly in relation with the consideration of site effects, but also in the probability level of the event that a nuclear facility should be required to withstand.

b) In many countries a probabilistic approach is adopted for the design, in some cases combined with a deterministic one; in other cases, like France, Japan or South Korea, a deterministic approach is followed.

c) The US and Japan have the more complete guidelines in relation with site effects. The former provide specific approaches for definition of the seismic input. The latter clearly recognizes the need to propagate the bedrock motion to foundation level, thereby introducing the site effect in some way.

d) The definition of bedrock is very heterogeneous in the various countries, although this should not constitute a serious problem if the starting information is reliable and is adequately incorporated to the analysis of the soil response.

An important recommendation of this study is that a sound and widely used approach should be provided for the seismic input for design and reevaluation of the nuclear power plants.

1. INTRODUCTION

1.1 Background

The report of the CSNI Working Group on Integrity and Ageing of Components and Structures (WGIAGE) provides a brief review of current practices regarding the definition of the seismic input to be used for design and re-evaluation of nuclear power plants (NPPs).

It should be noted that the problem has been dealt with in a variety of ways in different locations and at different times; even today the approach is far from uniform, hence the interest of the present review.

1.2 Object

It is taken for granted that, prior to conducting the seismic design of a nuclear facility, a seismic hazard analysis (SHA) has been conducted for the site where the facility is located. This provides some reference motions for defining those that will later be used as input for the dynamic analyses of the facility.

The specific objective of the present report is to clarify the current practices followed in the various OECD Member States for defining the seismic input to be considered in the dynamic calculations of NPPs, once the SHA results are already at hand. The final purpose would eventually be to converge to a sound and widely used approach to the problem.

1.3 Scope

In order to satisfy the previous objective, a number of activities have been carried out:

a) Gathering of the relevant information. This concerns both the essence of the problem at hand and the current practice at a number of OECD Member States.

b) Summary description of the current practice at a number of countries, namely the United States, Japan, Canada, Finland, France, Germany, South Korea, The Netherlands, Spain, Sweden, and the United Kingdom.

c) Presentation of the observations and conclusions that arise from the review conducted.

1.4 Layout of report

The rest of the present report is organised in another five chapters and one appendix.

Chapter 2 describes the problem under consideration and offers some comments on the physical guidance that should orient its solution.

Because of the importance and extent of their documentation on the issue, the next two chapters are dedicated to the current practice in two specific countries: chapter 3 presents the US position and chapter 4 that of Japan.

The current practices of a number of OECD Member States are gathered in chapter 5, namely those of Canada, Czech Republic, Finland, France, Germany, Slovenia, South Korea, Spain, Sweden, The Netherlands and the United Kingdom.

The last chapter is dedicated to the conclusions and recommendations that arise from the review work conducted.

Finally, the only appendix lists the bibliographic and documentary references mentioned in the text of the report.

2. DESCRIPTION OF THE PROBLEM

2.1 Background

The evaluation of the dynamic response of nuclear power plants and facilities to seismic demands requires the definition of the seismic motions that must be used as input in the evaluation.

The standard methodology for arriving at those input motions starts with the derivation of some reference motions that normally correspond to those expected at the site for some regulatory mandated return periods. The reference motions are produced as one of the results of a SHA, which typically follows a probabilistic approach.

The reference motions determined correspond to the ground surface and are derived assuming that the site is made of rock and that the ground surface is horizontal in the neighbourhood of the site. They therefore represent a reasonably neutral measure of the hazard at the site, which is a function of its location with respect to the possible seismic sources, but is independent of any other characteristics of the site, such as the specific mechanical properties of the local cross-section or the site topography.

Hence it is clear that the reference motions mentioned need to be modified in order to account for local conditions such as the dynamic characteristics of the site layers, the depth or elevation at which the seismic input is to be used, and possibly the effects of the local topography. A schematic view of the problem posed appears in Figure 1. .

The design seismic motions are normally described by means of design response spectra that are meant to represent conservative envelopes of the response spectra of the possible motions at the site. For approximately the last 40 years, by iterating equivalent linear calculations, there have existed reasonable procedures for determining the motions at any depth in a horizontally layered site if the motions are known at any other depth (see, for example, Schnabel et al, 1972). Although these procedures work with accelerograms, rather than with response spectra, this does not pose a problem since the generation of synthetic accelerograms to match a target response spectrum is a straight-forward activity (see, for example, Gasparini, 1975; Woo, 1987).

Consequently, if the motions are given at the surface of a horizontally layered soil site, there is no problem in determining the corresponding motions at bedrock level, a process known as deconvolution. Likewise, given the motions at the bedrock level at some depth, the convolution of the bedrock motions will yield the motions at the ground surface.

One final observation is that, depending on the characteristics of the local ground profile, during the vertical propagation of horizontally polarized shear waves, up and down the ground profile, some of the frequencies will inevitably experience amplifications while some others will be reduced; the specific frequencies affected are a function of the thicknesses and impedances of the intervening ground layers.

2.2 Site effects

The observations in the previous section are all well-known and recognised. The problems start to arise when trying to adopt a methodology for converting the reference motions produced by the SHA (at the surface of a generic rock site) to those that are needed as input for the dynamic analyses of the facility (at the appropriate depth in the local ground cross-section). The modifications that need to be introduced in order to go from the former reference motions to the latter design motions are generally gathered under the common denomination of “site effects”.

Many different situations may be found: in very few lucky cases, the soil where the SHA provides its results is the same as that on which the NPP will be founded; in some others the reference soil can be found at some depth below the NPP foundation; and finally there will be some situations in which that reference soil, usually characterised by a shear wave velocity, is completely independent of the one underlying the NPP. These situations are to be combined with the fact that the NPP can have a surface foundation or an embedded one, the latter being the more common situation. A graphical representation of the various possible cases is described by Figure 2. .

The problems encountered are not simple, as evinced by the variety of answers provided. Ideally the incorporation of the so-called site effects should allow establishing the input motions at any desired elevation, with any ground profile, and for any type of foundation (surface, embedded, or deep foundations). And this should be achieved while maintaining technical consistency, avoiding the paradox of obtaining different results when using theoretically equivalent means to reach a certain answer, and without introducing any penalties or benefits that lack a sound technical basis.

The rest of the report will briefly present the current approaches employed in a number of countries, thereby shedding additional light on the nature of the problem.

Figure 1. General outline of the problem

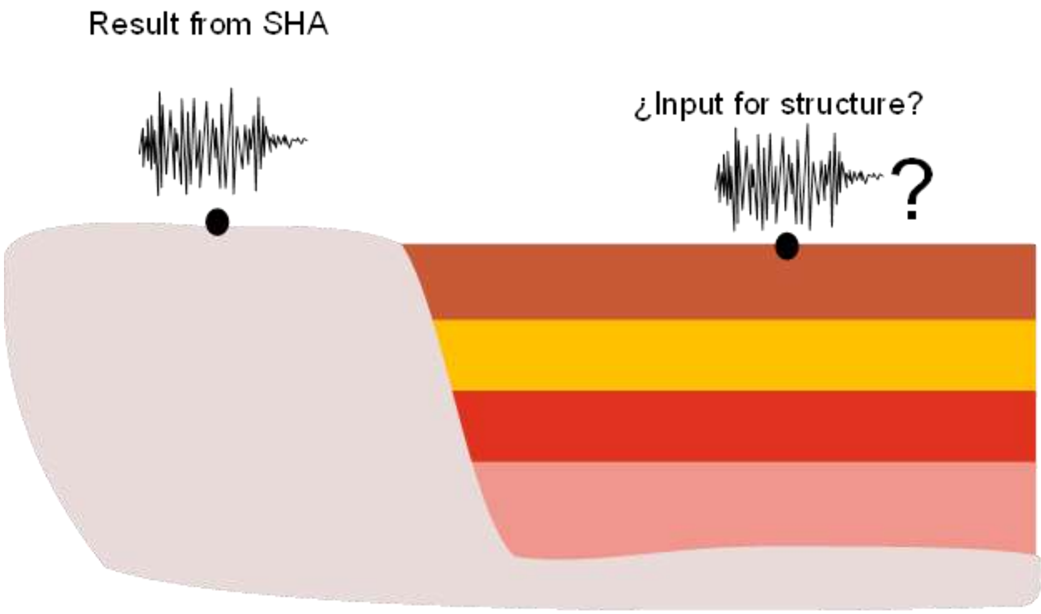
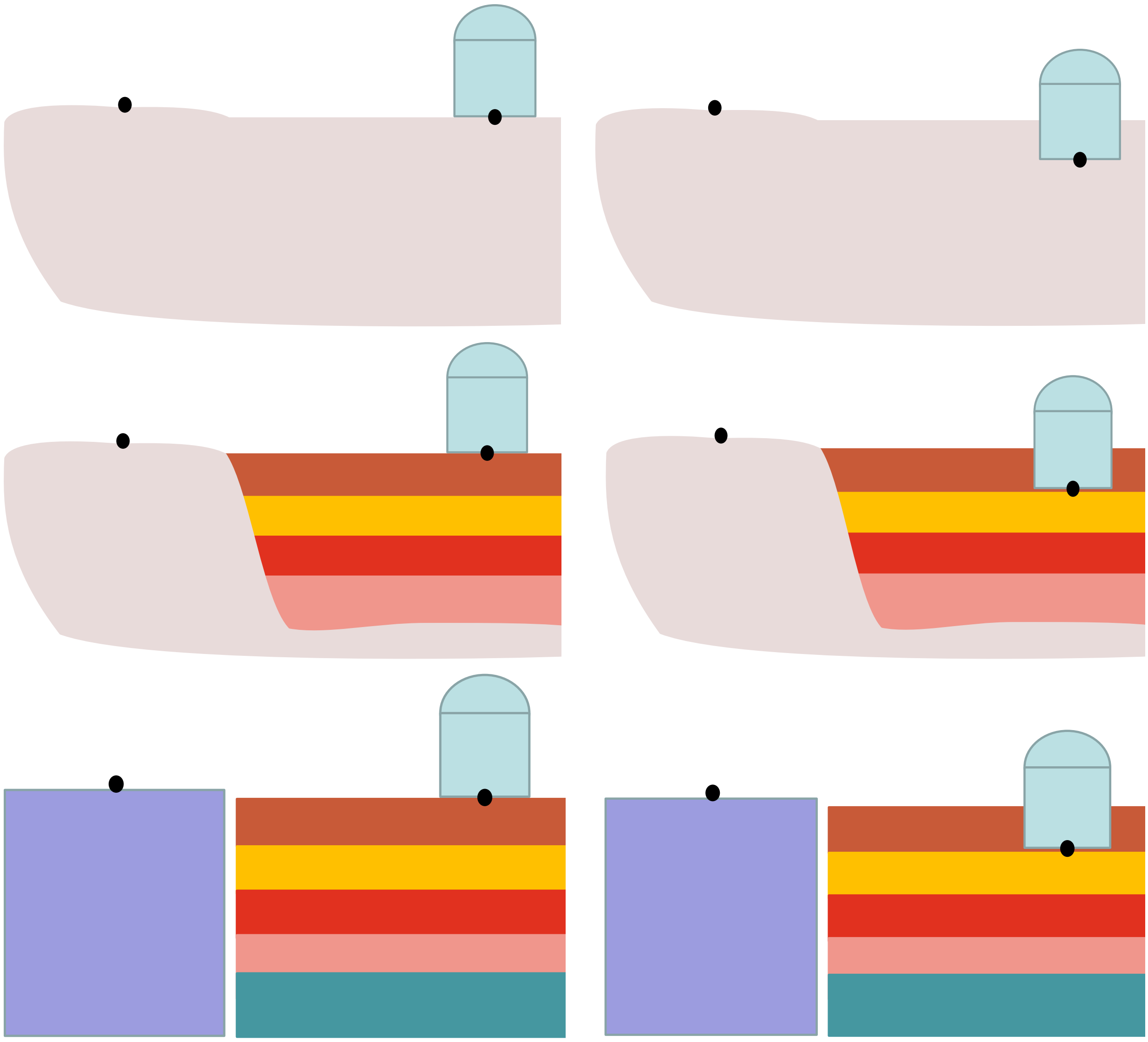


Figure 2. Examples of situations that might have to be faced



3. CURRENT PRACTICE IN THE UNITED STATES

The United States has produced extensive documentation in relation with the calculation of the site effect. The more relevant documents dealing with this issue of site effects are the following:

- Regulatory Guide (RG) 1.208, entitled "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion" (NRC, 2007).
- "Interim Staff Guidance on Ensuring Hazard-Consistent Seismic Input for Site Response and Soil Structure Interaction Analysis" (NRC, 2009).
- The NEI (2009) white paper entitled "Consistent Site-Response Soil-Structure Interaction Analysis and Evaluation".
- The BNL (2009) report entitled "Consistent Site Response - SSI Calculations".

RG 1.208, in its Appendix E, provides general guidance on methods acceptable to the Nuclear Regulatory Commission (NRC) staff for determining the characteristics of seismic wave transmission (soil amplification) of soil and rock sites and for determining site-specific Ground Motion Response Spectra (GMRS).

ISG-017 describes in detail the position of the NRC staff on, among a number of other points, how to derive Foundation Input Response Spectra (FIRS) that are consistent with the site response by employing either one of two options, namely the proposals presented in the reports by NEI (2009) and by BNL (2009), respectively.

In US practice the starting point is the determination of the UHS (Uniform Hazard Spectrum) for a rock site and for two levels of probability: 10^{-4} and 10^{-5} yr^{-1}. Following the concept of what constitutes a rock site, the UHS is expected to be defined at an elevation below which the shear wave velocity is higher than 3000 m/s.

The references to the consideration of the site effect, in both the NEI (2009) and the BNL (2009) reports, are made in the context of conducting SSI (Soil Structure Interaction) calculations. The objective is to obtain a FIRS, which is a site-specific motion in free field but already corresponding to the elevation of the foundation.

Although the methodologies proposed in the NEI and BNL reports present some differences and highlight different aspects of the process, they also share a number of common points:

- The question of whether it is a surface or embedded foundation is an important aspect to consider. In fact, the main differences between the two methodologies hinge on this particular aspect.

- The variability of the soil properties is taken into account by means of a random generation of a number of soil profiles along which the wave propagation is analysed.
- Considerable attention is paid to the definition of "outcrop", a point that is extensively discussed in the BNL (2009) report.
- The studies conducted prior to the SSI calculation must produce best estimate (BE), lower bound (LB), and upper bound (UB) sets of strain compatible soil profiles, all of which will then be taken into account in the SSI analyses.

In the case of a surface foundation, the soil column is modelled with its full height and the UHS is placed at outcrop competent material in free field. A number (some 60) of randomly generated soil profiles are to be calculated. The results to be retained are the strain compatible soil properties describing the BE, LB, and UB profiles (which will then be included in the SSI calculations), and the Soil Column Surface Response (SCSR), which in this case coincides with the FIRS.

In the case of an embedded foundation, as indicated previously, the differences between the two reports are more significant, the main one being the definition of "outcrop". Nevertheless, in both cases, as also was the case for a surface foundation, the soil column is modelled with its full height and the starting point is still the UHS placed in free field at outcrop competent material. In this case the SCSR and the FIRS are not the same and each of the two reports presents in detail its methodology for conducting the operations required for obtaining the FIRS.

4. CURRENT PRACTICE IN JAPAN

The three reference documents in relation with the seismic design of NPPs in Japan are:

- NSCRG L-DS-I.02 “Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities”; (NSC, 2006)
- Outline of New Regulatory Requirements for Light Water Nuclear Power Plants, (Earthquakes and Tsunamis); (NRA, 2013)
- JEAG4601-2008 “Design Code of the Japan Electric Association”; (JEA, 2008), (In Japanese).

The Japanese regulatory stance requires the SHA exercise to provide an earthquake magnitude and a focal distance, which will be taken into account when generating the motions employed in the NPP design calculations. The magnitude and distance are usually estimated for each identified fault/source by considering uncertainties in source size and location.

It is worth noting that, when the SHA is being carried out, two types of seismicity must be considered: the activity arising from specific seismic sources and the so-called diffuse seismicity.

Regarding the probability level for which the seismic input is to be determined, the regulations only indicate that a very low probability earthquake should be used for design, but they do not specify a specific return period or equivalent probability measure. This approach is therefore conceptually closer to deterministic than to probabilistic considerations.

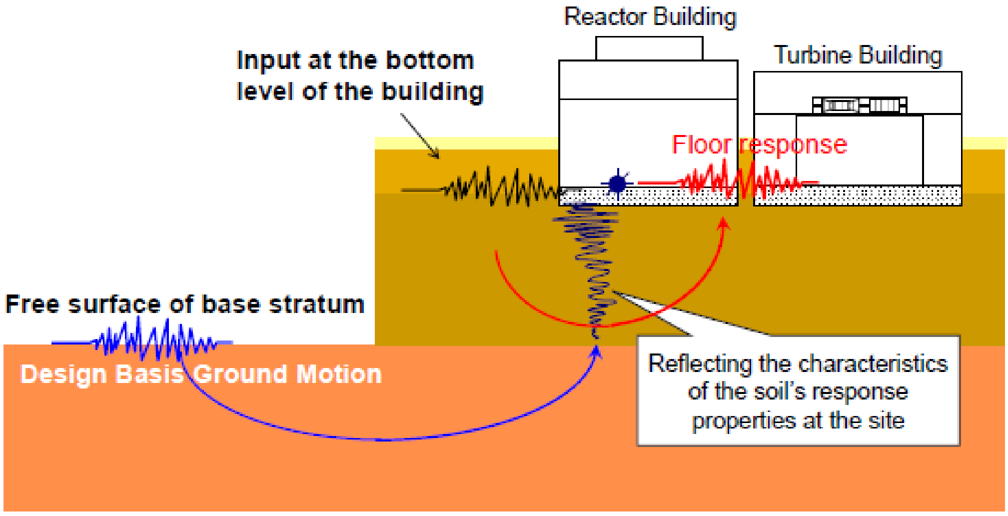
Once the SHA has been carried out, the resulting response spectrum has to be compared with the regulatory spectra given in JEAG4601-2008, one of which will have to be selected for the design of the plant.

Site-specific ground motions are required to be determined from those specific seismic sources on the basis of seismic source characterization and ground motion modelling. For diffuse seismicity, the regulation requires to appropriately formulating the ground motion by collecting and analysing strong motion records as well as taking into considers the site characteristics. As a result, pseudo velocity spectra are provided as the free-field motions on a certain stratum with Vs not less than 700m/s. These are known as the Design Basis Ground Motion (DBGM).

The regulations explicitly recognise the need to propagate the DBGM to the foundation level of the building being analysed. This propagation is conducted assuming that the DBGM occurs at bedrock level and taking into account the mechanical characteristics of the soil at the site. Figure 4-1, taken from a presentation by TEPCO (2012), provides a graphic visualisation of the process by which site effects are incorporated to the control motions imposed at the base of the structure.

It may me noted that, if the DBGM is a smooth spectrum, the convolution from bedrock to foundation level will produce amplifications at the lower vibration frequencies of the intervening strata, together with reductions at other frequencies.

Figure 1. Japanese idealisation for obtaining the site specific seismic input



5. CURRENT PRACTICE IN OTHER MEMBER COUNTRIES

5.1 Canada

The Canadian documents or standards that are most relevant to seismic input are published by the Canadian Nuclear Safety Commission (CNSC) and the Canadian Standards Association (CSA). They are the following:

- "Site Evaluation for New Nuclear Power Plants", Regulatory Document 346 (CNSC, 2008a)
- "Design of New Nuclear Power Plants", Regulatory Document 337 (CNSC, 2008b)
- "Ground Motion Determination for Seismic Qualification of Nuclear Power Plants", N289.2-10 (CSA, 2010a)
- "Design Procedures for Seismic Qualification of Nuclear Power Plants", 2010, N289.3-10 (CSA, 2010b)

CSA N289.2-10 requires a Probabilistic Seismic Hazard Assessment (PSHA) to be performed reporting the results for a 10^{-2} to 10^{-5} range of annual probability of exceedance, together with the associated confidence levels accounting for uncertainty. It is required that the reference ground condition associated with the PSHA results be given (i.e. in terms of shear wave velocity), so that the resultant seismicity can be associated with a specific elevation at site. The use of scenario earthquakes, derived through hazard deaggregation, as the strongest magnitude-distance contributors, is also considered. The specification of the Design Basis Seismic Ground Motion (DBSGM) is an outcome from the PSHA. As a minimum the design seismic ground motion, represented by a DBE, shall have a 10^{-4} annual probability of exceedance at the mean confidence level.

Use of standard shape spectra, based on Newmark and Hall (1978), is also maintained in the CSA framework. The main reason is the fact that there is still no established, precise, scientific correlation between UHS and its interpretation when used for engineering design purposes.

CSA N289.3-10 requires that the above defined response spectra shall be modified (i.e. convolved) to account for overburden above the elevation associated with it. The result of the modification to be used as input for SSI analysis is allowed to be at top surface or at foundation level.

5.2 Czech Republic

In the Czech Republic the general act governing all activities in the field of nuclear energy was adopted on January 1997; its Decree No. 215 entitled "Site Evaluation for New Nuclear Power Plant" sets out criteria for the siting of nuclear facilities and very significant ionising radiation sources. Additionally, there is a general seismic code, the Czech National Standard

CSN EN 1998-1 entitled “Design for Structures for Earthquake Resistance”, employed only for civil structures and which is Eurocode 8 that has been officially adopted; hence, none of the cited codes defines the seismic input required for NPPs.

At present in the Czech Republic there are two NPPs, one in Dukovani and the other in Temelin. The country is in an area of low seismicity and the level of acceleration of the seismic input was defined as the minimum PGA of 0.10g required by IAEA Safety Guide 50-SG-S1, today superseded by IAEA Safety Guide SSG-9.

For the calculations of the existing NPPs, actual time histories, scaled to the design PGA were employed.

It is foreseen that IAEA SSG-9 would be employed for future calculations. This guideline explicitly indicates that the seismic hazard analysis should take account of the site response, although no specific guidance is provided on how to do it. However, the IAEA is actively working on the development of detailed documents that enlarge the different areas covered by SSG-9, so it is most likely that over the medium term the IAEA will provide specific guidelines dealing with how to define a seismic input that takes into account the specific site conditions.

5.3 Finland

In Finland there is a recent regulatory guide that governs the consideration of internal and external hazards in a nuclear facility (STUK, 2013). Its chapter 4 is devoted to earthquakes.

Section 4.1 of the guide deals with the definition of the design basis earthquake. The SHA has to provide values for the peak ground acceleration (PGA) at the site corresponding to a probability of exceedance of 10^{-5} yr^{-1}. Additionally earthquakes stronger than the design basis one shall be taken into account as Design Extension Conditions (DEC), and suggest the use of fragility curves of equipment.

The guide indicates that relevant foundations shall be preferably founded directly on bedrock; in case this is not possible a soil-structure interaction analysis is required, in addition to the ground response spectrum. This may be taken to indicate that the consideration of site effects, if needed, would be specifically evaluated by the Regulator.

5.4 France

In France the regulatory guide “Règle fondamentale de sûreté no. 2001-01 relatives aux installations nucléaires de base” has as object the definition of the seismic hazard for nuclear installations, with the exception of long-term nuclear waste repositories. The definition of the seismic hazard is made in a deterministic way; two earthquakes are defined and response spectra are required for each earthquake in the horizontal and vertical directions.

In its section 2.3.4, it makes reference to how to consider site effects, indicating two possible site conditions as a function of the shear wave velocity. If the site under consideration does not belong to any of the two categories, a specific site analysis is needed.

Besides the previous standard, in France, since May 2011, the seismic code to be followed for all new buildings is Eurocode 8 (EC-8), namely Part 1 (CEN, 2005a), Part 3 (CEN, 2004), and Part 5 (CEN, 2005b).

The geotechnical aspects are dealt with in Part 5. Its Annex A, which is only informative at this point, is dedicated to the topographic amplification factor and provides some guidance on how the site effects should be studied and considered in the calculations.

More specific for NPPs is the "Règle Fondamentale de Sûreté no. 2001-01" (ASN, 2001) in relation with NPP installations. In its section 2.3.4 it makes reference to how to take site effects into account: the standard considers two possible site conditions as a function of the shear wave velocity in the upper 30 m. If the site does not conform to any of these two types, a specific site analysis is required.

Additionally, there is an ongoing research and development project, codenamed SIGMA, dealing with the characterisation of the seismic ground motions in France and nearby countries. Its Work Package 2, entitled "Improvement of Local Site Conditions Representations" is dedicated to the study of site effects through the development of methods and tools for evaluating sites where this type of effects are potentially important.

Finally, in December 2011 a new document was published by the French nuclear regulator (ASN, 2001) with complementary safety assessments in the context of the European Stress Tests. In this document it is also indicated that the approach used to define the seismic loads has to take account of soil effects.

5.5 Germany

The current standard in Germany is KTA 2201 "Design of Nuclear Power Plants against Seismic Events". Its first part, entitled "Basics", was translated recently into English and it appears that the second part, devoted to subsurface materials (soil and rock), will also be translated shortly.

According to this standard, both deterministic (scenario based) and probabilistic seismic hazard analyses have to be performed.

With the present regulation, the ground response spectra must be specified as free field response spectra for the site-specific uniform "reference horizon". There is no clear definition of the reference horizon in the regulation, although it is usually assumed to be the ground surface; however, in some cases the reference horizon may be the surface of a stiff soil characterised by a V_s above 300 m/s or the definition indicated in the corresponding seismologic study in agreement with the hazard results.

The standard pays particular attention to the events with a 10^{-5} yr^{-1} probability of exceedance.

5.6 Slovenia

The Slovenian Nuclear Safety Administration (SNSA), apart from licensing procedures with respect to siting, construction, trial operation, operation and decommissioning of nuclear facilities, is also responsible of the classification of such facilities between nuclear, radiation and less important radiation facilities.

There are Slovenian regulations generally dealing with the question of nuclear safety, specifically the Act on Ionising Radiation Protection and Nuclear Safety (Official Gazette of the Republic of Slovenia, 2004) and the Rules on Radiation and Nuclear Safety Factors (Official Gazette of the Republic of Slovenia, 2009). The latter explicitly mentions earthquakes among the natural phenomena that the nuclear installation has to withstand, but does not make specific reference to the seismic input.

As a matter of fact there are no standards that deal with the definition of the seismic input for the nuclear installations. For the existing SHAs the US NRC Regulatory Guides 1.60 (NRC, 1973) and 1.61 (NRC, 2007) have been considered, as well as some IAEA Standards.

The first SHA conducted in the seventies was deterministic; however, the analyses performed in the course of the re-evaluations were probabilistic and the target probability level for the SSE corresponded to median values for a 10,000 year return period.

The ground motion used in the original design complied with the NRC RG 1.60. The input ground motion was applied directly to the soil spring model without a previous deconvolution to the foundation level. The motions used were synthetic records matching the design spectrum.

During subsequent operations of the nuclear installations, like power upgrades or steam generator replacements, the site effects were taken into account using programs like SHAKE (Schnabel et al, 1972) or the STARDYNE computer software.

5.7 South Korea

The Nuclear Safety and Security Commission (NSSC) is the governmental regulatory authority for nuclear facilities in Korea. The Korea Institute of Nuclear Safety (KINS) is an independent technical organization that supports the NSSC in several regulatory activities such as safety reviews and inspections, research and development of regulatory standards or the development of policies and systems for nuclear safety regulation.

The Korean Nuclear Standards that constitute the reference for the definition of the seismic input for nuclear facilities are:

- KINS Regulatory Guide (RG) N01.07 “Determination of Site-specific Design Earthquake Ground Motions,” (KINS, 2011)
- KINS Safety Review Guidelines (SRG) for Light Water Reactors 3.7.1 “Seismic Design Parameters” (KINS, 2009)
- KINS SRG 3.7.2 “Seismic System Analysis,” (KINS, 2009)
- Korea Electric Power Industry Code (KEPIC) STB, “Seismic Analysis and Seismic Capacity Evaluation for Nuclear Facilities,” (Korea Electric Association, 2010)

The KINS RG and KINS SRGs were approved by the NSSC; KEPIC STB was endorsed by an NSSC Notice for application to nuclear facilities in Korea. They have not been translated into English yet.

KINS RG N01.07 requires a deterministic SHA for the definition of the site-specific design earthquake ground motions. The RG also requires the consideration of uncertainties in the estimation of the maximum ground motions, which should be evaluated with a probabilistic SHA. The annual probability of exceedance in the case of the probabilistic approach should be less than 10^{-3}.

The cited standards do not clearly define “bedrock” for determining site-specific design earthquake ground motions.

KINS SRG 3.7.1 and 3.7.2, as well as KEPIC STB require that the seismic input motion should be defined at outcrop or a hypothetical outcrop. They also require that the SSI effects (including site response) should be considered if there exist shear wave velocities below 2.4 km/s beneath the structure.

Regarding the methodological aspect, any state-of-the-art proven methodology could be utilized. KINS SRG 3.7.2 and KEPIC STB provide detailed guidance on several aspects related on how to take into account site and SSI effects in the seismic response analysis of structures; for instance, they require that at least three soil profiles (best estimate, lower bound and upper bound) be considered in SSI and site effect analyses. At the same time KINS RG N01.07 allows to use standard response spectra for seismic design of nuclear facilities provided they are scaled to the corresponding acceleration of the site-specific design earthquake.

5.8 Spain

Traditionally no specific standards or guidelines are issued by the Spanish nuclear regulatory authorities.

The licensing procedures used for the existing facilities have normally consisted in applying the regulatory framework of the country originating the main equipment of the plant. Although not all of those plants remain in operation today, Spain operates or has operated plants in which the main equipment originated in three different countries, specifically France, United States, and Germany.

5.9 Sweden

The Swedish regulations do not include specific guidance on how site effects should be handled in seismic analyses.

However in 1992 the Swedish Nuclear Power Inspectorate (SKI) sponsored the joint research program named “Project Seismic Safety”, directed SKI but also involving several other several institutions. As a result of this program, the SKI Technical Report 92:3 entitled “Characterization of seismic ground motions for probabilistic safety analyses of nuclear facilities in Sweden” (SKI, 1992) was published. At present this is the reference document for definition of the seismic input at the Swedish NPPs.

The aim of the project was to develop methods for calculating the ground response that could be used in the safety analysis of nuclear power plants in Sweden, as well as to demonstrate its application to the power plants at Ringhals and Barsebäck. In this document, a complete approach is presented for the generation of the seismic input of these two NPPs, including the construction of site specific design response spectra with the modelling of specific site conditions (i.e. soil layers). More specifically, the sedimentary bedrock and soil strata overlying the basement rock were modelled by finite elements. The basement rock where the finite element model starts has a shear wave velocitiy of 3400 m/s.

At present there is a Swedish Safety Guide, still in a draft status, which refers to SKI Technical Report 92:3 apart from other well-known standards. The annual exceedance probabilities of interest are 10^{-5} and 10^{-6}, as in the SKI Technical report 92:3; the Seismic Margin Assessment (SMA) method according to EPRI (1991) is recommended and the US NRC RG 1.61 (NRC, 2007) may be used when choosing damping values.

5.10 The Netherlands

The Dutch Nuclear Safety Regulations (abbreviated as NVR, from Nucleaire Veiligheidsregel in Dutch) are based on the guidelines of the International Atomic Energy Agency (IAEA). These guidelines are linked to the licence of the Borssele NPP (currently the only nuclear plant in The Netherlands). Guides like SSG-9 and NS-G-3.3 are part of the licence.

The Netherlands is a country with fairly low seismicity. Consequently earthquakes and ground motion have not been among the main subjects considered in the past. A 1996 attempt to regulate the protection of NPPs against external hazards resulted in a document, entitled "Guidelines for the Protection against External Hazards" and known as NVR3.1, which never became official. This document was based on the IAEA Safety Series No. 50-SG-S1 and No. 50-SG-D15, which were later superseded by SSG-9 and NS-G-1.6, respectively. However, recent initiatives to build new nuclear installations have led to a process of evaluation of the existing Dutch Safety Requirements, including those covering seismic issues, and to attempts to update the existing guidance. This process is still ongoing.

The document NVR3.1 provides values of the peak ground acceleration for five different zones of the country and for two probability levels. The latter are earthquake SL-1, which corresponds to an exceedance probability of 10^{-4} yr^{-1}, and SL-2, which corresponds to one of 10^{-6} yr^{-1}.

The recommendations refer to the definition of design spectra without accounting for any site-specific characteristics of the ground. It is expected that the consideration of the site effect will follow the provisions expressed in the IAEA guidelines.

For the Borssele NPP site, the intensity was originally determined by translating it into a ground response spectrum using the USAEC spectra which are mentioned in US NRC Regulatory Guide 1.60 (NRC, 1973). It is however considered that this standard is quite inadequate for the site (and even for The Netherlands). This was acknowledged in the recent stress test. In one of the safety evaluations new ground response spectra are defined using the Hosser (1987) methodology (more appropriate for low seismic zones).

5.11 United Kingdom

The regulation of the safety of nuclear installations in the United Kingdom is the responsibility of the Office for Nuclear Regulation (ONR). The ONR has developed and published a set of technical safety principles, which are the ones used to evaluate the licensees' safety cases; these are gathered in the Safety Assessment Principles for Nuclear Facilities, known as SAPs (ONR, 2006). The latest version of the SAPs, Revision 1 published in 2006, was benchmarked against the existing IAEA safety standards.

The SAPs are a set of integrated principles. Whilst the topic of seismic input definition is specifically considered in the SAPs, the selection of the control point is not explicitly addressed; nevertheless there are a number of safety principles that relate to what is expected from such an evaluation.

The site specific seismic hazard should be derived for an expected return period of 10 000 years (SAP EHA.4: The design basis event for an internal and external hazard should conservatively have a predicted frequency of exceedance in accordance with the fault analysis requirements (FA.5)). SAPs EHA.9 (The seismology and geology of the area around the site and the geology of the site should be evaluated to derive a design basis earthquake (DBE)) and

ECE.5 (The design of foundations should utilise information derived from geotechnical site investigation) provide information from which site response studies can be performed, a part of which will be to determine the control point.

In addition to the SAPs, ONR also has published the Technical Assessment Guides (TAGs) that provide guidance on the interpretation and application of the SAPs. In this respect the T/AST/013 (ONR, 2014) in its Annex 3 devoted to Earthquakes indicates "*...for natural hazards the design basis event should be that which conservatively has a predicted frequency of not being exceeded of 10-4 per year (often, though not strictly accurately termed the once in 10,000 year event)*". This same document refers to the local site effects. It requires that it is clear where the seismic motion is being derived for (outcropping, within layers, free field…), it recognises the potential need of deconvolution models and calls the attention on the high sensitivity that results may have on the assumptions made with respect to the soil profile characterisation.

In brief summary, and consistently with the spirit of the UK nuclear regulatory approach, the SAPs, supplemented by the TAGs, provide a general framework and some guidance for the regulatory process, helping to establish whether the definition of the seismic input and the selection of the control point are appropriate, it recognises the need of considering the local site effect, but no specific rules or requirements are explicitly stated.

6. IDENTIFIED ADVANTAGES AND SHORTAGES

At present, the site response calculations are not routinely included in the seismic hazard analyses, although the need to do so is recognised and demanded in many codes or standards.

Given that the scientific community agrees on the need to incorporate the site effect in the calculations, the codes and standards should include an explicit recognition of the need to perform such study. This is the case in many of the countries reviewed, namely Canada, France, Japan, South Korea and United States, although the level of detail provided about the characteristics that such study should have differs from one country to another.

The present section lists the advantages and shortages identified during the compilation performed. The object is to provide useful orientations to countries and organisations aiming at the development of guidelines or standards related to the site response calculation.

Additionally, a table the compares the main points that defines the situation in each country is presented at the end of this section (Table 1).

Some of the advantages identified in the different methodologies reviewed in the document follow:

- Having detailed guidance on a recommended procedure is a very helpful resource, even though other procedures could also be acceptable; the inclusion of practical examples is especially useful. This is the case, for example, of the United States and will probably be the case of France once the ongoing research project SIGMA is completed.
- Providing graphical visualization of the process to be modelled makes the calculation more intuitive. The material presented by Japan includes some graphical material of this type; additionally an example figure that shows some idealized situations that might have to be faced has been prepared for this document.
- The seismic hazard curve and/or the uniform hazard spectra should be associated with reference soil conditions. In particular, this is necessary if the input for the site effect calculation is to be consistent with the assumptions made during the first part of the SHA as stressed in the Canadian regulatory context.

Concerning the shortages, the following points have been pointed out:

- There is no uniformity on the target probability of the design. It is true that in principle each country is responsible of choosing its own design probability, but since the consequences of nuclear accidents do not respect political boundaries, a minimum international consensus would be very desirable.
- In some cases, codes or standards make reference to “bedrock”. The difference between geotechnical bedrock and seismic bedrock should be clearly stated. It should also be recognised that the characterization of the seismic bedrock can be region dependent, so depending on the country size it could vary within the area of application.

Table 1. Comparison between Member States

	Does it have national specific standards for definition of seismic input for nuclear sites?	**Is SHA expected to be deterministic, or probabilistic? (target probabilities)**	**Does it recognise the need to account for local response?**	**Is there specific guidance for the local site response calculation?**
Canada	Yes	Probabilistic (10^{-4})	Yes	No
Czech Republic	No, probably SSG-9 to be adopted	--	--	--
Finland	Yes	Probabilistic (10^{-5})	Yes, although it prefers founding directly on bedrock.	No
France	Yes	Deterministic	Yes	No, but gives two different spectral shapes depending on soil conditions.
Germany	Yes	Both (10^{-5})	Not explicitly, but defines input on “free field”	No
Japan	Yes	Deterministic	Yes	Yes
Slovenia	No, follows US regulation.	--	--	--
South Korea	Yes	Both (< 10^{-3})	Yes	No
Spain	No, follows US regulation.	--	--	--
Sweden	No regulations, but a technical research document serves as guidance, safety guide in draft	Probabilistic (10^{-5})	Yes (technical document)	Yes
The Netherlands	IAEA guides officially adopted, plus unofficial guidelines.	Probabilistic (10^{-4} and 10^{-6})	Yes (as per IAEA guidelines)	No
United Kingdom	No (only general principles)	Probabilistic (10^{-4})	Yes.	No
United States	Yes	Both (10^{-4} and 10^{-5})	Yes	Yes

7. CONCLUSIONS AND RECOMMENDATIONS

Once a seismic hazard analysis has been conducted for the location of a nuclear facility, some steps must be undertaken leading to the definition of the design motions that will be used for dynamic analysis of the facility. The current practices for performing this task in a number of OECD Member States have been reviewed in this report.

Following that review, a number of conclusions and recommendations can be offered:

a) It appears that the approaches followed by the regulatory bodies of the OECD Member States differ substantially, certainly in relation with the consideration of site effects, but also in the probability level of the event that a nuclear facility should be required to withstand.

b) On the probability levels that should guide the design, some of the countries bypass the question by adopting a near-deterministic approach, such as the "maximum", or a "very low probability", event. Countries like France, Japan or South Korea employ this approach.

c) The US and Japanese guidelines are the more complete ones in relation with site effects. The former provide specific approaches for the definition of the seismic input at the control point. The latter clearly recognise the need to propagate the bedrock motion to foundation level, thereby introducing the site effect in some way.

d) The definition of bedrock is very heterogeneous in the various countries, although this should not constitute a serious problem if the starting information is reliable and is adequately incorporated to the analysis of the soil column response.

APPENDIX I

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APPENDIX II

QUESTIONNAIRE FOR MS

1. Give a brief description of the role of the Nuclear Regulator in your country. This description should help the understanding of the existing regulations.

2. Which is(are) the standard(s) considered as reference for the definition of the seismic input for the NPPs?

Questions 3 to 9 refer to the document(s) indicated in question 2.

3. Is the SHA expected to be deterministic, probabilistic or both?

4. If a probabilistic approach is required, which are the target levels of probability?

5. Is “bedrock”, or an equivalent concept, defined in the standard?

6. Does the standard recognise the need to modify the result of the SHA for use in the dynamic analyses of the plant? (i.e. to consider the site effect)

7. Provide any other relevant information in relation with the definition of the seismic input.

If answer to question 6 is positive, go ahead with Questions 8 and 9.

8. Does the standard refer to any specific methodology?

9. Does it mention any specific software?

10. Provide any other relevant information in relation with the consideration of the site effect.