Seismic Isolation for Nuclear Power Plants

J.M. Eidinger

EDS Nuclear Inc., 220 Montgomery Street, San Francisco, California 94104, U.S.A.

This paper describes the key aspects of the decision to use seismic isolation in nuclear power plant design. To date, only French nuclear plants have used seismic isolation. This paper examines why this is the case, and what are future prospects of isolation systems.

Seismic isolation is a relatively new design philosophy. Data are presented showing the increased quantity of research done in this field during the 1970's. This increase is correlated to the appearance of actual application of seismic isolation systems, in the late 1970's.

Seismic isolation reduces the seismic response of the nuclear plant. Acceleration and base shears decrease by factors of 3. Floor response spectra decrease by factors up to 10, with typical spectral peak reductions from 21g to 3.4g.

Seismic isolation controls the shape and frequency content of the design response spectrum at the nuclear plant foundation level. This can reduce risk from finding near field faults after the plant has been designed.

Seismic isolation allows the use of standardized nuclear plant designs in high seismic regions. This affects cost of the plant, and is perhaps the most compelling reason to use seismic isolation in nuclear plant design.

1.0 INTRODUCTION

Seismic isolation of nuclear power plants is an excellent concept. There has been recent increased interest in the concept, and seismic isolation has already been applied by the French for selected nuclear power plants in South Africa and France. Questions facing the engineering community are why have only the French applied this design concept, and what are the prospects for future use of this design concept.

This paper presents four items the engineer must consider in deciding to select a seismic isolation system for use in a nuclear facility. First, the engineer requires data on how to design, analyse and construct seismic isolation systems. Tables are presented which summarize the large quantity of seismic isolation research and the practical applications that have been carried out over the past few years. Second, a seismic isolation system provides improved seismic performance of the nuclear plant. Analytical and experimental results are presented which show the magnitude decreases in accelerations, base shears and floor response spectra for a seismically isolated structure. Third, a seismic isolation system can control seismic risk for the nuclear plant. This paper discusses how a seismic isolation system effectively filters the design response spectrum, thus alleviating the risk of the discovery of near field faults. Fourth, cost considerations play a major role in the selection process. This paper thus reviews how the Standardized Nuclear Power Plant SNUPPs concept becomes perhaps the most critical point in the final decision to employ a seismic isolation system.

2.0 HISTORICAL PERSPECTIVE ON SEISMIC ISOLATION AND MODERN APPLICATIONS FOR FOR NUCLEAR PLANTS

For the engineer to decide to use a seismic isolation system in a nuclear plant, he needs adequate data regarding how to design it, and what its performance record is. Table I presents an historical list of roughly the amount of technical research done on isolation systems. We notice from this list that there has been a large growth in research in this field since 1970. Table II presents a list of actual practical design applications of various types of seismic isolation systems. These two tables show that the quantity of technical research and practical applications appear to be correlated. Given that this recent surge in research provides enough background proving the merits of seismic isolation systems, the engineer is next faced with choosing an appropriate system for a nuclear plant.

In seismic isolation, the engineer wants to detune the nuclear plant structures from the input earthquake vibration. This concept is similar to the design for foundations of vibrating machinery. Potentially, then, a seismic isolation system could consist of a simple rubber bearing system, of adequately low stiffness, placed below the nuclear plant's foundation mat. The rubber bearings would lower the structure's predominant natural frequencies to a range well below where there is significant earthquake motion energy.

However, such a simple rubber bearing system has strong drawbacks. These drawbacks are the following: first, an unusual earthquake could occur, having dominant energy just at the very low frequency of the rubber-bearing-isolated nuclear plant; second, the nuclear plant may experience significant motions in the design wind load condition; third, if an earthquake occurs which actually exceeds the design basis earthquake, displacements could occur outside the capacity limits of the rubber bearings. This could fail the rubber bearings in an undesirable 'brittle' fashion.

In practical design, the engineer desires an isolation system which behaves in ductile fashion at the highest possible design loads. Thus, an extra component needs to be added to the rubber bearings, to provide a 'ductile' isolation system. At least four types of devices are commonly suggested in the literature (1, 2 and 3) that could be added to fulfill this function:

1) Steel energy absorbers.
2) Mechanical fuses.
3) Hydraulic dampers.
4) Friction plates.

In actual nuclear plant construction, a combination of friction plates and rubber bearings have been employed. A combination of steel energy absorbers and rubber bearings also provides an excellent isolation system. Mechanical fuses are not suitable, due to their brittle and somewhat unpredictable behaviour. Hydraulic dampers are not suitable for nuclear plant isolation systems due to their constant need for inspection, testing and replacement.

3.0 NUCLEAR PLANT PERFORMANCE ON A PRACTICAL ENERGY ABSORBING ISOLATION SYSTEM

The results which follow are based upon a seismic isolation system using rubber bearings and steel torsion energy absorbing devices. This system has been previously experimentally tested (4), and analytical results have been prepared for this report. The test structure and isolation system components are shown in Figures 1, 2 and 3. Table III describes the key frequencies of the structure, for both the conventional foundation (FIXED) and the isolated (ISOLATED) foundation. Figure 4 shows the response spectra of the input motion, El Centro NS 1940, scaled to have zero period acceleration of 0.63g.

The following paragraphs discuss the response of the isolated structure. Figure 5 shows the time history response of the top of the building, both for FIXED and ISOLATED conditions, when subjected to the El Centro motion. Figure 6 shows the corresponding time history of base overturning moments and shears.

Accelerations: The FIXED structure amplifies the ground ZPA to about 2g on top, even though the steel frame structure undergoes some yielding. In contrast, the ISOLATED structure reaches peak top story accelerations of only 0.61g, which shows no amplification of the ground motion ZPA.

Moments and Shears: The ISOLATED structure exhibits lower base overturning moments and base shears by a factor of 3 as compared to the FIXED structure.

Even more striking than the above structural response quantities is the comparison of the floor spectra between the FIXED and ISOLATED structures. These spectra are shown in Figure 7.

Floor Spectra: The ISOLATED structure exhibits average floor response spectra reductions of 2 to 3 times, from the FIXED structure. There is as much as 10 times reduction at certain resonance frequencies. For example, the spectral peak goes from 21g for the FIXED structure to 3.5g for the ISOLATED structure. The reader should note that such high (21g) spectra are not uncommon in actual nuclear plants designed in high seismic zones.

4.0 CONTROLLED SEISMIC RISK FOR ISOLATED NUCLEAR PLANTS

As discussed in the previous section, an isolated nuclear plant easily out performs a conventional fixed-base plant, when both are subjected to the same earthquake motion. In essence the isolation system modifies the earthquake motion that actually reaches the nuclear plant. The engineer can use this fact in assessing the seismic hazard risk for a nuclear plant.

One major source of seismic 'risk' lies in our incomplete knowledge of what the 'worst possible' earthquake will be at a particular site. This incomplete knowledge can in certain instances become a large risk, as, for example, the case of the Diablo Canyon nuclear plant in California. After the seismic design had been initiated for this nuclear plant, a new near-field fault, known as the Hosgri fault, was discovered. The presence of this fault has led to much concern for the seismic safety of Diablo Canyon.

For the base isolated nuclear plant, however, the discovery of a major near field earthquake fault may not adversely modify the seismic response of the plant. This is because the earthquake motion the plant actually experiences is only that motion which has been filtered through the base isolation system.

Figure 8 shows, schematically, the difference in the response spectra just below and above the base isolation system described in section 3 of this report. We observe here that the isolation system is effective in controlling the frequency content and acceleration amplitude of the motion actually 'felt' by the structures.

Thus, should a new 'design response spectra' be required for a nuclear plant, due to discovery of a new fault, or increased regulatory concern for safety, than a base isolated plant has an inherently built-in margin against this form of seismic risk.

5.0 SEISMIC ISOLATION AND THE SNUPPs DESIGN CONCEPT

One practical method engineers have used to control the high cost of nuclear plants is to use the Standardized Nuclear Power Plant (SNUPPs) design philosophy. Essentially, SNUPPs means that one set of engineering calculations, and construction drawings, can be used over and over again for several nuclear plants of the same design, even at different sites.

To date, the French have been the most successful group to use the SNUPPs design philosophy. Their performance record in building the 900 MWe series is admirable. Several units have come on line each year for the past few years, and a total of thirty four units of the 900 MWe series have been ordered. Thus, SNUPPs is a practical time and cost saving design philosophy.

However, the engineer loses the benefits of using the SNUPPs design for a nuclear plant in a high seismic region. For example, the French 900 MWe SNUPPs plant is built to withstand a design response spectra earthquake roughly equivalent to a NRC Regulatory Guide 1.60-0.20g motion. However, for higher seismicity sites, to about 0.30g, the French have found it practical to retain the SNUPPs design, when mounting the nuclear plant on a base isolation system. This is done at Koeberg and Cruas. The base isolation system effectively filters the higher 0.30g motion down to an equivalent 0.20g motion.

By so using the base isolation system, substantial cost savings can be achieved. Essentially, the extra cost required to build the special isolation foundation system is offset by the cost savings from the reduced engineering effort needed for a SNUPPs plant, and the less elaborate earthquake protection within containment than would otherwise have been needed.

As of 1983, almost no SNUPPs plants have been built in the United States. This is chiefly attributed to the historical diversity in American plant design. In the U.S., there are several reactor vendors, more than a dozen architect-engineers, and very many nuclear plant utility owners. This lack of SNUPPs plants has reduced the need for designing a seismic isolated nuclear plant in the U.S.

6.0 CONCLUSION

We have discussed in this paper four major aspects in the decision process to employ a seismic isolation system in nuclear plant design. These aspects are the availability of a proven track record for such systems, the lowered seismic response and floor response spectra, the improved seismic safety, and the cost savings when seismic isolation is used in SNUPPs plant design.

Seismic isolation systems could play a role in the U.S. nuclear industry at some future date. The U.S. reactor vendors are moving closer to developing a NRC licensed SNUPPs plant design. Thus, in high seismic zones, a base isolated SNUPPs design may become a practical solution for U.S. domestic or export nuclear plants in the near future.

7.0 REFERENCES

1. Kelly, J.M. 'Aseismic Base Isolation', Proceedings, Second U.S. National Conference on Earthquake Engineering, Stanford University, 1979.

2. Kelly, J.M., 'Testing of a Natural Rubber Base Isolation System by an Explosively Simulated Earthquake', Earthquake Engineering Research Center, EERC 80-25, 1980.

3. Kelly, J.M. and Skinner M.S., 'The Design of Steel Energy Absorbing Restrainers and Their Incorporation into Nuclear Power Plants for Enhanced Safety: Volume 4 - A Review of Energy Absorbing Devices, EERC 79 - 10, 1979.

4. Kelly, J.M., Eidinger, J.M., Derham, C.J., 'A Practical Soft Story Earthquake Isolation System', EERC 77 - 27, 1977.

TABLE I - Published References on Base Isolation and Energy Absorbing Systems

		MAIN TOPIC(S)			
YEAR	TOTAL REFERENCES	SEISMIC ISOLATION	ENERGY ABSORBERS	TEST RESULTS	ANALYTICAL RESULTS
1972	2	2		1	1
1973	4	1	3		1
1974	4	4			4
1975	7	5		1	6
1976	5	2	3	1	1
1977	13	8	5	7	6
1978	11	5	5	3	5
1979	8	7	5	4	4
1980	12	3	9	5	4
1981	8	7	1	3	4
TOTAL	74	44	31	25	36

TABLE II - Applications World Wide of Seismic Isolation Systems

Application	Components	Country	Date of Application
Rangitikei - Railway Bridge	Energy Absorbers Rubber Bearings	New Zealand	1976
School	Rubber Bearings Mechanical Fuses	Yugoslavia	1969
High Rise Office Building	Rubber Bearings Mechanical Fuses	Greece	1972
Nuclear Stations Koeberg	Rubber Bearings Friction Plates	South Africa	1975
Nuclear Stations Cruas	Rubber Bearings	France	1980
Office Building 4 Story	Rubber Bearings Lead Plugs	New Zealand	1980
Schools	Rubber Bearings	France	1977 - 80
Chimney	Energy Absorbers	New Zealand	1980
Railway Bridge Decks	Rubber Bearings	New Zealand	1970's

TABLE III- Structure Frequencies

	FIXED FOUNDATION		ISOLATED FOUNDATION	
	1ST Mode	2ND Mode	1ST Mode	2ND Mode
FREQUENCY	2.27 Hz	7.83 Hz	0.68 Hz	3.84 Hz
MODE SHAPE				
3RD FLOOR	1.00	1.00	1.00	0.97
2ND FLOOR	0.77	-0.62	0.98	0.40
1ST FLOOR	0.41	-1.23	0.94	-0.34
BASE FLOOR	--	--	0.89	-1.00

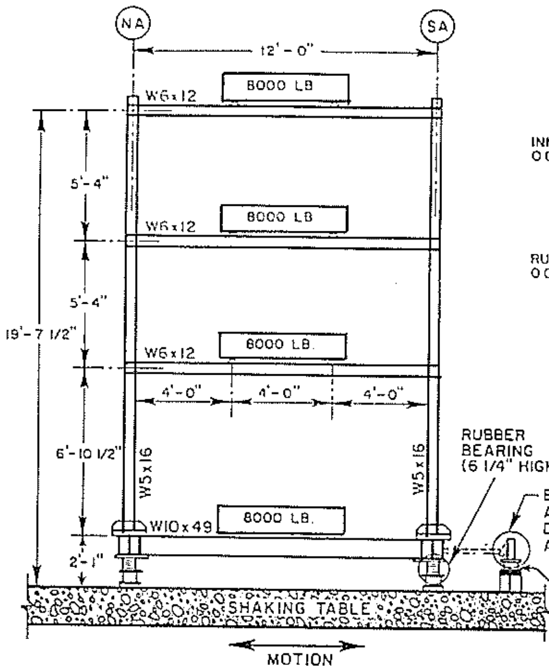
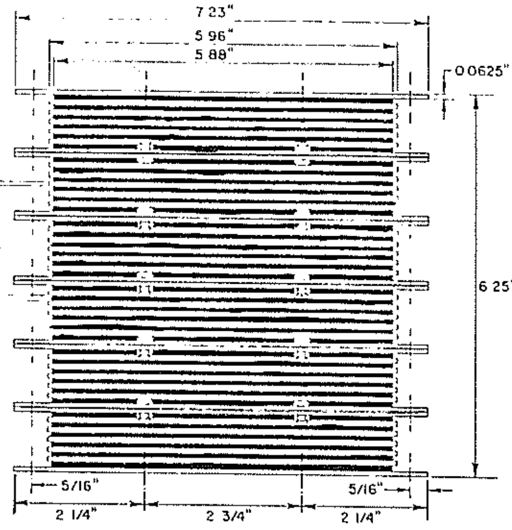
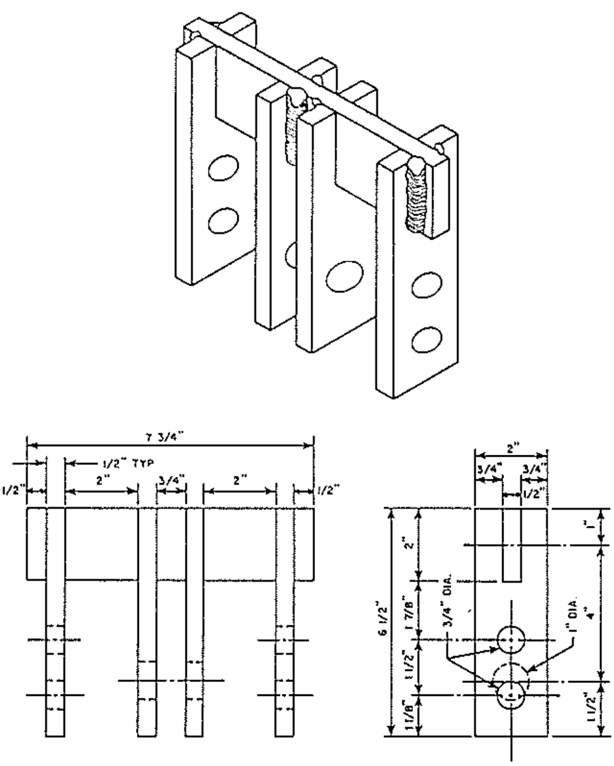


Fig. 1. Three Story Building on ISOLATED Foundation.



DIMENSIONS OF RUBBER BEARINGS

Fig. 2 Rubber Bearing Component



DIMENSIONS OF ENERGY ABSORBING DEVICES

Fig. 3 Energy Absorbing Device Component.

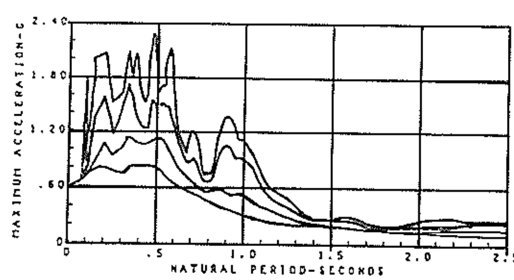


Fig. 4. El Centro Input Motion, Scaled to 0.63g.

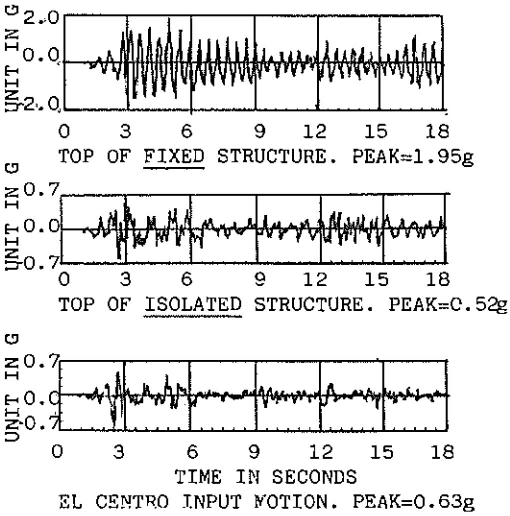


Fig. 5 Time History Response of ISOLATED and FIXED Base Structures- . Accelerations.

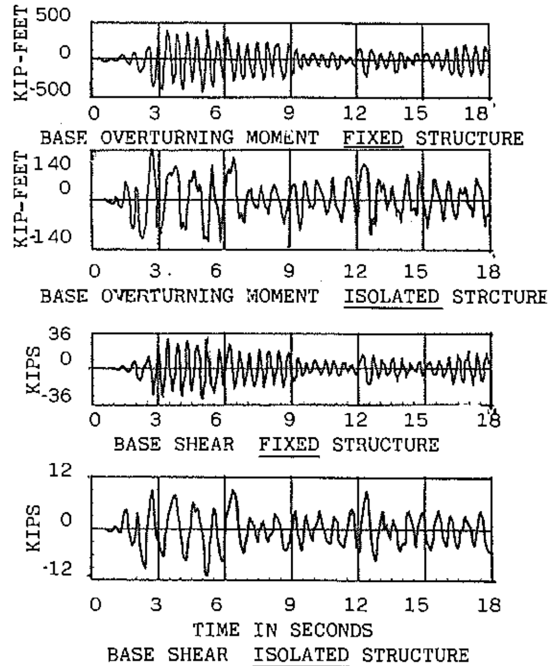


Fig. 6 Time History Response of ISOLATED and FIXED Base Structures - Base Shear and Base Overturning Moments.

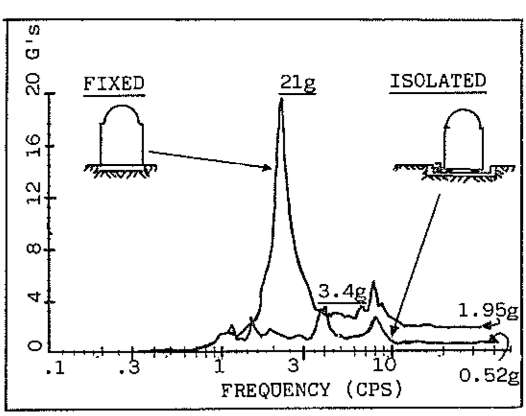


Fig. 7 Floor Response Spectra Comparison: Top of ISOLATED and FIXED Base Structures.

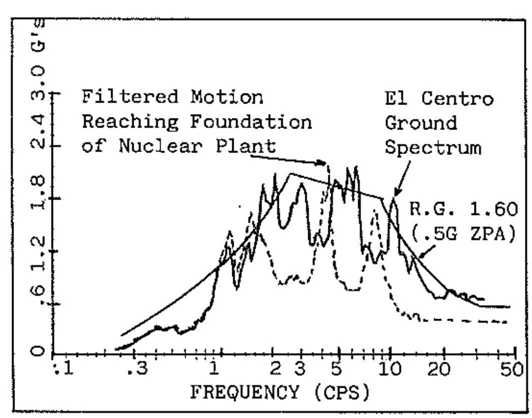


Fig. 8 Filtering effects of Isolation Systems - Design Response Spectrum.