Siting of Standard Design Power Reactors in High Seismicity Areas by means of Seismic Isolated Foundations

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Abstract – *ENEL and EDF are jointly developing a feasibility study for the seismic isolation of EPR™ Nuclear Power Plant.*
The application field of this project aims at broadening the adaptability of EPR standard design to all sites with moderate to high seismicity, characterized by more severe values of seismic actions than those defined in the EPR standard project. The particularity of this pioneering study consists also in the unfamiliar use of seismic isolation solutions with very soft soil characteristics, sometimes combined with high seismicity.
The seismic protection of the nuclear buildings by means of seismic isolators has been chosen in order to minimize changes to the standard design of the civil works and internal components of the EPR Nuclear Power Plant. The work will lead to the identification of the optimal design solution, in terms of type and location of seismic devices, to achieve compliance to the floor response acceleration spectra in horizontal and vertical direction as defined in the EPR standard project, with levels of horizontal displacements not exceeding the maximum acceptable values for structural and non-structural elements.
The ENEA agency was commissioned by ENEL to perform the sizing of the seismic isolation system and the definition of the preliminary layout of isolators. These results are used as starting point for transient dynamic analyses, including soil-structure-interaction, aimed at assessing the behaviour of the whole isolated structure.
Moreover, the study explores the main issues that raise in case of application of seismic isolation systems to nuclear installations such as durability and inspection requirements, maintenance, replacement and qualification process.

I. INTRODUCTION

In the framework of the EPRIT Project aimed at the development and construction of four EPR units in Italy, developed jointly by ENEL and EDF as a result of the agreement between the Italian and French Governments, a feasibility study aimed at identifying the most appropriate solution for increasing the seismic protection of the EPR Nuclear Island was launched by the two Companies.

Both Companies were interested to enhance the seismic capacity of the EPR nuclear systems, structures and components (SSCs) against earthquakes more severe than those considered in the EPR standard project in order to:

- reduce the influence of the site seismicity on siting criteria applied by ENEL for the selection of Italian sites suitable to accommodate a nuclear power plant,
- increase the standardization of the nuclear SSCs of the EPR Standard design, developed by EDF in collaboration with Framatome/AREVA, Siemens and major German utilities.

The EPR Standard design has purposely been developed to be suitable for a very wide site selection and compliant with the requirements of the major nuclear regulations. The standard level chosen for seismic design was 0.25g (peak ground acceleration) according to EUR[1] requirements evaluated for a wide range of soil's stiffness with shear wave velocities ranging from 280 m/s (softest soil) to 2500 m/s (hardest soil). Moreover, an additional safety margin of 1.4 on the seismic peak ground acceleration (0.35g) was ensured with a classical SMA at the design stage of the project. Nevertheless, the high seismicity of the Italian territory together with the difficulty to identify site with low population density required to do not exclude as suitable to house an EPR power plant those sites characterized by peak ground acceleration in the horizontal direction up to 0.5g and very soft soil condition, such as those of the Po Valley.

The most appropriate solution to protect SSCs against strong earthquakes was identified in the implementation of a seismic isolation system at the base of the whole EPR nuclear island, being at the same time a strongly effective and relatively inexpensive solution.

The seismic protection offered by the seismic isolation system is the de-coupling of the horizontal movement of the structure from the ground motion. The seismic devices realize a filter effect of seismic forces through their horizontal flexibility and energy absorption capability.

Accordingly, the main technical objectives to be achieved by the design of a seismic isolation system of the EPR nuclear island are:

- reduction of the seismic acceleration of the structure to avoid structural damage and lose of functionality during the earthquake ensuring that the structure remains in the elastic field for the design earthquake;
- reduction of the floor accelerations corresponding to high frequencies to achieve the compliance to the floor response acceleration spectra in horizontal and vertical direction as defined in the EPR standard project;
- limitation of the horizontal displacements inside the range of acceptable values so that they can be accommodated by expansion joints of piping;
- safe behaviour for earthquakes beyond the design level.

In this way major changes and structural improvements aimed at increasing the seismic capability of the buildings and components located inside them can be avoided with significant benefit in term of costs and time for engineering.

Different types of devices have been developed worldwide to achieve the above mentioned goals and a comparative analysis of main advantages and disadvantages lead to the identification of the most suitable technology for a nuclear installations (see Table I). The rubber bearing type was identified as a result of the analysis.

TABLE I

Advantages and Disadvantages of isolation device types

	Advantages	Disadvantages
Elastomeric	Low in-structure accelerations Low cost	High displacements Low damping No resistance to service loads P-Δ moments top and bottom
High Damping Rubber	Moderate in-structure accelerations Resistance to service loads Moderate to high damping	Strain dependent stiffness and damping Complex analysis Limited choice of stiffness and damping Change in properties with scragging P-Δ moments top and bottom
Lead Rubber	Moderate in-structure accelerations Wide choice of stiffness / damping	Cyclic change in properties P-Δ moments top and bottom
Flat Sliders	Low profile Resistance to service loads High damping P-Δ moments can be top or bottom	High in-structure accelerations Properties a function of pressure and velocity Sticking No restoring force
Curved Sliders	Low profile Resistance to service loads Moderate to high damping P-Δ moments can be top or bottom Reduced torsion response	High in-structure accelerations Properties a function of pressure and velocity Sticking
Roller Bearings	No commercial isolators available.	
Sleeved Piles	May be low cost Effective at providing flexibility	Require suitable application Low damping No resistance to service loads
Hysteretic Dampers	Control displacements Inexpensive	Add force to system
Viscous Dampers	Control displacements Add less force than hysteretic dampers	Expensive Limited availability

The paper has the objective to present the main results of the feasibility study about the EPR seismic isolation system and, at the same time, to highlight the main "open" issues which have to be assessed and finalized in order to validate the use of seismic isolation technology to enhance the seismic protection of nuclear power plants, such as:

- Site choice, i.e. effect of soil structure interaction in case of soft soil and site effects,
- Beyond-Design-Basis condition,
- Effects of vertical excitation,
- Durability and Service Conditions requirements and qualification process,
- Arrangement/layout of devices,
- Installation and replacement procedures,
- Deformability of basemat (stiffness of structure above and below the isolation interface to avoid differential movement),
- Structural changes to the existing Standard EPR Nuclear Island.

II. REQUIREMENTS FOR THE ISOLATION SYSTEM AND DESIGN CRITERIA

The feasibility study of the isolation system for the EPR power plant started at the end of 2010 and it has the scope of validating the seismic isolation technology as one of the most appropriate means of seismic protection of SSCs, with particular reference to nuclear applications.
The study leads to the identification of the optimized solution in terms of type and position of seismic isolation devices and aims at highlighting all issues related to durability and inspection requirements, maintenance and replacement, industrial production capacity and qualification of the process and finally costs, relevant to the nuclear field.
The performance criteria established for the design of the seismic isolation system are the following:

- Performance criteria at the design basis conditions:

a. Design Basis Earthquake

The Uniform Hazard Accelerogram Response Spectrum was chosen taking into account the spectral shape defined by the Eurocode 8[3] expression type 2 scaled at the peak ground acceleration (PGA) of 0,37g which was resulted from the seismic hazard studies for an Italian site (rock conditions), referring to the return period of 10000 years. A site specific wave propagation analysis was then carried out in order to take into account site effects, which resulted in the definition of a DBE scaled at the PGA of 0,40g.

b. Floor Response Spectra for Design Basis Earthquake

Horizontal/Vertical floor response spectra for Design Basis Earthquake of seismic isolated system should be enveloped by the floor response spectra defined in the EPR standard project, which have been evaluated by dynamic analyses performed with the EUR response spectra with PGA of 0,25g for soft, medium and hard soil conditions and damping 5%.

c. Horizontal Displacement at Design Basis Earthquake

The maximum horizontal displacements of the isolated system evaluated at the Design Basis Earthquake, calculated as the sum of maximum horizontal displacements of the soil and the displacement of the isolated system, should be less than those defined in the EPR standard project or less than the maximal distortion allowable by the specially designed expansion joints.

d. Vertical Displacement at Design Basis Earthquake

The maximum vertical displacements of the isolated system due to rocking motion, evaluated at the Design Basis Earthquake, should be limited by the maximum overcompression and/or tension stresses of isolation bearings induced by load re-distribution, as indicated in EN15129[(2)].
Also the Annex H of Eurocode 7[(3)] indicates limiting value of structural deformation and foundation movement for normal structures with isolated foundations of total settlements up to 50 mm. Larger settlements may be acceptable provided the relative rotations remain within acceptable limits and provided the total settlements do not cause problems with the services entering the structure, or cause tilting, etc. These guidelines concerning limiting settlements apply to normal, routine structures. They should not be applied to buildings or structures, which are out of the ordinary or for which the loading intensity is markedly non-uniform.

- Design performance at the beyond design basis conditions:

a. Beyond Design Basis Earthquake

The beyond design basis earthquake is estimated scaling the Design Basis Earthquake until the shear strain of the isolators reaches the maximum allowable value (and at least up to 1,5 time the design input motion), without losing the bearing capacity of these and of their supporting columns, whose stresses could be increased by the P-Δ effects.

- Layout criteria:

a. Uniformity on load distribution

The position of isolation pads should be defined in relation to the load path from the superstructure to the foundation. It should be optimized in order to obtain a stress level on all isolation devices almost uniformly distributed and to minimize the torsional mode of the isolated structure.

b. Inspection, maintenance and replacement of devices

Sufficient space around the devices shall be left in order to allow free movement with no hammering of persons and material during the activity of inspection, maintenance and replacement. Similarly, also in vertical direction, the minimum height between the upper and the lower basemat has been estimated to be at least 2 m;

c. Protection

The isolation device must be located in a protected area, between the upper and the lower basemat. This area should be protected against fire, chemical or biological attack and flooding.

- Manufacturing and installation criteria:

a. Manufacturing tolerances

Manufacturing tolerances are related to the sizes of steel plates in each direction, on the bearing planarity after completion, on the mechanical properties and all of them should be clearly defined by the manufacturer.

a. Installation tolerances

The installation tolerances are related to the planarity of isolation devices when located on its bearing foundation should be clearly defined by the manufacturer. It usually is 1.5 mm per m.
The maximum vertical tolerance due to differential settlement of isolation device does not exist in France. The service tolerances of planarity of isolation devices and of overall isolation system, deriving from differential settlement of soil, should be verified by numerical analysis by the designer taking account the SSI effects in static and dynamic conditions.

- Qualification criteria:

The bearing capacity of isolation devices should be tested at the Design Condition and at the Beyond Design Condition, considering the concomitance of seismic actions fatigue and ageing due to temperature, neutron radiation, life duration, in concordance with the most complete standard for seismic isolation (at the moment Standard EN15129).

The bearing capacity should be tested also against severe accident condition.
Besides the current manufacturing tests, for the seismic devices installed at the Cruas NPP, EDF required a wide range of tests or inspections on the constitutive materials (dimensions, mechanical characteristics for steel, rubber) and especially on the laminated bearings (acceptance tests):
- Static tests up to the shear strain of 200%,
- Dynamic tests including modulus and damping,
- Fatigue tests with a progressive distortion,
- Ageing tests.

Moreover, for the recent project Jules Horowitz research reactor, (less than 200 bearings) more than 1000 test have been conducted on specimens at the scale one. The total duration of the process was 2 years (2006-2007) due to the duration of artificial ageing tests (18 months).

- Cost criteria:

The cost assessment will take into account the additional costs due to all the studies, works and devices including the additional costs for maintenance in operation, balanced with the cost of designing and building a conventional EPR for 0.4g under soft soil conditions if possible.

The performance criteria were indentified on the basis of a deep analysis carried out considering existing seismically isolated nuclear and/or conventional plants and state of the art available at the moment of seismic isolation applications.
No indications from standards related to nuclear applications were found. The lack of existing specific standards is one of the most important problems in the application of seismic isolation to nuclear plants, especially for what concerns the isolators. New guidelines and/or recommendations shall be issued to regulate the qualification of these very critical components, maybe starting from the existing ones. *Should we cite the IAEA tecdoc in progress? (along with the NUREG, the French experience document, the Japanese guides?)*

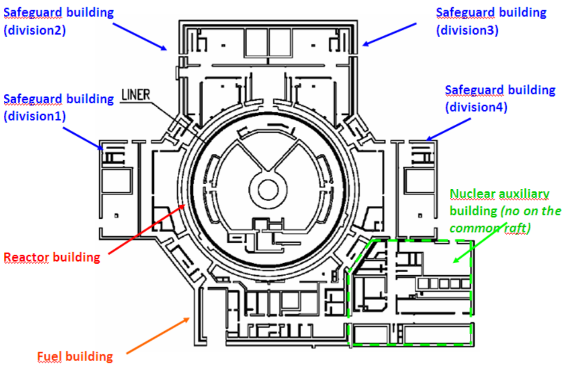
III. OPTIMIZATION OF THE ISOLATION SYSTEM (ENEA)

The EPR nuclear island includes five buildings (Figure I):

- Reactor building (HR)
- Fuel building (HK)
- Auxiliary building 2-3 (BAS2 and BAS3)
- Auxiliary building 1 (BAS1)
- Auxiliary building 4 (BAS4)

FIGURE I

EPR Nuclear Island (Areva)



All these buildings lie on a common foundation, a reinforced concrete slab with thickness of 3-4 m, total area of 6900 m2 placed at -15m under the ground level. The uniform pressure transferred to the ground is about 0,62 MPa and the total mass is 4.412×10^8 kg included the common basemat. In order to install the isolation system a new sub-foundation, below the common basemat, is necessary. The isolators will be positioned on pliers (pedestals), built between the existing and the additional sub-foundation.

The gap between the common basemat and the sub-foundation must respect the layout-criteria defined in Chapter II, it must be high enough to allow inspection, maintenance and possible replacement of the isolators.

Each isolator is equipped with two steel plates used to rigidly connect the isolator with the above and below structures.

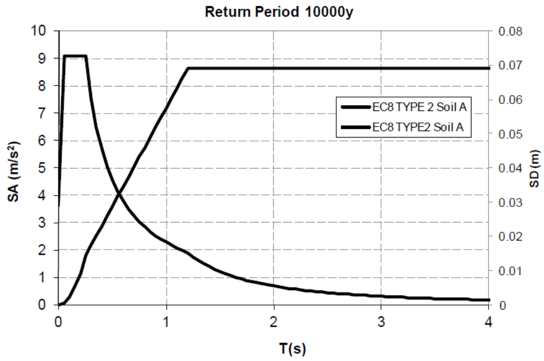
The site selected for the purpose of this study is relatively soft site, of Class C according to the current Italian seismic code[4] as well as Eurocode 8[(5)], characterized by:

- soil density between 1,85 kg/cm3 and 2,10 kg/cm3 where higher values are those of clayey silt material;
- clayey silt material is slightly over-consolidated: the values of the degree of consolidation decreases from about 2-3 of the more superficial strata to zero at depth of 50-55;
- variation of the shear modulus and damping ratio with the increasing of the shear strain level for both sand and silt layer known from laboratory tests.

The Uniform Hazard Accelerogram Response Spectrum was chosen taking into account the spectral shape defined by the Eurocode 8 expression type 2 scaled at the peak ground acceleration (PGA) of 0,37g which was resulted from the seismic hazard studies for an Italian site, referring to the return period of 10000 years (Figure II).

FIGURE II

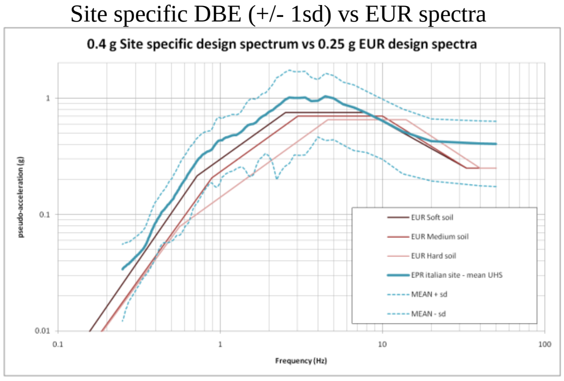
Uniform Hazard Acceleration and Displacement Response Spectra on rock soil and plain ground surface



The time-histories used for the analyses are represented by 2 set of 7 tern of real records (i.e. natural accelerograms), the first one accelerograms spectrum-compatible to the uniform hazard displacement response spectrum on rock site, the second one accelerograms spectrum-compatible to the uniform hazard acceleration response spectrum on rock site. The 2 set of spectrum compatible accelerograms are propagated using a linear visco-elastic model through the soil profile of the selected site. The resulting mean UHRS for soft soil reaches therefore a PGA of 0,40g. (Figure III)

FIGURE III

Site specific DBE (+/- 1sd) vs EUR spectra



A simplified finite element model of the Nuclear Island based on a known distribution of masses and loads of the upper structures, was built through the use of code ABAQUS (Figure IV). The model doesn't aim at obtaining information about the real buildings behaviour such as natural frequency or stress distribution, but just at reproducing the displacement at the base level. All the buildings and the common basemat are considered as rigid thus only the frequencies introduced by the isolation system are taken into account.

The isolators were implemented into the model using linear springs acting both in horizontal and vertical direction. The damping of the isolation system was introduced assigning a 10% damping to

the first three modes: horizontal translation and rotation around the vertical axis.
The correctness of the simplified model has been verified by comparing the mass and the position of the CoG of each building computed with the ABAQUS model with the ones computed by the complete finite element model provided by EDF.
The quasi-static and dynamic analyses allow the assessment of the compliance with the set technical objectives (such as maximum acceptable acceleration of the isolated structure and maximum acceptable lateral displacement).
The information obtained from this analysis regarding the response of the isolated structure is described in terms of (increased) natural period of oscillation, maximum lateral displacement at basemat level and (decreased) seismic acceleration transmitted to the structure, while the response of the isolation system is described in terms of deformations and maximum displacement of seismic devices.
In this phase the efficiency of the seismic isolation is verified. In fact, as a consequence of the increase of the period of vibration of the structure, a not desired resonance phenomena can occur, thus amplifying the structural response when soft soil condition are present. In soft soil condition maximum seismic accelerations occur at low frequencies which can be close to those of the structure.

FIGURE IV

Finite Element Model of the EPR Nuclear Island done by Abaqus

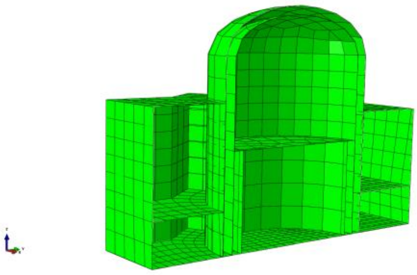


TABLE II

Summary of main characteristics of isolation devices

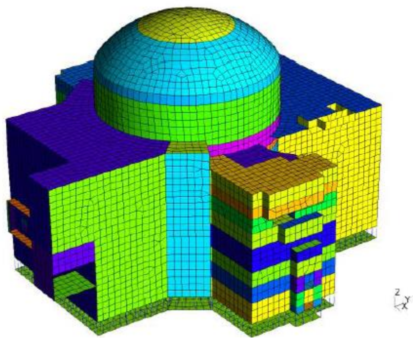
Period (s)	1.5	2
Total horizontal stifness (N/m)	$7.74x10^{9}$	$4.35\ x10^{9}$
Number of isolators	626	572
Rubber diameter (mm)	1500	1200
Rubber shear modulus G (Mpa)	1.4	1.4
Rubber height (mm)	200	208
Isolator horizontal stiffness (N/m)	$1.237x10^{7}$	$7.61x10^{6}$
Isolator vertical load max (kN)	26000	16670
Isolator vertical stiffness (kN)	$8.66x10^{9}$	$5.17x10^{9}$
Isolator damping	10%	10%

IV. VALIDATION OF THE SYSTEM ON THE FEM MODEL (EDF)

In order to perform the detailed numerical dynamic analyses, results from previous tasks, such as type and number of bearings, were used as input data (example : table II, HDRB characteristics for a period of isolation of 2 seconds).
A refined model of the EPR nuclear island was updated by adding a second raft and elements to represent the pedestals and the bearings (figure V).
The surrounding retaining wall was not modeled in this study.

FIGURE V

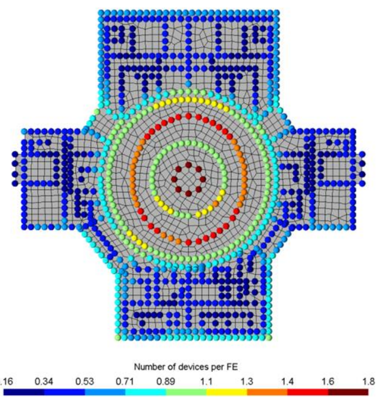
Detailed Finite Element Model of the EPR Nuclear Island, Salome-Meca platform[6]



An optimization procedure was used for the establishment of the bearings layout. The objective of the procedure is to minimize the dispersion of the compression value for each device under static loads, while minimizing the rotation effects under seismic loads. This is achieved with an iterative procedure that minimizes the distance between the center of rigidity of the isolation system and the vertical projection of the center of gravity of the EPR Nuclear Island. It provides a uniform load distribution on bearings (figure VI).

FIGURE VI

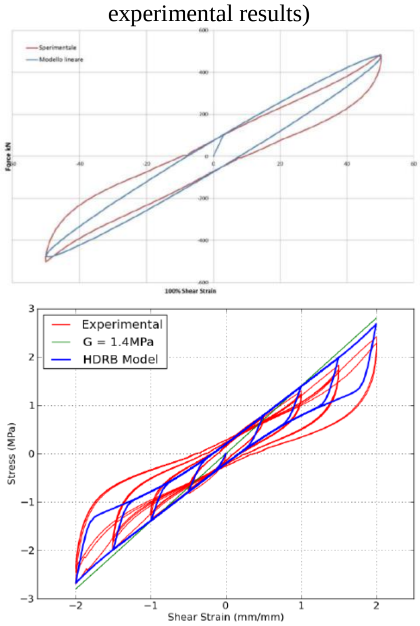
Common raft of EPR Nuclear Island, and beargin layout, Salome_Meca



Transient dynamic analyses, including soil-structure-interaction, are used to assess the behavior of the entire structure. The 14 triplets of natural acceleration time histories were used for the linear and non linear assessments. The non-linearity is taken into account in the HDRB constitutive law (bidirectional model of Grant[7]), implemented in *Code_Aster* [8] for this study. The linear and non linear laws used in the calculations were scaled to the manufacturer's specifications and available sample tests (figure VII).

FIGURE VII

HDRB constitutive laws (Linear and Non Linear vs. experimental results)



The following results are post-processed and compared to the EPR standard values:
- Floor Response Spectra at each floor of each building,
- Maximum displacement of the isolated nuclear island,
- Relative displacements between buildings, top displacements, interstory drifts,
- Rocking and rotation effects,
- Stress state in concrete elements and in surrounding soil.

Bearing verification criteria are also verified according to EN 15129 and EN 1337-3[9]: admissibility of the rubber shear strain, minimal thickness of the reinforcing plates, buckling stability, bearing decompression limit.

Modal analyses indicate that the structure and the soil foundation behave simultaneously as coupled dynamic system. It reduces the horizontal principal frequency to 0.43Hz, and adds a rocking movement of the nuclear island. 3 analyses were compared (table III) :

- seismic isolation + SSI
- seismic isolation + fixed base
- conventional foundation + SSI

TABLE III

Main modes obtained from the 3 analyses

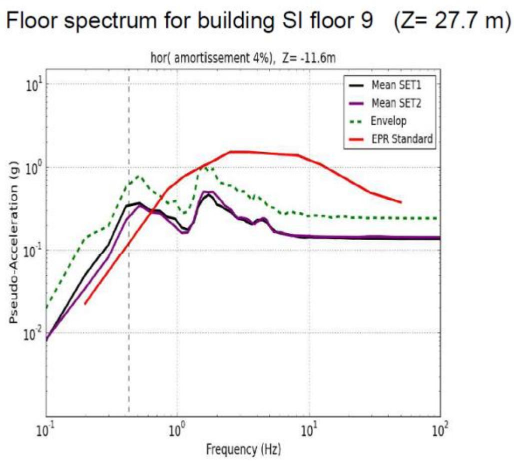
Mode	Seismic isolation + SSI	Seismic isolation + fixed-base	SSI only
translation X	0.428 Hz	0.494 Hz	0.78 Hz
translation Y	0.430 Hz	0.496 Hz	0.79 Hz
torsion Z	0.450 Hz	0.504 Hz	0.93 Hz
pumping Z	1.382 Hz	13 Hz	1.43 Hz

Due to poor soil conditions, the significant deflection of the basemat under static loading requires special care in order to compensate for differential settlements affecting the well functioning of isolation devices. This also has an impact on the efficiency of shear walls of the building with high stress concentrations and strong demand in reinforcement closer to the edges of the structure.

The 3D modeling is useful for the identification of possible coupling of vertical excitation and horizontal responses. Some secondary peaks are observed on some of the horizontal FRS. Those peaks are expected when using a 3 dimensional seismic input, and are attributed to the horizontal response of the structure due to vertical excitation. Secondary peaks are not due to the use of seismic isolation, but can be seen as a drawback since horizontal isolation is not able to filter out these motions. However in this application (transposition of a standard design), secondary peaks have low consequences since they are mostly covered by the EPR standard Floor Response Spectra (FRS), (Figure VIII).

FIGURE VIII

Comparison of FRS at top of internal containment

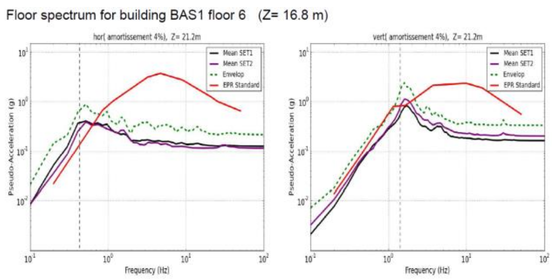


Horizontal and Vertical FRS were calculated for all floors of the nuclear island (Figure IX). The main conclusions are the following, for most floors and buildings:

- The main horizontal peak response occurs at 0.43Hz (coupled mode of bearing system and SSI),
- An important reduction of horizontal FRS is obtained for frequencies higher than 0.8Hz,
- A reduction of most of the vertical FRS, with a peak response at 1.4Hz that sometimes exceeds the EPR standard vertical FRS. This reduction is mainly due to the soft soil characteristics,
- The Zero Period Acceleration (ZPA) are similar for horizontal and vertical FRS, the vertical one being sometimes slightly higher than the horizontal,
- The ZPA never exceeds 0.2g for all floors (mean value of the 14 calculations), the maximum calculation gives a 0.3g ZPA,
- Base isolation is efficient for the reduction of FRS since the response spectra calculated for a 0.4g PGA ground motion are well covered by the standard FRS (0.25g PGA).

FIGURE IX

Comparison of FRS at floor 6 of BAS1



Additional outputs were compared to the elements available from EPR standard design. The project, still ongoing, will use these comparisons for the determination of modifications, reinforcements or new qualifications needed for this application.

A comparison of maximum top displacements (relative to basemat) of the Reactor Building (HR) and nuclear auxiliaries building (BAS1) was performed (Table IV). A reduction of 40% to 50% of the horizontal displacements is observed for the aseismic solution, and a reduction of 25% to 60% for the vertical displacements. Similar results are obtained for BAS23, BAS4 and HK buildings.

Relative displacements of the upper and lower rafts were also calculated. The preliminary design study results are compared to the displacements obtained in the detailed study (Table V). The objective of low displacements is achieved (lower than 200 mm, which corresponds to a distorsion of 100% for the bearings). This comparison also shows that pre-design calculations, based on simplified models and additional safety factors, can over-estimate the displacement results.

TABLE IV
Comparison of maximum top displacements of buildings relative to basemat.

d_{max} (mm)	HDRB model	BR & SI		BAS1	
		Isolated EPR	Standard EPR	Isolated EPR	Standard EPR
Horiz.	Linear	18.0	34	16.0	32
	Non Linear	20.0		17.5	
Vert.	Linear	11.5	18	7.5	20
	Non Linear	13.0		8.5	

TABLE V
Comparison of relative displacements: upper and lower basemat. Values from pre-design and from detailed study.

	Pre-design	Pre-design with safety factor	Design with linear HDRB	Design with NL HDRB
Relative displ. (mm)	142	188	123	111
Distorsion	71%	94%	62%	56%

Finally, 4 verification criteria from European standards EN 15129 and EN 1337-3 were calculated at each time-step of the calculations for each HDRB element:

- Rubber shear strain limit,
- Minimal thickness of the inner steel plates,
- Buckling limit,
- Decompression limit,

Margin factors calculated from these criteria are listed in Table VI. These margin factors help to identify to main contributor to the failure of the base isolation system for beyond design earthquakes. Failures resulting from excessive tension in bearings and excessive compression of inner steel plates are much more probable than buckling or excessive shear strain failure.

Among all of the 14 time-history calculations, only one bearing failed the decompression limit criteria. A sensivity study was performed with a hardening of the soil (representative of soil reinforcements), this resulted in a repositioning of the bearings at the edge of the raft, and showed a better load path in the structures and therefore no failure towards the decompression limit criterion.

TABLE VI
Verification of HDRB criteria - margin factors.

Margin factor γ	Rubber shear strain	Thickness of steel plate	Buckling limit	Decom-pression limit
Linear HDRB	2.84	1.61	5.83	1.65
Non-Linear HDRB	2.81	1.48	5.27	1.40

IV. CONCLUSION

Given the available results, the majority of the Floor Response Spectra, seismic displacements and forces in structures are covered by the standard design. The major modifications will therefore be concentrated on the foundation raft design, the flexibility of connected pipes and specific expansion joints, and probably the improvement of soil bearing capacity with the use of rigid inclusions or deep foundations.

This study shows that for soft soil conditions, SSI analyses must be carried out in order to identify the coupling between the isolation system and the soil. No unexpected behavior was observed in this case.

One of the major next steps of the ongoing study consists in the beyond design evaluations. The nuclear island behavior will be reassessed with time history calculations, up to at least 1.5 times the design seismic level, in order to identify any cliff-edge effect related to: bearing failure, effects of displacements for piping systems, impact with adjacent structure, or increase of Floor Response Spectra. A push-over analysis will also be performed.

Finally, the comparisons of the outputs of this study with the EPR standard values will be used in order to evaluate the cost and planning associated with the specificities of base isolation.

ACKNOWLEDGMENTS

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