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Nikken Sekkei Vibration-Controlled/Seismic-Isolated Building Design

Working with Clients to Create Reliable Buildings

NIKKEN SEKKEI LTD
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Proposing Appropriate Seismic Safety Measures to Meet Client Needs

- Seismic-resistant structures resist earthquakes by means of the strength and stiffness of the building. In contrast, vibration-controlled and seismic-isolated structures absorb seismic energy to reduce building damage.
- Nikken proposes appropriate measures tailored to each building, based on wide-ranging data (from soil analysis and earthquakes to damping and base-isolation materials) and a wealth of experience and achievements.
- The design is "performance-based" (in which products and manufacturers are not specified), using the principle of competition among manufacturers to reduce costs.

Degree of damage

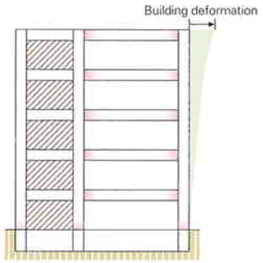
None | Slight | Moderate | Great

Notations

DAMAGE ··· Extent of building damage
RESTORATION ··· Restoration of building earthquake-resistance
SHAKE ··· Severity of building shake
DEFORMATION ··· Deformation of building itself
COST ··· Building cost
FLEXIBILITY ··· Degree of freedom in building planning
● ··· Excellent
■ ··· Good
▲ ··· Slightly poor

Seismic-Resistant structure

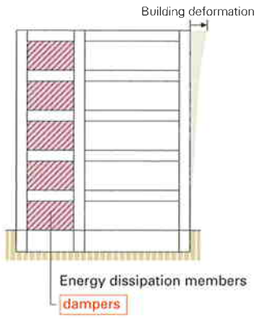
Resists earthquakes by means of building stiffness and strength



DAMAGE ▲ Damage might occur in the main skeleton (columns, girders, walls) in case of a major earthquake.
RESTORATION ▲ In the event of a major earthquake, a building-wide evaluation of the extent of damage is conducted and repairs are implemented to the greatest extent possible.
SHAKE ▲ Building shake is greater compared with vibration-controlled and seismic-isolated structures.
DEFORMATION ▲ Story drift in the building is greater than in vibration-controlled or seismic-isolated structures.
COST ● Economical cost-setting to match the seismic-resistance grade is possible.
FLEXIBILITY ▲ In order to reduce costs, it is important to maintain balance when placing walls, etc.

Vibratin-Controlled structure

Energy dissipation members (dampers) placed in the building absorb seismic energy



The dampers absorb seismic energy,reducing building shake. They can also reduce shake caused by strong winds.

DAMAGE ● The dampers absorb seismic energy, preventing damage to the main skeleton that supports the building weight. In the event of a major earthquake, by using these dampers, zero damage to the main skeleton is possible.
RESTORATION ● In general, the dampers do not need to be replaced even after a major earthquake. However, the extent of damage is evaluated, and if there is a reduction in performance in any of the members, these members are repaired or replaced. In this way, the building status prior to the major earthquake can be restored.
SHAKE ■ Vibration-controlled buildings experience less shake than seismic-resistant structures in the event of strong winds or earthquakes.
DEFORMATION ■ The dampers ensure that the building sustains less story drift than in case of a seismic-resistant structure.
COST ■ The dampers account for a small percentage of construction costs, providing cost efficient high seismic-resistant performance.
FLEXIBILITY ▲ Floor planning that enables appropriate placement of dampers is important.

Examples of vibration-control members

Buckling-restrained brace

Damping wall

Damping stud

Oil damper

Examples of vibration-controlled buildings

Government office

Saitama Regional City Common Building

Office building

Midland Square

Hotel

Hotel Keihan Universal City

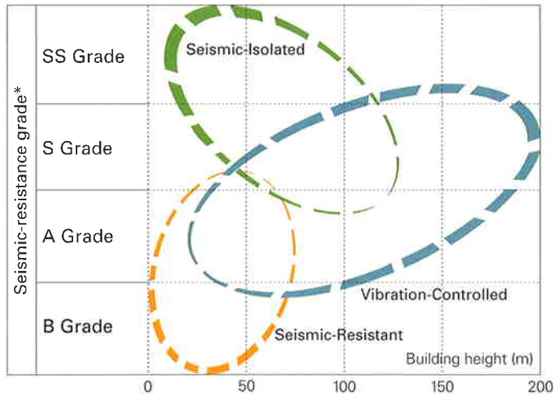
Apartment building

Roppongi Hills Residence Building (Nikken Housing System)

Structures Using Energy Dissipation and Seismic-Isolation Technologies are Safer and More Secure.

- Structures with energy dissipation reduce the violent shake and building deformation sustained by seismic-resistant structures.
- Seismic-isolated structures sway in a wide, gentle shake in the event of an earthquake. This helps prevent furniture and fixtures from toppling and being damaged, preserving building functions.

Seismic-resistance grades and structural types



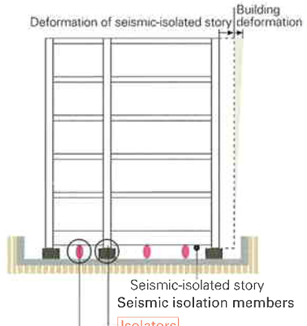
- Vibration-controlled and seismic-isolated structures are effective when a high seismic-resistance grade is needed.
- Use of energy dissipation system is an efficient design method for slender high-rise buildings.
- For medium and low-rise buildings, seismic-isolated structures offer the least shake.

- In addition to the seismic-resistance grade needed for the building, the individual building conditions, site, ground conditions and so on are important points when selecting the structural type.

* For a detailed discussion of seismic-resistance grades, see the separate pamphlet entitled "Nikken's Seismic-Resistant Design"

Vibration-controlled structure

The building "floats" on isolators and dampers "absorb" seismic energy



The isolators support the building weight and move gently in the horizontal direction. They also return the building to its original position.

The dampers absorb seismic energy and prevent shake. They also function to prevent shake of the buiiding due to strong winds.

DAMAGE ● The dampers in the seismic-isolated story absorb seismic energy and prevent the building from sustaining damage.
RESTORATION ● In general, the dampers do not need to be replaced even after a major earthquake. However, the extent of damage is evaluated, and if there is a reduction in performance in any of the members, these members are repaired or replaced. In this way, the building status prior to the major earthquake can be restored.
SHAKE ● Seismic-isolated buildings experience less shake than seismic-resistant and vibration-controlled structures.
DEFORMATION ▲ The seismic-isolated story must track deformation of several dozen centimeters. This floor can be used as a parking area, etc.
DEFORMATION ● The building sustains less story drift than in case of seismic-resistant and vibration-controlled structures.
COST ▲ Initial building costs are slightly higher, but this type of structure is most economical in achieving a high seismic-resistance grade.
FLEXIBILITY ● This type of structure provides great latitude in floor planning.

Examples of seismic-isolation members

Rubber bearing

Sliding bearing

Lead damper

Steel bar damper

Examples of seismic-isolated buildings

Hospital

Otsu Municipal Hospital

Art museum

Pola Art Museum

Computer center

Mitsui Sumitomo Insurance Chiba New Town Center

Complex of Hotel & Office (Middle story seismic-Isolation)

Shiodome Sumitomo Building

Nikken's Vibration-Controlled Buildings

Damage control and coupled vibration control for large office complex

Harumi Island Triton Square

The design has energy dissipation members placed around the perimeter of the building to protect the columns and beams, which support the building weight, from damagein the event of a major earthquake. Furthermore, the three buildings located adjacent to one another are also connected by a damping system, improving living comfort with respect to wind sway.
The damping system is activated automatically by computer control in the event of strong winds. This system controls the relative movement of the two buildings in order to reduce shake.

Improved seismic resistance for existing government buildings in preparation for a possible Tokai Earthquake (vibration-control retrofitting)

Shizuoka Prefectural Government Office, East Building Shear Panels Made of Low Yield Point Steel

It is predicted that a major earthquake is likely to occur in the Tokai region. To enable the Shizuoka Prefectural Government Office to function as the disaster control center in the event of such an earthquake, this building —constructed in 1970 as the first high-rise prefectural government office building in Japan—has been retrofitted with damping braces. These damping braces were placed around the perimeter of the building, so they also provided the building with a new appearance. Another notable feature of this project was that the building open during the retrofitting process without inconveniencing the building users.

Shear panels made of ow yield point steel

Nissei Shin-Osaka Building

The energy dissipation members and bearing walls placed in the space of the buildings created an interior space with few columns, providing great latitude in terms of interior design. The energy dissipation members were shear yield type panels built into brace frames. These panels were placed efficiently from top to bottom at both ends of the building.

Improved earthquake resistance provided by the combination of two types of energy dissipation members

Nikken Tokyo Building

Nikken Tokyo building (completed in March 2003) also uses energy dissipation system. Buckling-restrained braces made of low yield point steel were combined with viscous damping walls to achieve wide-ranging effectiveness, from safety in the event of a major earthquake to comfort during strong winds.

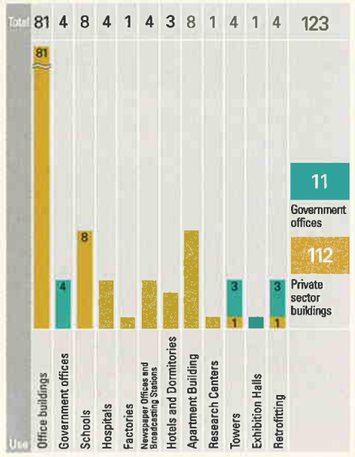
Energy dissipation members used as part of building design

IK Building

Buckling-restrained braces were placed around the perimeter of the building as energy dissipation members, and these members were actively used as a main part of the building design. The outer skeleton alone is able to resist earthquake force, so that fewer columns were needed in the interior and beam depth could be reduced. This makes it possible to create an office space with high ceilings and great latitude in terms of interior design.

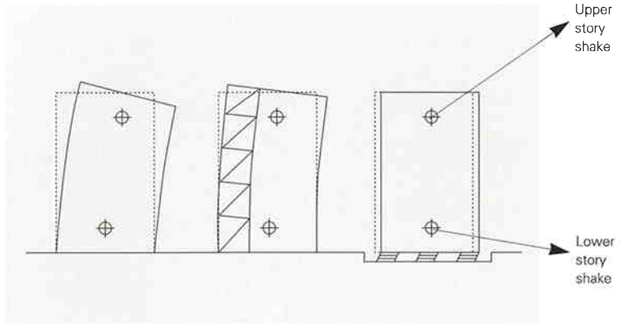
Nikken's Achievements in Vibration-Controlled Buildings

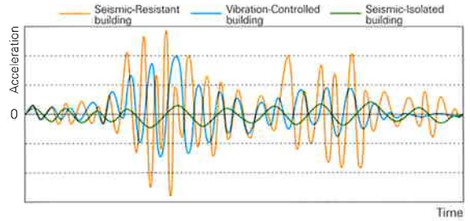
As of December 2006

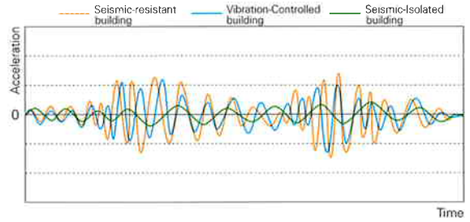


Effectiveness in Reducing Shake in the Event of a Major Earthquake

- The level of shake depends on the structural type and whether the story is an upper or lower story.
- A seismic-isolated building has the least shake on both upper and lower floors.







Seismic-Resistant Building
Both upper and lower stories shake violently at short, rapid intervals. The intensity of shake increases on the higher stories.

Vibration-Controlled Building
The intensity of shake increases on the higher stories, but the extent of shake is less than that of seismic resistant building.

Seismic-Isolated Building
The entire building shakes slowly, and the intensity of shake is low. There is almost no difference between upper and lower stories in terms of the manner of shake.

* The horizontal axis (time) indicates the progress of building shake during an earthquake.
* The vertical axis (acceleration) indicates the severity of the shake.
* The two graphs above show the shake on upper and lower stories, respectively, during the same earthquake.

Guide to Vibration-Controlled and Seismic-Isolated Structures and Their Relationship to Seismic-Resistance Grades

- With vibration-controlled structures or seismic-isolated structures, high seismic-resistant performance can be secured easily.

Seismic-resistance grade*	Medium Intensity Earthquake • Level of earthquake movement that is expected to occur several times during the building's service life • Approximately equal to Level 4–low 5 on the Japanese scale of earthquake intensity • Probability of occurrence during a 50-year period: approximately 80%	Major Earthquake • Level of earthquake movement which may occur once during the building's service life • Approximately equal to Level 6 on the Japanese scale of earthquake intensity • Probability of occurrence during a 50-year period: approximately 10%	Seismic-Resistant Building	Vibration-Controlled Building	Seismic-Isolated Building	Applicable Building Type
SS Grade	As arranged	As arranged				Nuclear power facilities and other buildings for which special care is needed
S Grade	Functions are maintained (no damage)	Major functions are ensured (minor damage)				Disaster mitigation centers, major hospitals and other buildings whose functions must be maintained after an earthquake
A Grade	Functions are maintained (no damage)	Limited functions are ensured (minor damage)				General hospitals, evacuation facilities, computer centers, head office, and other buildings for which earthquake damage must be minimized
B Grade	Major functions are ensured (minor damage)	Human life is protected (moderate damage)				General buildings that can accommodate a certain degree of earthquake damage

* For a detailed discussion of seismic-resistance grades, see the separate pamphlet entitled "Nikken's Seismic-Resistant Design."

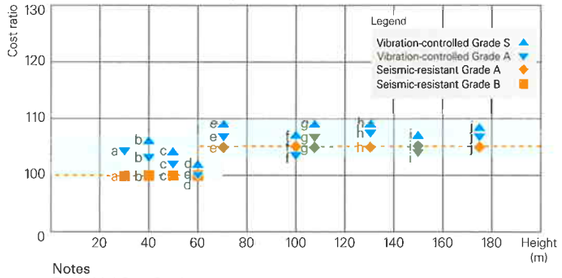
Economic Advantages of Vibration-Controlled and Seismic-Isolated Buildings

Building height and initial construction costs

Vibration-Controlled structure

- Although the use of a vibration-controlled structure increases costs by approximately 0–6%, a higher seismic-resistant grade can be attained (including non-structural members and equipment).
- Damping reduces seismic force, resulting in decreased costs of the main skeleton.

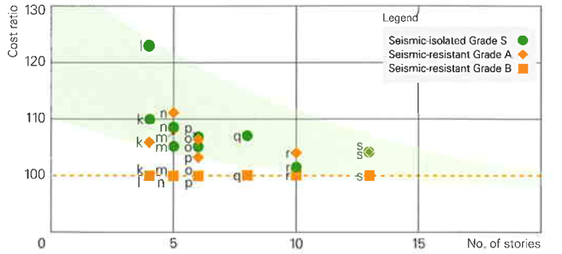
Notes
The Initial Cost Study
* Based on 10 vibration-controlled buildings designed by Nikken (indicated by a–j), trial designs were developed for thre e structural types (Grade S vibration-controlled structure, Grade A vibration-controlled structure and seismic-resistant structure) and the initial construction costs were calculated.
* Buildings exceeding 60 m in height are treated differently under the law. In general, Grade A is the lowest grade required.
* The comparison was conducted with a Grade B seismic-resistant structure 60 m in height or less as 100 and a Grade A seismic-resistant structure more than 60 m in height as 105.



Seismic-isolated structure

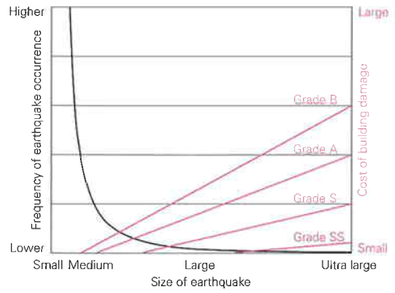
- Use of a seismic-isolated structure will increase costs by several % to approximately 30% as compared to a Grade B seismic-resistant building. The ratio, however, decreases as the number of stories increases.
- In case of a medium-rise or high-rise building, the main structure can be changed from steel-reinforced concrete to reinforced concrete, enabling high seismic performance to be achieved more economically than with a seismic-resistant structure.
- In case of a low-rise seismic-isolated structure, the costs of the construction of the seismic-isolation story, seismic-isolation members, and expansion joints constitute a large proportion of construction costs, making the building comparatively expensive.

Notes
The Initial Cost Study
* Based on 9 vibration-controlled buildings designed by Nikken (indicated by k–s), trial design of seismic-isolated structures was conducted for three structural types (Grade S seismic-isolated structure, Grade A seismic-resistant structure, and Grade B seismic-resistant structure).
* The comparison was conducted with a Grade B seismic-resistant structure as 100.



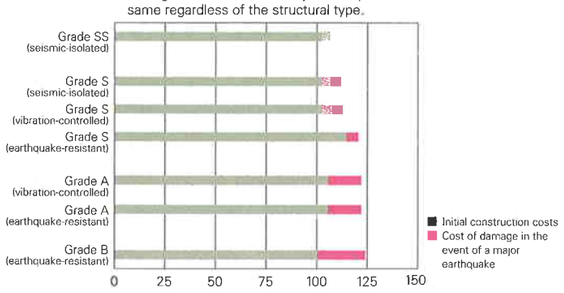
Initial construction cost and earthquake damage loss

- The building damage cost in the event of an earthquake is lower for buildings with a higher seismic-resistance grade.
- Buildings with a higher seismic-resistance grade can withstand larger earthquakes without sustaining damage.



- Buildings with a high seismic-resistance grade can be achieved economically through the use of a vibration-controlled or seismic-isolated structure.
- The total cost of initial construction costs and the cost of damage in the event of a major earthquake can be kept lower for buildings with a higher seismic-resistance grade.
- Regarding losses other than building damage —for example, suspension of economic activities and losses due to personal injury—buildings with a high seismic-resistance grade are even more advantageous.
- The damage cost can be evaluated through a consideration of the probability of earthquake occurrence.

Notes
* The comparison was conducted with the initial construction costs for a Grade B earthquake-resistant building as 100.
* For buildings with the same seismic-resistance grade, the cost of damage in the event of a major earthquake was assumed to be the same regardless of the structural type.



Nikken's Seismic-Isolated Buildings

A second ground level
at the top of an office building

Iidabashi First Building and First Hills Iidabashi

Located in an area that has long been a combined residential/commercial district this redevelopment project was designed to enable offices,residences, stores and other facilities to co-exist within the same building complex.
A five-story reinforced concrete wall type apartment wing was placed on top of a nine-story steel frame office/retail building. Between the two is a seismic-isolation story, making the structure a middle story seismic-isolated building.
The seismic-isolation design reduces the seismic response not only above the seismic-isolation story but of the bottom structure as well.

Symbolic use of
the seismic-isolation story

Toyo Technical Center

This complex combines testing laboratories for the study of tire properties with researcher offices.
The office wing was placed on top of the laboratory and storeroom wing, and a seismic-isolation story is located between the two. This building is unique in that the seismic-isolation story is actively used as a design element. The upper office wing has a box shape with windows placed in the outer wall at regular intervals.

Use of a seismic-isolated structure to preserve a historical building
(seismic-isolation retrofit)

The International Library of Children's Literature

Officially designated as one of Tokyo's historical buildings, this brick building (formerly the Imperial Library) is preserved and renovated by means of a seismic-isolation structure. As the artistry of both interior and exterior had sustained considerable damage, a seismic-isolation structure at the base was used to protect and reduce the impact of seismic force to the building and the artistry, and to minimize retrofitting.

Seismic-isolation structure designed to
accommodate sequential renovation plans

Yamanashi Prefectural Hospital

This building was planned to ensure a high degree of safety and functionality, so that emergency room and other main hospital functions can be maintained to enable the building to function as the central hospital in Yamanashi in the event of a disaster.
As there was an existing hospital on the site, that facility was divided into two parts in the approximate center. The side that did not obstruct the existing hospital was constructed as Phase 1 (completed June 2002). On the other side, the existing hospital was dismantled and reconstructed in Phase 2.

Central government building
designed to serve as a disaster
mitigation center

Ohbu City Hall

Planned to serve as the central government offices in Ohbu City, Aichi as well as the disaster mitigation center, the building is designed so as to maintain building performance in the event of a major earthquake such as the anticipated Tokai Earthquake and Tonankai Earthquake. The building has an L-shaped planar shape and uses a combination of rubber bearing isolators, lead dampers and steel bar dampers as seismic-isolation members.

Effective use of seismic-isolation stories
for national disaster operations center

Kushiro Regional Joint Government Offices

(Basic design: Building Equipment Division, Hokkaido Development Bureau)

This was the first national joint government office building to use a seismic-isolation structure. Designed to function as an operations center in the event of a disaster, the building uses seismic-isolation members at the column capitals on the first basement floor (B1). The B1 seismic-isolation story is used as a parking area and as a place to stockpile reserves for use in a disaster. As this is a cold region, the dampers and other seismic-isolation members are designed to withstand cold temperatures. (Design: Hokkaido Nikken Sekkei)

Nikken's Achievements in Seismic-Isolated Buildings

As of December 2006