Conceptual design of seismic isolation for the PRISM liquid metal reactor

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1 INTRODUCTION

This paper reviews the seismic design considerations for the PRISM (Power Reactor Inherently Safe Module) pool-type liquid metal reactor (LMR). PRISM is a compact modular reactor of a size corresponding to about 135 MWe. It can be installed in standardized multiple blocks to provide a range of power plant sizes Tippets et al. (1986).

Each reactor building consists of an underground reactor silo embedded to a depth of 23.5m below grade. Figure 1 shows a section through one silo. The reactor module, passive auxiliary cooling systems, air flow passages, the reactor head access, and supporting structure are housed in the silo. The reactor vessel consists of a relatively long slender stainless steel vessel which is supported near the top of the operating floor. In general, LMR components are relatively thin walled because of near atmospheric pressure operation and to accommodate large thermal transients. While such components have desirable thermal features, they usually result in large seismic amplifications. To enhance seismic safety, it is desirable to minimize seismic input to the reactor and to reduce amplifications caused by the flexibility of the reactor components. Two options were considered: taking full credit for embedment in reducing seismic input, and seismically isolating the reactor. The analysis results, the design of the seismic isolators, and the advantages of the selected isolation scheme are discussed in this paper.

2 SEISMIC RESPONSE OF NON-ISOLATED REACTOR MODULE

Three-dimensional soil-structure interaction analyses were performed using the computer program SASSI (Lysmer et al. 1981) to compute the response of the non-isolated PRISM reactor system. The program is a general-purpose finite element program which uses the flexible volume substructuring approach (Tajirian 1981 and Tabatabaie 1982). It was selected to take full advantage of embedment in reducing response. In a previous study by Tajirian et al. (1984), the capabilities of the program in predicting the response of deeply embedded structures was demonstrated by computing the response of the Humboldt Bay Nuclear Power Plant during the Ferndale earthquake of June 7, 1976. The computed motions were shown to be in good agreement with those recorded inside the plant during the earthquake.

The reactor was housed in a concrete caisson embedded to a depth of 27m, somewhat similar to the PRISM silo.

The model used for the PRISM analysis consisted of 114 nodal points. The silo structure was modelled with 52 solid elements and the reactor with 20 beam elements and 13 lumped masses. Due to symmetry conditions, only one-fourth of the system was modelled.

A synthetic design earthquake time history scaled to a maximum acceleration of 0.3g was specified at grade. The response spectrum of this record envelopes the NRC Regulatory Guide 1.60 design spectra. The site was modelled as a damped uniform elastic halfspace with a shear wave velocity of 625 m/s.

Horizontal accelerations and response spectra at the reactor vessel (RV) support and at the core support plate were computed. The accelerations were 0.30g and 1.25g respectively. Although the maximum acceleration at the RV support was close to the input, there was a 4.2 times increase in acceleration at the core support plate due to vessel flexibility. The acceleration response spectra for 2% damping at the same points are shown in Figure 2 (no isolation). Near 5 Hz the spectral peak at the core support is 16.8 g, 12 times higher than the support acceleration.

Designing the PRISM reactor internals to accommodate these levels of acceleration, though feasible, would be a complex effort. A means of reducing the seismic response was sought. One option considered a series of seismic keys to reduce the response. Such an approach was not selected because it would complicate the design. The other option considered was to seismically isolate the reactor assembly from horizontal motions.

3 SEISMIC ISOLATION OF PRISM

3.1 Background

Many forms of seismic isolation have been proposed. Kelly (1986) gives a general review of applied methods and a comprehensive bibliography. The most promising system for nuclear applications and the one selected for PRISM is steel-laminated natural rubber bearings. This type of isolation has been used in the only seismically isolated building in the US, the Foothills Communities Law and Justice Center in Southern California Tarics et al. (1986). Substantial data exists on the behavior of these bearings. In addition, the bearings are simpler to design and do not rely on additional components to perform satisfactorily.

The rubber compounds used in these bearings have sufficient damping to assure a controlled response without the need for external damping devices which may cause high frequency amplifications in equipment response Tajirian et al. (1987). A minimum damping of 10% can be achieved for all applicable strains. Additionally, these rubber compounds have other beneficial properties: at low strains they have a high shear modulus, as high as 3.45 MPa, and at higher strains, the modulus drops to 1.45 MPa and remains fairly constant. The high rubber stiffness at low strains means that wind loads and small earthquakes can be resisted without appreciable movements, eliminating the need for mechanical fuses. The proposed bearings are self-centering, and tests have shown that the rubber properties do not change appreciably due to cycling. Thus, they would be effective in the main shock and aftershocks, and there should be no need for replacing them after an earthquake.

The long experience with similar bearings in Europe, where they have been used to isolate buildings from ambient ground vibrations, indicates that no appreciable changes in the rubber properties are to be expected during the operating life of the plant. Such isolators would require minimum inspection and maintenance, and replacement during the life of the building is not foreseen, even though provisions are made for such replacement.

3.2 Design of PRISM seismic isolators

A 3-D schematic of the seismic isolation scheme is shown in Figure 3. The operating floor which supports the reactor module is supported on 20 isolators. The total weight isolated is 4450 tons. Details of a typical bearing can be seen in Figure 4. It consists of alternating layers of rubber and steel. The rubber is vulcanized to the steel plates. The bearing size and rubber compound were selected to give a horizontal isolation frequency of 0.75 Hz. Horizontal flexibility is controlled by varying the rubber properties, the total thickness of the rubber, and the diameter of the bearing.

In general, the total thickness of the rubber in the bearing depends on the maximum horizontal displacement expected to occur. For nuclear applications which require a high safety margin, the thickness can be selected such that the shear strain, which is the maximum horizontal displacement divided by the total thickness of rubber, is in the range of 50 to 60% when applying the maximum SSE displacement. Using this criteria the bearing shown in Figure 4 is designed to accommodate a maximum design horizontal displacement of 20 cm. It should be noted that tests on similar full scale bearings have shown that the bearings are able to accommodate shear strains in excess of 150% at full design load. Thus, even when the bearing is sheared to its design limit the available margin before failure is more than a factor of three. To minimize amplifications in vertical response, the bearing dimensions are selected to yield a high vertical to horizontal stiffness ratio in excess of 1000.

3.3 Results of seismic analysis

The dynamic response of the seismically isolated reactor module was computed. The same input motion and site properties described in Section 2 were used. In this analysis, embedment effects were neglected since the reductions in acceleration due to embedment would not affect the response of the isolated system.

Maximum accelerations and response spectra at the basemat (input to the isolators) and at the core support plate were computed. The horizontal accelerations were 0.31g and 0.25g respectively, a reduction of 1.24 times. A comparison of these response spectra is shown in Figure 2 (with isolation). The results show an even more dramatic decrease in accelerations. Spectral accelerations for frequencies above 1.2 Hz were substantially reduced. The maximum relative displacement between the isolated reactor module and the non-isolated silo was computed to be 11.5 cm.

A comparison of spectra at the core support plate for the isolated and the non-isolated plant shows that the peak spectral acceleration near 5 Hz was reduced from 16.5g to 0.25g. This is beneficial to all components with natural frequencies greater than 1.2 Hz.

Seismic analysis in the vertical direction has shown that vertical seismic response, without vertical seismic isolation is acceptable.

4 SUMMARY AND CONCLUSIONS

Seismic isolation results in substantial reductions in horizontal accelerations for all of the different reactor components. Incorporation of seismic isolation into the PRISM design results in reactor design simplification, reactor system safety and reliability improvements, and reactor design and licensing risk reduction.

Seismic isolation facilitates the standardization of the NSSS design, permitting a broad geographic deployment. Components developed for regions of low seismicity may be used in areas of high seismicity if the components are isolated. Furthermore isolation offers greater financial protection from the need to redesign the PRISM reactor due to the discovery of unexpected geological conditions or possible future upward revisions in design regulations.

REFERENCES

Kelly,J. M. 1986. Aseismic base isolation, review and bibliography. Soil Dynamics and Earthquake Engineering Vol. 5. No. 3.

Lysmer,J., M.Tabatabaie, F.F.Tajirian, S.Vahdani & F.Ostadan 1981. SASSI - A system for analysis of soil-structure interaction. Report No. UCB/GT/81-02. University of California, Berkeley.

Tabatabaie,M. 1982. The flexible volume method for dynamic soil-structure interaction anslysis. PhD dissertation, University of California, Berkeley.

Tajirian,F.F. 1981. Impedance matrices and interpolation techniques for 3-D interaction analysis by the flexible volume method. PhD dissertation, University of California, Berkeley.

Tajirian,F.F.,M.Tabatabaie & J.Lysmer. 1984. Truly three-dimensional soil-structure interaction analysis of the Humboldt Bay power plant. Dynamic soil structure interaction, University of Minnesota.

Tajirian,F.F. & J.M.Kelly 1987. Seismic and shock isolation system for modular power plants. Submitted to ASME symposium on seismic shock, and vibration isolation. San Diego.

Tarics,A.G., et al. 1986. Quality assurance and control of fabrication for a high-damping-rubber base isolation system. ATC-17 Seminar on base isolation and passive energy dissipation, California.

Tippets,F.E., S.M.Davies, L.N.Salerno, & C.R.Snyder 1986. PRISM: a passively safe, economic and testable advanced power reactor. Proceedings of the American power conference. Chicago, Illinois.

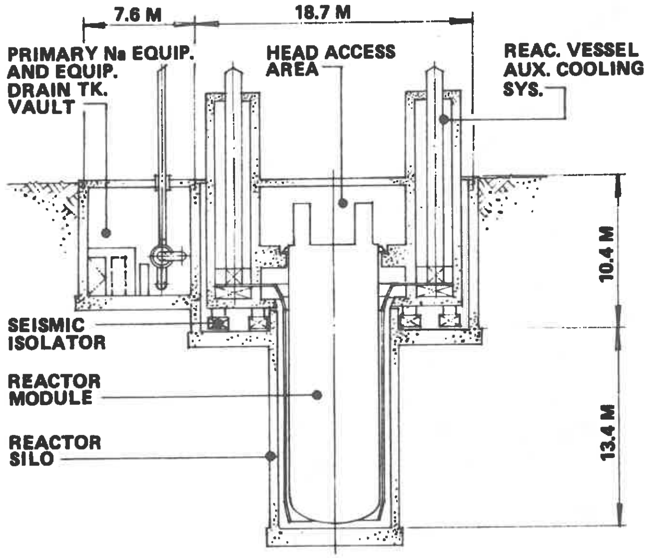

Figure 1. Section through PRISM silo

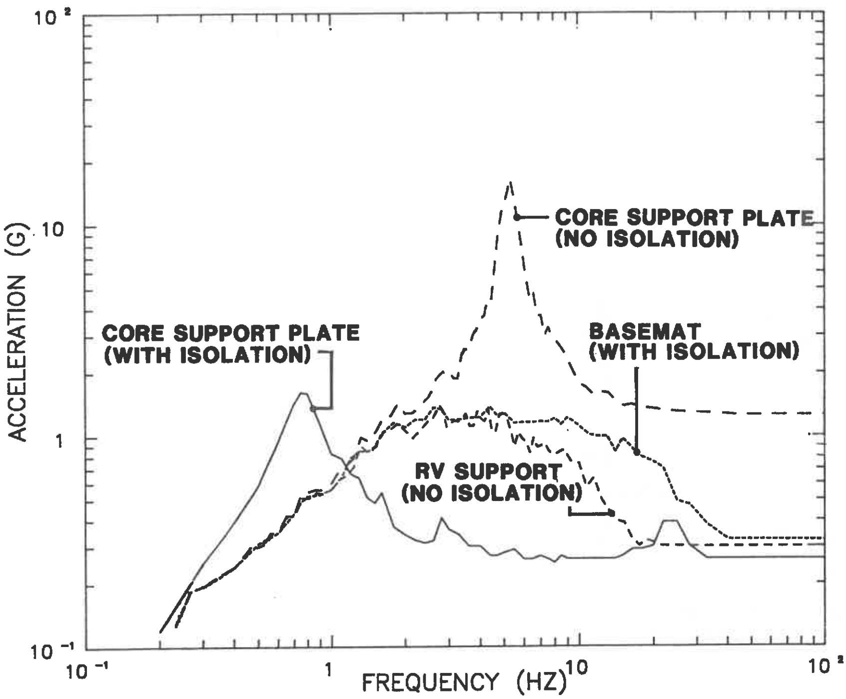

Figure 2. Comparison of response spectra damping = 2%

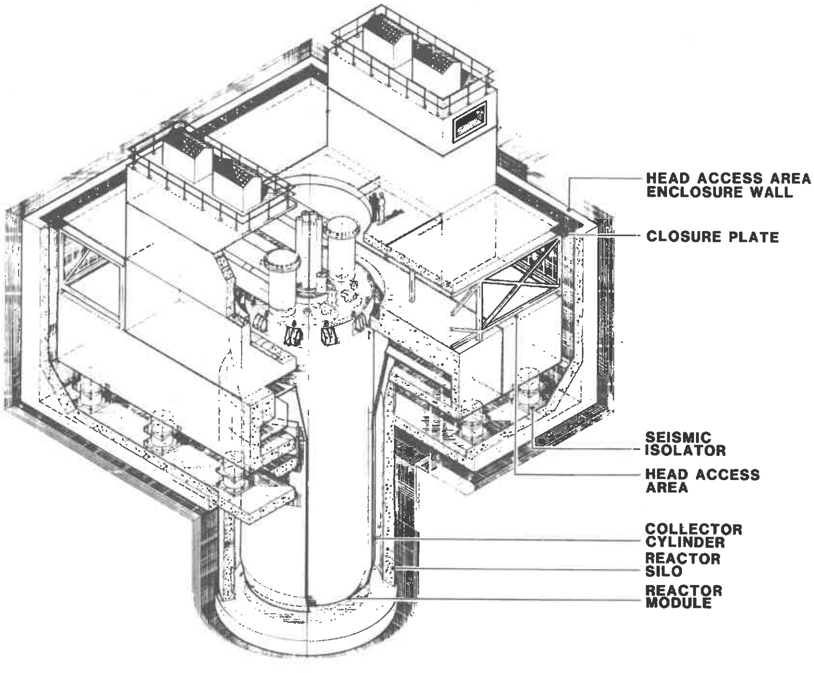

Figure 3. 3-D schematic of PRISM reactor module

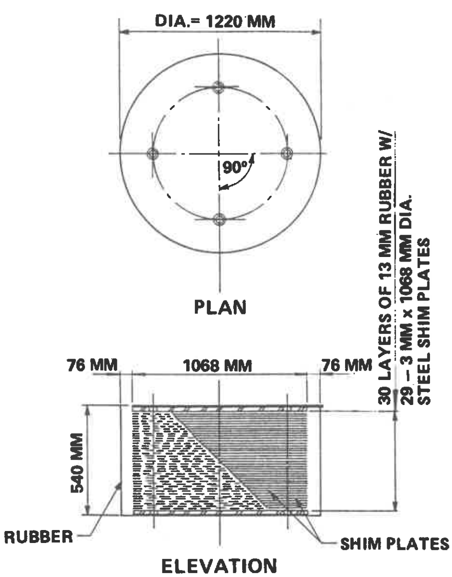

Figure 4. Typical seismic isolator