Priority Subjects with Limited Terms — **Establishment of Optimal Risk Management**

Improvement of the Safety Assessment on External Natural Hazards for Nuclear Facilities

Background and Objective

The Fukushima Daiichi nuclear disaster has severely impacted upon the reliability of nuclear safety and social trust. Most nuclear power plants remain out of service for these reasons. Since nuclear power could play an important role in the realization of a low carbon society, long-term shutdown should be avoided. In this project, safety assessment methodologies for nuclear power plants subjected to natural disaster are studied.

Main results

1 Evaluation of tsunami debris-induced risks

In order to establish the evaluation methods of tsunami debris-induced risks for NPPs, we developed simple criteria on generating/not-generating tsunami debris (Fig. 1), a new simple estimation method of tsunami debris impact load, and a probabilistic assessment approach of debris impact by using a numerical debris tracking model. These methods enable screenings of tsunami debris-induced risk and make it possible to estimate external force caused by tsunami debris in the fragility assessment of NPP structures or instruments.

2 Installation of a Large-scale Tsunami Physical Simulator

The Large-scale Tsunami Physical Simulator, which is a large test flume able to be used for the fragility evaluation test of NPP structures or instruments in the event of a tsunami, was designed and installed (Fig. 2), and verification tests for operation of the facilities were carried out. The facility was able to generate tsunami-inundation flow with a steep front and long-duration, as well as a fast and large-depth flow on a large scale. Using this facility, large-scale experiments can be carried out such as evaluations of tsunami hydrodynamic load, debris impact load, and damage mode of structures under tsunami-loading conditions.

3 Ultimate limit state of seismic isolators designed for light-water reactors based on full-scale break test*1

To examine the applicability of a seismic base isolation system to nuclear power facilities, the ultimate limit state of full-scale seismic isolators was experimentally evaluated. For a series of the tests, lead rubber bearings designed for light-water reactors with 1600 mm diameters and 900 tons rated load, were constructed as specimens. It was demonstrated that the full-scale seismic isolators exhibited good ductility capacity and their ultimate state was well correlated by the results in the conventional small-scale tests.

4 Development of a collapse analysis program for reinforced concrete structures

Seismic performance of reinforced concrete structures has been judged based on failure of only one member in the conventional evaluation system. Also, a numerical analysis technique which follows the behavior after partial failure is expected to enable quantification of structural redundancy and elucidation of phenomena beyond design. As such, an FEM program is being developed to simulate the experiment performed the year before last where specimens were loaded to collapse. Plate element with material nonlinearity of concrete and beam (rebar) element considering geometrical nonlinearity were implemented to the program and confirmed to function individually through trial (Fig. 4).

*1 This research was conducted as a part of the national Japanese project “Development for Evaluation Methods of Seismic Isolation Systems” with the participation of Chubu Electric Power, Japan Atomic Power, Hokkaido Electric Power, Tohoku Electric Power, Tokyo Electric Power, Hokuriku Electric Power, Kansai Electric Power, Chugoku Electric Power, Shikoku Electric Power, Kyushu Electric Power, J Power, Toshiba, Hitachi-GE Nuclear Energy, Mitsubishi Heavy Industries, and the Institute of Applied Energy.

[1] T.Hiraki et.al: Development of a evaluation method for seismic isolation systems of nuclear power facilities (Part 9), Proc. on the ASME-PVP,2004.

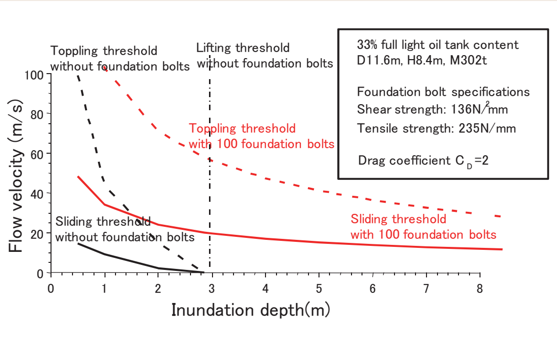


Fig. 1: Simple criteria on generating/not-generating tsunami debris

Relationships between flow velocity and inundation depth at sliding, toppling, and lifting thresholds for a light oil tank with (black) and without (red) foundation bolts are shown in the figure. The solid lines denote the sliding thresholds, the dashed lines denote the toppling thresholds, and the chain line denotes the lifting threshold. If the flow velocity and inundation depth around a target equipment are located lower than these lines, the target equipment is not slid, toppled, or lifted by the tsunami.

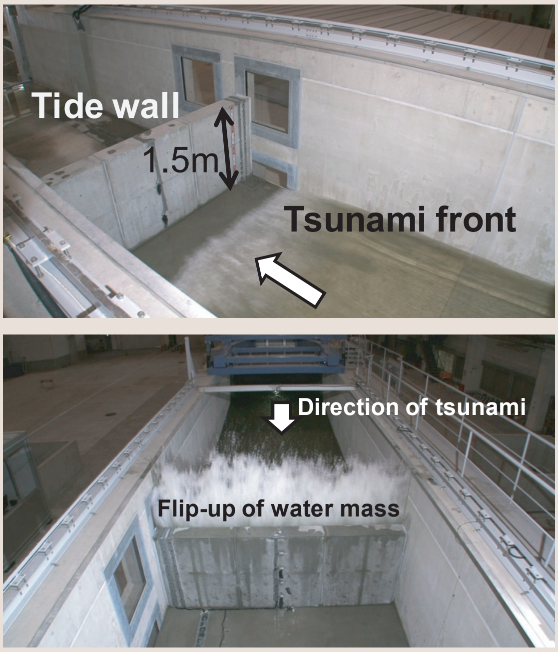
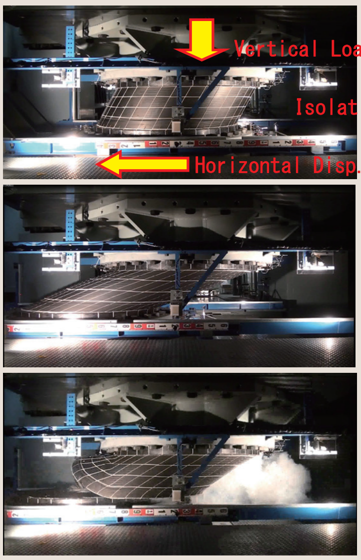


Fig. 2: An overtopping test of the tide wall by tsunami, using the Large-scale Tsunami Physical Simulator

The hydrodynamic force on a 15 m high tide wall was investigated. The top photo shows the flow just before the tsunami reaches the tide wall, while the bottom photo shows the flip-up of the water mass just after the tsunami strikes the wall.
than these lines, the target equipment is not slid, toppled, and lifted.



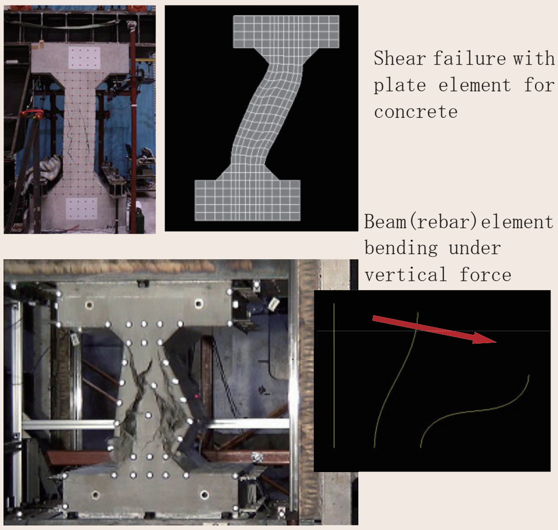
(a) Horizontal Strain 100% (Design Level)

(b) Horizontal Strain 450% (Just before the break)

(c) Horizontal strain 450% (After the break)

Fig. 3: Typical deformation of a full-scale seismic isolator under horizontal loading

In the typical load pattern, horizontal load was gradually applied to a specimen until its breaking under the constant vertical load corresponding to rated load (900 tons) as shown in Fig. 3. 13 specimens were tested under various loading patterns to evaluate the ultimate limit state. It was shown that full-scale seismic isolators exhibited good ductility capacity to have a large safety margin against an earthquake event exceeding design specifications.



Shear failure with plate element for concrete

Beam (rebar) element bending under vertical force

Target of simulation (in 2012)

Fig. 4: Development of a collapse analysis program for RC structures

Components of the FEM program for simulation of collapse process have been developed as shown in the lower left picture. The Maekawa model, which has high precision for concrete and beam elements considering large deformation of rebar, was utilized in the program and its operation was verified.