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Design study of the seismic-isolated reactor building of demonstration FBR plant in Japan

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ABSTRACT: In the design of FBR demonstration plant that has been developed in Japan, it is important to make the plant comparable to LWRs in terms of construction cost by introducing all kinds of innovative technology. An adoption of seismic isolation system that can reduce seismic load is necessary to compromise contradicting design conditions that are unique in FBR plant; large thermal load and seismic load. For this purpose, common research works among electric power companies have been carried out since 1989 on subjects necessary to realize a seismic-isolated FBR plant. In 1993, preliminary design of seismic-isolated FBR plant reflecting results of these researches is performed. This paper shows the result of the design study.

1 DESIGN OF SEISMIC-ISOLATED REACTOR BUILDING

1.1 *Fundamental Design Principle*

The principal specifications of the demonstration FBR are as follows:

Reactor type: loop type reactor with top entry system (3 loops)

Capacity: approx. 660,000 kWe

In studying a seismic-isolated plant the fundamental principles taking into consideration the features of a demonstration FBR are as follows:

(1) The seismic isolation design would be of horizontal seismic base-isolation with a seismic-resistant design for the vertical direction.

(2) There should be an outlook for the design to be realized under the maximum probable earthquake ground motions(S_2) in Japan.

(3) There should be seismic safety compatible to that of seismic-resistant LWR.

1.2 *Earthquake Ground Motion for Design*

With regard to earthquake ground motions, since a frequency characteristic of a period of about 2 seconds would be of importance in seismic isolation design, earthquake motions of long periods 2 seconds to about 10 seconds which are longer than stipulated in Regulatory Guide for Aseismic Design of Nuclear Power Reactor Facilities of Japan are taken into consideration. Standard earthquake ground motions (S_1-D, S_2-D) and the maximum probable earthquake ground motion in Japan (S_2-M) are set out in this study (Fig. 1). Designing is done using S_2-D while the S_2-M is used for evaluating feasibility on critical parts. As for vertical earthquake ground motion, 0.6 times the horizontal ground motion is taken.

1.3 *Design of Seismic Isolation Device*

Of the basic characteristics of the seismic isolation device what mainly govern responses are the isolated natural period T_2 and the ratio of yield force to building weight β. In this case, T_2 is taken to be 2 seconds (Kato,M.,1991). As for β, it is made 0.1 for S_2-M motion, and 0.05 for S_2-D motion since input level is small.

Preliminary response analyses are performed based on the basic characteristics selected, and seismic isolation devices are designed. The two points below are considered for allowable deformation of seismic isolation devices.

(a) Deformation in an S_2 earthquake is not to be more than 1/1.5 of displacement at the beginning point of hardening.

(b) Deformation in a $2S_2$ earthquake is not to be more than the rupture limit displacement.

The seismic isolation systems are laminated natural rubber bearing + steel damper system, leaded laminated rubber bearing system, and high-damping laminated rubber bearing system, but here, the laminated natural rubber bearing + steel damper system will be mainly discussed.

The design of seismic isolation devices are shown in Fig. 2 and Table 1.

1.4 *Layout Plan and Structural Plan of Seismic-Isolated Reactor Building*

The principles for the basic layout of the reactor building are taken as follows:

(a) It is necessary to provide a stable building configuration which will not cause the seismic isolation device to rupture in tensile and shear forces from overturning moment during earthquake.

(b) Since the amount of response of the superstructure would be reduced compared with an seismic-resistant design reactor building, it is to be aimed to reduce weight by making base mat thickness and shear wall thickness thinner.

(c) The arrangement of seismic isolation devices should be well balanced giving thorough consideration to weight distribution to match locations of center of gravity and center of rigidity so that torsional response will not occur.

(d) Equipment delivery routes, access routes, etc. in relation with adjacent buildings should be thoroughly taken into consideration, along with which space from adjacent buildings should be secured in order that functions of seismic isolation system will not be lost.

1.5 *Design of Seismic-Isolated Reactor Building*

The plan and sectional drawings of the nuclear reactor building are shown in Fig. 3. The ratio of the foundation width to gravity center height of the superstructure is 3.5, and it is confirmed that the superstructure is stable against both S_2-D and S_2-M motion. The reactor building possesses ample rigidity with its fundamental period 0.2 second at the fixed base.

The arrangement of seismic isolation devices is shown in Fig. 4. Laminated rubber bearings are laid out well balanced giving thought to arranging them under shear walls and columns in order that vertical axial forces would act uniformly on the individual laminated rubber bearings, with the center of gravity of the building and the center of rigidity of the seismic isolation story to coincide so that torsional vibration would not occur.

2 SEISMIC RESPONSE ANALYSIS RESULTS

2.1 *Integrity Assessment for Superstructure*

The maximum shear stress of the reinforced concrete walls under S2-D motion is 4.3 kgf/cm^2, while under S2-M motion the maximum value is 12.1 kgf/cm^2. The superstructure can be seemed to be linear from these results, and the superstructure is sufficiently sound.

2.2 *Integrity Assessment for Seismic Isolation Story*

The response of a laminated rubber bearing at an end portion satisfies the allowable limit set for a state of composite stress of shear strain and axial stress (Fig. 5). As a result of calculating cumulative fatigue damage rate Dk(n) of steel bar dampers by Miner's law, the value of Dk(n) is 0.0082 in case of S2-D and 0.0188 in case of S2-M, and smaller compared with 1.0 at which rupture would occur.

2.3 *Floor Response Spectra*

The floor response spectra at the reactor supporting floor in a seismic-isolated plant and an seismic-resistant plant are compared as shown in Fig. 6. The horizontal floor response accelerations of the seismic-isolated plant are greatly reduced in the fundamental period domain of equipment design. On the other hand, the vertical response accelerations are increased more than those of the seismic-resistant plant in the frequency range around 10 Hz that is influential on equipment design, it is considered to be mainly due to amplification at the seismic isolation story.

3 SEISMIC SAFETY MARGIN

Seismic response analyses whose input levels increase are performed to grasp the response characteristics until the superstructure or seismic-isolated device reaches the ultimate state. The maximum responses of the shear wall and laminated rubber bearing at input of S2-M amplified by factor are shown in Fig. 7.

It may be seen from these results that in case of S2-M the ultimate state is not reached up to S2 amplified by 2.25. As for S2-D, it is ascertained that the ultimate state is not reached up to input of S2 amplified by 3.0 . On the other hand, from the fact that a typical existing seismic-resistant LWR retains an allowance of double the S2-M until ultimate state, the seismic-isolated nuclear reactor building composed in this study possesses seismic safety equal to or greater than the seismic-resistant design reactor building.

4 PHYSICAL PROTECTION (PP) FOR SEISMIC ISOLATION PLANT

PP facilities of the seismic isolation plant are required to be capable of absorbing relative displacement during earthquake along with being of a sound construction. The concept of PP facilities taking these into consideration is shown in Fig. 8. The PP facilities are composed of a concrete pent roof provided in the vicinity of ground level at the exterior wall, a peripheral wall of concrete rising up from the retaining wall, and a seal between the pent roof and wall.

5 FIRE PROTECTION

The frequency of fire breaking out at the seismic isolation story of the building is extremely low, but because of the fact that the laminated rubber bearings are not flame retardants, a cover structure having fire-resistant efficiencies around rubber bearings is considered as the measure of fire protection assuming that a fire breaks out at the seismic isolation story. The fire-resistant cover is a blanket placed over the laminated rubber bearing, which would be capable of following displacements during earthquake, while also being detachable for inspection (Fig. 9). Furthermore, from the points of view of fire detection and fire extinguishing, fire detectors and water extinguishing and other fire extinguishing facilities are provided.

6 QUALITY CONTROL AND MAINTENANCE CONTROL

Seismic isolation devices are controlled for scatter in device characteristics to be within the specified ranges by inspections at the time of manufacture. While in service, it is confirmed that the functions of the seismic isolation device are secured through daily inspections, periodic inspections, and temporary inspections

Further, assuming a case of serious irregularities occurring with the seismic isolation device, the construction and arrangement of seismic isolation devices are to be such that replacement would be possible.

7 CONCLUSION

Conceptual design of a seismic-isolated FBR plant, which would be realized in earthquake country Japan, is studied. As a result of an analytical study on seismic safety which is important in realization of the concept, it was found that it would be possible to secure seismic safety equivalent to an existing seismic-resistant LWR.

Following this, a study is to be made for optimization of reactor buildings, seismic isolation devices, and equipment and facilities aiming for realization of a horizontal seismic base-isolation system whose technological progress is steadily being made.

8 ACKNOWLEDGMENT

This study is carried out as a part of the FBR common research of the electric power companies in Japan, entitled "Conceptual Design Study of DFBR ".

REFERENCE

Kato, M. et al. 1991. *STUDY ON THE SEISMIC BASE-ISOLATED REACTOR BUILDING FOR DEMONSTRATION FBR PLANT IN JAPAN.* 11th SMiRT, Vol.K2

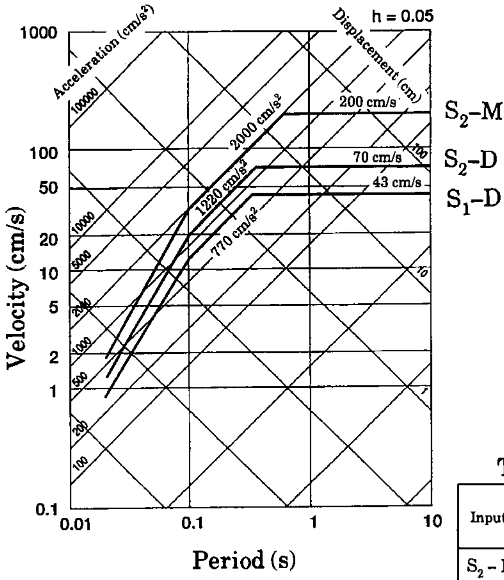


Fig. 1 Response Spectra of Horizontal Design Earthquake Ground Motions

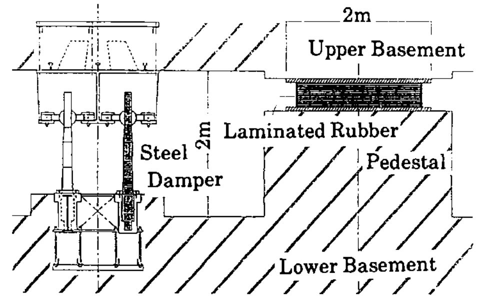


Fig. 2 Concept of Seismic - Isolation System

Table 1 Design of Laminated Rubber Bearings

Input	Supporting Load(ton)	Diameter (cm)	Thickness of Rubber (cm)	Deformation of S_2 (cm)	Axial Stress (kg/cm²)	Rupture Displacement (cm)
S_2 - D	750	160	15.3	14	37.9	68.9
S_2 - M	500	160	22.5	40	25.3	101.3

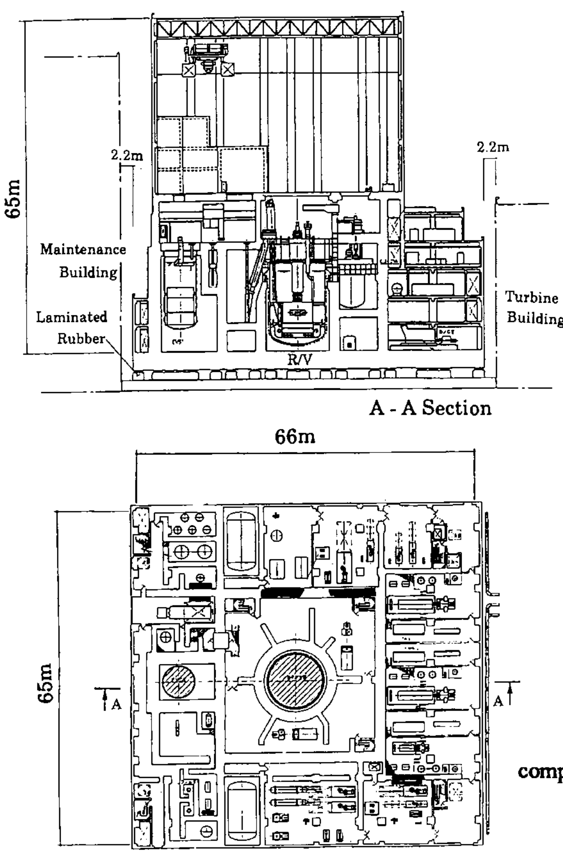


Fig. 3 Seismic Base Isolated Reactor Building for FBR

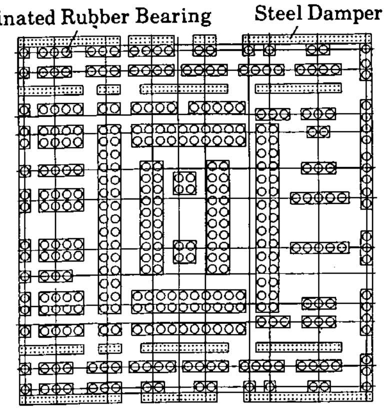


Fig. 4 Arrangement of Seismic Isolated Devices for S_2–M

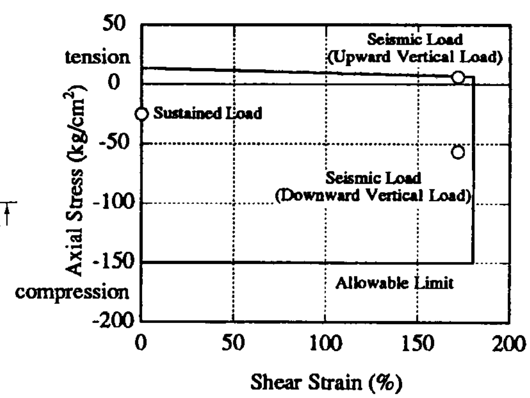
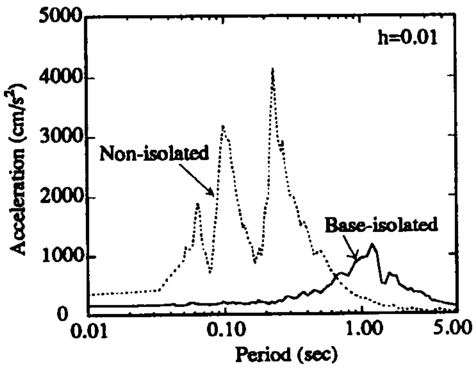
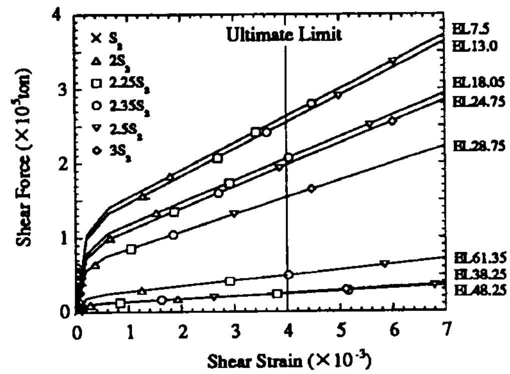


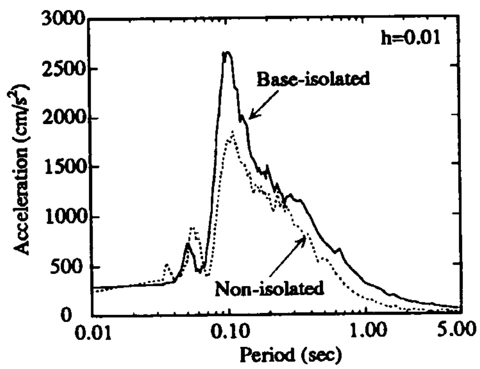
Fig. 5 Maximum Response of Laminated Rubber Bearing for S_2–M



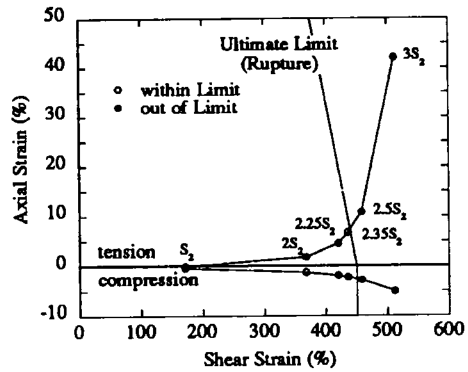
a) Horizontal FRS for S_2-M



a)Shear Wall



b) Vertical FRS for S_1-D



b)Laminated Rubber Bearing

Fig. 6 Floor Response Spectra at Reactor Vessel Support

Fig. 7 Maximum Response for Amplified S_2–M

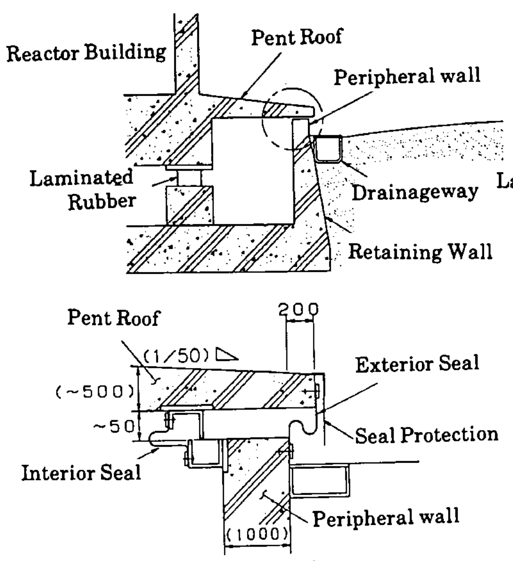


Fig. 8 Concept of PP Facilities

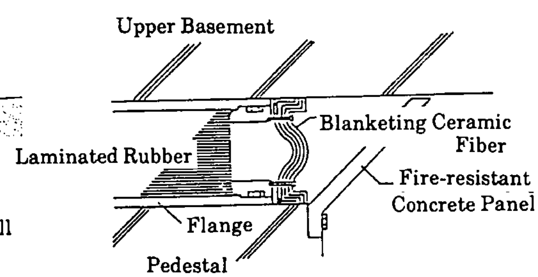


Fig. 9 Concept of Fire-resistant Cover