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Independent Administrative Institution
National Research Institute for Earth Science and Disaster Prevention

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Japan-US collaborative research on innovative seismic isolation solution

1. Background

A series of full-scale shaking experiments of Japan-US collaborative research on innovative seismic isolation solution were conducted in August, 2011 at the Hyogo Earthquake Engineering Research Center, "E-Defense" of the National Research Institute for Earth Science and Disaster Prevention, NIED.

Base-isolation is one of the most effective countermeasures to protect building structures and their nonstructural components from strong earthquake. The excellent performance of base-isolated systems has been established based on past research. Minimal damage is reported on base-isolated structures from the 2011 off the Pacific coast of Tohoku Earthquake. Nonetheless, base-isolated structures have not become a mainstream construction method perhaps because their cost benefit is not well understood in the structural engineering community. Only about 2000 buildings and 3000 houses in Japan, and around 200 to 300 buildings in US have been constructed using the base-isolation technique.

NIED and the University of Nevada, Reno (UNR) formed a Japan-US collaborative research project with a goal to promote rapid spread of base isolation systems in Japan and US. A full-scale five-story steel moment frame building, constructed for a previous project, was excited under three different support conditions; two different isolation systems and the fixed-base configuration. The difference in performance was compared for the three system to evaluate the performance of isolation systems under very rare and long-period earthquakes.

2. Shake table tests for performance evaluation of base isolation.

2.1 Specimen

A five-story steel moment frame building (Figs. 1 and 2), constructed and previously excited for a project to evaluate the performance of the supplemental damping systems, was reused. The height of the building was about 18m, each floor area was 120m² (12m×10m) and its total weight was 543t. Nine isolating devices were installed between the base of the building and the shaking table.

US style ceiling and partition walls were constructed on the 4th and 5th floors. Small enclosed rooms on 4th and 5th floors were used to simulate a hospital room and office room, respectively. Two precast concrete cladding panels were fixed to the corner of the specimen on 4th floor.

Fig. 1 A 5-story steel moment frame

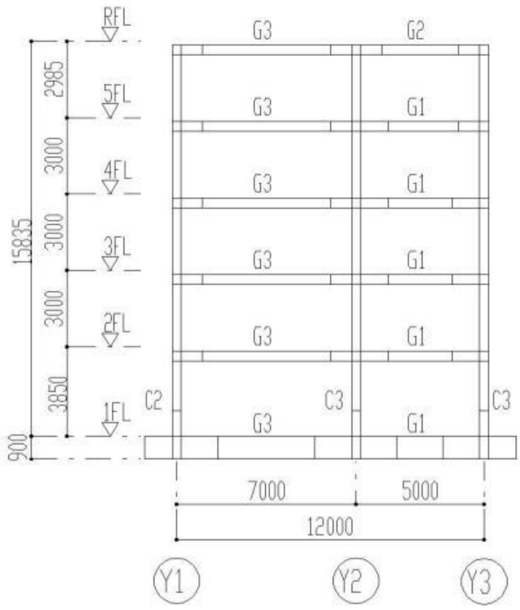


Fig. 2 Elevation view of the specimen

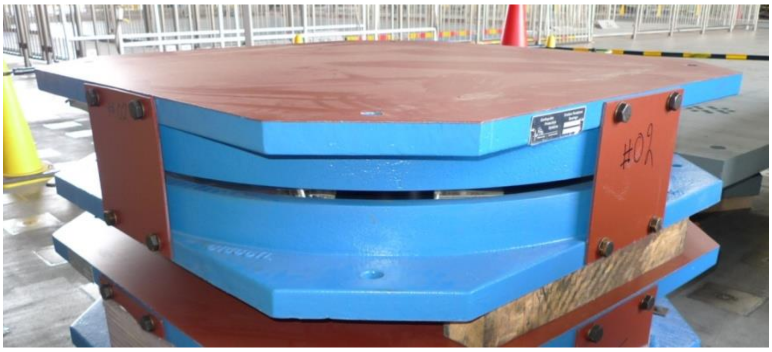
2.2 Base isolating devices

Two different base-isolation systems were used; one used triple friction pendulum bearings (TPBs) developed in US shown in Fig. 3, and the other used a combination of lead-rubber bearings (LRBs) shown in Fig. 4 and cross linear bearings (CLBs) shown in Fig. 5.

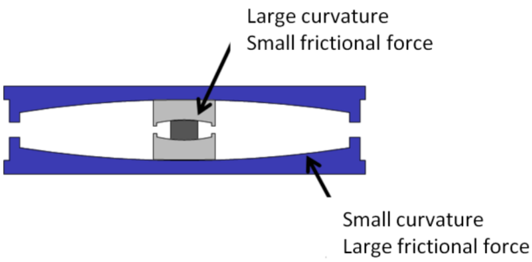
A TPB isolator consists of two large outer and two small inner steel plates with concave surfaces, and one steel cylinder as shown in Fig. 3. The TPB incorporates three pendulums, each with properties selected to optimize the structure's response for different earthquake strengths and frequencies. The inner slip surfaces (Fig. 3(c)) are designed for frequent earthquakes while the outer slip surfaces (Fig. 3(d)) are for very rare earthquakes.

The period of the TPB, which is controlled simply by the radius of curvature of the concave surfaces, is independent of the mass of the supported structure. Therefore, light weight superstructure such as low to mid-rise steel building can be base-isolated easily.

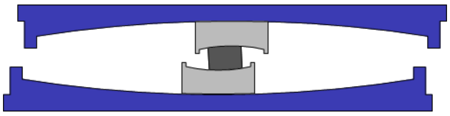
The LRB/CLB isolation system was a combination of LRBs and CLBs. The LRBs are designed for two functions; one is base-isolation by the soft laminated rubbers and steel plates, the other is energy dissipation by plastic deformation of lead plug. The CLB is a device which slides on the rail by ball bearing. It is designed to support vertical force of the superstructure while supplying minimal resistance in the horizontal direction. Noting that the period would become too short, and hence the base-isolation would become ineffective, if nine LRBs are used at the base of the structure in the way done for the TPBs, LRBs were used for only four of the nine locations.



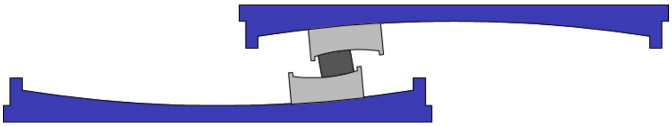
(a) TPB



(b) cross section



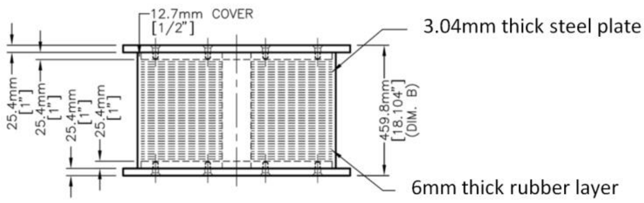
(c) frequent earthquake



(d) very rare earthquake

Fig. 3 TPB, triple friction pendulum bearing

(a) LRB



(b) cross section

Fig. 4 LRB, lead-rubber bearing

Fig. 5 CLB, cross linear bearing

2.3 Nonstructural systems

US style partition walls, ceilings and piping system were installed on the 4th and 5th floors of the specimen. (Fig. 6)

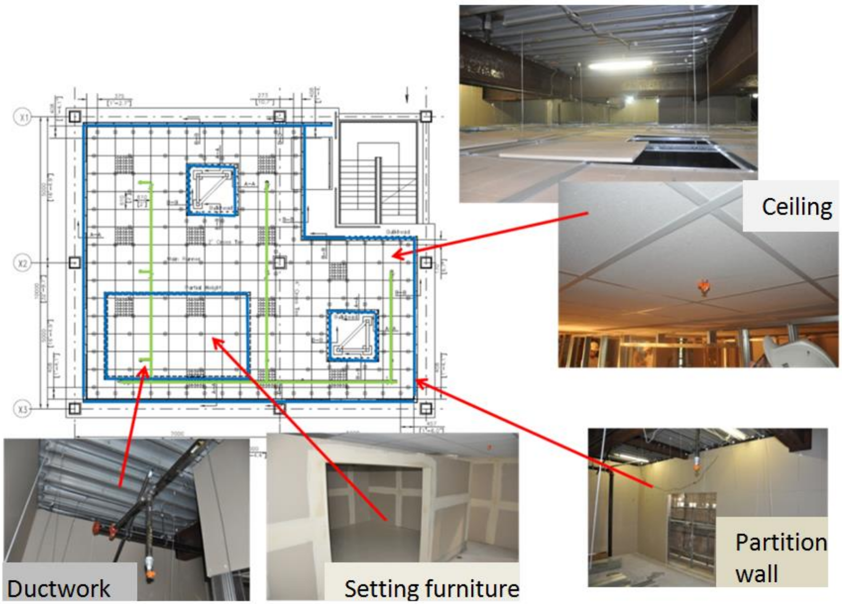


Fig. 6 Nonstructural systems on 4th and 5th floors

Hospital and office rooms were represented in the enclosed rooms on 4th and 5th floors, respectively. A bed, a shelf, lamps, and tables were installed in the hospital room as shown in Fig. 7. On the other hand, a desk, chairs, a copy machine and shelves were set in the office room as shown in Fig. 8. The room furnish was used to evaluate the dynamic behavior of contents and the damage to rooms in use.

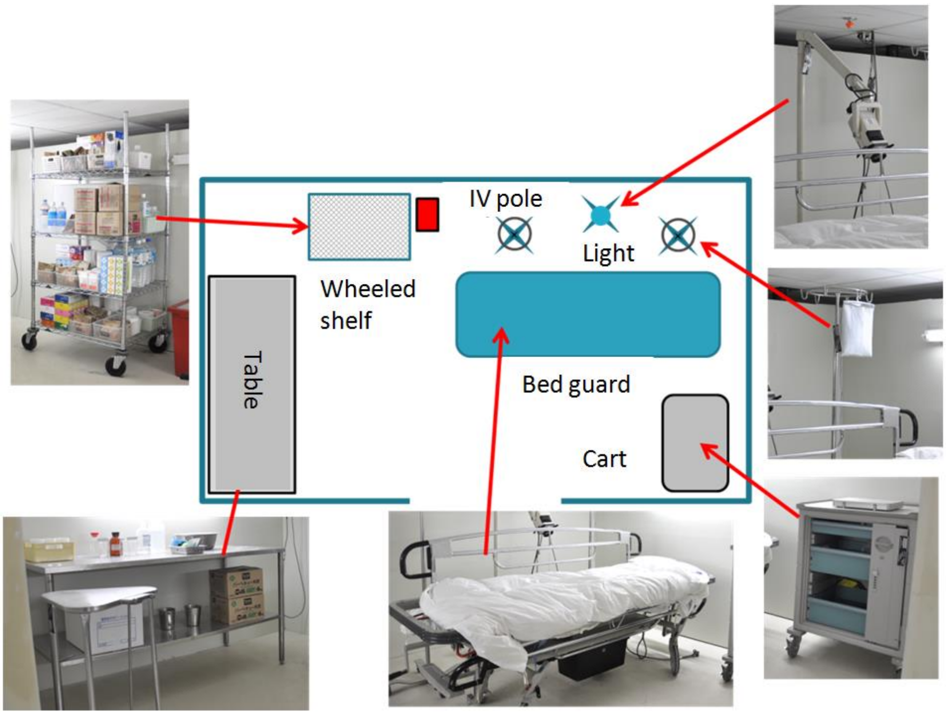


Figure 7, hospital room on 4th floor

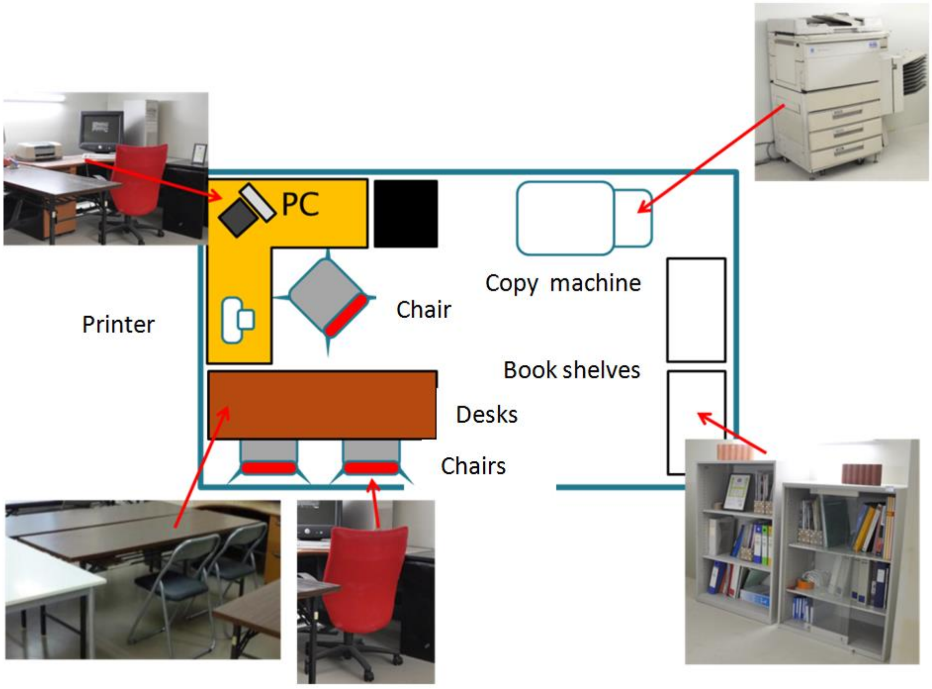


Figure 8, office room on 5th floor

2.4 ground motions

Various ground motion records were used for the table motion. The K-NET Iwanuma record measured at Iwanuma, Miyagi during the 2011 Tohoku earthquake was used for the first time at E-Defense. This record is one of the records stored in the Kyoshin Network (K-NET) database operated by NIED. Records measured during the 1995 Hyogoken-Nanbu earthquake, which has commonly been used at E-Defense, were also used.

Several US records including the 1994 Northridge earthquake were used as well. The specimen was excited 21 times for the TPB isolation system, 15 times for the LRB/CLB isolation system, and 5 times for the fixed-base configuration.

2.5 Experimental results during 2011 Tohoku earthquake

The Iwanuma excitation caused motion in some chairs with casters in both base isolation systems and caused no damage in the ceiling and partition walls. However, the same motion caused extensive damage in the fixed-base configuration: ceiling panels fell, and the shelves and the copy machine moved extensively and broke as shown in Fig. 9. Peak roof acceleration was reduced to 54% of the peak ground acceleration in the TPB isolation system and 63% of the peak ground acceleration in LRB/CLB isolation system. On the other hand, the peak roof acceleration was amplified to 3.3 times the peak ground acceleration in the fixed-base configuration. Therefore, the experimental results suggest that both the TPB and LRB/CLB isolation systems were effective to protect the building structure and its serviceability.

(a) ceiling

(b) office room

Fig. 9 Damage to the ceiling and office room on the 5th floor after Iwanuma excitation in the fixed-base configuration

2.6 Effect of vertical excitation

The Rinaldi excitation (recorded from the 1994 Northridge earthquake) caused significant damage to all three systems, such as falling of ceiling panels and rupture of ceiling grids as shown in Fig. 10. The extensive damage may be attributed to the violent vertical acceleration of the Rinaldi record, with a peak of 8.1 m/s^2, which is almost as large as the horizontal components. This issue is one of the key aspects that we plan to examine in the coming days.

(a) TPB isolation system

(b) LRB/CLB isolation system

(c) fixed-base configuration

Fig. 10 damage to the ceiling on 5th floor after Rinaldi excitation

3. Research team

[Main research members]

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