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Dynamic analysis of an advanced, isolated NPP assuming real HRDB properties

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CIRTEN - CONSORZIO INTERUNIVERSITARIO PER LA RICERCA TECNOLOGICA NUCLEARE

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Dynamic analysis of an advanced, isolated NPP assuming real HRDB properties

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Nomenclature

ASCE	American Society of Civil Engineers
DOF	Degree of freedom
EPR	European Pressurized Reactor or Evolutionary Power Reactor
FEM	Finite Element Method
FRS	Floor Response Spectra
HDRB	High Dumping Rubber Bearing
IRIS	International Reactor Innovative and Secure
NPP	Nuclear Power Plant
RB	Reactor Building
RPV	Reactor Pressure Vessel
SMR	Small Medium Reactor
SSC	Structures, Systems and Components
SSE	Safe-Shutdown Earthquake

1. Introduction

The energy policy developed at European and world level in the last decade was focused on the sustainability, competitiveness and security of supply. Decisions on the construction of several NPPs with evolutionary and/or advanced light water reactors[1] were taken (e.g. EPR in Finland and France, AP1000 in China, etc.) and more are under consideration for licensing in several countries (USA, RUSSIA, INDIA, etc.). Moreover there is a continuous interest in the development and application of advanced small and medium sized reactors (SMRs), which are mainly light water cooled reactor designs incorporating inherent and passive safety design features.

Generation III type NPPs are designed to be built in very broad siting conditions; therefore the safety aspects related to the external events might consider new scenarios and failure modes, different from those well known for the currently operated reactors.

Furthermore as the recent Fukushima accident (Tohoku-Taiheiyou-Oki earthquake of magnitude 9.0 and 14 m tsunami) showed, severe external events, such as earthquakes, tsunamis, flooding, etc., are not impossible, even if very unlikely, and can seriously impair the safety of the nuclear facilities, if not correctly taken into account in the design phase. Therefore nuclear power plants must be designed under very stringent requirements to ensure the safe shut down of the plant, the decay heat removal and the containment function, that is the confinement of radioactive materials. Consequently, beginning from the early stage of the design, the preliminary layout of the main nuclear plant buildings should be analyzed taking into account, among the required criteria [1], an earthquake event (strictly dependent on the site characteristics) to be considered as one of the most important external events that should trigger the safety of nuclear power plants.

In this study, the isolation approach, by means of the insertion of high damping rubber bearings between the reactor building foundation and the soil, has been applied to an advanced SMRs reactor in order to evaluate its influence on the propagation of dynamic loads in the building structures. In particular attention has been paid to the effects induced by a Safe-Shutdown Earthquake ground motion (SSE) on the overall nuclear structures, systems and components (SSCs), which should maintain their functionality, if the SSE occurs.

It is worth underlining that the seismic isolation approach has become very frequent in the recent years, essentially due to the necessity of finding new techniques capable to preserve

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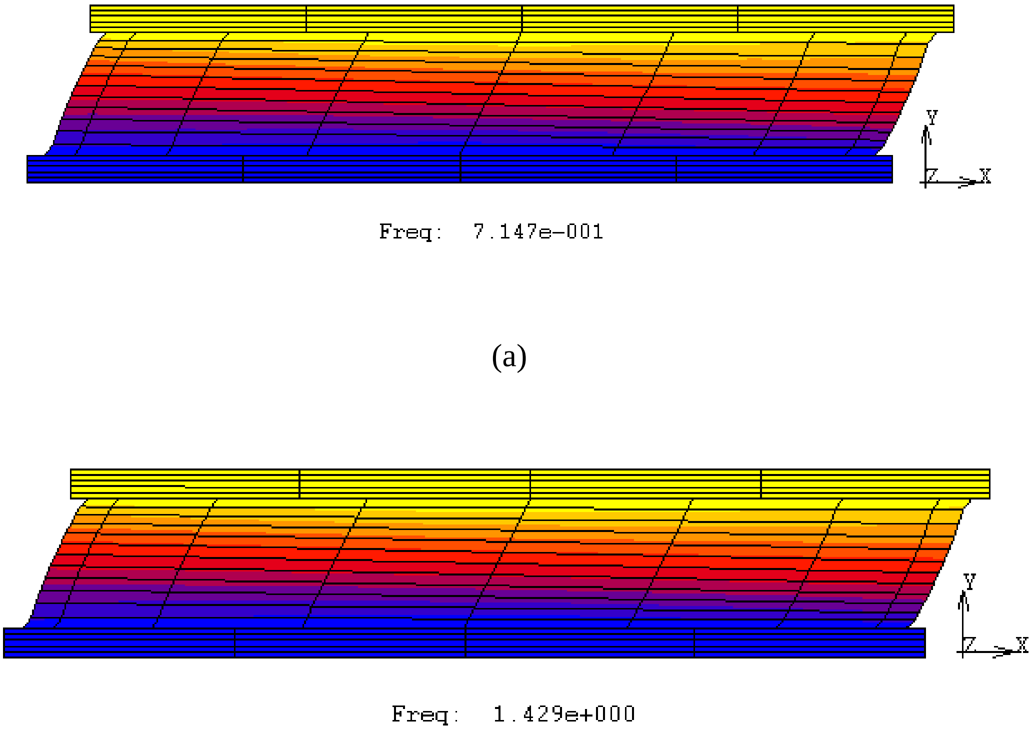
[1] Generation III type NPPs

5. Numerical Results

Before analyzing the response of the considered nuclear plant, the modal analysis has been carried out in order to verify the correct scaling up of the isolator properties.

Accordingly to the scaling theory the frequency of a scaled down isolator devices is proportional to the scaling factor, as indicated in the following Fig. 10, which shows the first frequencies of the HDRB in real dimension and in the scaled down one (scale factor 1:2).



(a)

(b)

Figure 10 - 1st frequency of two HDRBs in real (a) and scaled (b) dimensions

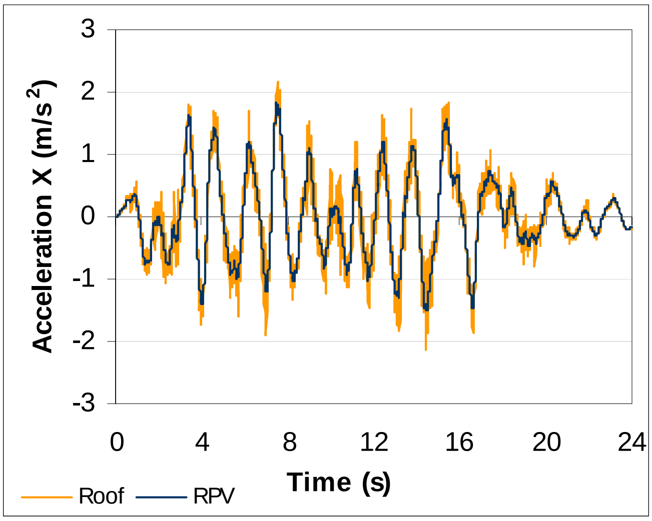
After having verified that the adequacy of the adopted methodology, non-linear transient analyses were performed on the RB structure subjected to the assumed SSE motion.

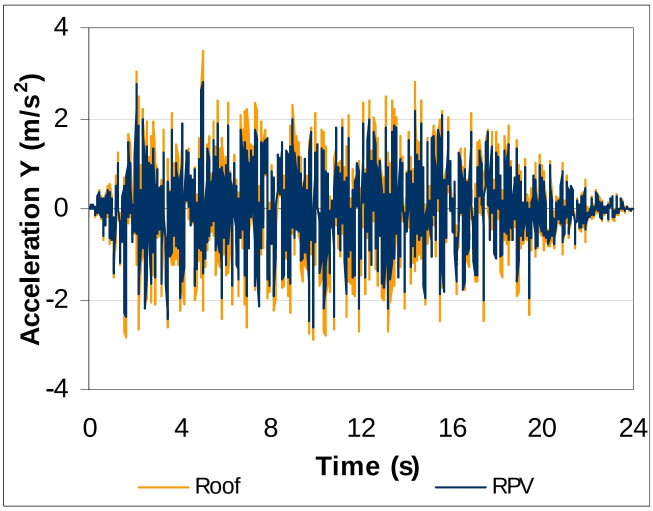
The dynamic response of the isolated plant and the effectiveness of the isolation system were evaluated by analysing the obtained accelerations and displacements at different locations and/or elevations, as for instance in correspondence of the RPV skirt restraints or at the RB roof.

Furthermore the results were compared with those obtained for the not isolated structure for highlighting and confirming, as foreseen and already mentioned, the positive influence of the isolation approach in siting with a seismic risk.

Overviews of the calculated accelerations and displacements behaviours are shown in the following Figs. 11, 12 and 13.

The obtained results in terms of accelerations highlighted the positive foreseen effects of isolation system in mitigating the propagation of both SSE horizontal acceleration components, which decreased of about 30 %.





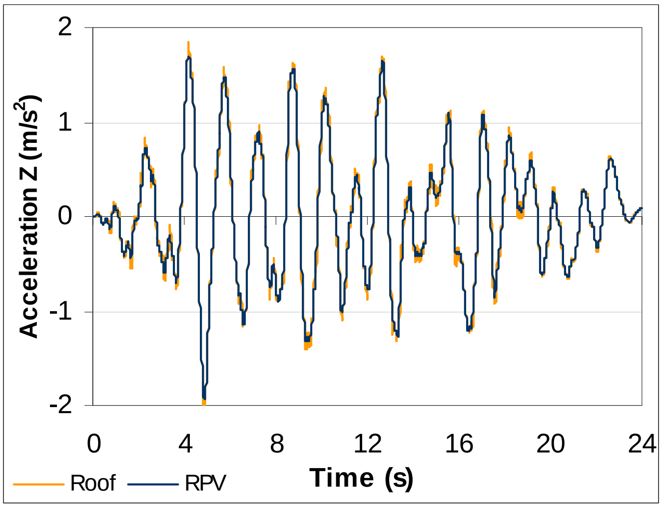
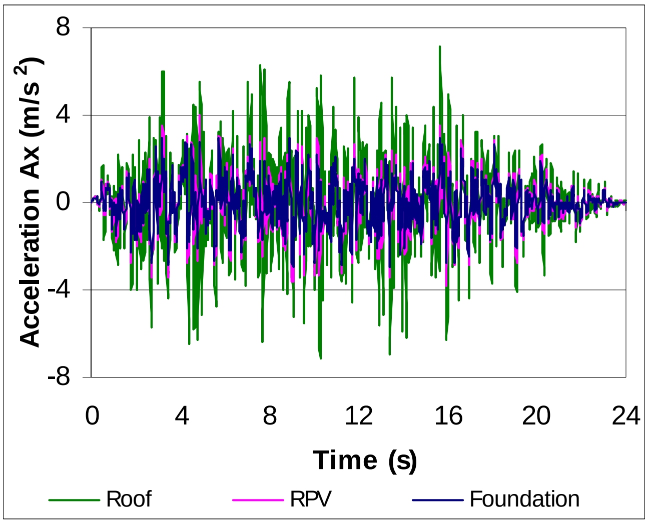


Figure 11 – Acceleration behaviours at different elevations in isolated RB

As for the vertical component of acceleration is concerned, it is worth underlining that this component remains almost still unchanged up to the RPV skirt restraints, while generally it results amplified along the RB height.

On the other hand the acceleration values (Fig. 12 (a) and (b)) obtained analyzing the dynamic structural response of the not isolated RB structure, subjected to the same SSE, highlighted an amplification of the accelerations along the height of RB itself, especially at the highest floors, which reached values of about 2 times higher than the earthquake PGA due to the overall containment building flexibility.



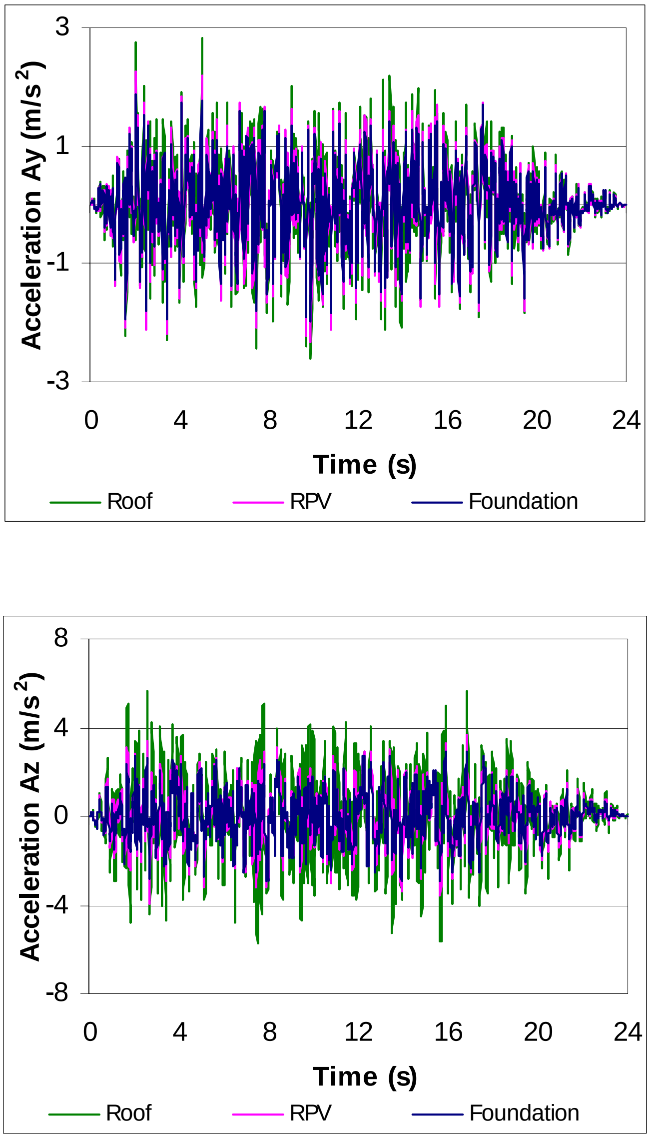
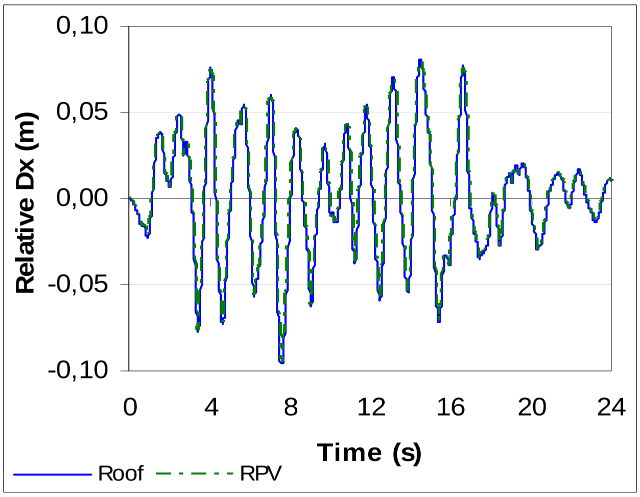
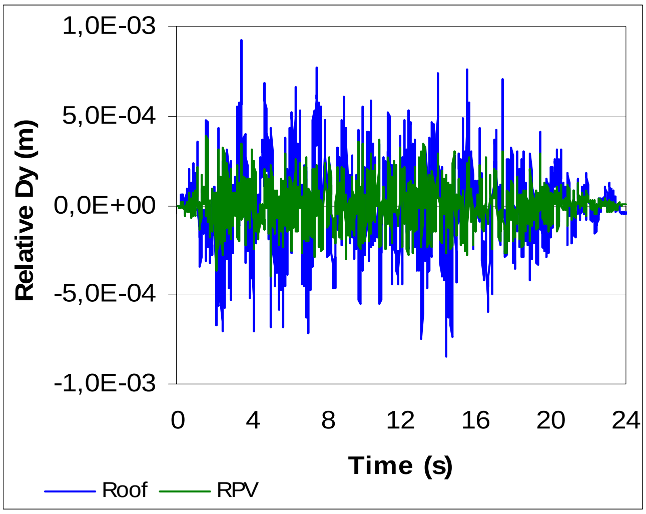


Figure 12 – Accelerations behaviours at different elevations in not isolated RB

As for the relative displacements is concerned (Fig. 13), it is important to note that they are a measure of the stability of the isolators behaviour: these values, although quite large with respect to the displacement calculated in the not isolated RB structure, should be less than the design displacement in order to guarantee the stability of the rubber bearing and allow the superstructure to dissipate the earthquake energy content moving in the horizontal plane as a rigid body.

The obtained horizontal displacements were of about 10 cm, while the vertical one of about 1 mm. These values confirmed the stability of the isolation devices subjected to the assumed ground motion (accordingly to the carried out experimental tests the considered isolators allowed about 300 % shear strain before the rupture).





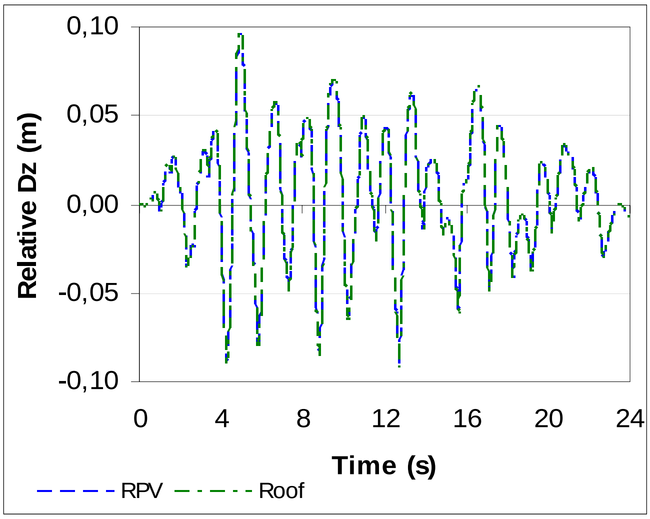


Figure 13 – Displacements behaviours at different elevations in isolated RB

Moreover, as a confirmation of the good performances of the adopted isolation devices, it is worth noting that the obtained results, in terms of both horizontal accelerations and displacements, are “similar” inside and along the isolated RB structure height, as foreseen, due to its mentioned almost “rigid” behaviour.

Finally the floor response spectra (FRS) were calculated into the frequency domain: the horizontal components of the input motion were reduced up to 30 % as shown in Fig. 14.

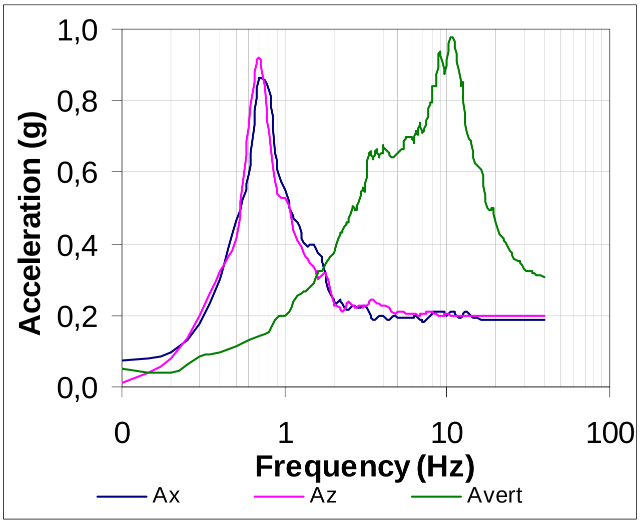


Figure 14 - FRS at the RPV elevation for isolated RB

The calculated FRS indicates and confirms the favourable effects of the implemented isolation bearings as well as the capability of the seismic isolation technique to increase the safety margin of the nuclear facility (Fig. 15).

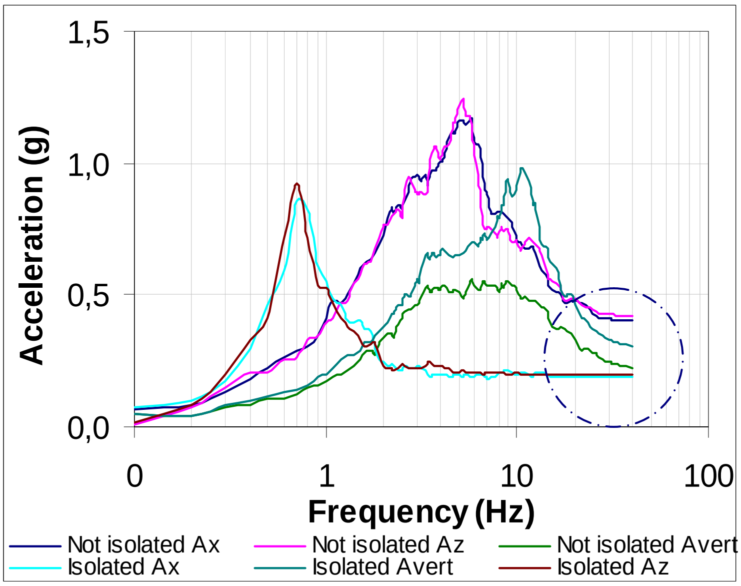


Figure 15 - FRS comparison

6. Conclusions

A preliminary evaluation of the safety margin of an innovative SMR (e.g. the IRIS one in the performed analyses) subjected to a severe seismic event (having PGA equal to 0.3 g) was carried out, using the Time History approach and considering the adoption of the seismic isolation.

The strength assessment of the isolated RB structure required considerations not only on the available geometry and material behaviour of the most important SCCs, but also on the characteristics of the seismic isolation type and of the rubber bearing itself.

To the purpose of this study the real behaviour and characteristics of the HDRBs (damping, stiffness, etc.), like the ones obtained from a rather extensive experimental test campaign on scaled down HDRB prototypic devices, were implemented in a quite refined RB FEM model.

The comparison of the obtained results with those of not isolated RB, in terms of acceleration, displacement and response spectra, highlighted the effectiveness of the isolation system, in mitigating the seismic response of the RB and its internal structure, like the RPV (which was not affected by relevant stress value).

The obtained results also confirmed the foreseen favourable effects of the isolators: the horizontal components of the input motion were reduced up to 30 % while the displacement increased as it was foreseen.

Finally the results allowed to check and confirm the consistency of this methodology compared with the simplified one (spring-mass dashpot approach), adopted in the preliminary analyses discussed in a previous document (CIRTEN-UNIPI RL 1058-2010).

The lateral shift of isolators resulted about 10 cm, close to the measured 300 % shear strain; therefore the isolators appeared capable to ensure a higher safety margin against failure (as experimentally confirmed) in the considered accidental conditions.

In conclusion, the NPPs seismic isolation is a technique to be implemented not only for increasing the safety margin from the safety viewpoint, but also for standardizing the design for a rather large range of site seismic characteristics.

References

1. NRC, Earthquake Engineering Criteria for Nuclear Power Plants, 10 CFR 50.
2. R. Lo Frano, G. Forasassi, Analysis of Seismic isolation problems of NPP buildings, Proceedings of ENC 2010, Barcelona 2010.
3. V. A. Matsagar and R. S. Jangid, Seismic response of base-isolated structures during impact with adjacent structures, Engineering Structures, 25 (2003) 1311-1323.
4. M. D. Carelli et al., The Design and Safety Features of the IRIS Reactor, Nuclear Engineering and Design, 230, 151-167 (2004).
5. M. Forni et al., Seismic isolation of the IRIS nuclear plant, Proceedings of the PVP2009 Conference, Prague, Czech Republic 2009.
6. ASCE, Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities, ASCE 43-05, 2005.
7. R. Lo Frano, G. Forasassi, Preliminary seismic analysis of an innovative near term reactor: Methodology and application, Nuclear Engineering and Design, 240 issue 6, 1671-1678, 2010.
8. M. Forni, Guidelines proposal for seismic isolation of Nuclear Power Plant, RdS/2010/86-NNFISS - LP2 - 038, AdP MSE-ENEA, 2010.