On Problems to be Solved for Utilizing Shock Isolation System to NPP

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§1 INTRODUCTION

Since the success of Super-phenix, the interest to develope a large fast reactor, so called LFBR, has become more realistic one in Japan. However, the anti-earthquake design of a pool-type large fast reactor is more difficult than that of light water reactors for high seismicity areas like Japan. The reason of difficulties come from the difference of the structural requirement for LFBR. Three major points are as follows:

i) Thin wall reactor vessel,
ii) Thin wall sodium loops,
iii) Large sodium pool with free surface.

If we apply the Japanese practice for light water reactors, the wall of a reactor vessel should be two or three times thicker than the thickness which is limited by the thermal stress requirement.

The minimum level of the S_1 earthquake, that is, Design Basis Earthquake, in Japan is 180 gal at the free surface of foundation rock layer. If this value will be cut down near to 100 gal, the design of main items would be easy. This fact is well known, however it is the problem how to reduce the seismic input to such a level.

Two methods have been considered since the project started. One is to lower the center of gravity as practical and to be embeding in soil. Another one is the use of a shock isolation system. We consider both methods will be practical for the purpose.

For a shock isolation, there are several choices, that is, from the isolation of a whole reactor building to that of a reactor vessel alone. Those were examined, and we understood that a simple, whole building isolation is most feasible for the first or second LFBR, which will operate from 2007 to 2010 in Japan.

In this paper, the authors will describe this subject along the conclusion above. However, it doesn't mean for us to abadon other choices. The isolation of main components including a reactor vessel, the second sodium loop and steam generator is still atractive.

§2 MERIT OF APPLYING SHOCK ISOLATING PADS

The authors believe that the principal part of Super-phenix I was designed to endure 0.1 G ground motion. On the other hand, the design basis earthquakes of nuclear power plants in Japan were evaluated from 180 gal to 480 gal, except very special cases of Hamaoka and Tokai #1. These figures are shown in Table 1. Also, the design procedure to decide the response and seismic load of main equipment in the reactor building is severer than other countries for light-water nuclear power plants in Japan. If we apply this standard procedure and design technique to the pool-type LFBR, the thickness of the wall of main reactor vessels may exceed over 100mm. Of cource, this value is depending on the details of its vessel support and other components surrounding the vessel. One of the turget of preliminary design is to reduce it to approximately 50mm.

Such a heavy vessel may cause problems of thermal stress, and ratcheting induced by sloshing of the sodium surface. On the contrary, if the vessel is thinner than this limit, shear-type buckling may occur. To avoid these failures,the shock isolation system is useful as described in the introduction. The shock isolation system is a kind of low-pass filter whose folding frequency f_0 is designed in the range of 0.3 ∿ 1 Hz. Transmissibility of sinusoidal acceleration input is easy to calculate as shown in Fig. 1 for a linear damping system.

To seismic inputs, the transmissibility of a filtering system depends on the wave form of inputs as we know the response analysis. Anyway, a peak ground acceleration may reduce into the level of 100 gal against S_1 earthquake, that is, the design basis earthquakes in Japan as shown in Table 1.

This means that a LFBR plant designed like Super-phenix may construct in a high seismic region in Japan by using an adequately designed shock isolation system. There are various combinations of design concepts as follows:

i) structure:	whole building
	significant part
	reactor vessel
ii) direction of axes of isolater:	horizontal
	vertical
	horizontal and vertical

The authors had been studying several types as a member of the committee in the Central Research Institute of Electric Power Industries (CRIEPI).[1] The final but current decision is the use of the horizontal isolation of the whole building, because this is the simplest technique even though the total weight of superstructure may be 200,000 to 250,000 ton. Also there will be several merits, for example, no flexible piping connection for main steam and other significant circuits is required, and all components mounted in the reactor building can be designed by lower design basis floor mlotion, and psychological and physical shocks to operational personnel may be reduced.

Of course, there would be many merits by employing other schemes, but we should solve some additional engineering problems such as flexible connection for the secondary main sodium circuit or the main steam line. The authors feel the necessity of the development of a partial structure isolation including a main reactor vessel and first and second sodium circuits at least.

Also the combination of use of isolating pads and servo-control system to suppress the sloshing phenomenon should be examined. As described later, the authors studied on a servo-controled system.[2]

It was evaluated whether or not the design basis response can be recuded to this level without using shock isolation system in Japan. One idea is to look for low seismisity areas in Japan. We found that such sites will be found in the far-north area of Hokkaido island as shown in Fig. 2.[3] This figure shows only a possibility obtained by a preliminary survey. Another idea is that decreasing the response of a reactor building as low as possible by embedding it. Japan Atomic Power Co. reported some examples of their design according to this design practice.

The choice of these methods have never been examined on with their merits and difficulties quantitatively until now. Even though, the use of a shock isolating system is one of realistic approaches to realize the pool-type large fast breeder plant in a high seismisity area like Japan.

§3 PROBLEMS TO BE SOLVED

In the previous chapter, the authors mentioned that there are many choices how to combine which shock isolation system with which portion for being isolated in the whole plant. The most significant problem is the estimation of response of structure and equipment including piping systems in relation to potential seismic inputs. It is true that many specialists in this field have a doubt on results of its response analysis. Especially, they consider whether or not the estimation of its relative displacement response will be highly reliable.

A sloshing phenomenon of sodium liquid surface has many unknown factors at this moment. Except the estimation of input ground motion, the sloshing phenomenon without any internal structure and the surface flow is clear for ordinary cylindrical vessels such as a cylindrical storage tank for oil and liquified gases. There are some discussions on input ground motions in the range of eigen-frequency of the fundamental sloshing mode and its response factor.(4)(5) There have been various examples of very large responses of liquid surface or a floating roof to the strong earthquakes through the world.(6)(7) A recent example in Japan, the response of floating roofs, whose eigen period are approximately 9 sec, reached to five meters in single amplitude even in the site which is more than 200 km from the epi-center. On the other hand, the results of response analyses obtained by using famouse earthquake time histories like El Centro, Taft and others have shown very low levels since TID 7024 reported on this subject. As the authors have reported in various occasion since 4WCEE in Chili,(7) there are two main reasons. Most of time histories which have been used for the analyses are accelerogram, and don't contain significant level of wave components in this range of periods, two ∿ ten seconds, because its level in acceleration is low and it is difficult to separate those components it from measuring error. Also the long period components depend on the source mechanism, especially its magnitude, and the geological structure, that is, the distribution of shear wave velocity in 1 ∿ 2 km depth at the site. In the worst case, the maximum single amplitude may be considered to reach to a half meter or 60 kine in this frequency range, and this value is employed for the code of liquefied gas storages in Japan.(8)(9) If the damping factor is 0.5% or less like liquid storage without any significant internal structure's flow disturbance, the response factor in displacement is over ten. In a case of a LFBR reactor vessel, a critical damping ratio of the fundamental mode has not been clear, and the response factor may be smaller than the above case because of the effect of internal structures. For preventing this phenomenon, a simple shock isolation system is not effective as discussing in Chapter 8.

Aging effect on isolation pads is not so clear at this moment, even though the manufacturers are studying it very hard. The quality assuarance of large isolation pads in Japan is fairly well, but still there is some difficulty to cure large size pads, like 500 ton capacity (in Fig.3), uniformly. Of course, its characteristics at the beginning is within a limit of the specification, but there would be a possibility to scatter their characteristics in certain extents after thirty or forty years use. The authors checked the effect of scattering its performance to the possibility to induce undisireded torsional response, as will be reported in Div.K.(10)

Another problem is unevenly seting of pads. This may cause some incline of a reactor building or a part of structures supported by deteriorated pads. A pool-type reactor is very sensitive to the incline of the reactor vessel because of its primary design scheme. This effect has not been exactly evaluated, but it is estimated not to be so large compare to uneven settlement induced by the ordinary defect of civil engineering construction procedure.

Other problems to be solved are more detailed ones. Those subjects are condensed to the following input problem except aging of the pad.

i) Setting the design basis earthquake including the frequency regions to govern the sloshing effect.

ii) Examining the probability of exceedence of the response over the design basis earthquake.

These two subjects are completely seismological problems. They have been one of main reasons to oppose the use of shock isolation system for highly critical systems like nuclear power plants. The authors believe that the adequate engineering assumption based on current, but exact knowledges on seismology may overcome this problem. However, the design basis response spectrum approach using for light water reactors either in the U.S. or in Japan is insufficient, because it is not the site and source dependent one completely.

§4 DESIGN GROUND MOTION

For the light water reactor, the regulatory guideline for aseismic design of nuclear power plants[11] designates to specify the following three items:

i) Peak amplitude of the ground motion,
ii) Frequency distribution characteristics and
iii) Duration of ground motions.

These parameters are considered as a function of the magnitude and the epicenter distance of the earthquake assumed for the design basis earthquake motion. As we know well, the effect of the change of a magnitude to the amplitude is most significant. If the value of a magnitude is changing by 0.3, the amplitude of ground motions, for example, PGA value changes by 2.8 times. This is more than the range of engineering allowance. Usually the estimation error of magnitude of a particular earthquake is said to be 1/4, and this value means the difference of 2.37 in an amplitude. One of the authors mentioned this fact in his early paper on the seismic-PRA problem. Again this becomes a very key issue on the reliability of a shock isolation system.

Before to discuss on the relation of such uncertainties to the design of a shock isolation system, the authors want to review Japanese practice[13] quickly.

The Japanese practice is similar to the U.S. practice in the view point of using a design basis response spectrum, so-called "Ohsaki" spectrum. This spectrum was defined based on accumulated informations on peak accelerations of ground motions in near-fields as described in his paper.[14] In Japan, it is understood that the shorter period of this response curve gives lower response compare to the results experienced in actual earthquakes. The attenuation formula officially used is based on Kanai's equation.[15] However, there are many uncertainties which come from the individual site-source relation, and this equation gives only an average relation. Several attenuation equations were presented even for the Japanese region, the uncertainty was evaluated from 0.3 to 0.7 in the variation coefficient under an asumption of lognormal distribution.[16]

Magnitude and attennation factor are directly related to the design uncertainty problem as well as the shape of the design response factor. Other parameters are not so seriously affected to the design of a shock isolation system. Also it is necessary to discuss on cumulative damage of components of the system. This will be described in Chapter 6.

Uncertainties of ground motions will be never solved as a deterministic prediction problem, however, we can estimate them in a probabilistic sense, maybe, as upper bounds of PGA. Most of models for PRA study are assumed to be rather simple mathematical form, but it should have some upper bound as a physical model. We can not conclude this discussion on the upper bounds in the deterministic sense so sharply at this moment, but we need to conclude it based on the exact knowledge of seismology.

§5 DESIGN AND TESTING OF SYSTEM

A shock isolation system is expressed by a mass-spring model with a damping device. Therefore, its response estimation is rather simple, even if it has a non-linear component in it. Damping devices may be categolized into the following two. One is an ordinary viscous damper whose hysterisis curve is shown in Fig.4(a). The energy absorbed by this device is proportional to the square of the amplitude. In the case of higher order relation including the square, the amplitude of a resonator is balanced at least one equilibrium state against the input sinusoidal motions. Another model is a friction type damper whose hysteresis curve is shown in Fig. 4(b).

In this case the energy absorption rate is proportional to the amplitude, therefore, the response doesn't reach to equilibrium, and it is going to deverge, if the input is sinusoidal and continues. Most of devices using the yielding phenomenon of metal have the similar characteristics to this case. Therefore, if the input is similar to simusoidal waves, that means, in the case of components responding to slightly damped building motion, they may behave in unfavorable way.

For the shock isolation system of a building structure, input ground motions may not bring such a problem to its behavior in general, but we should pay attention to the system for components in a building.

Some typical responses of a model building with different combination of damping devices are shown in Fig.5. This result of testings and simulations shows that the use of a high viscous shear type damper is better than the simple use of a lead metal damping device as the response of an isolated structure. If the eigen period is near to one of the dominant periods of ground motions, the peak of response of the system with a lead metal damping device becomes higher than that with the viscous damper. But in other viewpoints, the use of viscous material has more practical difficulties. To avoid this problem, the combined use of several levels of yielding metal type damper will be practical.

Against the input over the design level, the authors feel the necessity of more systematic study. One is on the multi-level damping device above-mentioned. And another one is the use of a non-linear spring which has a hardening characteristics like a leaf spring. Both may induce higher acceleration by its braking effect, and also higher harmonic frequency components. The longer buffer stroke is the better to decrease these effects, of course. How we choose this stroke is a matter of the confidence of the designer on the amount of the excess input. Other back-up devices have been considered. To protect an isolator pad itself, the use of a sliding pad is a typical one. But this can not avoid the shock caused by hitting the stopping device. Additional friction pad to brake the motion using lowering the hight of rubber pads was considered and tested. The design of this system should depend on the behavior of a rubber pad.

§6 DESIGN AND TESTING OF COMPONENTS

The design and proof-testing of components, especially an isolator pad is very significant. This has been studied by Fujita and Fujita for last several years with its fabricator.[17] They designed 500 ton capacity pad at this moment. And the Central Research Institute of Electric Power Industries is going to test it as described in Chapter 9.

One problem is the detailed analysis of strain distribution in a pad, and another is its quality assuarance during fabrication, especially curering stage. The size of 500 ton pad is 1800mm in diameter and 500mm thick. The uniformity of curering is very important as well as those of auxiliary damping devices. some major manufacturers of rubber tires have this capability, for example, the breaking limit of deformation can be controlled within 10% ranges. Parameters like stiffnesses can be controlled within this limit also. Adequate value of the safety factor for their strain, including connection between rubber and metal, has not been known, but usually it is taken as two.

Both round shape and square shape have been used. The fabrication cost for square shape is cheaper than round one's. However, there is a problem of skin or edge strain distribution of the square shape pad for a building which has similar vibration characteristics to both orthogonal directions, and this is the significant difference to the bridge bearing. At this moment, it is considered in Japan that the round shape pad is more reliable.

Tie bolts or anchor bolts are one of the key items for the safety of structures. This subject including the failure of concrete has been studied for a part of nuclear power plant safety projects last ten years in Japan.[18] Even though we believe that we know the detailed practice well, we had many examples of the tension-type failure of a bolt as shown in Fig. 6 caused by pure shear force-type load. The design practice obtained by the project above covers this problem sufficiently in Japan.

The behavior of lead plug has been tested for bridge pads in New Zealand.

The recrystallizing of lead had been studied for cover metal of telephone and power cables for long years. It is considered that the higher purity of the metal the better damping plug. This may be true in the viewpoint of brittlification at the grain boundary after repeating the recrystallization. The effect of inpurity in lead metal to damping has not been studied so seriously.

Various types of metal are planned to be used for yielding-type damping mechanism. Bending and torsional types of deformation are using for this purpose, but it is difficult to get large yielding volume by bending type from the same size metal piece. Ordinary mild carbon steel is used, but austenite stainless steel is also appropriate metal except its cost. The yielding curve is also different to that of mild carbon steel, and is crispy as we know.

Use of visco-elastic material for a nuclear power plant is under the study. Aging including by radiation for long years has not be known with high engineering confidence. It should be studied on the property as well as the detailed design of devices.

§7 SYSTEM RELIABIRITY

This subject includes both the response reliability and the component reliability. The response reliability is depending on uncertainties of ground motions as described in Chapter 3. However, it should be noticed that the shock isolation system improves the uncertainty of the response of components in the building by the filtering effect of the system as shown in Fig. 7. If the shock isolation system is not applied to the building, uncertainties including distribution of eigen-periods of the building, that is, peaks A and B in Fig. 7(A) may affect the response of components whose eigen-periods are in the region Z. On the other hand, as shown in Fig. 7(B), the filtering effect may decrease the variation of response level as well as level itself.

The peak C in Fig. 7(B) will be affected by the uncertainties both on the ground motions and the charactaristics of shock isolation components. The former one affects to the hight of the peak mainly, and the latter one to the position of the peak and the hight. The latter one may be controlled by engineering knowledges and techniques.

The effect of non-uniformity of isolation pads[10] was studied by the authors as reported in Division K, they are not so significant, because of the number of pads, for example, we need 400 pads for a 200,000 ton super-structure. This number reduces the effect by the random distribution of parameters of components under the structure. The authors' study was made for torsional response induced by the non-uniformity of pads' parameters, horizontal stiffness and yielding point. This conclusion may extend to other subjects, like uneven settlement of the super-structure, shifting of eigen-periods.

However, the authors assume that the aging effect would be non-biased and random. If the tendency of changing the parameters of each pads is one-direction, such as stiffness hardening and some other effects, then the shifting of the response peak should be considered.

For the components, based on the final result of PSA study in level one, we can present the limit values of variations of performance parameters on pads and other components. And their manufacturers control their products within the limit. It is more reasonable way compare to the way which has been done usually, that is, starting from the evaluation of the degree of the fluctuation of their performance.

§8 ACTIVE CONTROL SYSTEM

The fundamental idea is a feed back control as a servo-mechanism. By sensing acceleration on the structure, and compensating the response of the structure so as to minimize the acceleration response. The way of feeding back has a variety from an ordinary PID control to an adaptive control.

Several kinds of type of filter effect were mentioned.[2][20] The active control system can be realized by any of them. Recently, a tuned mass type one using an actuator was demonstrated. A tuned mass-spring type device compensates the response which is expected to sinusoidal one in its eigen-frequency. A servo-type mass device compensates the more irregular response. It is also considered that the mass is acting as an assumed wall fixed to the absolute co-ordinate by its inertia, and can overcome not only sinusoidal waves, but also random type input motions.

The authors have been studying on high-pass type servo mechanism for avoiding sloshing in a reactor vessel of LFBR. He used a linear motor instead of a hydraulic actuator, because it doesn't need to keep the hydraulic system under the stand-by operating condition. It is great energy loss to operate its oil pump through the life of it.

They employed "Linear Induction Motor (LIM)" at first. LIM has a non-linear characteristic including a dead zone in the relation of input signal to force output. By using a computer, such non-linearities are linearized, and the ordinary techniques like PI control were applied. To cover the response characteristics of a sloshing phenomenon, Housner model,(4) which is famous sloshing model introduced by Housner and is simple than the theoretical model, was used for the model to control adaptively.

§9 CURRENT R & D PROJECTS IN JAPAN

The Central Research Institute of Electric Power Industry(1) have been studied this subject last three years under the sponsorship of MITI. In advance to this project, Power Reactor and Nuclear Fuel Development Corp. (PNC) made the preliminary survey project in 1983 and 1984.(19) One of the authors, SHIBATA, has been working for these projects as a member committees. And also he organized a research committee on the aseismic design of FBR in 1982 by the supports of some utilities under the management of System Corp.. Fundamental study on the detailed designs of equipment and piping systems has been done by the three major manufactures of nuclear power plants under the sponsorship of electric power utilities. The use of the shock isolation system is proposed for the second LFBR for proving in principle.

The choice whether the use of a shock isolation system or reducing the seismic input to a reactor vessel and main components by the modification of the geometry and structural layout, especially lowering its center of gravity is a key issue for the design of the first LFBR which will be expect to be completed in 2008 ∿ 2010.

The whole project including the choice whether pool-type one, like Super-phenix, or a loop-type one, like Monju which is the Japanese proto-type FBR under construction, or a hybrid-type is going to be reviewed at the end of this F.Y., March 1990. And we are expecting to decide whether or not the shock isolation system will be applicable to the first LFBR or to the later one. We are planning to test several size models on shaking tables and in the field next four or five years. The exact schedule will be decided based on the decision above.

§10 ECONOMICAL CONSIDERATION

Because of the restriction by the Building Code in Japan, it is not clear how far we can reduce the total amount of super-structure, and the trial design with high accuracy has not been made. The design of base-mat and the distribution of wall and pads was discussed in the PNC report.(19) Even though, a thick uniform mat and a uniform distribution of pads are considered for systems employed in most of R & D studies.

If we can reduce the amount of the super-structure as well as equipment, by the guess of the authors, the cost for the aseismic design of 10,000MW light water reactor in Japan is less than ¥100B (=$1B). This amount may be not much difference to LFBR. The use of a shock isolation system may reduce 30% cost of this. However, the cost for a shock isolation system and supplemental components, such as lower mat, flexible connection pipings, may reach to 70% ∿ 80% of the reduced cost. Therefore, the reduction of total cost may be approximately ¥20B or $0.2B, for the first one including some part of R&D cost.

This reduction is not so large as we are expecting. But it is important to mention that the structural design of a main vessel, other auxiliary components, sodium piping systems and so on is very critical to the seismic input considered in Japan. It is rather difficult to design such structures to satisfy both seismic and thermal conditions. There is a possibility to overcome this difficulty only by employing the shock isolation system. Also it should be mentioned that the use of the shock isolation system may reduce the uncertainty for the aseismic design by its filtering effect. Structural design problems caused by sloshing effect are also significant in some cases in Japan. But it is impossible to supress this phenomenon by an ordinary passive type shock isolator in general. The choice of the site condition in the sense of engineering seismology is significant. The authors tried to develope an active control system for a main vessel and surroung systems as mentioned,(2) and it was proven that some active control systems are theoretically avairable, and required electric power is in the practical range. The cost has never been estimated, but it should be expensive compare to the cost which will be reducted.

§11 CONCLUDING REMARKS

The use of a shock isolation system is necessary to obtain the reasonably designed Large Fast Breeder Reactor in a high seismicity area like Japan. It is feasible in the engineering sense within a scope of R&D in Japan. The prototype of 500 ton isolation pad has been developed and tested already. We need several years more for developing the plant design itself. During these years, we are going to have more experiences on conventional buildings and industrial facilities. More practical R&Ds on related items will be made during this period. This means that the development of the plant itself may need more time than that for the shock isolation system.

Technical details for such systems were discussed in Ref.(20) and presented in a conference in Seoul last year.

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Table 1 Typical Level of S_1 and S_2 in Japan

Earthquake	Design Basis Seismic Coef. (Static)	Dynamic Zero-period Ground Acc. gal
S_2 Upper bound e. (Margin Check e.)	0.9	240 ∿ 480 , 600)*1
S_1 Design basis e. (Maximum level e./ Historical Max.)	0.6	180 ∿ 300 , 450)*1
S_0*2 Operating e.	---	50 ∿ 60

*1 : Hamaoka Nuclear Stations in Earthquake Predicted Area.
*2 : Not officially defined, as a reference.

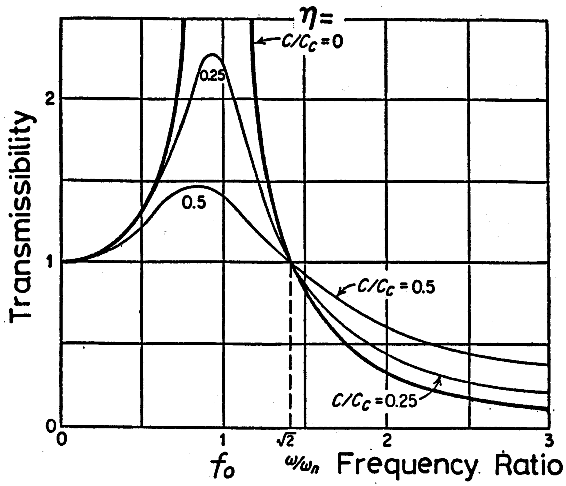

Fig. 1 Schematic Chart of Transmissibility of Shock Isolation System [After DenHartog]

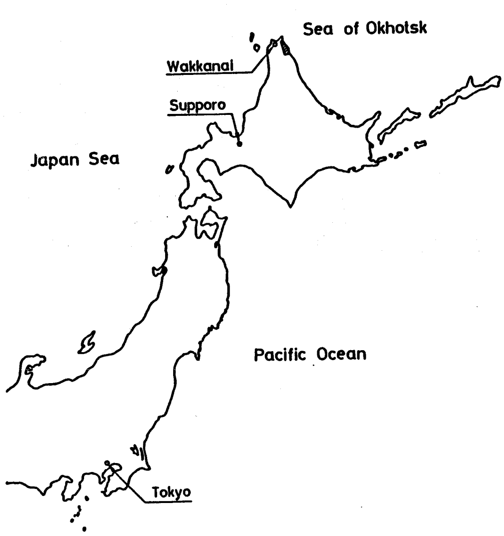

Fig. 2 Low Seismisity Area in Japan (Hokkaido Island)

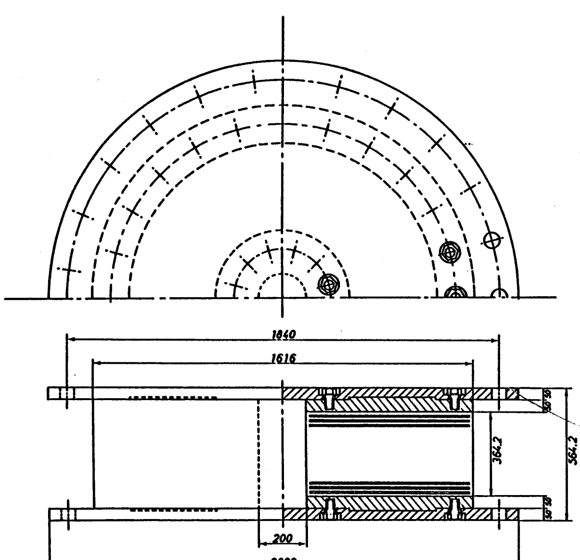

Fig. 3 500 ton Rubber Pad for Testing [After CRIEPI]

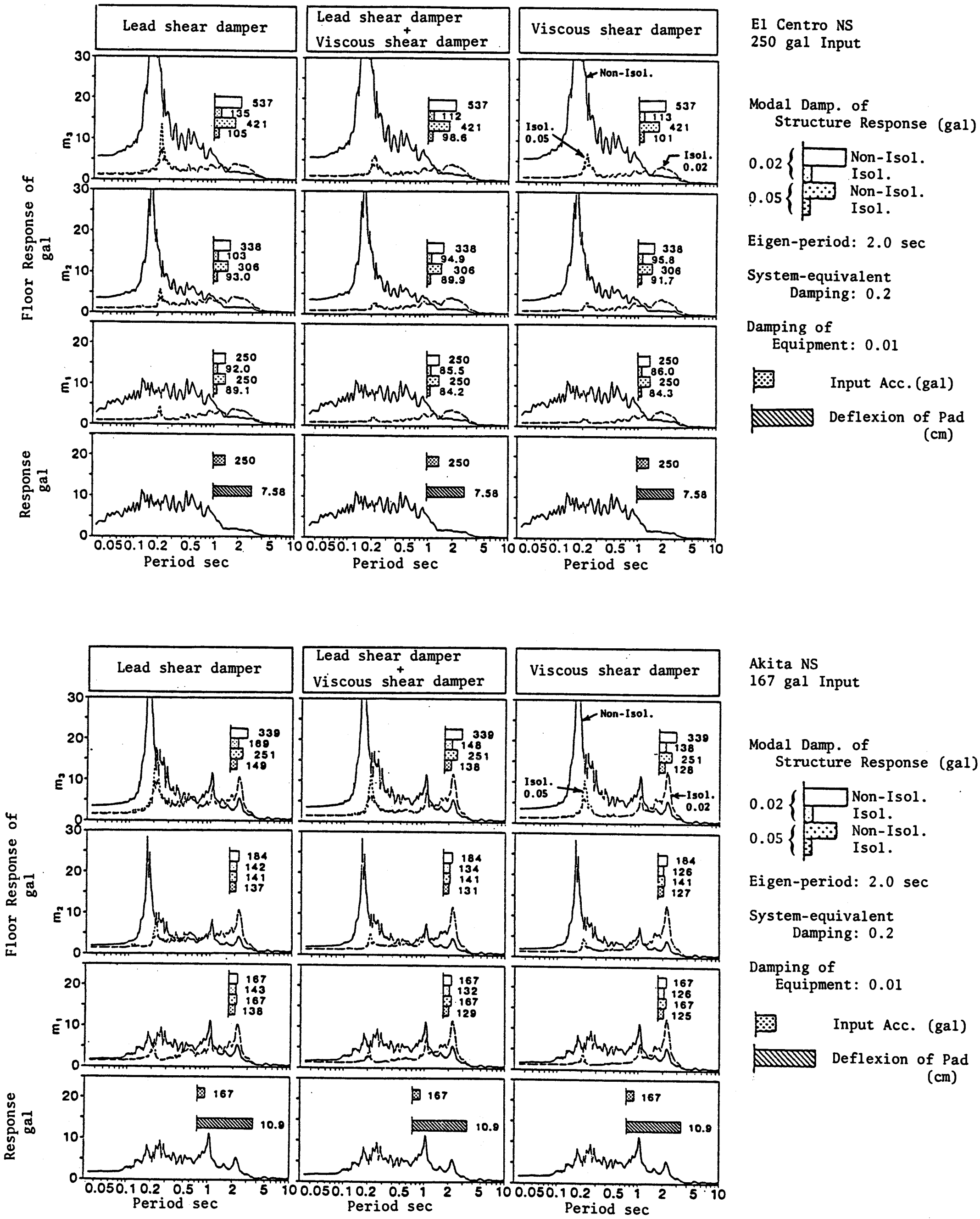

Fig. 5 Some Examples of Floor Response Curves with Different Combination of Damping Devices [Ref.(17)]

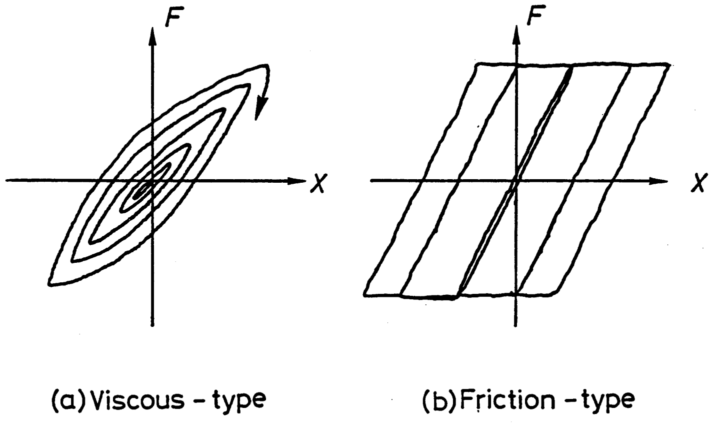

Fig. 4 Schematic Diagrams of Force *vs* Displacement of Damping Devices

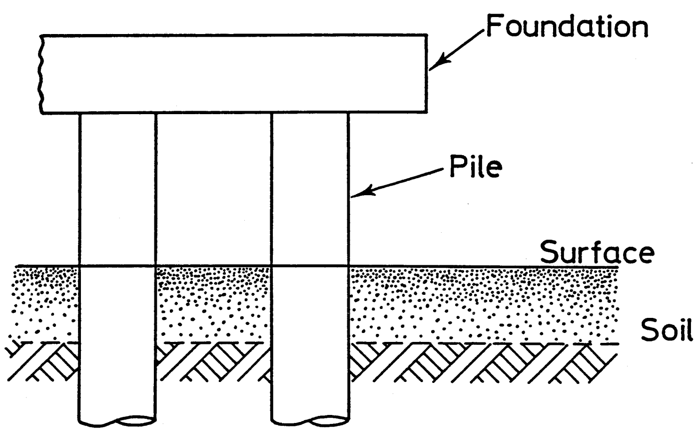

Fig. 6 Typical Failure Modes of Anchoring

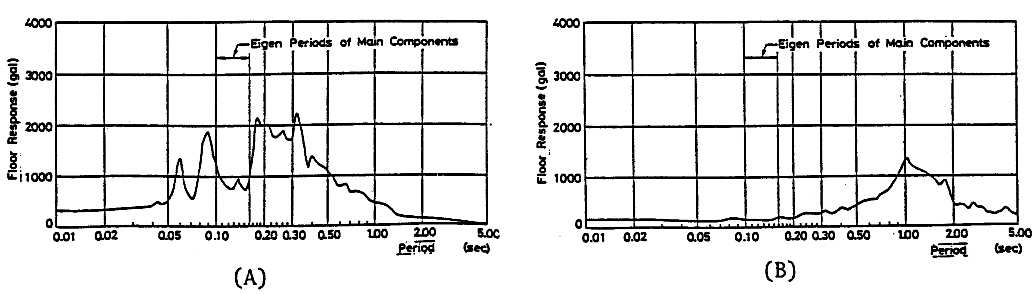

Fig.7 Schematic Drawings of Floor Response with/without Shock Isolation System; at Reactor Floor Level of LFBR [Redrawn from CRIEPI's Data]