Journal of the Korean Nuclear Society
Volume 30, Number 2, pp.83~90, April 1998

A Feasibility Study of Seismic Isolation for Wolsong Reactor Building

Kang Soo Kim and Tae Wan Kim
Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-gu, Taejon 305-353, Korea

Jeong Yoon Lee
Korea Power Engineering Co.
150 Dukjin-dong, Yusong-gu, Taejon 305-353, Korea

(Received August 26, 1996)

Abstract

To predict effects of seismic isolation,seismic isolation bearings were applied to the Wolsong reactor building and the analytical study was performed. For this study, the Wolsong reactor building was modeled using lumped masses and beam elements. Design Basis Earthquake with a ground acceleration of 0.2g was applied. And then,the behavior of the isolated structure was compared with that of the unisolated structure. The horizontal response acceleration at the top of the unisolated reactor building was 0.99g, while that of the isolated one was 0.14g(15% damping) and the acceleration response along the height of the structure was constant. The maximum displacement of the unisolated structure was 8.3mm,while that of the isolated structure was 66mm. The application of isolation bearings on the reactor building reduces seismic loads but increases the displacement of the structure on a large scale. Therefore,when using isolation bearings,the reactor building and BOP should be located on a common mat to cover the large displcement.

1. Introduction

Seismic isolation has been developed in the field of the earthquake engineering all over the world. It can be used to reduce the seismic loads on nuclear power plants and other structures located in high seismic region. These structures are designed to accommodate the effects of high levels of seismicity to meet safety and licensing requirements. Reduction of seismically induced loads results in an economic structural design. When using isolation bearings, the secondary components and systems located in the plant would require a less degree of seismic qualification. It results in cost savings in two ways. Firstly, it avoids strengthening and implementations of costly design features which are otherwise necessary. Secondly, due to the decrease in the seismic response levels, a relatively simple analysis procedure can be employed to predict the behaviour of secondary components. For example, supported systems will behave in a linear elastic way and the need for non-linear analysis considering impact, sliding, gaps, etc. can be reduced. Isolation devices that are developed today can increase the safety margin of structures. It is claimed that the behaviour of an isolated structure can be predicated with a higher degree of accuracy. The properties of bearing materials are tested and controlled during the manufacturing process whereas soil properties are subjected to a higher level of uncertainty. Isolation bearings increase the potential of using a standard design in different sites without undertaking costly redesign work [1].

The adoption of seismic isolation bearings for nuclear facilities has been slow. The Cruas nuclear power plant in France is the first one built with isolation devices in 1982 [2]. At present there are a total of six base-isolated standard PWR units. Four units are located in Cruas, France and two units in South Africa [3]. There is one fuel processing plant in England that uses isolation devices. Many studies and conceptual designs have included the use of base isolation using bearings. A nuclear waste storage facility was built in France using seismic isolation bearings [4]. Isolation bearings have been used in the conceptual design of the 1500 MW Liquid Metal Fast Breeder Reactor (LMFB). Countries interested in the development and use of this technology are sponsoring joint research activities. The U.K., EPRI and the Japanese Central Research Institute of Electric Power Industry (CRIEPI) have undertaken a joint international program for advancement of this technology. As part of this program, the technical feasibility of selected isolation systems have been evaluated for application in large Liquid Metal Reactors (LMR) and the European Fast Reactor (EFR) plants. Analytical work and testing of representative sample bearings for two U.S. compact LMR concepts have been reported [5].

At present, nuclear power plants which are being operated in South Korea are over 10 units. When seismic isolation bearings were applied to the actual reactor building , it is important to predict the behavior of that. Particularly, the Wolsong reactor can be characterized as on-power refuelling using fuelling machine. Since earthquakes can occur during on -power refuelling, the fuelling machine needs more conservative design. However, we can get higher margin and avoid more conservative design using seismic isolation bearing.

In this paper, the Wolsong reactor building is modeled using lumped masses and beam elements for this purpose and the analytical study was performed to predict effects of the seismic isolation bearing for the Wolsong reactor building.

2. Wolsong Nuclear Power Plant

The Wolsong nuclear power plant is a CANDU type nuclear reactor. Wolsong unit 1 has been operating commercially since 1983 and unit 2 is scheduled to operate commercially in June 1997. Also unit 3 and 4 are under commissioning and

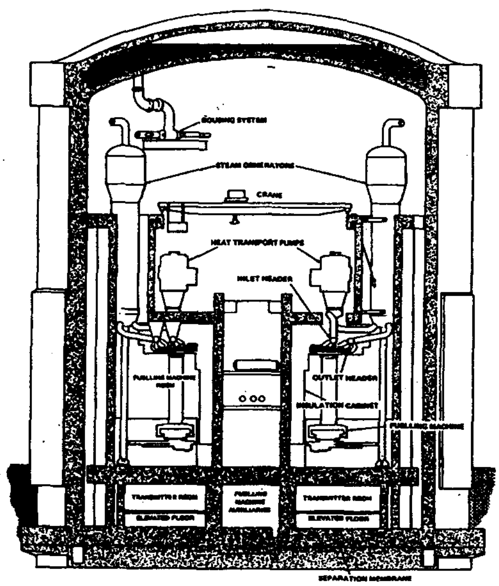

Fig. 1. Wolsong Reactor Building

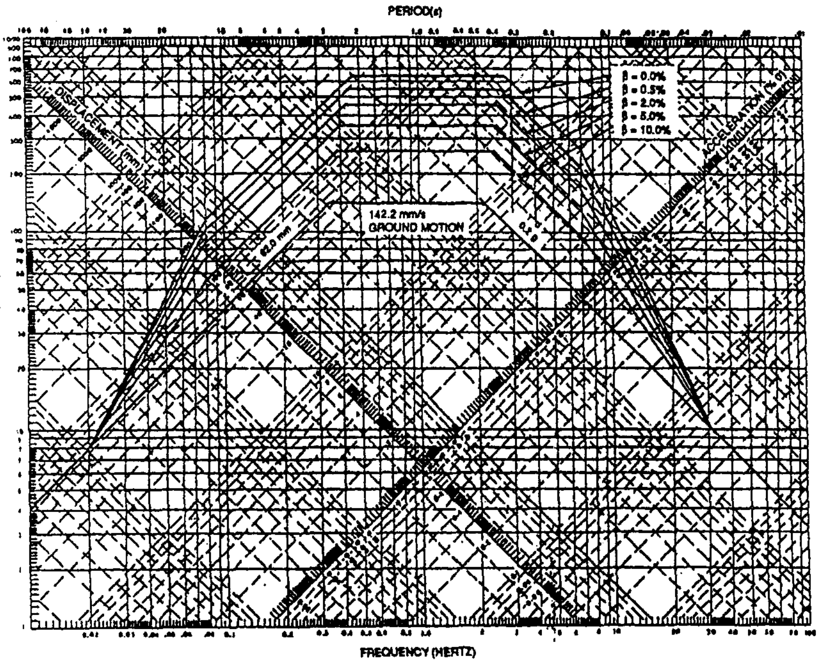

Fig. 2. Ground Response Spectra for Wolsong NPP

construction now. The CANDU can be characterized as on-power refuelling using fuelling machine. When the fuelling machine is attached to fuel channel for inserting or receiving fuels, both fuel channel and fuelling machine must maintain their structural integrity even under circumstances of seismicity including combined several postulated accidents and meet the safety design requirements because both of them contain pressure boundary of reactor primary system. All Wolsong units are designed to meet 0.2g maximum ground acceleration.

3. Seismic Isolation System

The Wolsong unit 2 reactor building is shown in Fig.1 and its total weight is 712000 KN.

For the Wolsong nuclear power plant, Design Basis Earthquake with a maximum ground acceleration of 0.2 g is applied. The ground response spectra for the design earthquake are shown in Fig. 2. It also shows that the frequency of building must be less than 2 Hz in the horizontal direction to obtain seismic isolation effects. In this study, the target design frequency of the isolated structure in the horizontal direction is chosen to be 0.7 Hz. To provide seismic isolation, a number of isomeric bearings having high shape factors are chosen.The seismic exitations in the vertical direction is generally low and therefore is not of concern in this study.

The configuration of the proposed bearing is shown in Fig.3 . The bearing is circular in shape, 0.4m in hight and has a diameter of 1.27m. The end plates are bolted to concrete slab for shear transfer. The chosen bearing has 24 shim plates impregnated in elastomers. This type of bearings is the typical one used for seismic isolation building construction. The material of the bearing will have to meet the design requirement in order

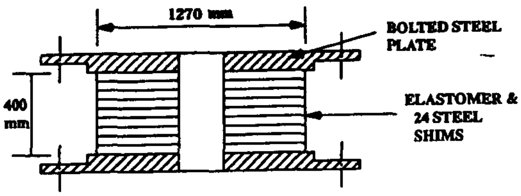

Fig. 3. Isolation Bearing

to meet its function and endurance limit such as aging and low cumulative irradiation etc., and these are under investigation by Japan[6].

The bearings will be located between a lower slab and an upper slab on top of concrete pedestals as shown in Fig. 4 .This arrangement provides space needed for inspection and replacement of these bearings during the life time of the plant.

The horizontal stiffness (kh) and the vertical stiffness (kv) of one bearing can be calculated using the following equations :

$$k_h = GA_t/nt \quad (1)$$

$$kv = E_cA_s/nt \quad (2)$$

where,

G : shear modulus of elastomer
E_c : effective compression modulus
A_t : bearing cross sectional area
A_s : shim area
n : number of layers
t : thickness of rubber layer

Using equations (1) and (2) the horizontal and vertical stiffness of one bearing are computed to be 2800 KN/m and 3000000 KN/m respectively[1].

Some degree of uncertainty exist in the stiffness estimation of these elastomeric bearings using the above formulae. To obtain better estimates of stiffness properties, finite element analyses of

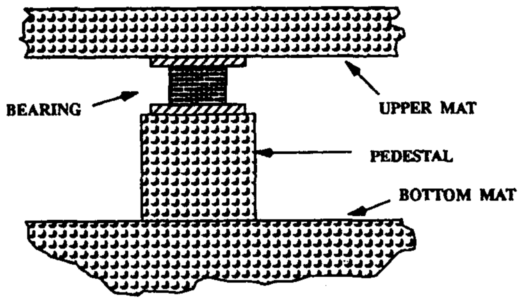

Fig. 4. Bearing Arrangement at the Base

these bearings are necessary. Additionally testing must be performed to define bearing characteristics precisely before adopting these bearings. However the present approximate estimates of the bearing stiffness are considered appropriate for this conceptual study. From testing of similar bearings, it is known that the properties of these bearings are nonlinear [7]. For the purpose of this study, the characteristics of this bearing are assumed to be linear.

4. Seismic Analysis

The Wolsong reactor building consists of an internal concrete structure and equipment modules enclosed by a cylindrical concrete containment structure. For seismic analysis, the reactor building was represented by a mathematical model consisting of lumped masses and beam elements as shown in Fig. 5. In this model the beam elements represent the stiffness of different structural parts of the building and the masses are lumped at a number of key locations.

The seismic isolation bearings are represented by one set of springs having equivalent stiffness values. The effects of all bearings are combined into one set of springs in the following way [1] :

$$K_h = Nk_h \quad (3)$$

$$K_v = Nk_v \quad (4)$$

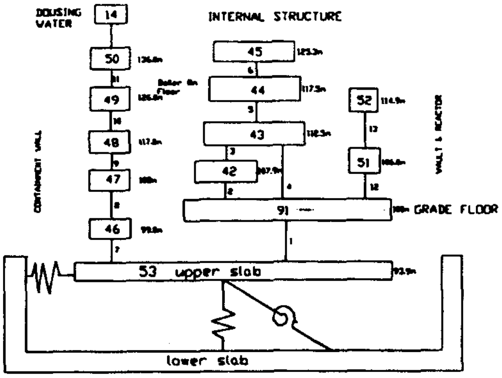

Fig. 5. Reactor Building Model for Wolsong NPP

$$K_r = K_v D^2/16 \qquad (5)$$

$$K_t = K_h D^2/8 \qquad (6)$$

where,

- K_h : horizontal stiffness
- K_v : vertical stiffness
- K_r : rocking stiffness
- K_t : torsional stiffness
- N : the number of bearings
- D : the diameter of the base slab (47.6 m)

A total of 316 bearings are used for this study. The spring properties of the isolation system are calculated using equations (3) to (6). In the present analysis, the effect of soil-structure interaction is ignored. The isolation system produces a low frequency dynamic response much lower than the soil-structure interaction frequency. Consequently,the response of the structure is predominantly influenced by the stiffness of the isolation system. The effect of soil-structure interaction for the hard soil condition is small and can be neglected.

The finite element computer program STARDYNE has been used for this analysis. The analysis is done using modal time history method and the time history applied is shown in Fig.6. The study is done for two cases with different

Table 1. The Natural Frequencies of the Unisolated and Isolated Case

Mode NO.	natural frequencies of unisolated case(Hz)	natural frequencies of isolated case(Hz)
1	5.4374	0.6950
2	5.4374	0.7018
3	6.6307	5.8602
4	7.0231	5.9502
5	8.5931	7.5873
6	11.5950	8.0050
7	12.1370	8.9896
8	14.5010	11.700
9	15.2870	12.520
10	17.1180	14.485

values of damping. The first case uses a damping value of 8% which is applicable for rubber bearings. The second case uses a damping value of 15% to represent the damping value of a high damping elastomer.

5. Analysis Results and Discussion

From the analysis, the natural frequencies of the fixed base case (unisolated case) and the isolated case are listed in Table 1. As shown in Table 1, the first frequency of the isolated case is 0.695 Hz ,which is much lower than that of the unisolated case.

The horizontal response accelerations along the height of the building are plotted in Fig. 7 and compared with those of the fixed base case. For the low damping case (8%), the accelerations at all points have a constant value of 0.21g. For the high damping case (15%), the building accelerations at all locations are 0.14g, which are lower than the ground acceleration. For the unisolated case,the horizontal response acceleration at the top of the reactor building (42m location above the base slab) is 0.99g, that at the boiler room (23m location above the base slab) is 0.61g and at the region of the reactor

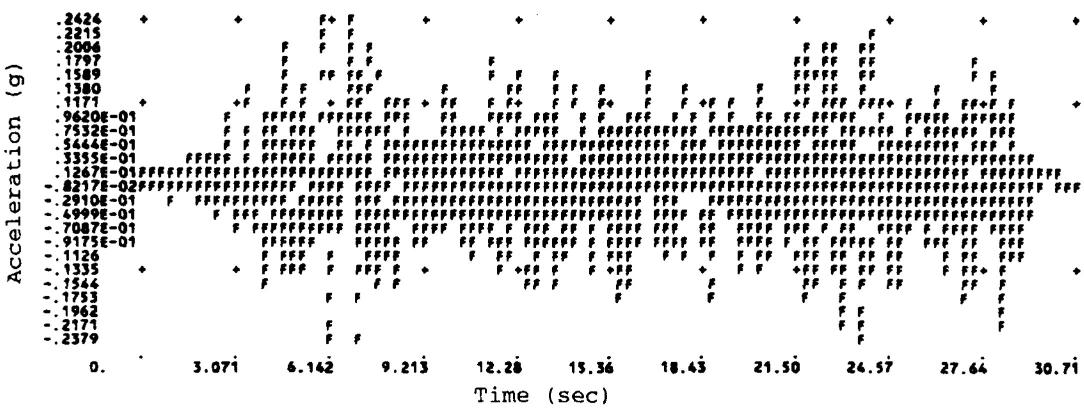

Fig. 6. Time History for Wolsong NPP

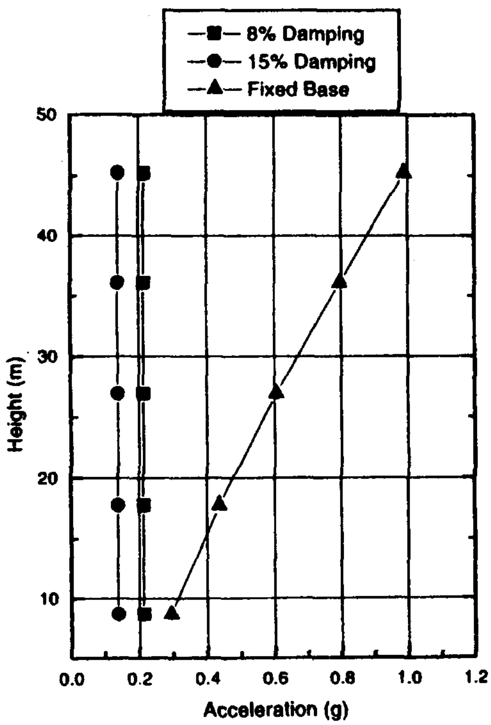

Fig. 7. Response Acceleration Plot

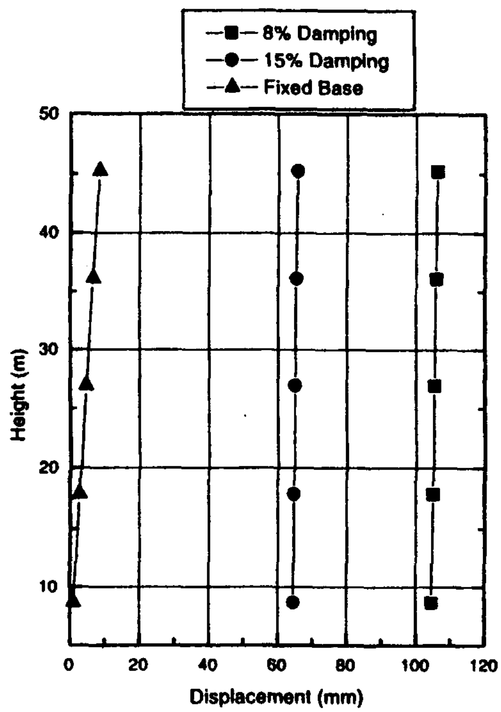

Fig. 8. Response Displacement Plot

which fuelling machines are located (14m location above the base slab) is 0.44g.

Comparing the isolated case with the unisolated case, the use of isolation bearings on the reactor building reduces seismic loads on a large scale and reduce seismic loads by 3.14 times at the region of the fuelling machine. Since the design of nuclear plants must have the sufficient design margin, the adoption of isolation bearings can increase more safety margin than that of current design and avoid more conservative design.

The horizontal displacements of the building along the height of the structure are plotted in Fig. 8 and compared with those of the fixed base case. Displacements of the isolated structure are 66mm (15% damping) and 106mm (8% damping),which are much higher than the displacement of the fixed base structure(8.3mm). Such increased displacement is the characteristic of an isolated structure and will require special considerations for interconnected systems such as the main steam line and other pipes connected to the BOP(Balance of Plant).

To cover such increased displacement and obtain full advantage of the base isolation, the reactor building and BOP of the plant should be located on a common mat. This will accommodate large relative displacements of each building.

The properties of the elastomeric bearings are nonlinear but are assumed to be linear in this study. Further researches and development works on properties of the elastomeric bearing are needed for the exact analysis and specifying bearing characteristics.

6. Conclusions

To predict effects of seismic isolation, seismic isolation bearings were applied to the Wolsong reactor building and the analytical study was performed. For this study, the Wolsong reactor building was modeled using lumped masses and beam elements. Design Basis Earthquake with a ground acceleration of 0.2g was applied. And then, the behavior of the isolated structure was compared with that of the unisolated structure.

The analysis results led to the following conclusions.

(1) The application of isolation bearings for the Wolsong reactor building reduces seismic loads of the structure and equipments by a large amount. Therefore, the use of isolation bearings can increase the seismical safety margin in designing internal equipments of the reactor building. Particularly, since the Wolsong reactor can be characterized as on-power refuelling using the fuelling machine, that needs more conservative design. However,we can get higher margin and avoid more conservative design using seismic isolation bearings. The use of isolations reduce seismic loads by 3.14 times at the region of the fuelling machine and the seismic response accelerations are almost constant along the height of the building.

(2) The application of isolation bearings increases the displacement of the structure by a large amount. Displacements of 66 mm will require special considerations for interconnected systems such as the main steam line and other pipes connected to the BOP. To cover such a large displacement and obtain full advantage of the base isolation, the reactor buildings and BOP should be located on a common mat.

References

1. Biswas, J. K. "Study of Seismic Responses of CANDU 3 Reactor Building Using Isolator Bearings," IAEA Specialist Meet. on Isolation Tech., San Jose, Cal. Mar. (1992).
2. Jolivet,F.,and Richli,M., Aseismic Foundation for Nuclear Power Stations,Transactions of the Fourth International Conference of Structural Mechanics in Reactor Technology, Paper K 9/2,August (1977).
3. Kircher, C.A., et al, Overview of Seimic Isolation and Application to Nuclear Facilities,

Proceedings of the Third Symposium on Current Issues Related to Nuclear Power Plant Structure, Equipment and Piping, Orlando,Florida, Dec. (1990).

4. Buckle I. G., Mayes R. L., "Seismic Isolation History, Application and Performances - A World Review," Earthq. Spec., EERC Vol.6, No.2, (1990).
5. Tajirian F. F., Kelly J.M., and Aiken I. D., "Seismic Isolation for Advanced Nuclear Power Stations," Earthq. Spec., Vol. 6, No.2, (1990).
6. Masanori I., " Recent Progress and Development of Building Vibration - Control Systems in Japan," Nuc. Eng. Des. 127, 273-280 (1991).
7. Pall,A.S., Verganelakis,V.and Marsh C., Friction Dampers for Seismic Control of Concordia University Building, Proceedings of the Fifth Conference on Earthquake Engineering, Ottawa, Canada, July (1987).