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EXAMPLES OF SEISMIC RETROFITTING IN JAPAN

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Summary

This paper shows some examples of seismic retrofitting designed by Nikken Sekkei. Because there are many earthquakes in Japan, buildings must not only be able to be simply repaired, but also be strengthened to resist large earthquakes so they can be used for a long time in the future. The theory and technology of earthquake-proofing is improving year by year. Here we will introduce two methods of seismic retrofitting: Seismic vibration control and Base Isolation retrofitting.

Example 1 is an examination of retrofitting using EAB: Energy Absorption Bracing with low-yield-point steel. The retrofitting is examined with an application to a 64m high-rise SRC (Steel framed Reinforced Concrete) building built in 1970.

Example 2 is a chapel in a university built in 1920. The 2-story building is 12.6m high and made of brick work. After many kinds of survey, we proposed three ideas of seismic retrofitting and selected Base isolation retrofitting to minimize reinforcement of upper part of building.

Examplee 3 is a renovation project for the International Library of Children`s Literature that successfully preserves the historical value of the original building while adding new functions of a contemporary library, A base isolation retrofitting system was introduced.

1. Introduction

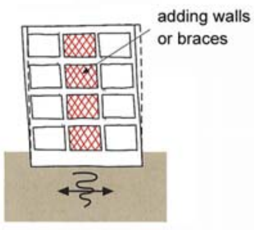
The 1995 Hyogoken-Nanbu Earthquake caused extensive damage to buildings. Most of the damaged buildings were designed in accordance with the aseismic design codes that preceded the enforcement of the revised Building Standard Law in 1981. Although it is urgently necessary for existing buildings to secure earthquake-resistant safety in preparation for possible major earthquakes, there are buildings that need to be seismically strengthened while they are in use, and other buildings of historic value that need to be seismically strengthened with their architectural designs preserved. This paper introduces examples that applied earthquake-resistant retrofitting techniques to such buildings for the assurance of earthquake-resistant safety.

2. Earthquake-resistant retrofitting techniques

Earthquake-resistant retrofitting techniques are classified as follows according to the principle.

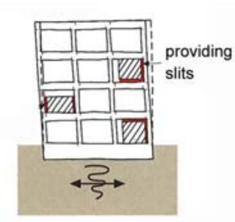
An important point in planning earthquake-resistant retrofits is the selection of an appropriate earthquake-resistant retrofitting technique from among the above-mentioned techniques according to the structural performances and characteristics required of the subject building.

A. Enhancement of bearing capacity



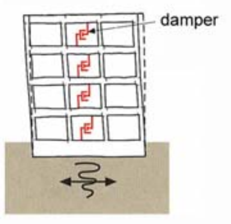
The bearing capacity of a structural body is enhanced by adding structural elements, such as walls and braces, capable of resisting horizontal loads during earthquakes.

B. Enhancement of ductility



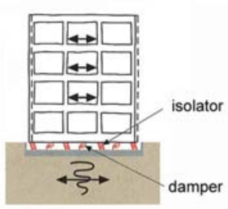
The ductility of structural members is enhanced by wrapping steel plates or fibers around the members, and the capacity of the structural body to follow deformations is enhanced by providing slits in structural elements, such as dado and hanging walls, where ductility is apt to be impaired during earthquakes.

C. Seismic vibration control



The damping capacity of a building is enhanced and the responses of the building are reduced during earthquakes by the installation of dampers constructed of materials that absorb seismic energy, such as steel, lead, oil, and viscoelastomer.

D. Base isolation



The period of building response is prolonged and a damping capacity is added to the building to reduce responses during earthquakes by isolating the building from the ground.

3. Example of seismic vibration control retrofit

3.1 Background of the retrofit

The subject building was built in May 1970 as the first high-rise prefectural office building in Japan. The building is characterized by the adoption of a soft core system with a layout of the skeleton and the M&E system not intersecting, and a large-span pure moment-resisting structure that uses the building body of SRC frames as an exterior finish.

After a lapse of a quarter century since its completion, the time to renew the building was approaching to serve the growing need for upgrading office functions to adapt to changes in social conditions, in addition to the need for repairs to the deteriorated finishes and equipment. In recognition of the utmost importance of retaining administrative functions in the event of the assumed Tokai Earthquake, Shizuoka Prefecture conducted various studies on what the prefectural office building should be. As a result, the prefecture worked out a policy to give the building a role of retaining administrative functions as a base for post-quake activities.

The seismic capacity of the building was evaluated immediately after the 1978 Miyagi-ken-oki Earthquake. The results of the evaluation indicate that the building would sustain damage but not collapse. The ductility ratio and maximum story drift of the building obtained from a dynamic analysis under input earthquake ground motions at the maximum acceleration of 500 cm/s2 (the maximum velocity of 70 cm/s) were about 4 and 1/60, respectively. These levels were insufficient in terms of the safety required of the building, and the need for earthquake-resistant retrofitting of the building was recognized.

3.2 Outline of the retrofit design

In consideration of the capacities of interior and exterior finishes to follow deformations and the degree of damage to the existing structural body, the target structural performance of the building under input earthquake ground motions at a velocity of 70 cm/s was set at a story drift not more than 1/150 to 1/100, keeping in mind that existing interior and exterior finishes should be used as much as possible. The earthquake-resistant reinforcement by enhancing the bearing capacity to attain the target structural performance was judged difficult because of an increase during earthquake input to the building due to the shortened period of vibrations of the building. Accordingly, a comparative study was made of the two possibilities, i.e. base isolation and seismic vibration control.

Base isolation system has the advantages that retrofitting work can be concentrated on the base isolation floor and the building will not sustain serious damage even if the interior and exterior finishes remain unchanged. But it shelved due to a decrease in the first floor parking function and a concern about the building height exceeding 60 m and the ratio of building height to width.

As regards seismic vibration control, many parametric studies were made of both viscous and steel damping systems. As a result, a steel damper capable of enhancing the existing bearing capacity as well as improving the balance was judged to be rational from the viewpoint of performance and cost effectiveness. Taking into account architectural design and constructability, an energy absorption bracing system of double steel tube capable of producing a stable effect from a small deformation were adopted. The double steel tube consists of an inner low-yield-point steel axial force-resisting tube that absorbs energy and an outer stiffened tube that restrains buckling. Figs. 1 and 2 show the outward appearances before and after the retrofit, respectively. Figs. 3 and 4 show the plan and elevation of braces, respectively.

The earthquake-resistant retrofit was conducted at the same time as the layout change and equipment renewal when the construction of the adjacent annex was complete. The building was retrofitted in incremental steps of one-third the height at a time while it was in use, with consideration given to the environment (safety, vibration and noise control).

Figure 1 Before the retrofit

Figure 2 After the retrofit

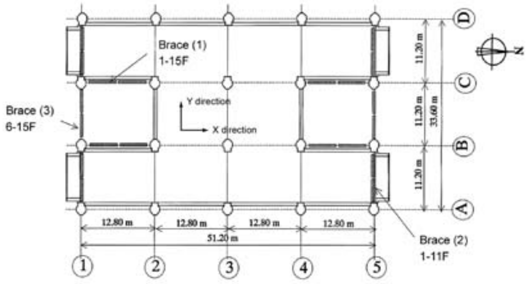


Figure 3 Floor plan

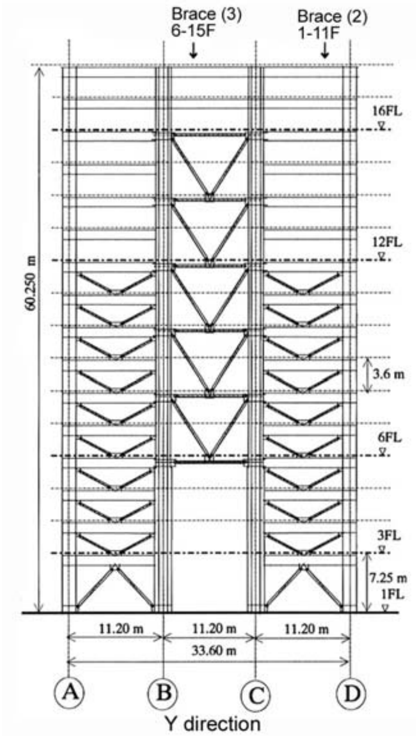


Figure 4 Framing elevation

3.3 Earthquake-resistant performance of the building after the retrofit

Fig. 5 shows the responses of the building(before and after the retrofit) obtained from a time-history analysis. The target structural performance of the building, or a story drift not more than 1/100, under input earthquake ground motions at a velocity of 70 cm/s is attained. Fig.6 shows time-history energy responses. The ratios of time-history energy absorbed by SRC frames and braces to the total energy input are 13% and 53%, respectively, indicating that the braces absorb much energy in spite of the reinforcement at a bearing capacity ratio of about 20%.

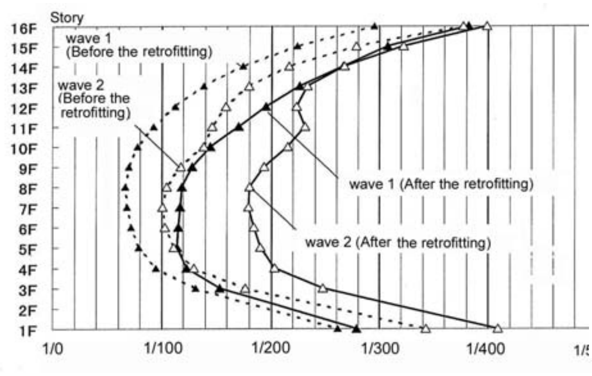


Figure 5 Maximum response story drift angle

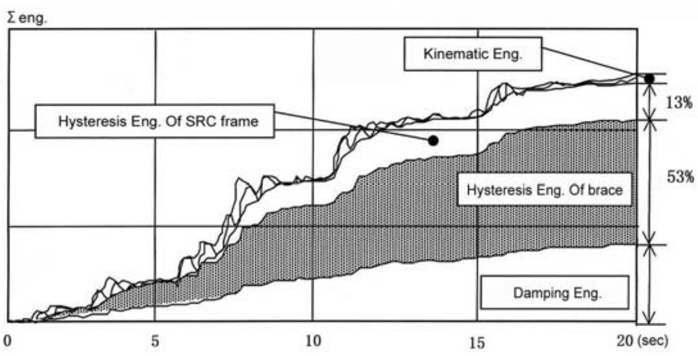


Figure 6 Time history of energy response

Data

Building name: Shizuoka Prefectural Office East Building
Location: Otte-cho, Shizuoka City, Shizuoka Prefecture
Use: Prefectural office building

Outline of the building before the retrofit:

Designer: Nikken Sekkei Ltd.
Constructor: Shimizu Corporation
Building area: 1,582 m^2
Total floor area: 25,159 m^2
No. of stories: 16 above ground and one-level basement
Height: 64.55 m
Type of structure: SRC moment-resisting frame
Type of foundation: Spread foundation
Completed in: May 1970

Outline of the building after the retrofit:

Reinforcement designer: Nikken Sekkei Ltd.
Constructor: JV of Shimizu Corporation and Hirai Kogyo Co., Ltd.
Work period: August 1997 to May 1999

4. Example of base isolation retrofit (1)

4.1 Background of the retrofit

The building of brick work constructed in 1920 is a symbolic building among the brick buildings at the Ikebukuro Campus of Rikkyo University as well as designated as a historic architecture in Tokyo.

The construction work of the building was suspended when the brick walls around the chapel, 11 m by 28 m in a plane, were built to a height of about 3 m. Thereafter RC walls were added on top of the brick wall but the interface between the brick and RC walls was not reinforced.

The hip roof was of such construction that roof boards were laid on wooden roof trusses. The RC foundation was laid out under the peripheral walls of the chapel and supported by the loam layer. The first floor was a slab on grade.

Thereafter, an anteroom and a pipe organ machine room were added in the chapel, and the second floor auditorium was added at the back of the chapel. These additions were not structurally integrated with the chapel.

A committee was established in 1996 to study the six buildings of brick work in the campus. Based on the results of surveys of building bodies and material tests, the earthquake resistance of the buildings was evaluated. The results of the evaluation indicated that the peripheral walls of the chapel having discontinuous interface and roof surfaces small in horizontal rigidity would undergo out-of-plane deformations ,and collapse and that the building would be damaged from impact of the additional rooms in the chapel. The need for retrofitting the building was pointed out.

4.2 Outline of the retrofit design

The University requested that both internal and external appearances of the chapel be preserved as much as possible.

The following two reinforcement plans were studied comparatively: reinforcement of the superstructure; and base isolation plus the reinforcement of the superstructure. The results of the study indicated that the target earthquake-resistant safety of the existing building can be ensured by either of the plans and there is no large difference between the two in terms of work period or cost effectiveness. In the final analysis, the base isolation capable of minimizing the reinforcement of the superstructure as well as the effects on both interior and exterior appearances was adopted. (See Figs. 7 and 8)

The important point in base-isolating the building was how to add a high base-isolation performance to the building light in weight, about 1,000 tons, which is distributed unevenly in a plane. Taking into account the durability of bearings in the semi-outdoor space on the base isolation floor, laminated natural rubber bearings (500 mm and 600 mm in diameter) and lead dampers were adopted. The dampers were installed separately from the bearings and the layout of the bearings was adjusted to effectively control torsional vibrations resulting from the unevenly distributed weight of the superstructure. The existing slab on grade was removed and large and thick RC slab was constructed to increase the weight of the building as well as lengthen the period of vibrations of the base-isolated building

For the reinforcement of the superstructure, braces in the same color as the wooden trusses were installed to increase the horizontal rigidity of the roof surfaces [1]. The discontinuous sections of walls and peripheral buttresses were reinforced ([2] and [3]). The chapel was integrated with the anteroom and second floor auditorium ([4] and [5]). A finishing touch was added to the sections [2] to [5] to make the reinforced and integrated parts inconspicuous. Fig. 9 shows the outline of the reinforcement.

The target earthquake-resistant performances of the building were set as follows: the building should sustain no damage in the event of Level 1 earthquake (at the maximum velocity of 25 cm/s), and local damage to the building is permitted but major damage should be avoided in the event of Level 2 earthquake (at the maximum velocity of 50 cm/s.)

The design earthquake load acting on the superstructure was set to satisfy most of the responses in the event of Level 2 earthquake. Under this design earthquake load, a study was made of the building using a 3D model that took into account the deformations of the roof and walls, and it was confirmed that stresses induced in the existing and reinforced building sections were within the short-term allowable stresses. The safety of the building obtained from the study was such that the building would sustain almost no damage in the event of Level 2 earthquake, which was higher than targeted.

Figure 7 Exterior after the retrofit

Figure 8 Interior after the retrofit

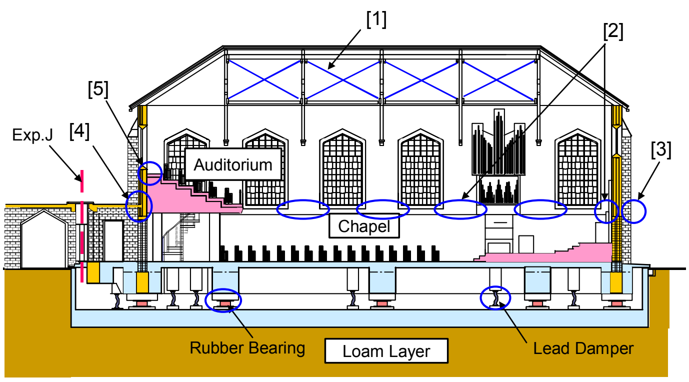


Figure 9 Reinforcement for the superstructure

4.3 Outline of the retrofit

There are many cases where temporary piles are constructed to support the weight of a building when installing a new foundation under the building for base isolation retrofitting. For this project, however, a construction method that eliminated temporary piles was adopted to limit construction cost increase. The new footing was constructed on an area-by-area basis so that the building is always supported on either of the new or old bearing layer. This was a safe measure taken to be prepared for earthquakes during construction.

The construction work was carried out in the following six steps.

(1) The floor was removed and excavation was carried out to the existing foundation bottom level.
(2) Reinforcing beams were installed at the side of existing foundation and footing beams.
(3) Existing foundation and reinforcing beams were tighted toghther by prestressing steel bars.
(4) Excavation was carried out to the bottom level of the new foundation, mat slab was constructed, and laminated rubber bearings were installed (on an area-by-area basis.)

(5) Dampers were installed, and peripheral retaining walls and first floor were constructed.
(6) Peripheral slab was constructed and backfilled.

Data

Building name: Rikkyo University Chapel
Location: Nishi Ikebukuro, Toshima-ku, Tokyo
Use: Chapel

Outline of the building before the retrofit:
Designer: MURPHY & DANA ARCHITECT
Constructor: Shimizu Gumi (present Shimizu Corporation)
Building area: 421 m^2
Total floor area: 505 m^2
No. of stories: 1 and partly 3 above ground
Height: 12.6 m
Type of structure: Brick wall, partly reinforced concrete structure
Type of foundation: Spread foundation and continuous footing
Completed in: 1920

Outline of the building after the retrofit:
Reinforcement designer: Nikken Sekkei Ltd.
Constructor: Obayashi Corporation
Work period: May 1998 to January 1999

5. Example of base isolation retrofit (2)

5.1 Background of the retrofit

The Phase I work (brick work) of the existing building was completed as the former Imperial Library in 1906, and the Phase II work (RC structure) of the extension was completed in 1929. The building with interior and exterior finishes of western design is designated as a historic architecture in Tokyo.

Several structural investigations have been performed in order to check the safety of the existing structural elements. The existing building was analyzed using both static and dynamic methods. It was determined that the brick walls would crack under moderate earthquakes with seismic scale values of 4 to 5 and that significant damages would be incurred under large earthquakes with seismic scale values of 6 to 7. Also it was estimated that the wood trusses could not provide enough constraint for out-of-plane bending at the top of the brick walls. Furthermore the separate brick and concrete structures could detach and move differently, because they were not stiffly tied together with an asphalt membrane.

A seismic reinforcing scheme was requested to preserve the original architectural design. Standard seismic bracing could have ruined both the interior and the exterior design. It was decided that a base isolation retrofit system was suitable for the project, because such a system would minimize the bracing required above the isolation interface. The system has advantages in terms of the construction in addition to being economical. There is a dry area around the building, which could adequately be converted into an isolation gap, and because the basement is not a historically valuable space, it could easily be converted to an isolation interface with its low (2.7m) story height.

5.2 Outline of the retrofit design

The structure consists of two parts, one above and one under the base isolation interface. Several mechanical rooms are located under the interface, while the rest are above it. The upper portion consists of six sub-portions including the existing brick structure, the existing concrete structure, two new concrete cores, and two steel and glass tubes (See Fig. 12).

Each has a different lateral stiffness and is tied to others with concrete slabs, which act as diaphragms. The slab on the first floor is especially important in this respect, so that the existing non-reinforced slab in the brick portion was replaced.

The brick portion of the structure has a bearing wall system. Concrete beams were set on the first floor on the both sides of the brick walls. These beams transfer uniform axial loads from the brick walls to the rubber bearings. The concrete beams and the brick wall are tied together with high strength rods.Concrete grade beams (continuous footings) are designed in order to distribute the concentrated loads from the rubber bearings to the existing non-reinforced concrete foundation. The building has high stress natural rubber bearings (600 mm and 700 mm in diameter) and lead dampers in its isolation interface. The locations of the bearings are coordinated with the design of the beams supporting the brick walls and the columns in the existing concrete structure (See Fig. 13).

The largest seismic bracing for the upper existing structure is a horizontal truss at the top of the brick walls that acts as a constraint for out-of-plain deformation. The top of the wall ends above the ceiling of the third floor and steel pieces for the truss were carried and set by hand at the lower chord level of the existing wood trusses thereby preserving the ceiling decoration.

In the expansion scheme, two steel and glass tubes are designed as if they are penetrating through the existing portion. In these tubes, 50mm thick steel plate mullions on the glass wall are braced by high strength rods and support floors and atriums. Most of the mullions are made of fire resisting steel without fireproofing. Pretension introduced to the high strength rods was high enough not to turn to compression with heat expansion in the case of fire (See Fig. 14).

The seismic behavior of the building was analyzed with various combinations of seismic loads, properties of the bearings and the dampers, and analysis models of the upper portion. The result of the analysis confirmed the safety of the design and satisfied the design criteria. The ultimate lateral strength of the building was also checked.

Figure 10 Main entrance elevation after the retrofit

Figure 11 Courtyard elevation after the retrofit

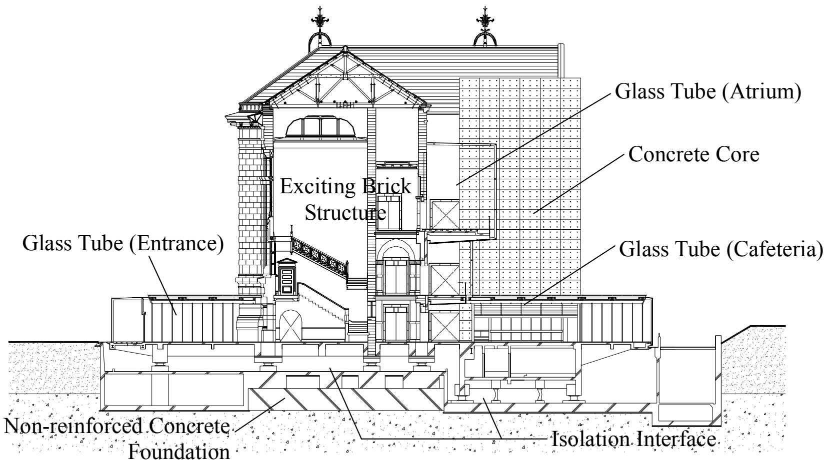


Figure 12 Section after the retrofit

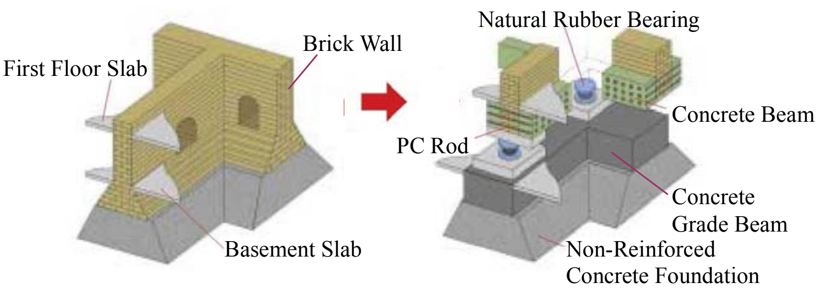


Figure 13 Constructions for the base isolation

Figure 14 Steel plate column-mullion

5.3 Outline of the retrofit

The base isolation interface was constructed in two phases. In the first phase, bearings and dampers were installed under the existing concrete portion. The existing brick wall at the basement was rebuilt as the isolation space in three steps. This step-by-step construction was economical, but also time consuming. In the latter phase, the brick wall in the basement under the brick portion was replaced at once in order to save construction time. The procedure was as follows:

(1)First floor concrete beams were set beside brick walls and tied together with high strength rods.

(2)The brick walls were partially demolished and removed under the concrete beams between bearing locations.

(3)The non-reinforced concrete foundation was set for the rest of areas.

(4)The temporary jack supports under the composed beams were set and jacked up to support the building. The rest of the brick walls and foundations were removed.

(5)The concrete grade beams and foundations for bearings were built and then the bearings and foundations were set above them.

(6)The jack supports were removed leaving the bearings to support the building entirely.

(7)The lead dampers were then set.

In order to avoid any damage during the construction and to provide sufficient safety, a system was created to constantly measure vertical displacements of each columns. The system automatically controls the forces of the oil jack supports and minimizes the deformation of the building.

Steel rings were placed at each bearing and horizontal bracing in the dry area to provide the lateral constraint for the isolation interface. The building had enough seismic capacity for the 0.2g level during construction.

Data

Building name: International Library of Children's Literature
Location: Ueno Koen, Taito-ku, Tokyo
Use: Library

Outline of the building before the retrofit:
Designer: Ministry of Education, Masamichi KURU & Hideo MAMIZU
Constructor: Work under direct management of the Ministry of Education (Phase I), Konoike Construction Co., Ltd. (Phase II)
Type of structure: Brick wall and reinforced concrete frame
Type of foundation: Rubble concrete foundation and brick continuous footing
Completed in: 1906 (Phase I), 1929 (Phase II)

Outline of the building after the retrofit:
Retrofit designer: Tadao Ando Architect & Associates and Nikken Sekkei Ltd.
Constructor: Konoike Construction Co., Ltd.
Building area: 1,930 m^2
Total floor area: 6,672 m^2
No. of stories: 4 above ground, one-level basement, and 7-story stack room
Height: 26.26 m
Work period: March 1998 to March 2002

6. Conclusion

This paper presented examples of seismic vibration control retrofit of building that attained higher earthquake-resistant performance than targeted in the design phase, and the example base isolation retrofits of historic architecture to meet the earthquake-resistant safety requirements under the law. It is said that seismic engineering is empirical engineering. Taking into account lessons learned from the damages caused by earthquakes, earthquake-resistant design is reviewed on a case-by-case basis. In order to limit damage caused when an earthquake strikes, the earthquake-resistance safety of not only newly-built but also existing buildings need to be maintained and upgraded. There are many restrictions on the earthquake-resistant retrofit of existing buildings, such as cost effectiveness, short work period, reinforce of buildings in use, and preservation of architectural design. It is of primary importance in the earthquake-resistant retrofit design to find an optimum solution under these restrictions. The authors shall be pleased if this paper will be useful for finding a solution.