Titolo

Preliminary seismic analysis on an isolated simplifield LFR reactor Type

Ente emittente CIRTEN

PAGINA DI GUARDIA

Descrittori

Tipologia del documento: Rapporto Tecnico/Techincal Report
Collocazione contrattuale: ENEA-MSE Agreement
Argomenti trattati: Generation IV Reactors

Sommario

This paper concerns the isolation methodological approach in order to gain a further reduction of response spectra at each floor along the height of the structure

Note

Autori: G. Forasassi, R. Lo Frano

Copia n. **In carico a:**

2			NOME			
			FIRMA			
1			NOME			
			FIRMA			
0	EMISSIONE	26/01/09	NOME		F. Bianchi	
			FIRMA	NA		NA
REV.	DESCRIZIONE	DATA		CONVALIDA	VISTO	APPROVAZIONE

CIRTEN
CONSORZIO INTERUNIVERSITARIO
PER LA RICERCA TECNOLOGICA NUCLEARE

UNIVERSITA' DI PISA

DIPARTIMENTO DI INGEGNERIA MECCANICA NUCLEARE E DELLA PRODUZIONE

Preliminary Seismic Analysis on an isolated simplified LFR reactor type

AUTHORS

Prof. G. FORASASSI

Dr. Ing. R. LO FRANO

CERSE-UNIPI RL 1064/2008

PISA, JULY 2008

Lavoro svolto in esecuzione della linea progettuale LP3 punto H dell'AdP ENEA-MSE del 21/06/07
Tema 5.2.5.8 – "Nuovo Nucleare da Fissione".

CONTENT

INTRODUCTION

The seismic analysis of a nuclear power plant is required as one of the conditions for the design and construction approval. NPP seismic problems derive from the fact that plant design is strictly dependent by the seismic hazard and safety aspects, related to the external events, possible in the site. Seismic risk results from the interaction among seismic hazard, vulnerability of structures and social-economical effects.

In order to improve the design of new NPPs, the vulnerability related to the dynamic behaviour of structures subjected to critical seismic excitations that may occur during their expected service life must be evaluated.

This paper concerns the isolation methodological approach in order to gain a further reduction of response spectra at each floor along the height of the structure.

Recently, many countries have been trying to apply seismic base isolation technology to their nuclear power plants, especially when liquid metal reactors such as EFR in Europe, DFBR in Japan are concerned [1].

The use of innovative anti-seismic techniques, such as seismic isolation (SI) and passive energy dissipation (ED), seems able to ensure the full integrity and operability of important structures in very severe seismic conditions: this approach could be necessary for both new constructions and retrofit of existing buildings. Seismic base isolation can give a significant reduction in seismic response and provide an economic aseismic design benefit.

The main objective of this report is to establish relationship between the ground motion and the effects on the isolated relevant structure (in term of seismic demand parameter) and to compare the isolated to not isolated LFR reactor response, with reference to the ELSY next generation reactor, in order to gain preliminary information/data on the isolation technique effectiveness in this specific case.

The ELSY general project (CEE-6 Framework Project) objective aims to demonstrate the feasibility of a competitive and innovative safe lead-cooled fast reactor design based on simple technical engineered features. This general objective should be complemented by an analytical effort to assess the existing knowledge base in the field of lead-alloy coolants (i.e., lead-bismuth eutectic-LBE- and also lead/lithium) in order to extrapolate the already available knowledge base to the use of pure lead, that achieves all of the GEN IV goals and gives better assurance of investment protection.

An efficient use of fissile fuel resources together with the ability to burn its own high-level wastes and also the ones coming from Light Water Reactors (LWRs) are primary design goals of several new reactor designs developed under the auspices of the mentioned Generation IV initiative [2].

In the course of the safety analyses, seismic input data attention should be focused on the procedures and methods to be used. According to the present Regulations (e.g. US.NRC ones) the seismic response spectra are applied and determined in correspondence of the main components reference points.

As for the mentioned purpose of NPPs design, a strong earthquake with a very small probability of occurrence is postulated to investigate the seismic isolation capability and to show the seismic isolation performance and the seismic safety margins. To establish the effects of earthquakes and proceed with design of earthquake resistant structures as well as to analyze existing structures, the first step is to develop representative models of real NPP structures to closely simulate their dynamic response behaviours as completely and as accurately as possible.

The analysis method is based on a deterministic seismic assessment which is made possible by means a numerical evaluation of wave propagation along the considered structure. Therefore in general deterministic numerical prediction of structural response has to be set up and accomplished by means of a finite element approach. Nuclear power plants are always composed of a number of adjacent structures, so in order to ensure adequate treatment of interaction effects the main buildings should be considered.

For instance, all relevant reactor structural components are present in the following proposed example model, with their real geometry and material characteristics.

To the purpose of this study a system (Figs.1) constituted with some mutually interacting components was considered: the reactor vessel containment building, the Safety Vessel (SV) and Reactor Vessel (RV) with its internal and metal coolant.

The problem of optimal modelling of coupled structures with different characteristics and also the adequate modelling of main buildings on a common base mat as well as the coupling due to the interaction with the soil structure had to be considered.

It is worthy to stress that the numerical isolated system model, that seems to be the most sophisticated available so far, for the chosen detail simulation, was derived in the same way/criteria as the not isolated case, therefore the calculation results obtained for the two structures may be compared more easily.

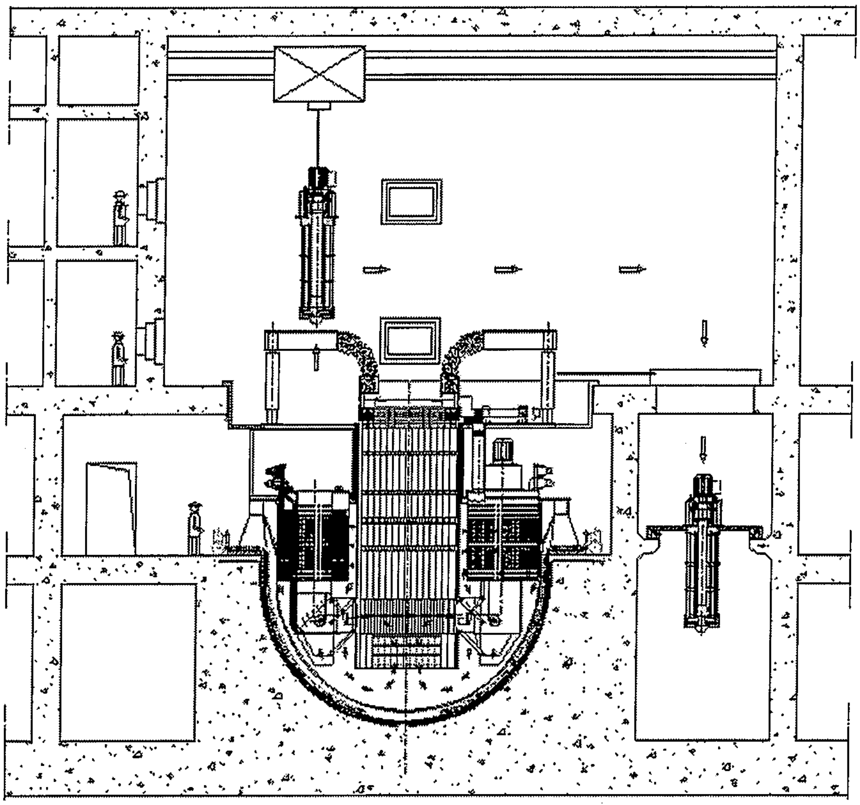


Fig. 1 - ELSY reactor vessel containment building elevation view

1. MODELS ANALYSIS CHARACTERISTICS

The dynamic responses of a nuclear liquid metal storage tank, like the reactor vessel, to a seismic motion differ from those of general structures such as buildings mainly due to the effect of hydrodynamic pressure on structures generated by the heavy metal coolant motion coupled to its interaction with the flexible RV wall.

The present preliminary analysis focused on the seismic effects is intended to evaluate the influence of the dynamic loads on the ELSY next generation reactor internals structures, accounting for their contribution to the overall damping of the system. The seismic response evaluation of isolated buildings and structures is performed to determine seismic forces and the in-structure input motion for systems and components in presence of isolator under the foundations.

The scope of this safety evaluation process is determined by the seismic capacity of as-built structures systems and components in the event of the Safe Shutdown (SSE).

The ELSY reactor type in comparison with LWRs is characterized, from a mechanical point of view by the relevant fluid weight and by the reduction and simplification of the primary system. The pool-type, instead of the loop-type configuration, was chosen for ELSY because of the possibility to contain within the main vessel all the primary coolant components.

An example of an improved scheme to be evaluated as a starting point for the ELSY primary system is the cylindrical inner vessel concept represented in Fig. 2.

The Reactor Vessel (RV) consists of a cylindrical shell with a hemispherical bottom head, without nozzle for out-of-vessel primary coolant circulation, and supported by an annular Y-shaped support structure.

The RV is characterized by a fixed roof with an annular central part to accommodate the extension of cylindrical inner vessel and contains two water-air decay heat removal systems (WA-DHR) and also eight internal primary pumps coaxially assembled in the steam generators (SG) [3].

The steam generator (SG) and primary pump (PP) assemblies are an integral part of the primary loop immersed in the cold pool that is arranged in the annular space between the cylindrical inner vessel and the reactor vessel.

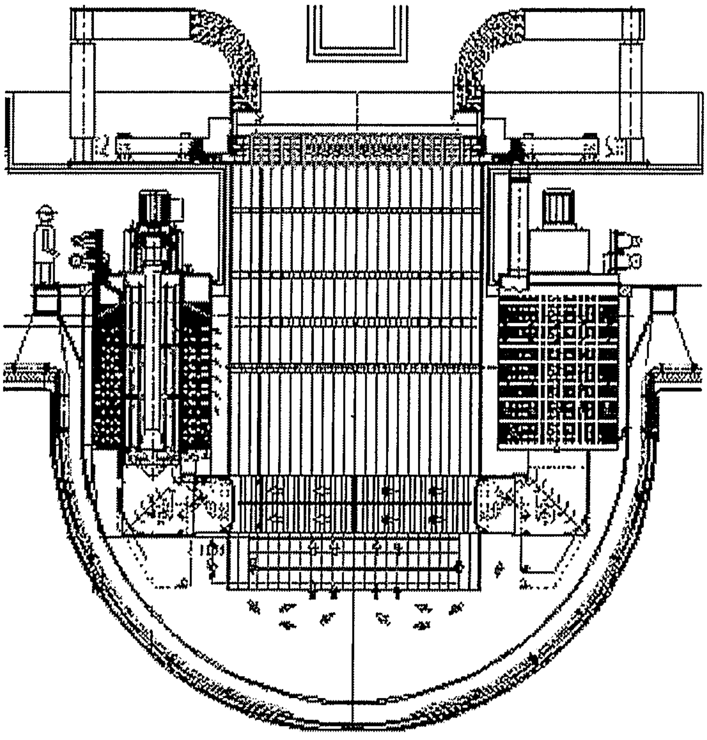


Fig. 2 – Overview of ELSY initial preliminary scheme

Moreover the RV is connected by means the mentioned "Y forged piece" at the Safety Vessel (SV), which is supported by and hangs from the Annular Boxed Structure (ABS), which is therefore the common support of both vessels. The upper part, already indicated as "Y forged piece", should transfer the whole weight of the RV/SV to the annular support and bear as well as sustain the Reactor Roof and the joined components.

The Safety Vessel (SV) is made of a SS cylindrical shell and is characterized by an upper cylindrical and bottom hemispherical shaped parts. The Reactor Roof ensures component support, reactor cover gas containment and the biological protection. Furthermore materials used in modelling ELSY nuclear reactor components are type 304L and 316L SS, while the choice of lead, as primary coolant, is motivated by good nuclear properties and thus, no intermediate coolant loop it is needed.

The proposed methodological approach to perform the isolation of a rather complex system is based on the increasing of total energy dissipation of NPP buildings and structures.

The main idea of this preliminary analyses approach is to use general systems and subsystems, in form of springs coupled to dashpots to simulate rubber bearing behaviour components (isolators), which can independently move under the effect of external loads.

To the purpose of the assessment in this preliminary study a system constituted by the following main and mutually interacting sub systems was considered, as the followings:

- Safety Vessel with its annular box structure;
- Reactor Vessel and its support system;

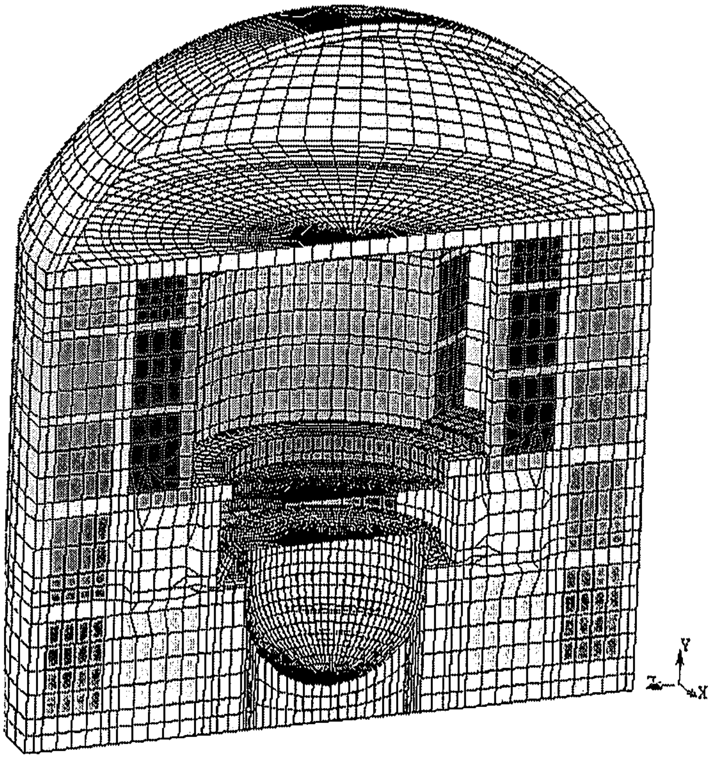
In order to ensure adequate treatment of interaction effects and account for an adequate representation of the favourable isolation effects, the same 3D finite element model of the RV containment building structure (Figs.3) was used to provide the in-structure response spectra at the same reference location or subsystem supports.

To set up RV containment building FEM model, its most important characteristics were taken into account in order to reproduce as accurate as possible the main ELSY plant features.

For that reason the separation between safety related and non safety related systems was represented, considering that the ELSY containment building structure design incorporates and surrounds the main nuclear system components such as the safety and reactor vessel.

The cylindrical containment building structure is assumed to be characterized by a hemispherical shape roof and to be based on a rigid foundation, which is the interface between the building structure and the soil.

The isolators type was chosen taking into account of the fact that in general, the response acceleration decreases as the isolation frequency is lowered, while the relative displacement increases.



Figs. 3 - ELSY building FEM model section views

It is worthy to note that the isolators frequency must be far from the first one of the liquid metal cooled reactor (generally less than that of a traditional LWR due to the heavy metal coolant mass) in order to avoid a dangerous coupling between the mentioned RV and isolators.

In order to obtain a suitable three-dimensional base isolation system, a combination of base horizontal and vertical isolation components were considered into the mentioned complete model assuming some hypotheses and performing a preliminary non linear analysis approach. Moreover, the isolation devices were mainly placed on a common foundation at under ground level.

To accommodate also lateral movements of the isolated building, a clearance space, or "seismic gap," was provided around the perimeter of the base. At this preliminary stage, this gap space should be adequate to assembling, inspection and maintenance, etc. needs.

1.1 CRITERIA TO SELECT ISOLATORS

Besides the positive effects of controlling the overall system frequencies isolators energy dissipation characteristics play a positive role that results in a reduction of response levels of structures during dynamic extreme loads such as earthquake, etc. The energy dissipation level of NPP buildings and structures can be largely increased by a suitable system like isolators which could bring significant positive effect in decreasing the overall structure dynamic response in terms of accelerations.

The rubber bearing seismic isolation devices can support the heavy weight of the superstructure and dissipate the horizontal seismic input energy within stable horizontal deflection. Since the rubber bearing is the main element for shear deflection, the understanding of its mechanical response behaviour can provide an insight view into its behaviour.

Due to the large difference between the typical isolators and the system structures stiffness and damping characteristics, the preliminary isolation type evaluation may be done by means of a simple spring-mass-damper system that looks very much like the one in the picture (Fig. 4).

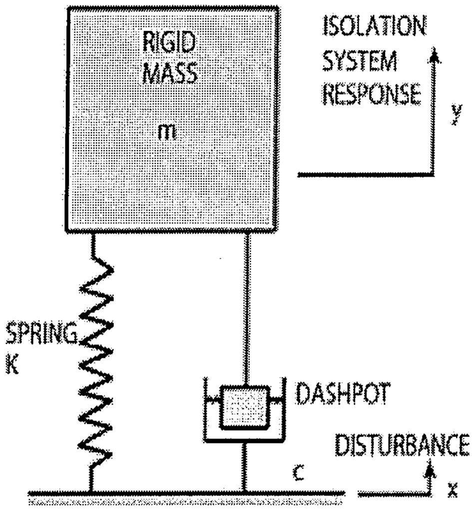


Fig. 4 – Scheme of simple spring-mass-damper isolation system

More generally, however, the spring mass system is used to represent a complex mechanical system. In this report, the preliminary seismic analysis of the isolated RV containment building structures subject to a Safe Shutdown Earthquake is discussed and, the isolation 'efficiency', in term of maximum acceleration ratio between the systems with and without dampers has been determined [4-5].

The applied methodological approach may be characterized by the following main three steps (Fig.5):

1. Definition of the peak ground acceleration of the input earthquake, since effective isolation characteristics would be obtained by the chosen artificial seismic waves;
2. Definition of type and number of isolators based on a preliminary fixed frequency;

3. Determination of the dynamic behaviour as well as the response of the RV building isolated system, in term of acceleration and displacement.

To the purpose of determining a preliminary appropriate number of isolators to be integrated in the system, the maximum allowed isolator displacement might be calculated in order to adequately identify the isolation characteristics suitable assure the required spectral displacement. For a PGA of 0.3 g (with a 5% of damping), the mentioned displacement was determined as follows:

$$S_d = \frac{S_a * g}{\omega^2} \tag{1}$$

Where S_d and S_a are the spectral displacement and acceleration respectively, while ω is the frequency. Substituting the acceleration value (S_a) corresponding to the period T = 2 s (f = 0.5 Hz), the maximum allowed displacement results:

$$S_{a(T=2)} = 0.249g \Rightarrow S_d = 248 \text{ mm}$$

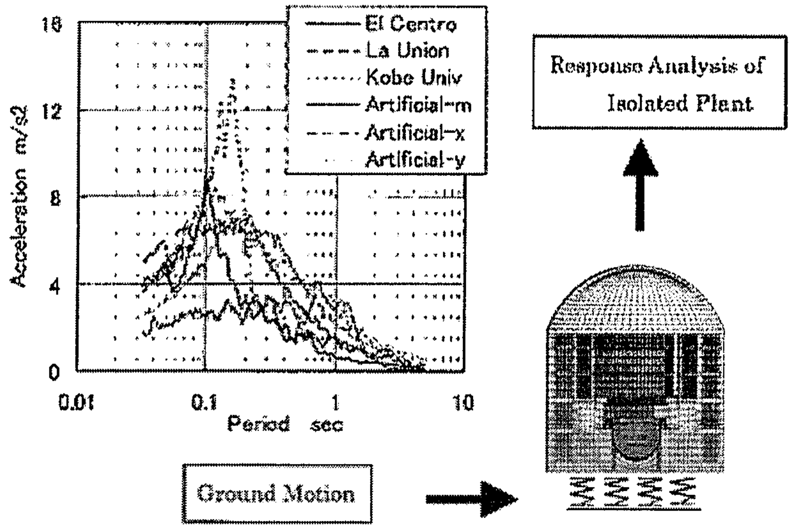


Fig. 5 – Scheme of isolation approach

With this displacement and the known total RV building mass it is possible to choose the stiffness of each isolator, K_{ABi}, e.g. in an industry list of available isolators, and to determine the necessary number of isolator according to the simplified formula (that refers to a 1 DOF system)[6]:

$$f = \frac{1}{2\pi}\sqrt{\frac{K_{AB-Tot}}{M_{AB}}} \quad (2)$$

$$K_{AB-tot} = M_{AB} \times 4 \times \pi^2 \times f^2 \quad (3)$$

$$N_{isolator} = \frac{(2\pi f)^2 * M_{AB}}{K_{ABi}} \quad (4)$$

where K_{AB} is the structural global stiffness, M_{AB} is total mass of the containment building structure, roughly assumed equal to $7.232*10^7$ Kg; f is the chosen isolation frequency preliminarily assumed equal to 0.5 Hz. Substituting the above values, the necessary global stiffness resulted to be $7.1302*10^8$ N/m.

In the considered application (T= 2s, f =0.5 Hz) 109 isolators (SI-N/1000(mm-diameter)/168 type, 15% damping), are required to represent the ELSY isolated containment building.

The isolators properties were (with reference to [6]). Therefore according to the previous hypotheses, as it was already indicated, a simplified FEM model was set up by means a system of springs coupled to dashpot.

This isolator model is characterized by:

- Rubber diameter: 1000 mm;
- Maximum vertical load under seismic event: 14050 KN;
- Maximum horizontal load: 22590 KN;
- Horizontal stiffness: 6,55 KN/mm;
- Vertical stiffness: 4254 KN/mm;

Moreover this number in the proposed application example seemed to be adequate to support the AB system mass and meet the global stiffness requirements.

An example of plant layout employing the isolation devices suitable for the updated ELSY plant design is shown in Fig. 5.

To study the effectiveness of the damping system in mitigating the seismic response of the buildings (represented through detailed discrete spatial models) the maximum accelerations and displacements of the considered structures were obtained from the results of each analysis at the same reference points, chosen for not isolated structures analysis.

As already mentioned, base isolation is expected to reduce the overall dynamic loadings therefore allowing to upgrade the design of the structures, equipment, and piping that might be significantly standardized.

In order to understand the dynamic response of the building and to evaluate its dynamic characteristics an input ATH was applied at the base of the isolation system of the nuclear power plant structure.

The input acceleration data in form of ATH ones were derived from the response spectra referring to the Landers Earthquake event and calculated (U.S. Geological Survey) according to the Regulatory Guide US NRC 1.60, for an appropriate damping as in the case of the calculation performed for the not isolated system.

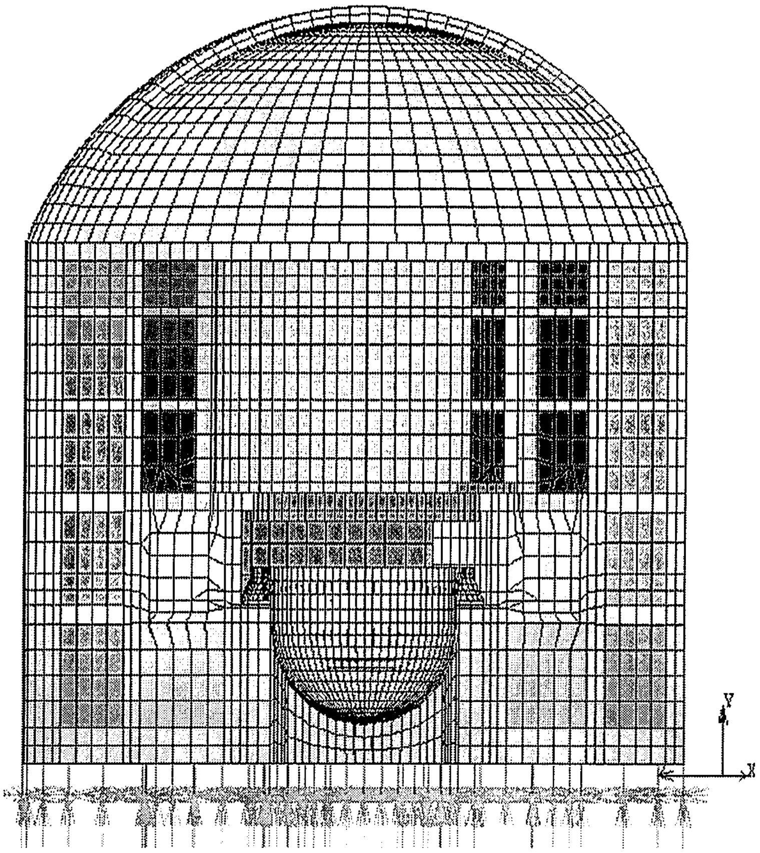
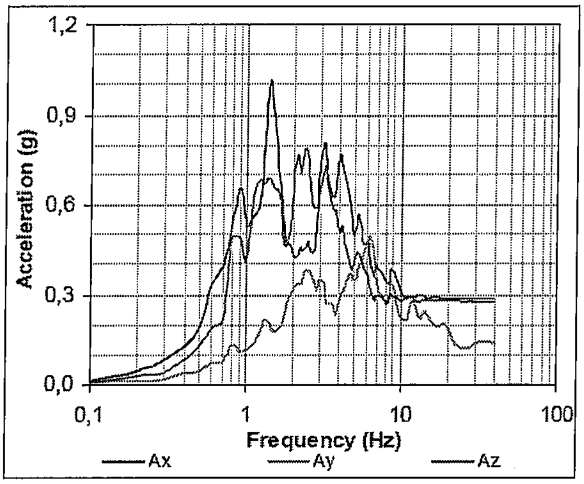


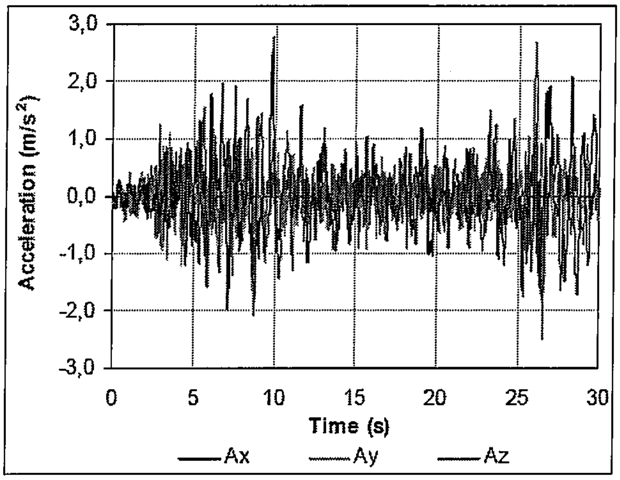
Fig. 5 – Isolated IRIS AB FEM model

Therefore seismic excitation was represented by an artificial time history compatible with the given free-field spectra (Figs. 6) applied at the base of the nuclear island as an excitation which represents the ATH of a Safe Shutdown Earthquake at a hypothetical embedment in stiff rock.

The vertical acceleration (indicated in Fig.6 (b) like Ay) was taken equal to 2/3 of the horizontal one in the entire frequency range.



(a)



(b)

Figs. 6- Seismic free-field spectra PGA=0.3g (a) and artificial time histories (b)

As already mentioned three dimensional (3D) seismic isolation devices have been considered for the base isolation of heavy building like a nuclear reactor building; besides for the practical application to the present case, the characteristics and performances of the integrated three-dimensional seismic isolation system were verified assuming that the isolated system could be represented by a single degree of freedom schematization composed of mass, springs and dashpot. After having performed the analysis, the required comparison between the two ELSY models, with and without isolators, was carried out in order to determine the isolation efficiency.

2. NUMERICAL RESULTS

The used methodology, implemented on the MSC MARC FEM Code, allowed to assemble the mass, stiffness and damping matrices and solve the equations of dynamic equilibrium at each point and time step. Before the development of the dynamic transient analysis, a modal analysis was carried out to evaluate the natural frequencies and modes of all the most relevant components of the considered system.

A preliminary modal analysis, that provided information about the total nuclear island significant response modes, should be performed to establish that a sufficient number of discrete mass degrees of freedom have been included in the dynamic model to predict the natural dynamic behaviour of structures with a sufficient number of modes.

After the mentioned simplified preliminary analysis, three-dimensional dynamic analyses of the mentioned structures have been done (with high computational demands and memory requirements), with the available computational capability that allows to describe and analyze the main relevant structures of the ELSY system.

The first step in the solution of seismic analyses, applying either modal superposition or direct integration methods coupled to the time history and substructure approaches; corresponds to the evaluation of frequency domain (modal analysis) which has to be considered also to evaluate the damping of structures.

All seismic transient analyses were performed assuming a proportional damping for each structure, according to the equivalent Rayleigh damping. Mass and stiffness damping may be used to represent the energy loss due to the impact forces (if any) and the rate of deformation.

Damping values used for the internal component are 5 and 7 % of critical ones, respectively for welded steel and reinforced concrete structures (NRC Regulatory Guide 1.61 USNRC, 1973). It is worthy to note that for base isolated nuclear plants, the effects of simultaneous horizontal and vertical shaking needs to be studied to adequately highlight the influence of vertical acceleration.

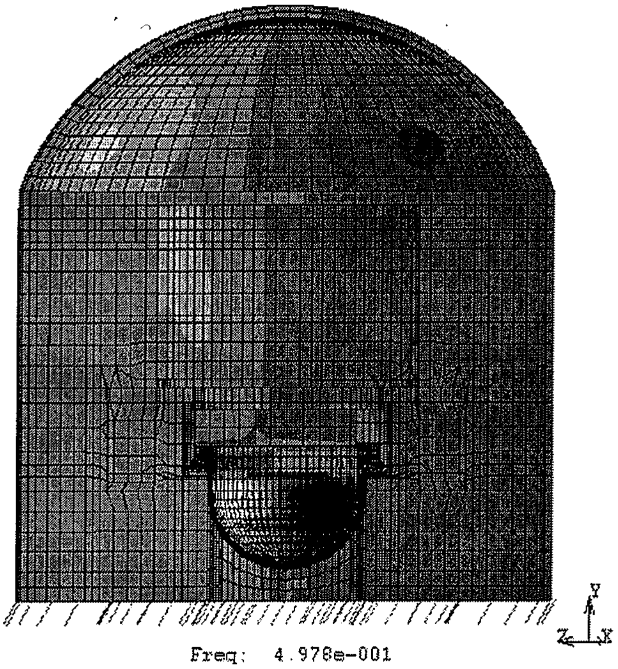
2.1 Modal Analyses Results

As previously mentioned, a modal analysis was carried out to evaluate the natural frequencies and modes of all the most relevant components of the considered system to predict/describe the natural dynamic behaviour of structures. The natural frequency values and modal shapes provided information about the nuclear island seismic responses characteristics such as earthquake amplification factors, which are strictly related to the dynamic characteristics of each considered material.

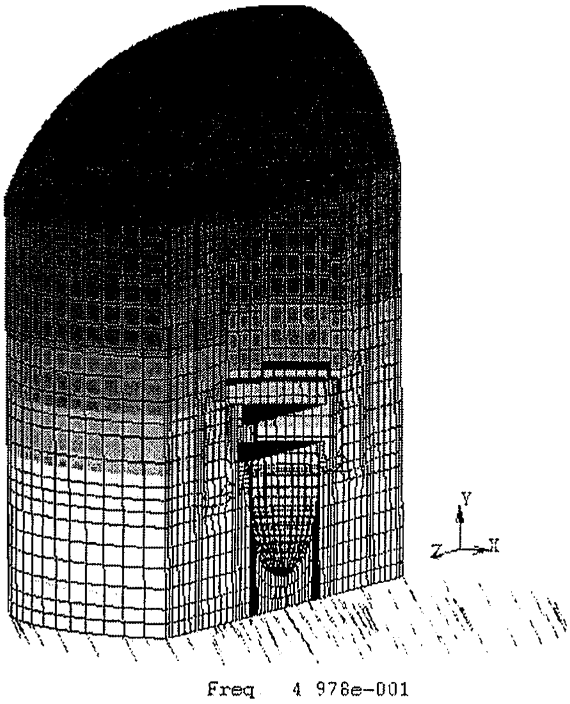
The response of a system to dynamic loads is a function of the amount and type of damping existing in the system; the energy absorbed by the structure is dependent on both the forcing and the natural frequencies, and such dynamic characteristics of the structure affect the response of the structure under seismic excitation.

The change of the natural frequency is of the structure results in a variation of the amount of energy being transferred to the system. In the present work the 3-D finite element models were used to evaluate the main modes and frequencies of the RV containment building structures, whose deformed shapes are shown in Figs. 6 and 7(a) (b) (c), corresponding respectively to the calculated 2nd and 3rd modes in the translational horizontal directions (along z and x axis) and 1st one is observed to be a torsional mode, for the isolated and not isolated structure..

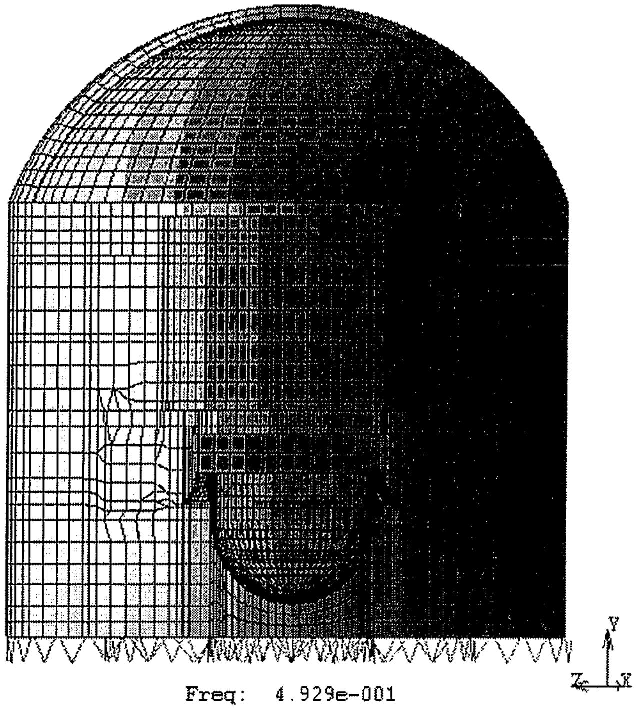
The effect of the non-structural components, such as interior partitions or the coolant inventory did not add any significant contribution to the mentioned structure modes/frequencies, but they would add some initial mass and stiffness to the building. The modal analysis frequencies results obtained from the isolated reactor vessel containment structure confirms that the design objective might be reached.



(a)

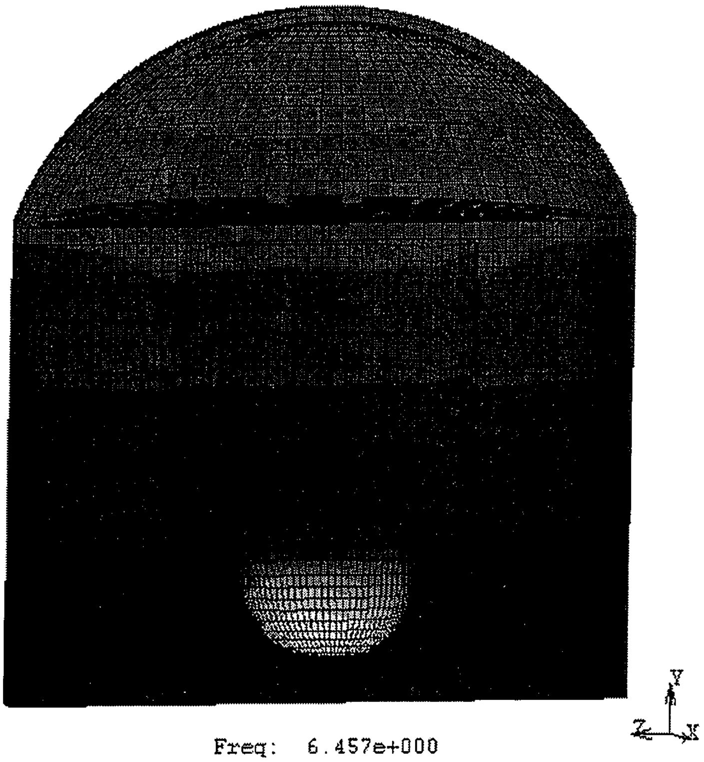


(b)

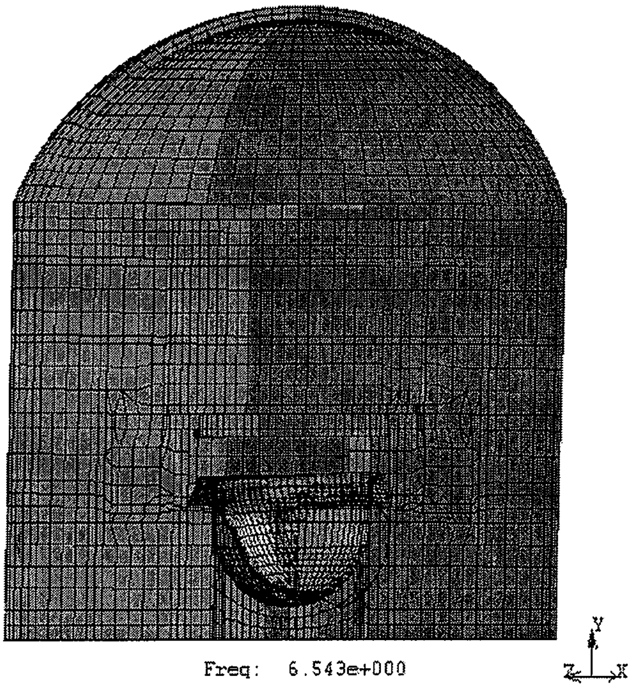


(c)

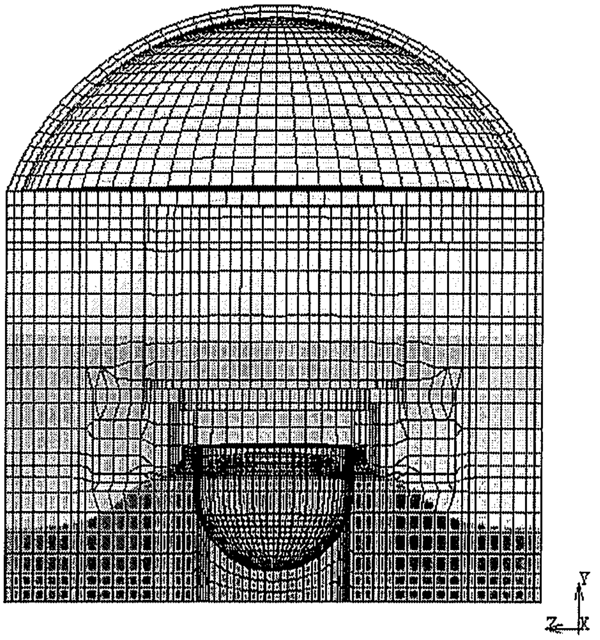
Figs. 6 - First three deformed modal shapes of reactor vessel containment structure



(a)



(b)



Freq: 6.760e+000

(c)

Figs. 7 - First three deformed modal shapes of reactor vessel containment structure

2.2 Transient Analysis Results

The mentioned modal analysis results were used to calculate the damping ratio necessary for the structures dynamic analysis development as well as for the time histories evaluation.

Structural performance is usually specified in terms of structural response quantities, such as strains and displacements, stresses and forces.

In order to analyze the effects of a SSE on the present by assumed nuclear island buildings type and to obtain the amplification or decreasing factor which may influence the seismic response accounting for the isolators characteristics, further in depth analyses have been carried out.

The isolated structural model was coupled with the free-field input motion (in time domain) by using the mentioned Time History approach to obtain the transfer function in terms of acceleration and displacement. As for the seismic demand of the major components, it is necessary to analyse the propagation of dynamic loads from the free field for a rather "severe" earthquake, characterized by peak ground accelerations equal to 0.3 g.

For this purpose the previously indicated (Fig. 6(b)) three different input acceleration time histories were considered.

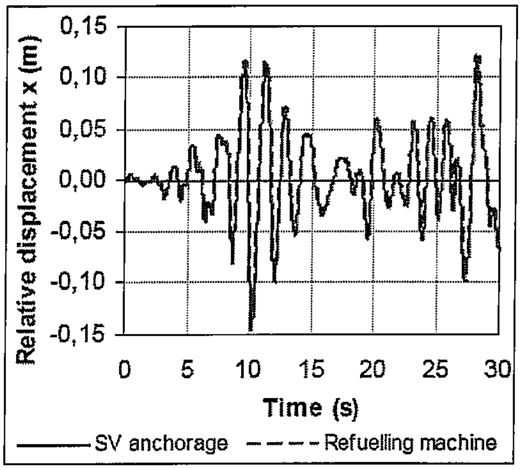
The input motion, in term of acceleration time history, was applied with all the three acceleration components in the three mutually orthogonal directions - two horizontal and one vertical - at the isolators bases in order to obtain the propagation of seismic waves from the ground level up to the RPV skirt restraints and the internals components supports.

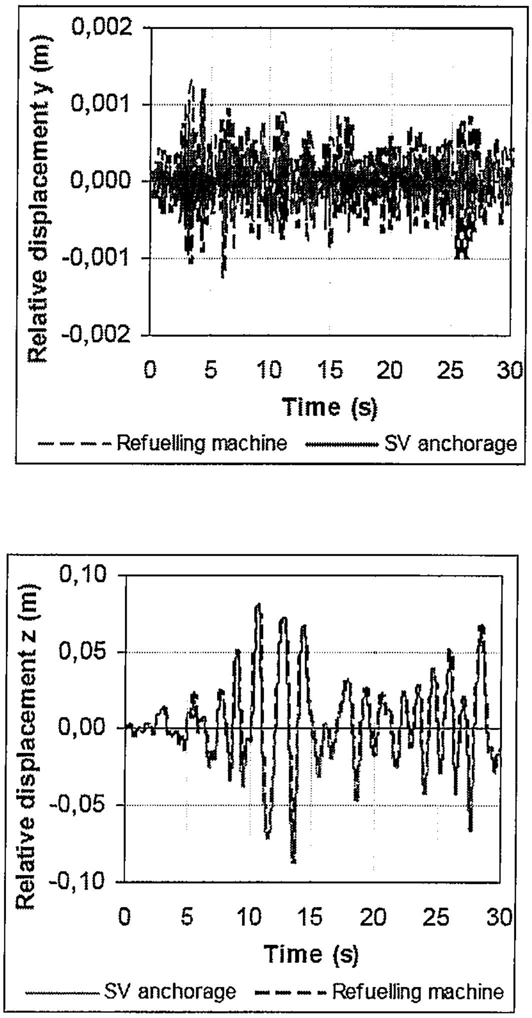
For isolated nuclear plants, the effects of simultaneous horizontal and vertical shaking were studied to adequately capture also the influence of vertical acceleration. To study the effectiveness of the damping system in mitigating the seismic response of the building, the maximum accelerations and displacements of the considered structures at chosen reference points (corresponding to different structures and elevation inside the reactor vessel containment), were obtained from the results of each analysis carried out on a suitable3-D model of the structure.

The output position of ELSY reactor vessel containment model might be used for design loads and further detailed structural analyses as well as necessary data to determine the fragility curve for the considered PGA.

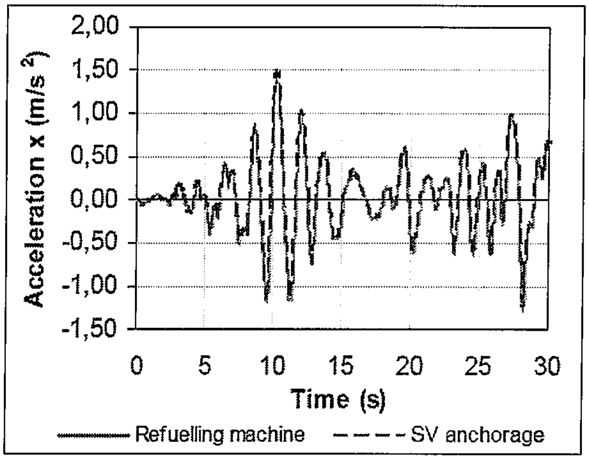
In the performed analyses the obtained results highlighted that the whole structure body is characterized by an almost rigid motion (as a 1 DOF system).

Overviews of obtained displacement and acceleration values propagated inside the auxiliary building are shown in the following graphs (from Figs. 8 to Figs. 11) for the three mentioned frequencies and for the three mentioned input ATHs.

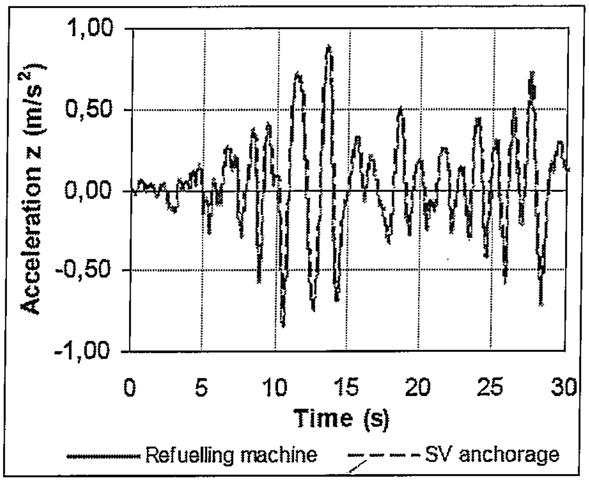




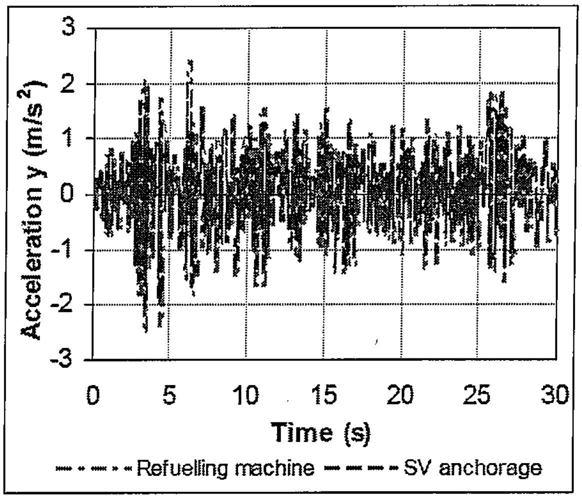
Figs. 8 – Relative displacements for isolated RV containment



Figs. 9 – Horizontal acceleration (along x axis) components for isolated RV containment



Figs. 10 - Horizontal acceleration (along z axis) components for isolated RV containment



Figs. 11 - Vertical acceleration (along y axis) components for isolated RV containment

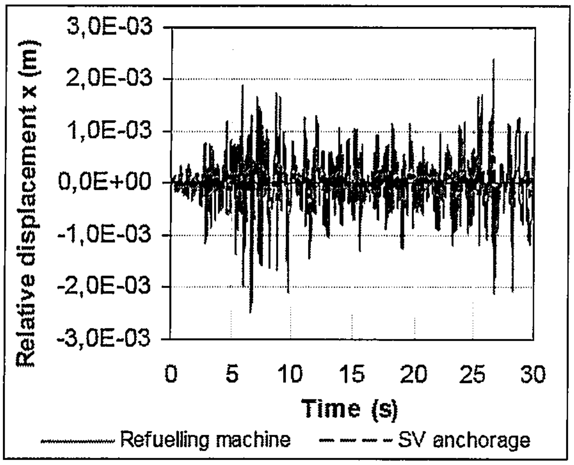
The results have highlighted an evident "similarity" for all the points inside the auxiliary building, due to the mentioned almost "rigid" behaviour of the structure; therefore the seismic waves might considered to be propagated in the same way inside the reactor vessel containment.

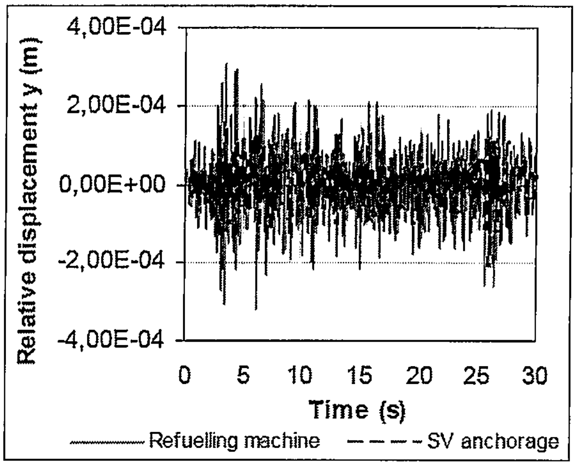
These results may be thus useful for the possible determination of the fragility curves for the considered PGA.

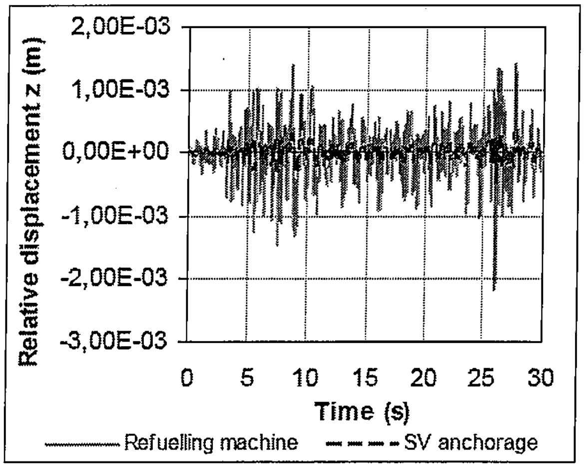
Moreover, in the performed preliminary analyses the horizontal accelerations increase as well as the displacements decrease with the first isolated system frequency, while the vertical component of acceleration still remains unchanged. In fact the value of vertical acceleration results to be equal about to 2 m/s^2, at the SV restraints reference point, even if generally it was amplified along the reactor vessel containment height, reaching at the base of roof (refueling machine position) a value of about 2.5 m/s^2.

It is worthy to note that if the isolators damping coefficient could be increased up to about 20% the displacement could be reduced by about 5%.

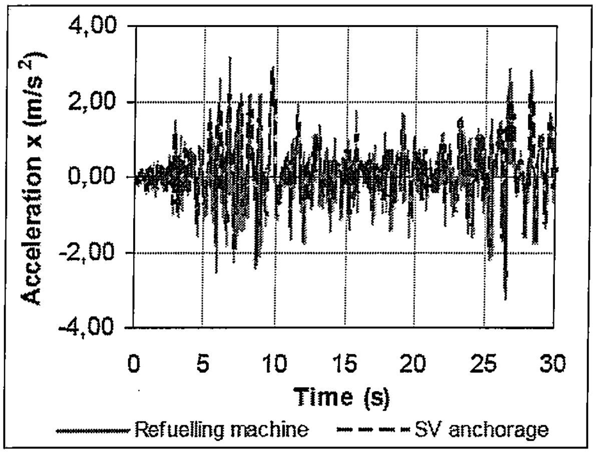
For not isolated reactor vessel containment structure different behaviours among the three acceleration and relative displacements components were observed depending on the effects of the building flexibility (from Figs. 12 to Figs. 15).



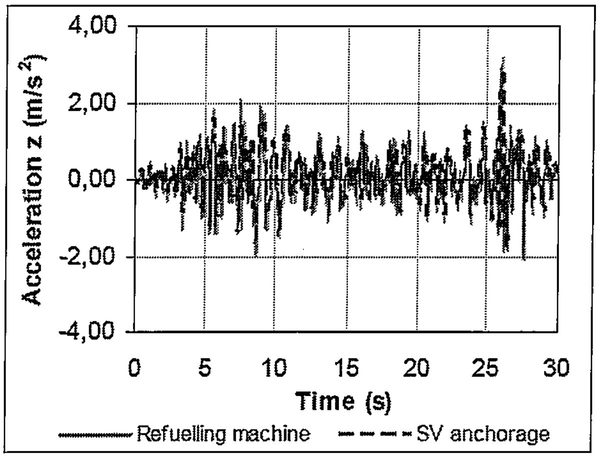




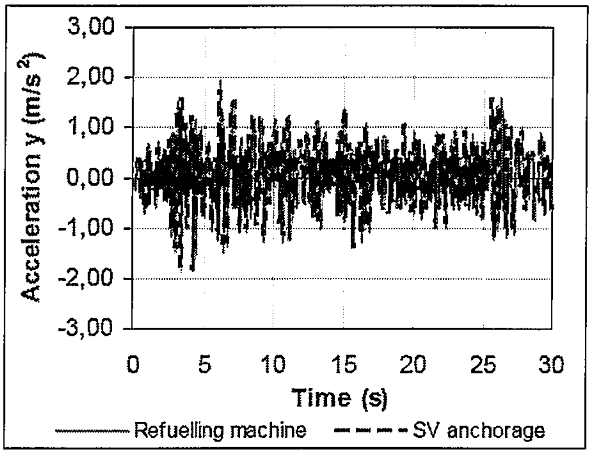
Figs. 12 – Relative displacements for not isolated RV containment



Figs. 13 – Horizontal acceleration (along x axis) components for not isolated RV containment



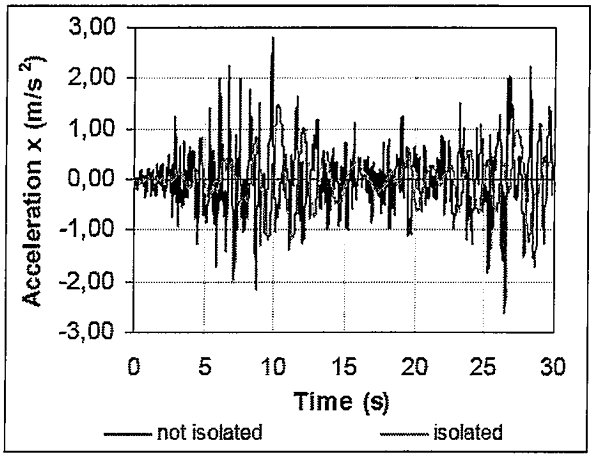
Figs. 14 - Horizontal acceleration (along z axis) components for not isolated RV containment

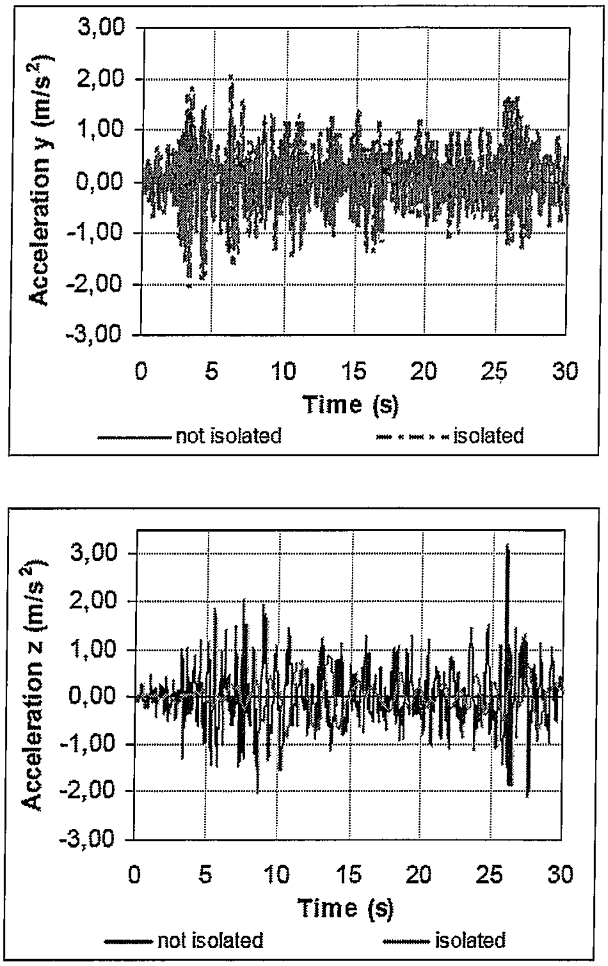


Figs. 15 - Vertical acceleration (along y axis) components for not isolated RV containment

The obtained results for both containment structures highlighted an amplification of acceleration along the containment structure height up to 3.5 m/s^2 and a decreasing of about 50% in comparison to the input one (0.3g), at the refuelling machine position, respectively for the not isolated and isolated RV containment structures.

Moreover a comparison between the shown calculated accelerations has been done in order to indicate and confirm the favourable effects of isolation system in terms of the seismic acceleration propagated from the ground to the considered levels inside and along the ELSY containment structure (Figs 16).





Figs. 16 - Accelerations comparison between isolated and not isolated RV containment structure at the SV anchorage reference position

It is worth to stress also that the isolated ELSY containment dynamic response, in term of the propagated acceleration as well as the calculated relative displacement, is strictly depending by the SSE intensity in form of the input ATHs.

CONCLUSION

The preliminary seismic analyses were carried out using the Time History method coupled to the substructure approach applied to a hypothetical ELSY nuclear island design, represented by the reactor vessel containment, safety vessel, reactor vessel 3-D FEM models, in order to evaluate the seismic response of the structures and internal components that are particularly sensitive to the seismic events due to the large coolant mass in LMFR.

On the base of the obtained preliminary analyses results on not isolated structure, it is worth to note that the seismic accelerations resulted to increase along the height of reactor vessel containment building, reaching at the elevation of +30 m a value almost equal to 0.35 g.

An approach for essential reduction of structures' dynamic responses under SSE extreme external events was investigated by means of isolator devices application.

Preliminary dynamic analyses on the same isolated containment building were performed with the same input earthquake characteristics using a simplified isolation system, based on springs and dashpots in order to highlight the isolation system favourable effect.

A comparison of obtained results in term of acceleration, displacement and response spectra highlighted the effectiveness of the damping system, in mitigating the seismic response of the building.

It is worthy to note that the necessary number of isolators depends roughly on their isolation frequency as follows (e.g. with reference to the FIP supplier catalogue data [6]): for a chosen value equal to 0.5 Hz 109 isolators ($K_h = 6.55$ KN/mm, $K_v = 4254$ KN/mm, $\Phi = 1000$ mm, $D_{allowable} = 300$ mm) are required to isolate ELSY RV containment building.

The results highlight also that, as it was foreseen, the isolated system response results considerably smaller in term of maximum acceleration values (e.g. in correspondence of the SV anchorage restraints the horizontal acceleration value along x axis was equal to 1.47 m/s^2 in the place of 2.89 m/s^2) and larger in term of relative displacement (e.g. in correspondence of the SV anchorage restraints the horizontal displacement value along x axis was equal to 14.5 cm in the place of about 1 mm) than in the not isolated case for the same corresponding points in the considered system.

REFERENCE

1. B. Yoo et al., "Seismic base isolation technologies for Korea advanced liquid metal reactor" Nuclear Engineering and Design 199 (2000) 125–142.
2. K. Tuˇcek et al., "Comparison of sodium and lead-cooled fast reactors regarding reactor physics aspects, severe safety and economical issues", Nuclear Eng. and Design 236 (2006) 1589–1598.
3. L. Cinotti, et al.," LFR "Lead-Cooled Fast Reactor"" UCRL-CONF-221396, FISA 2006, Kirchberg, Luxembourg, May 2006.
4. U.S. Nuclear Regulatory Commission (NRC), Regulatory Guide 1.60, Revision 1, "Design Response Spectra for Seismic Design of Nuclear Power Plants," NRC: Washington, D.C., December 1973.
5. R.A. Ibrahim, "Recent advances in nonlinear passive vibration isolators", Journal of Sound and Vibration 314 (2008) 371–452
6. FIP Industriale S.p.A.," Isolatori elastomerici Serie SI"- 2008