Seismic Retrofit of the Existing RC buildings in Japan

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Building Research Institute,
Japan

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Contents

1. Basic concept of seismic retrofit
2. Retrofit design procedure
3. Examples of retrofitted buildings
4. Temporary repair and permanent strengthening after earthquakes
5. Conclusions

2001 revised version

Guidelines for Seismic Retrofit of Existing Reinforced Concrete Buildings, 2001

The Japan Building Disaster Prevention Association(JBDPA)

JBDPA seminar note

History of Seismic Retrofit Guideline

1977 First version was issued

★Back data of experiments and practical examples are included in the guideline

1990 Revised

1995 Hyogoken Nanbu (Kobe) Earthquake

★Practical examples of seismic evaluation and retrofit are performed.

★Development of easy construction technology

★Development of new technology

1998 Revision of Japanese seismic code

2001 Revised

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History of seismic retrofit technologies

1977 version	• RC column • RC shear wall • RC wing wall
1990 version	• Steel frame
2001 version	• Carbon fiber sheet • External frame • Precast Concrete frame • (SI unit)

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Technical terms

Repair	Recovering the original capacity by repairing
Strengthening	Improving the capacity by strengthening more than original capacity
Restoration	Making reusable by repairing and/or strengthening
Retrofit	The general term of repair, strengthening and restoration

JBDPA seminar note

Target capacity by retrofit

- **Is index after retrofit（$_{R}Is$）**

$$_{R}Is \geqq \alpha \cdot Iso = \alpha \cdot Es \cdot Z \cdot G \cdot U$$

- **Accumulative strength index after retrofit（$_{R}C_{TU} \cdot {}_{R}S_{D}$）**

$$_{R}C_{TU} \cdot {}_{R}S_{D} \geqq \alpha \cdot 0.3 \cdot Z \cdot G \cdot U$$

Where,

α	：Construction factor（1.0 ～ 1.2）
Z	：Zone index
G	：Ground index
U	：Usage index
$_{R}S_{D}$	：Irregularity index after retrofi
Es	：Basic seismic demand index
	1st evaluation：Es＝0.8
	2nd evaluation：Es＝0.6

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Target capacity by retrofit

★Demand Iso index

Iso＝0.6～0.7

Discussion with owner of building

★Recommended retrofit method

Strength type;

It can avoid the concentration of damage of structural member and/or the non-structural elements

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Basic concept of retrofit design

Point to consider for retrofit design

- ★Target demand seismic capacity
- ★Basic principle of retrofit
- ★Selection of optimum retrofit technology
- ★keeping the function of buildings
- ★Easiness of retrofit construction work

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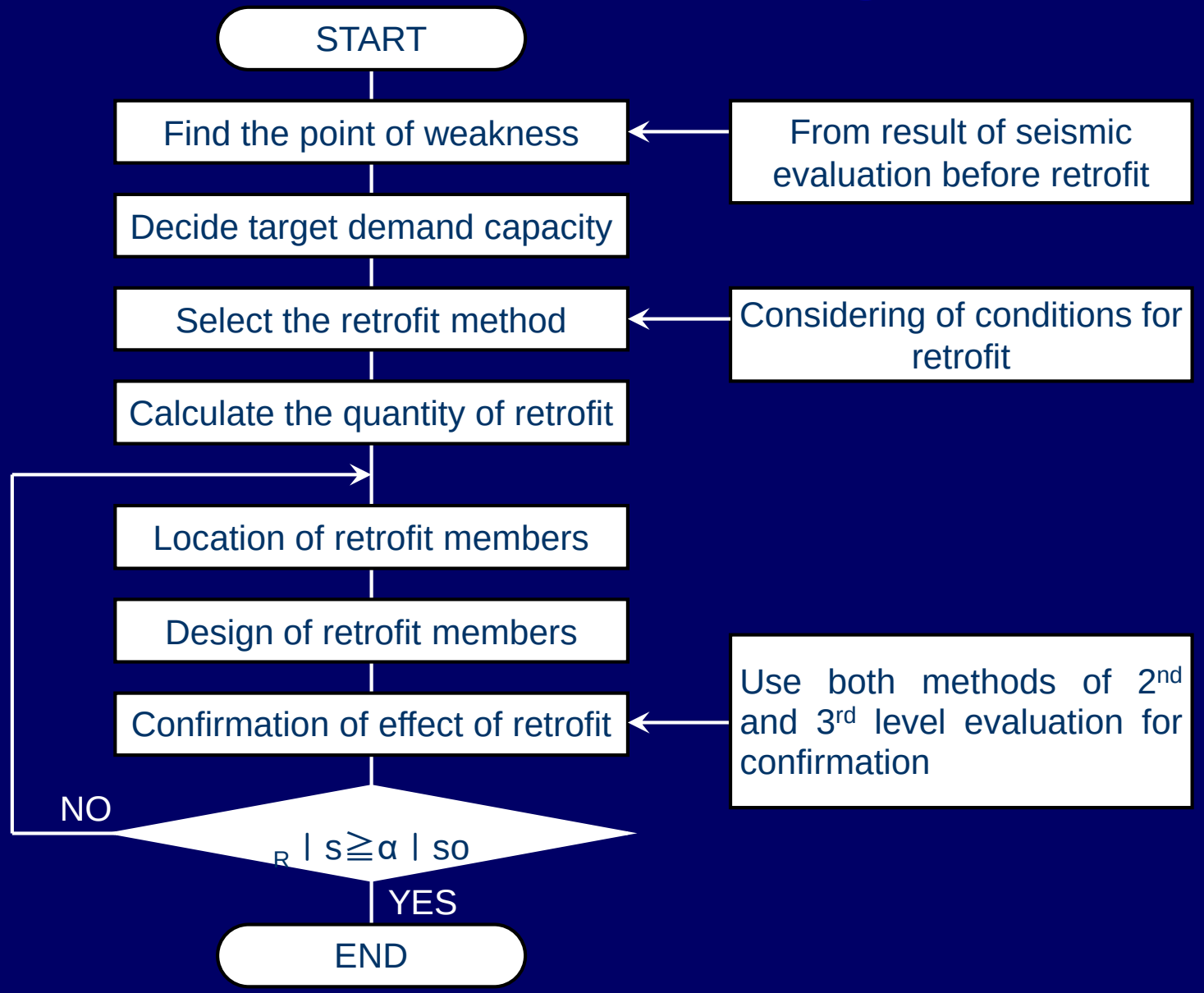
Flow of retrofit design



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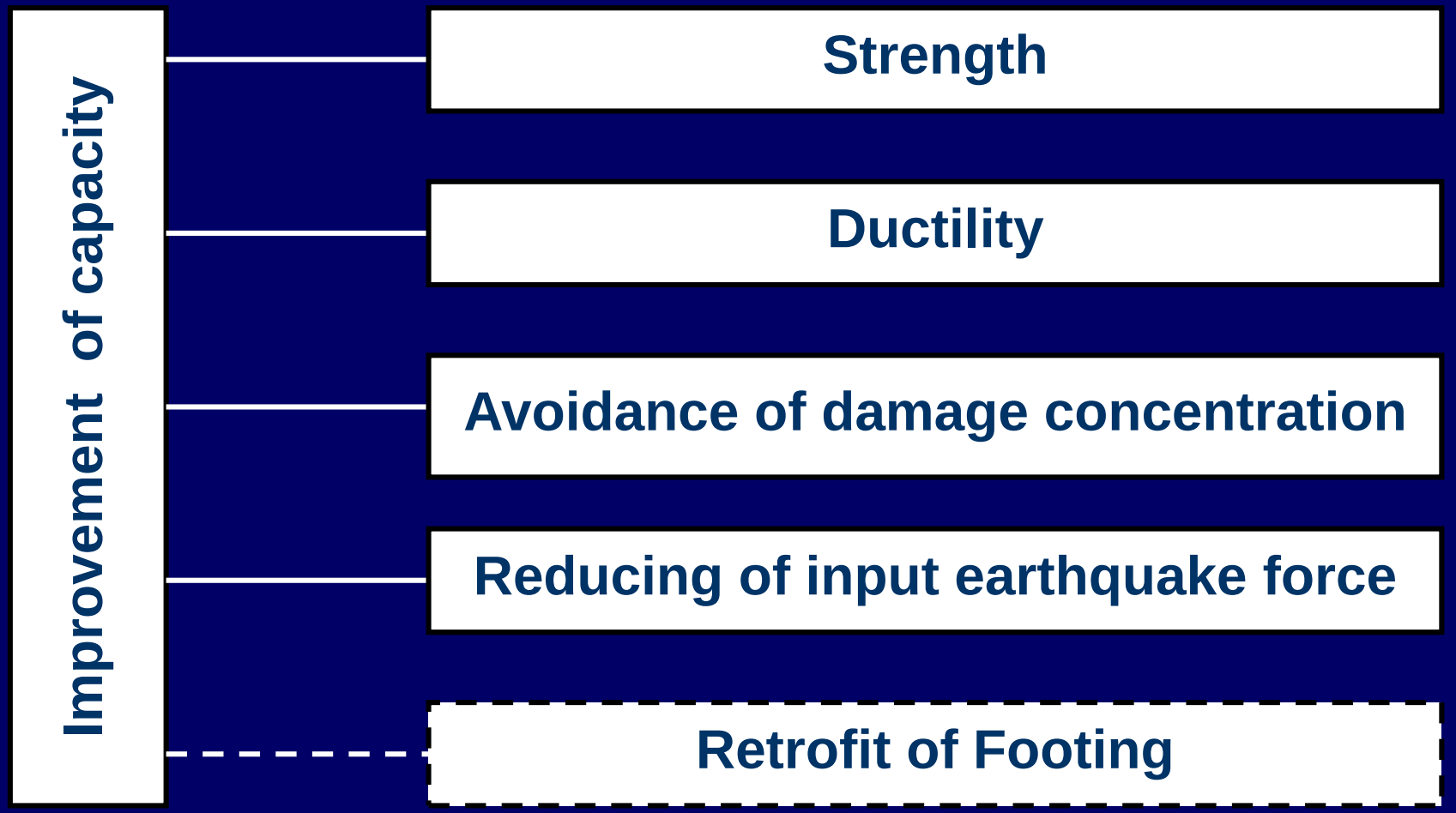
Classification of retrofit methodology



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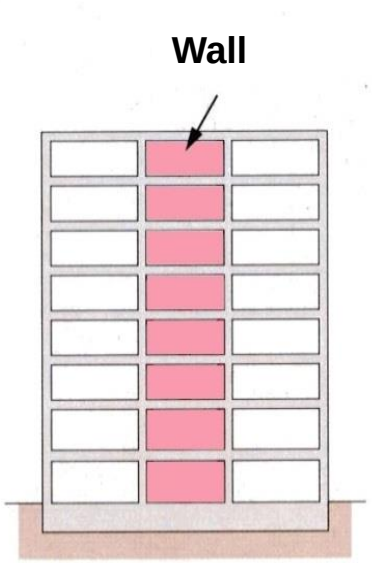
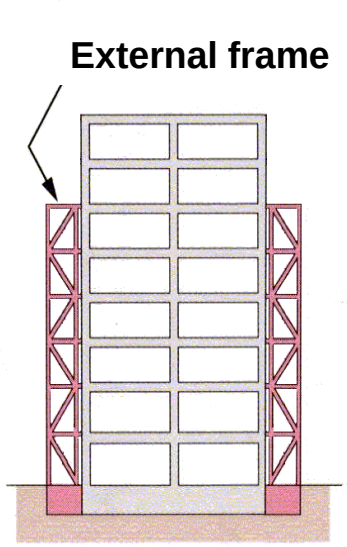
Classification of retrofit methodology

Strength

Wall, Brace

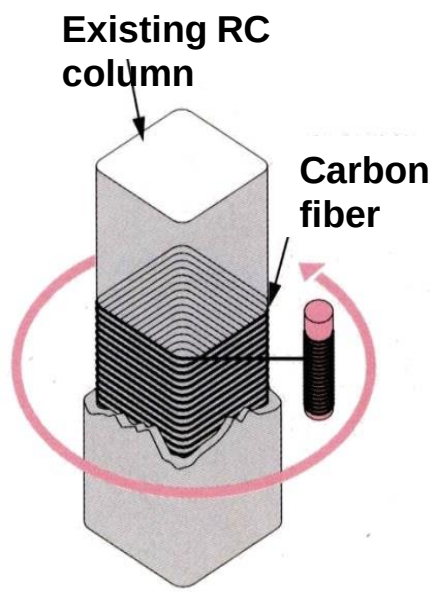


External Frame



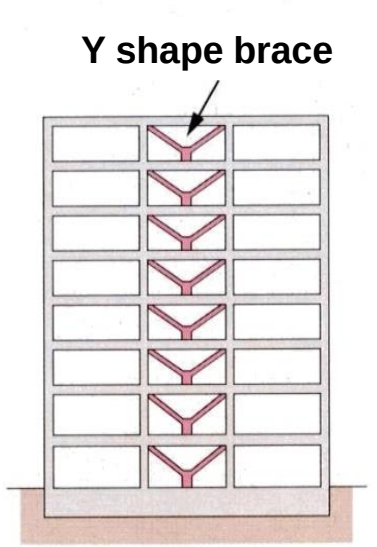
Ductility

Carbon fiber
（Steel plate）

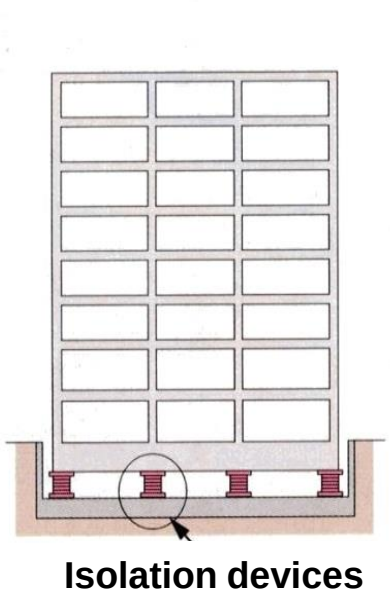


Reducing of input earthquake force

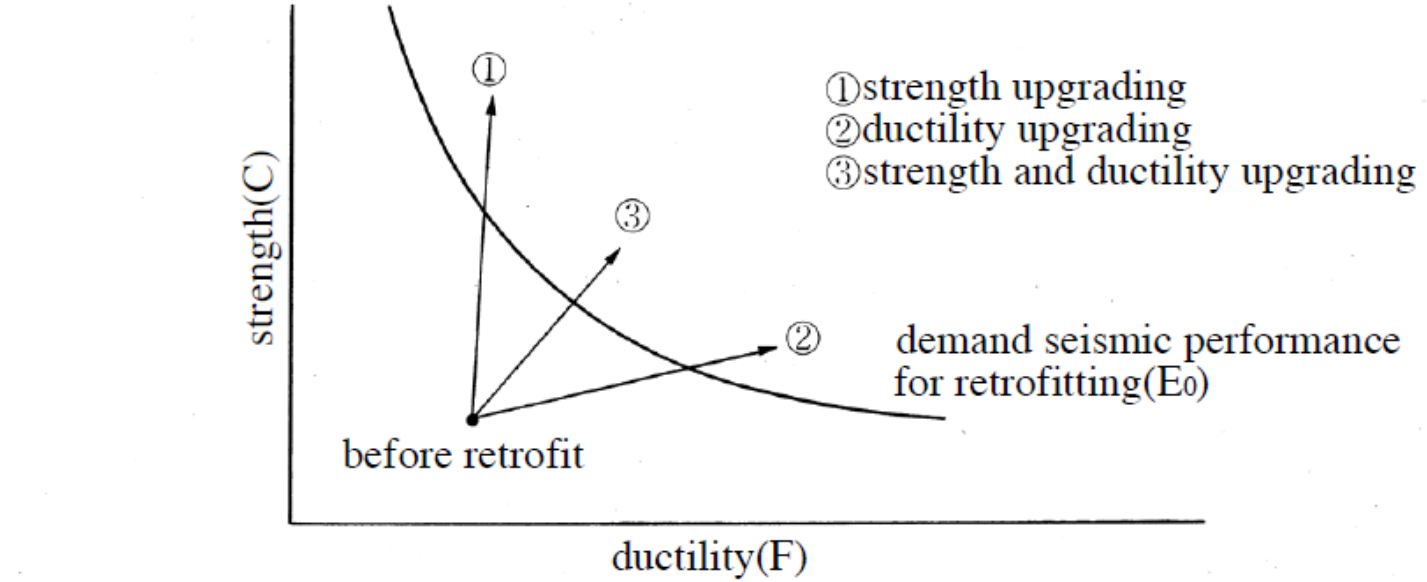
Vibration control
（Brace, Oil damper）

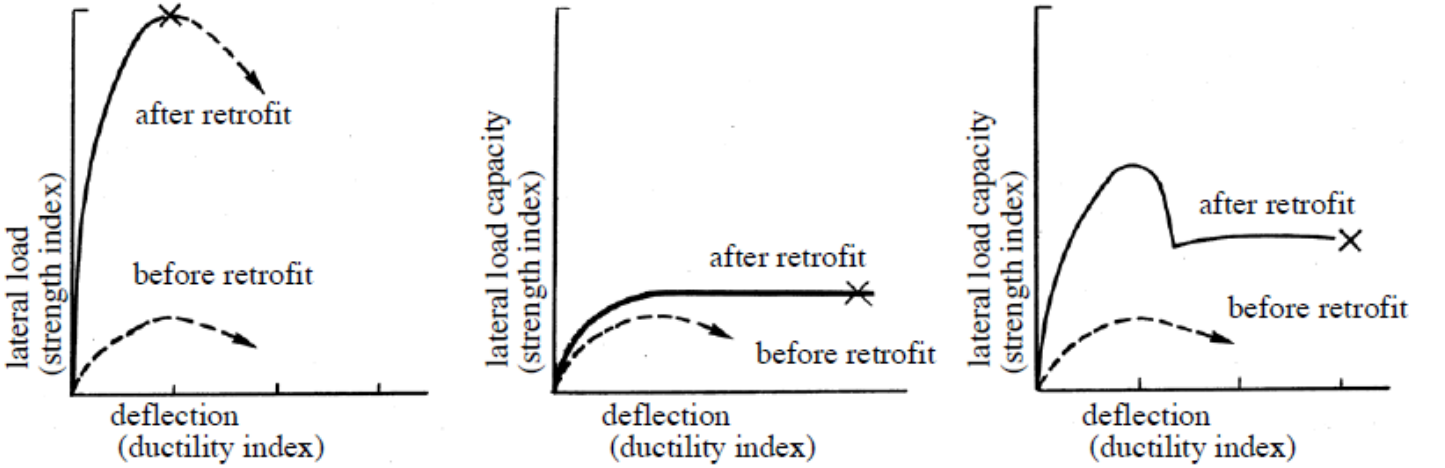


Seismic isolation
（Isolator, Dampers）



Improvement of Capacity





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Classification of retrofit methodology

Improvement of capacity

- Strength
  - Shear wall
  - Steel frame
  - External frame
  - External new frame
  - Others

Shear wall

Steel brace

External frame

Buttress

Lattice brick

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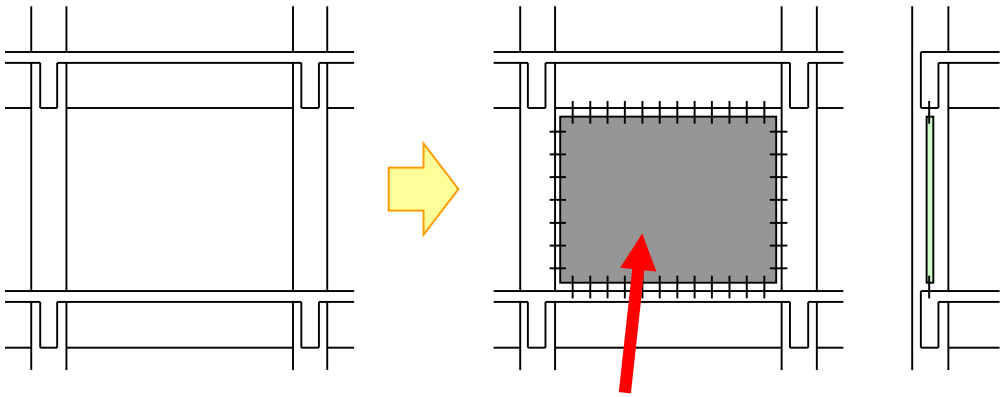
Classification of retrofit methodology

Post installed RC wall (strength type)

Shear wall



Shear wall

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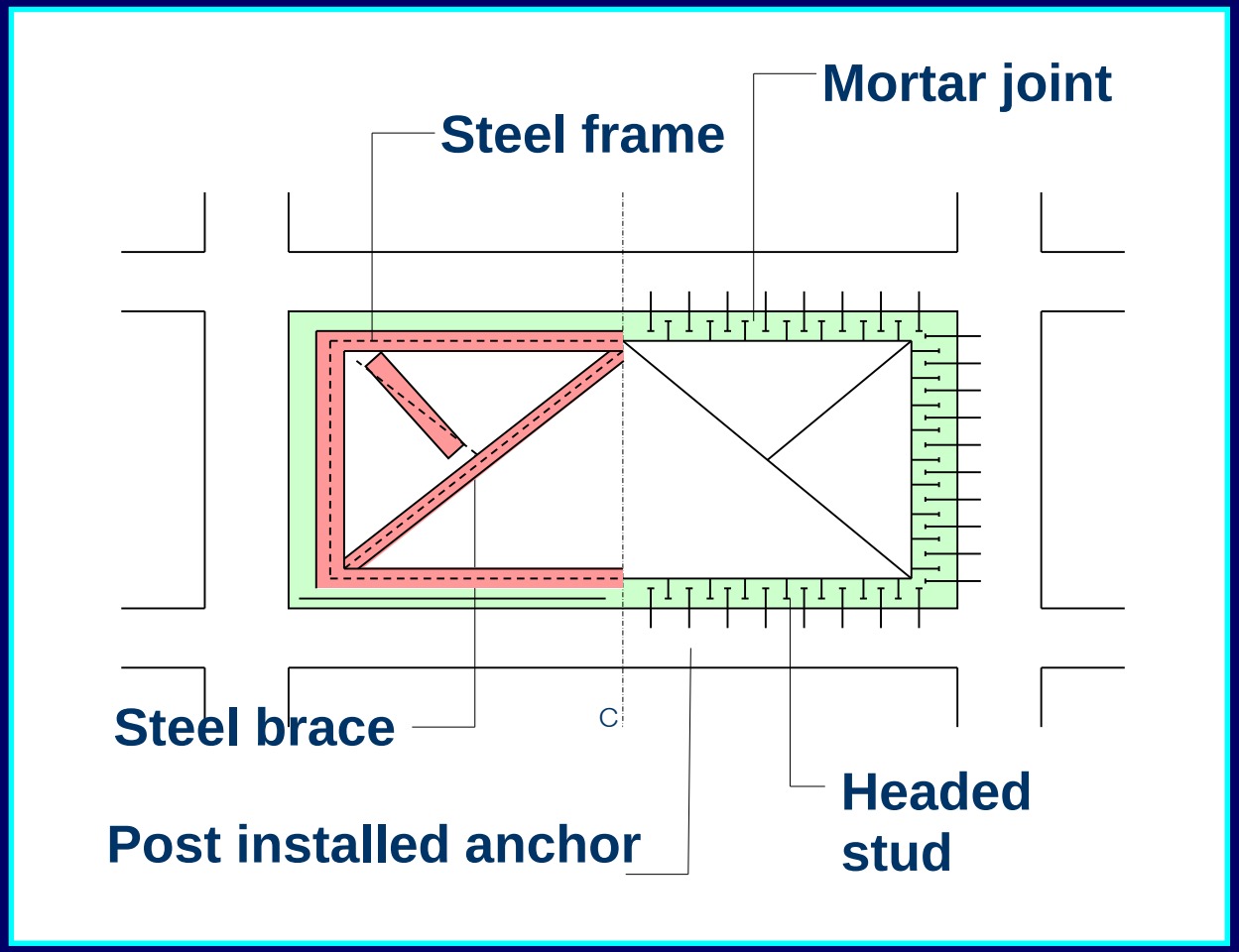
Classification of retrofit methodology

Steel brace retrofit (strength type)



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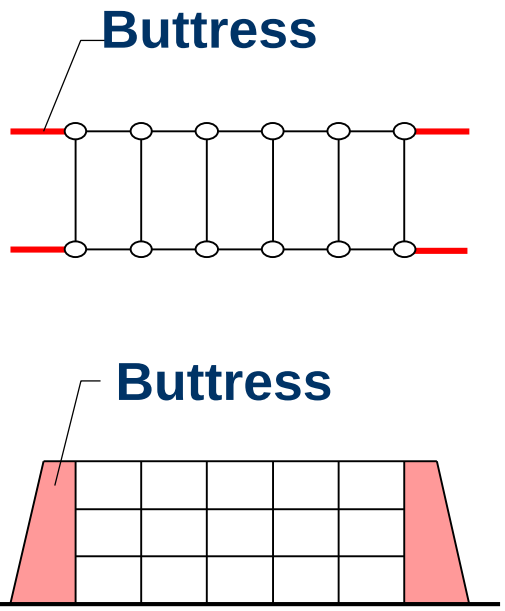
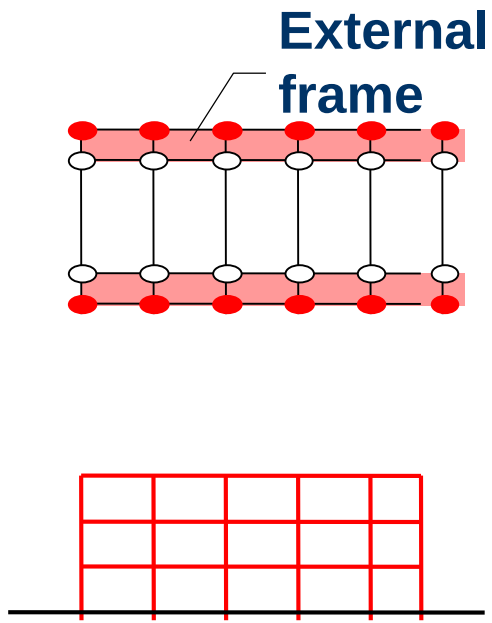
Classification of retrofit methodology

External retrofit (strength type)

Buttress



External frame



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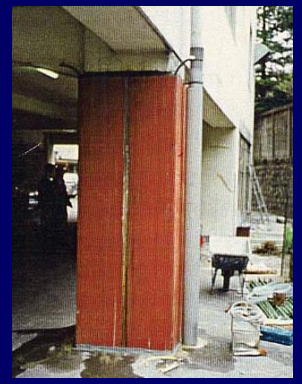
Classification of retrofit methodology

Improvement of capacity

Ductility

- RC Jacketing
  - Welded mesh

- Steel plate Jacketing
  - Rectangular, round steel



- Carbon fiber rapping
  - Sheet, Strand

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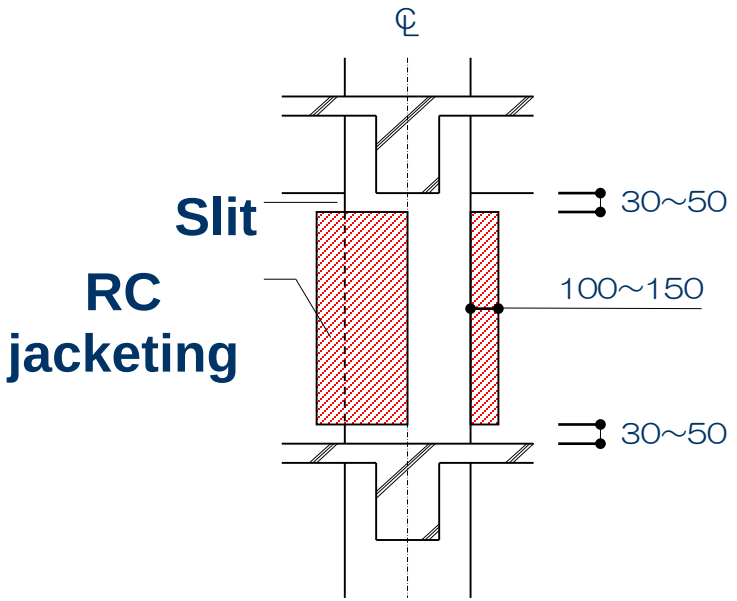
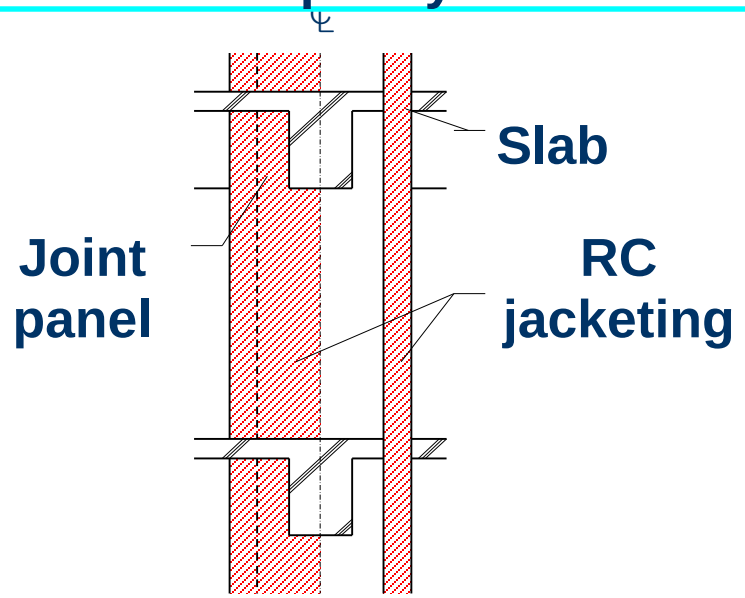
Classification of retrofit methodology

Reinforced concrete Jacketing (ductile type)

Increase of shear capacity



Increse of shear and flexural capacity



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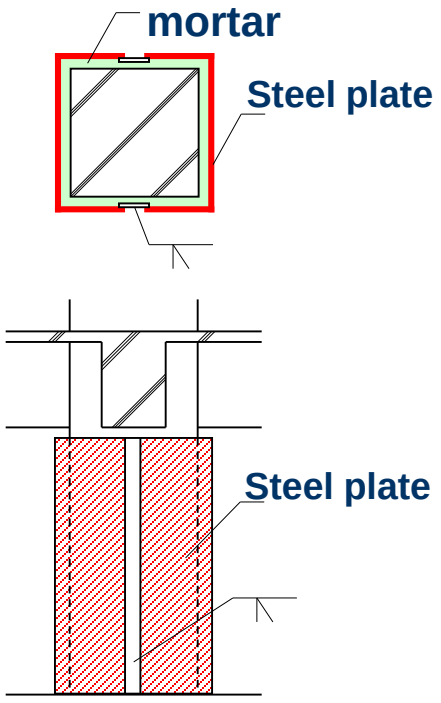
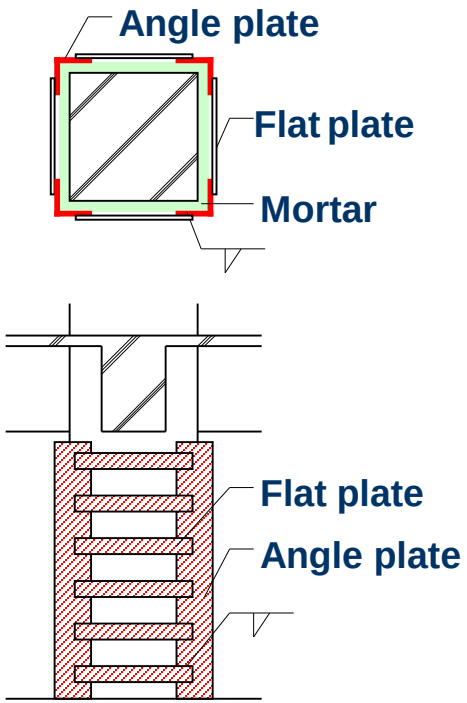
Classification of retrofit methodology

Column retrofitted by steel plate (ductile type)

Rectangular steel plate



Steel flat plate



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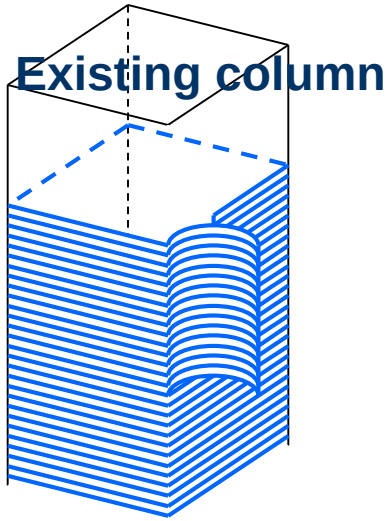
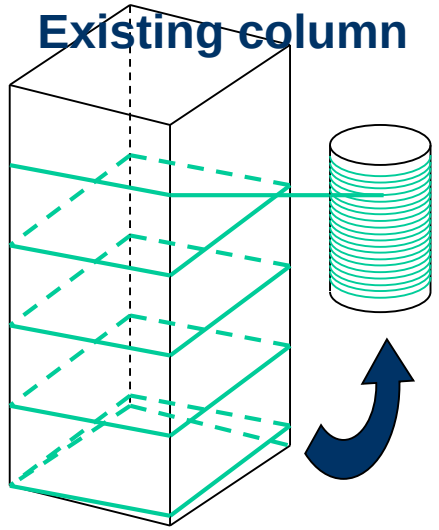
Classification of retrofit methodology

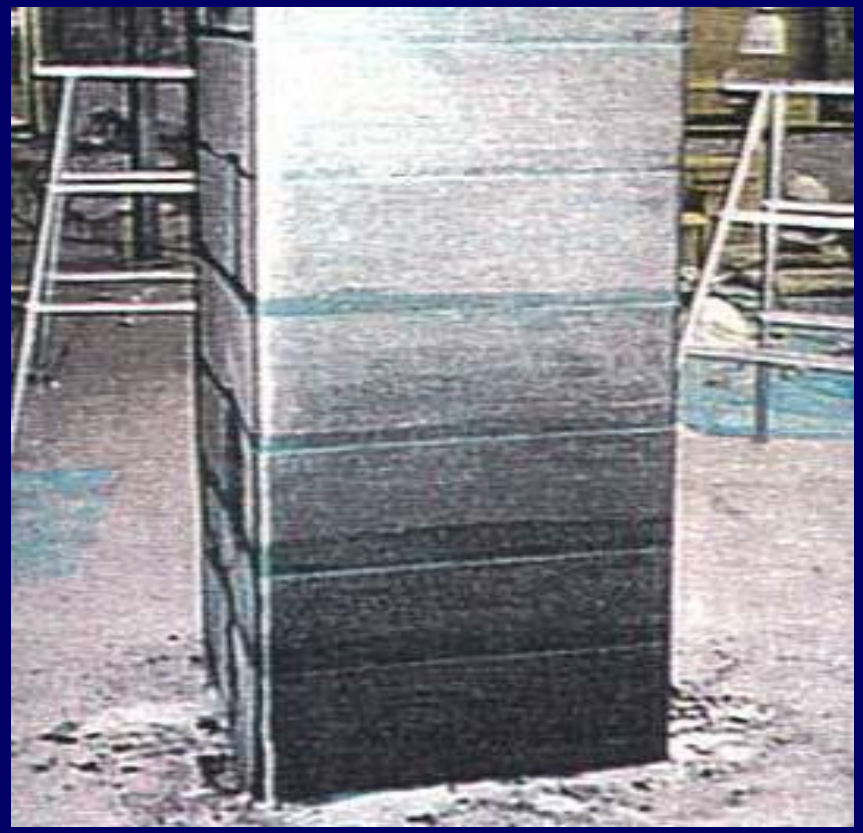
Column retrofitted by carbon fiber sheet (ductile type)

Sheet



Strand





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Column retrofitted by carbon fiber sheet (ductile type)

Spandrel wall

Existing RC column (Taking off cover mortar)

1

Rapping of carbon sheet

2

After Rapping

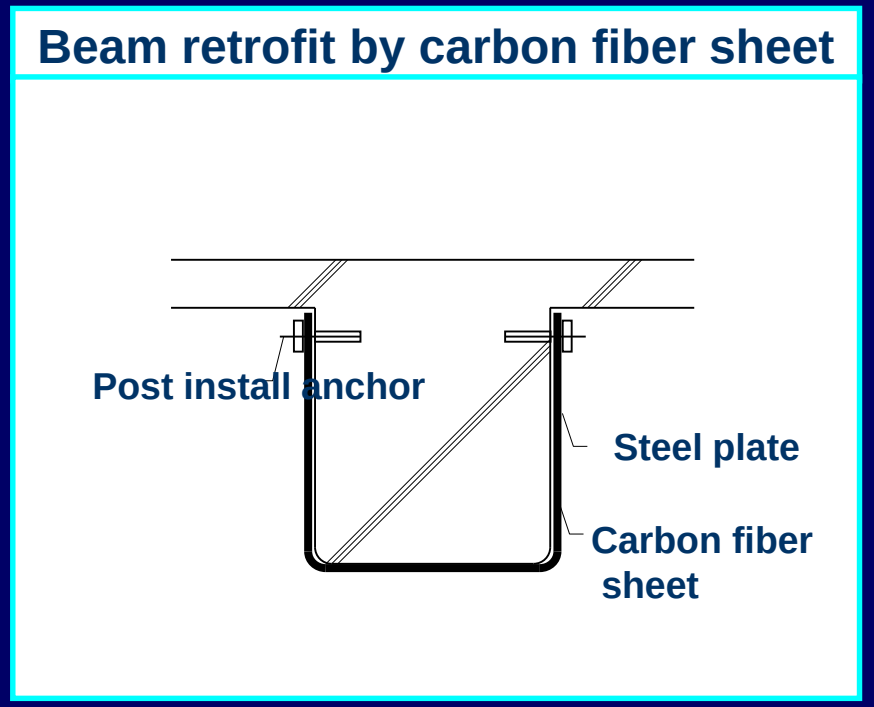
3

Finishing

Construction process

Classification of retrofit methodology

Beam retrofit by carbon fiber sheet (ductile type)



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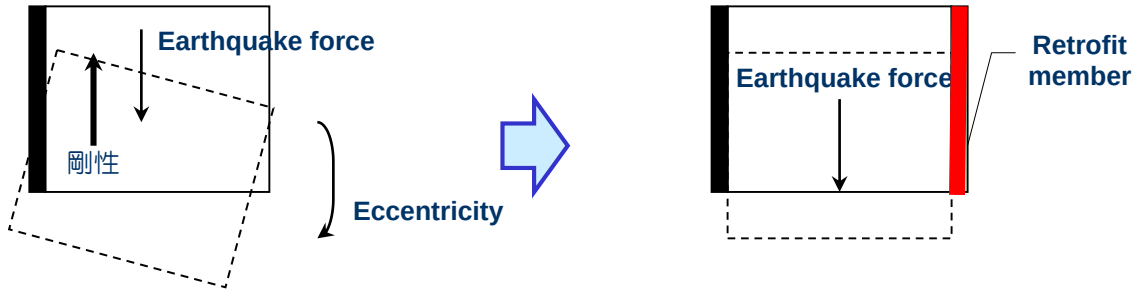
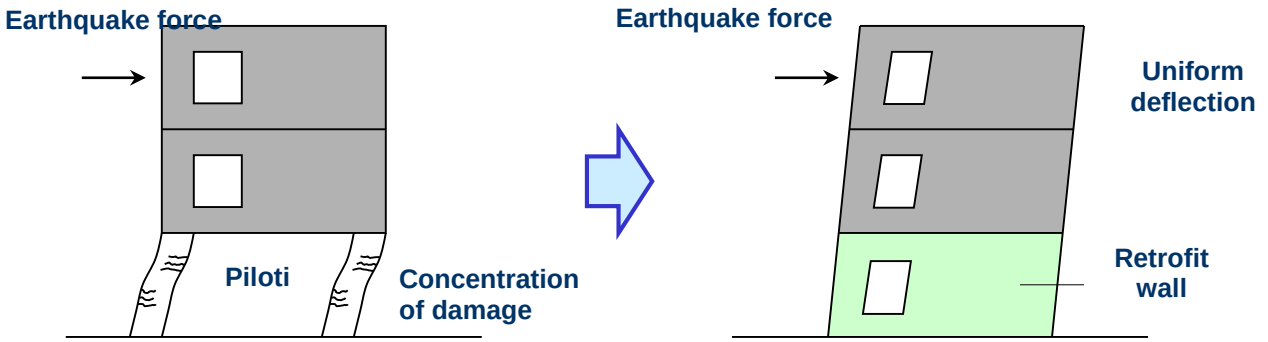
Retrofit design

Avoidance of the concentration of damage

Improvement of eccentricity



Improvement of stiffness ratio



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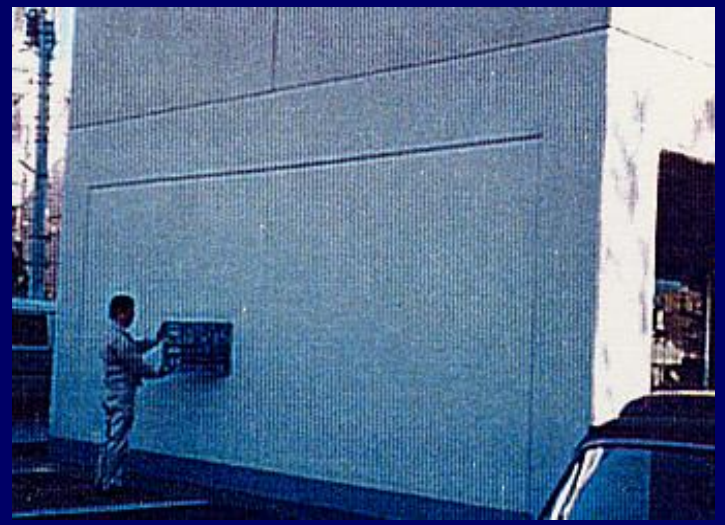
Classification of retrofit methodology

- Improvement of capacity
  - Avoidance of concentration of damage
    - Improvement of vibration disadvantage
      - Eccentricity
      - Stiffness unbalance
      - Expansion joint
    - Cancel the extreme brittle member
      - Making of the slit

Making of slit



Improvement of eccentricity

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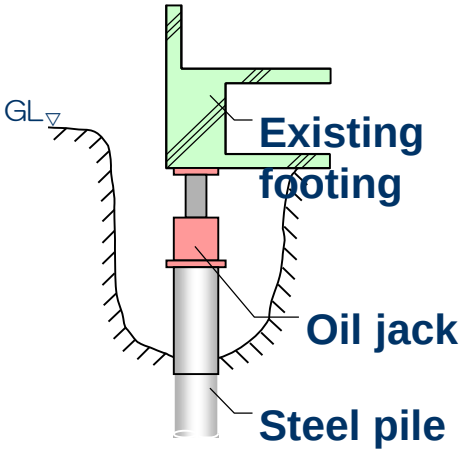
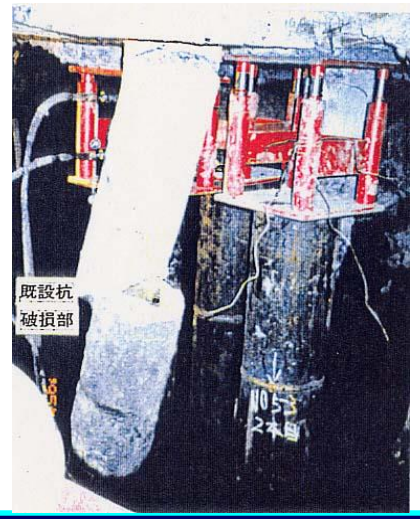
Classification of retrofit methodology

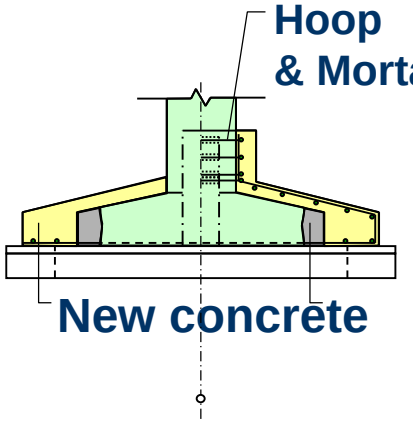
Footing and Pile

Under pinning

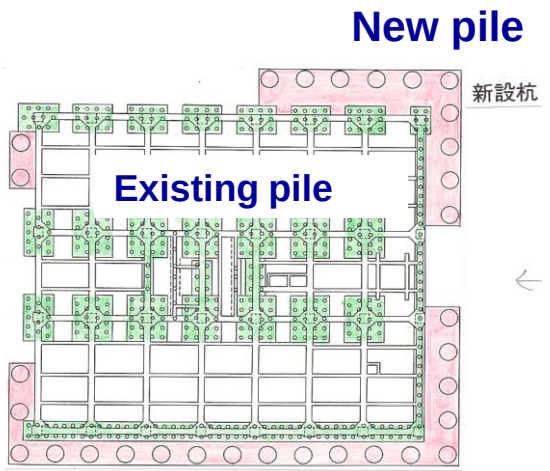




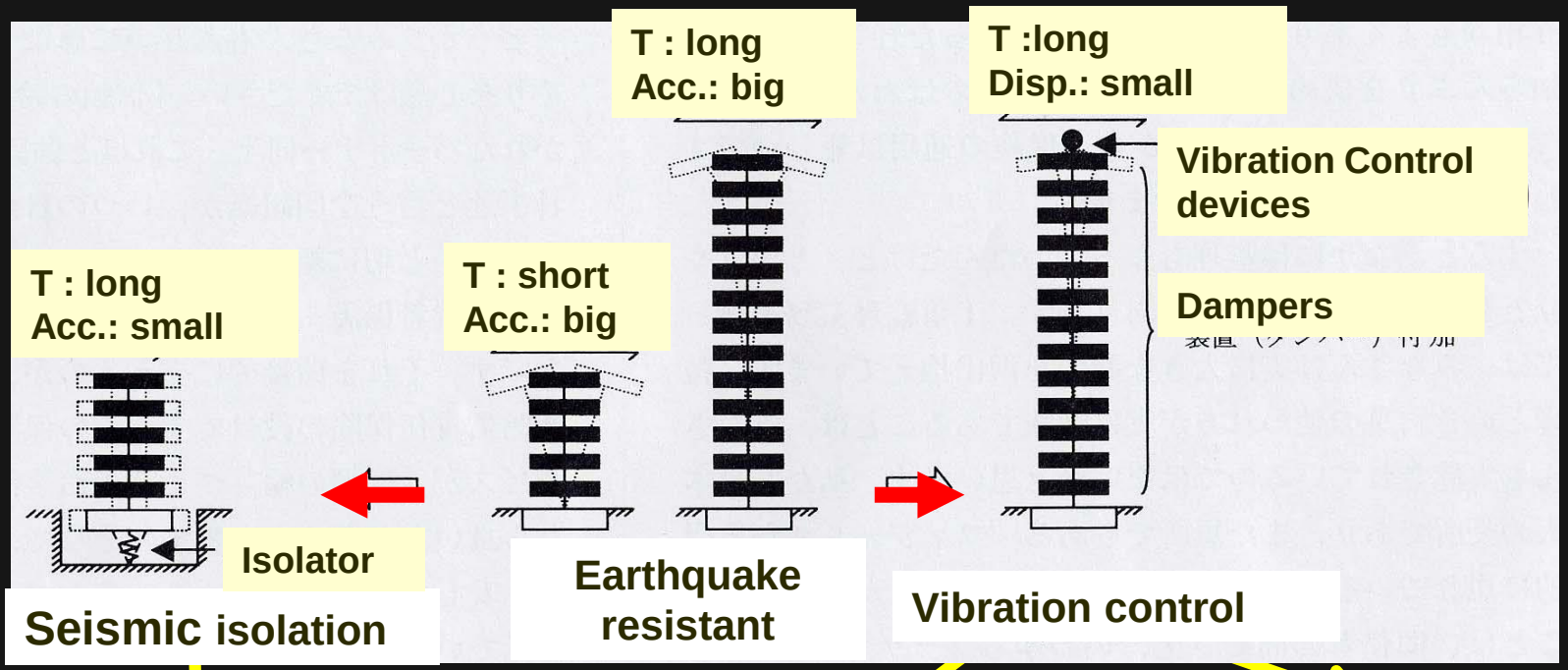
Expansion of footing

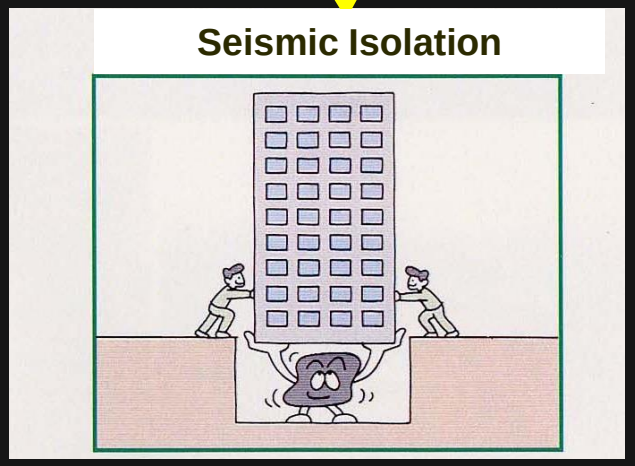


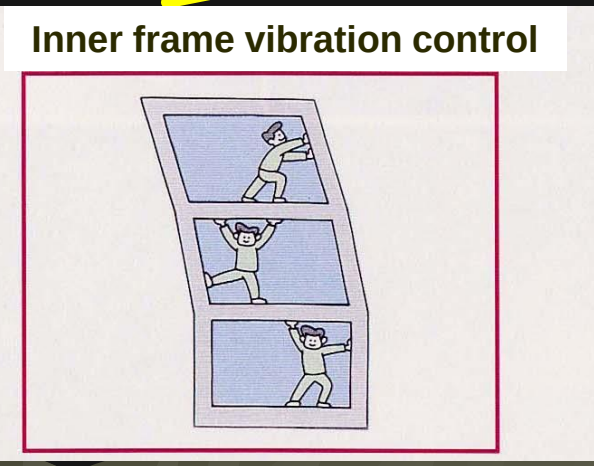
Increasing of piles



Retrofit by seismic isolation and vibration control





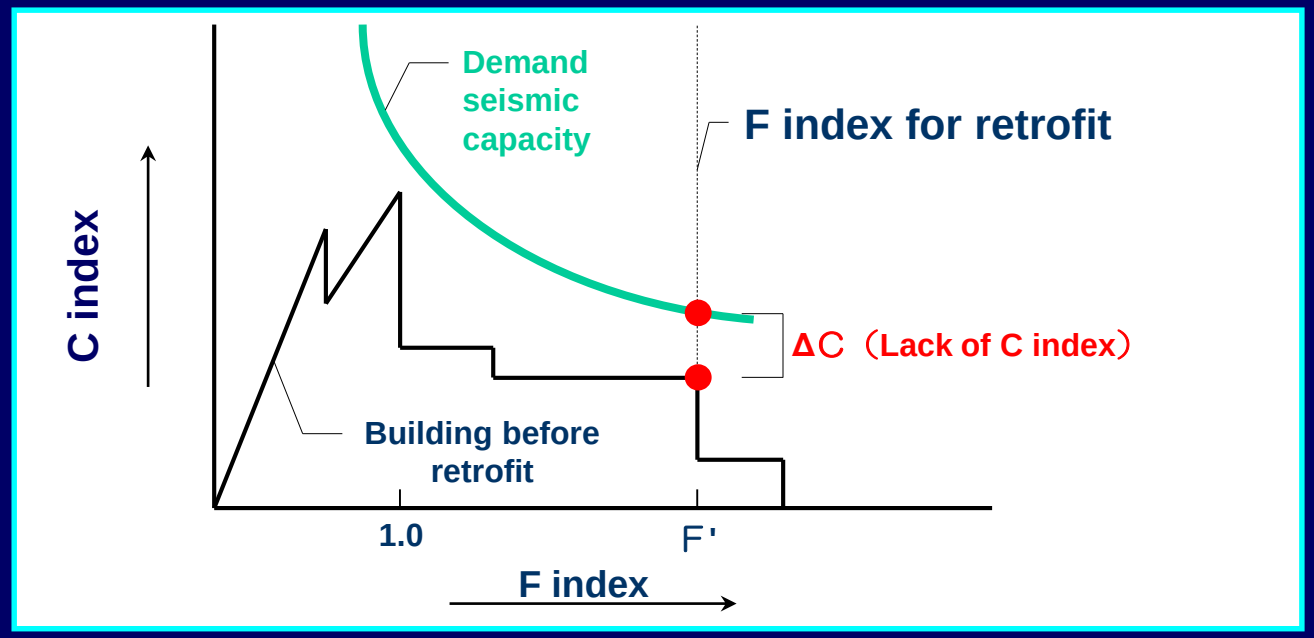


Basic concept of retrofit design

Required strength

$$\Delta Q_i = \Delta C_1 \times \Sigma W_i = \left(\frac{n+i}{n+1}\right) \times \frac{1}{F'} \left(\frac{{}_R I_S}{S_D' \cdot T'} - \frac{I_S i}{S_D \cdot T}\right) \times \Sigma W_i$$

△Qi	: Lack of strength	Ｉsi	: Is index before retrofit
△Ci	: Lack of C index	ＳD,ＳD'	: irregularity before and after retrofit
Ｆ'	: F index after retrofit	Ｔ,Ｔ'	: T index before and after retrofit
Ｒ Ｉ s	: Is index after retrofit	ΣWi	: Summation of weight of building



Seki M., UTCB Lecture note, May 2017, BRI, Japan

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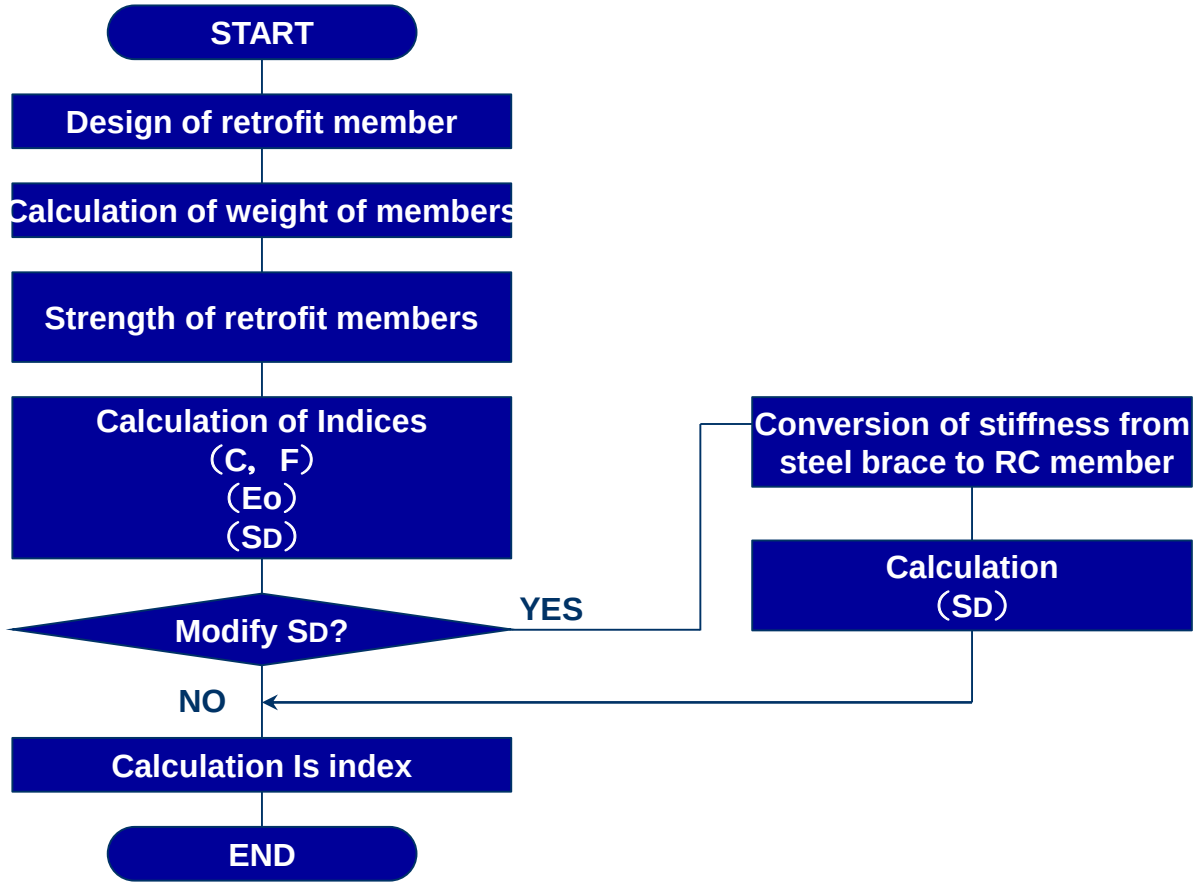
Confirmation of retrofit effect

Calculation of Is index after retrofit



JBDPA seminar note

Verification of retrofit effect

1. Shaking table test

2. Static Loading test

E-Defense (National Research Institute for Earth Science and Disaster Resilience)

Shaking table test of RC Buildings

Three stories school buildings

Before retrofit

After retrofit by steel braces

Shaking table test of RC Buildings

Before strengthening

After strengthening

Shaking table test of Timber Houses

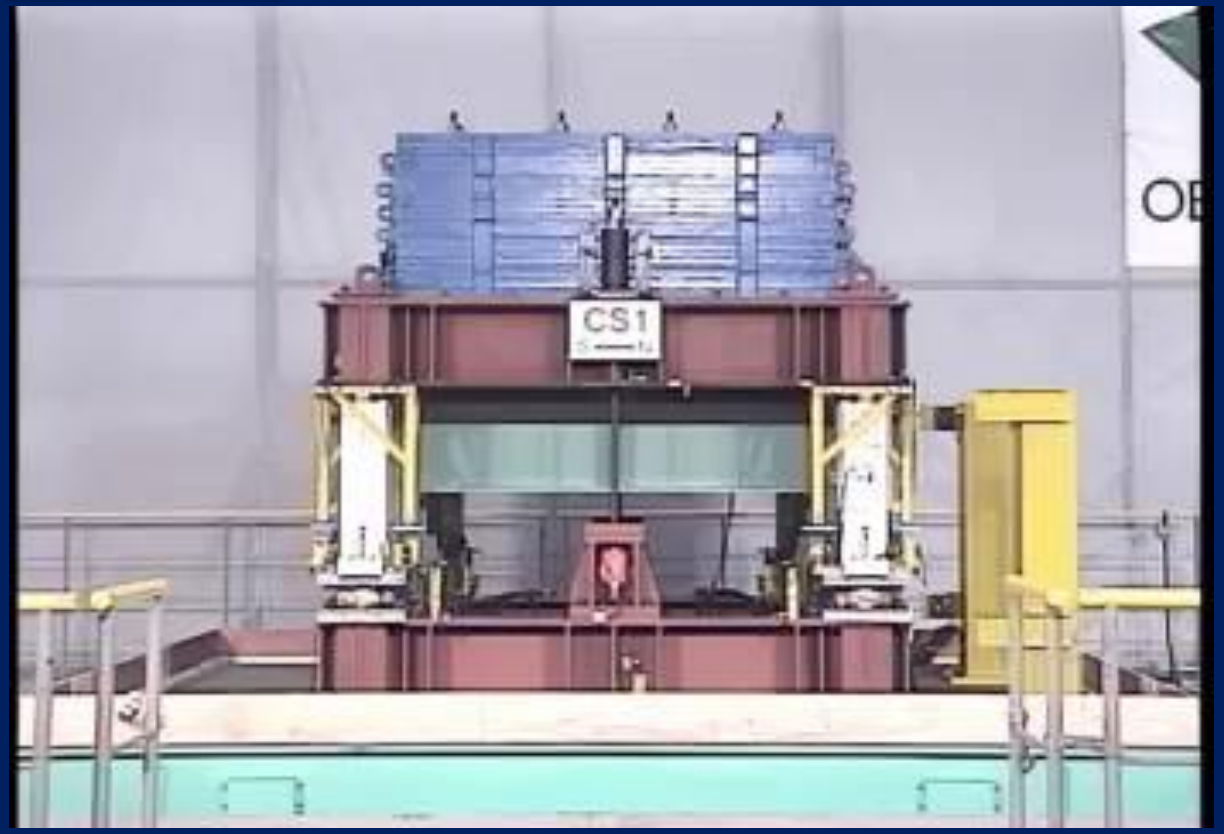
NIED 独立行政法人 防災科学技術研究所
National Research Institute for Earth Science and Disaster Prevention

E-Defense 兵庫耐震工学研究センター 実大三次元震動破壊実験施設 E－ディフェンス
Hyogo Earthquake Engineering Research Center

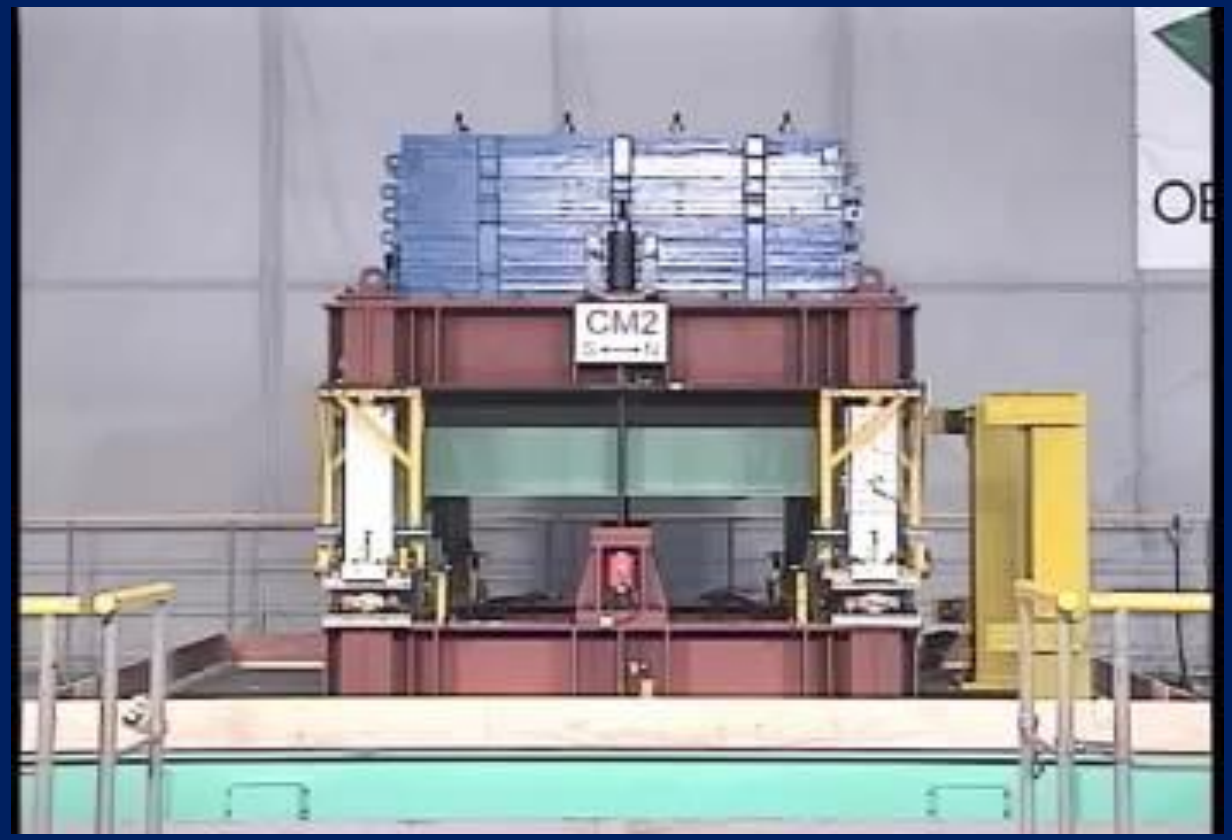
Shaking table test of RC columns

VIDEO

Obayashi corporation



Shear failure column

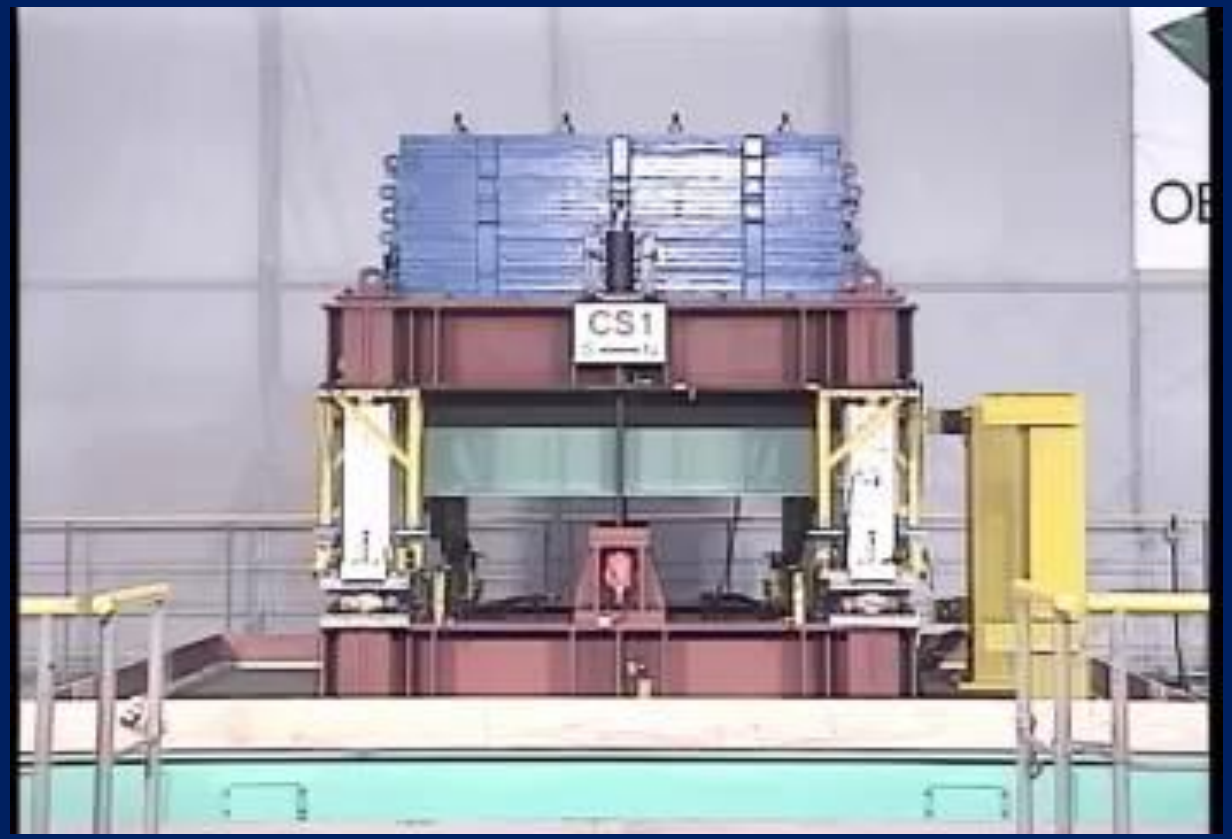


Flexural failure column

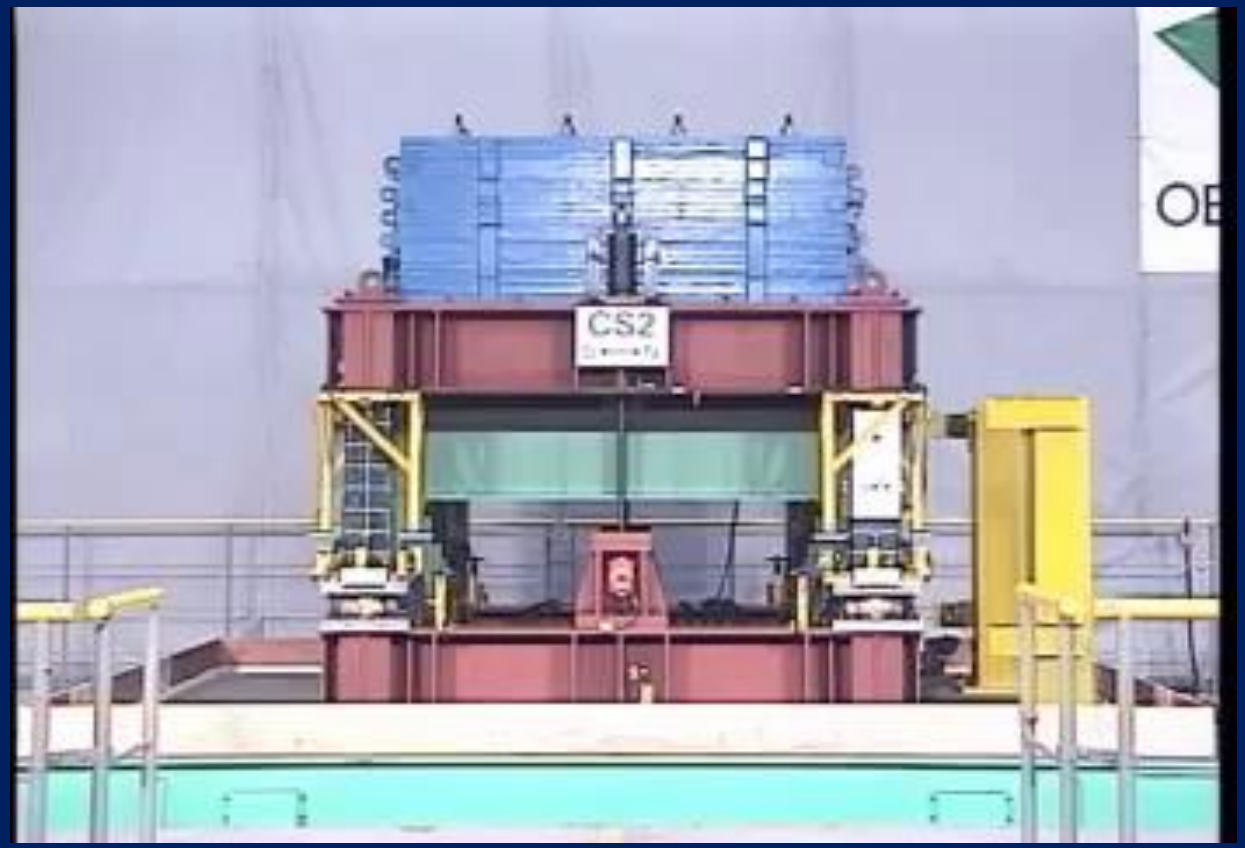
Shaking table test of RC columns

VIDEO

Obayashi corporation



Shear failure column



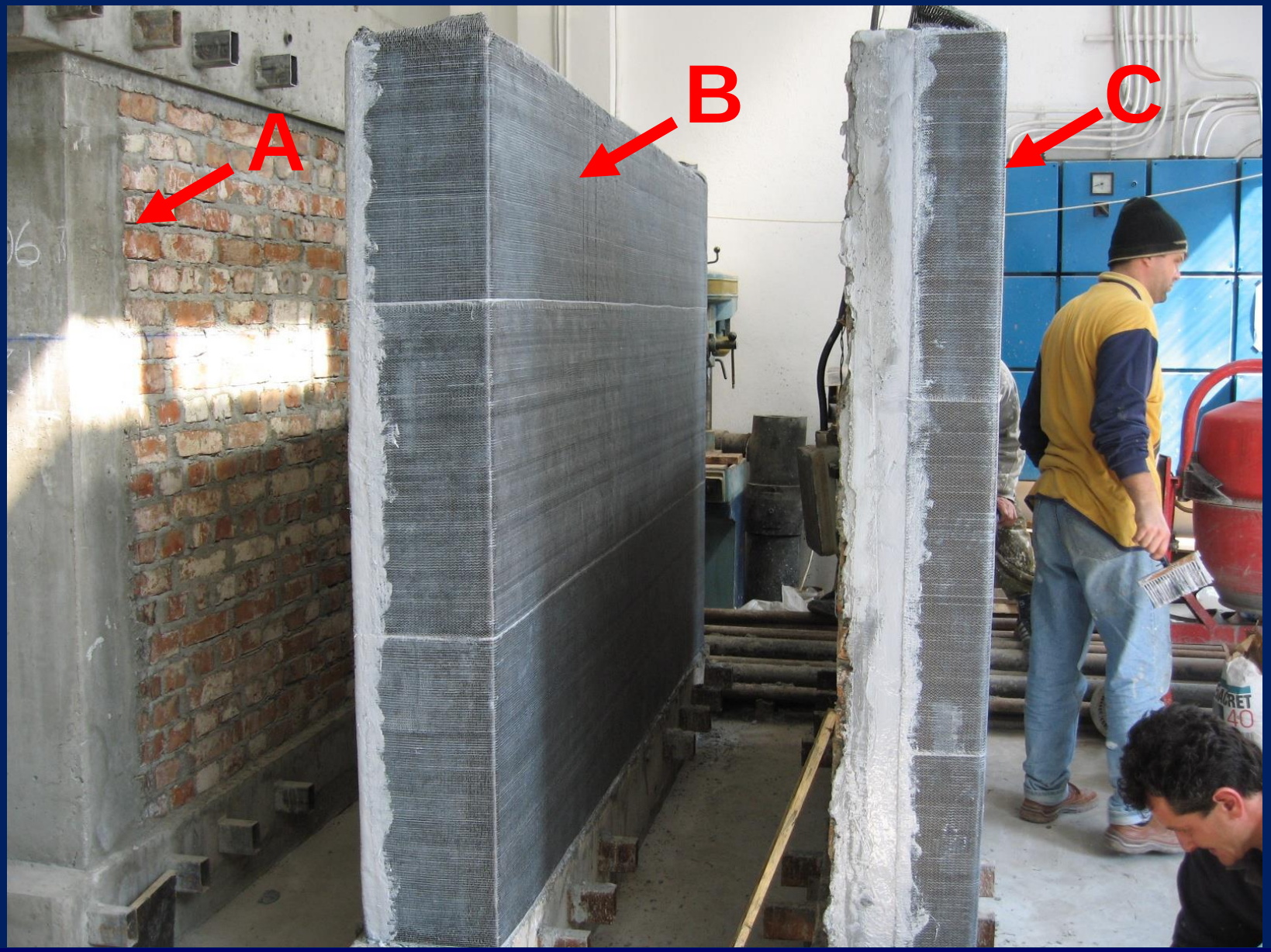
Column retrofitted
by carbon fiber

14th WCEE, 2008,Beijing, China

CYCLIC SHEAR TESTS ON PLAIN AND FRP RETROFITTED MASONRY WALLS

M. Seki, R. Vacareanu, T. Saito,
D. Cotofana, E. Lozinca,
V. Popa, A. B. Chesca

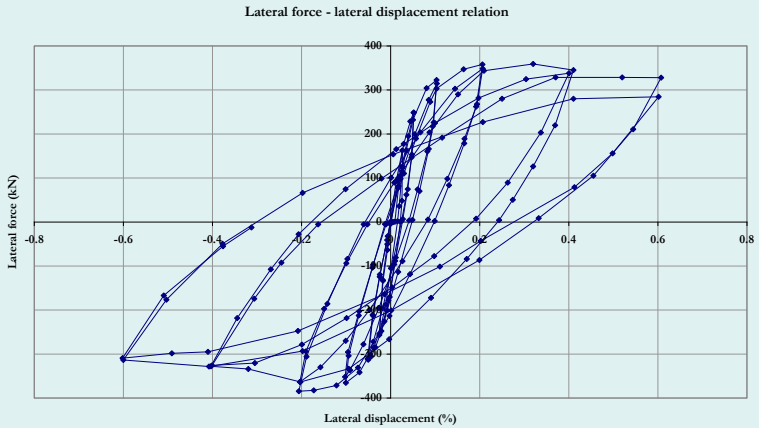
Test specimens



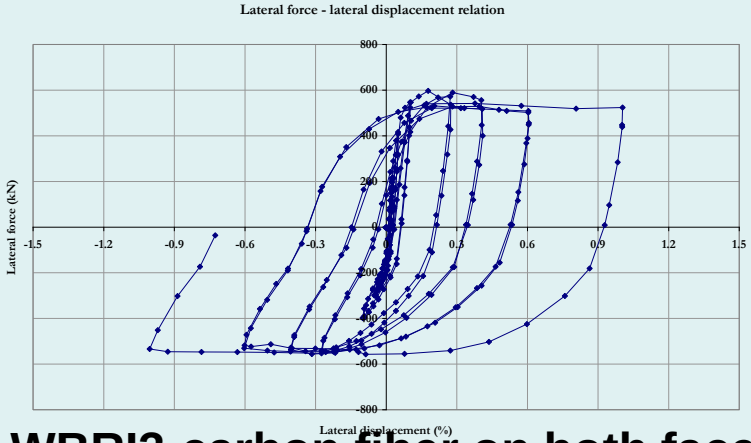
Reaction frame at UTCB

TESTS' RESULTS

Lateral force (kN)-lateral drift (%) curve

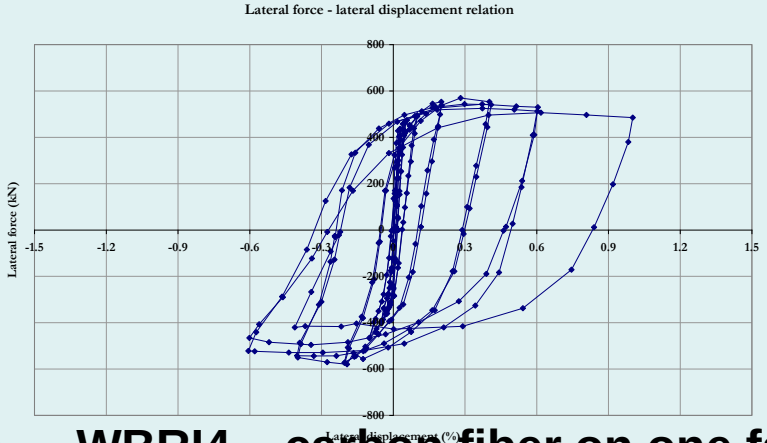


WBRI1 (A)



WBRI3-carbon fiber on both faces

(B)

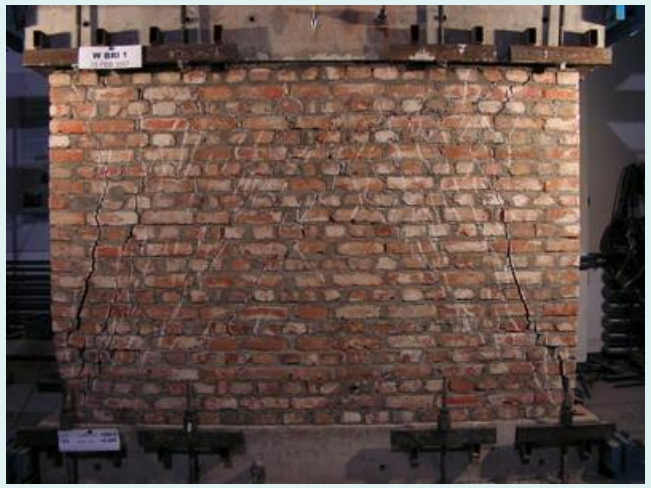


WBRI4 – carbon fiber on one face

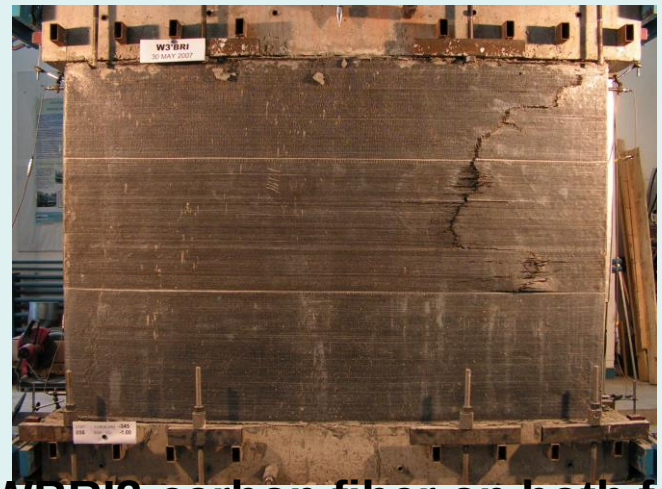
(C)

TESTS' RESULTS

Damage state of the Specimens at Collapse

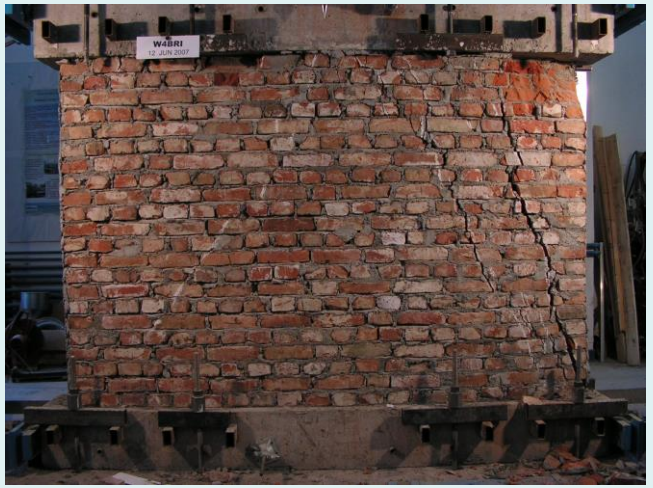


WBRI1 (A)



WBRI3-carbon fiber on both faces

(B)



WBRI4 – carbon fiber on one face

(C)

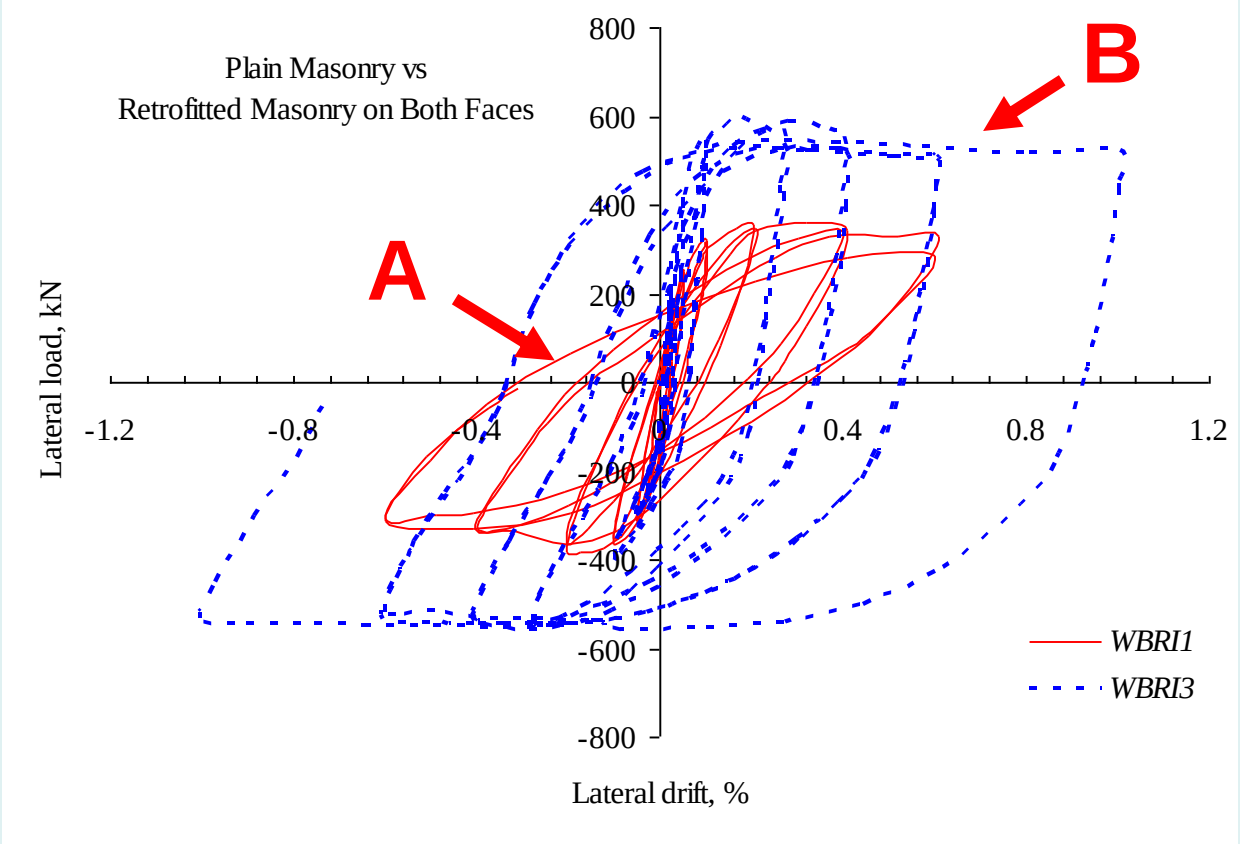
Ultimate Damage

WBRI3-carbon fiber on both faces (B)

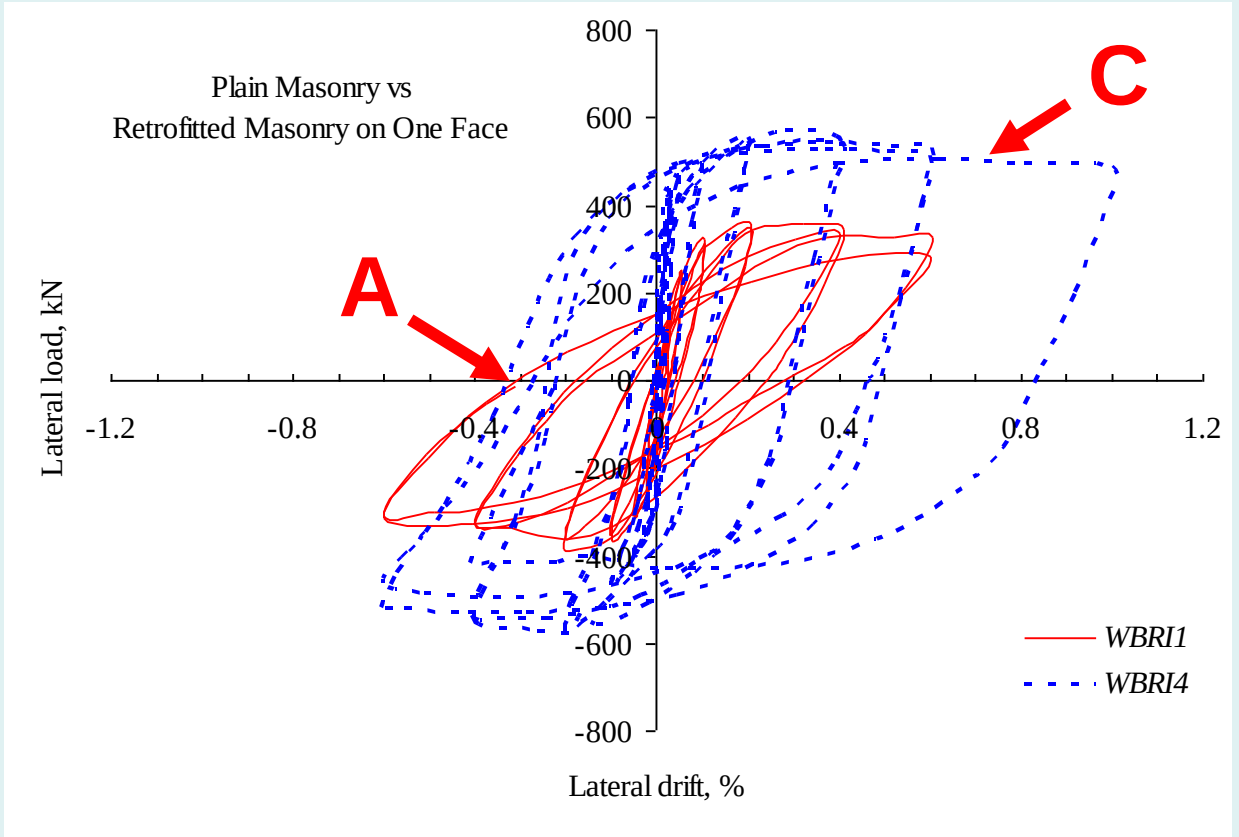
Ultimate Damage

WBRI4 – carbon fiber on one face(C)

Comparison of Load –deflection curve



Lateral force – lateral drift curves Plain Masonry vs. Retrofitted Masonry on Both Faces



Lateral force – lateral drift curves Plain Masonry vs. Retrofitted Masonry on One Face

Examples of retrofit buildings

Retrofit of Department store by outside steel frame

Usage: Department store
Location: Osaka Toyonaka-city, Japan
Story: 7 stories, 1 basement , 2 pent house
Structure: Reinforced concrete: B1F-5F, Steel: 6-7 F, PH
Moment resisting frame with shear wall (RC),
Moment resisting frame (S)
Total floor area: 20,368 m^2
Original construction: 1970
Retrofit construction: 2007-2008

JBDPA 2014

Before retrofit

After retrofit

JBDPA 2014

After retrofit

JBDPA 2014

After retrofit

JBDPA 2014

Retrofit concept

1.Reservation of Architectural façade design

➡ *Triangle steel frame*

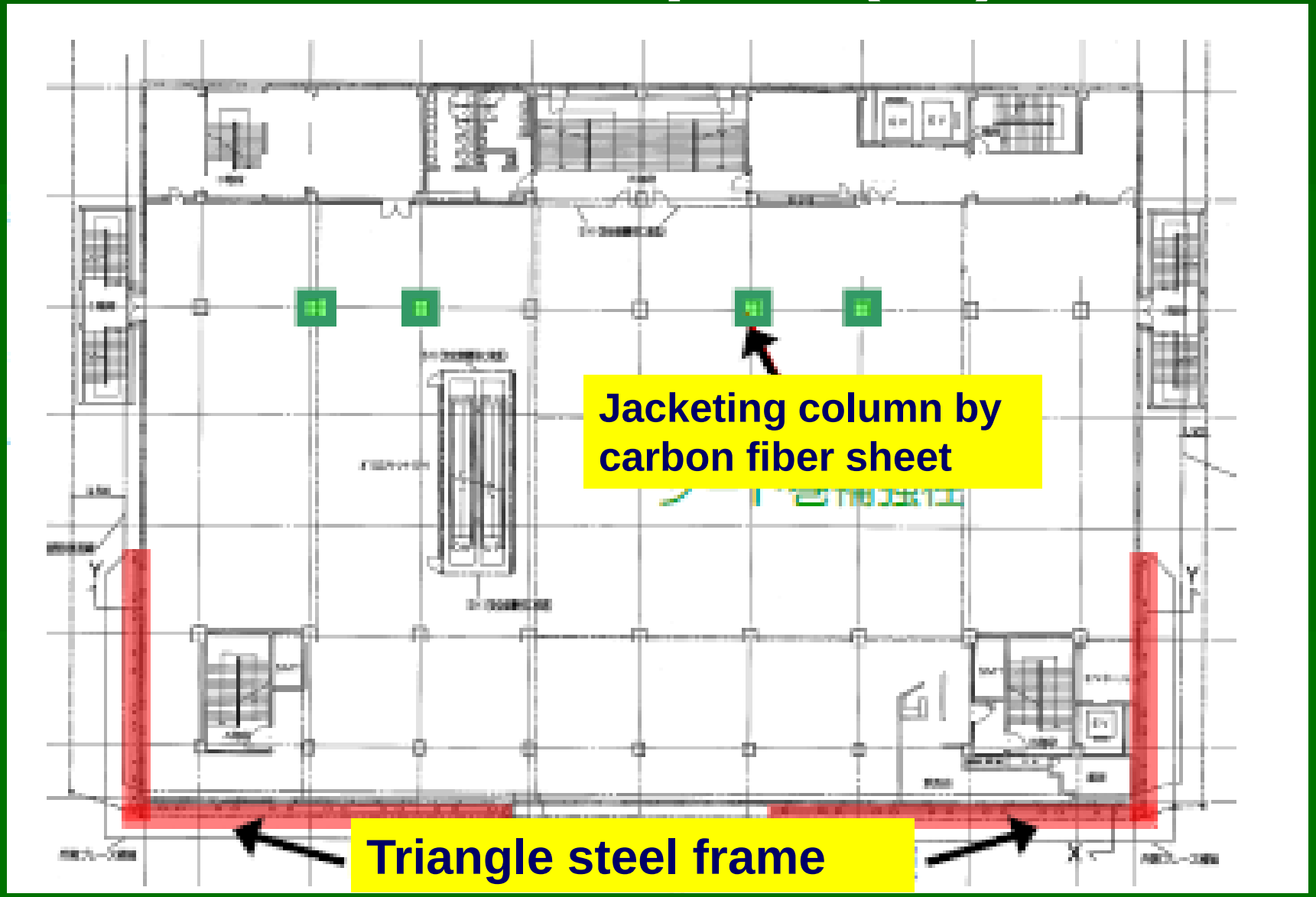
2. Retrofit without disturbing the habitability

➡ *Outside steel frame*

3. Construction procedure considering the approach of customers

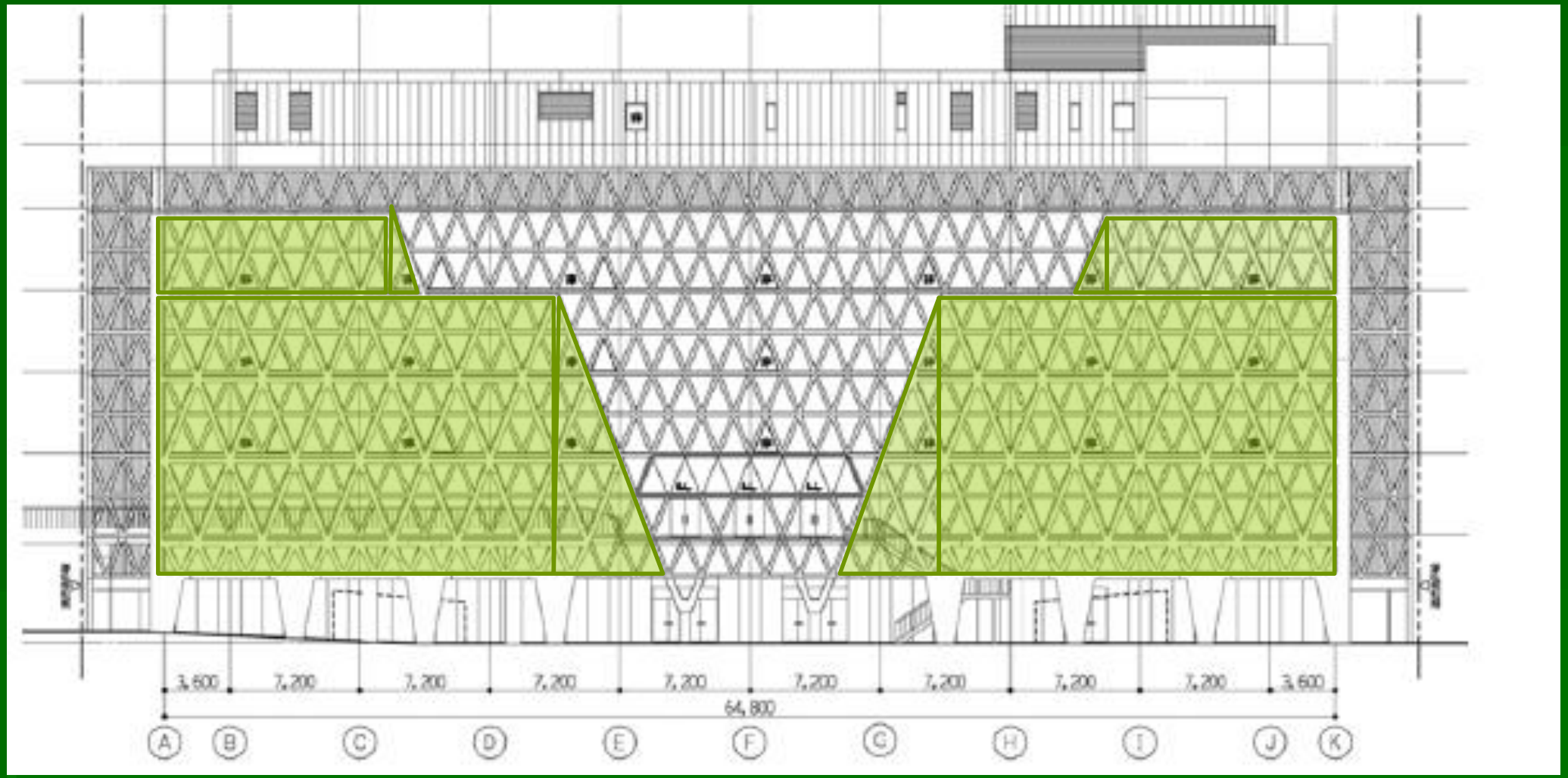
JBDPA 2014

Retrofit plan (4F)

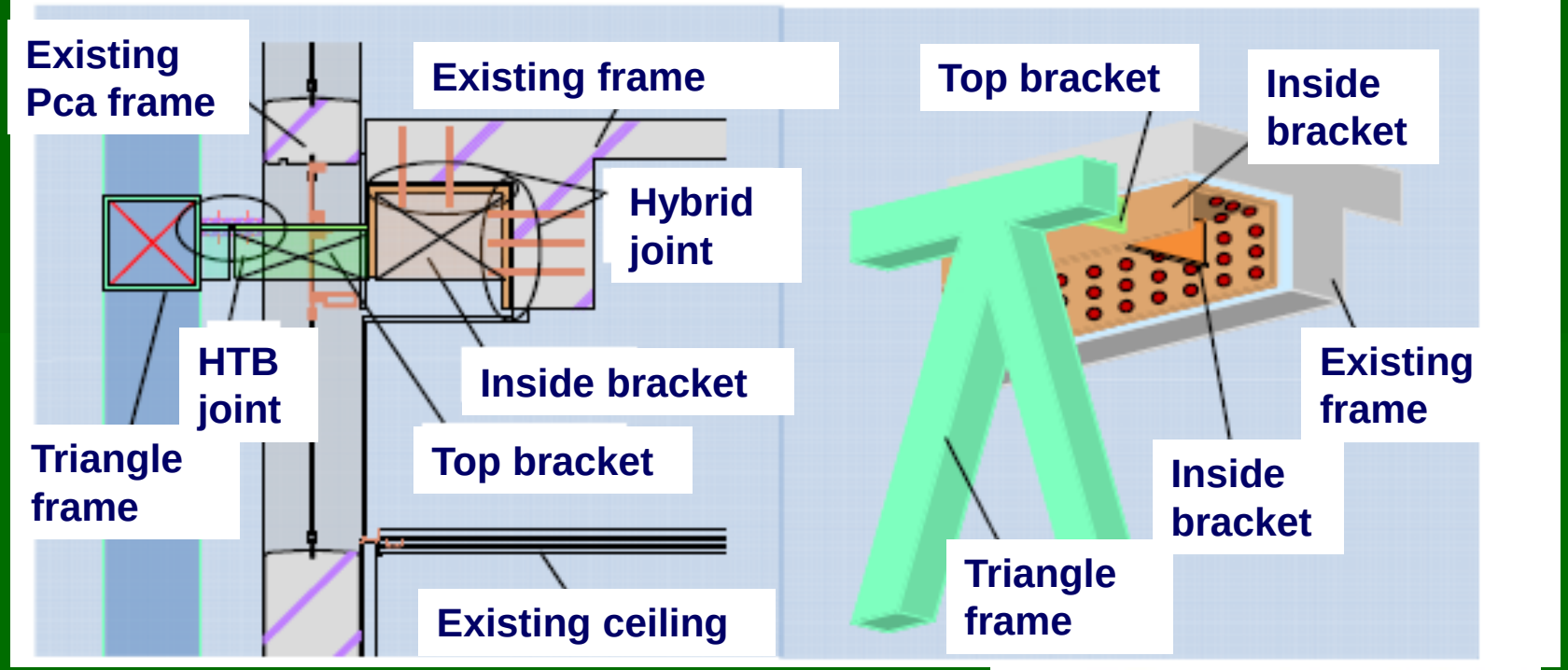


JBDPA 2014

West elevation drawing



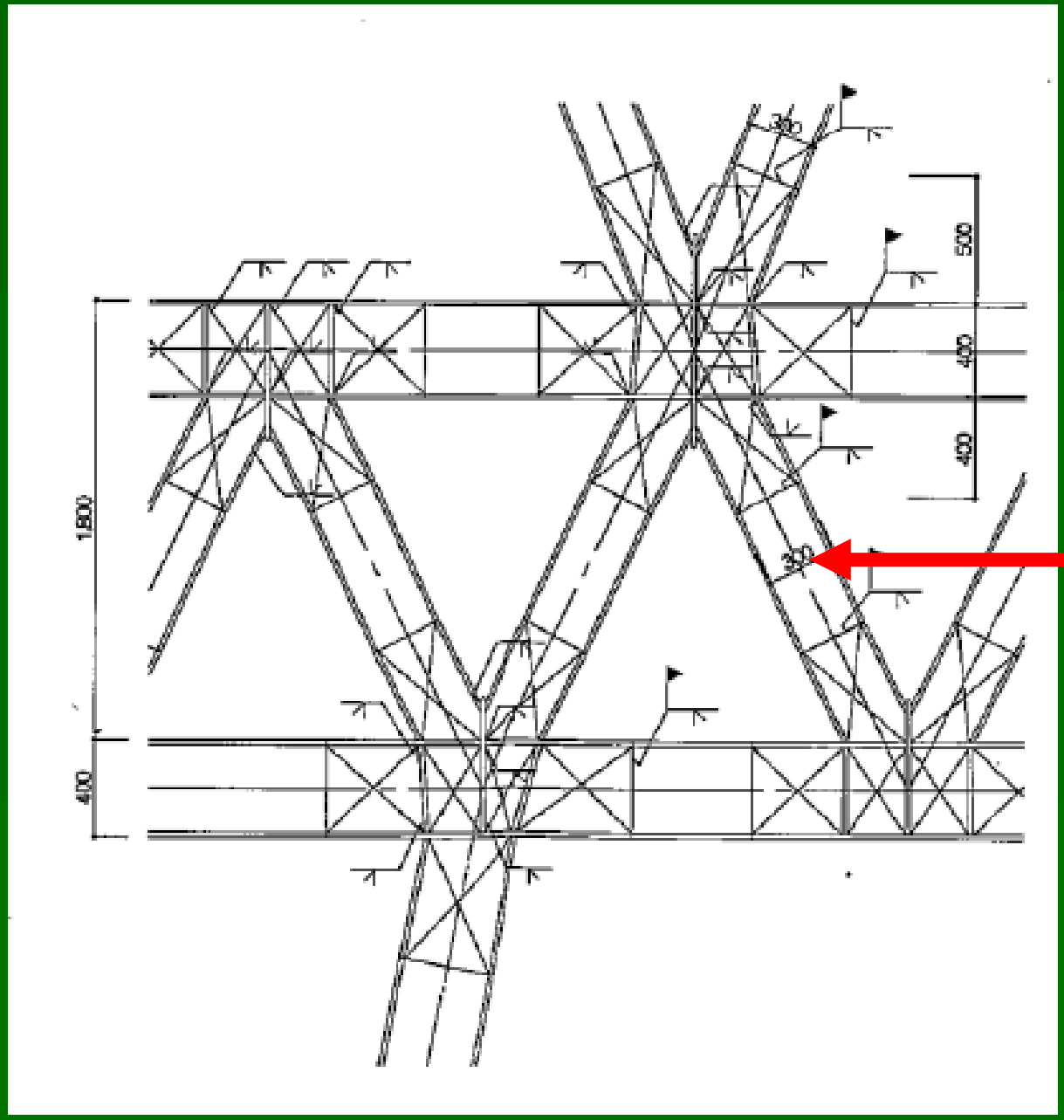
JBDPA 2014



Joint of triangle frame and top bracket

JBDPA 2014

Triangle steel frame (1)

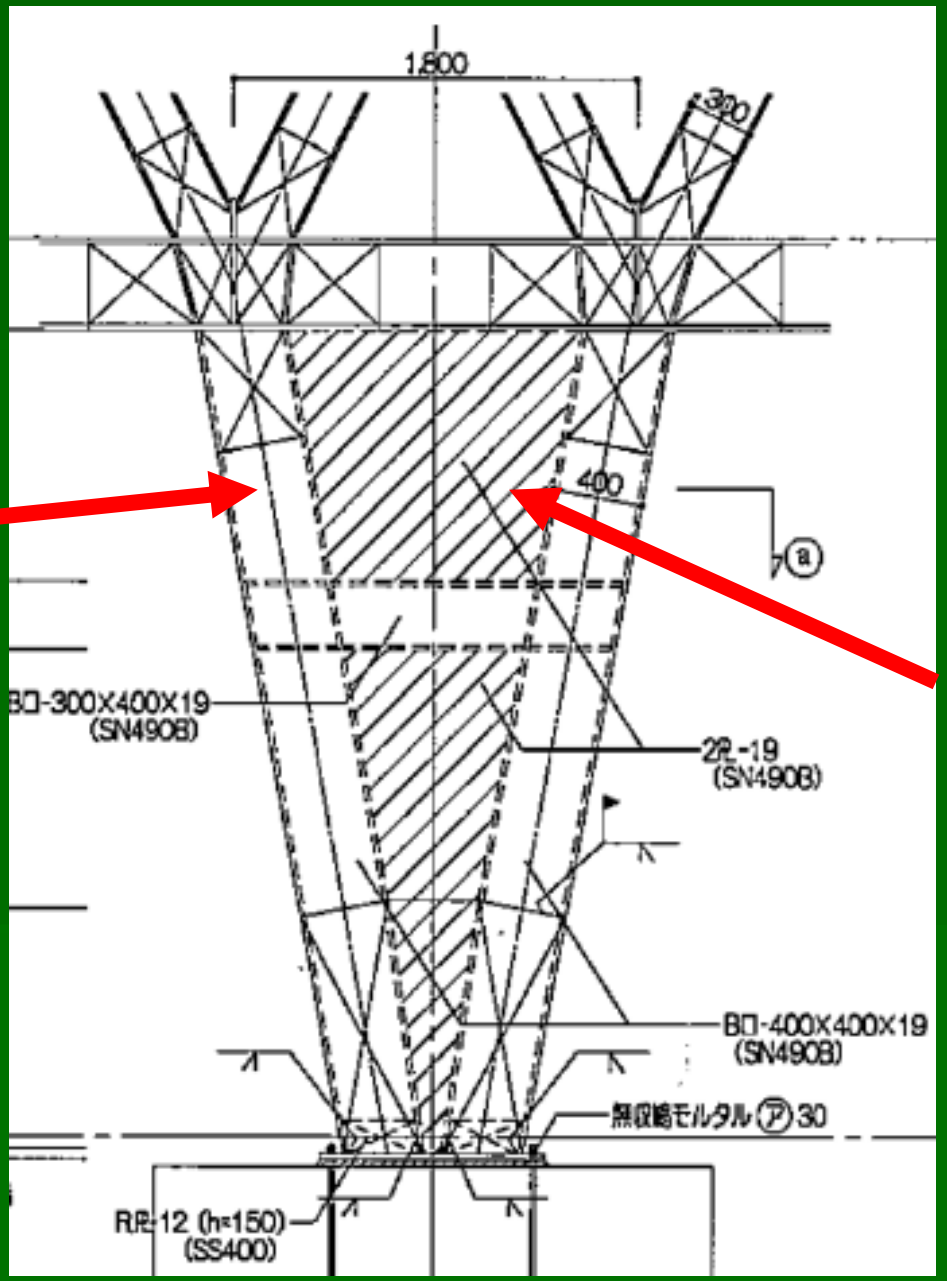


Square steel tube
□—300×300×19

JBDPA 2014

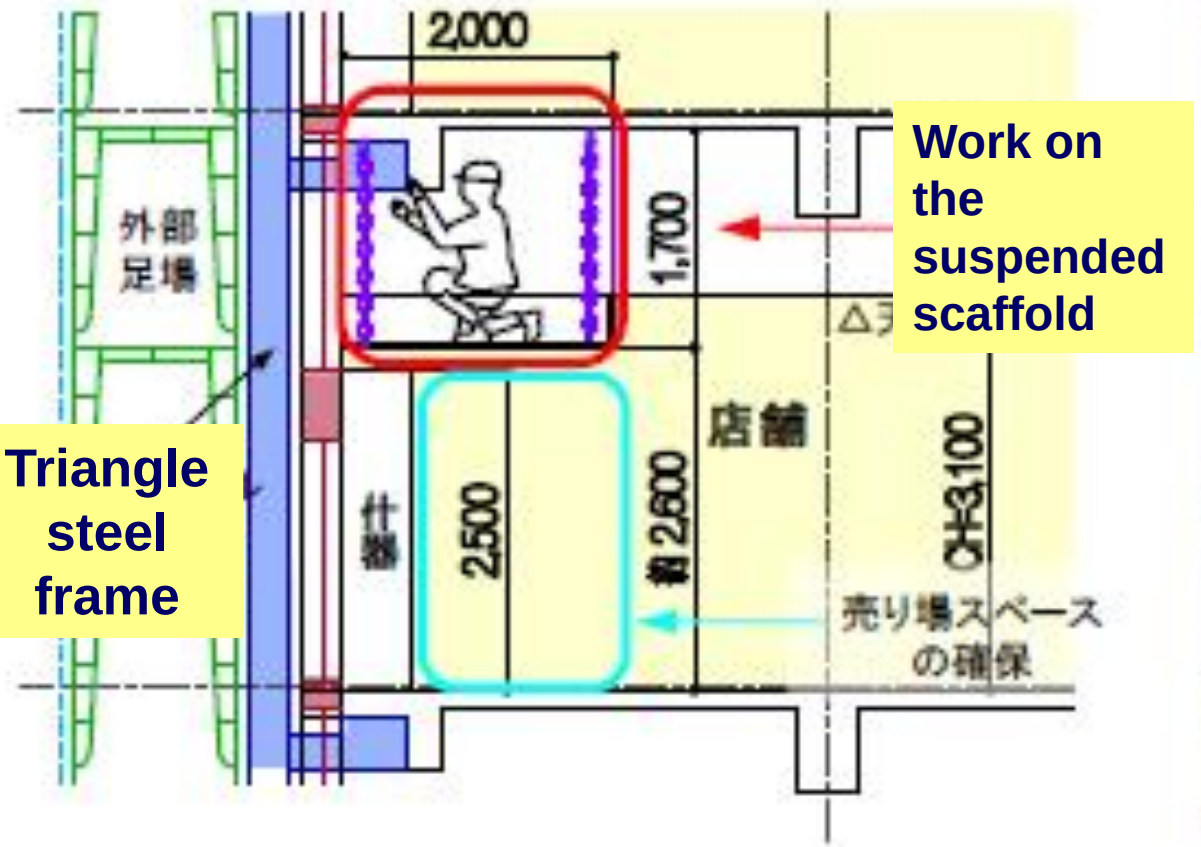
Triangle steel frame (2)

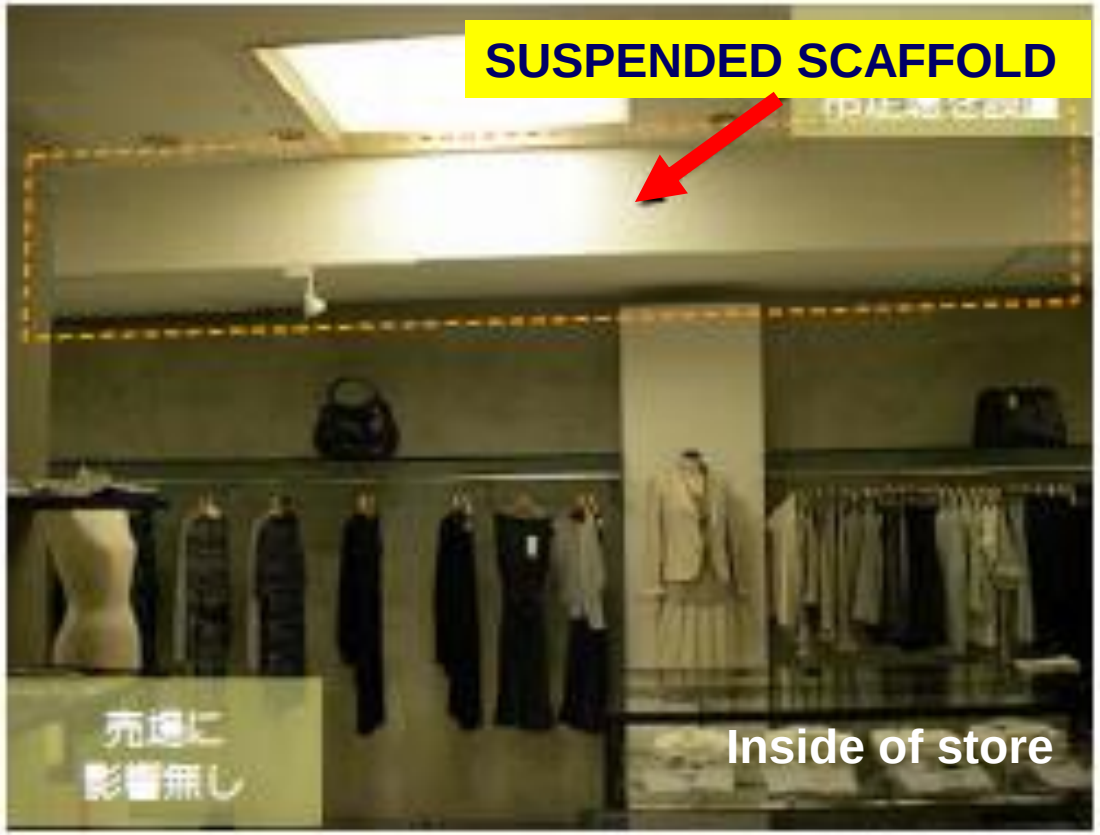
Square Steel tube
□—400×400×19



Steel plate PL-19

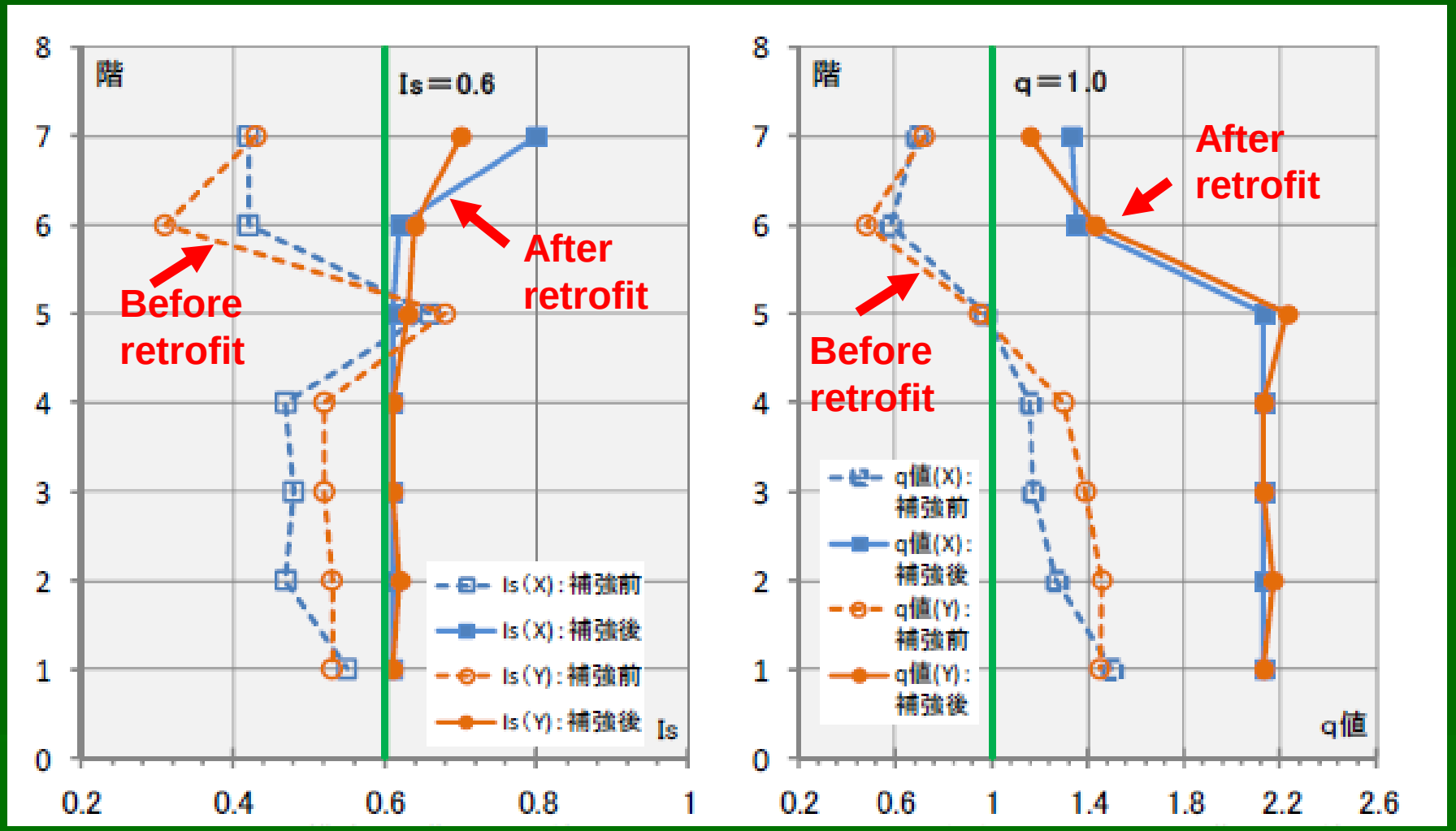
JBDPA 2014





Retrofit without disturbing the habitability

JBDPA 2014



Comparison of Is index

Comparison of q index (Ratio of strength and required strength)

JBDPA 2014

Construction process of triangle steel frame

① excavating for pile

② Top of pile

③ Rebars of footing

④ Casting of footing concrete

⑤ Setting of inside bracket

⑥ Tightening of bolt

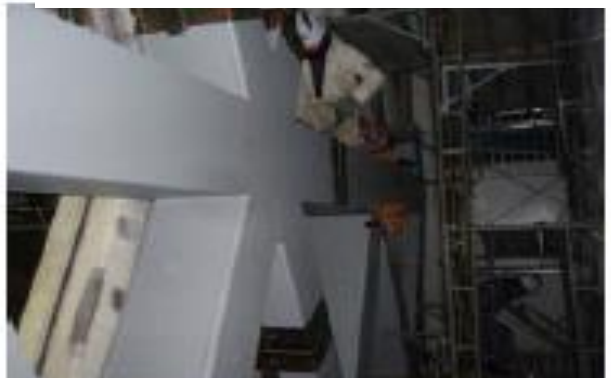
⑦ Setting of top bracket

JBDPA 2014

⑧ Injection of epoxy resin

⑨Suspending bottom part

⑩ Setting of bottom part



⑪ Setting of triangle frame

⑫ Welding of joint part

⑬ Rust prevention painting

⑭The finish painting

⑮After setting

⑯ Bottom part

JBDPA 2014

Retrofit by outside steel frame

M.Seki (BRI,IISEE)

Retrofit by outside steel frame

JBDPA

Seki M., UTCB Lecture note, May 2017, BRI, Japan

Retrofit by outside steel buttress frame

M.Seki (BRI,IISEE)

Retrofit of National Museum of Western Art, Japan

国土交通省 関東地方整備局
Ministry of Land, Infrastructure, Transport and Tourism, Kanto Regional Development Bureau

Outline of Building

Location : Tokyo
Land area : 9,287.88m^2
Building area : 1,692.61m^2
Story : 3F, B1F, PH 1
Structure : Reinforced concrete (RC)

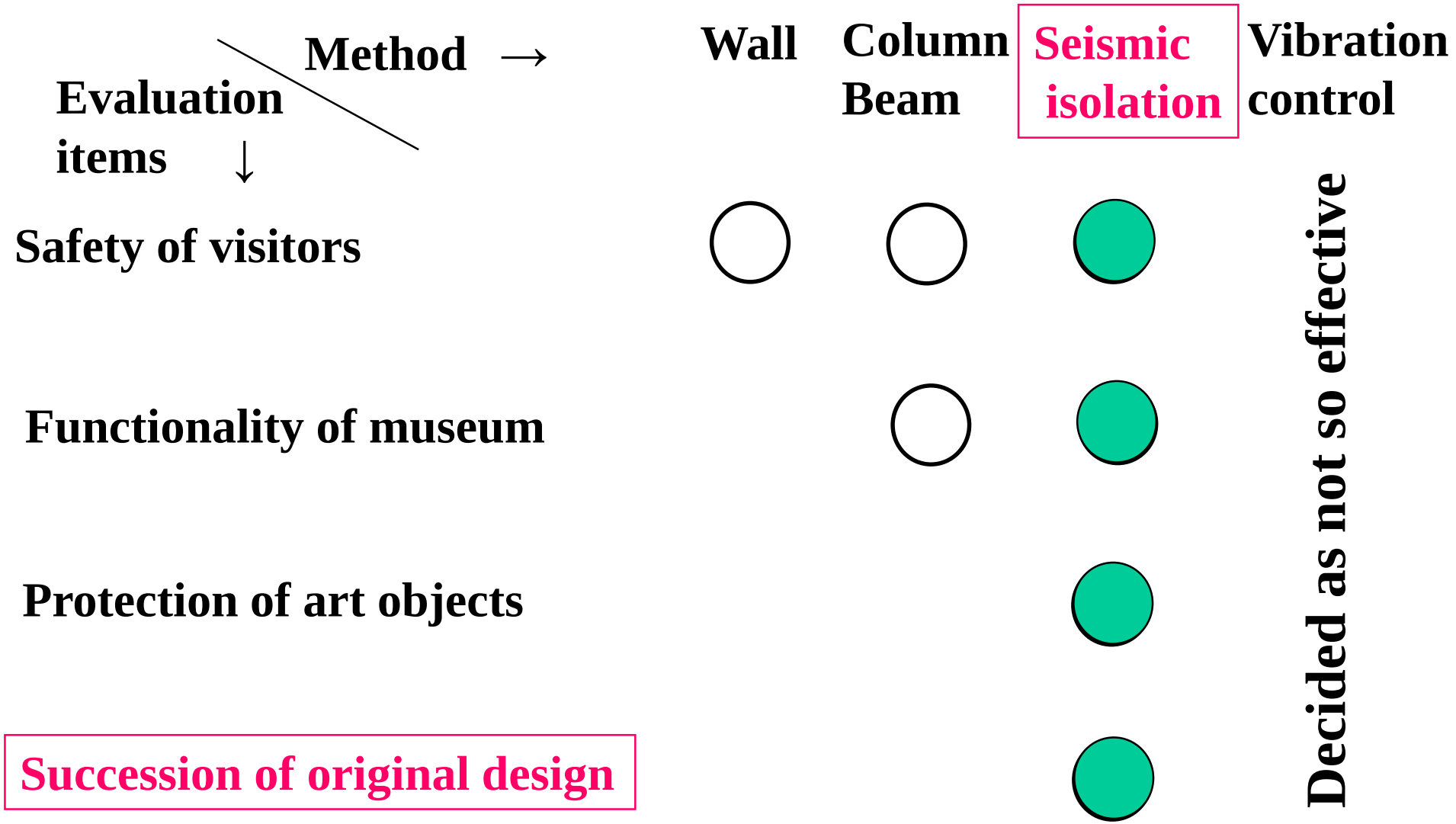
(Original construction)
Design : Le Corbusier
Completion : May,1959
(Retrofit construction)
Construction term : May 1996 - March 1998
Construction Company: Shimizu corporation

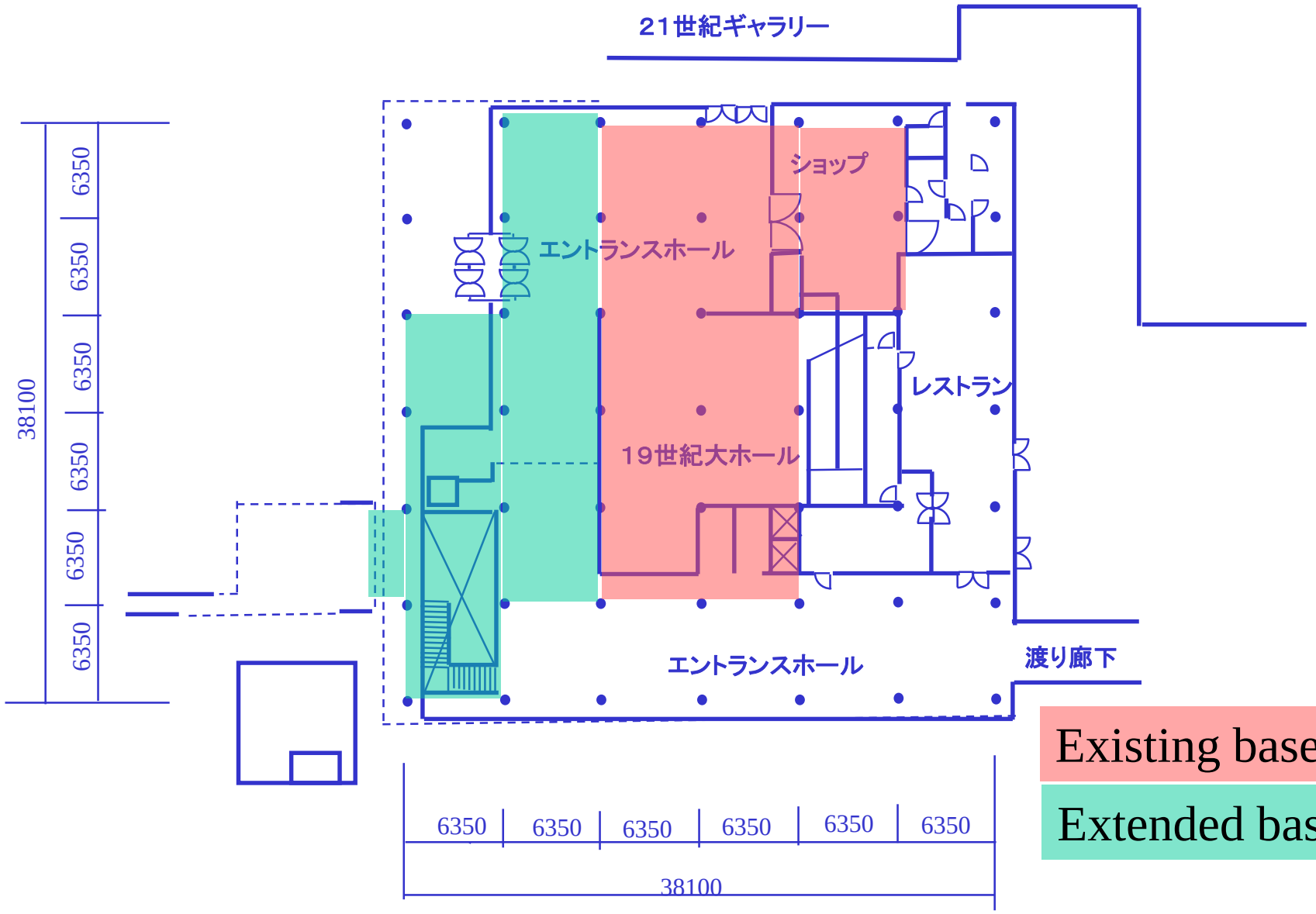
Designed by Le Corbusier in 1957

[Charles-Edouard Jeanneret-Gris] (1887-1965)

Characteristic of his architectural design:
Module, Piloti, Without finishing

Preliminary investigation of retrofit methods

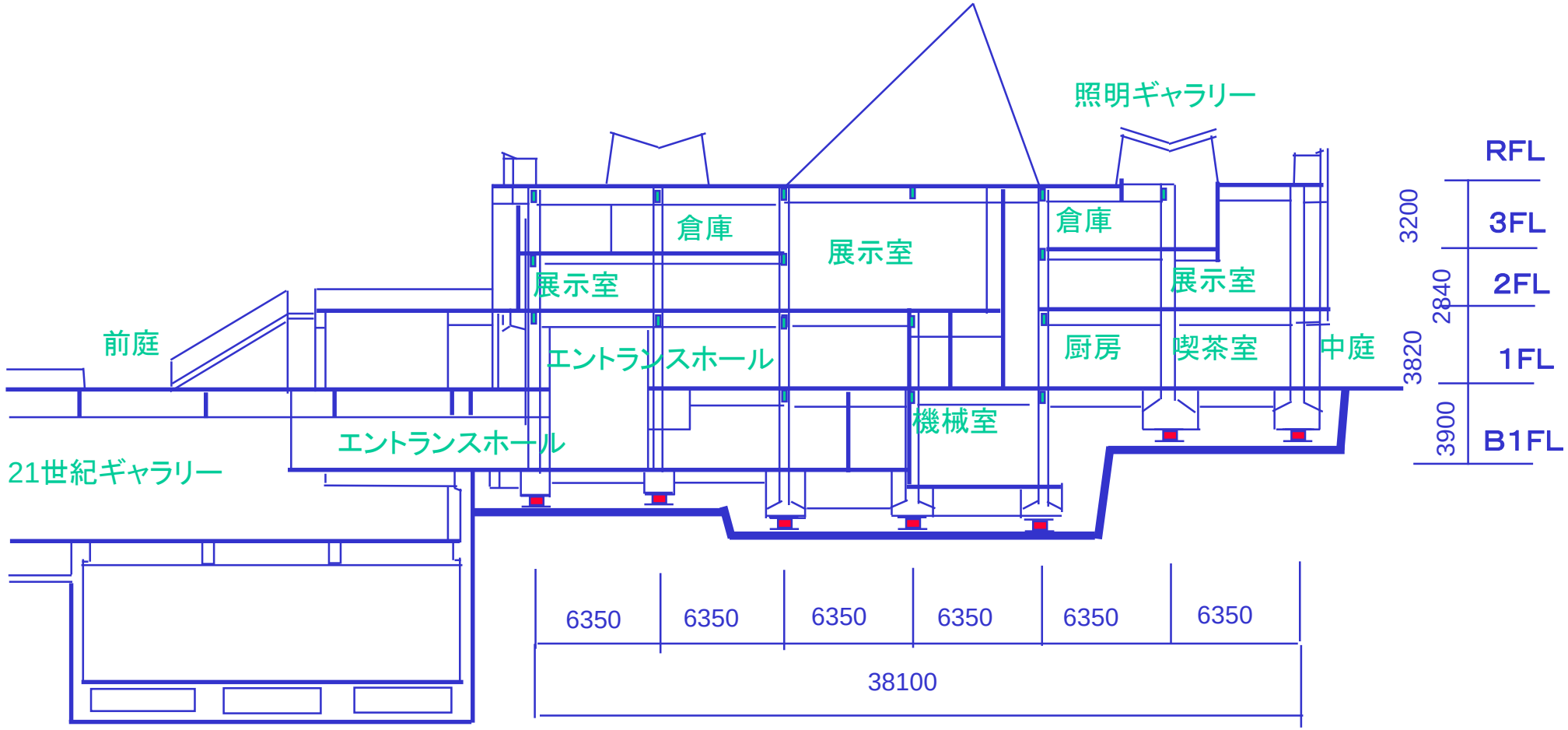




Existing basement

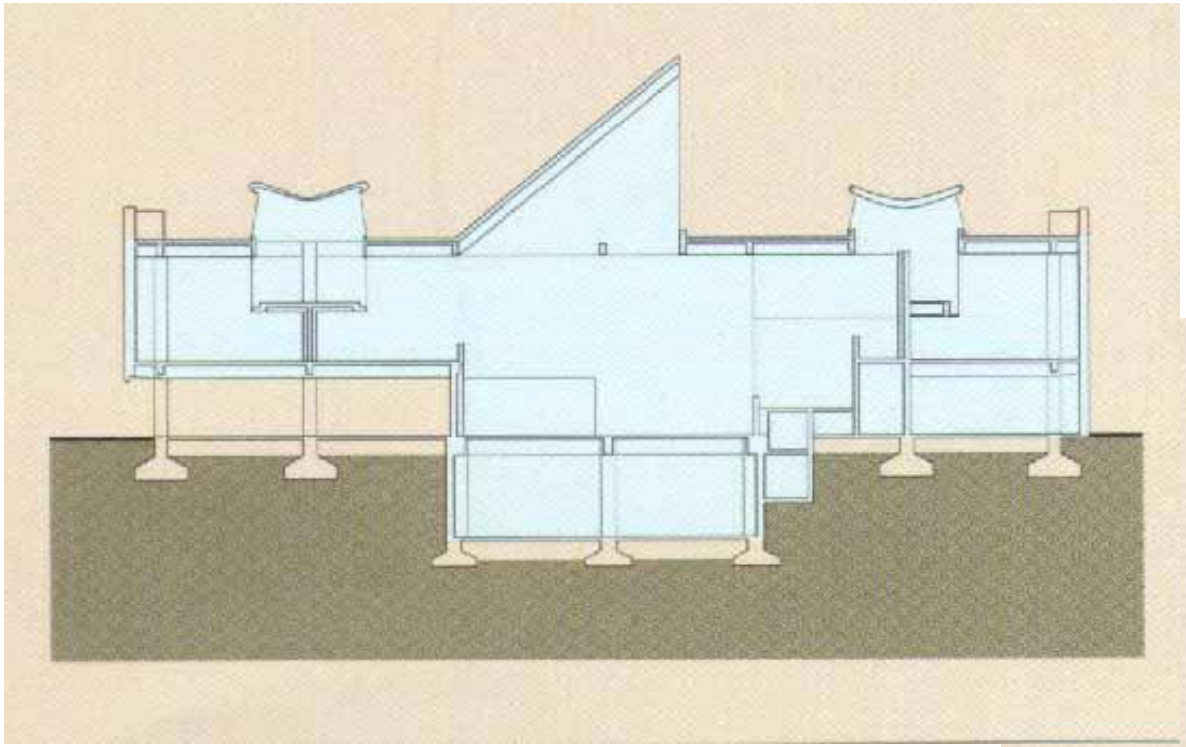
Extended basement

1st floor plan



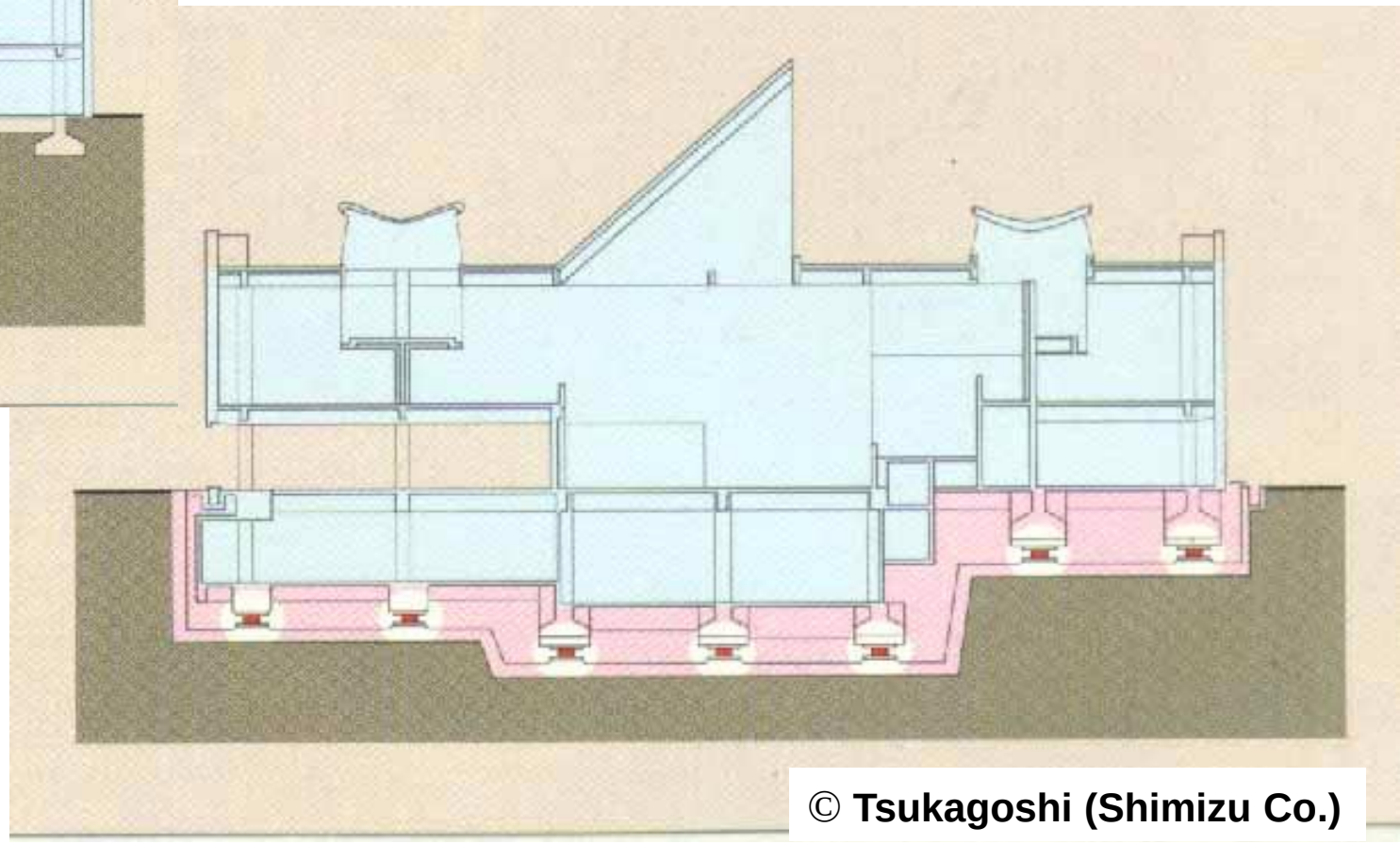
Section

Section of museum

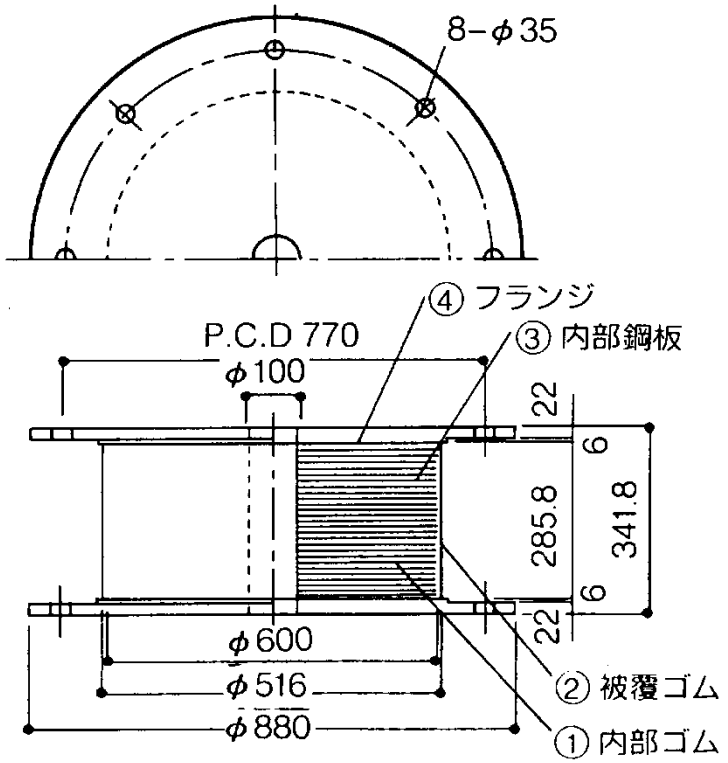


Before retrofit

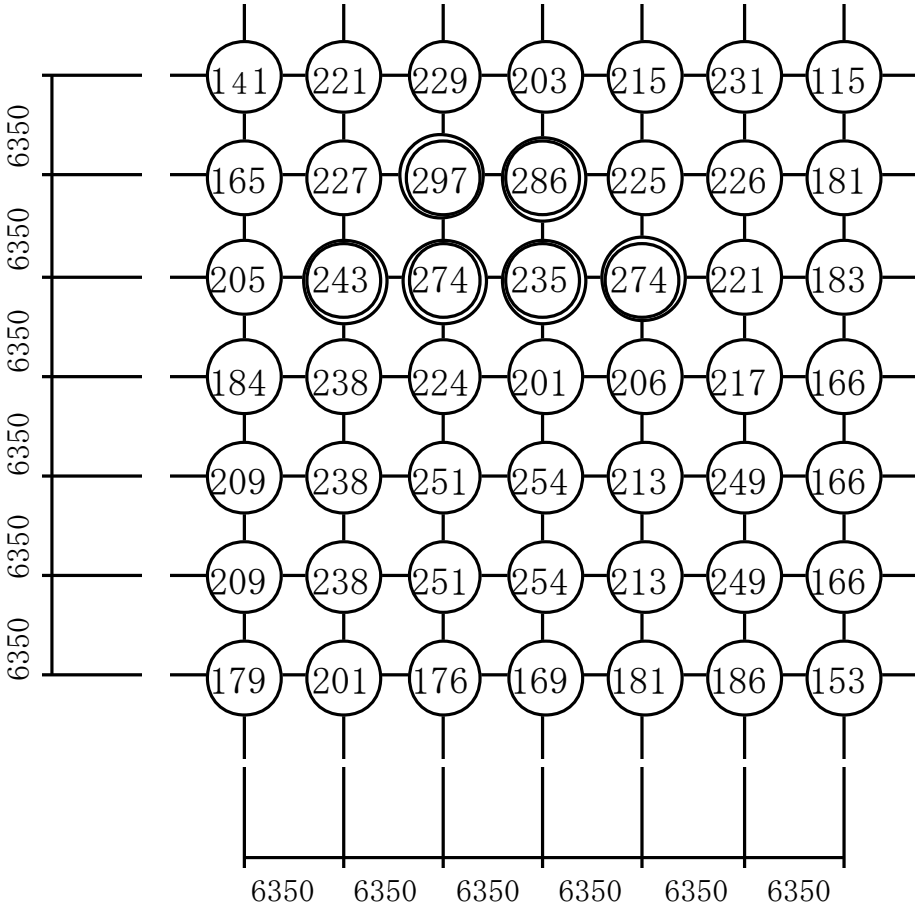
After retrofit



Property and location of isolators

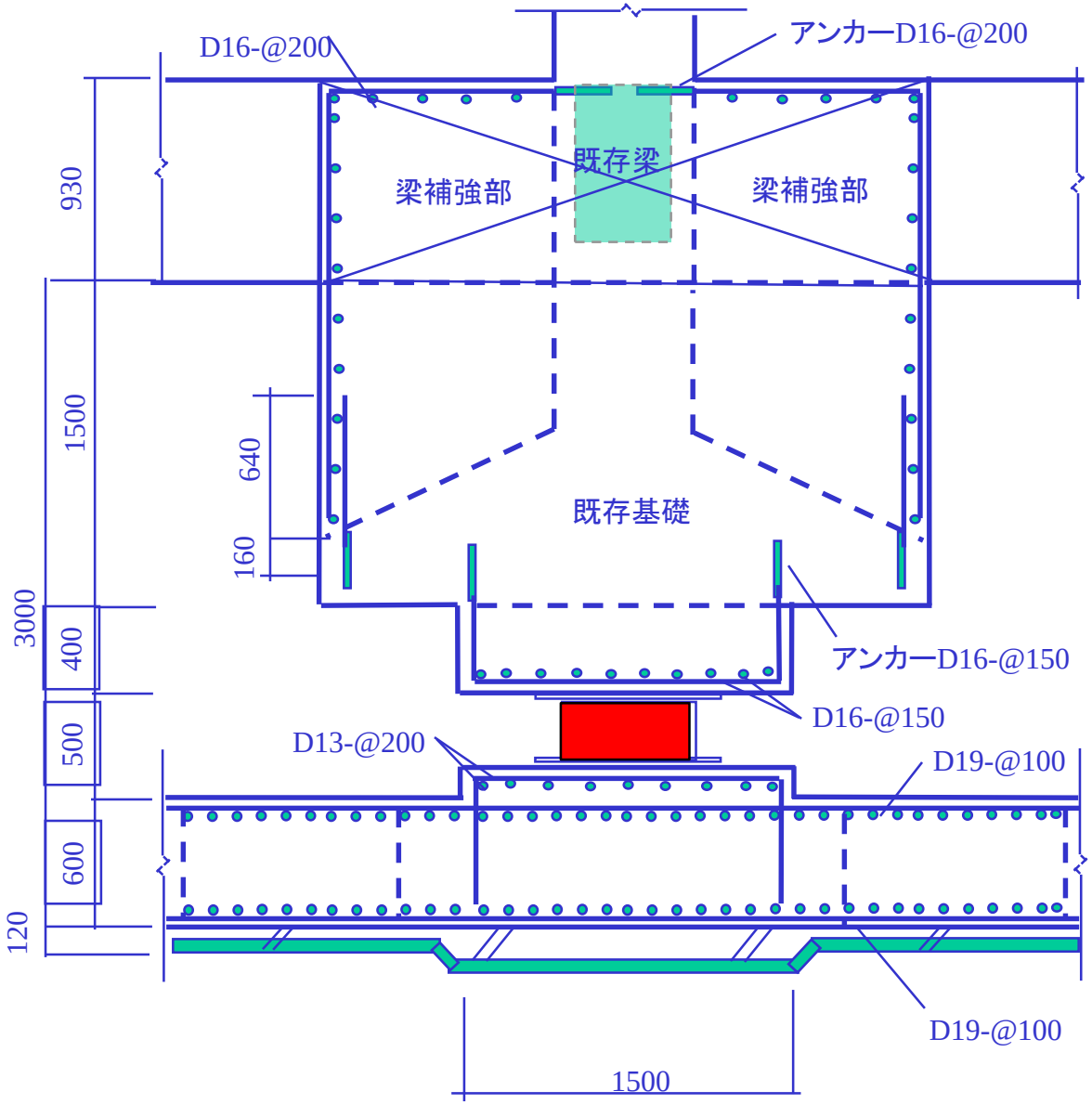


High damping rubber bearing

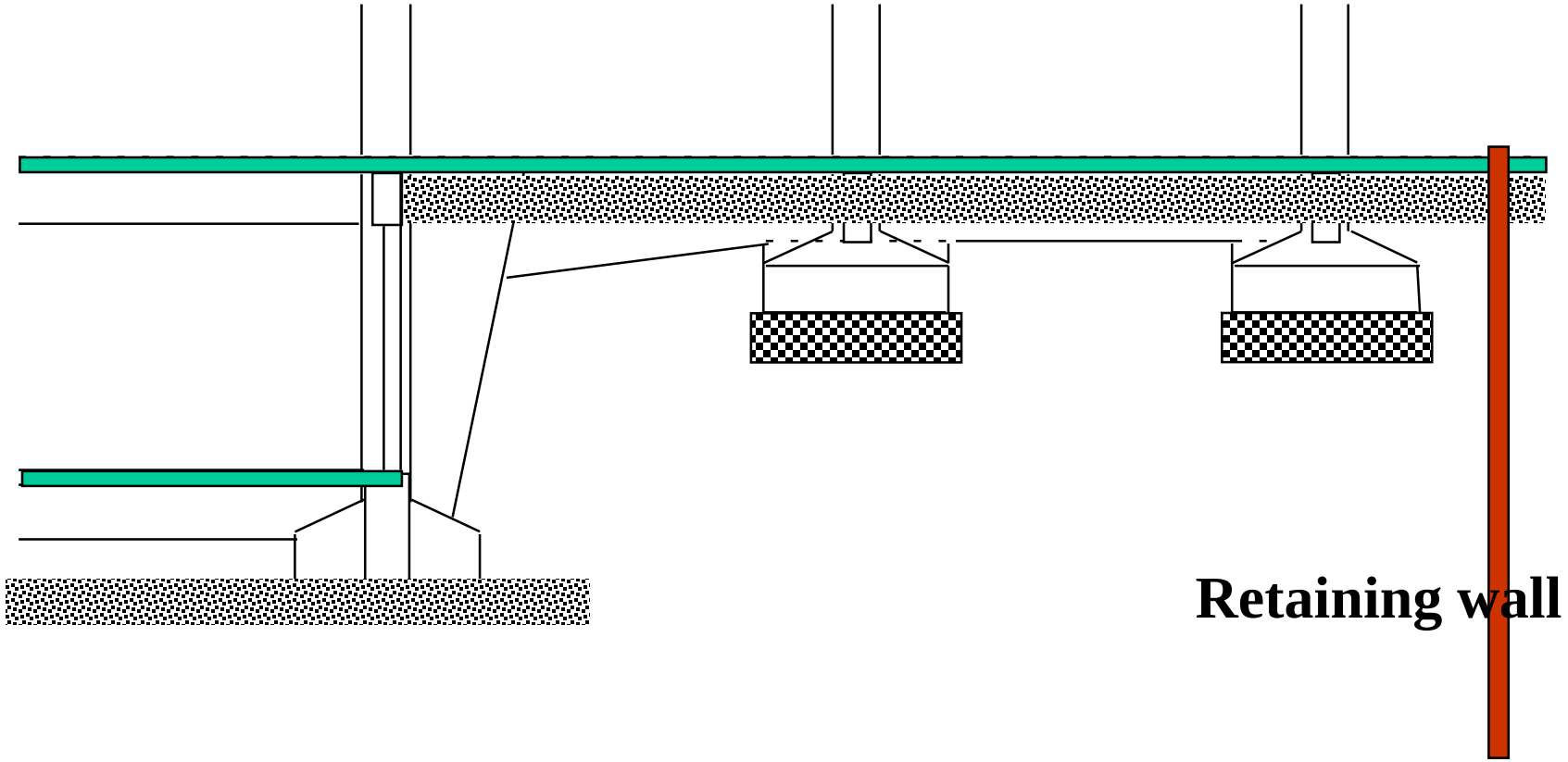


○ **Diameter 600** ◎ : **Diameter 650 figure: axial force (tons)**

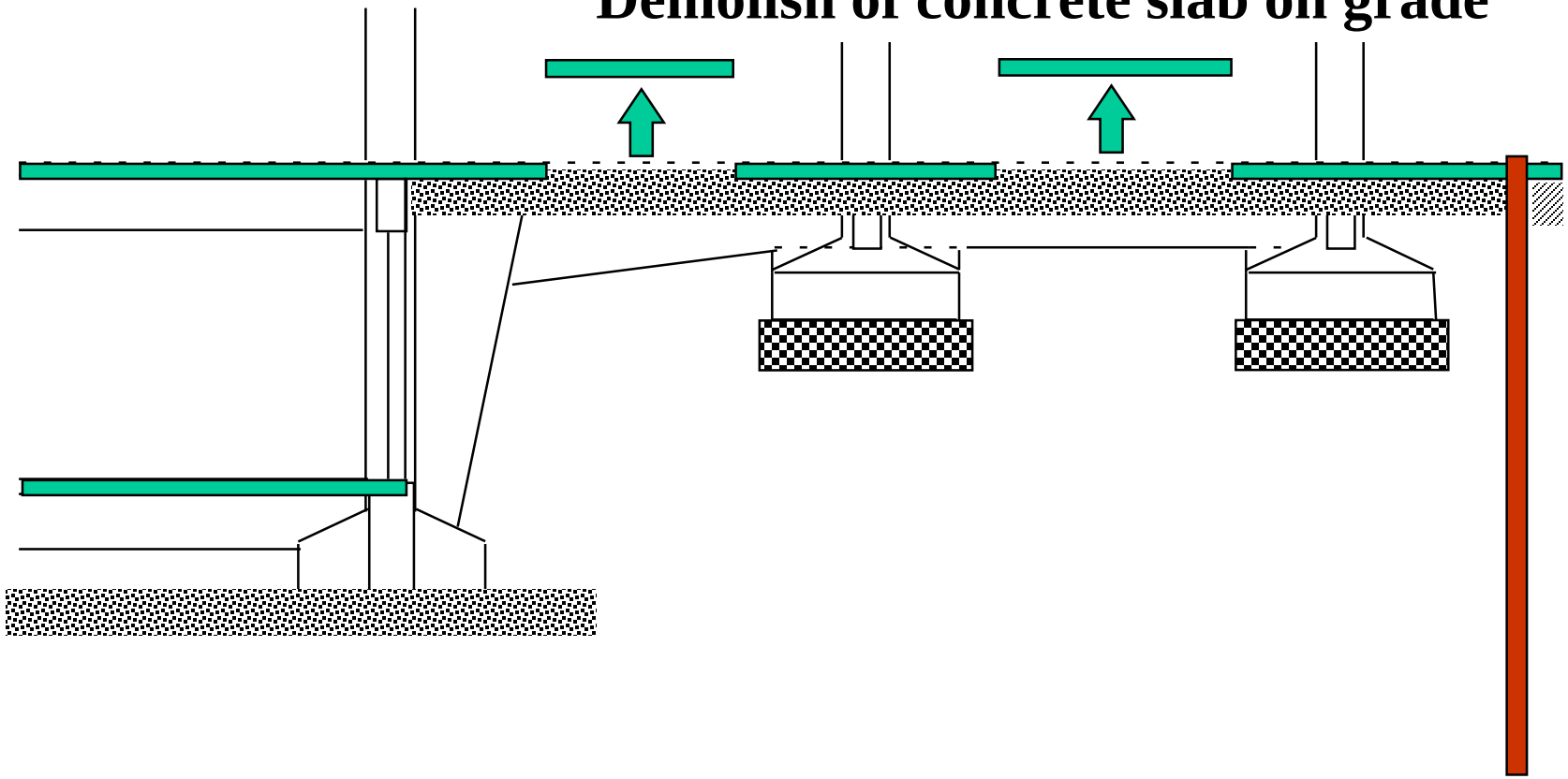
Construction process

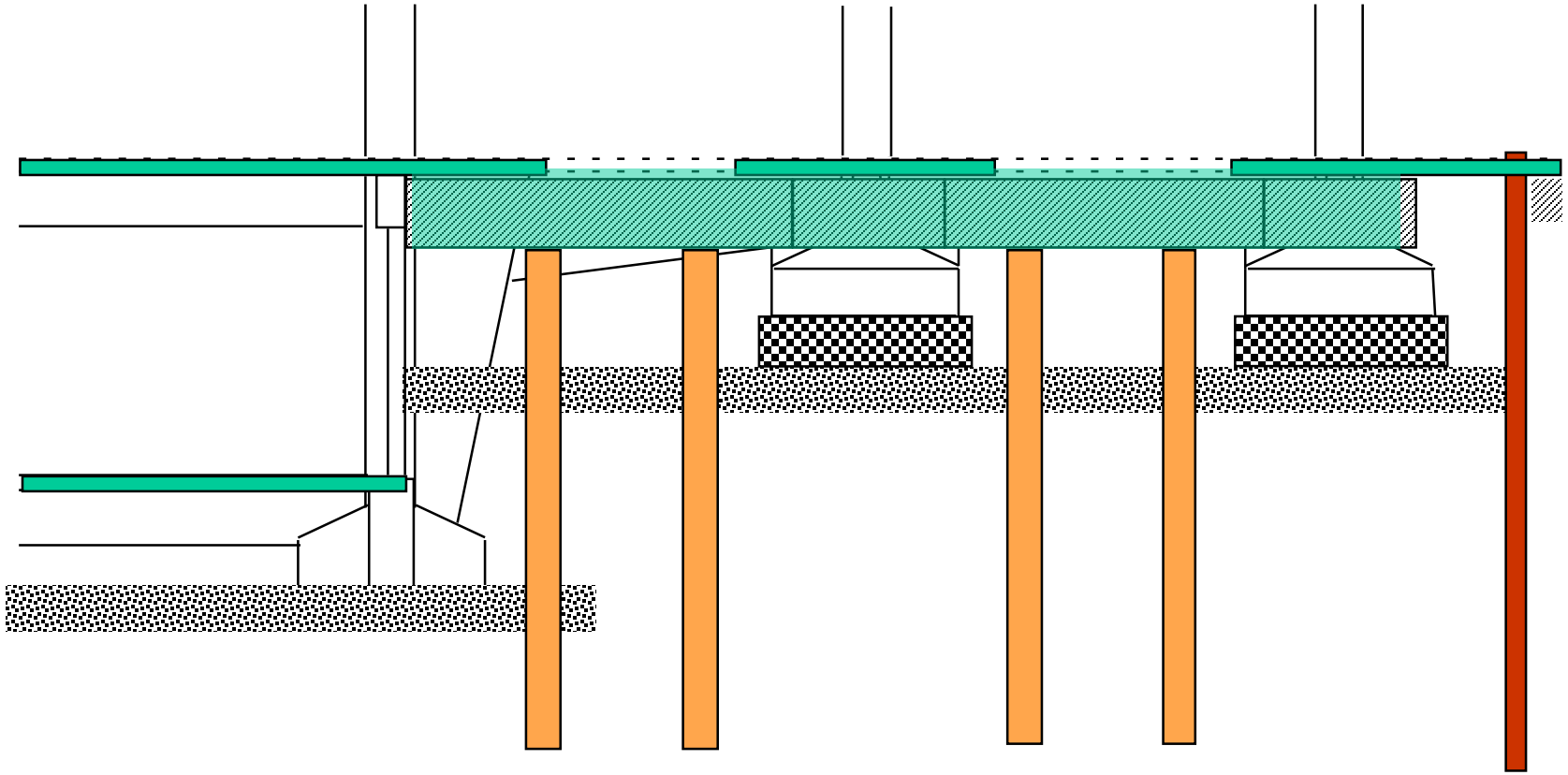


Section of Isolator surrounding detail after completion

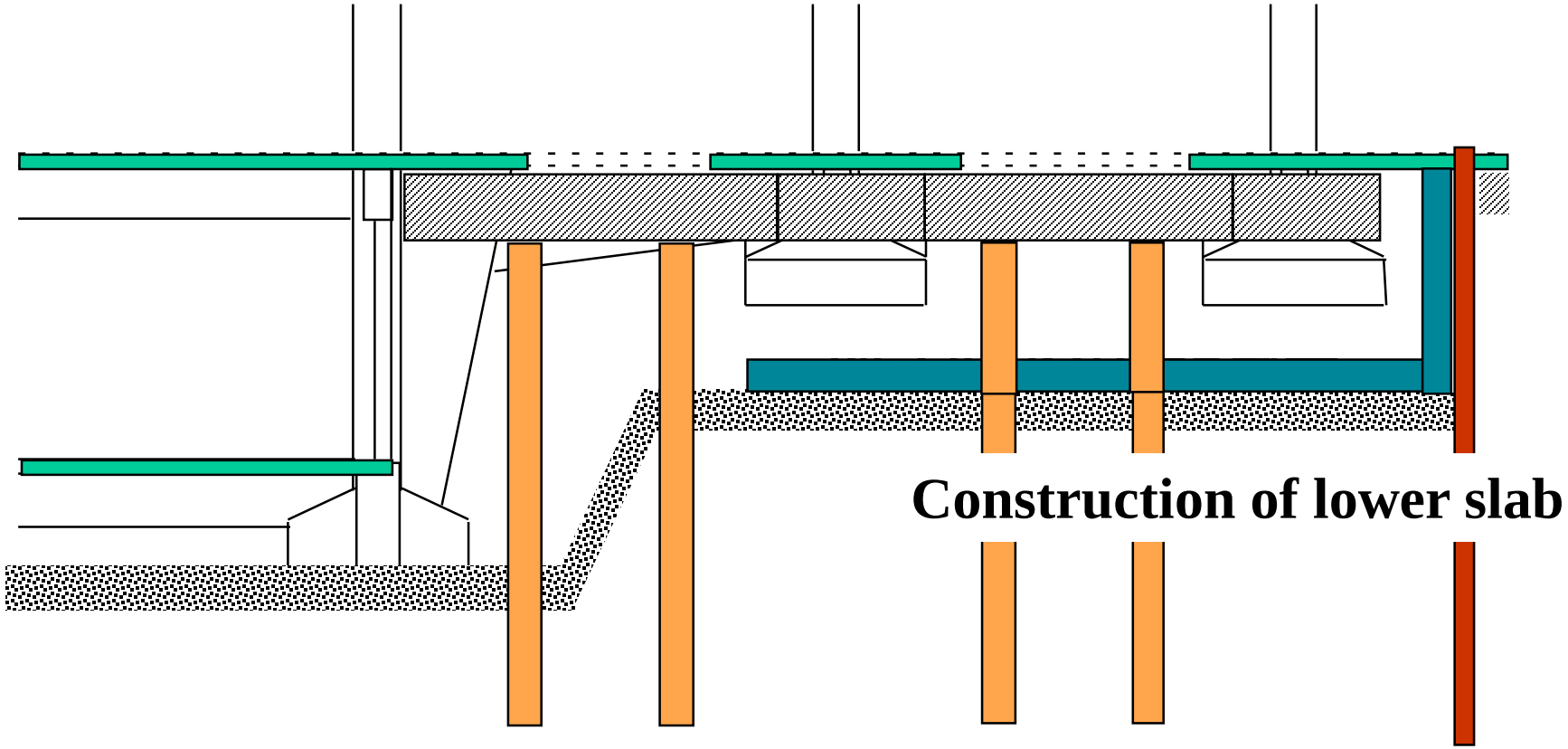


Demolish of concrete slab on grade

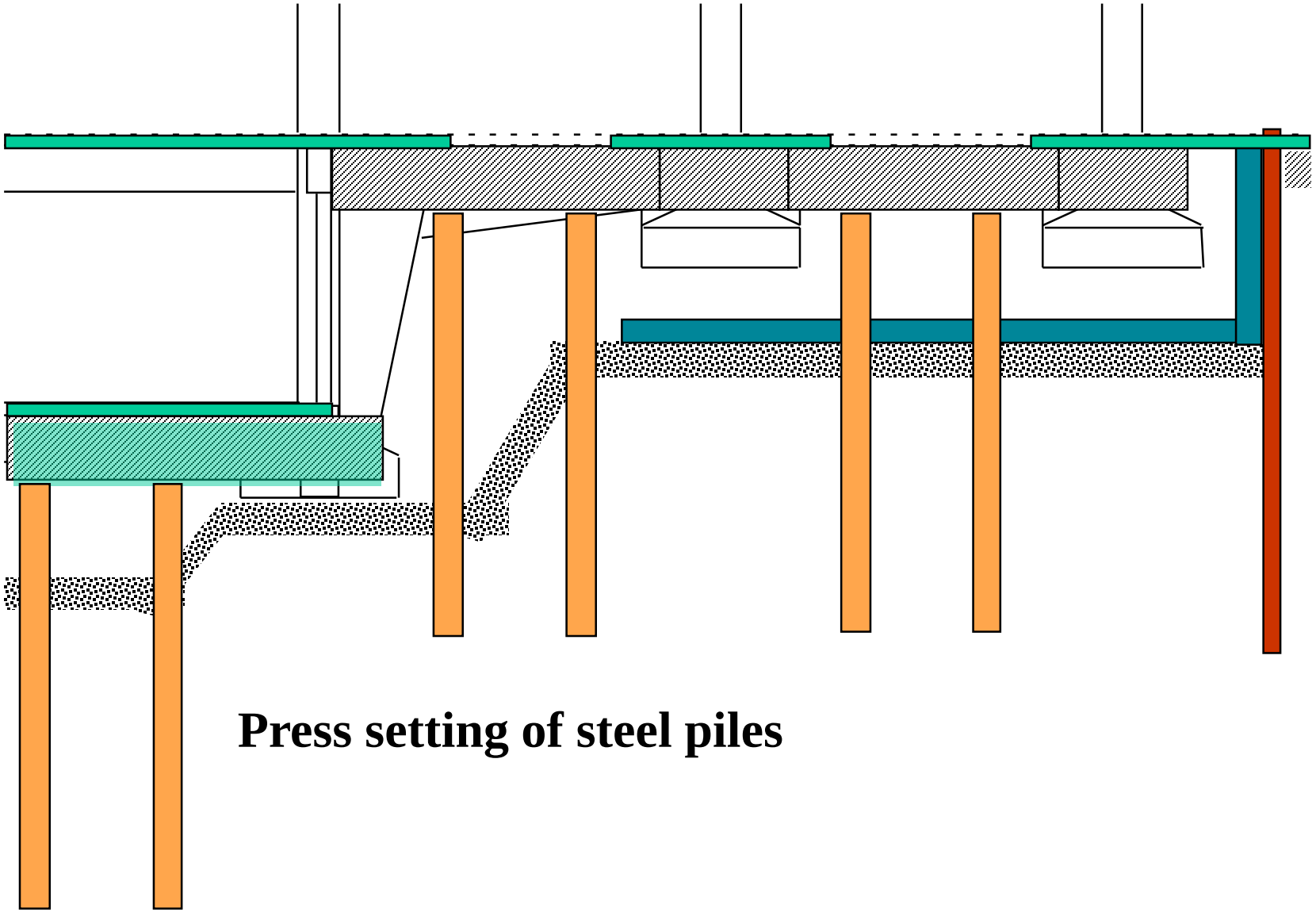




Press setting of steel piles



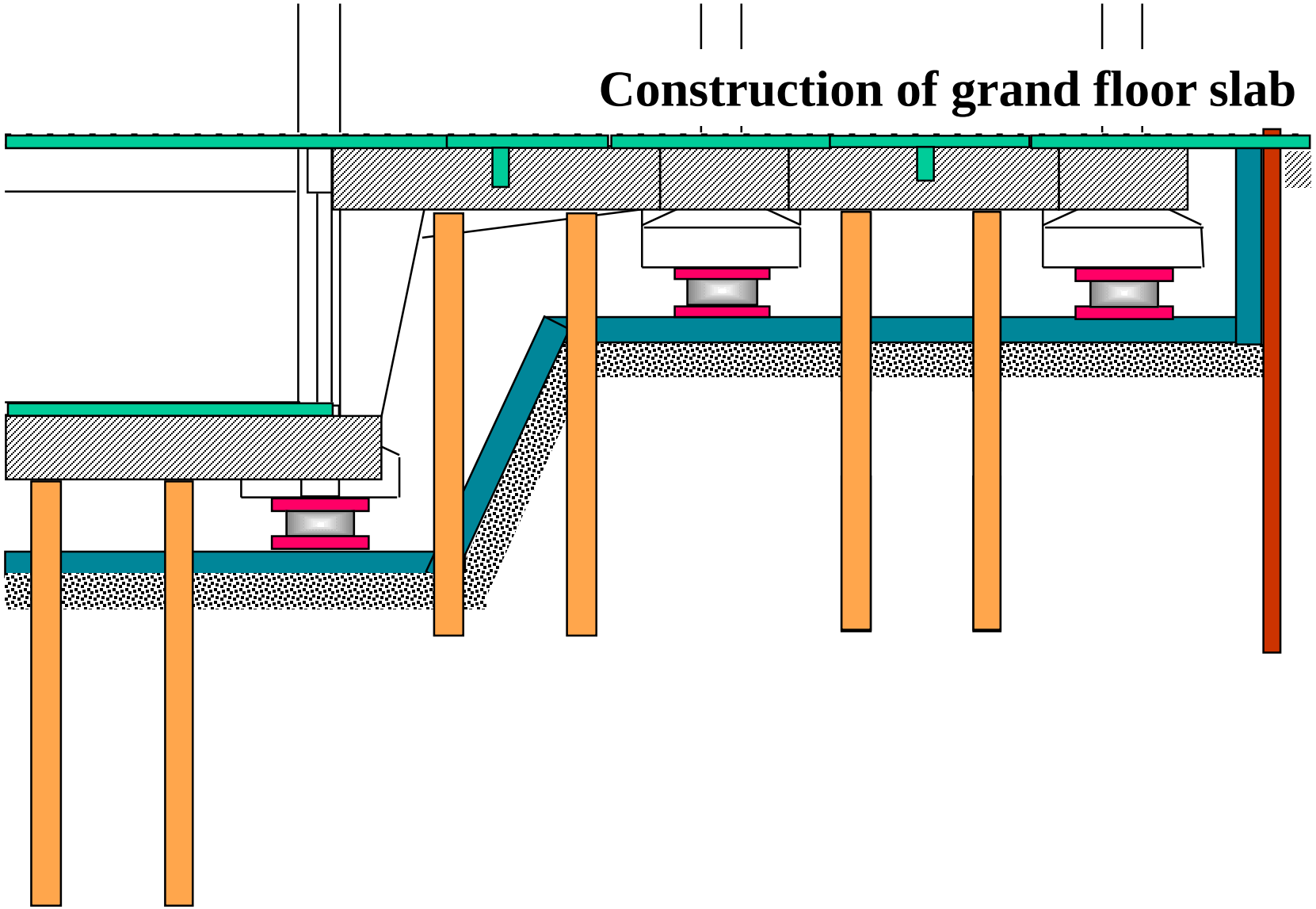
Construction of lower slab

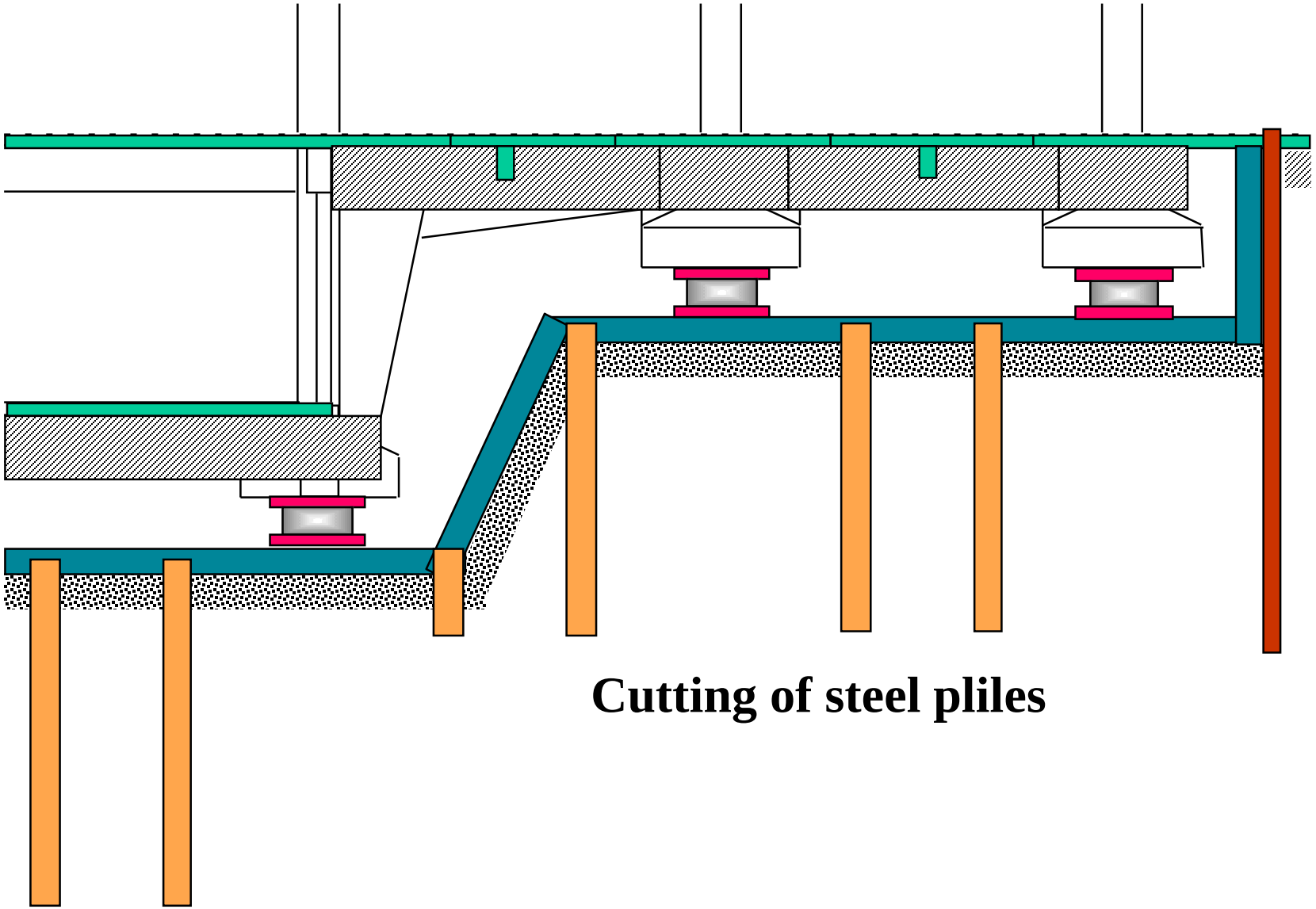


Press setting of steel piles

© Tsukagoshi (Shimizu Co.)

Construction of grand floor slab





Cutting of steel pliles

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Pressing of steel piles

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Excavating machines

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Removal of rubble concrete

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Setting of seismic isolators

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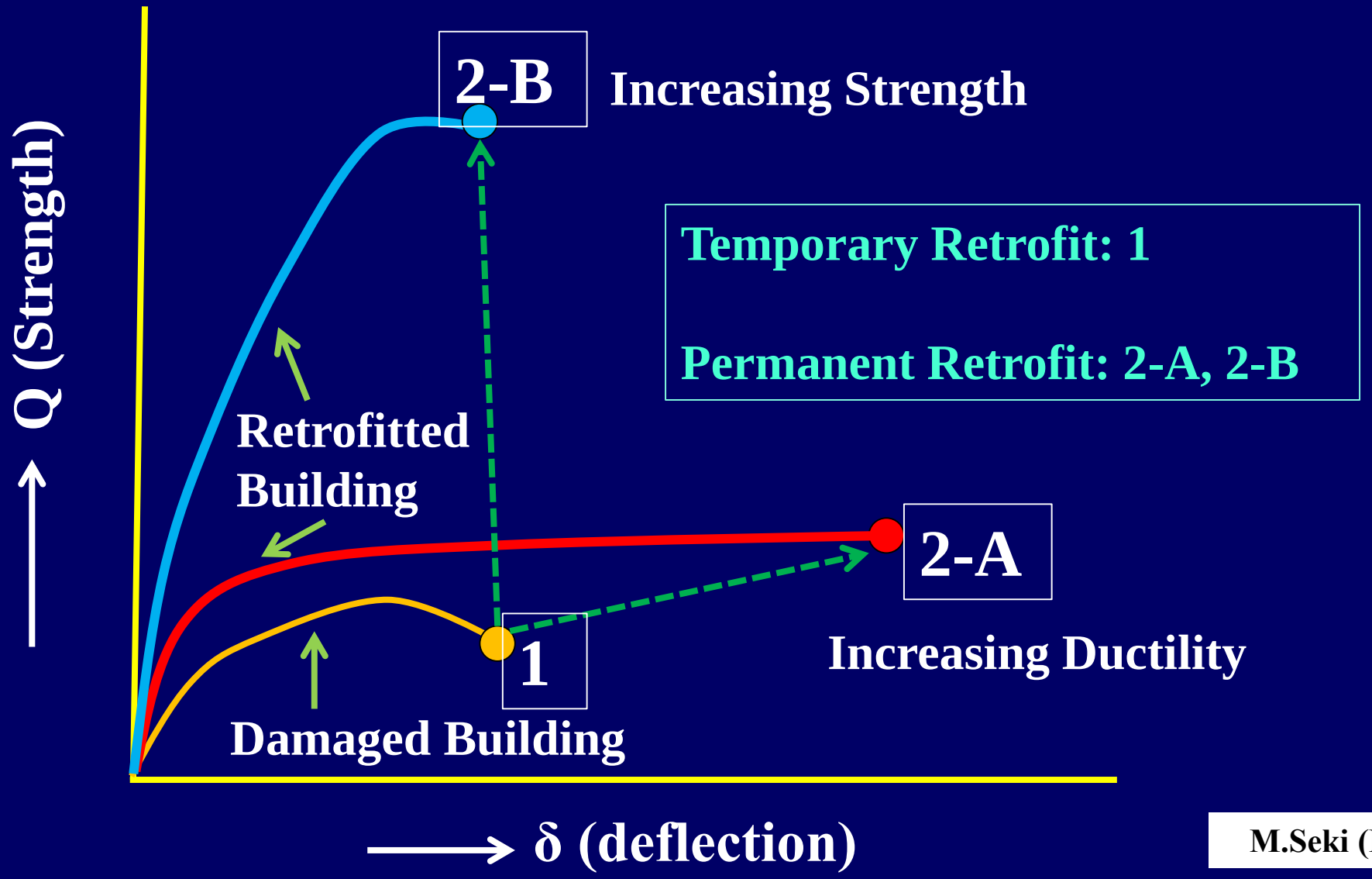
Seismic isolation retrofit in NZ

NZ Retrofit Video

Temporary repair and permanent strengthening after earthquakes

Temporary Retrofit Permanent Retrofit of damaged buildings in 1995 Hyogoken Nanbu (Kobe) earthquake

Definition of Retrofit for Damaged Building



M.Seki (BRI,IISEE)

Seki M., UTCB Lecture note, May 2017, BRI, Japan

Temporary retrofit

Steel post

Photo:M.Seki)

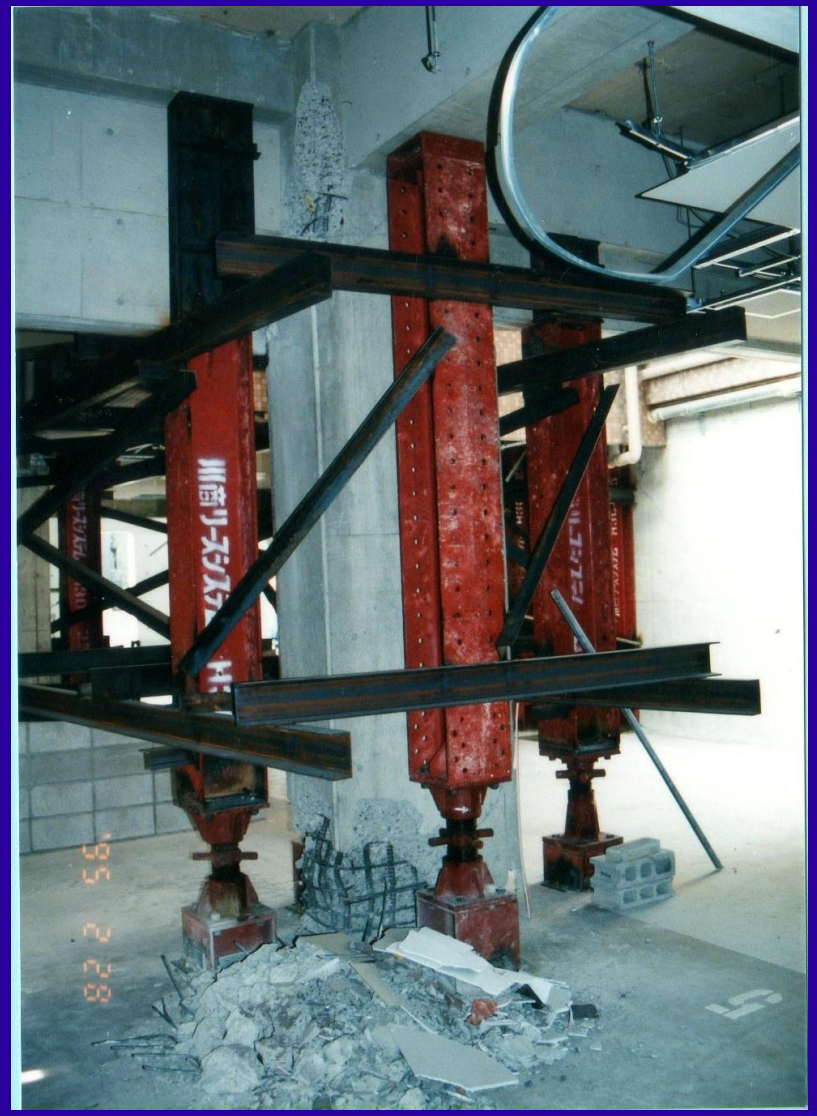
Temporary retrofit

Steel post

M.Seki (BRI,IISEE)

Temporary retrofit

Steel post



M.Seki (BRI,IISEE)

Temporary retrofit

Steel band plate

M.Seki (BRI,IISEE)

Temporary retrofit

Severely damaged column (1994 Sanriku EQ, Japan)

Temporary retrofit

Steel post and restress steel wire (1994 Sanriku EQ, Japan)

M.Seki (BRI,IISEE)

Temporary retrofit

Residential building (Superstructure: no damage)

M.Seki (BRI,IISEE)

Temporary retrofit

Residential building (Piles: damage)

Steel post

M.Seki (BRI,IISEE)

Temporary retrofit

Residential building (Superstructure: no damage)

M.Seki (BRI,IISEE)

Temporary retrofit

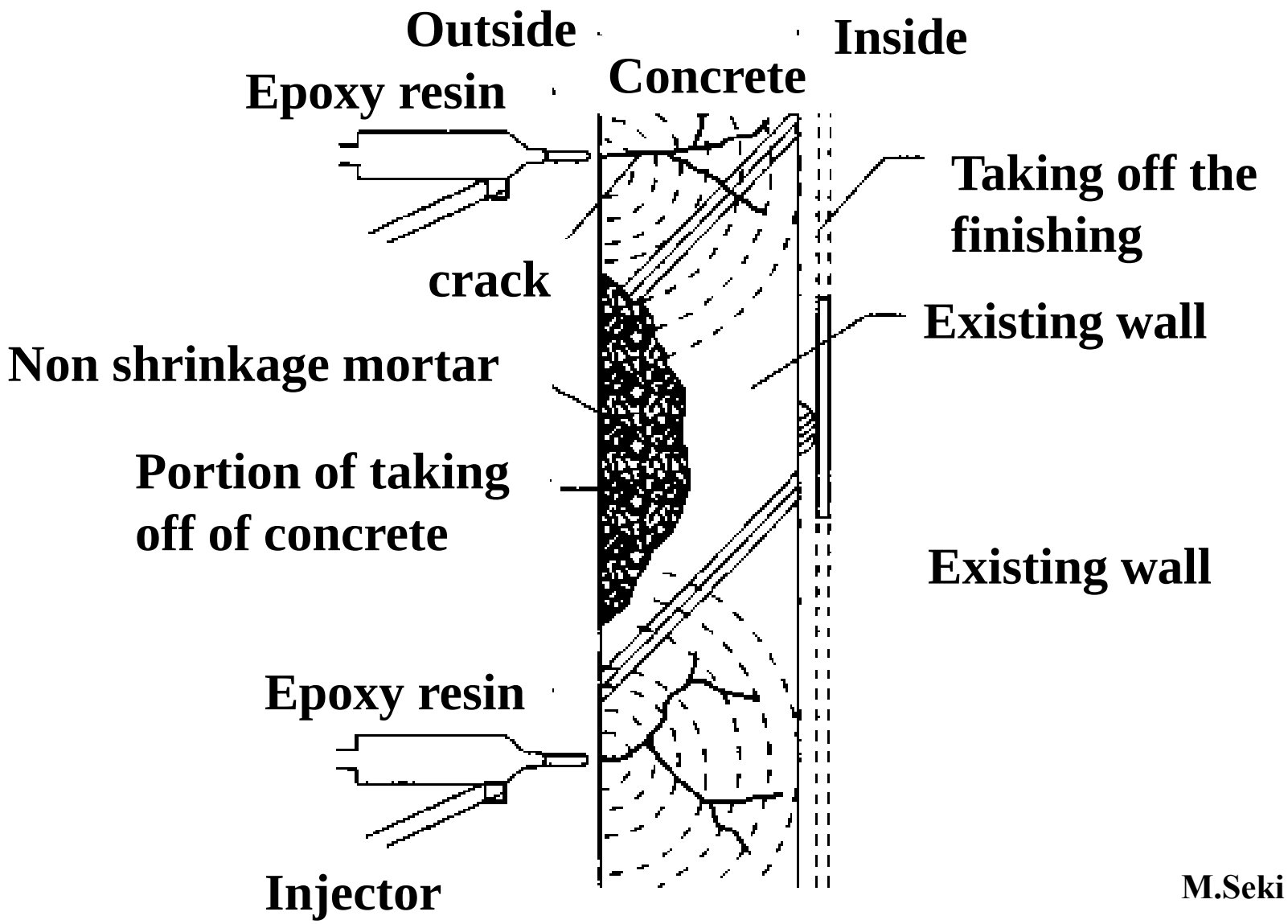
Residential building (Piles: damage)

Steel post and jack

M.Seki (BRI,IISEE)

Permanent retrofit

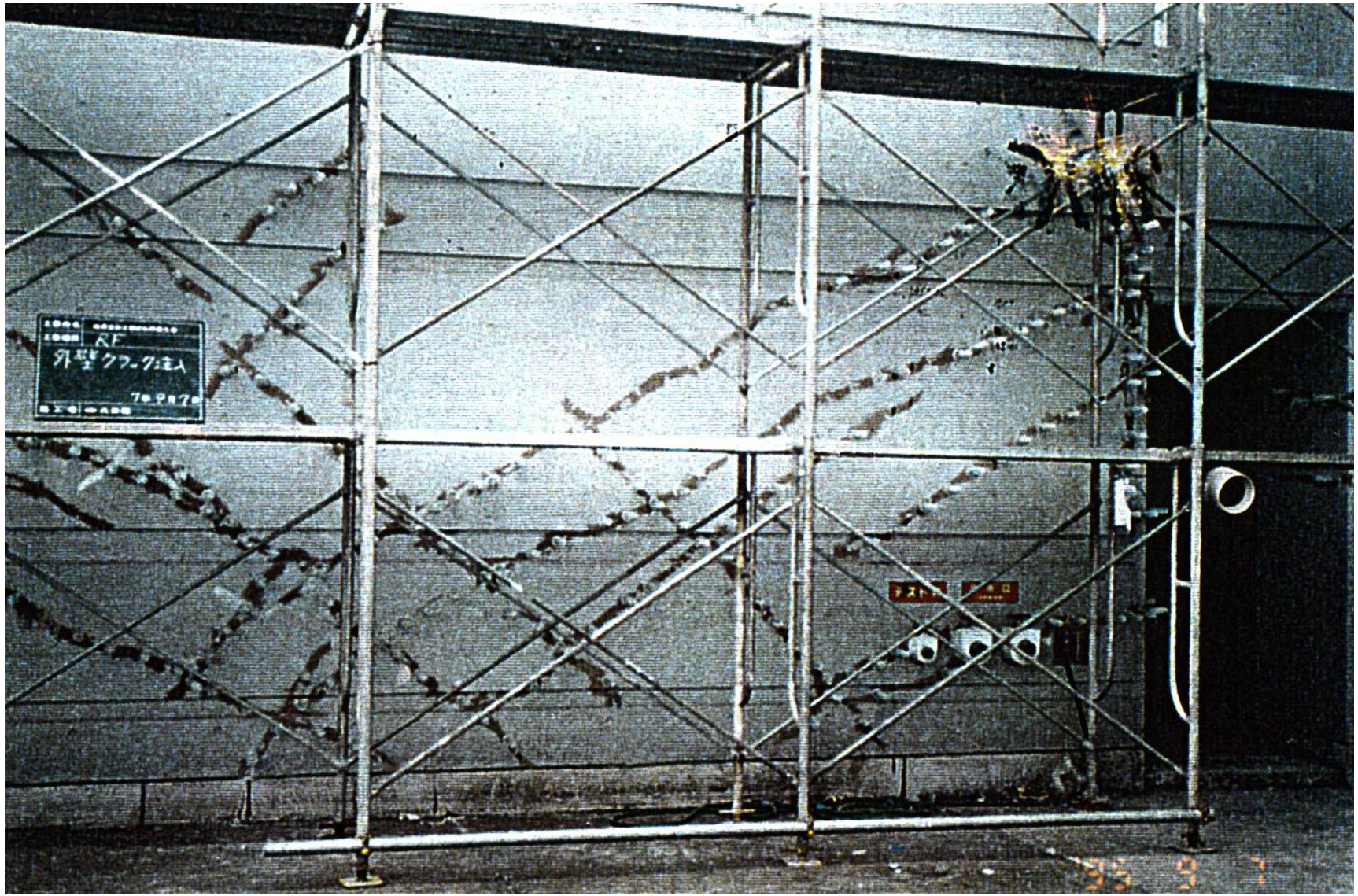
Epoxy resin injection



M.Seki (BRI,IISEE)

Permanent retrofit

Epoxy resin (wall)



M.Seki (BRI,IISEE)

Permanent retrofit

Epoxy resin (outside wall)

M.Seki (BRI,IISEE)

Permanent retrofit

Epoxy resin (floor slab)

M.Seki (BRI,IISEE)

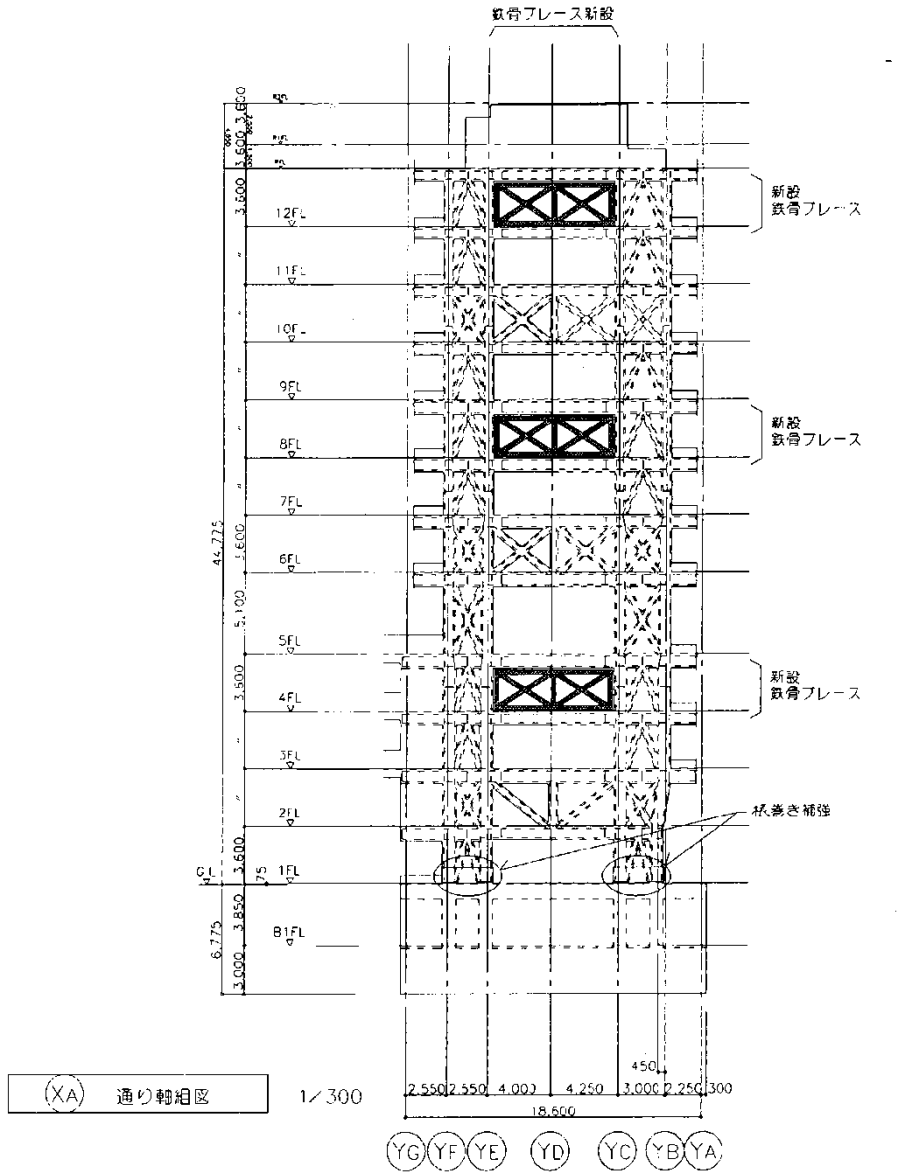
Permanent retrofit

Epoxy resin (ceiling)

M.Seki (BRI,IISEE)

Permanent retrofit

Elevation of damaged building



Steel and ceinforced concrete building (SRC)

M.Seki (BRI,IISEE)

Permanent retrofit

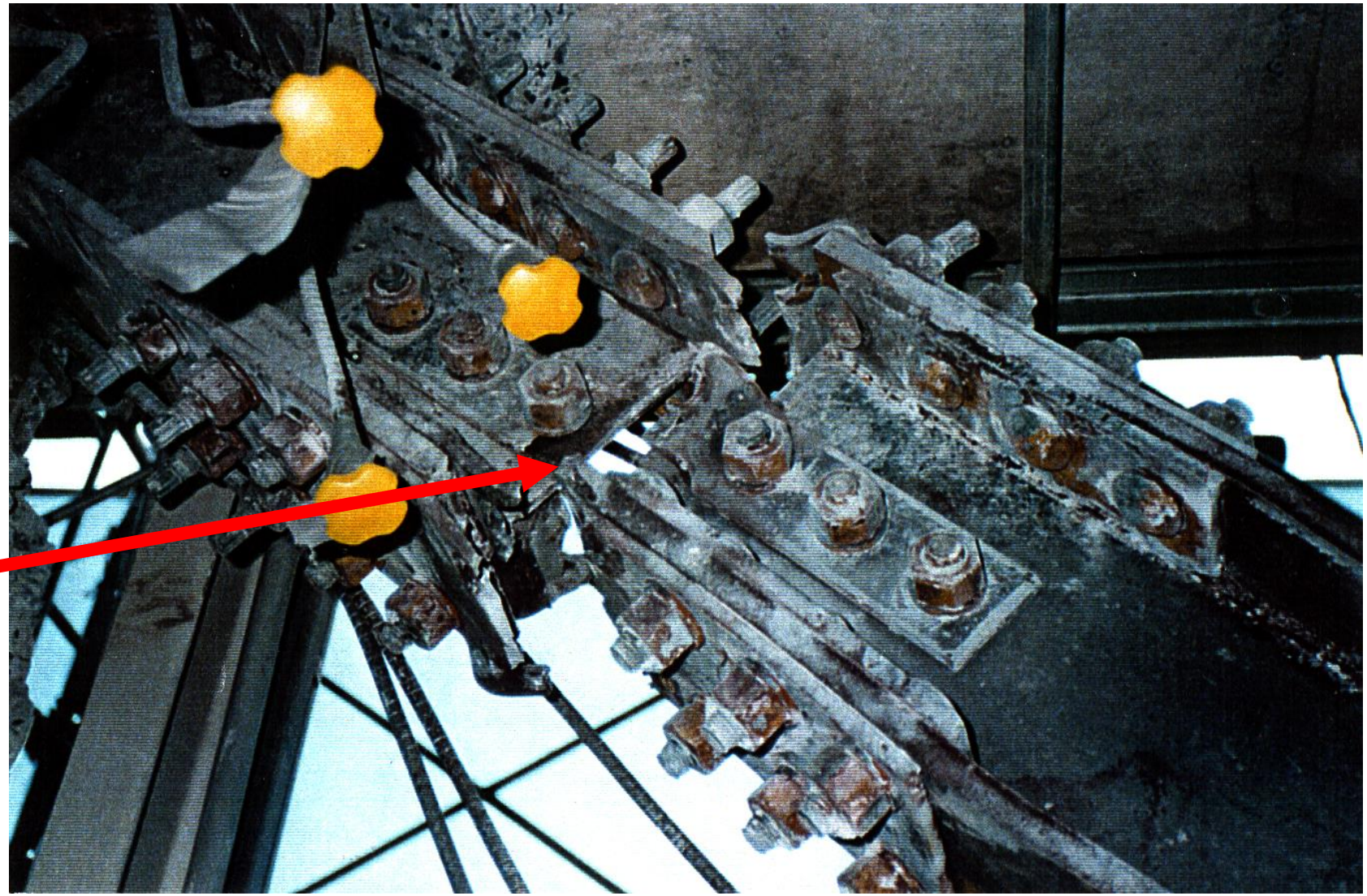
Damage of SRC brace

M.Seki (BRI,IISEE)

Permanent retrofit

Damage of SRC brace

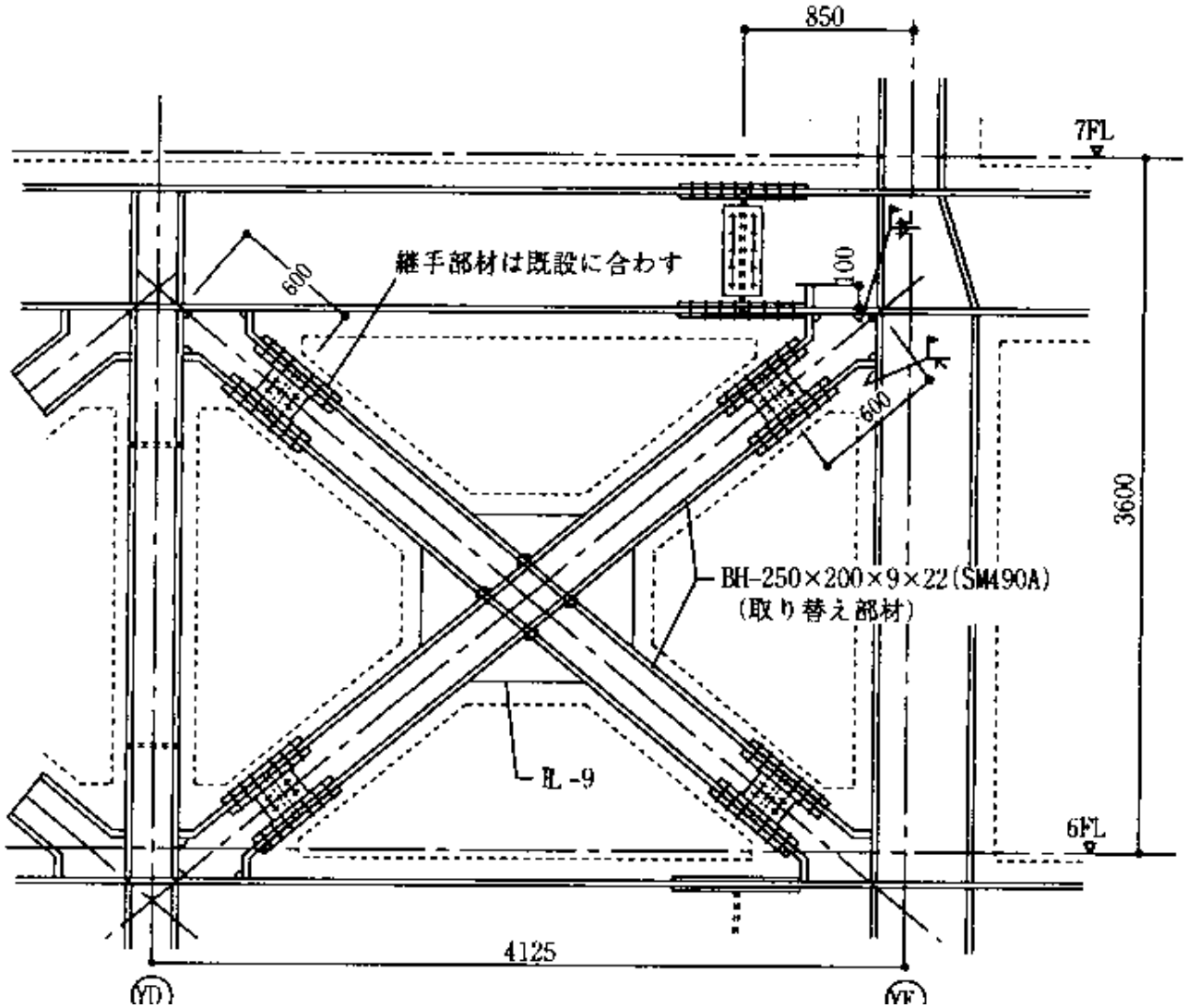
Damage detail of joint plate



M.Seki (BRI,IISEE)

Permanent retrofit

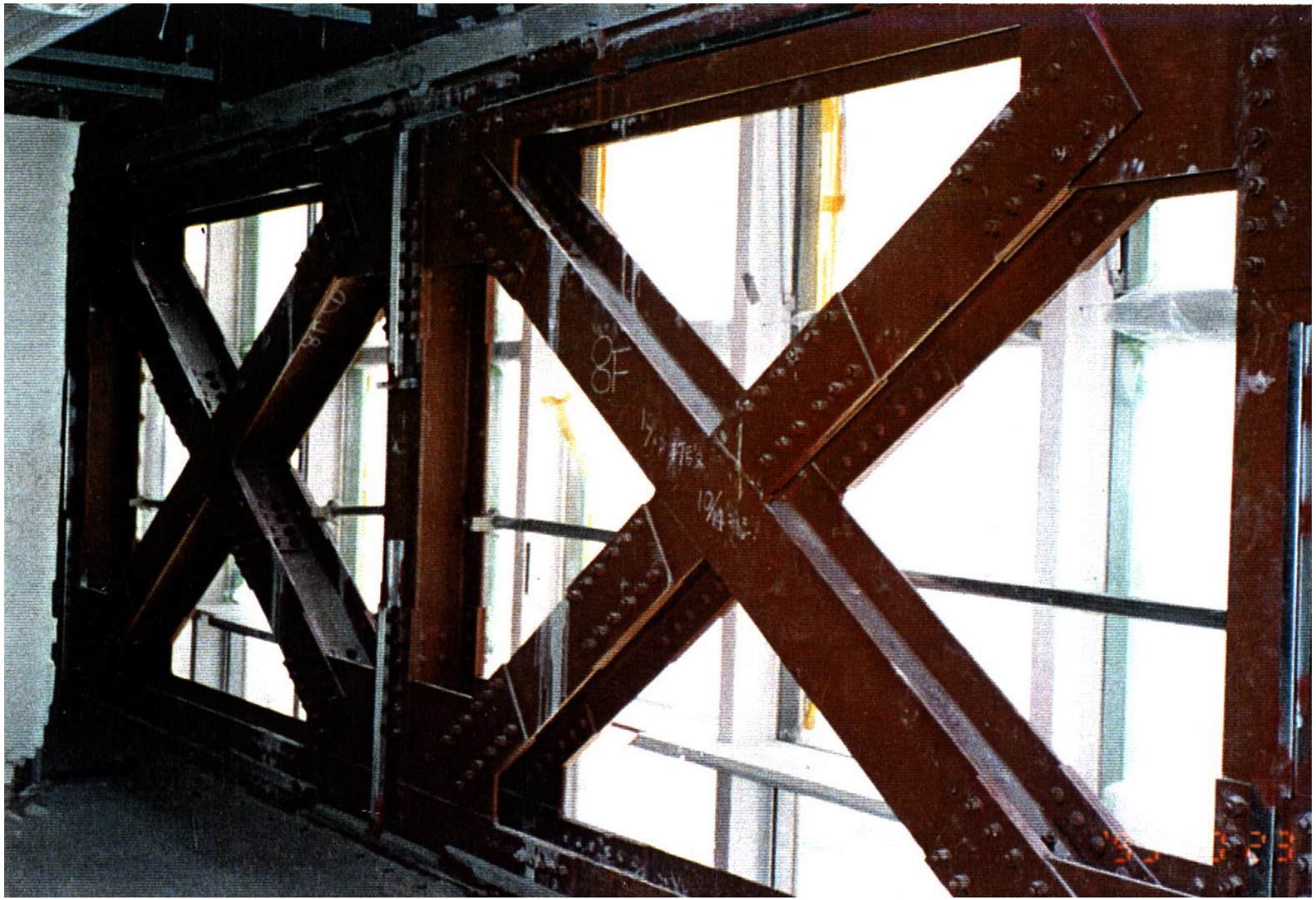
Retrofit detail of SRC brace



M.Seki (BRI,IISEE)

Permanent retrofit

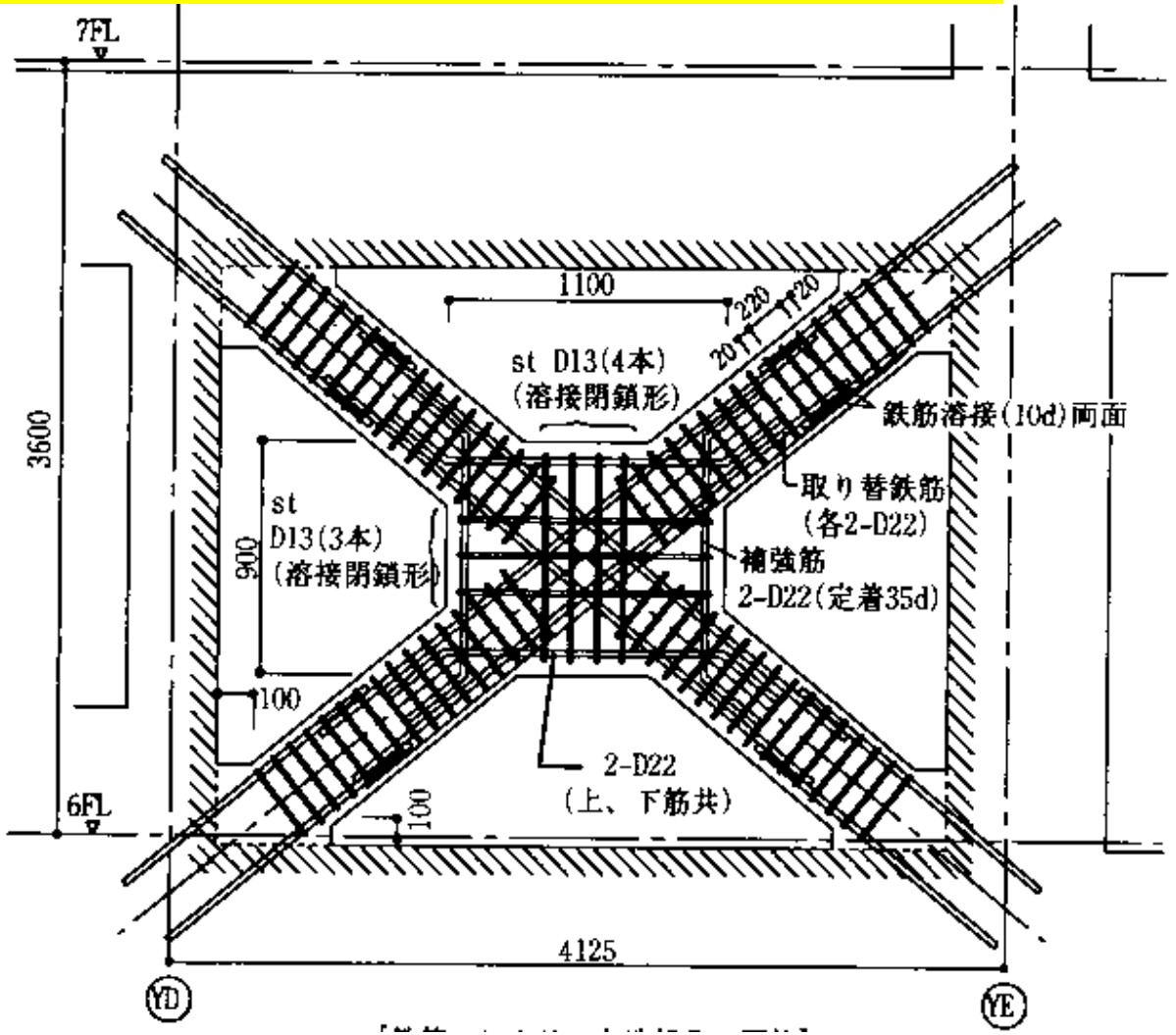
Newly installed steel brace



M.Seki (BRI,IISEE)

Permanent retrofit

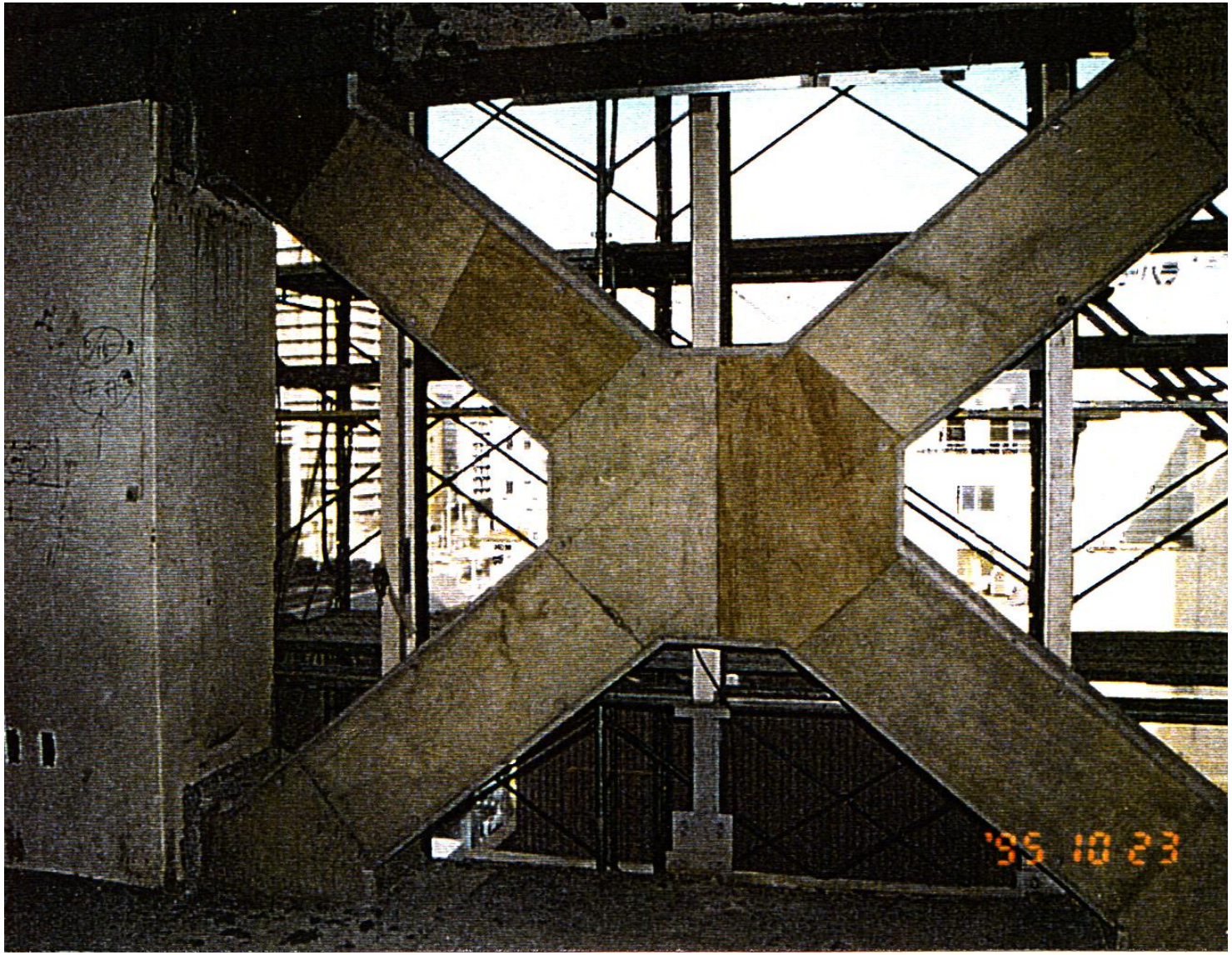
Retrofit detail of SRC brace (Rebar)



M.Seki (BRI,IISEE)

Permanent retrofit

After casting of concrete



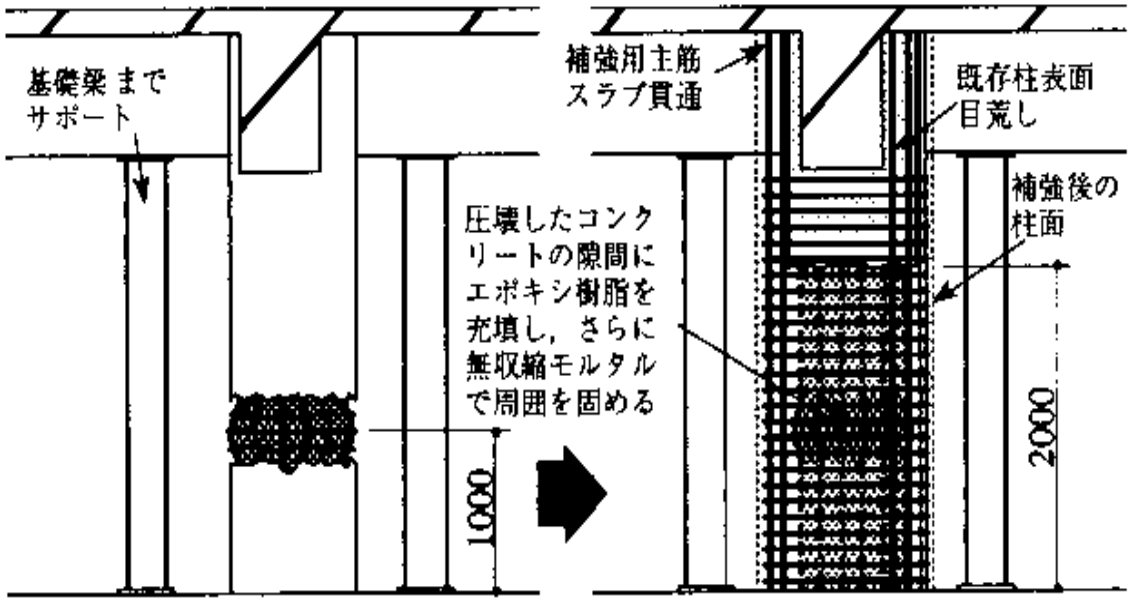
M.Seki (BRI,IISEE)

Permanent retrofit

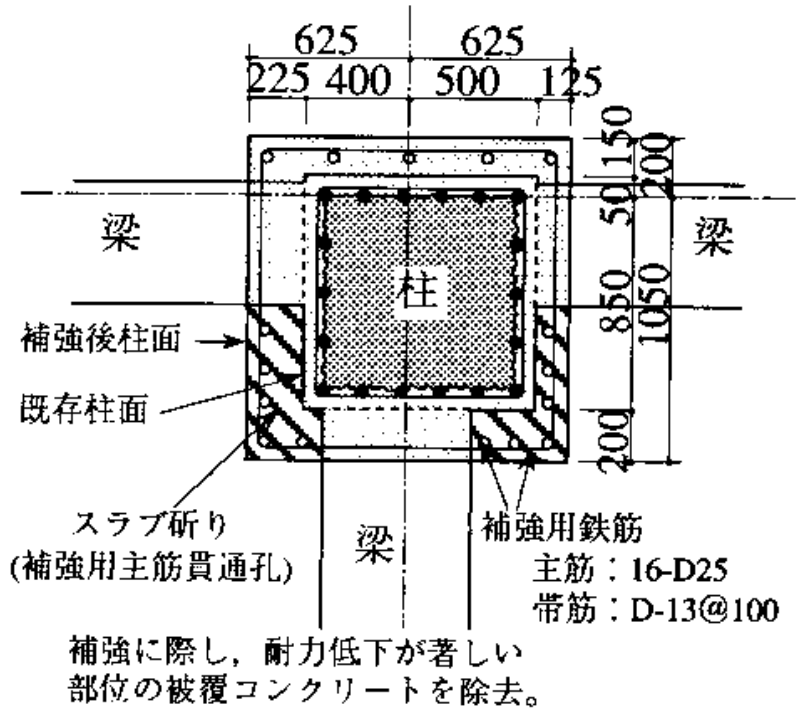
New steel brace

M.Seki (BRI,IISEE)

Permanent retrofit



Section

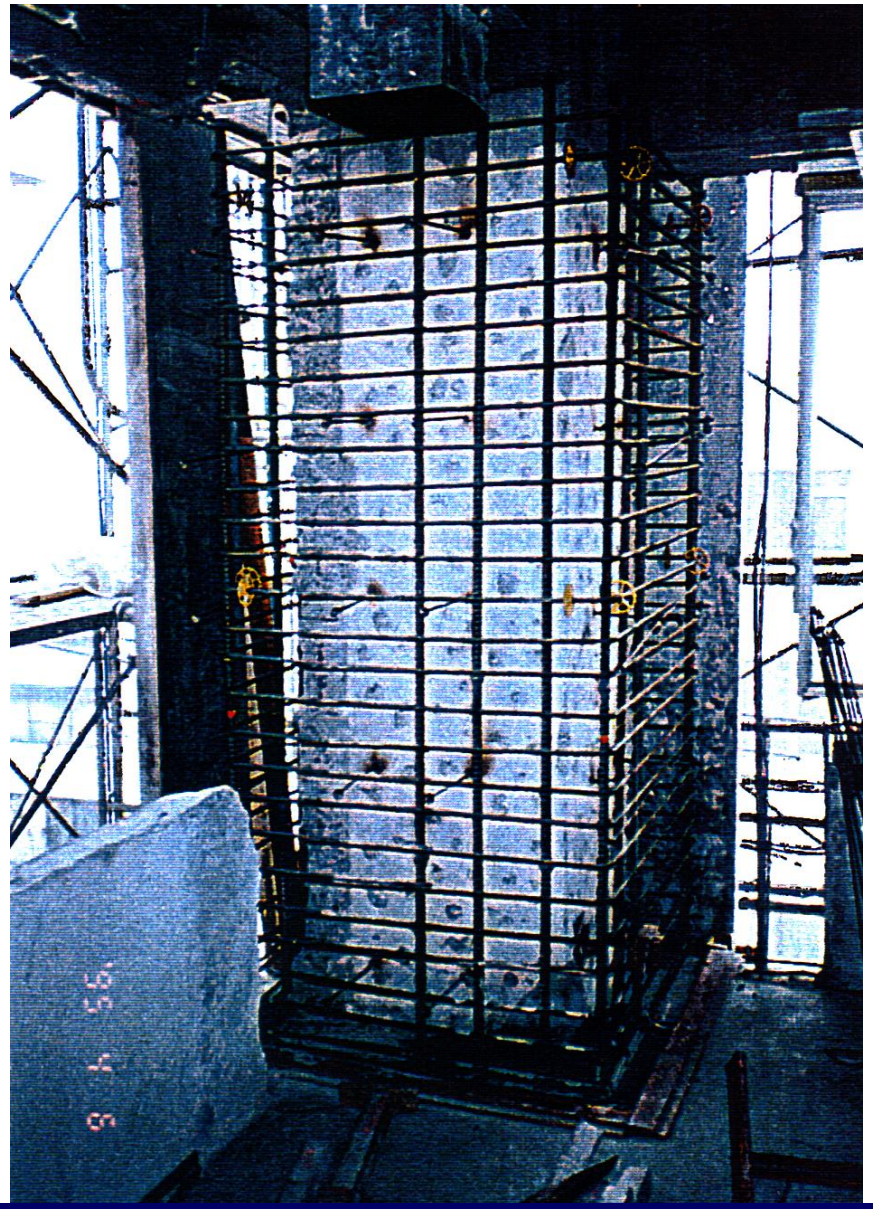


Plan

Concrete jacketing for column

M.Seki (BRI,IISEE)

Permanent retrofit



New rebars for concrete jacketing

M.Seki (BRI,IISEE)

Permanent retrofit

Increasing of section
at the bottom of column

M.Seki (BRI,IISEE)

Permanent retrofit

Steel plate jacketing

Taking off of damaged concrete portion

M.Seki (BRI,IISEE)

Permanent retrofit

Steel plate jacketing

Cutting the buckled steel bars

Steel bars connected by couplers

M.Seki (BRI,IISEE)

Permanent retrofit

Steel plate jacketing

M.Seki (BRI,IISEE)

Permanent retrofit

Steel plate jacketing for steel building

M.Seki (BRI,IISEE)

Permanent retrofit

Steel plate jacketing and steel brace

M.Seki (BRI,IISEE)

Permanent retrofit

Repair of beam bars

M.Seki (BRI,IISEE)

Permanent retrofit

After jacketing by steel plate (Beam)

M.Seki (BRI,IISEE)

Permanent retrofit

Welding retrofit of damaged beam plate

M.Seki (BRI,IISEE)

Permanent retrofit

After welding of beam plates

M.Seki (BRI,IISEE)

Permanent retrofit

After welding of beam plates

M.Seki (BRI,IISEE)

Permanent retrofit

RC column after binding the carbon fiber strand

M.Seki (BRI,IISEE)

Permanent retrofit

Binding the carbon fiber strand around the damaged column

M.Seki (BRI,IISEE)

Current state of seismic retrofit in Japan

Public Buildings

Definition of **Earthquake resistant ratio**

=Number of Earthquake resistant accomplished buildings/ Total number of buildings

■ Earthquake resistant accomplished buildings (2015)

Total ratio: 90.7 % (165,665 buildings)

(1)After completion by new 1981 seismic code (51.8%)

(2)Higher capacity by seismic evaluation (13.4%)

(3)Seismic retrofit done (25.5%)

■ Vulnerable buildings (2015)

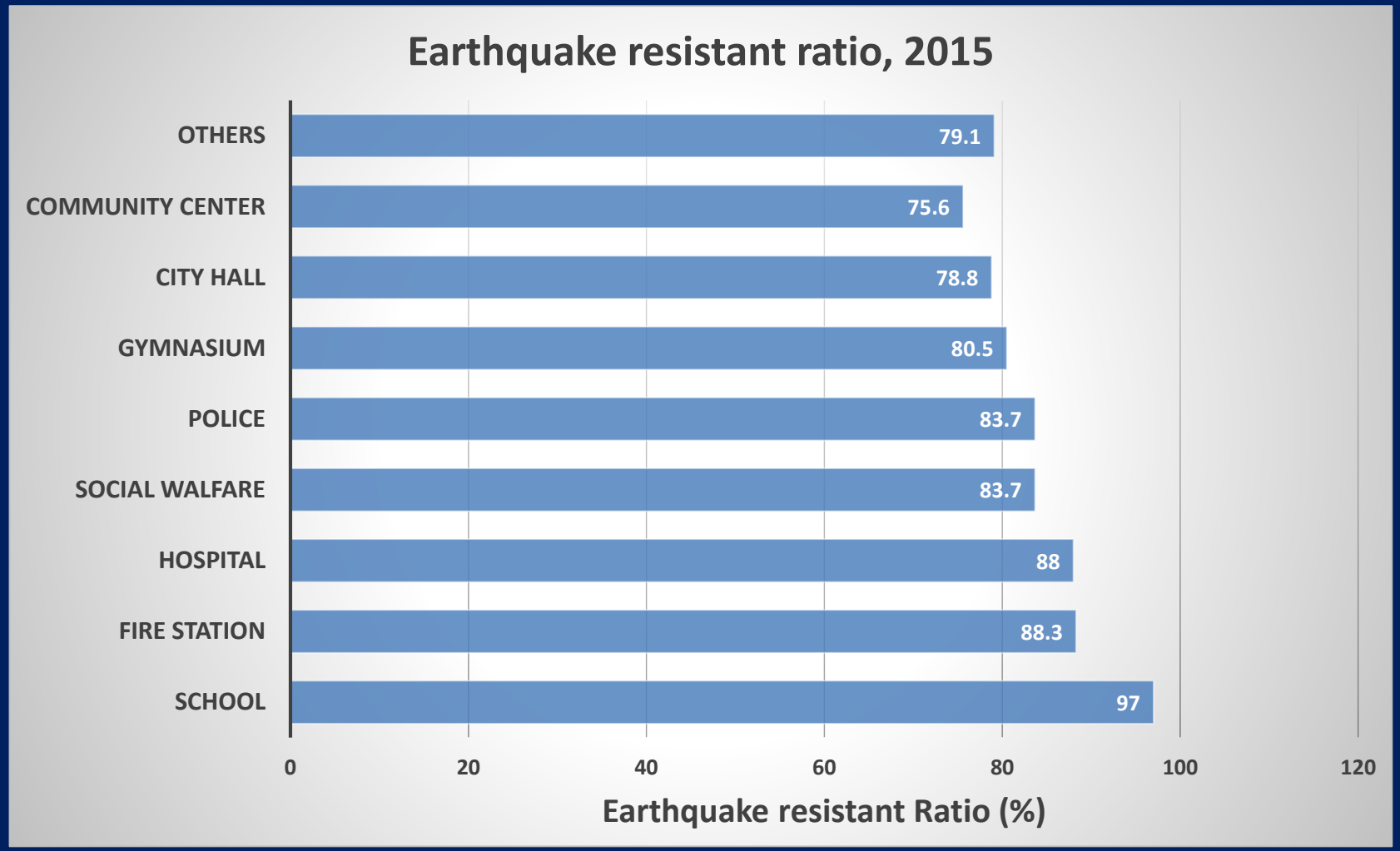
Total ratio: 9.1 % (16,625 buildings)

(1)Not yet retrofitted (4.0 %)

(2)Not yet seismic evaluation for before 1981 designed buildings(5.2%)

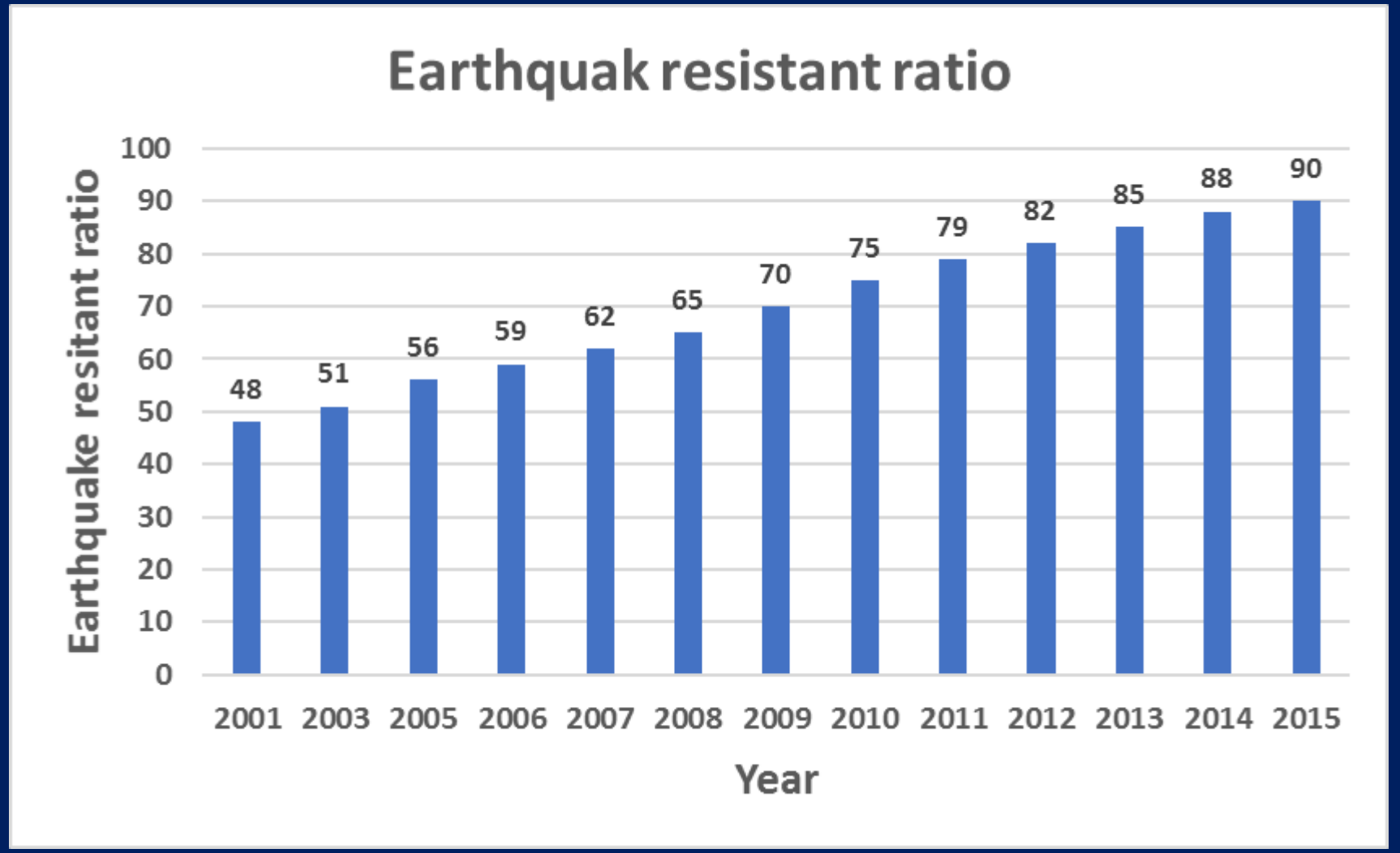
Current state of seismic retrofit in Japan

Public Buildings



Current state of seismic retrofit in Japan

Public Buildings



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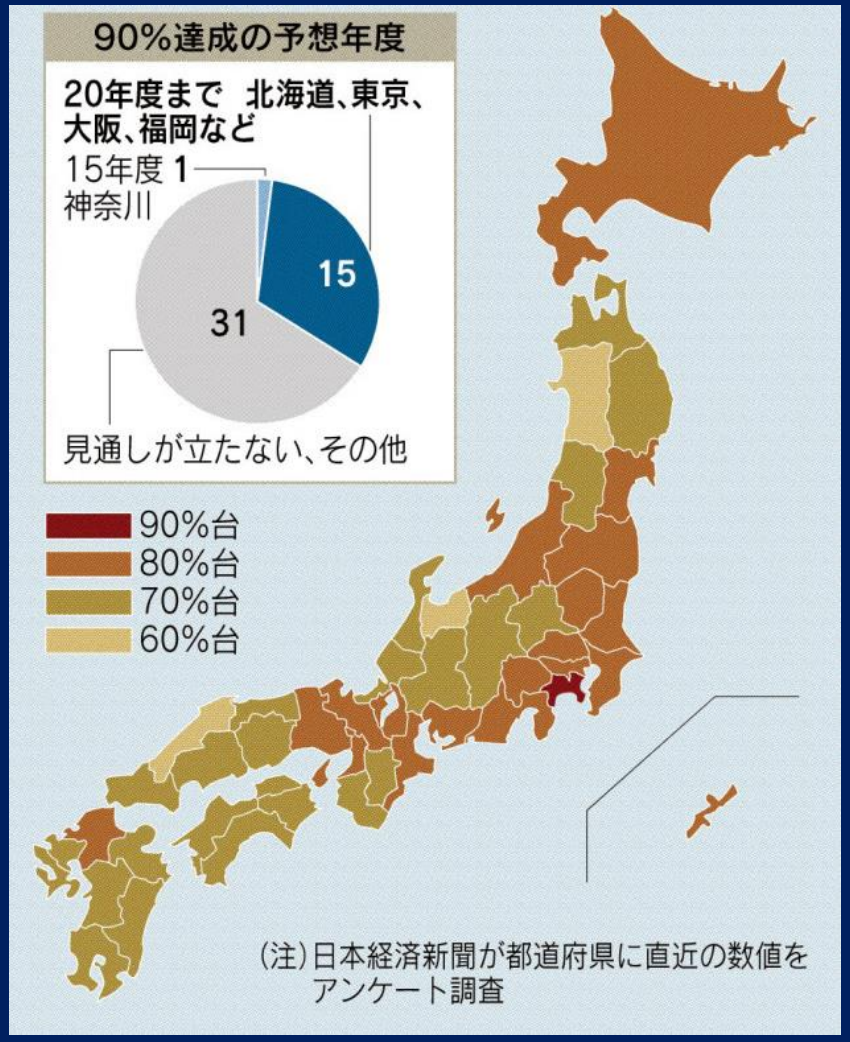
Current state of seismic retrofit in Japan

Private residential Buildings ,March 2016



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Goal of earthquake resistance rate by Japanese government

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90 % by 2020

Conclusions

1. The are still lots of vulnerable existing buildings in Japan. Retrofit will be continuing in the future especially for the private buildings.

2. The simple and easy construction retrofit technology is necessary to be developed.

3. After strong earthquake, first of all the damaged buildings should be retrofitted in order to avoid the collapse as soon as possible.

Thank you for your attention

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