English

つながる教材

国立大学法人　豊橋技術科学大学
安全安心地域共創リサーチセンター

Diagnosis and Reinforcement of buildings

Civil & Architecture Department

Tomoya Matsui

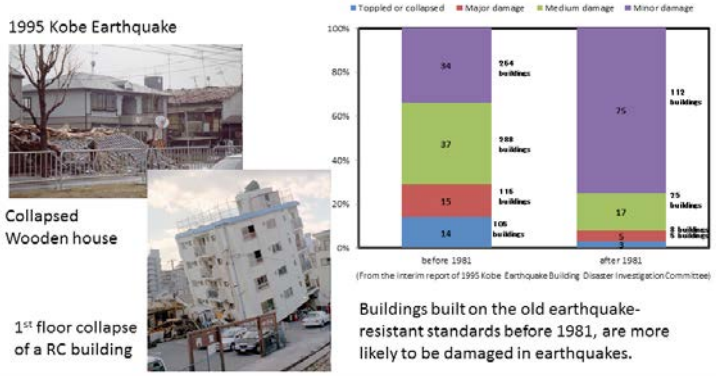
Contents

- Act on Promotion of Seismic Retrofitting
- Seismic Diagnosis
  - Seismic resistance index (Is) value of Structure
- Seismic Retrofitting
  - Types of reinforce method
  - Retrofitting example
  - Cost of retrofitting

Act on Promotion of Seismic Retrofitting

Seismic retrofitting promotion act（Law concerning the promotion of Seismic retrofitting）

Purpose: To protect the life, body and property of citizens from damage such as collapse of buildings due to earthquake, improving the safety measures of buildings.



The law concerning the promotion of seismic retrofitting of buildings which is called earthquake-proof repair promotion law, was established and enforced on the occasion of the Kobe Earthquake of 1995, when structures including buildings suffered severe damage. The purpose of this law is to improve the safety of buildings against earthquakes by taking measures to promote seismic retrofitting of buildings in order to protect the life, body and property of citizens from damage such as therefore, assisting in securing public welfare.

The seismic safety standard was revised in 1981. From the result of damage investigation, it was revealed that the buildings built before 1981 were more damaged than the buildings built after 1981. As a result, the necessity for seismic diagnosis and retrofitting of existing buildings, especially buildings built with old earthquake resistance standards before 1981, has increased.

This video is about how building collapses on occasion of an earthquake.
It is a seismic experiment of a 6-story reinforced concrete building.

Collapse of building

- Seismic Experiment of 6-story Reinforced Concrete Building

Video：
National Research Institute for Earth Science and Disaster resilience
http://www.bosai.go.jp/hyogo/index.html (2014.10)

Collapse of building

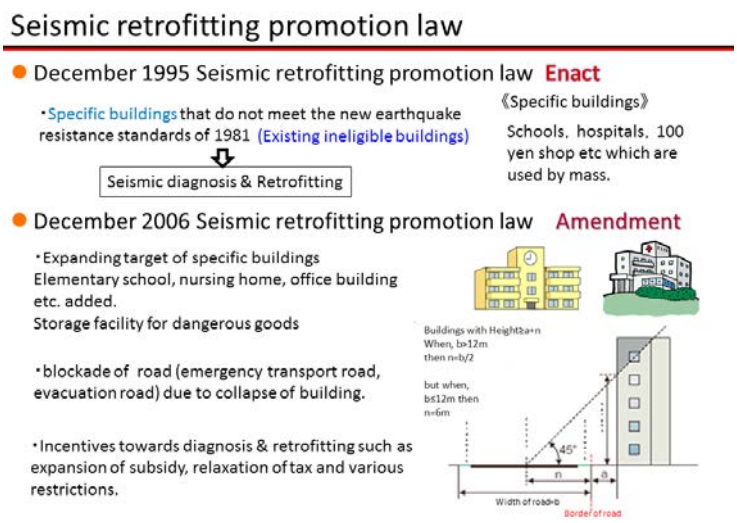
- Oscillation test of wooden house

2 wooden houses built before 1981, one house with reinforcement [left] and the other one without reinforcement [right] which were relocated.

Seismic wave input: 1995 Kobe earthquake JR Takatori observation wave 100%

Let's see this video.
2 wooden houses built before 1981, one house with reinforcement [left] and the other one without reinforcement [right] which were relocated.
Building without reinforcement collapse, housing with reinforcement does not collapse.

Video：
National Research Institute for Earth Science and Disaster Resilience
http://www.bosai.go.jp/hyogo/index.html (2014.10)

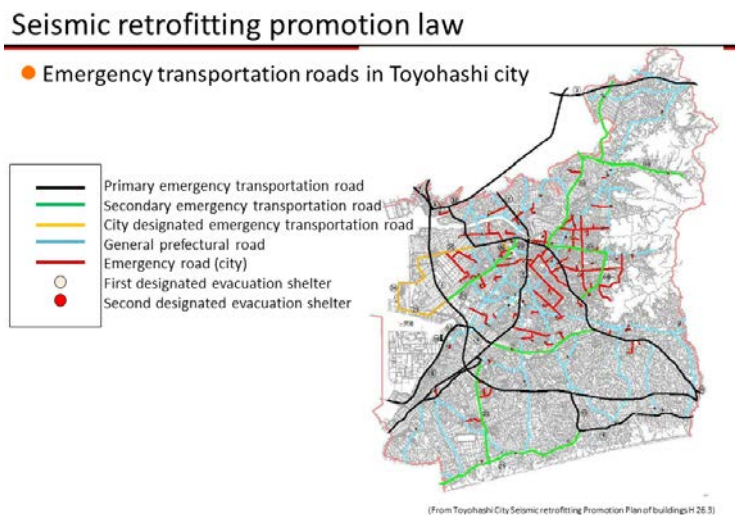


In the Seismic Retrofitting Promotion Act of December 1995, buildings built with old earthquake resistance standards used by a large number of people are designated as "specific buildings". The owners of such buildings must take all reasonable endeavors to perform seismic diagnosis (checking earthquake resistance), and if necessary, in case the earthquake resistance performance does not satisfy the new earthquake resistance criteria, must implement seismic retrofitting; as an obligation.

Subsequently, the Seismic Retrofitting Promotion Act was revised in December 2006. In addition to the expansion of the range of specific buildings, incentives related to seismic diagnosis and retrofitting were added.

In the expansion of the range of specific buildings, elementary school, nursing home, office building, storage facilities for dangerous goods were added. In addition, buildings that might collapse and block the emergency transportation and evacuation roads due to earthquake were added. As shown in the figure, when the width of the road exceeds 12 m, then buildings with height equal to or greater than the distance from the center of the road to the building, and when the width of the road is 12 m or less, buildings with height greater than or equal to 6 m will be subject to specific buildings.

This figure shows Emergency Transportation Road in Toyohashi City.



An emergency transportation road is a road on which emergency vehicles such as rescue, emergency, medical treatment, fire fighting activity and goods transport preferentially pass when the declaration of warning of the earthquake or any disaster occur, and it is based on uniform selection criteria for country, prefectures and cities.

There are four kinds of emergency transportation roads, for example, the primary emergency transportation road is a road that communicates important ports, airports, wide-area logistics bases, etc. and carries out wide-area emergency transportation.

The second emergency transportation road is a road that links the primary emergency transportation road, municipal government office, major disaster prevention base (government agency, public agency, police station, fire department etc).

The evacuation centers are also shown in the figure. In Toyohashi City, there are primary designated evacuation shelter and secondary designated evacuation shelter. The primary designated evacuation shelter is set as a place to evacuate in the event of loss of one's own home, like when it is damaged so badly that unsuitable for living in the event of a disaster or in case when there is a risk of being damaged. 70 school district city halls are specified as primary designated evacuation shelter.

The secondary designated evacuation site is set as a shelter to be opened when the first designated evacuation shelter exceeds the capacity, and 90 facilities such as elementary and junior high schools are designated in Toyohashi city.

Seismic retrofitting promotion law

- November 2013 Seismic retrofitting promotion law Amendment
  - the expansion of the range of specific buildings, incentives related to seismic diagnosis and retrofitting buildings with old earthquake resistance standards are subject to this. Moreover, buildings like mansion, small scale architecture.
  - Specific buildings such as large scale facilities used by general people, buildings used by vulnerable people etc are regulated to seismic diagnosis and result publication.
    Kindergarten, elementary and junior high school, nursing home, hotel, library etc
  - Mitigation of construction regulations subject to retrofitting.
    →Relaxation of regulations of Building Standard Law & Special measures (volume ratio, building coverage)
  - Establishment of display system of earthquake resistance certificate
    Buildings that are certified as earthquake resistant, the certificate must be displayed.
    (Buildings that don't have earthquake resistant certificate, doesn't always mean they aren't earthquake resistant)

《Feeble to Evacuation》
Elderly people, people with disabilities, infants, children, foreigners who don't understand Japanese etc.

Due to the occurrence of a huge earthquake such as the Great East Japan Earthquake, the imminence of the Nankai Trough's massive earthquake and the Epicentric earthquake of Tokyo is obvious. Steady proceeding with earthquake resistance of buildings, and reducing human and economic damage as much as possible is now an urgent necessity.

Therefore, the Seismic Retrofitting Promotion Act was further revised in November 2013.

Here, we expanded the range of the specific building. Buildings that were built according to the old earthquake resistance standard & do not meet the current earthquake resistance standards, are subject to the seismic diagnosis & retrofitting obligation. In addition, it is mandatory to do seismic diagnosis of the specific buildings such as large-scale facilities used by general people and specific buildings used by vulnerable people. It's an regulation to publish that result.

Meanwhile, as measure for smooth promotion of earthquake resistance, restrictions can be relaxed on constructions subject to the approval of the retrofitting such as the regulation on the volume ratio and building coverage can be eased for the qualified buildings.

In addition, the subsidy is introduced for seismic diagnosis & retrofitting, and income tax deduction for retrofitted buildings are being expanded.

The earthquake resistant building rate of Toyohashi

- Percentage of earthquake-resistant buildings in Toyohashi City

data: April, 2013

Classification	Number of buildings	Buildings built after New earthquake resistance law (earthquake resistant) ①	Buildings built before New earthquake resistant law		Earthquake resistant buildings ①+②	Percentage
			Earthquake resistant ②	Not earthquake resistant		
Wooden house	82,100	54,600	13,630	13,870	68,230	83.1%
Excluding wooden house	59,300	48,000	9,310	1,990	57,310	96.6%
Sum	141,400	102,600	22,940	15,860	125,540	88.8%

(From Toyohashi City Seismic retrofitting Promotion Plan of buildings H 26.3)

Building conversion Rate to Earthquake resistance: The number of buildings which are seismically diagnosed or statistically estimated that they have earthquake resistance (meets earthquake resistance criteria)is divided by the total number of buildings.

- Current condition:
  Buildings: 78.8% (2003) → 88.8% (2013)
  Specific existing incompetent buildings (public): 50 buildings (2007) → 8 buildings
  Specific existing incompetent buildings (private): 488 buildings (2007) → 330 buildings
- Target:
  Fiscal year 2015 90% (Cabinet decision in Fiscal year 2006)
  Fiscal year 2020 95% (Cabinet decision in Fiscal year 2010)

It has been 20 years since the establishment of the renovation promotion law, and conversion of buildings to earthquake resistance has made good progress.

The table shows the ratio of earthquake resistant buildings in Toyohashi City. The number of buildings which are seismically diagnosed or statistically estimated that they have earthquake resistance (meets earthquake resistance criteria)is divided by the total number of buildings, is building conversion rate to earthquake resistant. As of 2003, the building conversion rate to earthquake resistant was 78.8%, but rate has improved to 88.8% as of April, 2013. So it can be said that conversion of buildings to earthquake resistant has made good progress. Moreover, the target until the fiscal year 2025 is assumed to be 90%, and the figure is almost likely to be achieved. Incidentally, in fiscal year 2020, the goal is to reach the rate of 95%.

If we breakdown the conversion rate to earthquake resistance, then we get about 14,500 new buildings, about 9,900 renovated buildings, about 1000 buildings with earthquake resistance facilities.10% of these buildings had government subsidies.

Existing ineligible specific buildings are decreasing as well, so far there are only 8 public buildings and 330 private buildings left.

Subsidy for Seismic diagnosis & Retrofitting in Toyohashi

(Partially extracted)

- Subsidy and assistance to Seismic diagnosis & Retrofitting

  ・Implementation of free seismic diagnosis for wooden houses which were built before the new earthquake resistance law.

  ・Assistance for seismic diagnosis cost of non-wooden houses before new earthquake resistance law
  2/3 of the cost, the maximum limit is 86 thousand yen

《Seismic diagnosis cost》
Depending on the scale, Seismic diagnosis cost of general wooden houses is about 15 to 25 thousand yen

- Subsidy for Seismic Retrofitting

  ・If the value of free diagnosis of wooden house is less than 1, then the value is increased to 0.3 or more that; and if the value is 1 or more, then the 23% subsidy of Seismic retrofitting cost, 2/3 of the design cost, maximum 1.2 million yen will be provided by Government.

《Seismic retrofitting cost》
Seismic retrofitting cost of most of the wooden houses is about 1.5 to 2 million

- Subsidy for dismantling work (Rebuild)

  ・If the value of free diagnosis of wooden house is 0.7 or less, then 2/3 of dismantling construction cost will be covered by subsidy; maximum 200 thousand yen.

(From Toyohashi City Seismic retrofitting Promotion Plan of buildings H 26.3)

It is very important to ensure earthquake resistance of people's residence in order to preserve human lives at the time of earthquake and secure residents after the earthquake. For that purpose, each municipality is preparing a subsidy system in order to conduct seismic diagnosis, confirm safety, and promote seismic retrofitting.

As an example of the subsidy system related to seismic diagnosis & retrofitting, partly excerpted subsidy system in Toyohashi city is shown.

There are subsidy for seismic diagnosis, retrofitting & disassemble work etc. As for seismic diagnosis assistance, seismic diagnosis of wooden houses built before new earthquake resistance law can be implemented free of charge, which is considered to lead to promotion of seismic retrofitting towards the target value of earthquake resistance rate.

Depends on the scale of construction but anyway Seismic diagnosis cost of general wooden houses is about 15 to 25 thousand yen.

Towards promotion of Seismic retrofitting

Buildings constructed complying with the old earthquake resistance law have incentives for Seismic diagnosis and retrofitting.

First, Need to confirm whether the building was built before 1981 or not.

For buildings built before 1981
→Seismic diagnosis and retrofitting investigation
→Assistance and subsidy

While seismic diagnosis, seismic performance of buildings depends on four factors: strength of building, tenacity, shape, and degree of deterioration age.

Here, important part is “strength” which is the strength of the building and “toughness” which is tenacious strength against deformation.

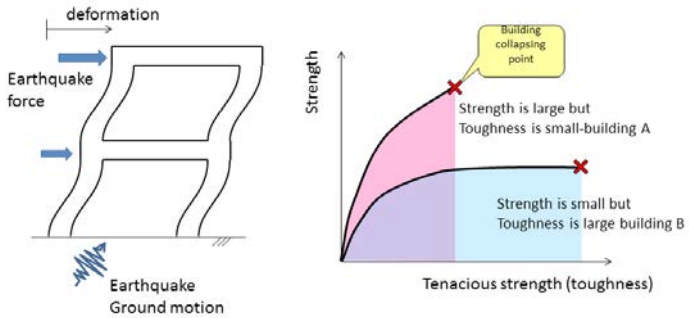
When earthquake occurs, the inertial force due to the earthquake motion acts as a horizontal seismic force to buildings causing deformation.

In the figure on right, it’s assumed that buildings collapse when they are deformed up to the x mark. The earthquake energy absorbed is represented by the relation between the force (strength) & the deformation (toughness) and it’s the colored area under the curve.

Approach to Seismic Diagnosis (review)

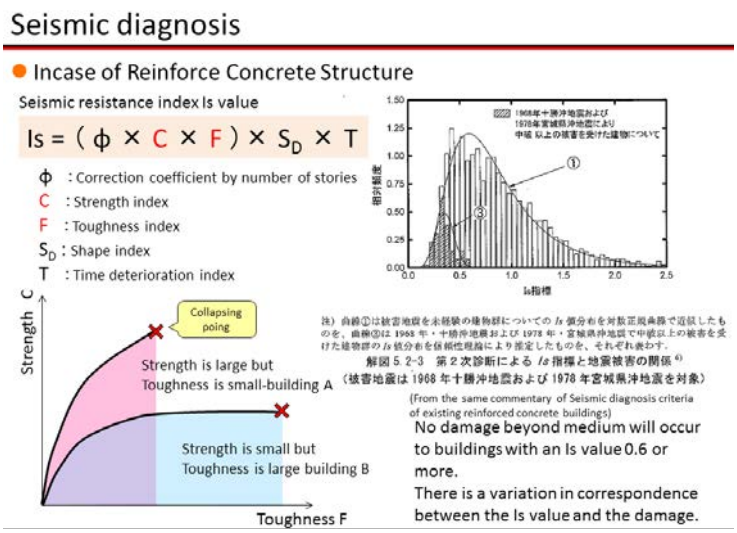
Seismic performance by seismic diagnosis

=(strength × toughness) × shape × degree of deterioration



For example, assuming that the area of the colored portion of the building A with larger strength but smaller toughness and the colored portion of the building B with lower strength and higher toughness are same, which means the energy absorbing capacity of both these buildings are the same. Therefore, the seismic performance of the two buildings can be regarded as the same. Based on this viewpoint, the seismic performance of the building can be represented by a simple index called Is value.

In the case of a reinforced concrete structure, I will show the seismic performance of buildings judged by seismic diagnosis.

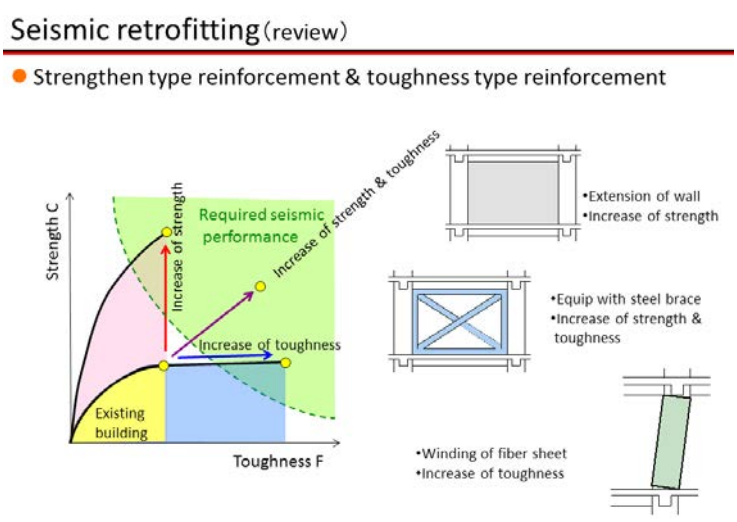


First, the structural seismic index Is value is used as an indicator of seismic resistance of the building. The Is value is calculated from the above equation, where the strength index C is the strength of the building, the toughness index F is an index showing the tenaciousness of the building, and Is is obtained by multiplying them. In addition, apart from these indexes, correction coefficient , shape index which is a reduction coefficient considering the irregularity of the building (if the building is rectangular, L-shaped, or the wall is biased on one side of the building) , and there are time deterioration index which is an aging indicator (building years and the presence or absence of cracks) which are reduction factors considering aging of the building. These will also be multiplied.

This Is value is a numerical value of the performance up to the point where the building is broken as shown in the figure on the right, and this value evaluates whether the building will collapse or not. In other words, when an earthquake of certain size occurs, building may not collapse but it could be damaged.

The figure on the right compares the secondary diagnosis results of the existing reinforced concrete buildings that have not yet experienced the earthquake, with the building that suffered beyond medium damage in the 1968 Tokachi-offshore earthquake and in the 1978 Miyagi prefecture offshore earthquake. It can be seen that the building with the Is value of 0.6 or more is not damaged beyond medium damage. If the Is value gets lower the possibility of damage increases, and you can also notice that there are variations in the diagnosis result when the value is below 0.6.

For these reasons, the Is value, required by the building, is 0.6 or more as one of the guidelines.



Based on the Is value in the seismic diagnosis, unless the earthquake resistance performance required by existing buildings is satisfied, we will consider seismic retrofitting / reinforcement.

There are four ways to improve the seismic performance of existing buildings. These are strength type, toughness type, damping type and base isolation type.

Strength type is a way to increase the strength of the existing building as shown in the figure. Toughness type is a method to increase the toughness of existing building as shown in the figure. In this way we can have the necessary earthquake resistance performance.

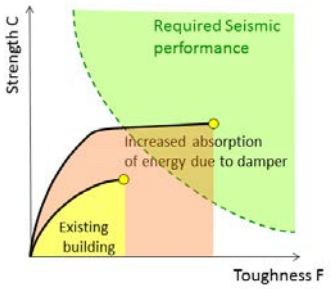
The damping reinforcement is a method of increasing the energy absorption performance of buildings by using seismic dampers.

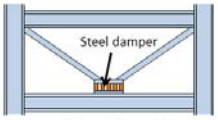
As shown in the figure, the idea is to improve seismic performance by increasing the area obtained from the relationship between strength and toughness.

The seismic damper is installed with brace or frame.

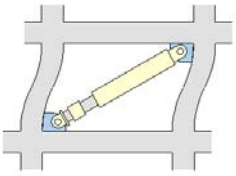
Seismic retrofitting (review)

● Reinforcement by damping: Damper





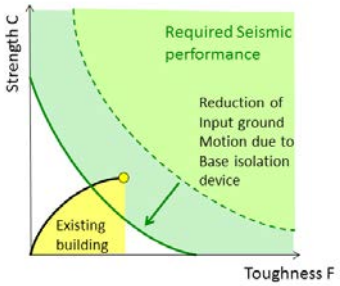
Incorporation of brace into steel damper

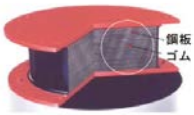


Incorporation of oil damper into frame

Seismic retrofitting (review)

● Reinforcement by base isolation





Laminated rubber isolator

Oil damper

Furthermore, the seismic isolation type is a method of weakening the seismic force transmitted from the ground by installing a seismic isolation device between the ground and the building.

A typical seismic isolation system consists of "isolator" and "damper", and "isolator" has the role of changing a shorter periodic seismic motion to a longer periodic seismic motion. On the other hand, "damper" is an energy absorbing device which has the role of stopping the deformation of the buildings.

INDEX: 日本免震構造協会
http://www.jssi.or.jp/menshin/m_kenchiku.html（2014.10)

Perspective of considering seismic retrofitting

● Fulfill required seismic performance

Is ≧ Iso

Is : Seismic index of structure
Iso : Seismic judgment index of structure

Target value

Although the basic target value is set to be 0.6, it may be increased according to the Importance of the facility.
(Shelter, earthquake countermeasure base, etc.)

● Cost

● Usability during construction

- Usage of residence or office even during construction.
- Problems of noise and dust
- Temporary relocation is necessary for construction inside the building
- Construction period should be shorter

● Ensuring of usability and functionality

- Avoid blockage the opening by adding walls.
- Function as a passage; lighting.

Based on the above concept of seismic retrofitting, what kind of seismic retrofitting will be suitable for a certain building depends on various considerations.

First of all, how far to improve seismic performance. It is necessary to make it larger than the structural seismic judgment index Iso, which is the target Is value of building after earthquake repair work. Generally, the structural earthquake resistance judgment index is set to 0.6, etc. However, the school facilities should be set at 0.7, evacuation centers and earthquake countermeasures bases will be increased by 1.25 times or 1.5 times taking the importance of facilities into account.

To do so, probably the most annoying problem is cost. It is also an option to choose an inexpensive construction method to reinforce at least against collapse. If the target service period is long, one option is to improve seismic performance so that it can be used continuously even after the earthquake.

Next is the usability during construction. Even during retrofitting work, it is often troublesome if you can not use it as a residence or office. In that case, if there is too much noise, dust and vibration, the living qualities will be impaired. So it is desirable to keep construction as small as possible. In addition, it is better to implement a shorter construction term , as temporary relocation is sometimes necessary. For this reason, there is a construction method that carries out seismic retrofitting only on the outside of the building.

Finally usability, functionality must be insured. For example, the reinforcement method like to add walls can improve strength at a relatively low price, but it will close the opening. As a result, the function as a passageway and lighting are disturbed. That's why, we've to consider selecting other construction methods.

Here, we summarized the method of seismic retrofitting for buildings other than wooden houses such as RC structures and Steel structures.

Since each construction method has its features, the construction method to be adopted based on advantages & disadvantages.

Types of Seismic retrofitting

● RC Structure & Steel Structure (excluding wooden house) 1

Types	Reinforced portion	Main characteristics	Method of construction, Materials
Expansion of RC wall	Frame	•Increase of strength & stiffness •Closure of opening	Cast in site wall (anchor or no anchor) Precast
Boost of RC Wall	Wall	•Increase of strength & stiffness	
Brace	Frame	•Increase of strength, stiffness & toughness •Lighting, Securing passage	Steel brace Concrete brace
Winding of steel sheet	Column	•Increase of toughness	
Continuous fiber winding	Column	•Increase of toughness •Simplicity of construction as no use of heavy machinery	Carbon fiber Polyamide fiber Polyester fiber
Expansion of sleeve wall	Column	•Increase of strength & toughness	
Newly built structural slit	Column	•Increase of toughness	

Types of Seismic retrofitting

● RC Structure & Steel Structure (excluding wooden house) 2

Types	Reinforced portion	Main Characteristics	Method of construction, Materials
External reinforcement	Frame	Increase of strength & stiffness Retrofitting while using the residence.	Wall Brace Frame
Buttress reinforcement	Frame	Increase of strength & stiffness Retrofitting while using the residence Need space outside	
Base isolation	Building	Decrease of Seismic motion.	Natural rubber type laminated rubber Sliding bearing Rolling bearing
Seismic mitigation damper	Frame	Increase of energy absorption	Viscoelastic damper Friction damper Low yield point steel damper

Expansion of RC Wall

•Increased RC wall to existing frame to improve stiffness & strength
•Might close the openings.
•Compared to other construction methods, strength is ensured through relatively inexpensive way.

● Seismic retrofitted wall with anchor

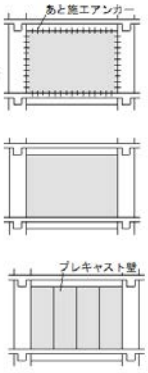
General construction method to join frame work by post installed anchor.

● Seismic retrofitted wall without anchor

As post installed anchor wasn't used, vibration and noise are small (adhesive bonding by epoxy resin etc.)

● Precast reinforced wall

No need to cast concrete in site
Shorter construction period



From here on, we will discuss compactly about seismic retrofitting method.

This is the reinforcement method by adding the RC wall. In this method we increase the stiffness and strength by adding RC wall in the existing frame as shown in the picture. Compared with other construction methods, it is characterized by being able to secure strength at a relatively low price. There are several types of this construction method. In general, in the seismic retrofitted wall with post installed anchor, existing frame is joined by using anchor. The wall part is cast in the site. In this case, problems such as vibration and noise due to connecting anchor to the wall will emerge.

As a construction method to mitigate the problem, there is a non-anchor seismic reinforced wall construction method. As a replacement of anchor,adhesive bonding such as epoxy resin etc. are used. In addition, there is a precast reinforced wall reinforcement, which is a method of manufacturing wall panels at the factory and then attaching them to existing frames. There is no need to cast concrete at the site. there is also a merit, and that is the construction period can be shortened.

This is brace reinforcement. By attaching steel brace and concrete brace to existing frame, it is possible to improve stiffness, strength and toughness. Additionally, it is possible to secure lighting and ventilation characteristics unlike the addition of RC walls which completely block the opening. The shape of the brace is X, V, etc. The mansard type brace can secure a passage through it as shown in the figure below on the left.

Also, with the addition of RC walls, there are anchor installed RC walls and non anchor RC walls.

Expansion of braces

Adding brace to existing frame to increase the strength and stiffness.
Lighting & Ventilation are secured.

Retrofitted by V shaped steel brace

Retrofitted by Mansard shaped steel brace

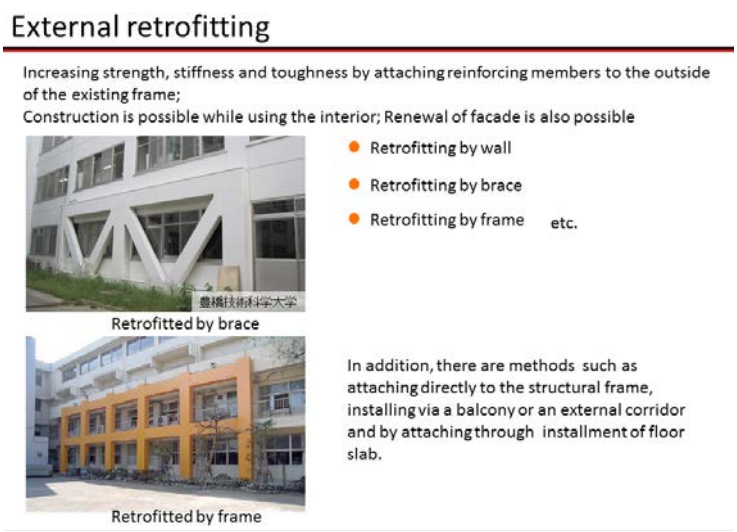
● X shape brace

● V shape brace

● Mansard brace

Opening could be secured.

Photo：文部科学省　耐震補強工法事例集



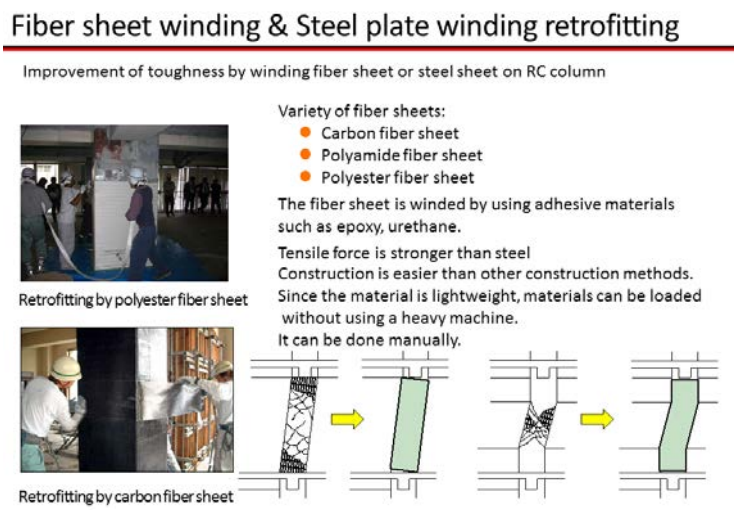
Photo：文部科学省　耐震補強工法事例集

As the name suggests external reinforcement refers to a construction method that reinforces by attaching a reinforcing member to the outside of the building .

The main characteristic is that construction can be done while using the interior because of the method of attaching the reinforcing member to the outside of the building. There are types of reinforcing elements such as wall, brace, frame, and in the case of retrofitting by frame , the window space can be secured as shown in the lower left figure. Residence area such as housing complex or apartment, where lighting and ventilation is very important, in such places this retrofitting by frame is recommended. In addition, there are methods such as attaching directly to the structural frame, installing via a balcony or an external corridor and by attaching through installment of floor slab.

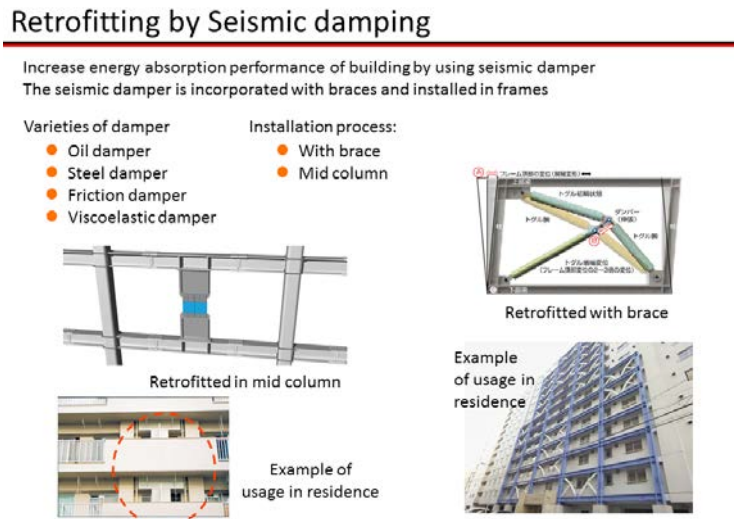
This is retrofitting by fiber sheet winding & steel plate winding. Unlike the retrofitting methods that raise the strength shown up to now, it is a construction method aimed at improving toughness, in particular.

As shown in the photograph, winding the fiber sheet or steel sheet around the RC column with an adhesive such as epoxy resin to bond it. If an excessive force (deformation) is applied to the column, there is a possibility that brittle shear failure may occur and support to the upper floor may fail. It is a method for improving toughness by winding a fiber sheet around column and restraining it from being damaged. As this material is lightweight, it can be carried in without heavy machinery and construction can be done manually.



Photo：繊維補修補強協会：http://www.fir-st.com/index.html（2014.10)

So it can be said that construction is easy and inexpensive compared to other construction methods.



As mentioned above, seismic retrofitting by the seismic isolation system is a method of absorbing energy by a damping control system such as a damper and reducing shaking of the entire building during the earthquake.

Dampers are installed in mid columns or incorporated with braces as shown in the figures, and they can be attached inside or outside the building.

Figure：飛島建設
https://www.tobishima.co.jp/technology/architecture/seishin_index.html（2014.10)

Retrofitting by Base Isolation

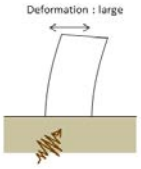
By installing a seismic isolation device between the ground and the building, seismic force transmitted from the ground can be reduced largely.
The isolation device consists of an isolator (bearing) and a damper.

The isolator supports the building and moves it slowly at the time of an earthquake.

The damper works to quickly stop the continuous shake of the building.

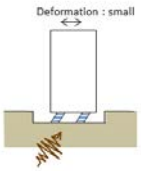
Natural rubber type laminated rubber bearing

Steel damper



Sliding bearing

Lead damper



Photo：日本免震構造協会　http://www.jssi.or.jp/menshin/m_kenchiku.html（2014.10）

Seismic retrofitting using a seismic isolation device is a method of weakening the seismic force transmitted from the ground by installing a seismic isolation device between the ground and the building.

A typical seismic isolation system consists of "isolator" and "damper", and the "isolator" has the role of changing a short period of seismic shake to a long period. And the "damper" is an energy absorbing device which works swiftly to mitigate buildings shaking. Although seismic retrofitting by base isolation equipment has cases such as Tokyo station building and Nagoya city office, but still they are just handful. The reasons for this are the price of the seismic isolation device, the necessity of the isolation pit (such as the basement floor) where the isolation device is placed, and the high cost due to the necessity of plumbing facility that can follow the large deformation.

There are various shapes and conditions in the buildings, and there are many ways of retrofitting in compliance with those shapes & conditions. The cost may not be said unconditionally, but anyway we will introduce some modification examples.

This is a construction method which adopts the external frame construction method which can do construction while using the interior and does not impair the functions of the passage and the lighting property of the window.

Index：愛知建築地震災害軽減システム研究協議会：耐震改修事例集
http://www.aichi-gensai.jp/ （2014.10）

Example of Retrofitting: Case 1

- Building overview

Structure: RC structure
Scale: 5 story
Built: 1970

- Construction overview

Cost: Approx. 20 million yen
Period: 4 months
Construction: Yahagi Engineering

- Construction method overview

Retrofitting by external frame (CESRet method)
Column 10 pieces (5 facades)

- Is value before and after retrofitting (X direction)

Story	Before	After
5	1.35	1.35
4	0.76	0.76
3	0.69	0.69
2	0.54	0.68
1	0.46	0.65

Ensure entrance

Protect aesthetic view

Example of Retrofitting : Case 2

- Building overview

Structure: RC structure
Scale: 3 story
Built: 1965

- Construction overview

Cost: approx. 13 million yen
Period: approx. 9 months
Construction: Yahagi Engineering

- Construction method overview

Retrofitting by external frame (CESRet method)
Column 4 pieces (2 façades)

- Is value before and after retrofitting (X direction)

story	Before	After
3	1.68	1.68
2	1.31	1.31
1	0.41	0.74

Securing entrance and protecting aesthetic view

Similarly, this is a construction method that can be executed while using the interior such as adopting an external frame construction method that does not impair the function of the passage and the lighting property of the window.

Index：愛知建築地震災害軽減システム研究協議会 耐震改修事例集
http://www.aichi-gensai.jp/ （2014.10）

Example of Retrofitting : Case 3

- Building overview

Structure : SRC structure
Scale : 10 story
Built : 1974

- Construction overview

Cost : Appro. 2 hundred 40 million yen
Period : approx. 7 months
Construction: Yahagi Engineering

- Construction method overview

Retrofitting by external frame
(Frame type pit column method)
Column 128 pieces

- Is value before and after retrofitting(South-west direction)

story	Before	After
5	0.46	0.87
4	0.43	0.85
3	0.45	0.78
2	0.41	0.77
1	0.37	0.63

Before retrofitting　After retrofitting

This is an example of retrofitting of pretty large scale building.

Index：愛知建築地震災害軽減システム研究協議会　耐震改修事例集
http://www.aichi-gensai.jp/ （2014.10）

There are various kinds of construction methods. It's necessary to pick the right method so that it doesn't impair the functionality and aesthetic appearance of the building.

Example of Retrofitting : Case 4

- Building overview

Structure : RC structure
Scale : 14 story
Built : 1962

- Construction overview

Cost : Approx. 630 million yen
Period : Approx. 1 yr 2 months
Construction : Takenaka Corporation

- Construction method overview

Expansion of RC earthquake resistant wall
(Adhesion method, add-on method)
Expansion of steel brace
Expansion of latticed steel sheet panels
Expansion of SRC external frame
Column RC winding stand
Structure slit

- Is value before and after retrofitting (South west direction)

Story	Before	After
5	0.46	0.87
4	0.43	0.85
3	0.45	0.78
2	0.41	0.77
1	0.37	0.63

Facade

Latticed steel sheet panels

Expansion of RC earthquake-resistant wall

Index：愛知建築地震災害軽減システム研究協議会　耐震改修事例集
http://www.aichi-gensai.jp/ （2014.10）

Types of Seismic Retrofitting

- Long span structures（Gymnasiums，factories etc），Steel structures

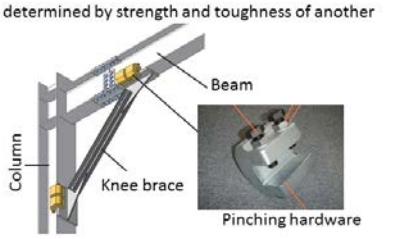
Types	Reinforced portion	Main Characteristics	Method of construction, Materials
Reinforcement by brace	Frame	Increase of strength, toughness and stiffness	Steel brace Concrete base
Horizontal brace retrofitting	Roof	Increase of strength & stiffness Transmission of horizontal forces through roof	Steel brace
Rib plate retrofitting	Beam to column joint	Reinforcement of beam to column joint & column to column joint	
Knee brace retrofitting			
Plate retrofitting			
Retrofitting by base wrapping concrete	Column base	Retrofitting of column base	
Retrofitting of ceiling	Ceiling	Prevention of fall or damage of ceiling	Reinforcement of the ceiling hanger

Here, we summarized the construction method of seismic retrofitting for large span structures such as gymnasiums, factories and Steel structures.

Retrofitting of Beam to Column joint

By raising the stiffness and strength around the column joint by using steel plates and knee braces, it is possible to prevent breakage of the welded joint around the beam joint and its surroundings.
As a result, the seismic performance is determined by strength and toughness of another member

Retrofitting by Rib plate



Retrofitting by Knee brace of Pinching joint

For joining retrofitting members, welding and bolt are used.
At sites where fire can not be used, pinching joint may be adopted instead of welding.

Here we show the retrofitting method of the column to beam connection in Steel structure.

This is a method of raising the stiffness and strength by using a steel plate (rib plate) or knee brace for beam to column joint like this image. By retrofitting, it is possible to prevent breakage of the welding joint around the beam joint and its surroundings. By improving the seismic performance such as strength and toughness of members, in a whole the seismic performance of the entire building will be improved.

Welding and bolt joining are common and inexpensive for joining of reinforcing members. But in the sites where fire is prohibited, or bolt holes are difficult to open because of vibration, pinching joints by using pinching hardware such as the one shown on the right are adopted.

Photo：文部科学省：耐震補強早わかり　地震に負けない学校施設－耐震補強事例集
Figure：矢作建設工業：http://www.yahagi.co.jp/solution/resist/achieve.html（2014.10)

In buildings with large spans like the gymnasium, there are cases where the roof is reinforced, and the strength and stiffness are improved by the horizontal brace.

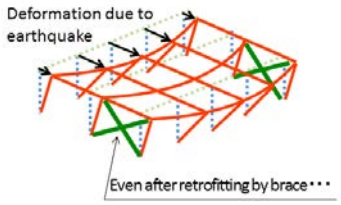
This is to suppress the deformation and damage of the roof at the time of earthquake and to prevent the fall of the ceiling. Also, if the stiffness of the roof is low, the center of the building will deform larger than the end, as shown in the right figure.

In this case, even if retrofitted with walls and braces at the end part of building, the retrofitting member is not effectively working against the seismic forces. In such case reinforcement may become necessary.

Retrofitting of roof by horizontal brace

Improve strength and stiffness by horizontal bracing of the roof
In addition to suppressing deformation and damage of the roof during earthquakes, it prevents the ceiling from falling.
Transmit the seismic force to the brace or extension wall through the roof.

Retrofitting of roof surface by horizontal bracing



If the horizontal stiffness of the roof is small, a large deformation happens in the center part

（左写真）文部科学省：耐震補強早わかり　地震に負けない学校施設－耐震補強事例集

Types of Seismic Retrofitting

● Wooden house

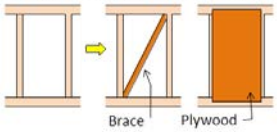
Types	Retrofitting portion	Main Characteristics	Construction method, Materials
Expansion of load bearing wall		Increase of strength and stiffness	Structural plywood
Expansion of brace		Increase of strength and stiffness	Wooden brace Metal brace
External Retrofitting		Increase of strength and stiffness Using interior while retrofitting	Brace Frame
Retrofitting of base	Base	Making base stronger	RC beam extension
Retrofitting of floor (2 story or above)	Floor	The whole building is made to be earthquake resistant	Brace, Angle brace beams
Retrofitting of joint	Joint	Prevent collapse of building due to coming off beam to column joints	Joint hardware
Making roof lighter	Roof	By reducing weight of roof, seismic force can be reduced	
Base Isolator	Building	Reduction of Seismic force	

Here, we have summarized the method of retrofitting for wooden houses.

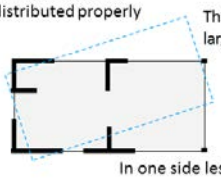
Retrofitting by Load Bearing Wall

Increase of strength of building through load bearing wall

Load bearing wall: A load bearing wall refers to a wall with diagonally installed braces within the columns and walls with structural plywood hammered with nails.



If the load bearing wall is not distributed properly



Examples of wall standard yield strength used in general diagnostic methods

Types	Standard wall resistance (kN/m)
Clay wall (Paint thickness40~50mm)	1.5
Brace(15×90mm, Fixed with metal)	2.4
Structural plywood	5.2

Many of the buildings collapsed by the earthquake are said to have a small amount of load bearing walls. First of all, increasing the load bearing wall and increasing the resistance to earthquake shaking becomes the basis of earthquake resistant reinforcement.

A load bearing wall refers to a wall with diagonally installed braces within the columns and walls with structural plywood hammered with nails.

It shows an example of a wall with standard yield strength used in the general diagnostic method. The standard wall strength is the strength of a wall of 1 m of length. It is a value that varies depending on the thickness and mounting conditions. The value is 1.5 for clay wall, 2.4 for the brace and 5.2 for the structural plywood. Retrofitting method by reinforcement of structural plywood makes it easier to ensure strength comparatively.

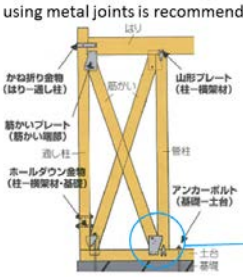
However, even if the amount of wall is sufficient, if the position of the wall is biased towards one side of the building or not well-balanced, it will not be able to hold on strong against earthquake. For example, if you have a large opening on the south or may not place a wall because of parking space, the building will be twisted, and deform in the less wall part resulting in collapse.

For that reason, we need to install a load bearing wall in the zone of few walls.

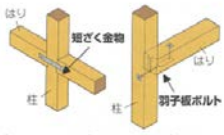
Although we mentioned the retrofitting method by using the load bearing wall, in order to make effective use of columns, load bearing walls as members resisting the seismic force , it is necessary to make the joint part secured.
Unless the joints are solid, there is a risk that the braces and columns may come off resulting in building collapse due to seismic force.

Retrofitting by Metal Joint

In order to make effective use of load bearing walls, columns etc. as members of resisting the seismic force, it is necessary to make the joint part secure.
For that purpose retrofitting of the joints of the braces, beams, columns and foundation using metal joints is recommended.



Example of brace joining on load-bearing wall



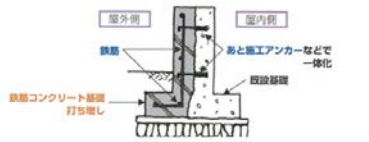
Side beam to column metal joint retrofitting

Brace end & Column base metal joint retrofitting

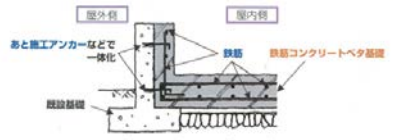
(Index) 豊橋市：命を守る家づくり～木造住宅の耐震対策のすすめ～

Retrofitting of Base

In order to make effective use of load bearing walls, columns, etc. as members resisting seismic forces, it is necessary to make the base firm too.
For that purpose we make expansion of reinforced concrete fabric base, mat foundation etc.



Retrofitting by reinforced concrete fabric base



Retrofitting by mat foundation

Figure：豊橋市　命を守る家づくり～木造住宅の耐震対策のすすめ～
Photo：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

The foundation of wooden houses is also an important structural element. Like the metal joints, for the load bearing walls to work effectively, the foundation must also be solid.

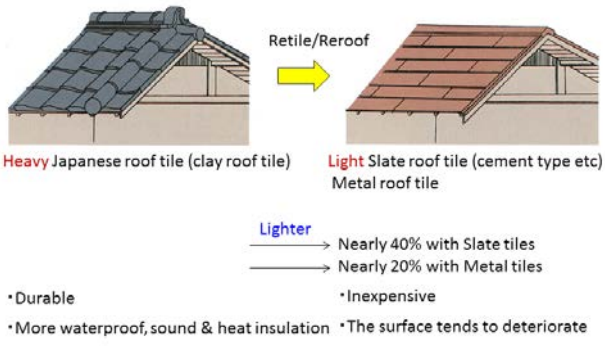
If there is no reinforcing bars in the existing base or if there are large cracks, the base may be broken and the upper building may collapse. In such case, we will build a base with new reinforcing bars and make the foundation strong.

The increase of only width to the existing fabric foundation below the base is considered a type of foundation.

Adding that, the other type is called solid foundation, and that is under the ground floor solid foundation of reinforced concrete.

Making Roof Lighter

By reroofing the roof tile to a light one to lighten the weight so that the seismic force gets reduced, Seismic resistance performance is improved.



Figure：豊橋市　命を守る家づくり～木造住宅の耐震対策のすすめ～

The heavier the house, the heavier the seismic force will be. This is because weight × acceleration due to earthquake motion = horizontal force acting on the building,
Therefore, the lighter the weight the smaller the seismic force the building will be. That is why, while retrofitting, when roof is covered with clay roof tiles, one of the recommendations is that to reduce the seismic force by changing heavy tiles to light tiles.

By reducing the weight of the roof, it is possible to improve seismic performance or have to reduce the amount of walls required.

Cost of Seismic Retrofitting（Wooden house）

This shows the seismic retrofitting cost of wooden houses.

Seismic retrofitting construction costs will vary depending on the size and condition of the housing.

The cost ranges from less than 1 million yen to about 5 million yen, but the most construction cost is 1 to 1.5 million yen. In addition, more than half of the works are done at about 1.87 million yen or less.

If the structure seismic resistance index Is value is considerably small, there is a possibility that the cost will be higher in order to satisfy the new earthquake resistance criteria. However, instead of doing seismic retrofitting at once, it is better to proceed step by step. For example, if we have weak buildings with an Is value of about 0.2, we first set the Is value to 0.7 by installing load-bearing walls etc. As next step of retrofitting, we re-roofed the roof and set the Is value to 1.2. We should approach forward to make buildings earthquake resistant even though we have our limitations, as our small contributions can lead us to reducing the loss when earthquake occurs.

Estimated cost for each seismic retrofitting construction

- **Load bearing wall (Exterior wall)**
  - 130～150 thousand yen/Width 910mm — Average 147 thousand yen/width 910mm
- **Load bearing wall (Interior wall)**
  - 90～120 thousand yen/Width 910mm — Average 121 thousand yen/Width 910mm（Interior）
  - Average 107 thousand yen/Width 910mm (Closet)
- **Roof**
  - 15～20 thousand yen/m^2 — Average18 thousand yen/m^2 (Steel sheet tile)
  - Average 15 thousand yen/m^2 (Slate sheet tile)
- **Base**
  - 40～55 thousand yen/m — Average 44 thousand yen/m (Additional)
  - Average 53 thousand yen/m (Newly built)
- **Joint**
  - 40～60 thousand yen/4 places — Average 50 thousand yen/4 places

Indicates the estimated cost for each seismic retrofitting construction.

When seismic retrofitting is concurrently performed with reforming, the cost of seismic retrofitting itself tends to be somewhat cheaper.

Example of Retrofitting: Case1

● Method of Retrofitting

Retrofitting of existing wall
(Earthquake resistant wall) 23 places

● Building overview

Number of stories: 2 story
1st floor: approx. 62m²
2nd floor: approx. 39m²
Built: 1981

● Is value before and after retrofitting

	1st floor X dir.	1st floor Y dir.	2nd floor X dir.	2nd floor Y dir.
Before	0.58	0.68		
After	1.03	1.24		

● Construction cost

Retrofitting of base crack	180,000	
Retrofitting of wall	1,776,000	23 places
Various expenses	156,000	
Total cost	2,112,000	

＊工事費用は参考としてください

It is an example of seismic retrofitting mainly by wall reinforcement.

Index：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

It's an example of retrofitting of base.

Index：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

Example of Retrofitting : Case 2

● Method of retrofitting

Retrofitting of existing wall
(Load bearing wall) 2 places

Existing base retrofitting 32m

● Building overview

Number of stories: 2story
1st floor: approx. 53m²
2nd floor: approx. 27m²
Built: 1978

● Is value before and after retrofitting

	1st floor X dir.	1st floor Y dir.	2nd floor X dir.	2nd floor Y dir.
Before	0.47	0.80	0.70	1.09
After	1.06	1.27	1.01	1.57

● Construction cost

Base retrofitting	1,470,000	32m
Wall retrofitting	223,000	2 places
Various expenses	84,000	
Total cost	1,777,000	

＊工事費用は参考としてください

Example of Retrofitting: Case 3

● Retrofitting method

Retrofitting of existing wall
(Load bearing wall) 30 places
Lightening of roof 160m²

● Building overview

Number of stories: 2 story
1st floor: Approx. 108m²
2nd floor: Approx. 47m²
Built: 1972

● Is value before and after retrofitting

	1st floor X dir.	1st floor Y dir.	2nd floor X dir.	2nd floor Y dir.
Before	0.40	0.40		
After	1.23	1.39	2.67	3.93

● Construction cost

Base retrofitting	2,050,000	160m²
Wall retrofitting	4,145,000	30 places
Various expenses	210,000	
Total cost	6,405,000	

＊工事費用は参考としてください

It is an example where seismic retrofitting is carried out mainly by basic reinforcement and weight reduction of the roof.

Here we have retrofitted roof from Japanese roof tiles (roofing) to flat roof slate roofing.

Index：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

Information on Seismic Retrofitting

- Ministry of Education

  Ministry of Education homepage
  「Example of Seismic retrofitting」,
  「耐震補強早わかり　地震に負けない学校施設ー耐震補強事例集」.
  学校施設の補強例が掲載．全体工事費，補強部分の概算も記載．

- Aichi Earthquake Disaster Reduction System Research Council of Building

  http://www.aichi-gensai.jp/　　(2014.10)

  「 Low cost seismic retrofitting guidance for Wooden houses 」

- Building Disaster Prevention Association

  http://www.kenchiku-bosai.or.jp/　　(2014.10)

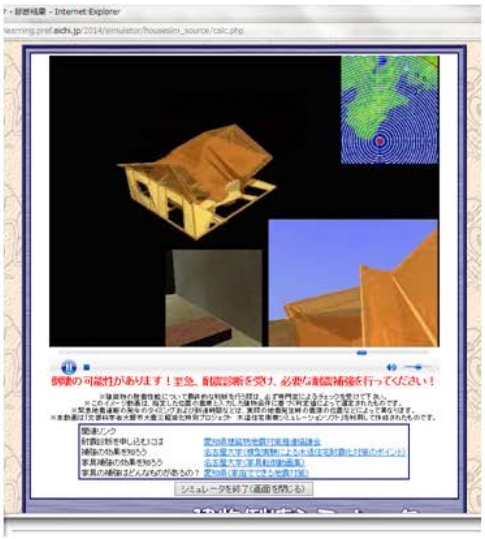
  「誰でもできるわが家の耐震診断」

Other information

- Aichi Prefecture Disaster Management Bureau: Aichi Prefecture Disaster Learning System

  http://www.quake-learning.pref.aichi.jp/　　(2014.10)

Simulation of building collapse



This is Aichi Prefecture disaster prevention learning system.

In the disaster prevention map, when the seismic motion of past large scale earthquake is input, you can see the seismic intensity distribution, liquefaction risk, tsunami flooding depth, etc. corresponding to Aichi prefecture.

In the "Building collapse simulator", if you enter simple information on a wooden two-story house, you will see animation whether it will collapse or not, in occurrence of earthquake.