Evaluation of Ultimate Behavior of Seismically Isolated FBR Plants Using a Large Shaking Table

Background

Seismic isolation technology is planned for introduction to the next generation's fast breeder reactor (FBR) plants, because of seismic safety and rationalization of components in the plants to reduce seismic load. On the other hand, the "Regulatory guidelines for seismic design of nuclear facilities in Japan" were revised in 2006. In the regulatory guidelines, the method of evaluation of design earthquake motions was revised with a view to the possible introduction of seismic probabilistic safety assessment (seismic PSA) of the plants in the future. We conducted tests of seismically isolated structures with laminated rubber bearings to grasp ultimate behavior of the structures under extremely strong earthquake motions for the design using the largest three-dimensional shaking table in E-defense of National Research Institute for Earth Science and Disaster Prevention (NIED) of Japan.

Objectives

The purpose of this study is to obtain the integrity under design earthquake motions and ultimate behavior under extreme motions of seismically isolated structures by shaking table tests with large test specimens, which were modeled based on an FBR plant.

Principal Results

1. Ultimate behavior of seismically isolated structure in the shaking table tests with large test specimen

The shaking table tests were planned and carried out with the test specimens (Fig. 1), which consist of the upper structure and the isolation layer. The upper structure of 600 tons was supported by six lead rubber bearings (LRBs) with diameter of 505 mm (reduced scale: about 1/3) in the isolation layer. In the tests, reduction of seismic load in seismic isolation was confirmed under a design earthquake motion which was fit to the velocity response spectrum of 150 cm/sec in slightly long period range. Furthermore, a reinforced concrete wall in the upper structure and LRBs were damaged according to the increase of acceleration of input earthquake motions, so that the data on ultimate behavior of the test specimen including failure of LRBs was obtained. The failure of LRBs occurred from 4.0 to 4.8 times as large as the design earthquake. The failure strain of LRBs was 550% to 600%; it was almost the same as the result of static loading tests (Fig.2).

2. Evaluation of ultimate responses in the seismic isolated structure

We obtained precious data to evaluate seismic safety of components of the plants. After hardening of LRBs occurred, the peak of response spectra at the top of the upper structure in the high frequency range occurred remarkably. On the other hand, response spectra at the near center of gravity of the upper structure had no peak in the same frequency range. Moreover, the ultimate response of the test specimen could be simulated with the analytical model of LRBs based on the results of the static loading tests. (Fig.3)

3. Mechanism of failure of LRBs

We verified that failure of LRBs occurred by breaking of rubber material from observation of failure surfaces and material tests with LRBs after shaking table tests. The integrity of the bond between rubber sheets and inner steel plates of LRBs was confirmed.

Future Developments

The test results are expected to apply to the seismic design and risk assessment for nuclear power plants, including FBR plants.

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Main Researcher: Shuichi Yabana, Ph.D.,
Senior Research Engineer, Civil Engineering Research Laboratory

Reference

S. Yabana et al., 2009, "Shaking Table Tests with Large Test Specimens of Seismically Isolated FBR Plants, Part 3: Ultimate Behavior of Upper Structure and Rubber Bearings", ASME PVP2009-77229

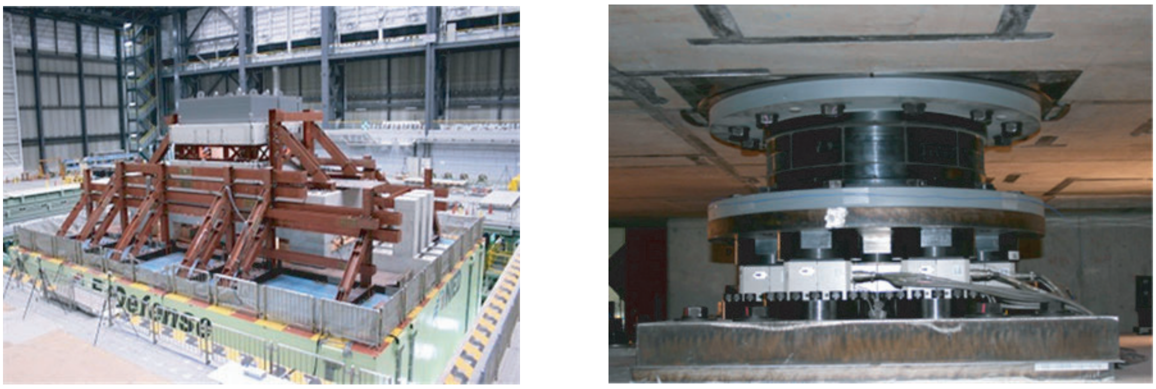

Fig.1 Test specimen of seismically isolated structure and lead rubber bearing (LRB)

Left photo shows the test specimen on the shaking table of E-defense (NIED). This is the largest test specimen for dynamic failure test of rubber bearings up to the present. Right photo shows an LRB set under an upper structure of the test specimen. In the test, stress state of each LRB was measured by load cells under the LRB.

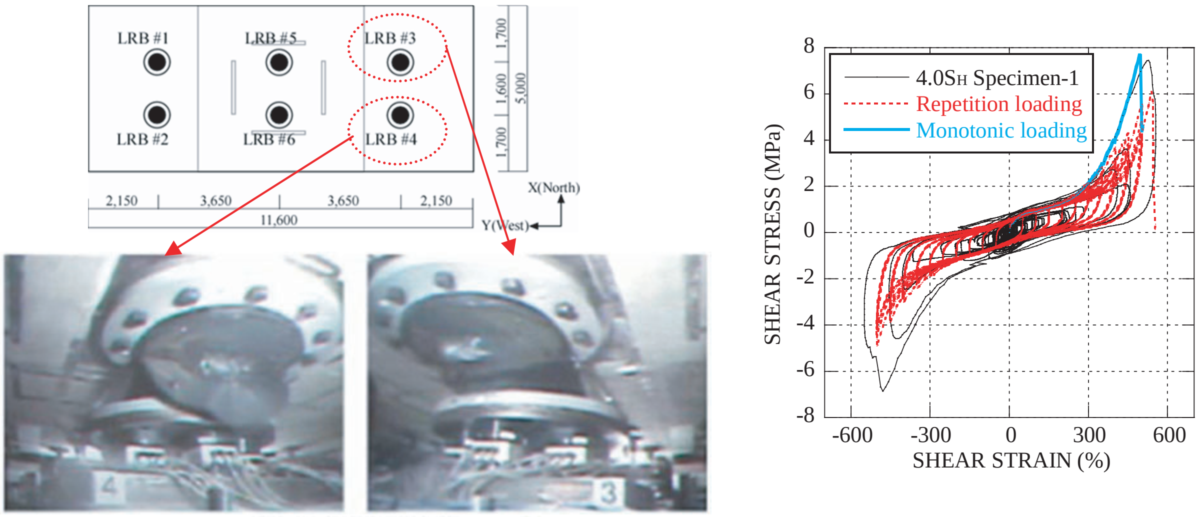

Fig.2 Moment of breaking and stress - shear strain relationship of LRB

Left figures show the layout of failure of LRBs in the isolation layer and photographs of the moment of breaking of LRBs. The failure occurred at the corner LRBs of the isolation layer. In this test, two LRBs were simultaneously broken at four times the design earthquake motion (4.0SH). In right figure, failure strain of the shaking table test is almost the same as that of monotonic and repetition loading test.

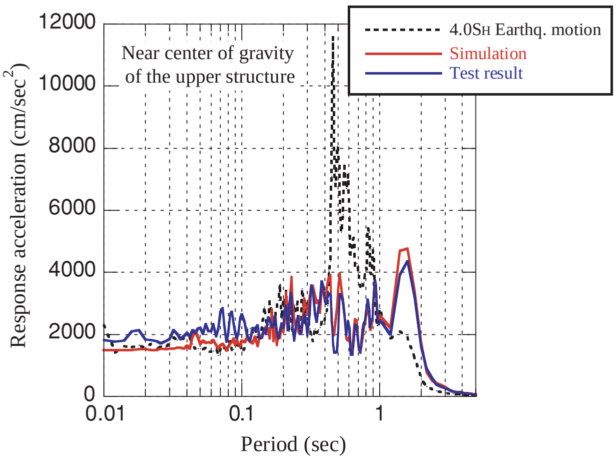

Fig.3 Response spectra (damping factor: 1%) of the test and simulation at near center of gravity of the upper structure

The simulation result almost agrees with the test result in the case of 4.0SH.

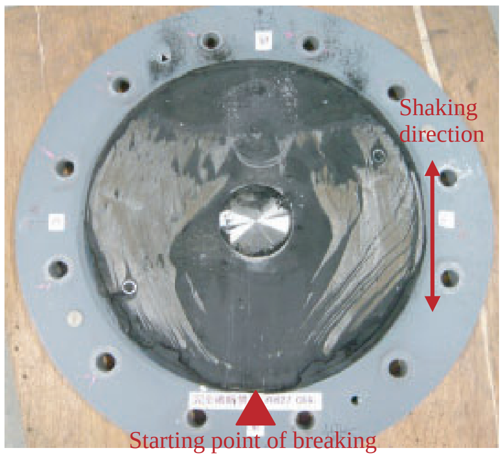

Fig.4 Failure surface of broken LRB

The starting point of breaking of LRB is a rubber layer.