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Development and application of back-up systems for base-isolated buildings

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ABSTRACT: Base Isolation aims to realize buildings that can safely resist very strong earthquake motions, but no system is perfect. Three kinds of back-up systems for base-isolated buildings were developed to increase and guarantee the safety of those buildings in the case that they meet earthquake motions much stronger than their design level. These systems are : Uplift Restraint, Horizontal Stopper, and Horizontal Shock Absorber, and their performance was confirmed by full scale tests. Furtheremore, the fire-resistance ability of multi-layered rubber bearings was confirmed by fire tests, and fire protection systems were developed. Subsequently these back-up systems were applied to three actual base isolated buildings.

1 INTRODUCTION

Base Isolation is an effective technique for buildings to safely resist very strong earthquake motions. The author usually designs base isolated buildings so that they do not suffer any damage against level 2 maximum credible earthquakes.

There are many studies and reports on rubber bearings and various dampers for base isolated buildings. Concerning the fail-safe systems, there has been an opinion that since the degree of redundancy is low in base-isolated buildings, fail-safe systems are indispensable. However, studies and applications of fail-safe systems or back-up devices are very few. This author does not agree with that opinion completely, but believes that the designer should consider how to deal with an unexpected input far exceeding the design level, as long as there is difficulty and uncertainty in the estimation of future seismological events.

The purpose of this paper is : to present back-up systems for base-isolated buildings that have special design constraints thereby increasing and guaranteeing their safety, and to realize base-isolated buildings using these back-up systems.

2 BASIC CONCEPT

The author calls the developed devices "back-up systems", not "fail-safe systems". A fail-safe system supposes a failure or a loss of the main functions, and in base isolation it means the loss of load supporting ability of the isolators, or the rupture of isolators themselves.

But the author believes that the isolators must support the structure's weight in any case, even if the earthquake input intensity far exceeds the design level. In such cases, peak acceleration response might reach a very

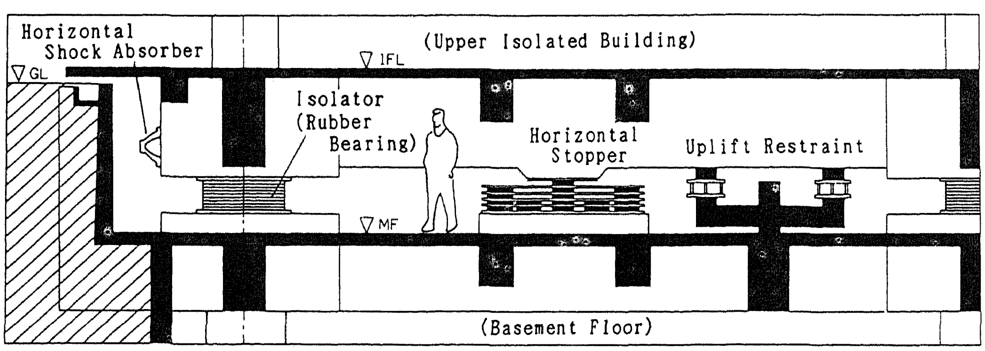


Fig-1 Schematic Location of Isolators and Back-up Devices

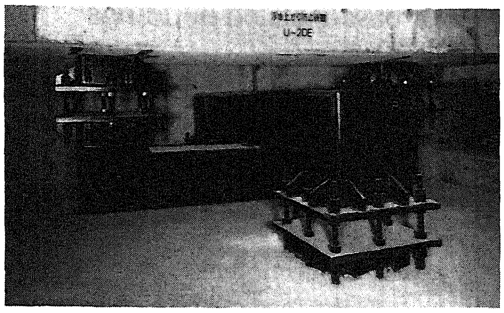


Photo-1 Installed Uplift Restraint

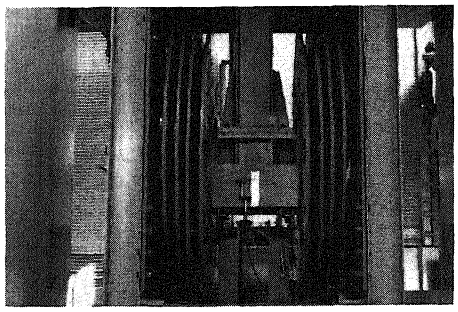


Photo-2 Full-scale Test of H.-Stopper

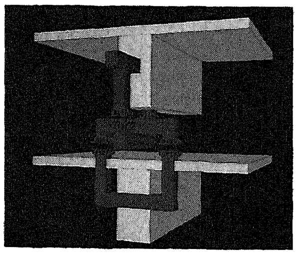


Fig-2 Uplift Restraint

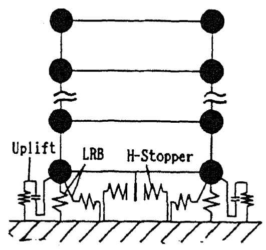


Fig-3 Analysis Model

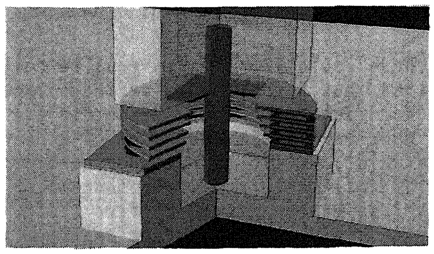


Fig-4 Horizontal Stopper

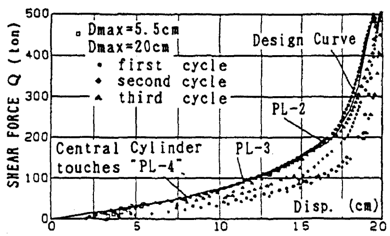


Fig-5 Performance of H.-Stopper

large value by the restaint of the back-up systems, but it should be allowed. Because such a strong attack would perhaps come in the early stage of the event, if the isolators can maintain their load supporting ability, the building will enjoy the benefits of base isolation during most of the earthquake's duration and also during aftershocks.

Therefore, the back-up systems in this paper aim to prevent dangerous isolator deformation, thereby keeping isolators in the normal working range.

3 UPLIFT RESTRAINTS

Since multi-layered rubber bearings have a very high vertical stiffness and are strong in compression but not in tension, base-isolated buildings are usually designed so as not to induce tension in the isolators. But slender buildings with large height/width(H/W) ratio, have a high potential for building uplift and bearing tension.

The mechanism of the Uplift Restraint is as follows: Two U-shaped interlocking steel arms are fixed to the foundation and upper structure respectively, aligned at 90° with a vertical clearance of 1cm.(Figure-2) When uplift motion tries to exceed the clearance, the steel arms engage, preventing further vertical movement. The engaging surface is covered by a hard solid lubricant to allow for horizontal movement.

This device was developed for the design of a 10 story base-isolated apartment building the "EXCEL MINAMI-KOSHIGAYA" (Photo-7) with a H/W ratio of about three. Photo-1 shows the device installed in the building.

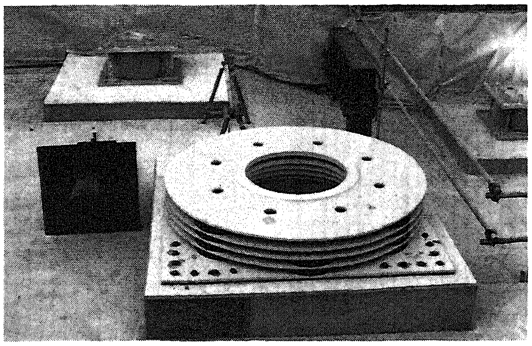
4 HORIZONTAL STOPPERS

A Horizontal Stopper consists of a 30cmϕ solid steel cylinder, surrounded by a stack of steel rings. The steel rings have a varying clearance of 30cm to 50cm to the central cylinder and are connected by rubber pads.

Figure-4 shows the mechanism of the device. When the horizontal deformation of isolators exceeds the minimum clearance of 30cm, the central cylinder engages the rings one by one from the top ring down, gradually giving the building an increasingly resisting force of a hardening type.

Photo-2 shows a test view of a set of two devices with a maximum resisting force of 500 tonf, and Figure-5 shows the results.

Two sets of the devices were manufactured, and after confirming very good conformance to the design values, they were installed into two isolated buildings: the 7 story mezzanine isolated "ASANO BUILDING"(Photo-8) in Nagoya city, and a 10 story apartment building(Photo -7) in Saitama-prefecture. Photo-3 is a view of this device during the construction work.



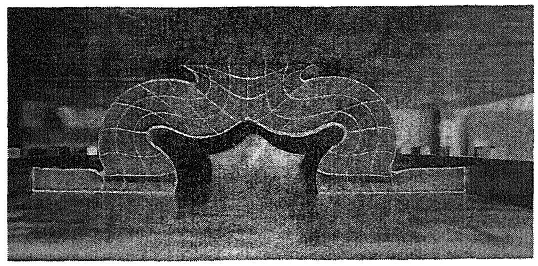


Photo-4 Full-scale Test of Shock Absorber

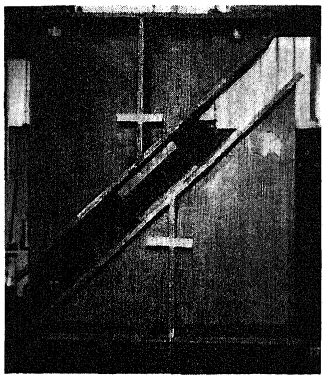


Photo-5 Biaxial Compression Test

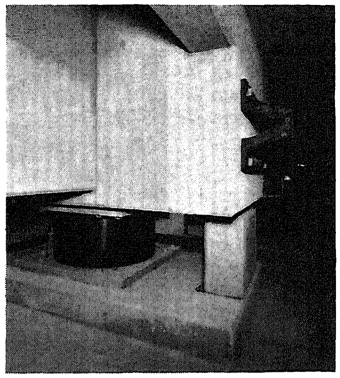


Photo-6 Installed Shock Absorber and LRB

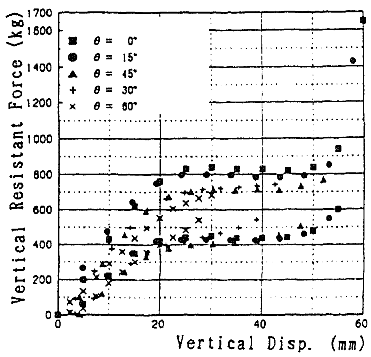


Fig-6 Results of Model-Test

Photo-7 "EXCEL MINAMI-KOSHIGAYA"

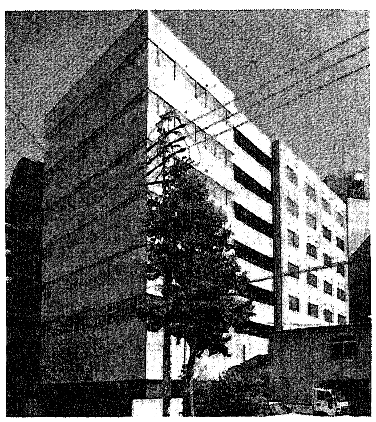


Photo-8 "ASANO BUILDING"

Photo-9 "MSB-21 MINAMI-OHTUKA"

Figure-3 shows a dynamic analysis model used to evaluate the effects of horizontal stoppers and uplift restraints, subject to simultaneous excitations by horizontal and vertical ground motions.

5 HORIZONTAL SHOCK ABSORBERS

Horizontal Shock Absorbers are devices similar to dock fenders which are used at wharfs to absorb the shocks and energy of approaching ships.

Photo-4 shows a full scale test and photo-5 shows a model test used to confirm the energy absorbing capacities under biaxial compression conditions. From the results shown in Figure-6, it was confirmed that the energy absorbing capacity can be estimated independently in the vertical and horizontal directions.

The twenty-four units of this device were used in a 50m high 12 story building with 2 basement floors, the "MSB-21 MINAMI-OHTUKA BUILDING"(Photo-6,9) in Tokyo. This building

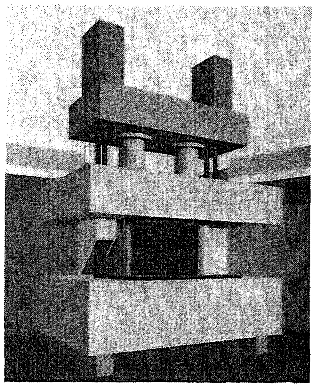


Fig-7 Fire Test Method

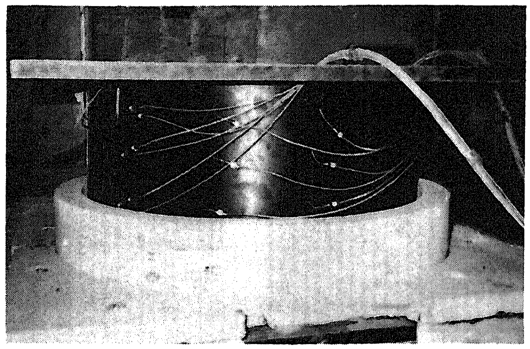


Photo-10 650mmφ LRB before Fire Test

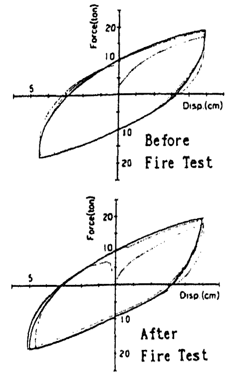


Fig-10 Performance of LRB Before/After F.T.

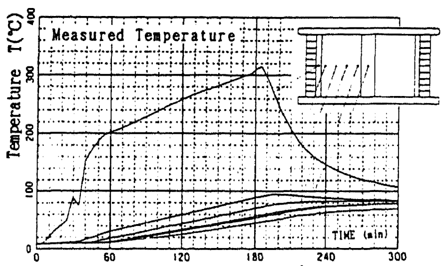


Fig-8 Temperature of Fire-Protected LRB

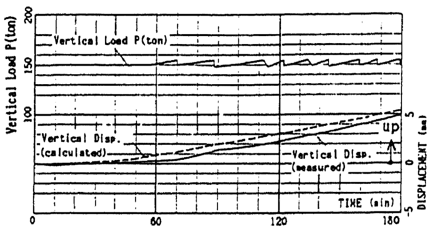


Fig-9 V.-Load and Deformation during F.T.

is the tallest isolated building in Japan, and is isolated between the first floor and the basement, which is used for a parking garage.

6 FIRE RESISTANCE

Fire resistance ability is an important aspect for the design of actual isolated buildings. There are some reports on the fire resistance of rubber bearings,[1,2] but there is no report which has directly confirmed the load supporting capacity under fire conditions.

Three-hour fire tests using 650mmφ-diameter multi-layered rubber bearings with and without fire protection, were carried out under a 150 tonf compressive load. Figure-7 shows the fire test method using two 100tonf hydraulic jacks.

Photo-10 shows a rubber bearing before the fire test. Figure-8 shows the measured temperature of a fire protected bearing under a three-hour test. Figure-9 shows time histories of the vertical load and of the vertical deformation during the fire test.

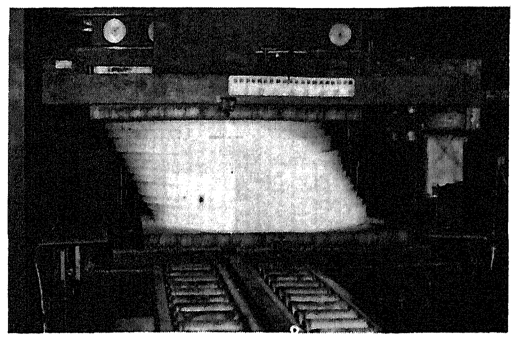


Photo-11 Deformation Test of Fire Protection

Photo-11 shows a deformation test of the fire protection which is made of sliced ceramic fiber rings. Figure-10 shows the horizontal hysteresis loops of a Lead Rubber Bearing before and after a fire test.

From these tests, it was confirmed that rubber bearings can support a vertical load for at least three hours with appropriate fire protection, and two hours without protection, and that Lead Rubber Bearings retain their original performance after exposure to fire.

7 CONCLUSION

The fire resisting ability of rubber bearings was confirmed, and three kinds of seismic back-up systems for base isolated buildings were developed.

Based on this research and development, three isolated buildings from 7 stories to 12 stories were designed and constructed using these back-up systems in Japan.

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1) C.F.Derham, "Fire resistance of steel-laminated natural rubber bearings",1976 NR Technology Vol.7 Part 2
2) "Recommendation for the Design of Base Isolated Buildings", 1989, Architectural Institute of Japan, p270-274