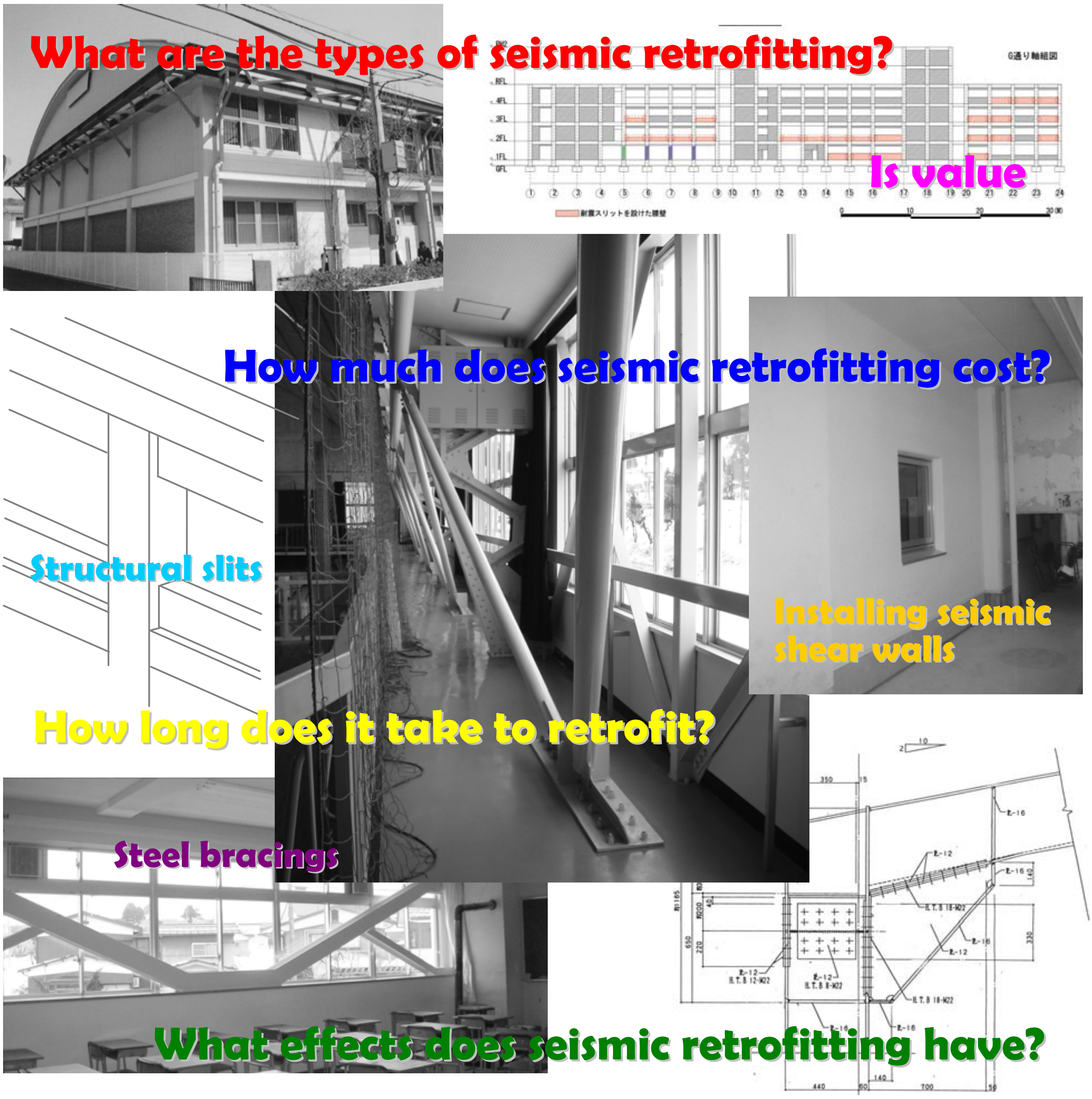
Seismic Retrofitting Quick Reference

School Facilities that Withstand Earthquakes

Examples of Seismic Retrofitting



Ministry of Education, Culture, Sports, Science and Technology

Introduction

In recent years, there have been frequent large earthquakes, such as the 2004 Mid-Niigata Prefecture Earthquake and the 2005 Fukuoka Seihou-oki Earthquake. In our country, there is no knowing when and where such earthquakes could occur.

Improving the seismic resistance of school facilities is a pressing issue, because children spend a large part of their daily lives in school, and schools need to secure the safety of children as well as act as emergency evacuation facilities for local communities when an earthquake occurs.

Therefore, the Ministry of Education, Culture, Sports, Science and Technology has taken measures to promote early application of seismic retrofitting on school facilities by producing the "Guideline for Promoting the Seismic Retrofitting of School Facilities" etc.

Furthermore, there is great demand for the effective, efficient and systematic improvement of school facilities under the tight financial situation of the government and regional authorities. There is a need to study methods for more effective improvements, such as by shifting from the reconstruction of buildings to the seismic retrofitting and refurbishment of buildings in the future.

However, the general public and those in charge of school facilities are usually not acquainted with seismic retrofitting, and there were opinions that it is difficult to imagine what seismic retrofitting is about and how much it would cost.

Therefore, in 2005, the Ministry of Education, Culture, Sports, Science and Technology commissioned the Research Institute of Educational Facilities, the "Investigative research on seismic retrofitting of school facilities" which performed the survey on examples of seismic retrofitting methods that were performed on school facilities throughout Japan.

This quick reference is based on the "Report on the investigative research on seismic retrofitting of school facilities", which was published as a result of the above research, and then, by adding explanations, it was rearranged to make it easier to understand for those who are not specialized in architecture.

It is our hope that this quick reference will contribute in improving the understanding of the importance of seismic retrofitting as well as for further applications of seismic retrofitting.

September 2006

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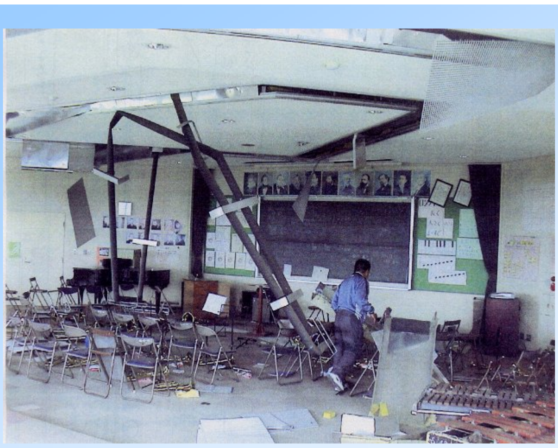
Schools Facilities that Withstand Earthquakes
Examples of seismic retrofitting

Content

South Hyogo Prefecture Earthquake (Kobe Earthquake):
(Seismic Intensity 7) January 17, 1995, 5:45am

Damage to Past Major



Miyagi-oki Earthquake:
(Seismic intensity 6 lower)
May 26, 2003, 6:24pm

North Miyagi Earthquake:
(Seismic intensity 6 lower)
July 26, 2003, 0:13am

Mid Niigata Prefecture Earthquake:

(Seismic intensity 7) October 23, 2004, 5:56pm

Schools by Earthquakes

Fukuoka Seihou-oki Earthquake:

(Seismic Intensity 6 lower) March 20, 2005, 10:53am

Preface

Background Information

- The I_S Values
- Buildings with Seismic Resistance
- Target of Seismic Performance

Background Information 1: The I_S Value

● I_S value

The I_S value (structural seismic performance index) is an index that shows the seismic performance of structures.

The index becomes higher as the (1) strength of the structure against earthquakes, and (2) ductility (deformation capacity) of the structure becomes higher, i.e. the seismic performance becomes higher.

● Obtaining the I_S value

The seismic performance is obtained from the following equation.

$$I_S = E_0 \times S_D \times T$$

E_0: Basic capacity index (The basic seismic performance index of the structure)
>>> The most important index for obtaining the I_S value.
= C (Strength index) × F (Ductility index)

S_D: Structural balance index (The index that considers the non-regularity of plane and elevated shapes)
From a reference value of 1, the value becomes smaller as the structural shape or layout balance becomes irregular.

T : Aging index (Index that considers deterioration with age)
From a reference value of 1, the value becomes smaller as deterioration becomes heavier.

Therefore, structures with;

(1) Low strength and low ductility
(2) Irregular shapes or imbalanced layout
(3) Significant deterioration

⇨ **Low Seismic performance**

The I_S value is obtained through seismic evaluation. The evaluation consists of three evaluation levels, from the first to third levels. The evaluation level to be applied is chosen according to the aim of evaluation and the structural characteristics of the building, but the “strength” and “ductility” are obtained in all levels of evaluation.

● Criteria of I_S value

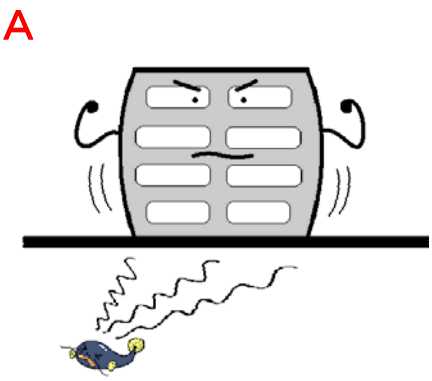
(according to Notification No. 184, Ministry of Land, Infrastructure and Transport, January 25, 2006)

$I_S < 0.3$	there is high risk of collapsing by earthquake
$0.3 \leq I_S < 0.6$	there is potential risk of collapsing by earthquake
$0.6 \leq I_S$	there is low risk of collapsing by earthquake

Considering the safety of children in case of earthquakes and the function of schools as refuge shelters, the Ministry of Education, Culture, Sports, Science and Technology requires that the supplementary requirement for seismic retrofitting of public school facilities, the I_S value, after retrofitting, to be approximately above 0.7.

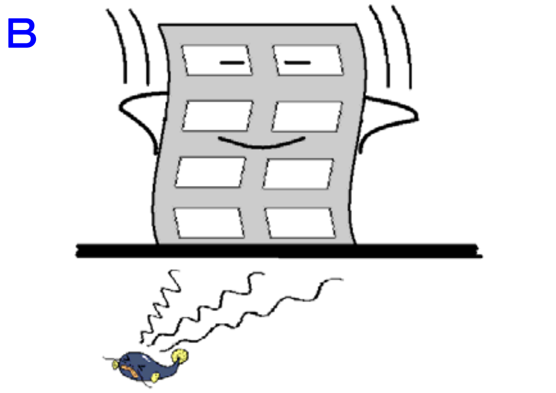
Background Information 2: Buildings with Seismic Resistance

As mentioned previously, the seismic performance of a structure is dictated by strength and ductility.



Structure with high strength, low ductility.

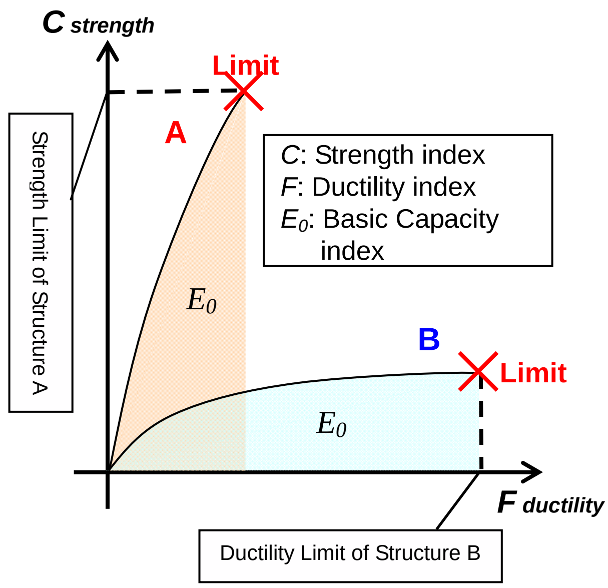
***C* high** ***F* low**



Structure with low strength, high ductility.

***C* low** ***F* high**

A structure with high strength A may appear to be more resistant to earthquakes. However, Structure A lacks ductility, and when the acting force exceeds the limit, the structure would suddenly collapse. On the other hand, the strength of Structure B is low, but the structure shows tenacious resistance before collapsing. Therefore, increasing the seismic performance of structures is possible ***by increasing the strength, such as in Building A, or increasing the ductility of the structure, such as in Building B***. It is not always the case that a structure with higher strength is more resistant to earthquakes. It is important to consider the resistance against earthquakes from two indices; strength and ductility.



Background Information 3: Target of Seismic Performance

The current Building Standard that is in force assumes the following seismic performance.

<u>Moderate size earthquakes (Approximate seismic intensity 5)</u>
Required to prevent damages to buildings

<u>Large scale earthquakes (Approximate seismic intensity 6 to 7)</u>
Required to prevent major damages, such as building collapse, to avoid fatality, although the building sustains partial damages.

Chapter 1

Examples of Seismic Retrofitting and their Performance under Earthquakes

【Outline】

	School name	Outline of structure	Retrofit method	Seismic performance (I_S value)	Project cost Duration of work
School building	Niigata Prefecture Tokamachi Sogo Senior High School	Constructed 1966, 67, 3 story, RC structure, Total floor area: 3,196 m^2	Install steel bracings, Add seismic shear walls, Add wing walls to the extreme brittle short columns.	Before → After x-direction 0.30 → 1.01 y-direction 0.69 → 0.88	173.508 million yen 3 months x 2 years
School building	Niigata Prefecture Tokamachi Senior High School	Constructed 1974, 75, 76, 4 story, RC structure, Total floor area: 5,843 m^2	Install steel bracings, Add slits in spandrel walls, Add seismic shear walls, Steel jacket around columns, Carbon fiber jacket around columns	Before → After x-direction 0.42 → 0.80 y-direction 0.39 → 0.75	343.815 million yen 3 months x 3 years
Gymnasium	Niigata Prefecture Kawaguchi Town Kawaguchi Junior High School	Constructed 1976, 2 story, Steel structure, Total floor area: 1,670 m^2	Install Steel tube bracing	Before → After x-direction 0.08 → 0.73 y-direction 0.70 → 0.70	101.621 million yen 4 months x 1 year
Gymnasium	Miyagi Prefecture Wakuya Town, Wakuya Junior High School	Constructed 1979, 2 story, RC structure, Total floor area: 1,302 m^2	Replace roof panel that had the risk of falling	Before → After x-direction 0.74 → 1.16 y-direction 0.94 → 1.70	154.560 million yen 7 months x 1 year

Note) Project costs are total costs that include costs other than seismic retrofitting work.

Legend
RC: Reinforced concrete structure
Steel: Steel structure
RS: Gymnasiums with RC structure at the lower level and steel structure at upper level.

Retrofitting Structures with Steel Bracings and Seismic Shear Walls

Niigata Prefecture, Tokamachi Sogo Senior High School Number of students: 592 Number of classes: 15

Constructed: 1966, 1967 Structure and number of stories: RC, 3stories Total floor area: 3,196 m^2

After retrofit（outside view）

Steel bracings（diagonal）

After retrofit（Inside view）

Wall girder

Before retrofit（outside view）

installed shear wall

After retrofit

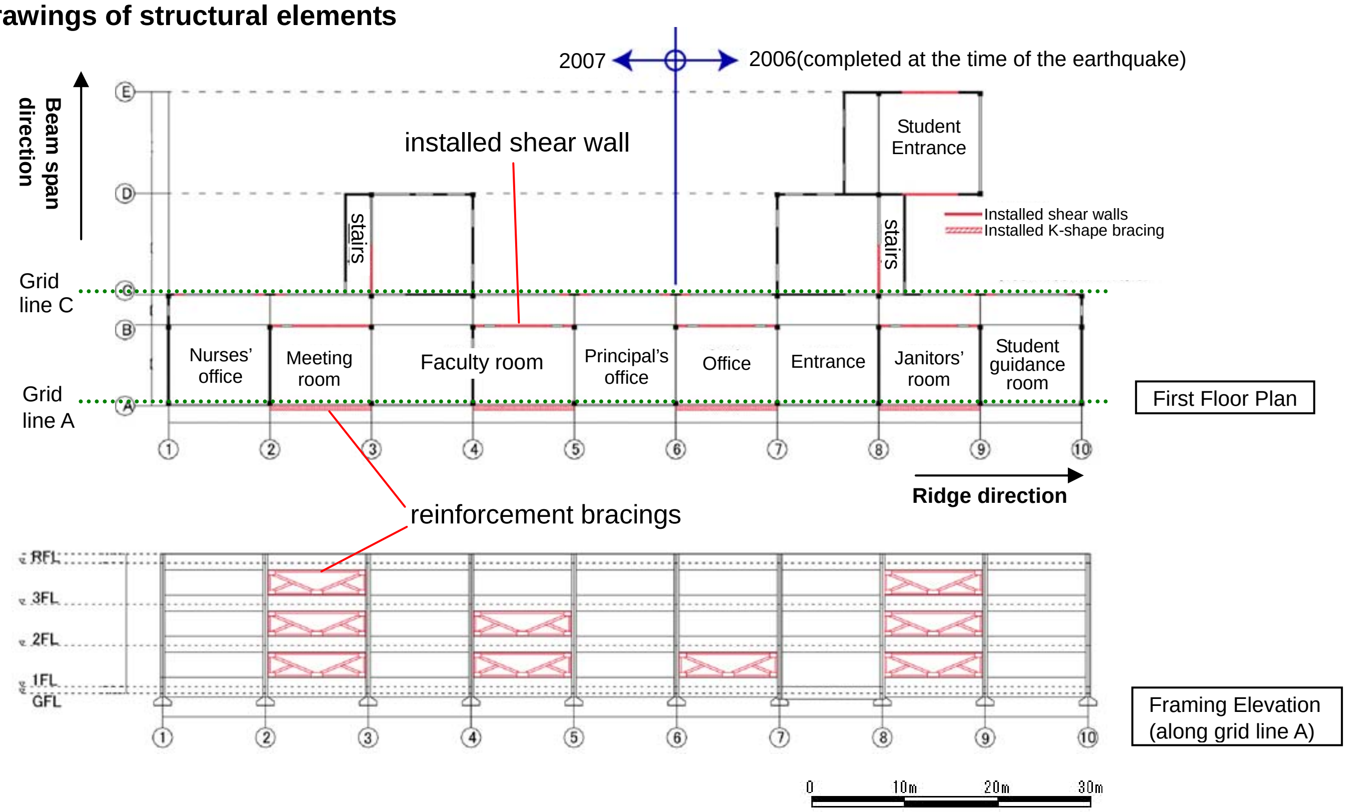
■ Project Outline

Duration	July 2004～December 2005 (3months of 2 years)
Total Cost	173,508,000 yen
Approx. cost of retrofitting	Steel bracings (254,000yen / m^2) RC wall (140,000 / m^2)
I_S Value Before → After	I_{sx}=0.30 → I_{sx}=1.01 I_{sy}=0.69 → I_{sy}=0.88

■ Outline of Seismic Retrofitting Method

The building has two staircases at the west side of the structure. Although shear walls are installed in the ridge direction of the structure, there are wide openings and other multiple openings, and it is assumed that the shear walls are not very effective. The external frame of the structure at both grid lines A and C are wall girders, and the columns along grid line C were extreme short columns[1). From seismic evaluation results, the first and second floors showed I_S values of 0.30 in the ridge direction and the first floor showed I_S values of 0.69 in the span beam direction. Therefore, the planned retrofitting method was to resolve the extreme brittle columns[2) by installing wing walls, sealing openings, and to improve the structure that lacks strength by installing steel bracings at openings and shear walls.

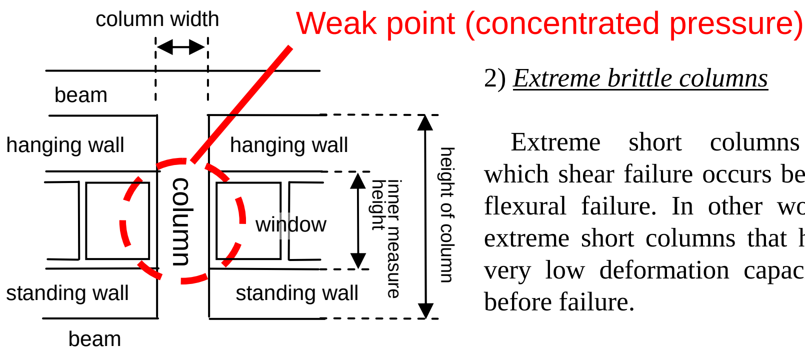
■ Drawings of structural elements



Keyword

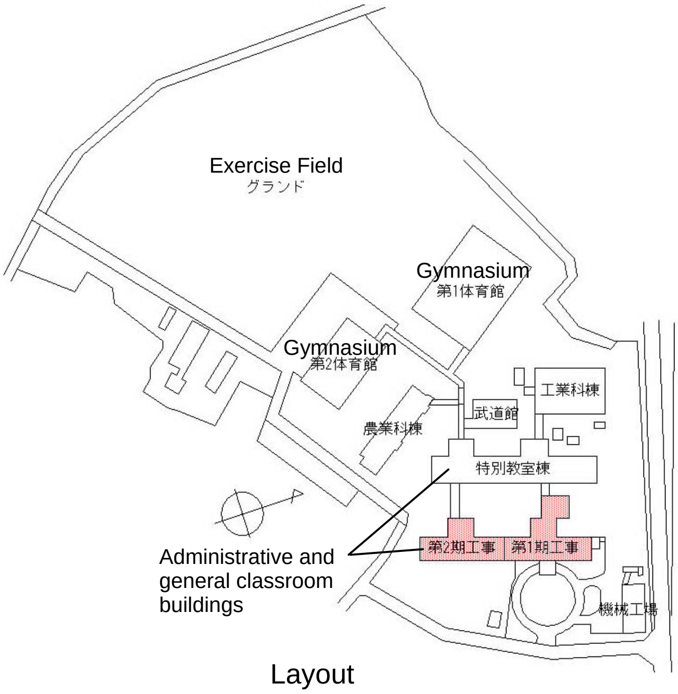
1) *Extreme short columns*

Columns with reduced deformation capacities by having hanging and standing walls attached to an independent column which results in columns having low ratios of less than 2.0 between the width of the column and the inner measurement between retaining and hanging walls.



2) *Extreme brittle columns*

Extreme short columns in which shear failure occurs before flexural failure. In other words, extreme short columns that have very low deformation capacities before failure.



Layout

■ Condition after the Earthquake

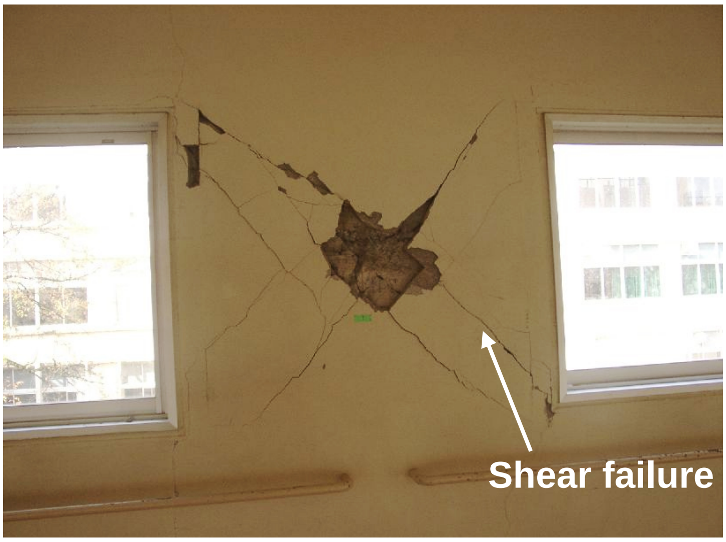


Photo of condition after the earthquake

■ Condition of the Facility

The facility is a reinforced concrete three-story structure for an administrative and general classroom building that was constructed in 1966 and 67. This was designed according to the previous seismic design method and is a rigid frame structure with shear walls installed in the ridge direction (refer to the first floor plan in the structural outline drawing) and in the beam span direction of the structure. The school building has side corridors and is connected to the special classroom building with a connecting corridor. The retrofitting work was performed in two phases of three months each during the year 2004 to 05. By the time the earthquake occurred, the retrofitting at the east side, between grid-lines 6 to 10 (approximately half of the entire structure) had been completed.

Under the above condition, the Mid-Niigata Prefecture Earthquake (seismic intensity 6 lower) occurred in October 23, 2004 and the structure sustained minor damages.

Outline of the Earthquake

Date and time: October 23, 2004, approx. 17:56

Epicenter: Chuetsu region of Niigata Prefecture
(latitude 37° 1.5' north, longitude 138° 52.0' east)

Depth of seismic center: Approximately 13 km

Scale of earthquake: Magnitude 6.8

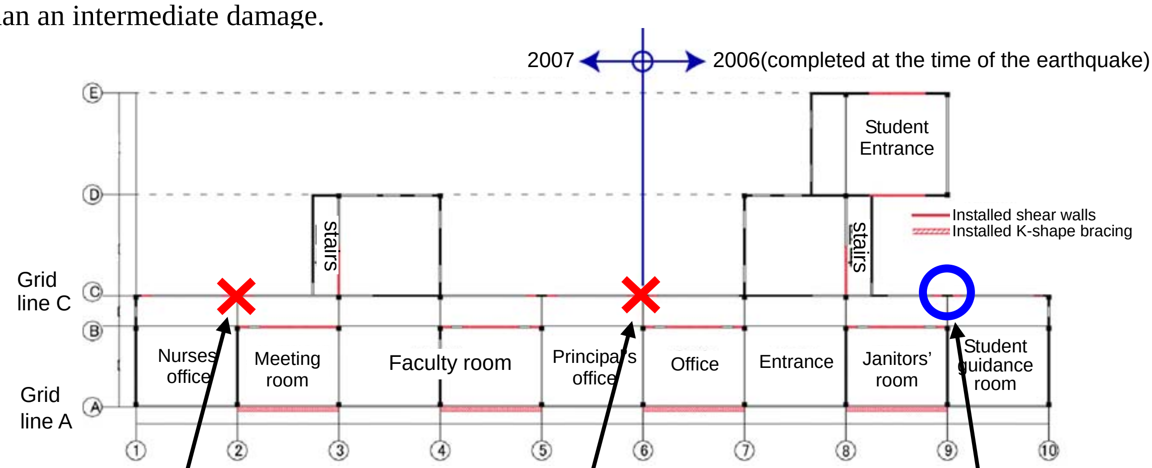
Seismic intensity near the school: 6 lower

The structure of this building had sustained damages from the earthquake. Therefore, investigation of damages and determination of disaster levels were performed after the earthquake. From the investigation, damages on two columns along grid line C at the first floor, and two columns along grid line C at the second floor were identified. The "Photo of condition after the earthquake" shows the damage at the second floor column. These columns had become extreme short columns because of the openings, and showed shear failure[3]. At the first floor, the main reinforcement in the column had buckled.

Along grid lines A and B, the columns showed no damages. At shear walls that were installed at the openings, only minor cracks were observed around the openings. Therefore, it is assumed that the shear wall had effectively resisted the seismic force. Columns that were retrofitted with wing walls showed minor shear cracks, but shear cracks occurred at the wing walls and the vicinity of the wing walls.

At the first floor, the wall column at grid point 2 - C, which was to be retrofitted, sustained shear failure that showed crack widths of about 5 mm. At grid point 6 - C, the wall column at the first floor had wing walls installed on both sides, but at the second and third floor, installations of wing walls were completed only on one side of the column (toward grid line 7) . At the second floor, the retrofitted portion had sustained shear failure. With this column, it is assumed that differences in rigidity at the floors above and below this floor had caused greater deformation at the second floor than at other floors. Retrofitting of the column at grid point 9 - C was completed and had wing walls installed at both sides of the column. At this grid point, cracks were observed at the column and installed wing walls. However, it is assumed that there was no local concentration of stress, and the column and installed wing walls have contributed in resisting the shear force. From these damages, retrofitting zone that installed wing walls on both sides of the column, together with the added effect of installing bracing reinforcements, was effective. The students' impressions during the aftershock showed that classrooms where retrofitting had been completed felt more safe.

From the damage levels according to the determination of disaster levels, assuming the seismic performance before the earthquake as 100%, the seismic performance survival rate in the beam span direction of the structure was calculated as 89.0 to 96.0%. The second floor, which showed the lowest value, the disaster level would be a minor damage. When considering that reduction of seismic performance had been suppressed by seismic retrofitting, if seismic retrofitting was not installed, it is assumed that the damages could have been quite serious and would be more than an intermediate damage.



Not retrofitted	Being retrofitted	Retrofitting Completed
-No wing wall -Shear failure (columns on all floors)	-Wing wall installed on one side of the column (first and second floors) -Shear failure (column on second floor)	-Wing wall installed at both sides of the column (first, second & third floor) - No shear failure, only cracks

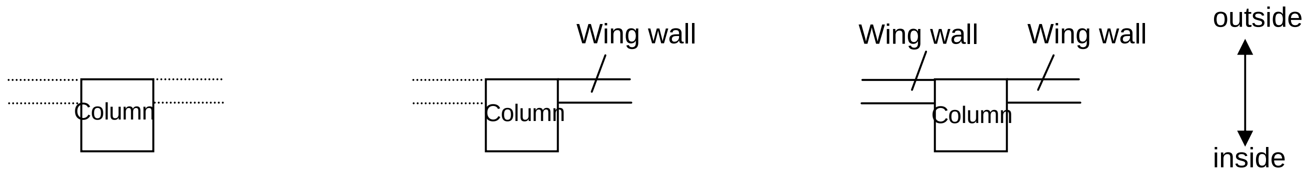
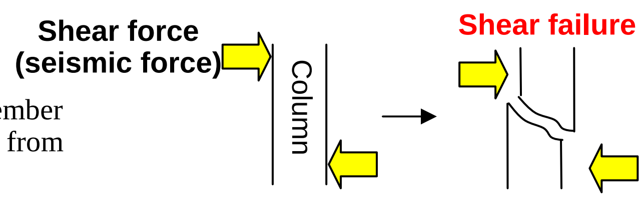


Diagram of view from above

Keyword

3) *Shear failure*

Shear force increases the shear deformation of the member and lead to shear failure. Most often are brittle failures from lack of ductility.



Retrofitting by Installing Steel Bracings and Structural Slits

Niigata Prefecture, Tokamachi Senior High School Number of students: 939 Number of classes: 24

Constructed: 1974, 75, 80 Structure and number of stories: RC, 4 stories Total floor area: 5,843 m^2

After retrofit (outside view)

steel brace

Before retrofit (outside view)

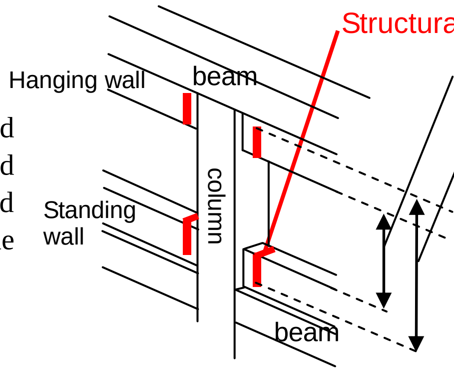
Structural slits[1)]

After retrofit (outside view)

Keyword:

1) *Structural slits*

Slits are gaps that are placed between the spandrel walls and column to prevent failures caused by concentration of strength at the columns during earthquakes.



By installing slits in spandrel walls, the increased inner dimension allows deformation of the column.

■ Project Outline

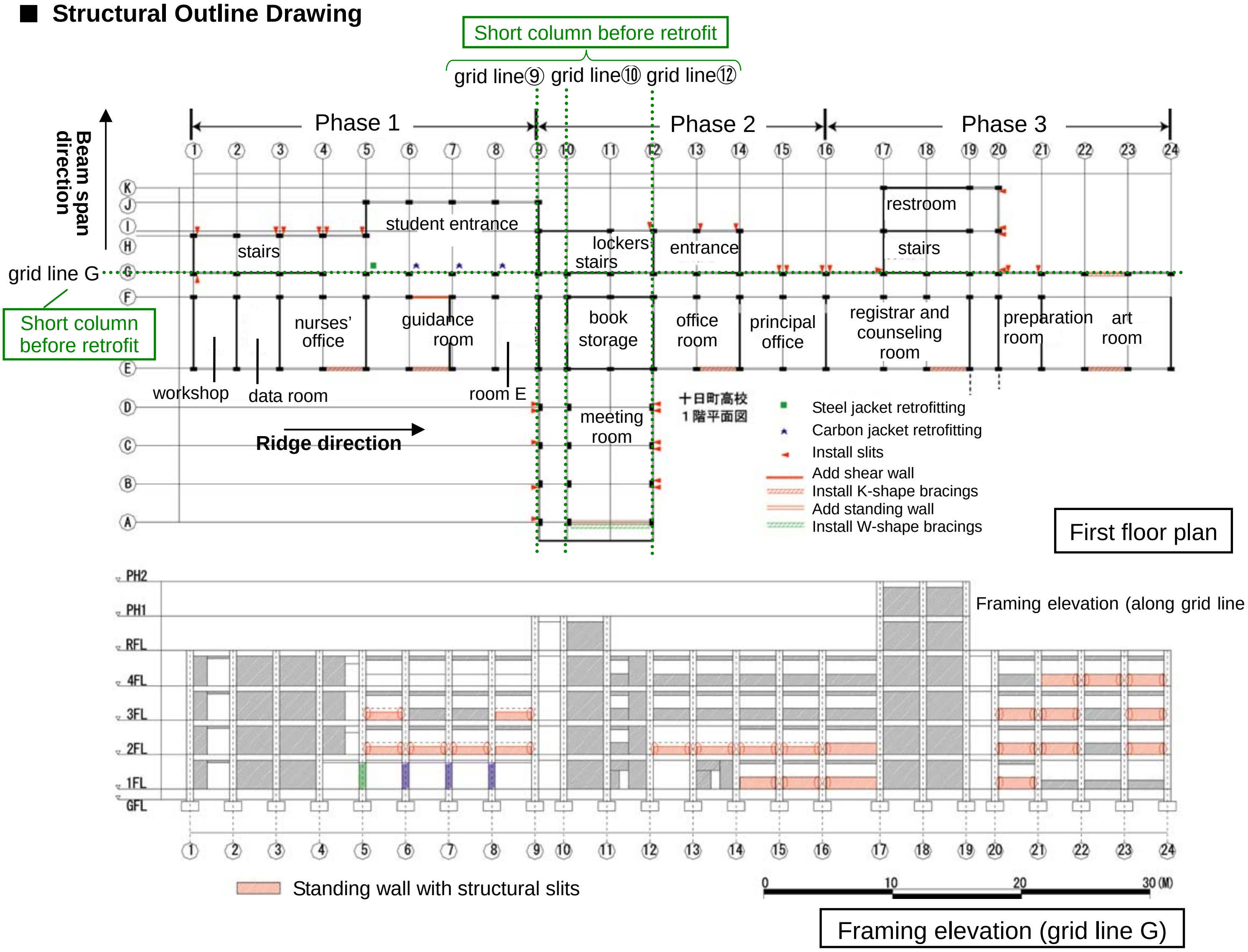
Duration	2003 to 2005 (3 months x 3 years)
Total Cost	343,815,000 yen
Approx. cost of retrofitting	Install steel bracings 125,000 yen/m² Install RC wall 88,000 yen/m² Steel jacket reinforcement of columns 254,000 yen/each Carbon fiber jacket reinforcement of columns 385,000 yen/each
I_S Value Before → After	I_{sx}=0.42 → I_{sx}=0.80 I_{sy}=0.39 → I_{sy}=0.75

■ Outline of the Retrofitting Method

The building has three staircases at the north side, and the plan was to install a specific amount of seismic shear walls that will be effective in the ridge direction of the structure as well. Before retrofitting, the frames in the ridge direction along grid line G and those in the beam span direction along grid lines 9, 10 and 12 had spandrel walls attached to the columns and produced short columns. At the south side, the frames along grid line E are wall girders and also produced short columns. The frames near the east end of the structure along grid line 22 and 23 have span lengths of 10 meters without center posts.

From seismic evaluation results, the first floor showed I_S values of 0.42 in the ridge direction and a value of 0.39 in the beam span direction. Therefore, the planned retrofitting method was to resolve the extreme brittle columns by installing structural slits in spandrel walls, and steel bracings (or shear walls with openings at some locations) to improve the resistance of the structure.

■ Structural Outline Drawing



■ Outline of the Seismic Retrofitting Method

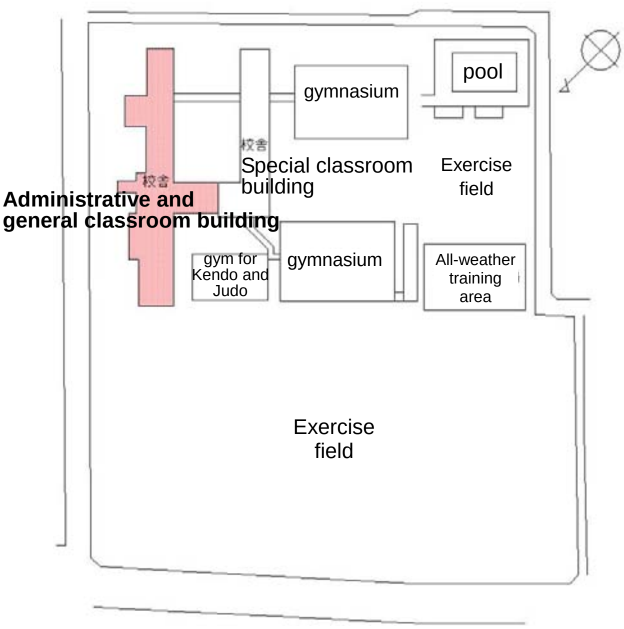
Installing a steel bracing

The retrofitting methods were as follows: new installation of steel bracings; installation of 'structural slits' by placing vertical slits adjacent to columns in standing and hanging walls in each floor; for columns that are structurally important, jacketing columns with carbon fiber; or for soft story columns, wrap with steel plates to reinforce the columns; as well as, installation of additional shear walls with openings to columns (only on the first floor). The new steel bracings are K-shaped and W-shaped bracings. Along grid line A, facing the special classroom building and where it is possible to close all except the doorway, W-shaped steel bracings are installed At other openings that are outward facing and in the ridge direction, the distinctive K-shaped bracings that are angled at almost 45 degrees were installed.

Adding the seismic shear wall

Carbon fiber jacket column reinforcement

Steel jacket column reinforcement



LAYOUT

■ Condition of the Facility

This structure is a 5,952 m^2 administrative and general classroom building constructed in 1974, 75 and 1980. It was designed according to the previous seismic design method and is a rahmen structure with shear walls installed in the ridge direction and in the beam span direction. The school building has side corridors, and seen from the plan, it is connected to the special classroom building. The retrofitting work was performed in three phases during the year 2003 to 05. It was struck by the 2004 Mid-Niigata Prefecture Earthquake when the phase-2 retrofitting was completed, but the damages were minor.

Condition After the Earthquake

Surface cracks after the earthquake

Outline of the Earthquake

Date and time: October 23, 2004, approximately 17:56

Epicenter: Chuetsu region of Niigata Prefecture
(latitude 37° 1.5' north, longitude 138° 52.0' east)

Depth of seismic center: Approximately 13 km

Scale of earthquake: Magnitude 6.8

Seismic intensity near the school: 6 lower

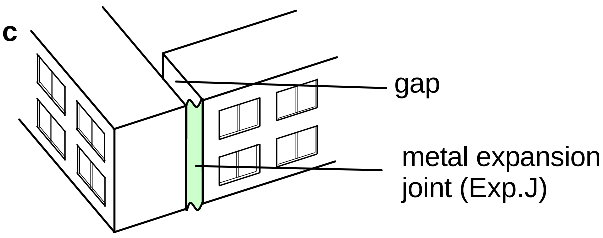
It is assumed that the structure sustained a significantly high maximum acceleration from the earthquake that was equivalent to seismic intensity 6 lower. However, the damage level was minor even when some parts of the retrofit work were not completed. In the building, there were overturned furniture, broken expansion joints[2], and shattered glass. However, in the ridge direction of the structure, damages were minor and only microcracks were observed, apart from the standing wall. Columns along grid line G, where vertical slits were placed at spandrel walls, showed flexural cracks[3] and verified the effectiveness of the slits. Columns that were reinforced by carbon fiber jackets showed significant cracking of the surface finish. Technically, it is assumed that the column had effectively resisted the seismic forces. However, it was difficult for the users to distinguish these cracks from structural cracks and made them feel rather insecure. In the beam span direction, shear cracks[3] were rather significant at the shear walls and corners of openings. Therefore, damages were rather more significant in the beam span direction. This seems to be related to the directionality of the earthquake, which was strong in the north-south direction.

Keyword

2) *Exp.J (Expansion Joint)*

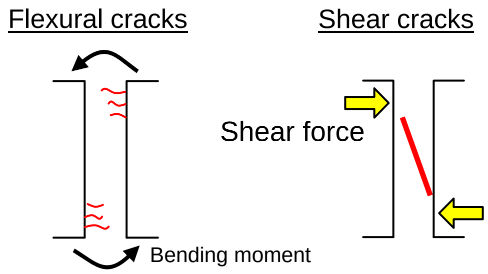
In adjacent structures arranged in an L-shaped layout, or linked with connecting corridors, the structures are constructed with a gap in between the two to avoid concentration of forces from heat expansion and from swaying caused by earthquakes. Expansion joints are metal plates, such as made of aluminum or stainless steel that cover the gap and follow the deformation of structures during earthquakes. This could be likened to the coupler that connects train carriages.

Schematic Drawing



3) *Flexural cracks and shear cracks*

Flexural cracks are relatively minor cracks that occur in members subject to bending moments (distance × force).
However, shear cracks are those that occur in diagonal directions to the axis of members that are subject to shear forces. These lead to shear failures and are dangerous.



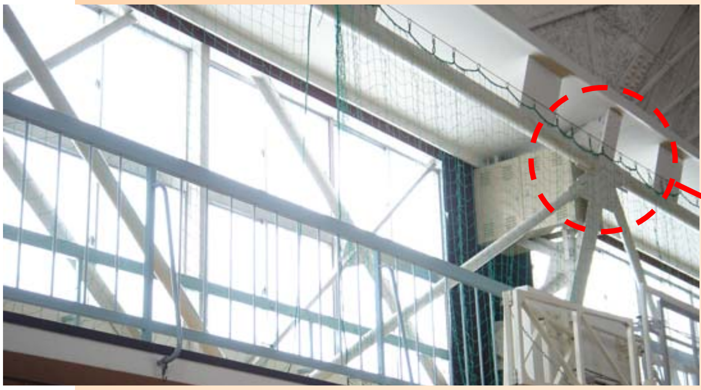
Retrofitting of Structures with Steel Tube Bracings

Niigata Prefecture, Kawaguchi Junior High School Gym Number of students: 155 Number of classes: 6

Constructed: 1976 Structure and number of stories: Steel, 2 stories (1F: RC, 2F: Steel) Total floor area 1,670 m^2

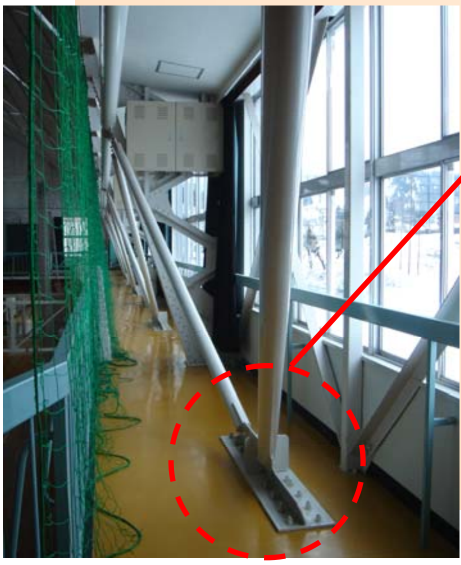
After retrofit（inside view）

Steel Tube Bracings



Upper frame of steel tube bracings

Photo of retrofit details



Anchor section of steel tube bracings

Anchors

Anchors to fix bracings. In this case, the steel tube bracings were anchored to the floor at the second floor instead of the lower base of the column to avoid stress acting on columns.

Photo of retrofit details

■ Project Outline

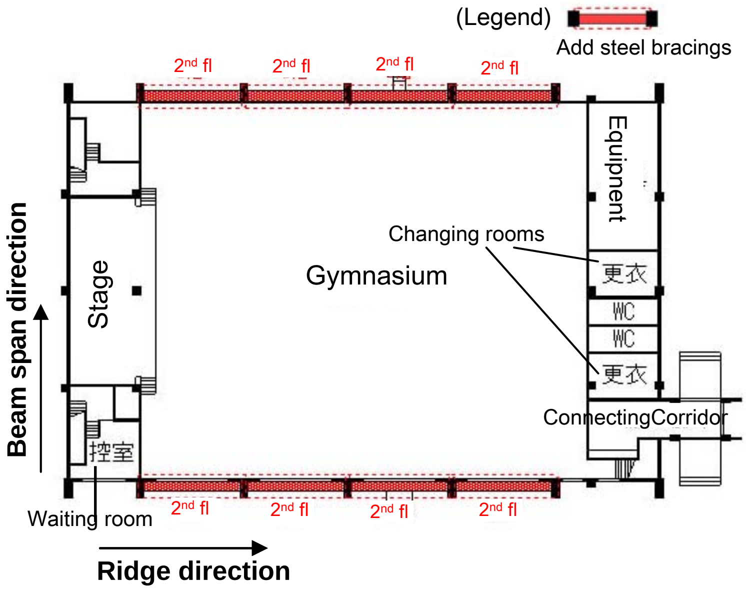
Duration	July to November 1997 (approx. 4 months)
Total Cost	101,621,000 yen
Approx. cost of retrofitting	Steel bracings 10,000 yen/m^2 (8 sections × 3.1 m^2 each)
I_S Value Before → After	I_{sx}=0.08 → I_{sx}=0.73 I_{sy}=0.70 → I_{sy}=0.70

■ Outline of Seismic Retrofitting Method

From the seismic evaluation, in the ridge direction, the I_S value was 0.77 at the first floor and 0.08 at the second floor. Therefore, by adding steel bracings at eight positions in the ridge direction at the second floor, the I_S value after retrofitting was 0.73. This type of roof allows load transfer. Since the column - beam joint in the beam span direction is not a welded joint and the column base did not have a problem, the I_S > 0.7 was secured. The lack of load bearing capacity in the ridge direction was reinforced by adding K-shaped steel tube bracings. Since the column is a latticed1) member, and could not bear the installation of bracings, this was reinforced by installing an upper chord member with the bracings in an inverted triangular formation.

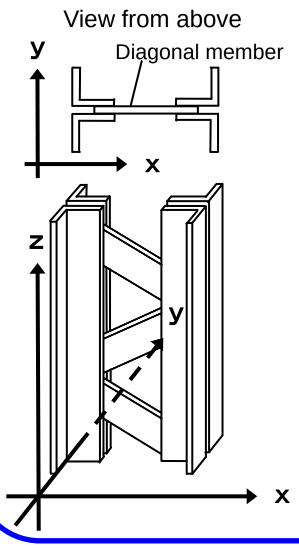
At the lower intersection of the inverted triangle, the bracings are anchored to the gallery floor to avoid imposing loads onto the existing column base.

■ Structural Outline



Keyword

1) *Latticed Column*



Latticed columns are columns in the form of the drawing to the left. The built-up column is fabricated from steel plates.

Normally, columns can resist forces in the x and y-directions, but latticed columns do not have diagonal members in the y-direction, and can not resist forces in the y-direction.

■ Condition of the Facility

This gymnasium was constructed in 1976. The 1,670 m^2 structure is two stories high, and the first floor is a reinforced concrete structure and the second floor is a steel structure.

Seismic retrofitting of the facility was performed as part of the long-term maintenance project, with major refurbishment of the arena ceiling and floor, through the duration of four months from July to November 1997. In this case, the structure was subject to the Mid-Niigata Prefecture Earthquake in October 23, 2004

■ Condition After the Earthquake

This gymnasium in Kawaguchi Town was subject to seismic intensity 7 as it was located at about 2.3 km from the seismic center of the Mid-Niigata Prefecture Earthquake that occurred in October 2004. Damages from the earthquake were limited to the lamps in the lighting fixtures (although the light fixtures did not fall) and a gap, which is about 40 mm wide, that had appeared on the stage wooden floor frame. The damages did not prevent the graduation ceremony, which was held in March 2005. Since this gymnasium was retrofitted, it was one of the few gymnasiums in the surrounding area that could be used normally after the earthquake. This allowed the graduation ceremonies of other surrounding schools to be held in this gymnasium on different dates. This is one of the cases where the seismic retrofitting was highly effective.

Retrofitting the Structure by Replacing the Roof

Miyagi Prefecture, Wakuya Town Junior High School Gymnasium Number of students: 391 Number of classes: 13

Constructed: 1979 Structure and number of stories: RC, 2stories (1F: RC and 2F: Steel) Total floor area: 1,302 m^2

After retrofit（outside view）

Steel structured roof

Roof replacement

After retrofit（inside view）

Before retrofit（inside view）

Precast slab roof

After retrofit（outside view）

Before retrofit（outside view）

■ Project Outline

Duration	February to August 1999 (approx. 7 months)
Total Cost	154,560,000 yen
Approx. cost of retrofitting	Remove precast concrete roof Lump sum 5.562 million yen Steel beams Lump sum 13.951 million yen
I_S Value Before → After	I_{sx}=0.74 → I_{sx}=1.16 I_{sy}=0.94 → I_{sy}=1.70

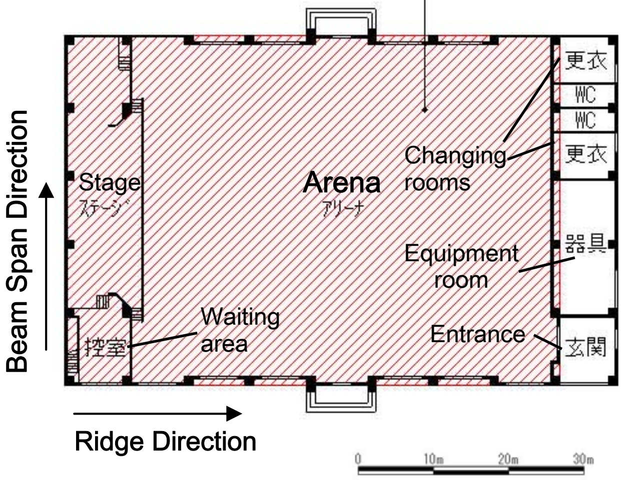
■ Outline of Seismic Retrofitting Method

The gymnasium is a two-story, 1,302 m^2 RC structure (constructed in 1979) with a PC (precast concrete slab) roof. The retrofit work duration was seven months, from February to August 1999. In this case, the structure was subject to the Sanriku-minami Earthquake (Miyagi-oki Earthquake) in May 26, 2003.

The in-plane seismic performance of the frame along the periphery was secured, but the precast concrete slab roof lacked in-plane rigidity and strength. Due to concerns that the precast concrete slab could fall, the roof was replaced with a steel framed roof to improve seismic resistance by reducing the dead load and increasing in-plane rigidity and strength.

■ Structural Outline

Remove existing precast concrete slab roof.
Reduce dead weight by replacing with steel plate roof.



Keyword

PC(Precast concrete slab)

A reinforced concrete slab that was prefabricated at the plant. Because of its heavy weight, the joint between the roof and structure could fail, and the roof could fall down when subject to earthquake.

↓ **Replacing roofs that are in danger of falling**

Steel plate roof panel

Steel framed structure is lighter in weight

*Generally, the lighter the weight of the structure, the lower the seismic forces that are imposed on the structure.

■ Condition After the Earthquake

In Wakuya Town, where this school building is located, a seismic intensity of 6 lower was recorded by the Miyagi-oki earthquake that occurred in May 26, 2003.

From this earthquake, cracks in the reinforced concrete shear walls in the northwest section were the only damages, and the roof that was replaced with a steel framed roof was not damaged.

Damage to the structure was minimized by replacing the precast concrete panel roof, which could have fallen during an earthquake, with a steel plate roof and reducing the weight of the structure. It appears the seismic retrofitting was effective.

Generally, damages to non-structural members occur more often in gymnasiums. Therefore, it is necessary to consider the design and details of the attachments and construction of non-structural members.

Outline of the Earthquake

Date and time: May 26, 2003, approx. 18:24

Epicenter: Offshore Miyagi Prefecture

(latitude 38° 48.3' north, longitude 141° 40.9' east)

Depth of seismic center: Approximately 71 km

Scale of earthquake: Magnitude 7.0

Seismic intensity near the school: 6 lower

Chapter 2

Detailed Examples of Seismic Retrofitting

【Outline】

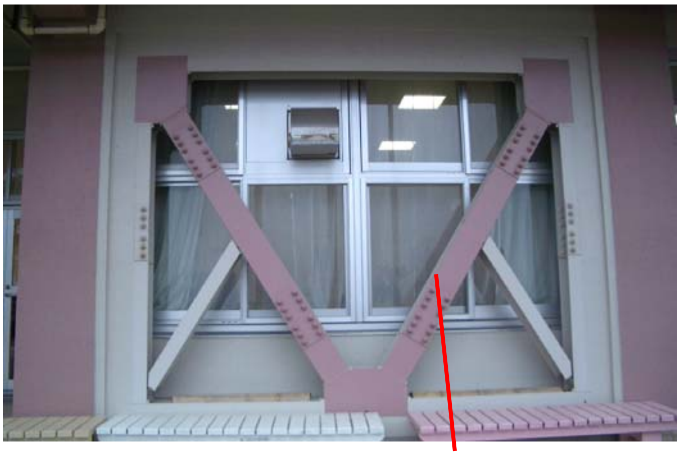
	School name	Outline of structure	Retrofit method	Seismic performance (I_s value)	Project cost Duration of work
School building	Chiba Prefecture Shiroi City, Shiroi No.2 Elementary School	Constructed 1977, 4 story, RC structure Total floor area: 2,923 m^2	Install steel framed bracings Install shear wall	Before After x-direction 0.48→0.71 y-direction 0.86→0.85	454.658 million yen 8 months x 1 year
	Shizuoka Prefecture Sizuoka City Shizuhata Junior High School	Constructed 1977, 4 story, RC structure Total floor area: 3,656 m^2	Install steel framed bracings Install shear wall	Before After x-direction 0.57→1.19 y-direction 1.30→1.30	150.248 million yen 6 months x 1 year
Gymnasium	Tokyo Metropolitan Ota Ward Shinjuku Elementary School	Constructed 1973, 1 story, RS structure Total floor area: 614 m^2	Install bracings along roof Install steel framed bracings	Before After x-direction 1.11→1.11 y-direction 0.56→1.21	13.577 million yen 6 months x 1 year
	Kochi Prefecture Kochi City Joto Junior High School	Constructed 1964, 2 story, Steel structure Total floor area: 903 m^2	Install external horizontal steel truss	Before After x-direction 0.18→1.01 y-direction 0.18→0.82	36.129 million yen 3 months x 1 year

Note) Project costs are overall costs that include costs other than seismic retrofitting work.

Legend
RC: Reinforced concrete structure
Steel: Steel structure
RS: Gymnasiums with RC structure at the lower level and steel structure at upper level.

Retrofitting of Structure with Steel Bracings and Seismic Shear Walls

■ Photo after retrofitting



Steel bracings

Installed shear wall

■ Project outline

Duration	April to November 2003 (approx 8 months)
Total Cost	454,650,000 yen
Approx. cost of retrofitting	Steel bracings 9,000,000 yen/32 m^2 RC seismic wall installation 6,000,000yen/30 m^2
I_S Value Before→After	I_{sx}=0.48 → I_{sx}=0.71 I_{sy}=0.86 → I_{sy}=0.85

Details of steel bracings

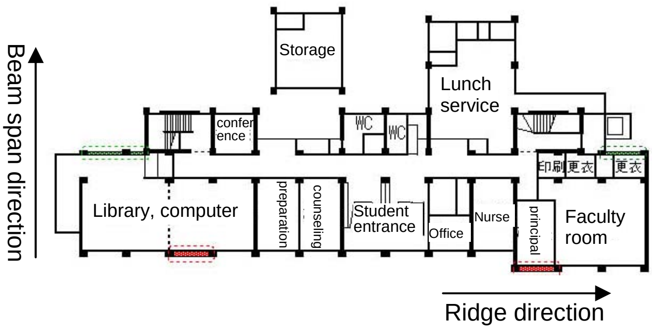
■ Outline of the Seismic Retrofitting Method

This school building is an RC structure that is four stories high. The beam layout is 2 spans; 7.2 and 3.2 meters in the span direction, and 14 spans; 4.5 meter each in the ridge direction, which results in a horizontally long floor layout.

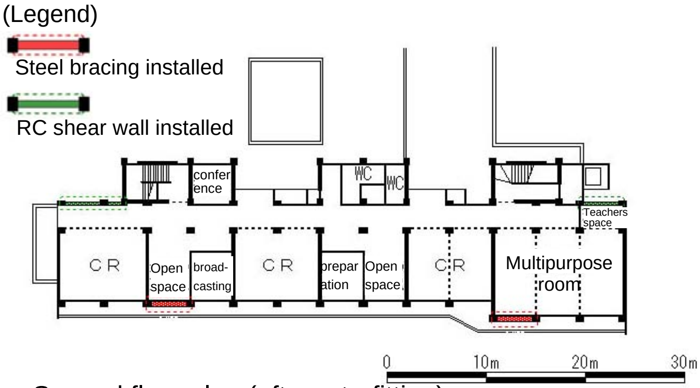
In the beam span direction, shear walls along partition walls that separate classrooms secure the necessary seismic resistance in all floors. However, there were not enough shear walls in the ridge direction, and many columns were prone to shear failure. Therefore, it was judged that the structure does not have the necessary seismic resistance at the first and second floors. The I_S values in the ridge direction for the first and second floors were evaluated as 0.52 and 0.48.

The seismic retrofitting intends to achieve I_S values of more than 0.7 at the first and second floors. In the aim to achieve improvement in seismic resistance through the strength increase type of retrofitting, two sets of steel bracings were installed along the plane of the southern framework, where it is necessary to let in natural light, and 2 RC shear walls were installed along the northern framework. The steel bracings can be seen from the exercise ground to the south. Since the layout is well balanced, it blends in naturally with the school building, giving a sense of security to the observer.

■ Structural Outline



First floor plan (after retrofitting)

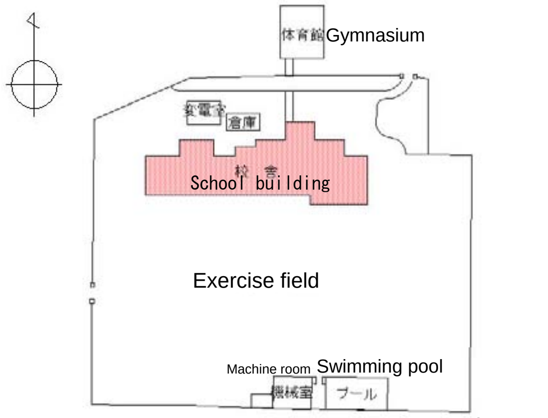


Second floor plan (after retrofitting)

Shiroi City, Shiroi No.2 Elementary School

Chiba Prefecture

[Outline of the school] Number of students: 149, Number of classes: 6 Lot area: 12,686 m2, Total floor area: 2,923 m2, Building name: School building, Constructed: 1977, Structure and number of stories: RC, 4 stories



Layout


Overall view (south side)


Multipurpose room made after interior modification


Two previous classrooms were converted to a library and computer room which is opened to the local community.

■ Outline of the facility

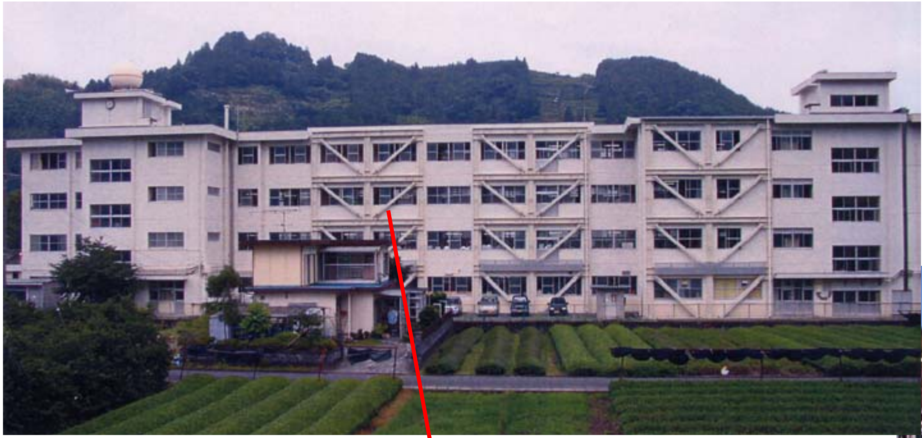
Shiroi No.2 Elementary School was rebuilt from the previous wooden structure to a reinforced concrete school building in March 1977. In September 2003, seismic retrofitting, together with the following refurbishment, was completed.

- The first floor classrooms were converted into a library and computer room, with an exclusive entrance so as to make the facility open to the local community.
- The teachers' office, which was previously on the second floor, was moved to the first floor. At the same time, the school office was placed next to the student entrance for the purpose to give attention to the children and the security within school.
- By replacing the wall between classrooms and corridor with movable partitions, and made into open classrooms.
- On the second floor, the lower grade classrooms were consolidated and the special classroom was refurbished into a multipurpose room to provide space that could be used for teaching large or small groups, and used also as a lunch room.
- On the third floor, the higher grade classrooms were consolidated. To coordinate with the special classroom that was consolidated on the fourth floor and the previous science room was refurbished as a multipurpose room for use as children's hall, changing room, and consultation room.

■ Focal point of the project

Because of the reduced classes, the available floor space is comparable to that of a newly constructed six grade school building. Since this is a single class per grade school, it was possible to place open areas between each classrooms. In terms of functionality, the school compares favorably with newly constructed schools. When renovating the school, the room layout was rearranged. Rooms that are to be opened to the public and for administration were placed at the first floor, and layout was clearly zoned according to the floor. The interior and facilities were renewed and made barrier-free. The layout of the seismic shear walls are well planned to avoid general classrooms. The project was successfully completed with minimum effect on school operations, by adjusting the school annual timetable, and through careful design and project planning.

Retrofitting the Structure by Installing External Steel Bracings and Seismic Shear Walls



After retrofitting (exterior)

External steel bracings

Before retrofitting (exterior)

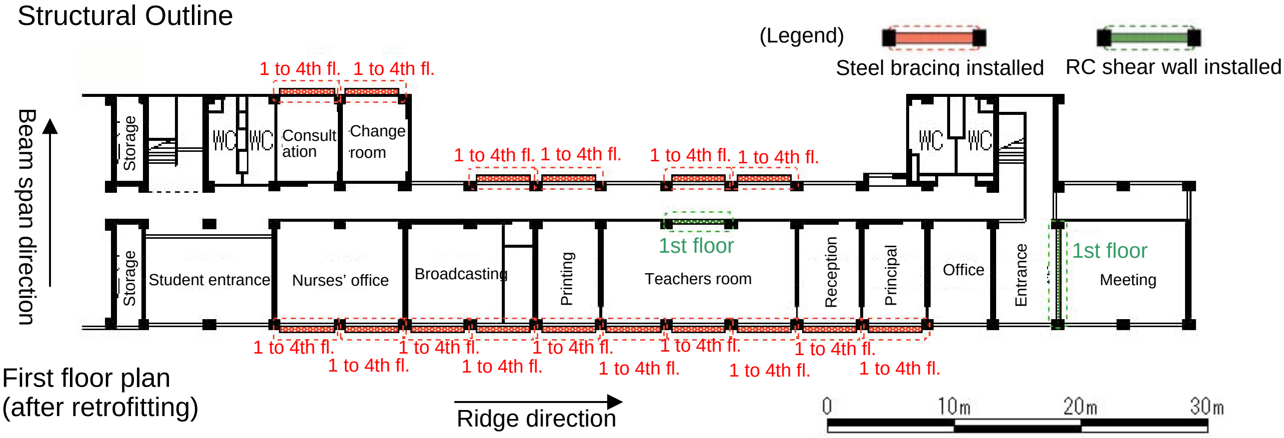
■ Project outline

Duration	June 2003 to January 04 (approx. 6 months)
Total Cost	150,248,000 yen
Approx. cost of retrofitting	Steel bracing 4,500,000 yen/each RC wall installation 2,000,000 yen/each
I_S Value Before→After	$I_{sx}=0.57$ → $I_{sx}=1.19$ $I_{sy}=1.30$ → $I_{sy}=1.30$

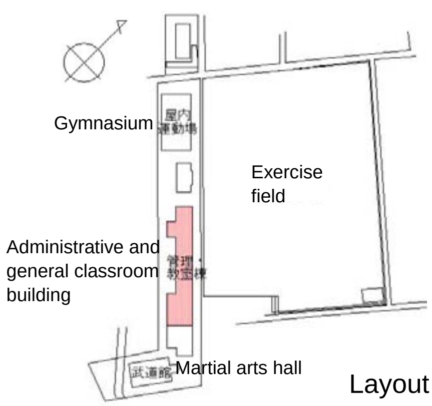
■ Outline of the Seismic Retrofitting Method

Retrofitting the school building was performed by installing external steel bracings and reinforced concrete shear walls, and by making the roof lighter to reduce the weight of the structure. 32 sets of external steel bracings and 2 sets of reinforced concrete shear walls were installed.

■ Structural Outline



First floor plan (after retrofitting)



Layout

■ Condition of the Facility

The Shizuhata Junior High School was established in 1954, and from 1976 to 81, the facilities were gradually converted to reinforced concrete structures. There is significant difference in ground elevation between the school building, which is on top of the relatively narrow high ground, and that of the outdoor exercise field. This resulted in the in-line layout of the cluster of buildings in the north-south direction, and the floor layout of the four-story school building.

Seismic retrofitting of the structure was performed in 2003, in accordance to the school facility retrofitting plan, which was established by Shizuoka City.

Sizuoka City Shizuhata Junior High

Shizuoka Prefecture

[Outline of the school] , Number of students: 380, Number of classes: 11, Lot area: 22,026 m^2, Total floor area: 3,656 m^2
Building name: Administrative and general classroom building, Constructed: 1977, Structure and number of stories: RC, 4 stories

After retrofitting (exterior)

After retrofitting (details)

After retrofitting (interior)

■ Focal point of the project

In principle, the policy by Shizuoka City for the seismic retrofitting of school structures is as follows: "Steel bracings are to be distributed and installed inside the framework in a way to avoid obstructing natural light and ventilation". Furthermore, the policy is to "make use of redundant classrooms instead of constructing temporary school buildings". However, in this school, it was not possible to prepare redundant rooms for use as general classrooms during the construction, and therefore, the project used the method where steel bracings are installed onto the outer framework to reinforce the structure. This method was designed according to the "Handbook on the Outer Framework Retrofitting for Refurbishing Existing Reinforced Concrete Structures: Reinforcement by installing steel framed bracings", Japan Building Disaster Prevention Association (2002).

The reinforcement may seem rather in excess than usual, whereby the Ministry of Education, Culture, Sports, Science and Technology specifies a seismic demand index I_{S0} of 0.7. However, Shizuoka Prefecture has a separate standard of its own, because it is designated as an Area of Intensive Measures against Earthquake Disasters, according to the Large-Scale Earthquake Countermeasures Special Act.

To balance the reinforcement, steel bracings are positioned line-symmetrical to the center of the school building, and are installed onto the eastern and western outer framework in the north-south direction, at the first to the fourth floors of the structure.

Construction work such as embedding anchors, which generates noise, was completed during summer vacation. By the end of summer, work such as frame erection that does not generate noise had been performed. With this method, school lessons could be continued during construction, and it was reported that construction work, such as frame erection, did not obstruct the lessons. Furthermore, the work schedule was not too tight, because there was no interior work performed together with the retrofitting.

By indicating and clarifying the construction area with a temporary enclosure, to secure the flow of movement for students and workers, it was possible to use the school exercise ground without obstruction.

Silicon resin coatings were applied over the anticorrosive coat on steel members, such as bracings. Since it is just two years after completion of work, there is no problem, but it is preferable to establish a maintenance plan, such as against corrosion in the future.

This method is effective when there are no redundant classrooms, or when constructing temporary school buildings are not planned.

For your reference, the major points of concern in using this method are as follows:

1. Secure space for erection work.
2. The concrete of existing structures need to have compressive strengths of more than 18 N/mm^2.
3. Carefully install anchor into existing concrete (this applies to all methods).
4. Consider the foundations of columns where reinforcements are installed.
5. Ensure that seismic shear walls are installed in the transverse direction of reinforcements.
6. The external bracing design should have some strength margin above the strength of an internal bracing design.

Retrofitting Structures by Installing Steel Frame Bracings and Bracings along the Roof

■ After retrofitting


Bracings along the roof


Steel bracings

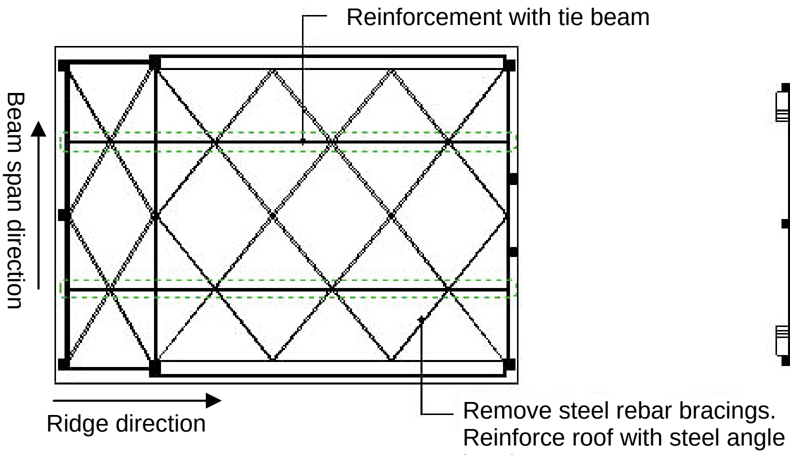
■ Project outline

Duration	June to November 2000 (approx. 6 months)
Total cost	13,577,000 yen
Approx. cost of retrofitting	Install steel frame bracing 16,000 yen/m^2
I_S Value Before→After	I_{sx}=1.11 → I_{sx}=1.11 I_{sy}=0.56 → I_{sy}=1.21

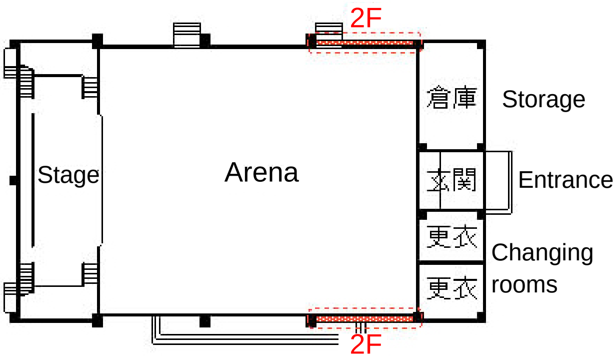
■ Outline of the Seismic Retrofitting Method

Retrofitting method for the gymnasium at Shinjuku Elementary School is as follows: Install bracings along the entire ceiling to increase rigidity of the roof. Install K-shaped steel framed bracings at two positions to increase seismic resistance in the ridge direction. Install rib-plates to reinforce the column-girder joint.

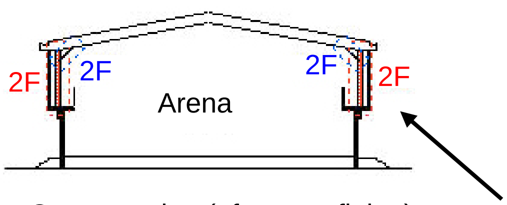
■ Structural Outline



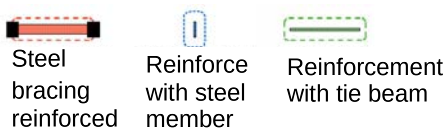
Ceiling plan (after retrofitting)



First floor plan (after retrofitting)



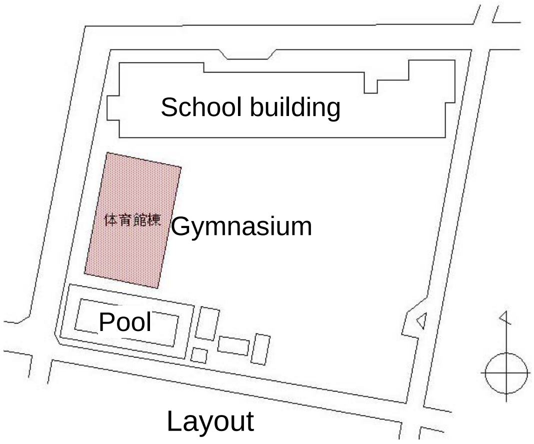
Cross section (after retrofitting)



Ota Ward Shinjuku Elementary School

Tokyo Metropolitan

[Outline of school]Number of students: 288, Number of classes: 11, Lot area: 10,588 m^2, Total floor area: 614 m^2
Building name: gymnasium, Constructed: 1973, Structure and number of stories: RS, 1 story

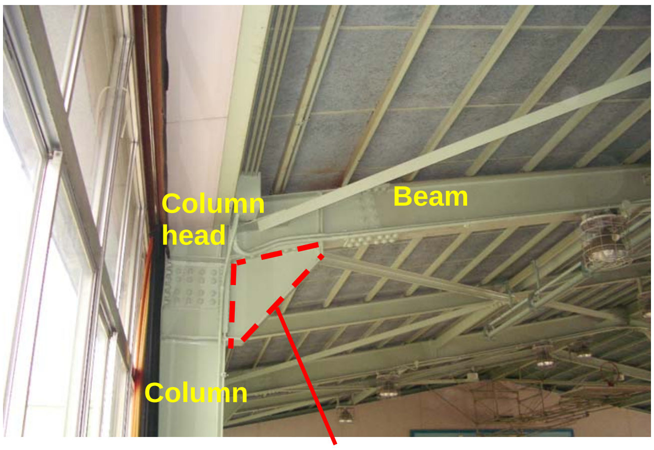


Layout

Bracings along the roof Detail

Steel bracings Detail-1

Steel bracings Detail-2



Reinforce column-beam joint by installing rib-plates

■ Condition of the Facility

The Shinjuku Elementary School was established in 1933 as the Tokyo City Kamata Shinjuku Elementary School, but was completely burnt in 1945 during the war. In March 1946, the school was closed down, but in 1953, it was established as the Ohta Ward Shinjuku Elementary School.

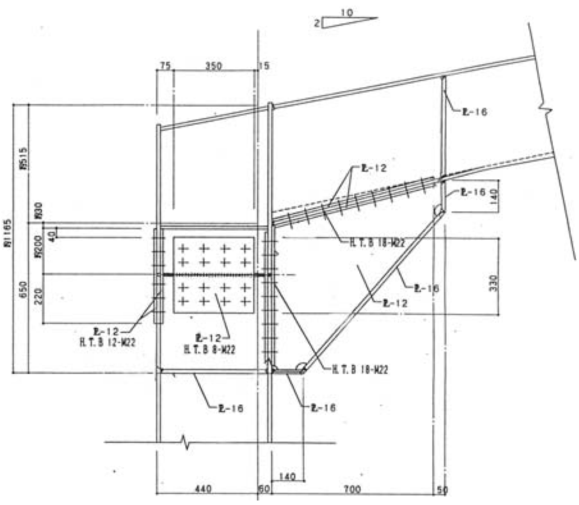
Originally, the school was a wooden structure, but from 1971 to 73, the school building was made into a fireproof structure, then in 1974, the gymnasium was made into a fireproof structure. There are 288 students and 11 classes in this school. The seismic retrofitting of the gymnasium was performed in 2000, together with the school building, according to the Earthquake Disaster Countermeasure Five Year Plan.

■ Focal point of the project

The gymnasium is an RC structure at the lower portion and steel structure at the upper portion, which is a standard structure for elementary and junior high schools.

The retrofitting was as follows: Install horizontal bracings along the entire ceiling to improve load transfer along the roof. Install K-shaped bracings (with upper and lower frame members), made of wide-flange structural steel, in the ridge direction to improve the lack of seismic resistance at the second floor. This is a common retrofitting method.

For the beam span direction, it was judged that the weld strength of the welded column-beam joint at the column head was insufficient. Therefore, rib-plates were installed at the corner of the column-beam joint to reinforce the joints. The reinforcement with rib-plates simultaneously supplements the two weaknesses; the column-beam joint and the welded column joint. By fastening the rib-plate to the lower flange of the beam and to the column with high-strength friction grip bolts, it straddles the welded column joint to connect the beam and column.

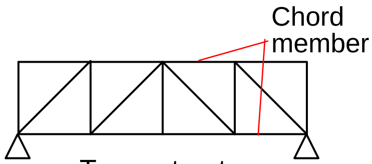


Details of the column head

Retrofitting Structures by Installing External Horizontal Steel Truss

After retrofitting (exterior)

Truss
Frame structure where members are placed diagonally.

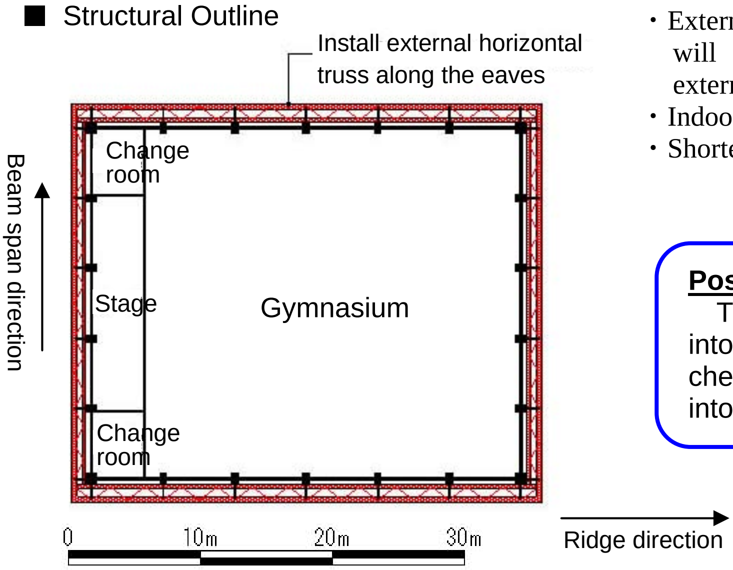


Before retrofitting (exterior)

■ Project outline

Work Duration	June to September 2000 (approx. 3 months)
Total project cost	36,129,000 yen
Approx. cost of retrofitting	External horizontal truss 220,000 yen/m
I_S Value Before→After	I_{sx}=0.18 → I_{sx}=1.01 I_{sy}=0.18 → I_{sy}=0.82

■ Structural Outline



First floor plan (after retrofitting)

■ Outline of the Seismic Retrofitting Method

This retrofitting method applies reinforcement to the exterior of the structure. The existing columns and beams are to be left untouched, and a horizontal structure is installed around the height of the eaves to make this peripheral structure resist out-of-plane forces acting on the structure. The horizontal structure is a truss that consists of chord members made of wide-flange structural steel and steel tubing diagonal members. To connect the truss to the existing structure, post installed anchors were used. Then, non-shrinkage mortar was injected into the space between the existing concrete structure and new steel members.

Reasons for choosing this method

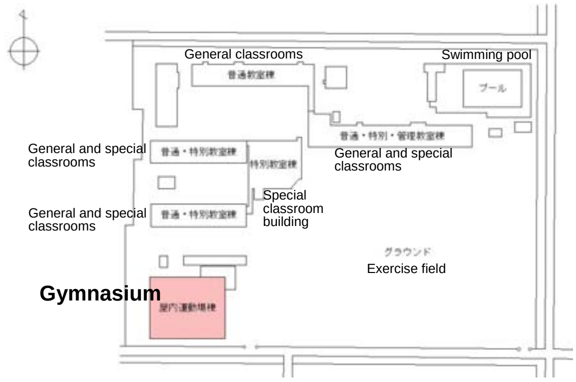
- External retrofitting reduces cost, since the building interior will not be touched. (Considerations were given to the external design)
- Indoor space will not be sacrificed by retrofitting.
- Shorter work duration.

Post installed anchor
The type of anchor, whereby a hole is drilled into the existing concrete and a mechanical or chemical type anchor bolt is inserted and fixed into the hole.

Kochi City Joto Junior High

Kochi Prefecture

[Outline of school] Number of students: 324, Number of classes: 14, Lot area: 21,336 m^2, Total floor area: 903 m^2
Name of building: gymnasium, Constructed: 1964, Structure and number of stories: Steel, 2 stories



Layout

■ Condition of the Facility

The gymnasium, which was constructed in 1964, is one of the structures where seismic retrofitting of older structures had started in 1996, after the Great Hanshin Awaji Earthquake Disaster of 1995 (the Kobe Earthquake), which became the turning point.

Retrofitting of this structure was performed from June to September 2000, in the 2 months of summer vacation.

Erection of steel frame

■ Outline of the retrofitting project

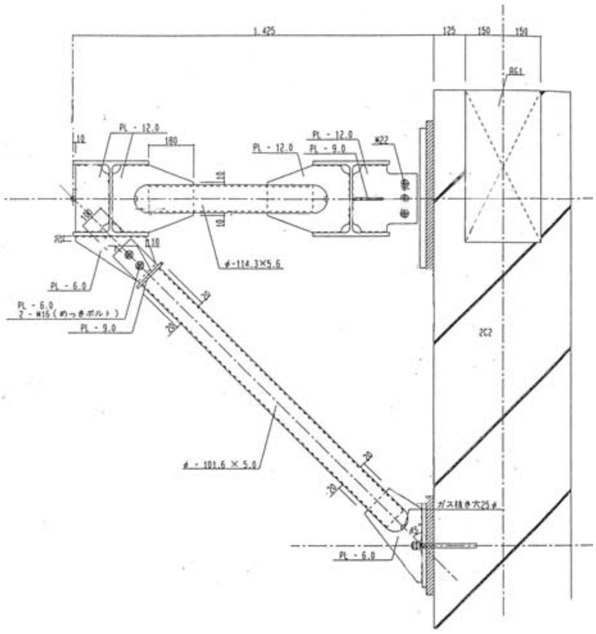
The gymnasium has a reinforced concrete lower structure with a steel roof structure on top.

The roof, which may seem uncommon in elementary and junior high school gymnasiums, is made of steel tubings that compose a single layer lattice shell. This structure is heavy for a gymnasium, because of the reinforced concrete framework. Frequent issues in this type of structure are the out-of-plane vibration of the structure, and the connection between the steel frame and the reinforced concrete portion. In this example, the reinforced concrete framework was reinforced to resist out-of-plane forces by installing a horizontal steel structure (like placing a hoop) around the structure at the position of the eaves.

Furthermore, the color tone of the horizontal structure was decided from the point of coherence with surrounding structures.

The retrofitting is mainly applied to the exterior of the structure. Therefore, sufficient care is necessary for liftingwork and anticorrosive measures of the steel frame.

After retrofitting (details)



Joint detail

Chapter 3

Other Examples of Seismic Retrofitting

● Examples of seismic retrofitting on school buildings

Aomori Prefecture, Kaijo Town, Ohja Elementary School
Saitama Prefecture, Gyoda City, Saitama Elementary School
Toyama Prefecture, Toyama City, Hagiura Elementary School
Nagano Prefecture, Matsumoto City, Meizen Elementary School
Wakayama Prefecture, Koya Town, Koyasan Junior High School
Tottori Prefecture, Nanbu Town, Hoshoji Junior High School
Hiroshima Prefecture, Kure City, Shiratake Elementary School
Ehime Prefecture, Saijo City, Nishi-Saijo Junior High School

● Examples of seismic retrofitting on gymnasiums

Yamanashi Prefecture, Tanbayama Village, Tanbayama Junior High School
Aichi Prefecture, Nagoya City, Nakane Elementary School
Okayama Prefecture, Tsuyama City, Kamo Junior High School
Kagawa Prefecture, Yamamoto Town, Ohno Elementary School
Kumamoto Prefecture, Goshi City, Goshi Junior High School
Ohita Prefecture, Ohita City, Munakata Elementary School

Legend
RC: Reinforced concrete structure
Steel: Steel structure
RS: Gymnasiums with RC structure at the lower level and steel structure at upper level.

Examples of seismic retrofitting of school buildings

Aomori Pref	Kaijo Town, Ohja Elementary School

Outline of the facility

Structure, Story, Floor area	RC structure, 2 stories Total floor area: 1,326 m^2
Work Duration	March to May 2005 (approx. 2 months)
Total project cost	81.340 million yen
Approx. cost of retrofitting	Carbon fiber jacket column reinforcement 187,200 yen/m^2 Install RC wall 85,600 yen/m^2
I_S Value Before → After	I_{sx}=0.49 → I_{sx} =0.82 I_{sy}=1.40 → I_{sy} =1.40

Outline of Seismic Retrofitting Method

Wrap carbon fiber sheet around column along the corridor, and install RC shear wall adjacent to the corridor.

Before retrofitting

After retrofitting

Details of the retrofit

Saitama Pref	Gyoda City, Saitama Elementary School

Outline of the facility

Structure, Story, Floor area	RC structure, 3 stories Total floor area: 3,074 m^2
Work Duration	June to September 2004 (approx. 3 months)
Total project cost	92.4 million yen
Approx. cost of retrofitting	Steel bracing 1.78 million yen/each External steel bracing (3 levels) 14.45 million yen/each
I_S Value Before → After	I_{sx} =0.31 → I_{sx} =0.76 I_{sy} =0.78 → I_{sy} =0.78

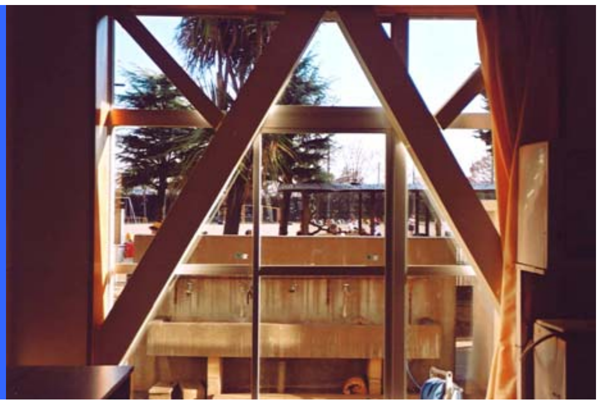
Outline of Seismic Retrofitting Method

Retrofitting is applied only in the ridge direction, and the south side frame is reinforced with V-shaped steel bracings. On the north side, external steel bracings that are one-piece from 1st floor to 3rd floor are installed.

Before retrofitting

After retrofitting

Details of the retrofit



Toyama Pref	Toyama City, Hagiura Elementary School

Outline of the facility

Structure, Story, Floor area	RC structure, 4 stories Total floor area: 1,246 m^2
Work Duration	June 2002 to February 2003 (approx. 9 months)
Total project cost	102.99 million yen
Approx. cost of retrofitting	Install RC wall 78,800 yen/m^2 Install steel bracings 122,500 yen/m^2
I_S Value Before → After	I_{sx} =0.43 → I_{sx} =0.77 I_{sy} =1.30 → I_{sy} =1.30

Outline of Seismic Retrofitting Method

Add shear wall in the ridge direction, to achieve strength increase type of retrofitting

Before retrofitting

After retrofitting

Details of the retrofit

Nagano Pref	Matsumoto City, Meizen Junior High School

Outline of the facility

Structure, Story, Floor area	RC structure, 3 stories Total floor area: 2,105 m^2
Work Duration	June to September 2004 (approx. 4 months)
Total project cost	Total project cost 42.735 million yen
Approx. cost of retrofitting	Install RC wall 101,200 yen/m^2
I_S Value Before → After	I_{sx} =0.47 → I_{sx} =0.96 I_{sy} =0.89 → I_{sy} =0.93

Outline of Seismic Retrofitting Method

Applied the common method of retrofitting and installed RC shear walls. Two seismic shear walls were added in the ridge direction at the first floor, as well as at the second floor.

Before retrofitting

After retrofitting

Details of the retrofit

Examples of seismic retrofitting of school buildings

Toyama Pref — Koya Town, Koyasan Junior High School

Outline of the facility

Toyama Pref	Koya Town, Koyasan Junior High School
Structure, Story, Floor area	RC structure, 3 stories Total floor area: 2,229 m^2
Work Duration	April to December 2004 (approx. 8 months)
Total project cost	62.85 million yen
Approx. cost of retrofitting	Steel bracings 184,000 yen/m^2 Structural slit 12,000 yen/each
I_S Value Before → After	I_{sx} =0.46 → I_{sx} =0.90 I_{sy} =1.06 → I_{sy} =1.06

Outline of Seismic Retrofitting Method

Install steel bracings at a total of 17 positions in the ridge direction. Vertical slits are placed on walls at the third floor to increase the ductility of columns.

Before retrofitting

After retrofitting

Details of the retrofit

Tottori Pref — Nanbu Town, Hoshoji Junior High School

Outline of the facility

Tottori Pref	Nanbu Town, Hoshoji Junior High School
Structure, Story, Floor area	RC structure, 3 stories Total floor area: 2,281 m^2
Work Duration	July to August 2004 (approx. 2 months)
Total project cost	264.81 million yen
Approx. cost of retrofitting	Install wing walls 556,000 yen/each Steel jacket column reinforcement 1.131 million yen Precast bracings 2.071 million yen/each Steel bracings 1.912 million yen/each
I_S Value Before → After	I_{sx} =0.39 → I_{sx} =0.75 I_{sy} =1.34 → I_{sy} =1.34

Outline of Seismic Retrofitting Method

Installed steel framed bracings (8 positions) and precast bracing (1 position) in order to supplement the lack of strength at the first and second floor in the ridge direction. The independent column in the soft story is reinforced by wrapping with reinforced concrete and steel jacket, as well as installing wing walls to the column.

Before retrofitting

After retrofitting

Details of the retrofit

Hiroshima Pref	Kure City, Shiratake Elementary School

Outline of the facility

Structure, Story, Floor area	RC structure, 3 stories Total floor area: 576 m^2
Work Duration	July to November 2004 (approx. 5 months)
Total project cost	Total project cost 7.688 million yen
Approx. cost of retrofitting	Steel bracings 226,500 yen/m^2 Carbon fiber jacket column reinforcement 235,500 yen/m^2
I_S Value Before → After	I_{sx} =0.33 → I_{sx} =0.79 I_{sy} =1.24 → I_{sy} =1.28

Outline of Seismic Retrofitting Method

To improve ductility, structural slits were placed and reinforcements with carbon fiber sheet and steel bracings were performed. The steel bracing joints are the one-piece type, and are shop welded.

Before retrofitting

After retrofitting

Details of the retrofit

Ehime Pref	Saijo City, Nishi-Saijo Junior High School

Outline of the facility

Structure, Story, Floor area	RC structure, 4 stories Total floor area: 2,984 m^2
Work Duration	August 2004 to February 2005 (approx. 6 months)
Total project cost	62.918 million yen
Approx. cost of retrofitting	Steel bracings 1.159 million yen/each
I_S Value Before → After	I_{sx} =0.45 → I_{sx} =0.88 I_{sy} =1.36 → I_{sy} =1.41

Outline of Seismic Retrofitting Method

Stable reinforcement is expected by having the steel frame retain strength and rigidity. Make wide openings to secure sufficient natural light and ventilation

Before retrofitting

After retrofitting

Details of the retrofit

Examples of seismic retrofitting of gymnasiums

Yamanashi Pref	Tanbayama Village, Tanbayama Junior High School
Outline of the facility	
Structure, Story, Floor area	Steel structure, 1 story Total floor area: 862.5 m^2
Work Duration	July to September 2004 (approx. 2 months)
Total project cost	10.6 million yen
Approx. cost of retrofitting	Column brace reinforcement 1.919 million yen/each Steel bracings 5.058 million yen/each
I_S Value Before → After	I_{sx} =0.22 → I_{sx} =0.76 I_{sy} =0.79 → I_{sy} =1.01

Outline of Seismic Retrofitting Method

reinforcement at column head by adding knee brace (10 positions at the second floor)
Bracings along side wall (4 positions at first floor and 4 positions at second floor)

Before retrofitting

After retrofitting

Details of the retrofit

Aichi Pref	Nagoya City, Nakane Elementary School
Outline of the facility	
Structure, Story, Floor area	RC and steel structure, 2 stories Total floor area 1,228 m^2
Work Duration	June 2003 to January 2004 (approx. 8 months)
Total project cost	46.532 million yen
Approx. cost of retrofitting	Remove the precast roof and replace with steel roof 76,000 yen/m^2
I_S Value Before → After	I_{sx} =0.17 → I_{sx} =0.81 I_{sy} =0.17 → I_{sy} =1.76

Outline of Seismic Retrofitting Method

Secure seismic capacity by removing the precast roof to prevent the roof from falling in and to reduce the dead weight.

Before retrofitting

After retrofitting

Details of the retrofit

Okayama Pref — Tsuyama City, Kamo Junior High School

Outline of the facility

Structure, Story, Floor area	RC and steel structure, 2 stories Total floor area 1,924 m^2
Work Duration	June to August 2003 (approx. 2 months)
Total project cost	13.335 million yen
Approx. cost of retrofitting	Steel bracing 150,000 yen/each Install RC wall 1.603 million yen/each
I_S Value Before → After	I_{sx} =0.36 → I_{sx} =0.92 I_{sy} =0.48 → I_{sy} =0.8

Outline of Seismic Retrofitting Method

On the 2nd floor, to secure the view, natural light, and ventilation, steel bracings were used. The steel bracings allowed retrofitting without removing the openings at the periphery of the building that made the structure vulnerable to earthquakes. At the first floor, there was considerable displacement in the plan because of the shear wall. Therefore, reinforced concrete shear walls and steel bracings were installed to remedy the displacement as well as improve the strength and rigidity.

Before retrofitting

After retrofitting

Details of the retrofit

Kagawa Pref — Yamamoto Town, Ohno Elementary School

Outline of the facility

Structure, Story, Floor area	RC structure, 3 stories Total floor area 636 m^2
Work Duration	June 2003 to January 2004 (approx. 8 months)
Total project cost	107.1 million yen
Approx. cost of retrofitting	Steel bracings 4.305 million yen/each Install RC shear wall 3.286 million yen/each
I_S Value Before → After	I_{sx} =0.4 → I_{sx} =0.91 I_{sy} =0.48 → I_{sy} =0.83

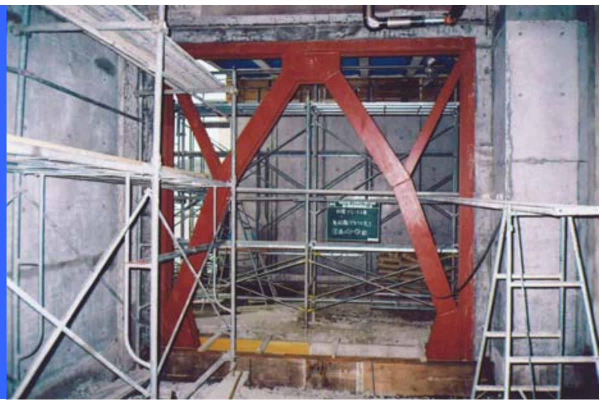
Outline of Seismic Retrofitting Method

In the beam span direction, the structure is reinforced by installing K-shaped steel framed bracings at the first to third floors. The roof is reinforced by changing the steel bar bracings into steel angle bracings.

Before retrofitting

After retrofitting

Details of the retrofit



Examples of seismic retrofitting of gymnasiums

Kumamoto Pref — Goshi City, Goshi Junior High School

Outline of the facility

Structure, Story, Floor area	RC and steel structure, 2 stories Total floor area 1,297 m^2
Work Duration	June to December 2004 (approx. 6 months)
Total project cost	143.945 million yen
Approx. cost of retrofitting	Steel bracings 1.019 million yen
I_S Value Before → After	I_{sx} =0.42 → I_{sx} =0.84

Outline of Seismic Retrofitting Method

To increase the ductility of existing bracings, the brace member at 4 positions were changed. To increase strength, new bracings were installed at 4 positions.

Before retrofitting

After retrofitting

Details of the retrofit

Ohita Pref — Ohita City, Munakata Elementary School

Outline of the facility

Structure, Story, Floor area	RC and steel structure, 1 story Total floor area 886 m^2
Work Duration	July to September 2005 (approx. 2 months)
Total project cost	3.969 million yen
Approx. cost of retrofitting	Roof bracings 1,152,000 yen/each Wall bracings 672,000 yen/each
I_S Value Before → After	I_{sx} =0.17 → I_{sx} =0.89 I_{sy} =0.79 → I_{sy} =0.79

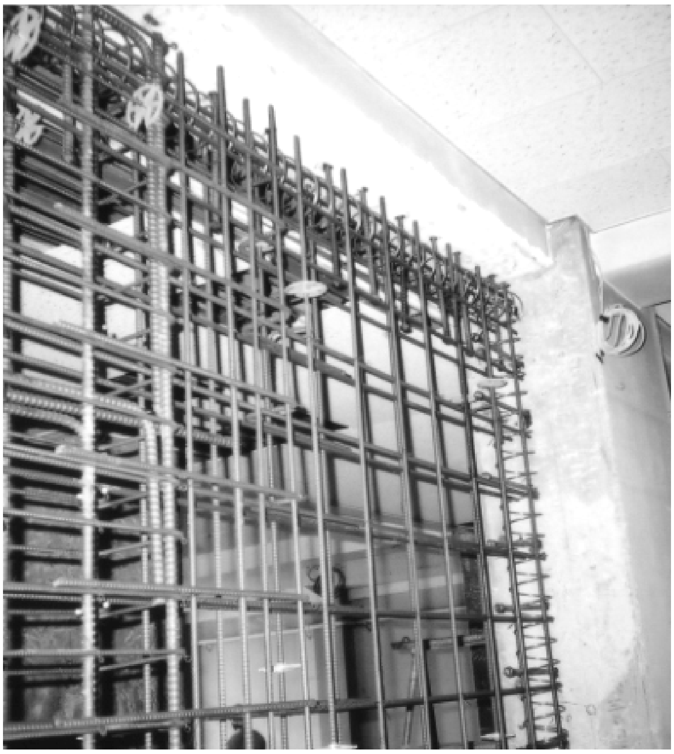
Outline of Seismic Retrofitting Method

Reinforcing by installing steel bracings to the roof and bracings were also added to the walls.

Before retrofitting

After retrofitting

Details of the retrofit



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