Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999

A Primary Study of Base-Isolation Technology in NPP

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ABSTRACT Earthquake is one of the damage factors to nuclear plant Safety. This paper was about the research of Base-Isolation Method of NPP in China, financed by Nuclear Industry Science Funds of China. In the subject, Φ440Lead-Rubber Bearing was manufactured, its mechanical characteristics was tested and the quasi-static force-displacement curves were obtained. On the other hand, the effect of the containment base-isolated was analyzed and compared the seismic responses of containment with that non-isolated, the advantage of using base-isolation technology was qualitative presented.

1. BACKGROUND

Base-Isolation System was developed as one of remarkable technology to reduce the seismic load of building and equipment in recent year. For example, in Japan, only 80 base-isolated buildings had been constructed for about 10 years -from 1986 to 1994, but after the Great Henshin earthquake in 1995, the number including under-construction is increasing to over 400 until now, It was applied widely in computer center, office building and residential building.

Isolation system consisted of isolators and energy dissipaters. It was located between foundation and superstructure, having two main functions: the first, to reduce the first natural frequency of building for avoiding in resonance with main energy frequency of earthquake wave; the second , to absorb the earthquake energy.

Today, there were two nuclear power plants (PWR) applied the Base -Isolation System , One was CRUAS in France, another was KOEBERG in South Africa .In Japan ,a series studies about base-isolation technology had been done ,the range including Light Water Reactor, Fast Breeder Reactor and International Thermo-Nuclear Experimental Reactor.

This subject had been subsidized by Nuclear Industry Science Foundation of China .It was the first time in China to study how to apply the Base-Isolation Technology in NPP. In the subject, special rubber material to manufacture bearing was developed and three Φ440 Lead-Rubber bearing specimens were produced and tested. Then, adopting this system's characteristics, a seismic response analysis of containment of Daya Bay NPP was carried out to investigate the effect of this technology. The test and analysis results were introduced in this paper.

2. PROPERTY TEST OF LEAD -RUBBER BEARING

In this test, the quasi-static characteristics of three bearing specimens (A, B, C, Φ440mm) were determined. The specimen size is indicated in Fig.1, diameter: 440mm(including 6mm thickness rubber Protection around); design thickness of rubber sheet: 6mm, 16 layers (actual total thickness of rubber was 97.9mm); steel sheet thickness: 2mm, 15 layers; Lead core diameter: 50mm; design load: 1000N/cm^2; design shear deformation: larger than 400%.

The contents and results of test:

a. Vertical loading test

In non-bias vertical loading condition, the relationship of vertical load and vertical deformation was measured. Force- Displacement curves were recorded (refer to Fig.2).

b. Pressuring- shearing test

In non-bias vertical loading condition (1000KN), loading circulation force in horizontal direction with 50 sec/circle speed, the relationship of horizontal shear force and shear deformation was measured, and the hysteresis curves were plotted (refer to Fig.3).

From Fig.2 and Fig.3, it could be seen that the characteristics of specimen A and C were identical with full hysteresis curve, better than specimen B. The cause was that specimen B was over- vulcanized during manufacture. For the limited ability of instruments, all of specimens were not destroyed in test, but the max. shear-strain was up to 196%,and from observation, it could be predicted that the shear-strain still had potentiality to increasing. Vertical loading was up to 1800N/cm^2. It was presented that the bearing had mid -high loading ability. So, it was concluded that the manufactured bearing in this subject had good properties to get to the design goal successfully.

3. SEISMIC RESPONSE ANALYSIS OF CONTAINMENT

In order to study the seismic response properties of containment base-isolated and investigate the characteristics of Lead - Rubber bearing, the Finite -Element Analysis was carried out, Daya Bay NPP containment was the analysis object. El centro wave was input.

3.1 Model

Analysis Model: Lumped mass model and 3-dimensional model for
containment
Bi-linear model for base-isolation system (refer to Fig.4)

Analysis Method : 1) Modal Analysis
2) Time-History Response Analysis

Hypothesis : 1) The Soil-Structure Interaction was overlooked;
2) Containment was directly set on an infinite rigid body;
3) The traveling wave effect was ignored.

This analysis was completed by ANSYS4.3 on VAX780 .

3.2 Modal analysis

The results were shown on table 1.

It was concluded that the first natural frequency of containment was decreased from 5.22Hz(non-isolated) to 0.42~1Hz range (isolated), laid away from main energy frequencies range (2~10Hz) of earthquake wave.

The results came from Lumped Mass model were similar to those from 3-dimensional model.

3.3 Time-history response analysis

Input Intensity : 0.1g, 0.2g, 0.4g, and 0.8g

Wave Shape : El centro

Input Direction: Horizontal

The analysis results (refer to table 2, Fig.5 and Fig.6) showed:

1) In non-isolation case, the seismic acceleration response at the top of containment was very large(reduction ratio=Max. response acceleration / max. input acceleration=2.07), but in isolation case, the reduction ratio was decreased to 0.41~0.9 corresponding to difference input seismic intensities, and the bigger seismic intensity that was input, the more decreasing of the reduction value was.

2) In isolation case, the movement of superstructure in earthquake was gently, but its displacement was increased obviously. For instance, responding to 0.8g inputting, the horizontal displacement that Lead Rubber bearing generated was 150 millimeter. So a good shear deformation-ability was required for Base-Isolation System. In general, the design shear deformation of it was up to 400%, having enough safety for application in NPP.

4. CONCLUSION

This subject lasted two years. It was completed by cooperation with NPIC、factory and university. The results was achieved the goal that we predicted. Main achievements were showed as follow:

I) Following international development tendency, a lot of base-research works were completed, such as nationalization developing rubber material、 seismic isolation theory analysis、 setting up mechanical model of isolated system of NPP and so on. It was a basement for isolation technology applied in NPP.

II) The production technology of Φ440 Lead-Rubber bearing was successful had in hand. The tested characteristics were presented that the property of this kind of bearing was better than Φ250 Lead-Rubber bearing's manufactured a few years ago: hysteresis curve had more containing room; ability of absorbing energy was increased and loading ability was improved. It was the biggest one in size of China. Its characteristic parameters came up to advanced world standards at the beginning of 1990s.

III) In China, it was the first time to completed the effectiveness analysis of isolated containment of NPP. The results was showed that adopting Lead-Rubber bearing developed in the subject, acceleration peak of containment response was cut down obviously. In severe earthquake, the maximum response in isolation was 1/4~1/5 times of those in non-isolation. The Lumped Mass model could be applied in actual calculation.

From the results, it could be concluded that the achievements attained in the subject filled in the gaps in the fields of isolation technology applied in NPP of China. The analysis model of isolation system and the manufactured Lead-Rubber bearing came up to advanced world standards in the end of 1980s or the beginning of 1990s.

In future, some aspects may be improved:

a) To improve the reliability of estimation for relative long period earthquake wave.

b) To reduce the quantity of isolators by heightening the vertical pressure for cost down.

c) To develop 3-dimensional isolation device.

d) To set up design code of isolation system.

References:

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4. Argonne National Laboratory , "On the French Nuclear industry Experience in the Design of Seismic Isolation of NPP" , 1989,12
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Table 1. Natural frequencies of containment

Non-isolation		
natural frequency(Hz)	lumped mass model(Hz)	3-dimensional model(Hz)
the first	5.22	5.38
the second	19.48	17.50
Isolation		
the first	1.07(0.42)	1.09(0.44)
the second	6.13	6.63
the third	20.43	18.72

Table 2. Input El Centro Wave

Non-isolation			
input intensity	Max. accel response at	the top of containment	reduction ratio
(g)	m/s^2	g	Max.res/Max.input
0.1g	2.025	0.207	2.07
0.2g	4.051	0.413	2.07
0.4g	8.102	0.827	2.07
0.8g	16.204	1.654	2.07
Isolation			
0.1g	0.915	0.09	0.90
0.2g	1.318	0.13	0.65
0.4g	1.997	0.20	0.50
0.8g	3.245	0.33	0.41

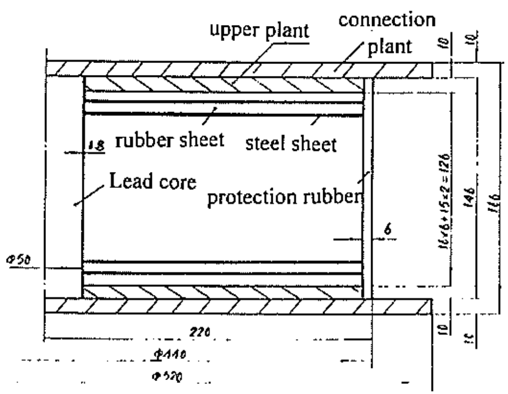


Fig.1 The Section of Φ440 Bearing

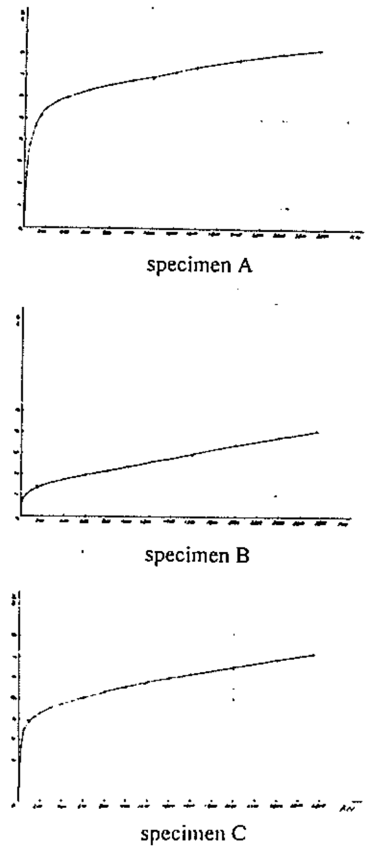


Fig.2 Vertical Loading-Deformation Curve of Φ440 Bearing

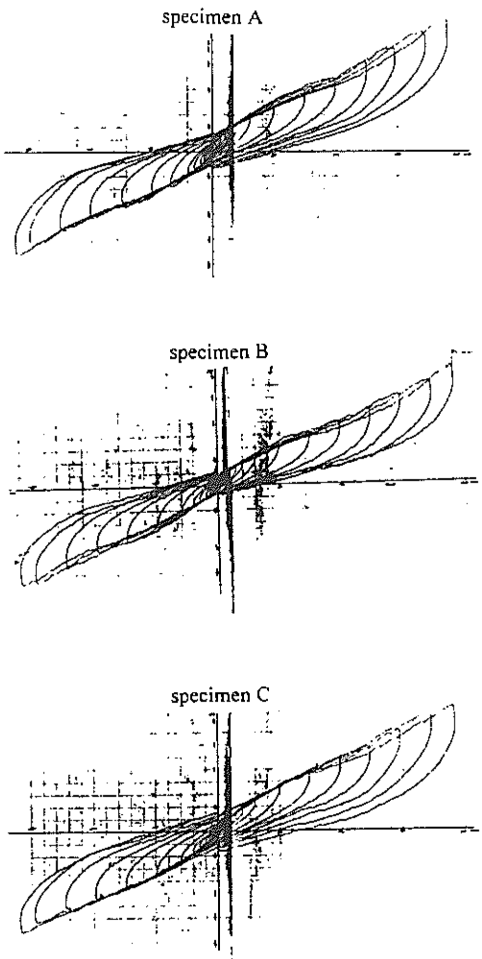


Fig.3 Hysteresis Curve of Φ440 Bearing

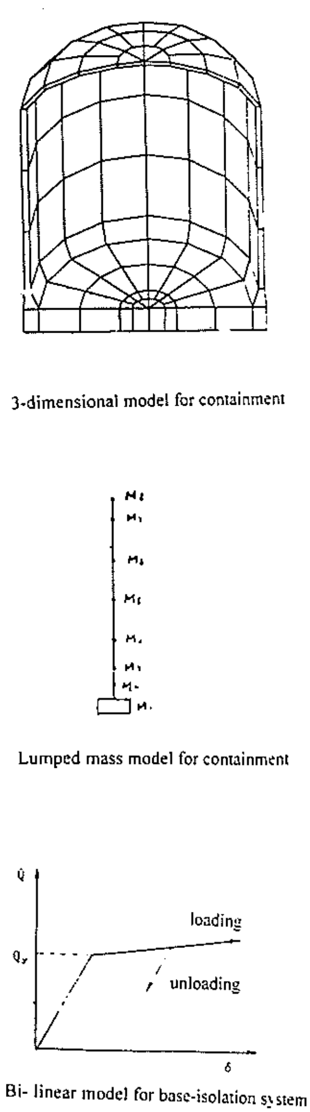
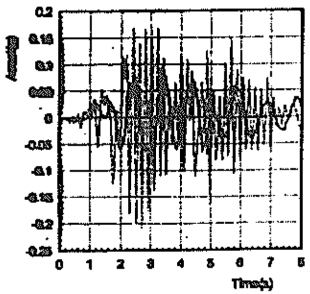
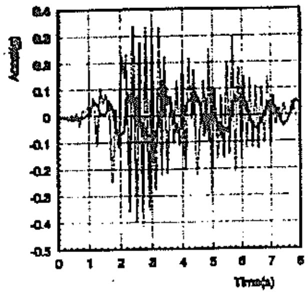


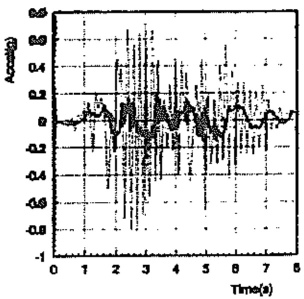
Fig.4 Analysis moadel



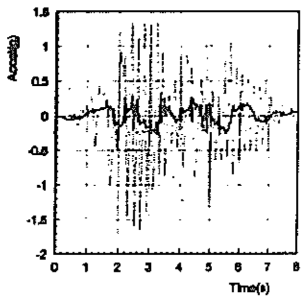
Input El centro Wave (0.1g)



Input El centro Wave (0.2g)



Input El centro Wave (0.4g)



Input El centro Wave (0.8g)

Imaginary Line: Non-isolated

Real Line: Isolated

Fig.5 Acceleration Response History at the Top of Containment in Isolated and Non-isolated

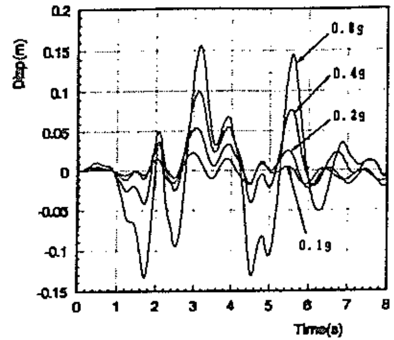


Fig.6 Relative Displacement Time-History Response Between the Upper and Bottom of Bearing (Input Intensity: 0.1g, 0.2g, 0.4g, 0.8g)