Qualification of seismic isolation for the PRISM liquid metal reactor

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ABSTRACT

Lateral seismic isolation has been included in the PRISM liquid metal reactor design in order to minimize seismic influence on the reactor design and to provide a design independent of site selection. The slender vertical orientation of the reactor provides high strength vertically while the lateral seismic isolation provides low response laterally. The seismic response analysis is presented for the isolated reactor concept. Additionally, testing is discussed for the isolators and isolation system.

1 BACKGROUND

The application of lateral seismic isolation to the PRISM liquid metal reactor (Berglund 1986, Tippets 1986) has been made in order to minimize seismic influence on the reactor design and to provide a design independent of site selection. The entire isolated PRISM nuclear structure weighs only 40 MN with an isolated basemat approximately 18 meters square (Figure 1).

Several isolation concepts were considered for use in this application. Concepts with a substantial base of technology, testing and application were given preference to facilitate acceptance by regulatory agencies.

The parameters considered in the design selection were simplicity, sufficient damping, self centering capability, and resistance to environmental factors and degradation.

The concept selected for this application is a layered natural rubber and steel bearing as developed by the Malaysian Rubber Producers' Research Association in England and the University of California at Berkeley. The design uses a special high damping rubber compound with damping capability in excess of ten percent of critical. This bearing is of the type used in the first base isolated building in the United States; the Foothill Communities Law and Justice Center, County of San Bernardino, California (Derham 1985, Tarics 1984).

A design that achieves a low lateral isolation frequency without unduly sacrificing vertical support stiffness (Figure 2) was developed. The lateral isolation frequency is 0.75 Hertz. To minimize vertical amplifications in response the vertical stiffness of the bearings is selected to be at least one thousand times stiffer than the lateral stiffness, and will be specifically determined by test. Details of the bearing design are discussed in Tajirian (1987).

2 SEISMIC RESPONSE ANALYSIS

A soil-structure interaction analysis was performed and documented in Tajirian (1987). In that analysis, the reactor is modeled in sufficient detail to evaluate levels of seismic response at component supports. Different damping values are included for the soil, seismic isolators and reactor structure. A synthetic time history is input, for which the response spectrum envelopes the NRC Regulatory Guide 1.60 spectrum, with a 0.3g zero period acceleration.

A response spectrum analysis is also performed, using the same structural model without including the soil. The isolators are included in the model. A single damping value of 3% is used. The analysis is intended to identify frequencies of vibration and mode shapes, as well as seismic response.

Fifty-seven degrees of freedom are modeled to evaluate any potential amplification through the isolated structure (Figure 3). The model is two dimensional and is used in both the horizontal and vertical analyses. The small size of the structure, and its direct support to ground through the isolators require that a coupled model be used in which all the major components are modeled. The input spectrum is obtained from the soil-structure interaction analysis at the foundation (Figure 4).

Results of the horizontal spectrum analysis (Table 1) show the structure to respond in a single significant mode of vibration at 0.75 Hertz. All modes of vibration couple with the dominant isolation frequency and all the secondary frequencies are insignificant. All motion is in phase. Acceleration response throughout the structure is nearly uniform. This behavior will allow the component seismic responses to be evaluated using simplified static analysis.

The displacement and acceleration response of the response spectrum analysis are excessively conservative. A response spectrum corresponding to 3% damping is used, while the isolators exhibit damping in excess of 10% of critical. The amount of conservatism is demonstrated in Table 1 where results from the soil-structure interaction analysis (Tajirian 1987) are also presented. These results show the response spectrum analysis results to be 2/3 greater. This is consistent with NRC Regulatory Guide 1.60 spectra, where at 0.75 Hertz the acceleration is also 2/3 greater for 3% versus 10% damping.

The vertical response of the system exhibits several significant modes of vibration between 14 and 32 Hertz. Individual modal responses are combined to derive the total response (Table 2). Amplifications in vertical response are small by comparison, which is why vertical seismic isolation is not included in this design.

3 VALIDATION TESTING

A series of static and dynamic tests are planned to confirm the material properties of the rubber compounds, design characteristics of the bearings, cyclic stability (degradation), and the safety margin of the bearings.

The test plan includes the following:

1. Material tests on the rubber compound to confirm properties such as damping, dynamic shear stiffness, and tensile strength.
2. Dynamic tests of the bearings under a combined static vertical load and a cyclical horizontal load to verify bearing stability under conditions far beyond the design basis SSE.
3. Vertical and horizontal stiffness tests of the bearings for various

strain levels.

4. Hysteric behavior determination of the bearings.
5. Fragility testing under vertical dead load.
6. Sustained compression set testing.
7. Property evaluation before and after cycling.

Full scale qualification using a prototype structure is being evaluated. Snap back tests conducted to verify response characteristics such as frequency and damping are under consideration(Popov 1986, Hunter 1986). The snap back test would be performed by applying a lateral force to the isolated basemat sufficient to induce a static deflection of several inches. The restraint is then released and the structure is allowed to respond. The resultant damped free vibration response is monitored; from which the dynamic stiffness and damping of the isolators, as well as the fundamental frequency of vibration is determined.

4 ACCEPTANCE TESTING

The physical properties (shear modulus and damping) of each batch of rubber used in manufacturing the bearings will have to be verified by testing. Each individual bearing must undergo acceptance testing prior to installation. Bearings shall be tested under the combined effects of vertical and horizontal design loads.

Prior to shipment, each bearing will be cycled through ten complete cycles at the maximum design displacement, currently 11.5 cm. Stiffness and hysteric properties will be measured to assure stiffness and damping properties are within design tolerance levels.

5 PERFORMANCE ASSURANCE/INSERVICE INSPECTION

The seismic isolation support system functions as vertical supports for the silo and reactor module at all times, but only in the case of a large seismic event is the seismic isolation function required. The seismic support system is classified as a nuclear safety class system for the PRISM design. It is essential to plant safety to insure that the system will function in the event of a large seismic event.

The seismic isolators are fabricated from layers of steel and rubber. Experience has shown this type of bearing and this type of natural rubber to be extremely age resistant. Additionally, a three inch protective rubber layer around the circumference is included in the design. This provides fire proofing for the bearing as well as protecting the steel plates from rusting.

The most appropriate inservice inspection (ISI) for this system is visual inspection. Sample rubber coupons and bearings will be located adjacent to the isolators and will be removed for functional testing and detailed examination if the visual examination indicates damage to the seismic supports. However, the seismic isolators are designed and expected to last the entire plant life without degradation or replacement. All bearings are replaceable on an individual basis.

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Table 1. Horizontal SSE seismic response.

Component	Response spectrum analysis Displacement* (cm)	Response spectrum analysis Acceleration (g's)	SSI analysis Acceleration (g's)
Isolated Basemat	**	0.44	0.25
Reactor Vessel	0.76	0.46	0.26
IHX	1.24	0.47	0.26
Sodium Pump	1.04	0.47	0.26
UIS	2.13	0.49	0.31
Core Support	0.80	0.47	0.26

* Relative to the isolated basemat (see Figure 2). All displacements in phase.
** Maximum isolator differential displacement = 11.5 cm (SSI analysis).

Table 2. Vertical SSE seismic response.

Component	Response spectrum analysis Displacement (cm)	Response spectrum analysis Acceleration (g's)
Isolated Basemat	small	0.19
Reactor Vessel	small	0.82
IHX	small	1.28
Sodium Pump	small	0.75
UIS	0.064	0.68
Core Support	0.112	0.90

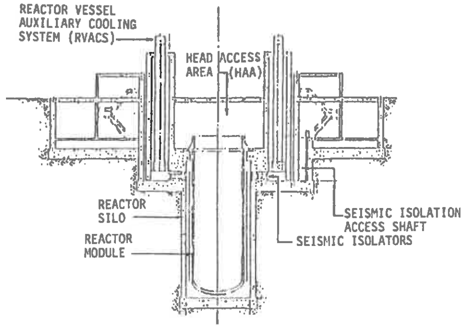

FIGURE 1 ISOLATED PRISM REACTOR MODULE

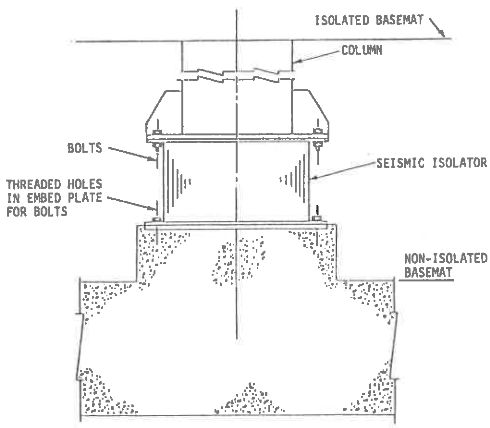

FIGURE 2 TYPICAL SEISMIC ISOLATOR MOUNTING

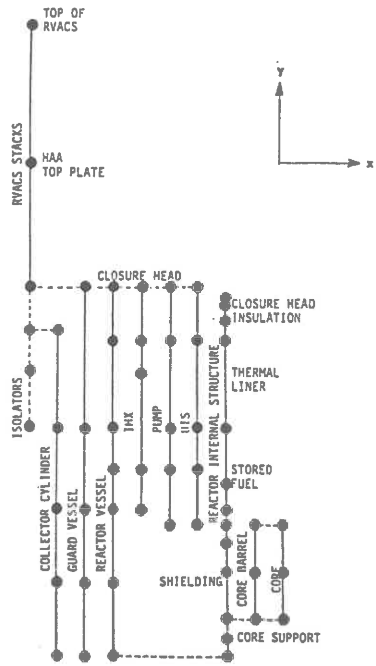

FIGURE 3 PRISM SEISMIC MODEL

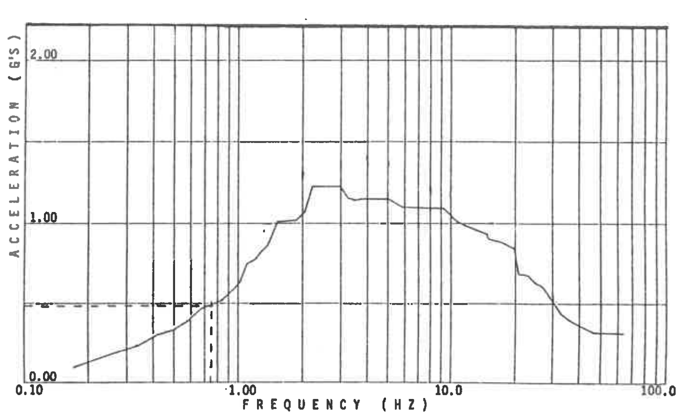

FIGURE 4 HORIZONTAL SPECTRUM, DAMP = 3%