Structural design for seismic isolation

-design practice, construction and maintenance-

February 9th, 2021

KEITA SAKAKIBARA

Structural Engineer
Engineering Department
Nikken Sekkei Ltd.

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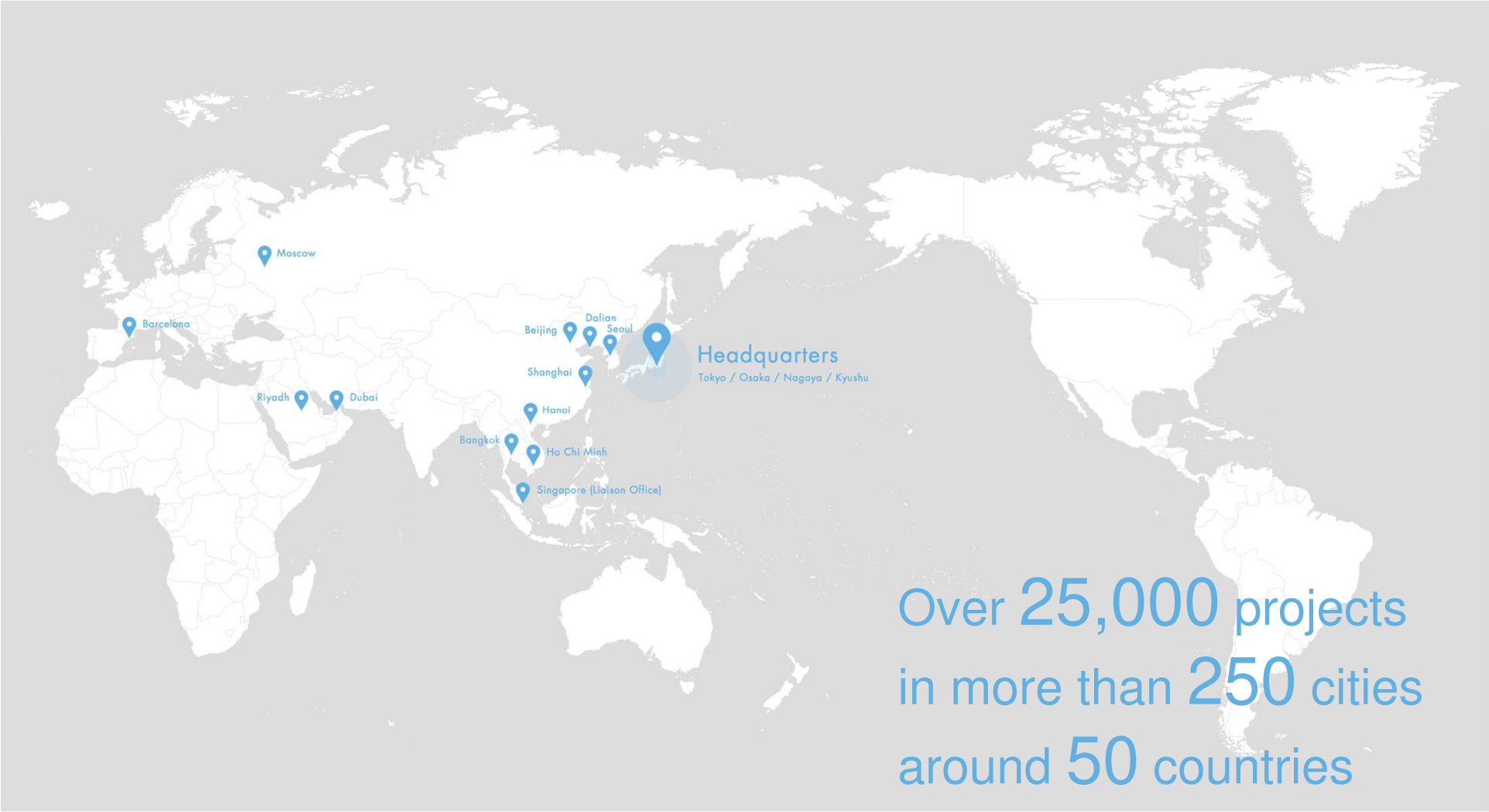
Introduction of Our Company
- Nikken Sekkei -

Sky Tree :
Nikken Sekkei was the main design office of this tower.

Nikken Sekkei Corporate Data

Name of Company	Nikken Sekkei Ltd.
Registered Address	Iidabashi, Chiyoda-ku, Tokyo, Japan
Founded	1890 (as a Department of Sumitomo Bank)
Established	July 1, 1950
Number of Employees	Total: 2,764
Main Offices Oversees Offices	Tokyo, Osaka, Nagoya, Kyusyu, Shanghai, Beijing, Dalian, Seoul, Hanoi, Ho Chi Minh, Singapore, Bangkok, Dubai, Riyadh, Moscow, Barcelona

Our Offices



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Brief Introduction of my self & recent work

Professional Experience :

2008 Structure Engineer, Nikken Sekkei Ltd.

Structures : RC, SRC, S, Timber

Structural Systems : Earthquake-Resistant Structure
Base-isolated Structure

Education :

2008 Architectural Engineering, Nagoya University, ME

My Recent Work　Tokoname city hall

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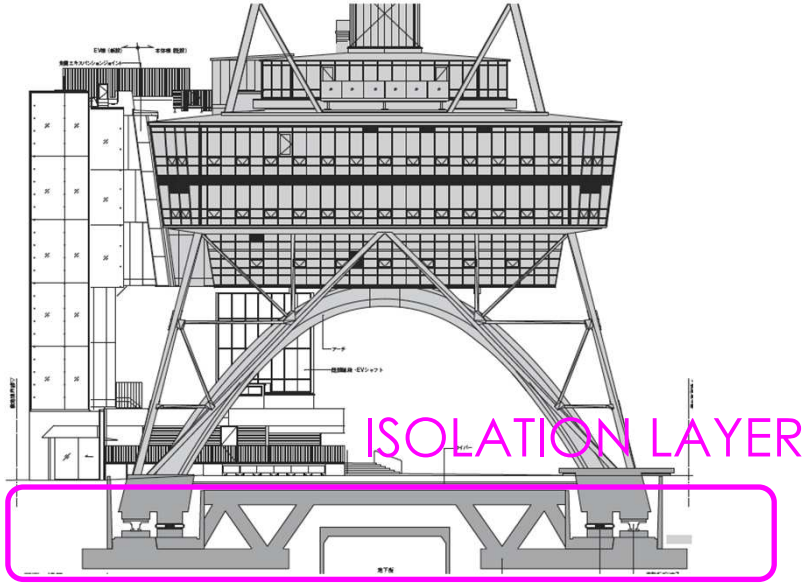
My Recent Work

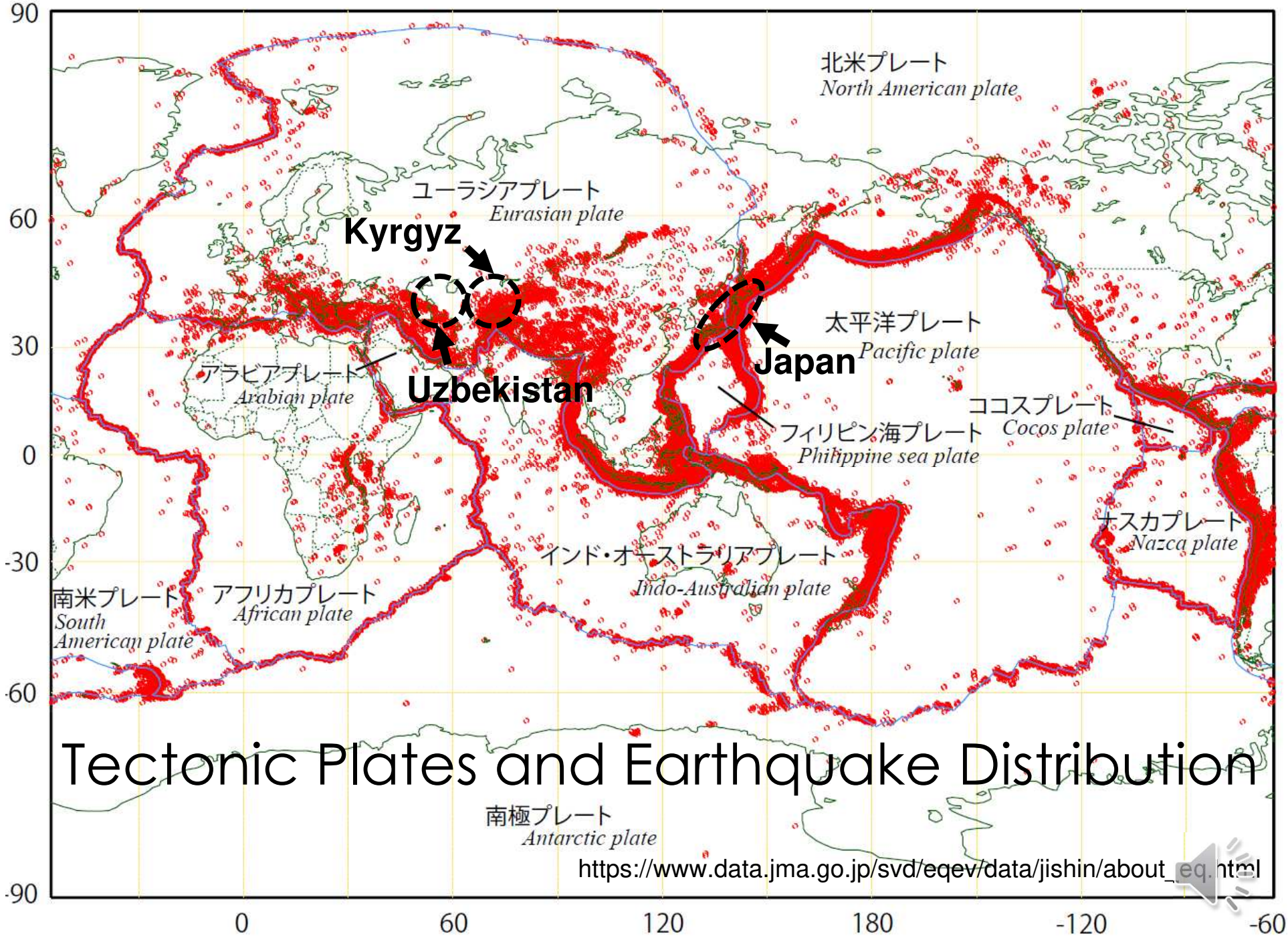
Nagoya TV-tower(Seismic Retrofit)

Height:180m



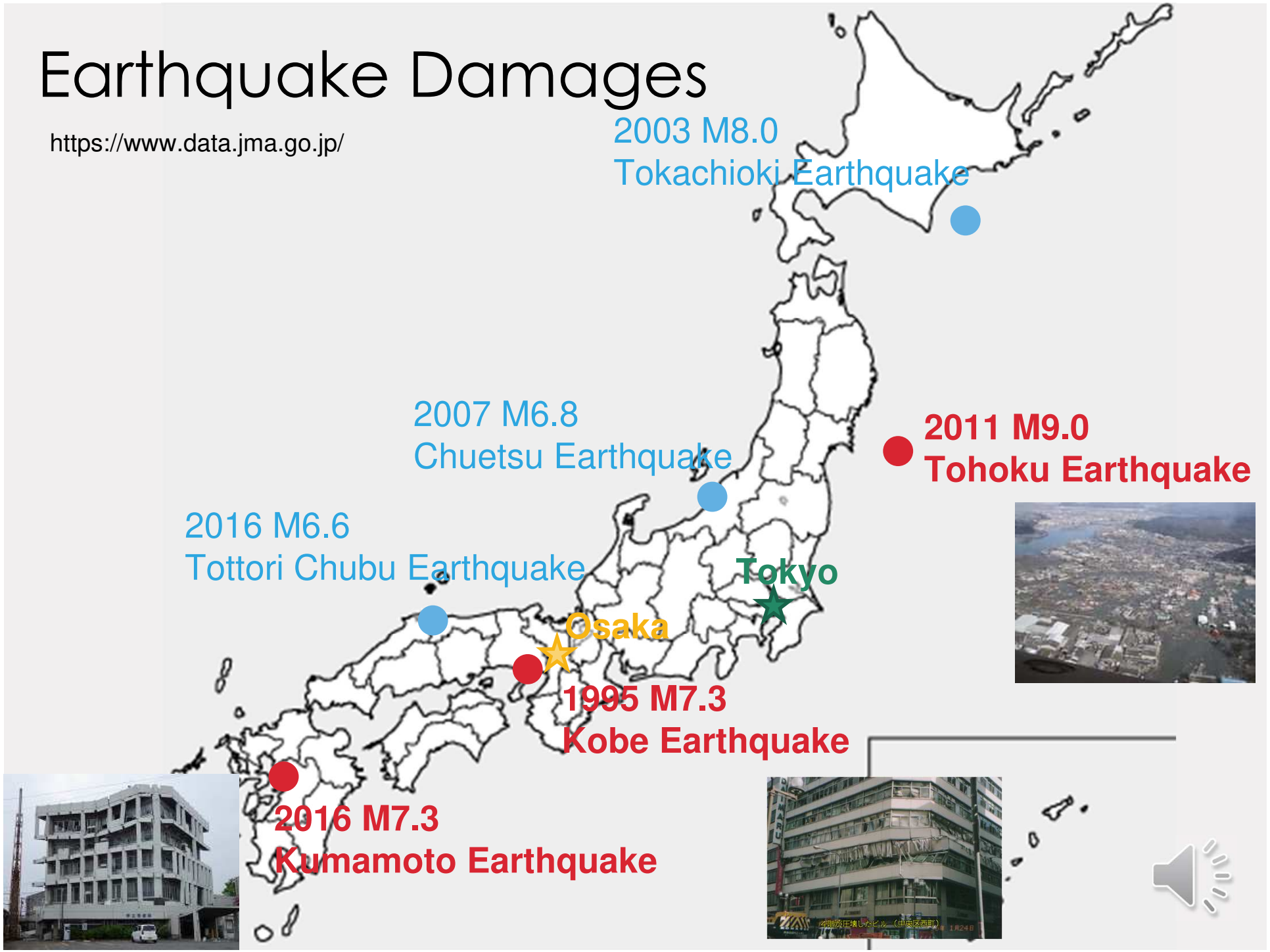
Reference :SHINKENCHIKU January 2021

Introduction


北米プレート
North American plate
ユーラシアプレート
Eurasian plate
Kyrgyz
Uzbekistan
Japan
太平洋プレート
Pacific plate
アラビアプレート
Arabian plate
ココスプレート
Cocos plate
フィリピン海プレート
Philippine sea plate
ナスカプレート
Nazca plate
インド・オーストラリアプレート
Indo-Australian plate
南米プレート
South American plate
アフリカプレート
African plate
南極プレート
Antarctic plate
90
60
30
0
-30
-60
-90
0
60
120
180
-120
-60
Tectonic Plates and Earthquake Distribution
https://www.data.jma.go.jp/svd/eqev/data/jishin/about_eq.html

Earthquake Damages

https://www.data.jma.go.jp/



Earthquake Damages

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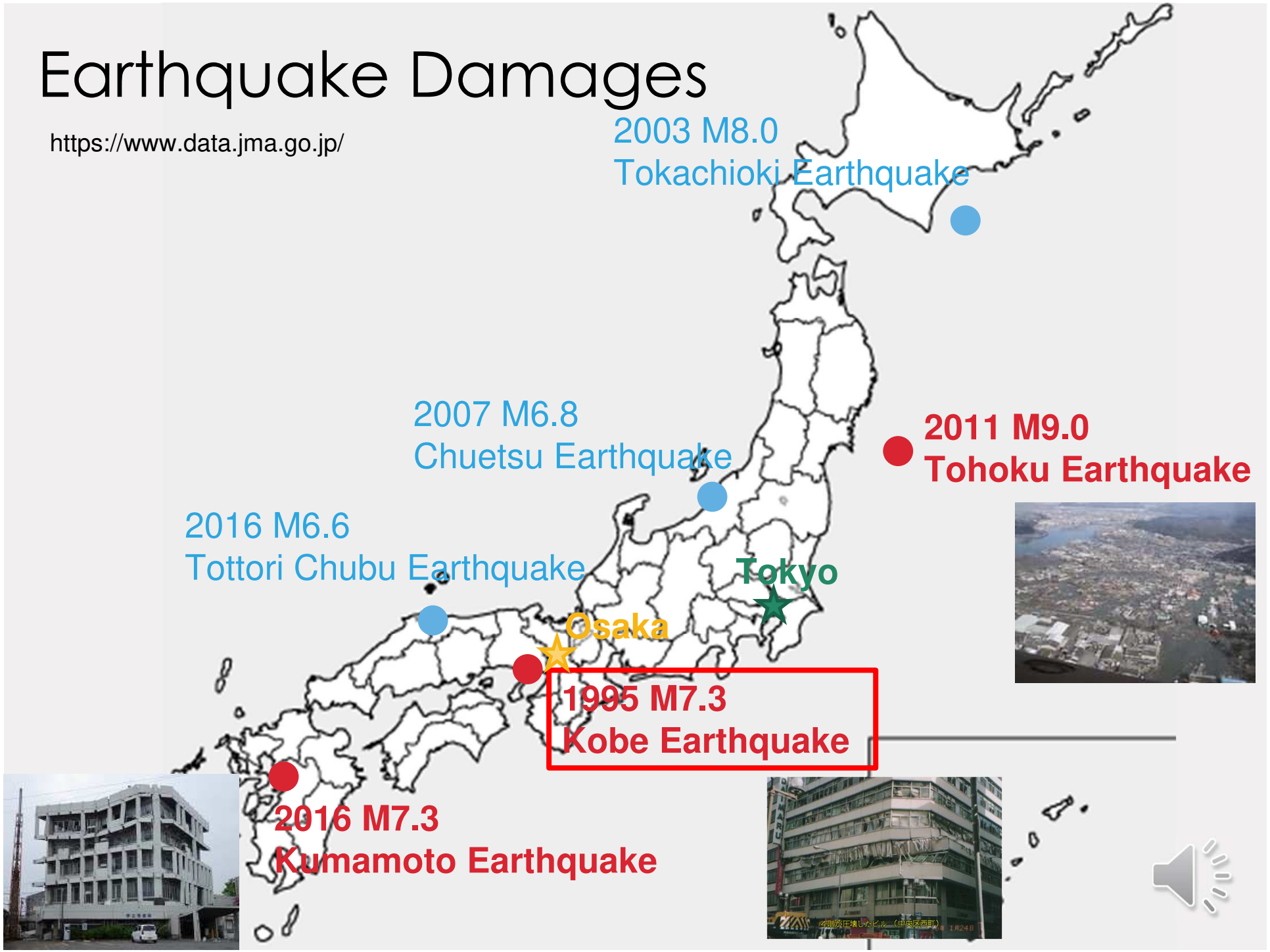



https://webronza.asahi.com/

4階が圧壊したビル （中央区西町）

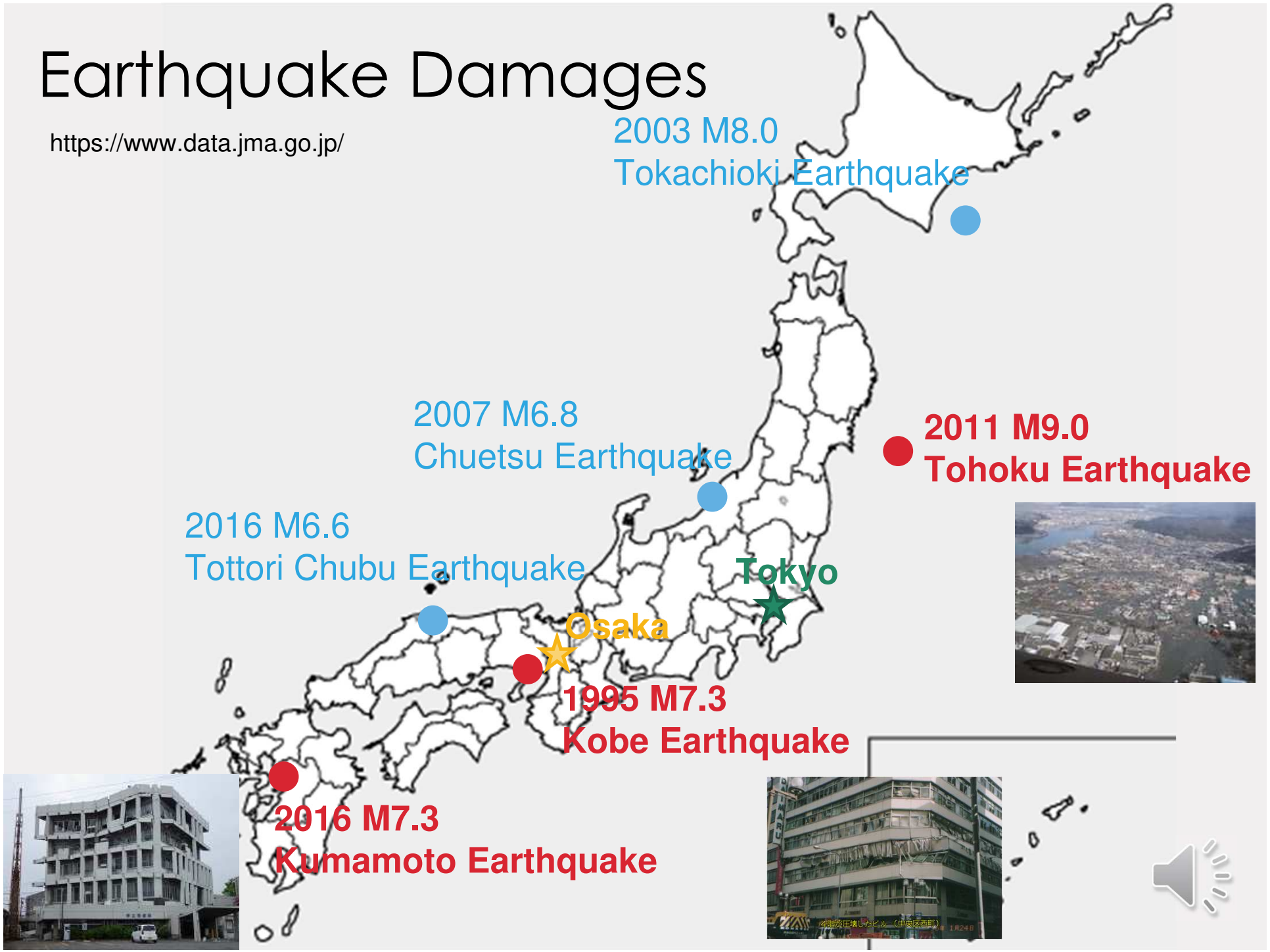
Damage by the Kobe Earthquake

兵庫県南部地震(‘95)被害事例

Some buildings built by old design standard was damaged in the Kobe Earthquake.

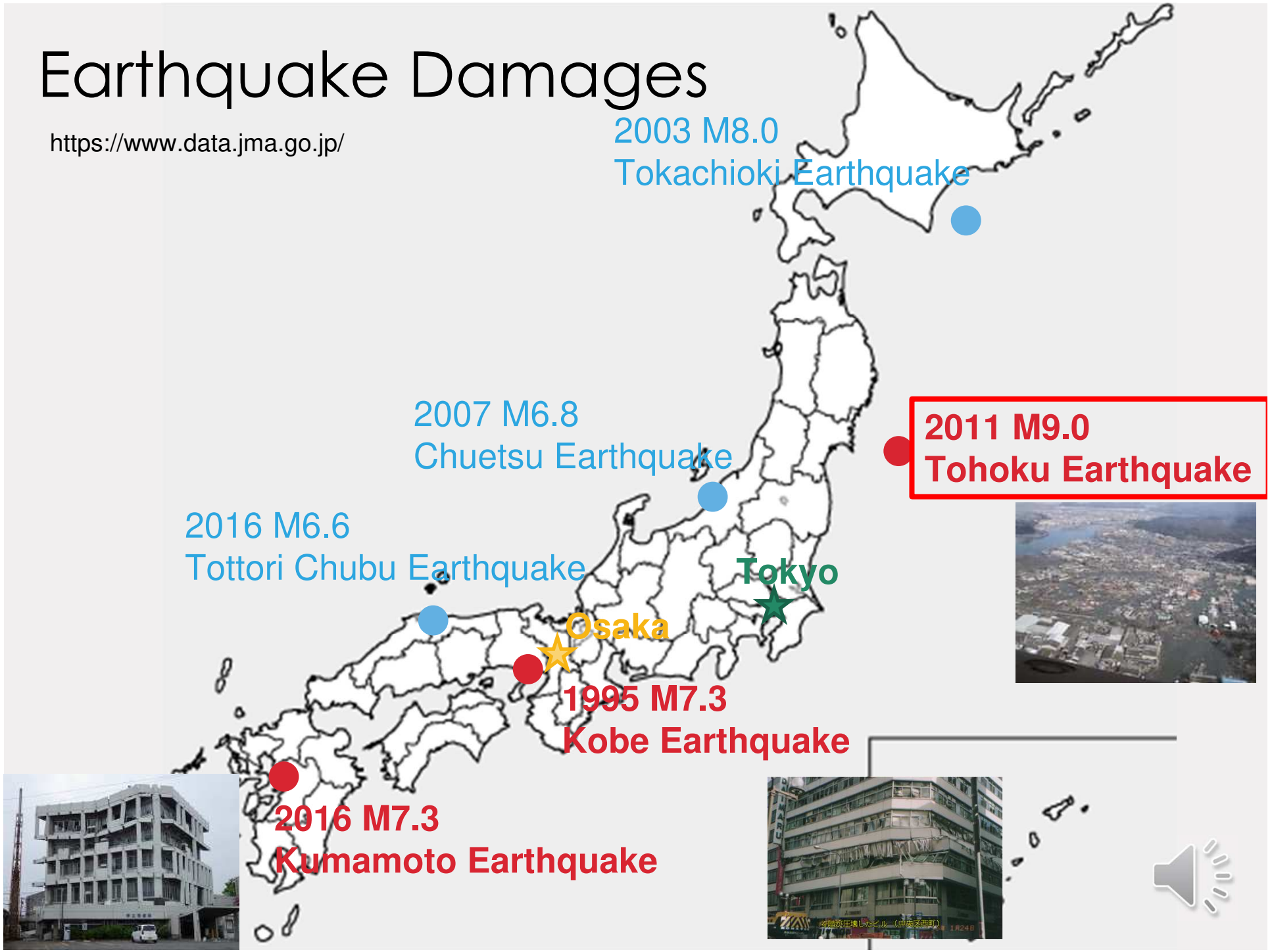
Earthquake Damages

https://www.data.jma.go.jp/



Earthquake Damages

https://www.data.jma.go.jp/



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https://www.jiji.com/

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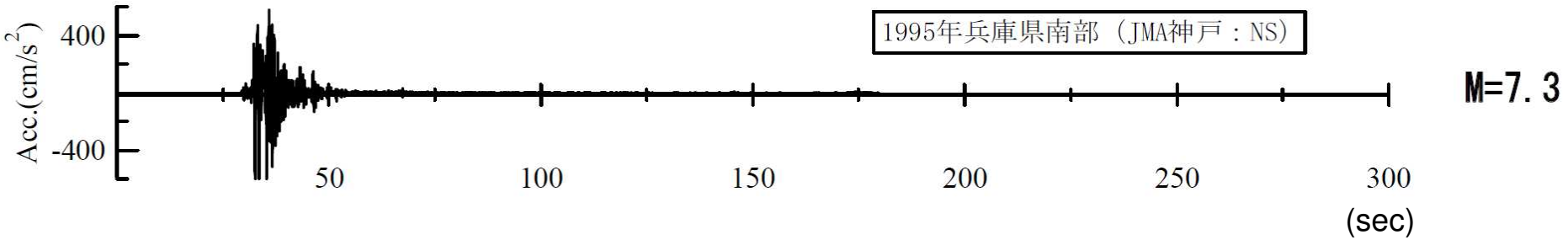
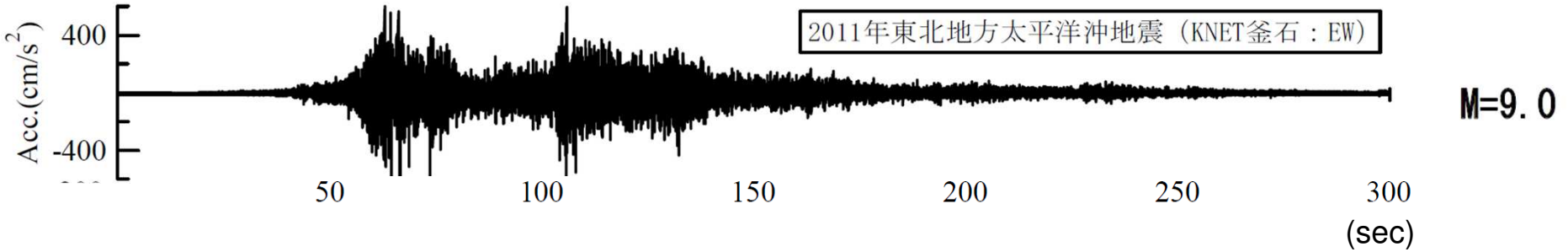
Differences in seismic records

1995 M7.3
Kobe Earthquake



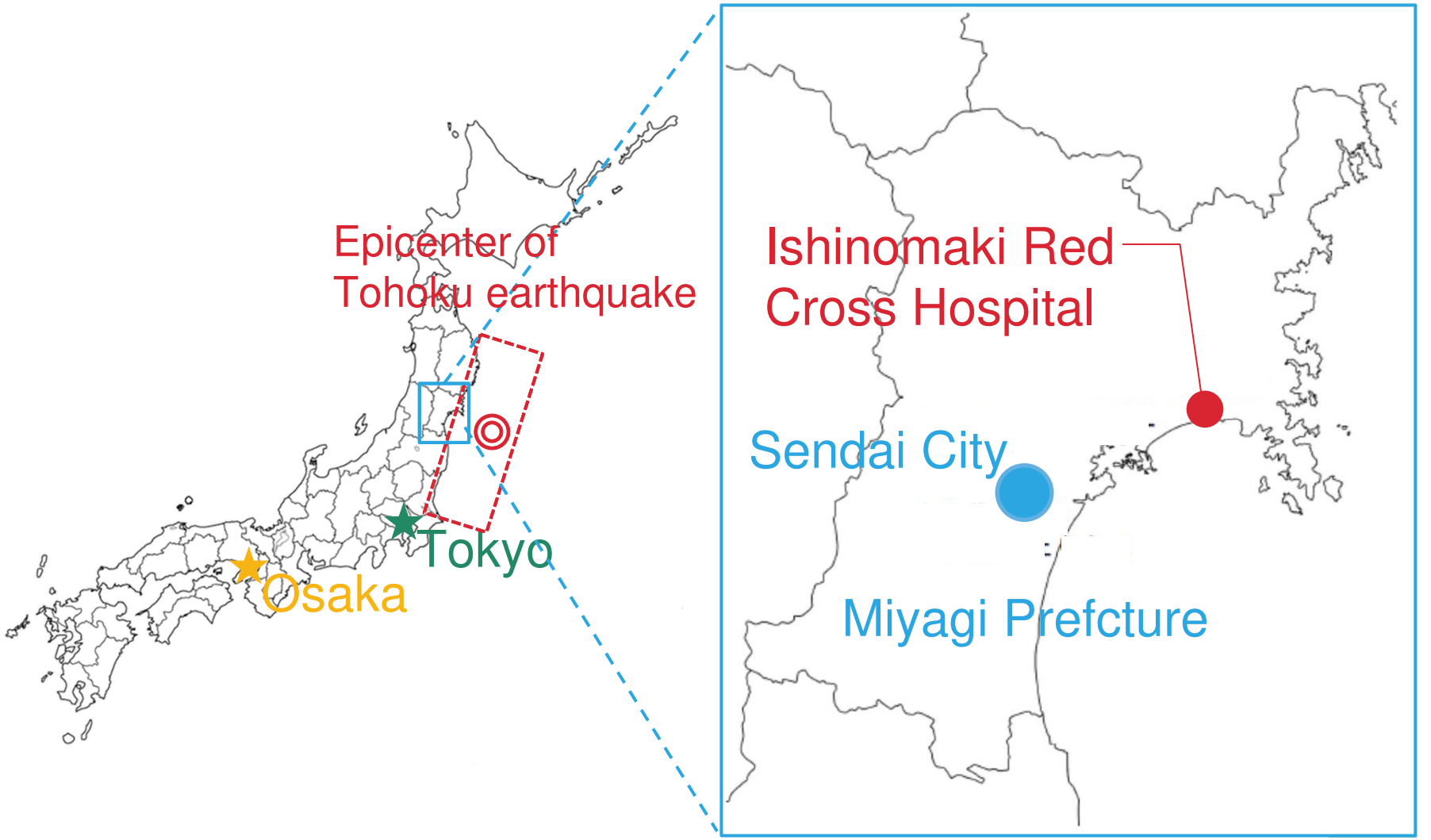
2011 M9.0
Tohoku Earthquake



Example of Seismic Isolation Building Damages observed in 2011 Tohoku Earthquake - Ishinomaki Red Cross Hospital -

日本赤十字社 Japanese Red Cross Society　石巻赤十字病院

Tohoku Earthquake 2011



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Ishinomaki Red Cross Hospital

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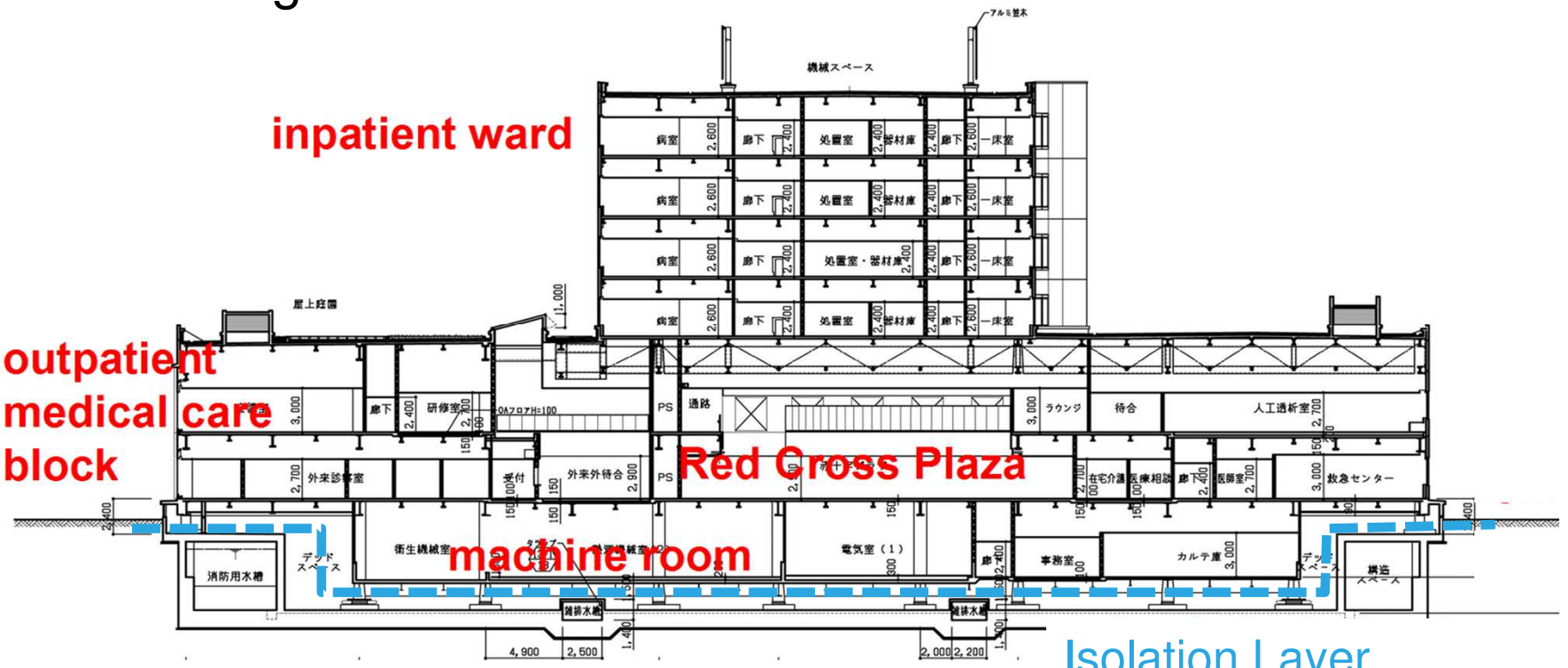
Cross Sectional Plan

日本赤十字社 Japanese Red Cross Society　石巻赤十字病院

- Total Floor Area: 32,500m^2
- Floors: 7F above ground floor, 1F below basement
- Total Height: 33.5m



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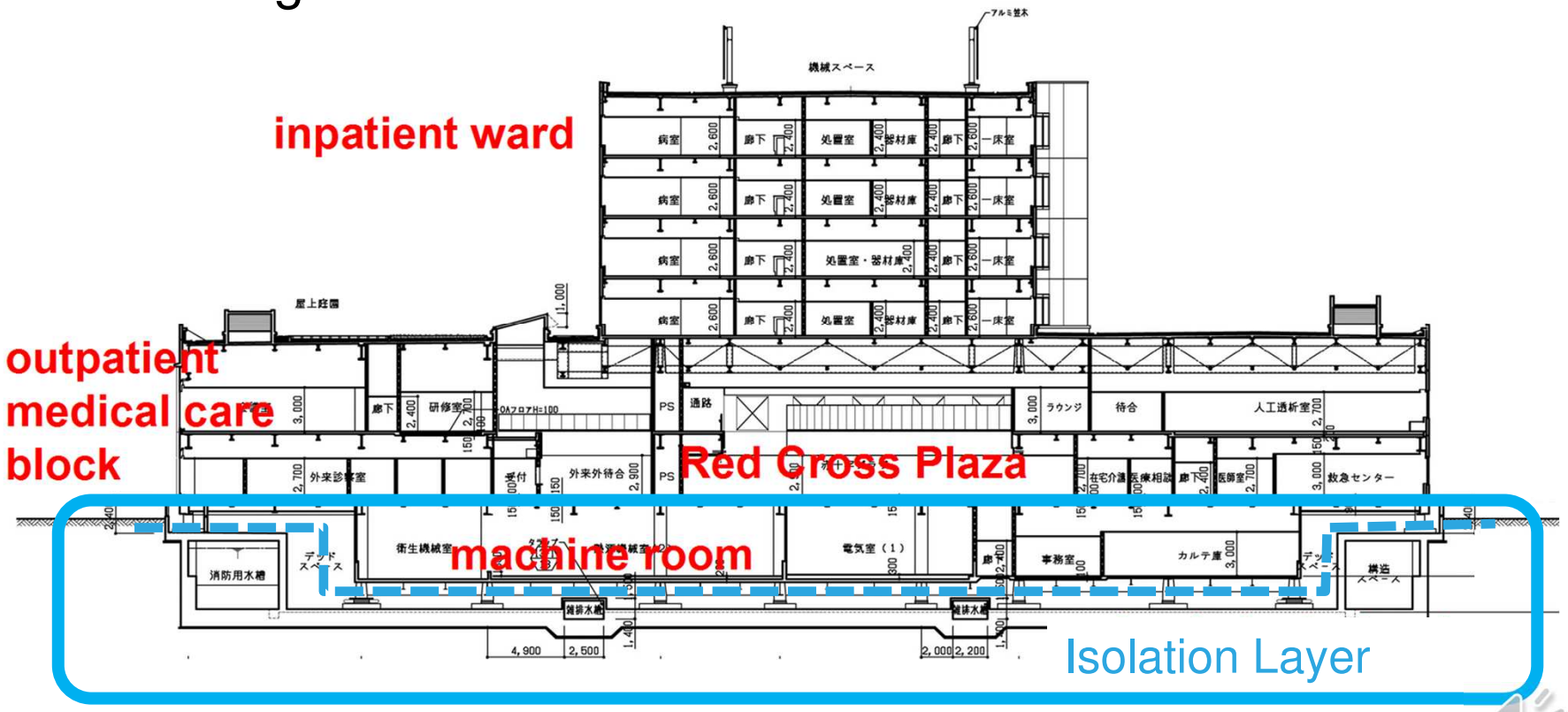

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Lobby

日本赤十字社 Japanese Red Cross Society　石巻赤十字病院

Lobby
(in normal condition)

Lobby
(after the earthquake)

This hospital was designed so that the required function is maintained even after an earthquake.
The seismic isolation system protected the building function during the earthquake, and the hospital operators could establish emergency responses immediately.

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After Earthquake

日本赤十字社 Japanese Red Cross Society　石巻赤十字病院

Mercy flight

Lobby
(after the earthquake)

Ishinomaki Red Cross Hospital was the only one hospital survived after the earthquake, and many patients were delivered from other hospitals in Miyagi Prefecture.

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Cross Sectional Plan

日本赤十字社 Japanese Red Cross Society　石巻赤十字病院

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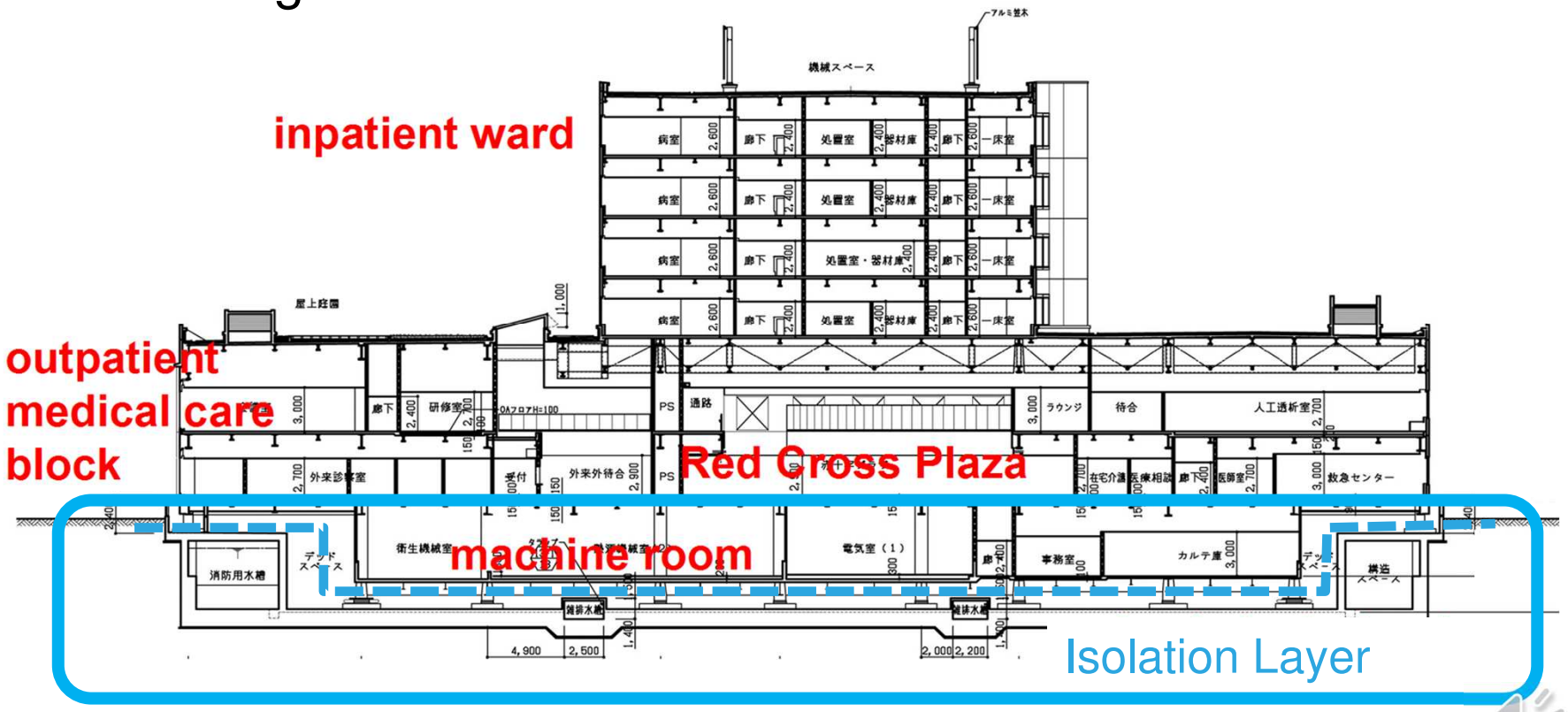

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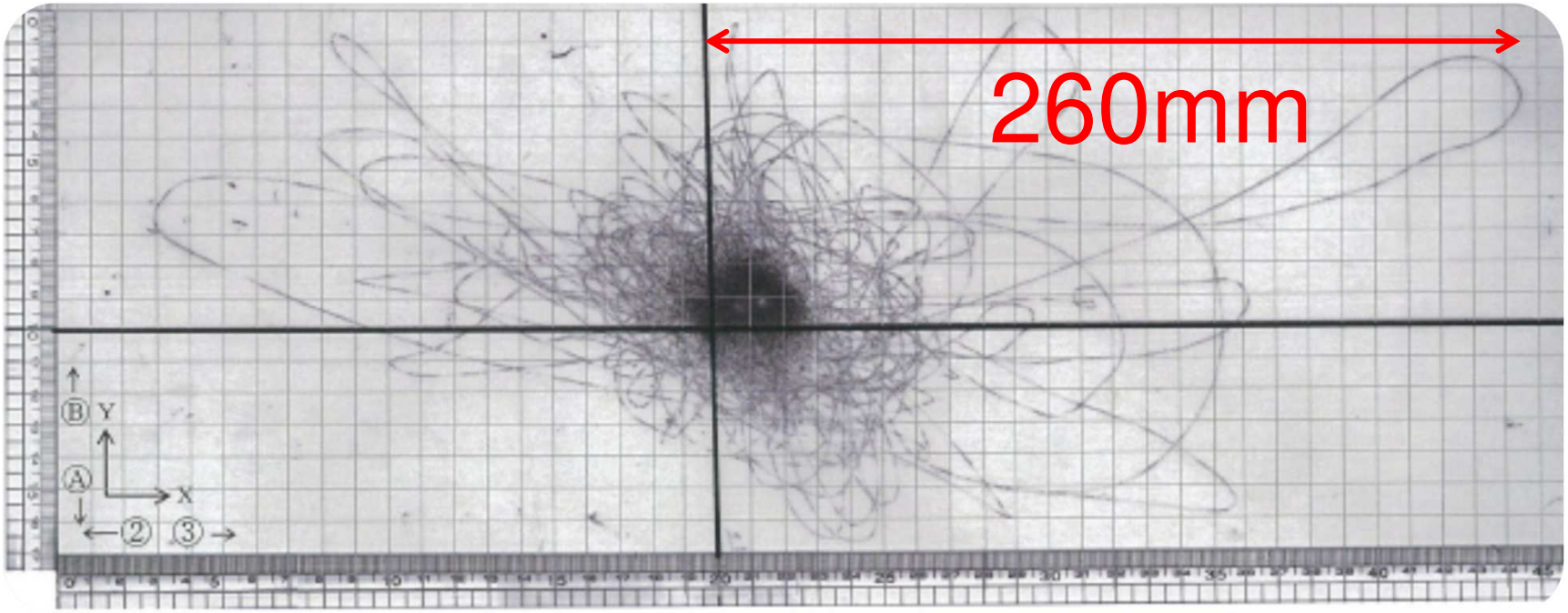
Orbit Record: How much this building deformed ?



Orbit Record on
Metal Sheet

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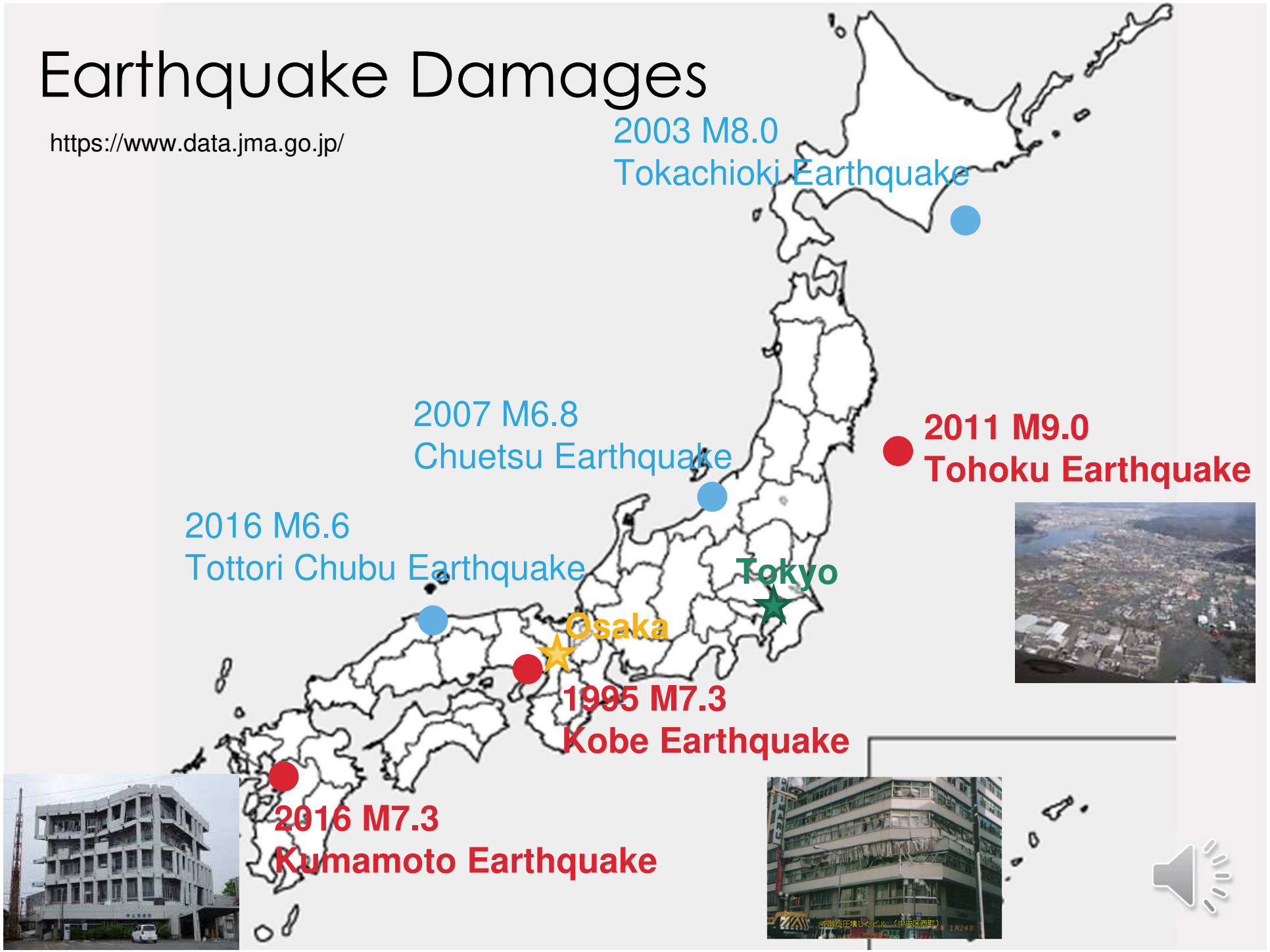
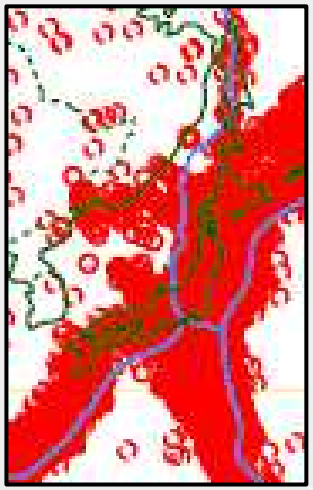
Earthquake Damages

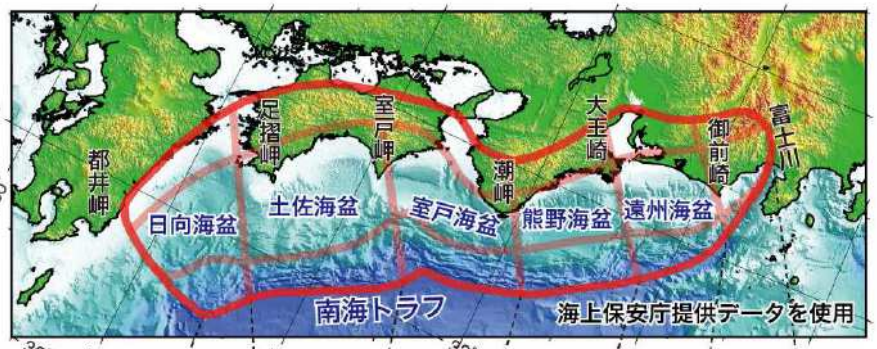
https://www.data.jma.go.jp/

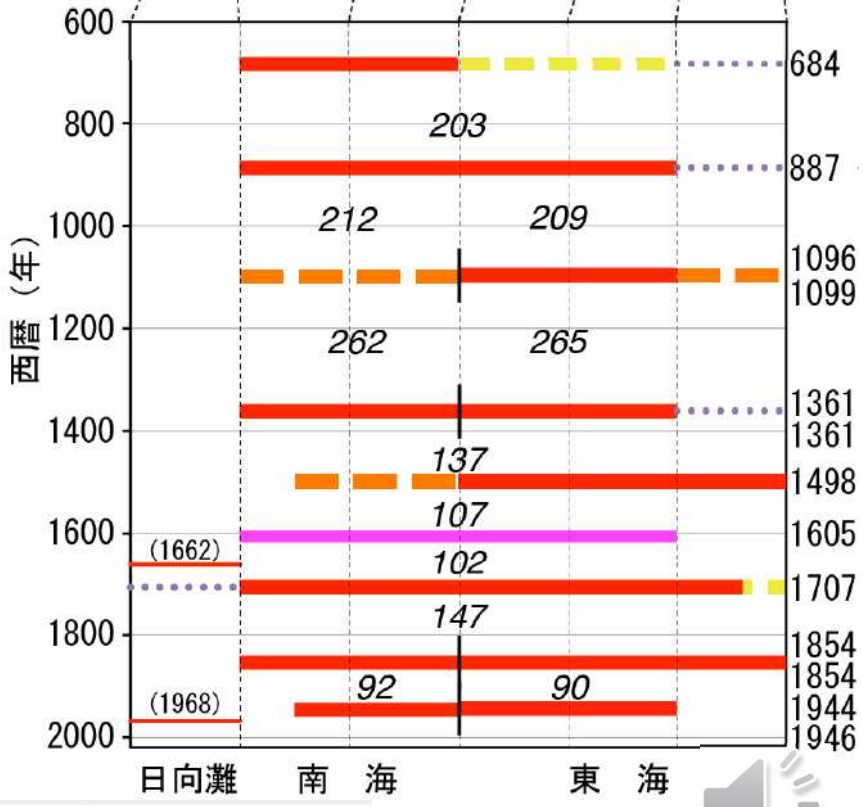


IN ADDITION ・・・

20××
Nankai Trough Earthquake







Assumed Area of Hypocenter

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https://www.data.jma.go.jp/

https://www.data.jma.go.jp/svd/eqev/data/nteq/nteq.htm

Summary

1 Building Performance Design

2 Design Method of Seismic Isolation Structure in Japan

3 Example of Seismic Isolation Design

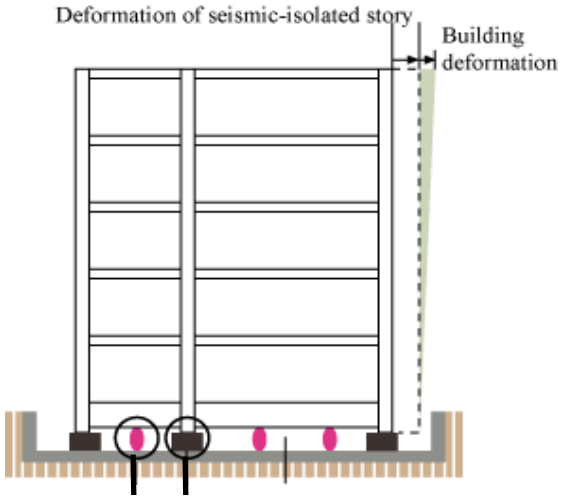
4 Examples of Construction, Operation & Management for Isolated Structures

1 Building Performance Design

ADVANTAGES OF SEISMIC ISOLATED BUILDING

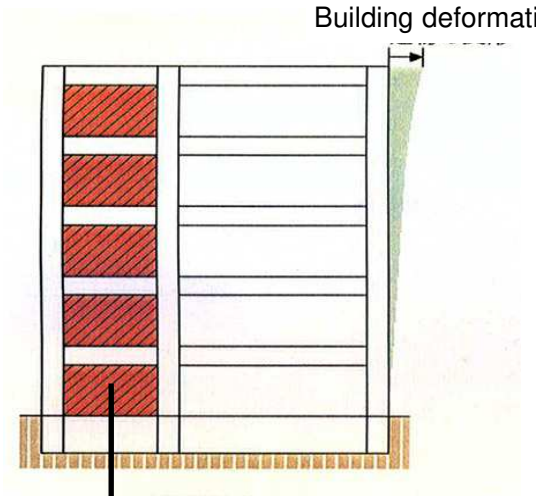
*Comparing structural systems

Small Building deformation → **Large Building deformation**



Seismic Isolated Building

Isolation devices
- Bearing
- Slider
- Damper

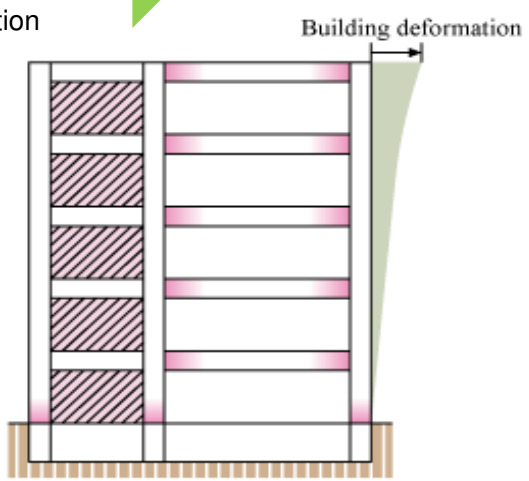


Vibration Control Building

Energy dissipation members

dampers

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



Seismic Resistance Building

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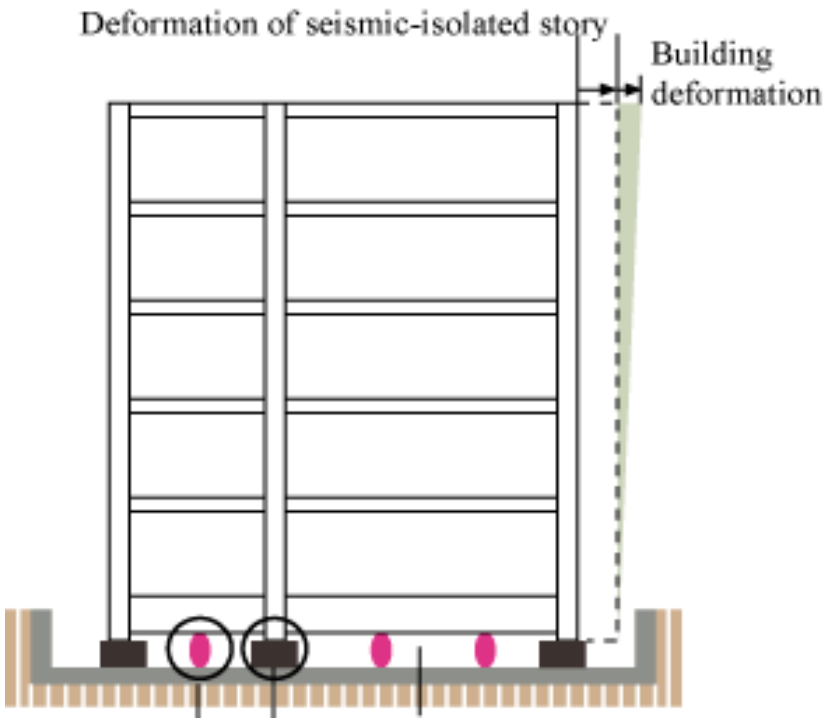
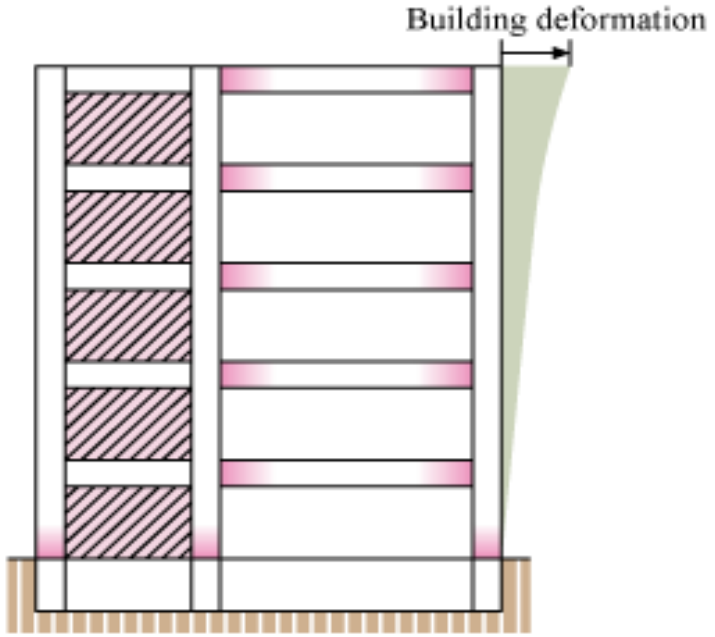
ADVANTAGES OF SEISMIC ISOLATED BUILDING



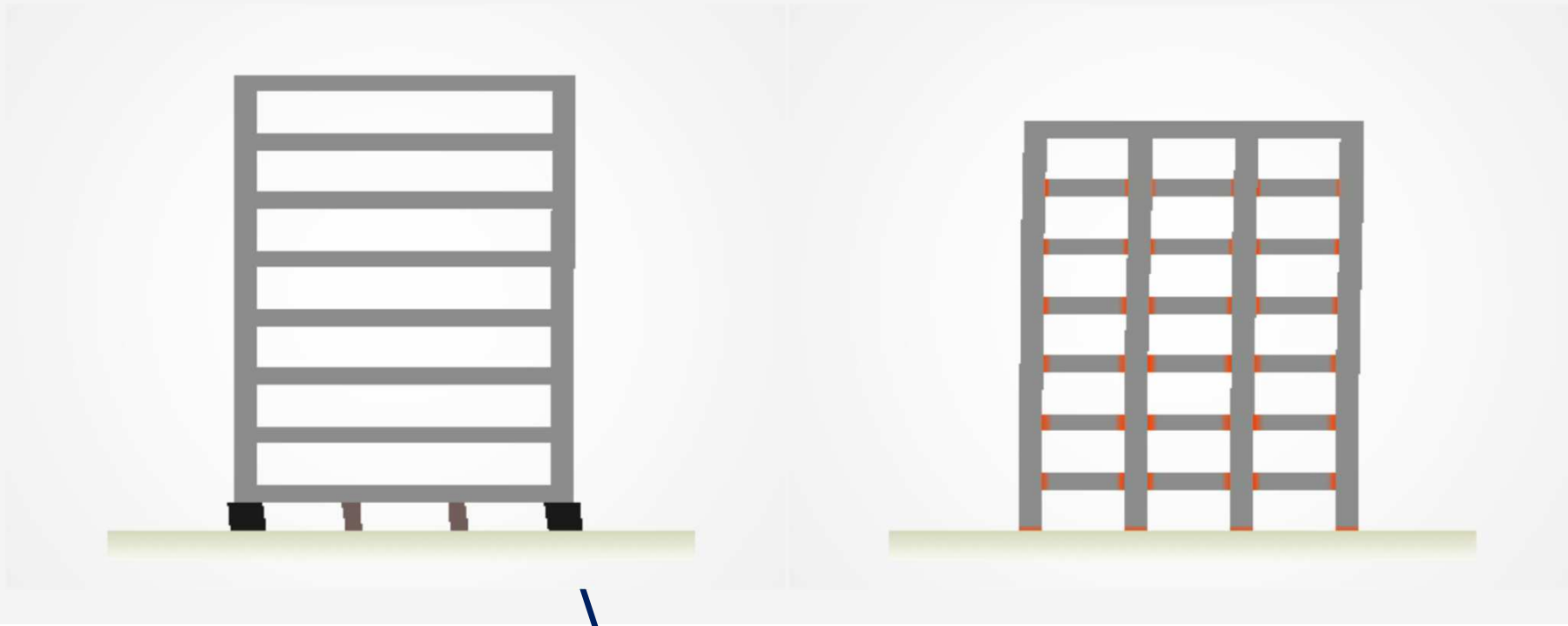
Seismic Isolated Building



Seismic Resistance Building

Isolators lead to long natural period (4~6 sec)
→Less seismic energy input →Less damage in the frame
→Mode shape has changed →Less story drift in the frame

ADVANTAGES OF SEISMIC ISOLATED BUILDING



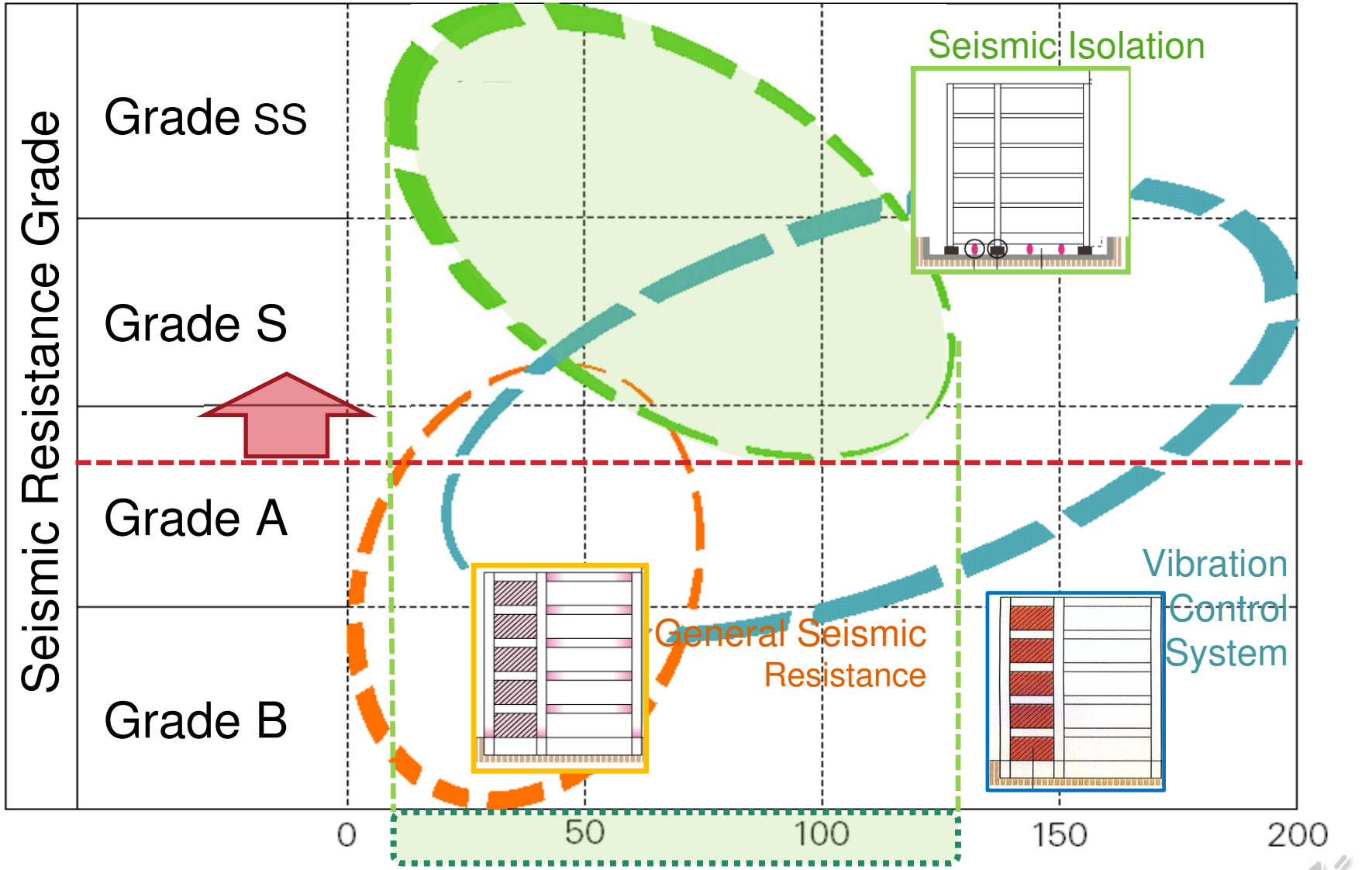
Seismic Isolated Building

Seismic Resistance Building

Energy dissipation by dampers

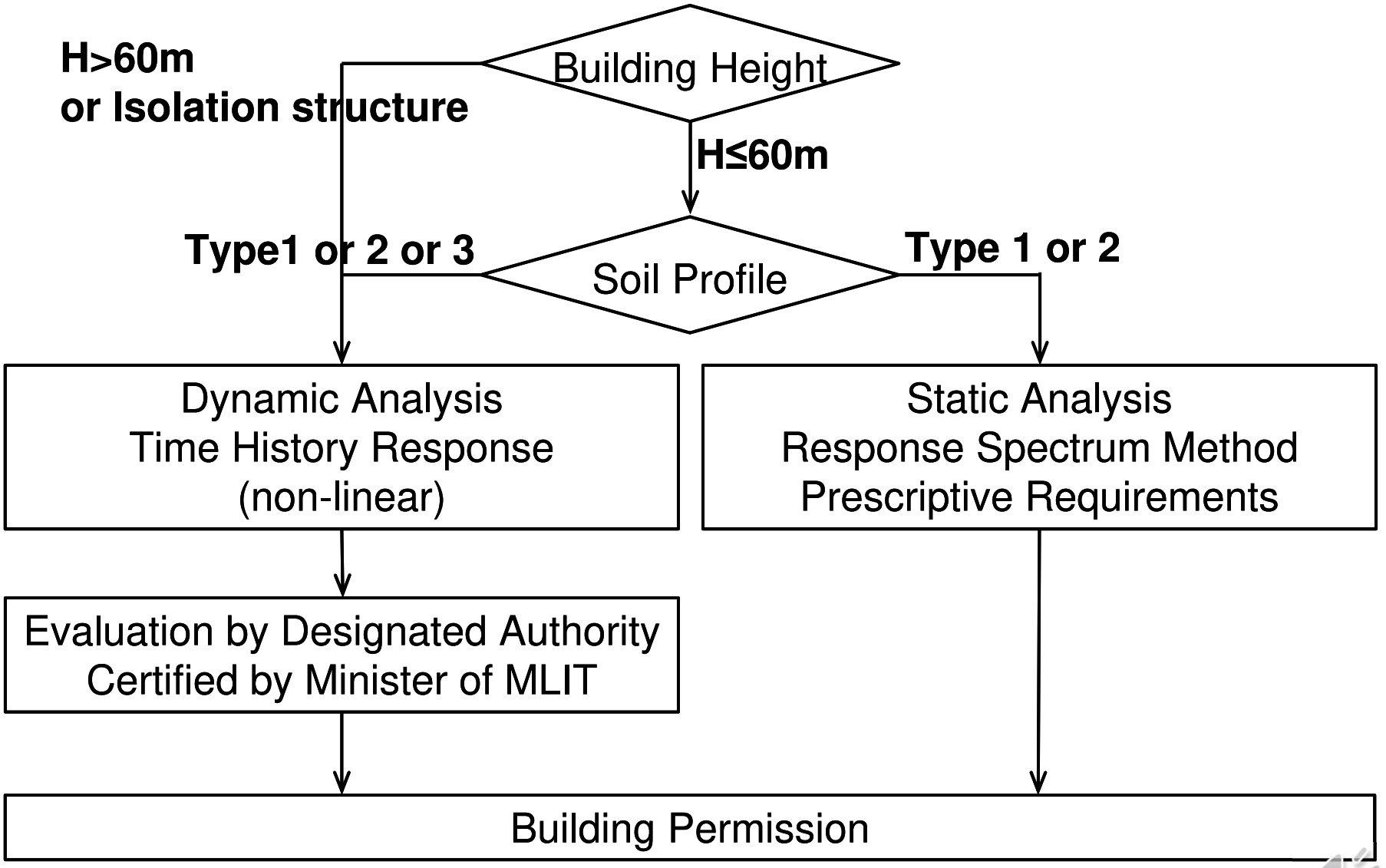
→ Less damage in main frame

Seismic Isolation System

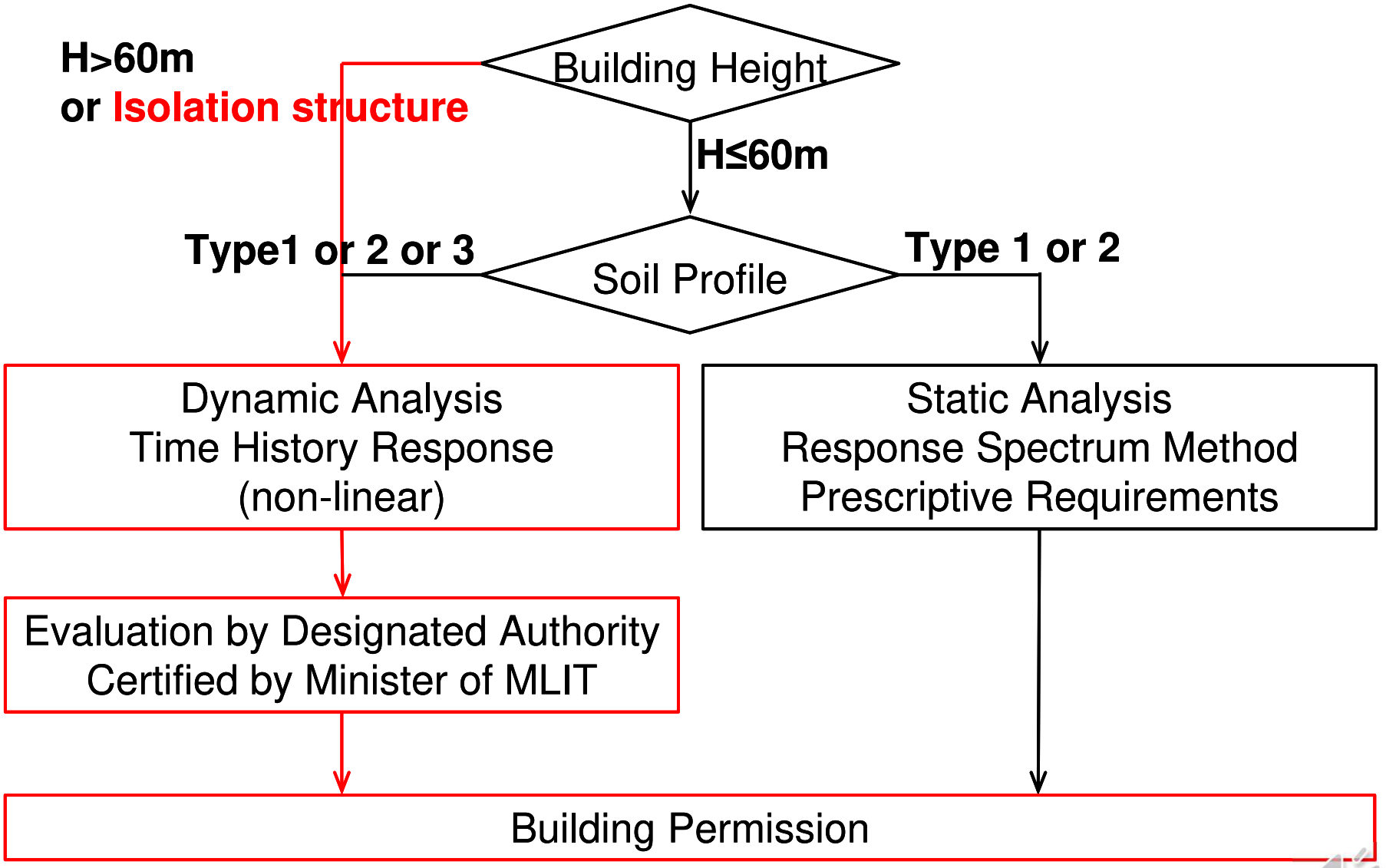


2 Design Method of Seismic Isolation Structure in Japan

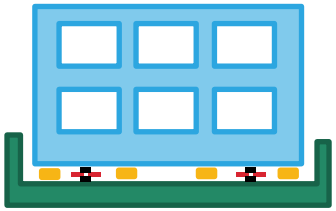
Design Procedure of Building in Japanese Building Law

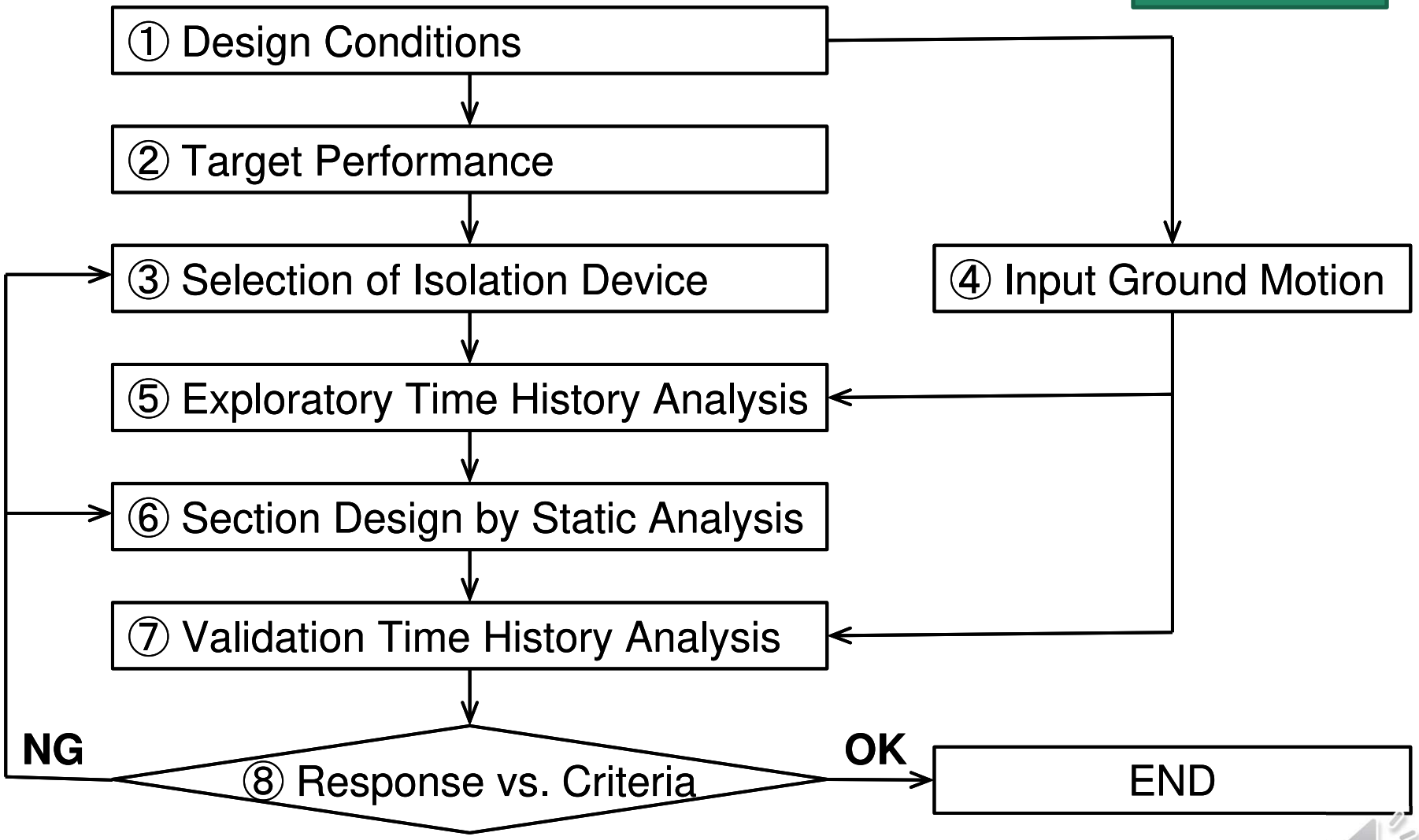


Design Procedure of Building in Japanese Building Law



Typical Structural Design Flow





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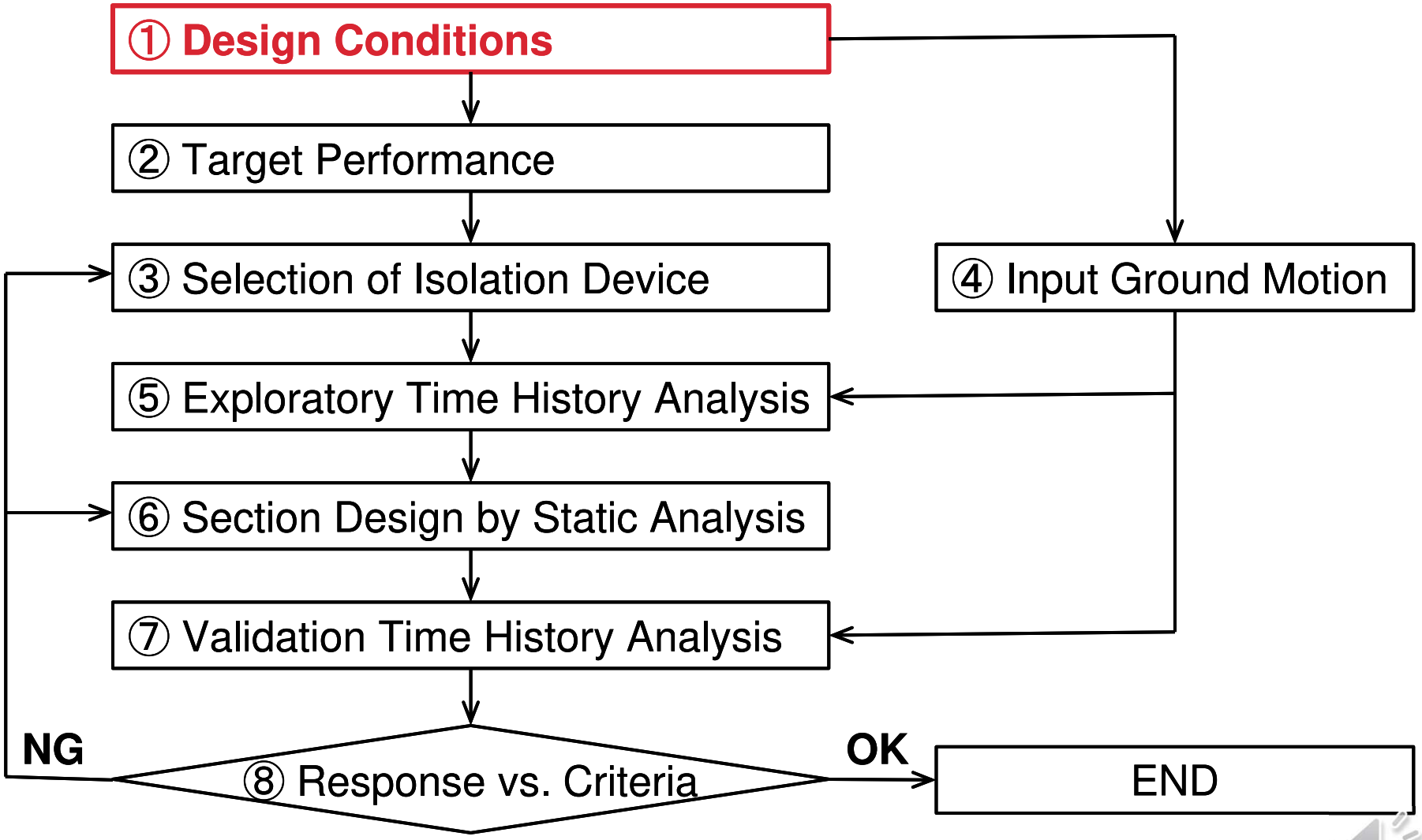
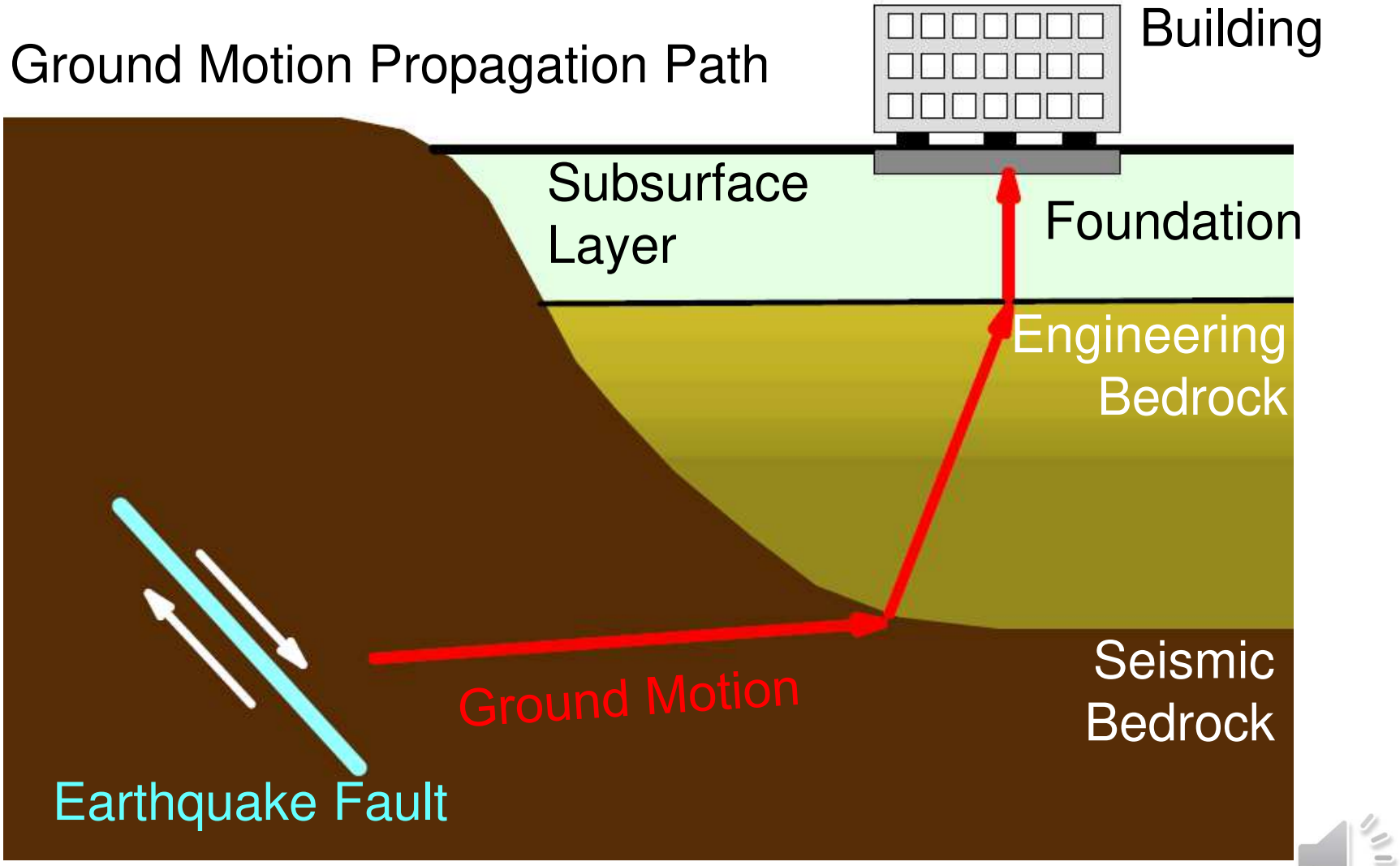


① Design Conditions: Site Soil Condition



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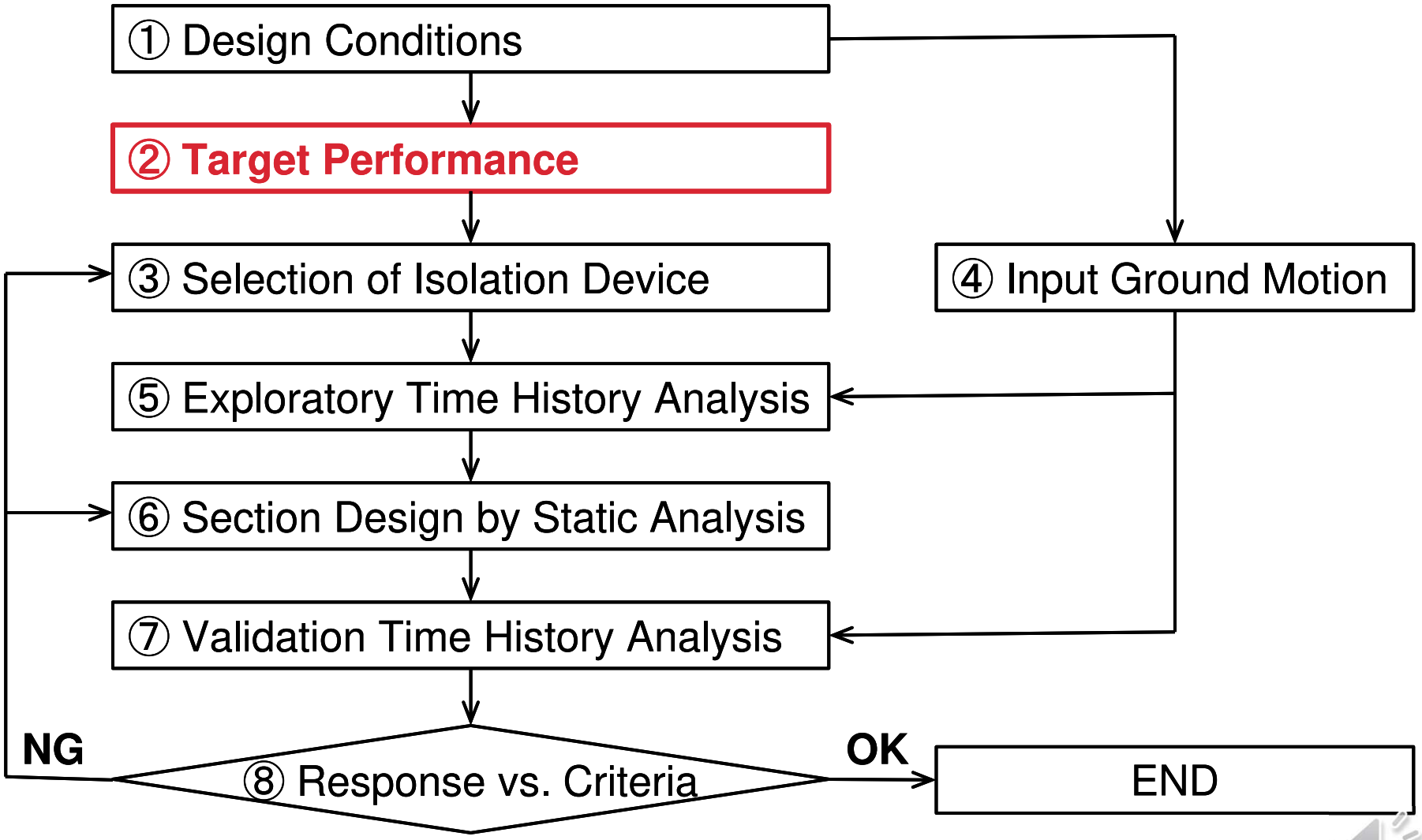


② Target Performance

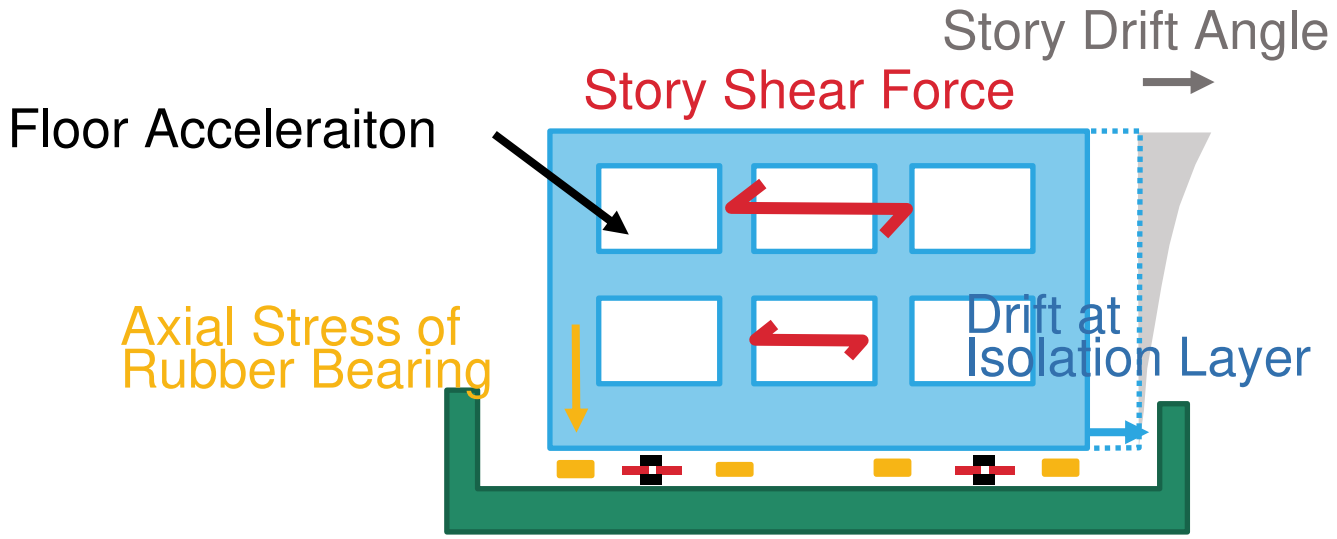
1 Story Shear Force ≤ Design Story Shear Force

2 Story Drift Angle ≤ 1/150~1/200 (Level 2)

3 Floors Acceleration ≤ 200~250 cm/s^2(Level 2)

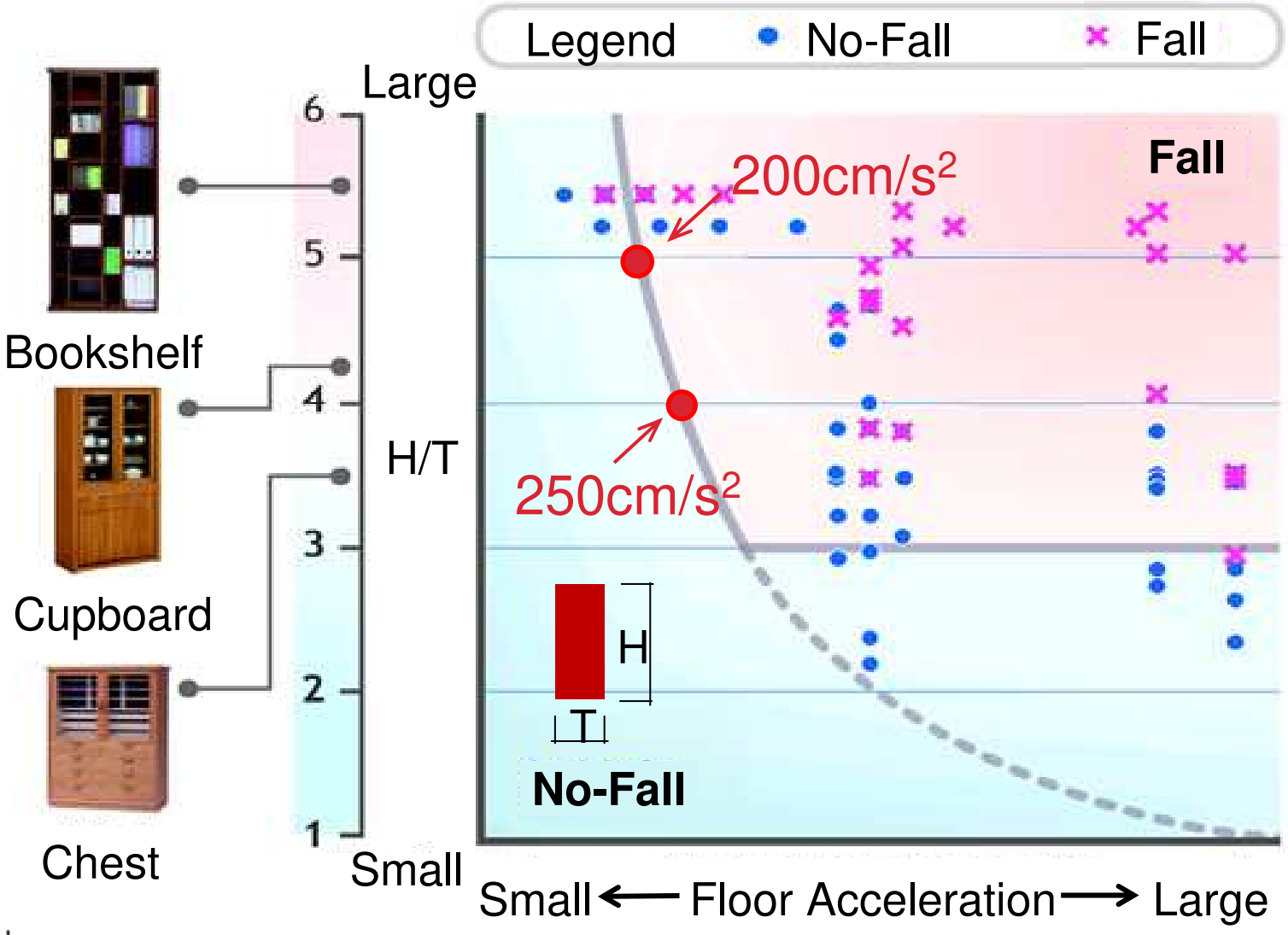
4 Drift at Isolation Layer ≤ Clearance at Isolation Story

5 Axial Stress of Rubber Bearing ・・・etc.



3. Response Acceleration : A_{max}

$A_{max} \leq 200\sim250\ cm/s^2$ (Level 2)



4. Drift Limit

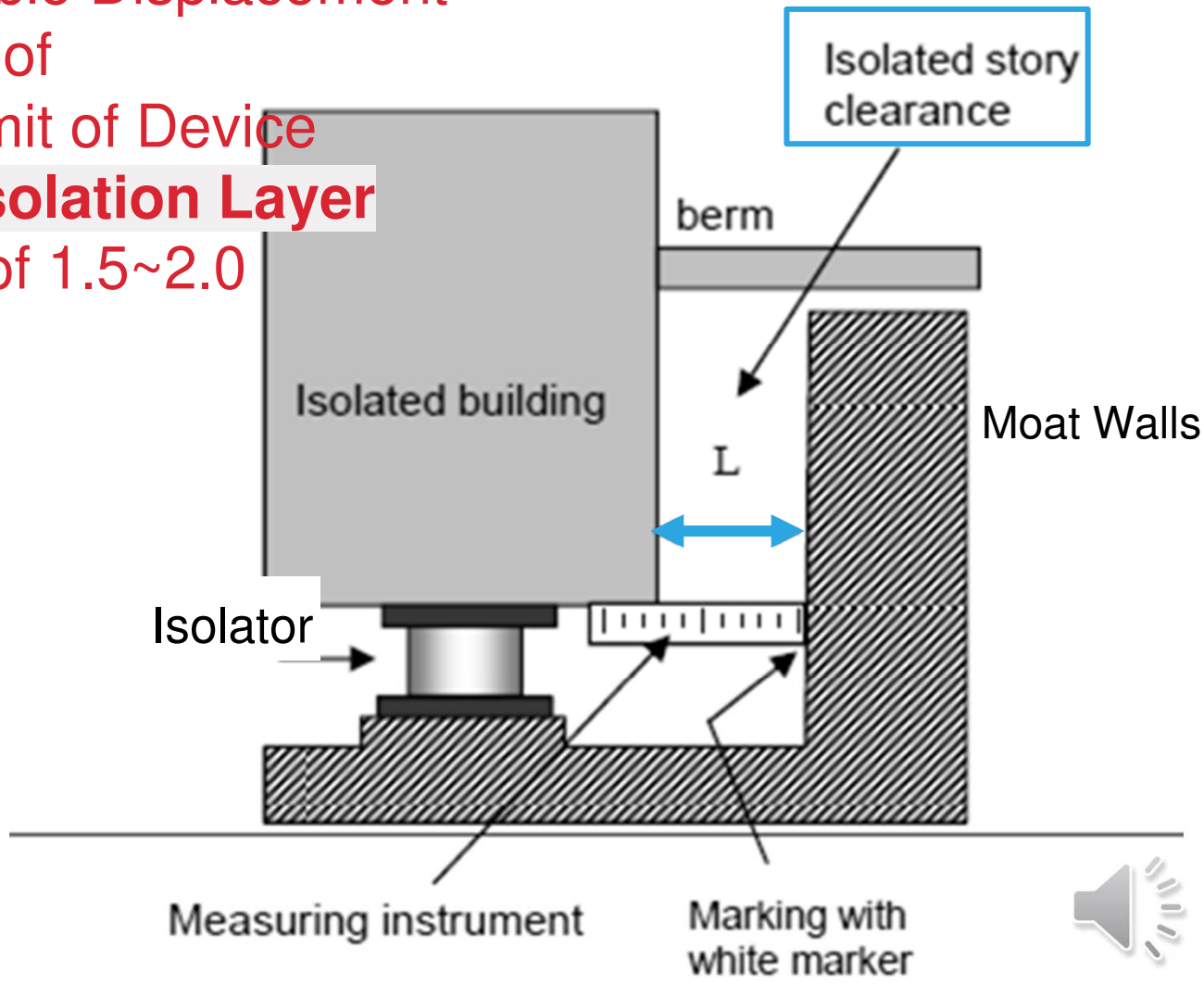
Drift at Isolation Layer: $\delta_{max} \leq \delta_a$, $\delta_a = \delta_u/\alpha$

δ_a: Design Allowable Displacement

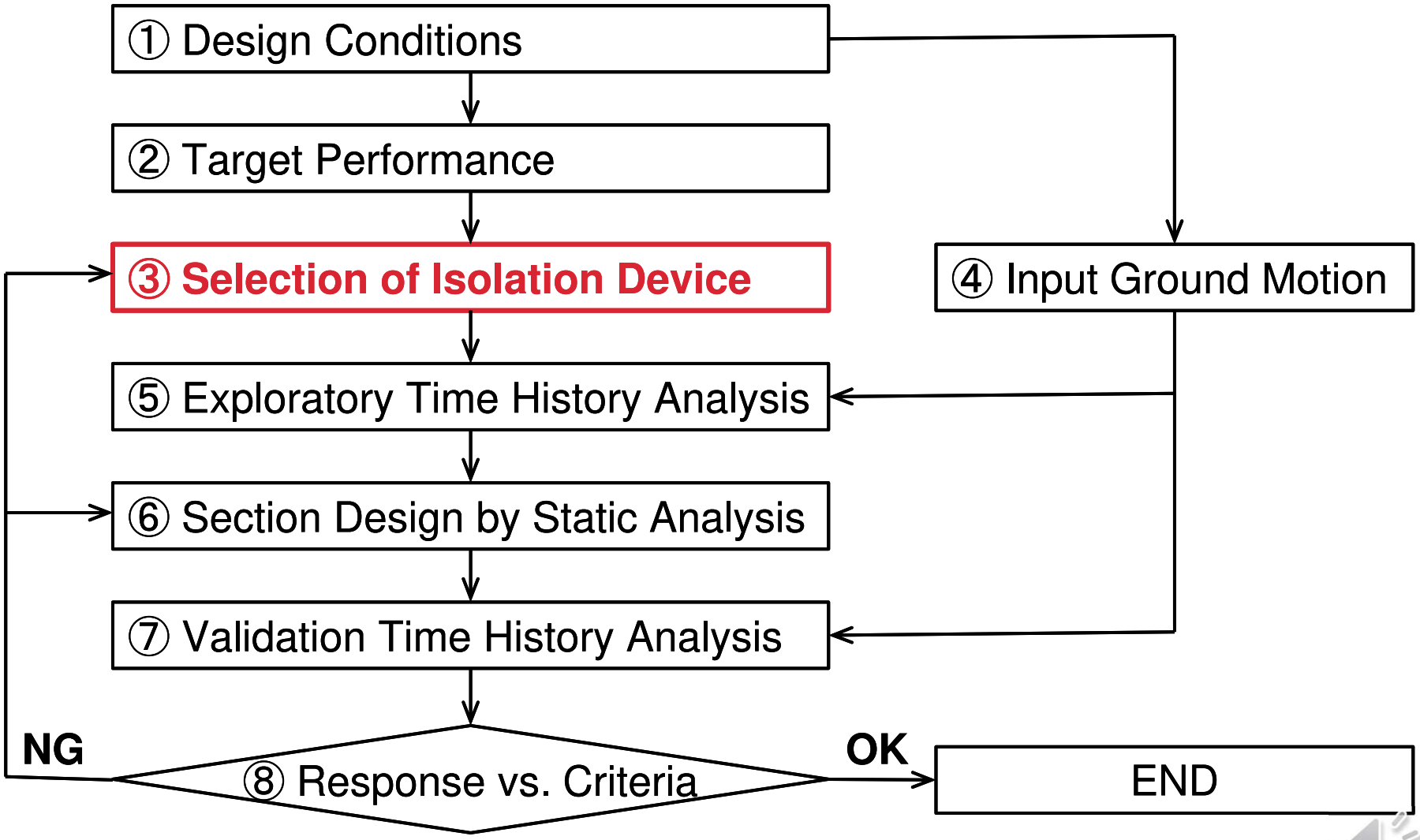
δ_u: Smaller Value of

- Deformation Limit of Device
- **Clearance at Isolation Layer**

α : Safety Factor of 1.5~2.0

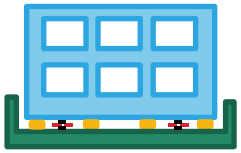


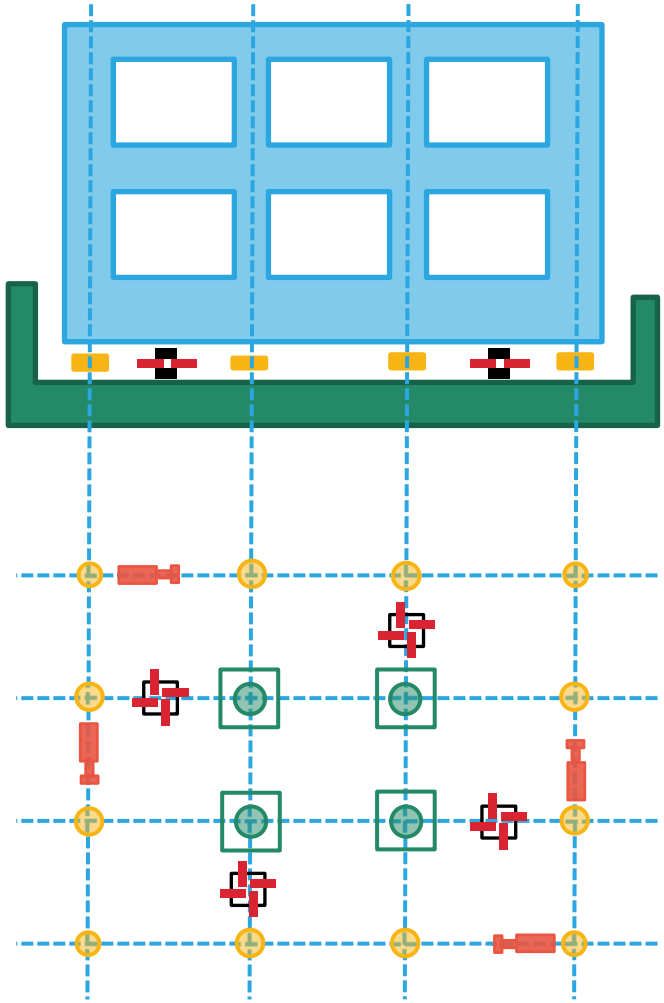
Typical Structural Design Flow

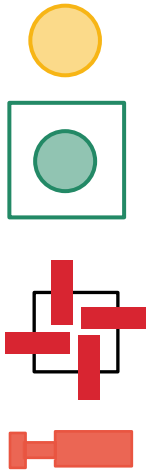


③ Selection of Isolation Device

- Setting of Isolation Layer -







Target Period
of Isolation Layer
Target Damper Ratio

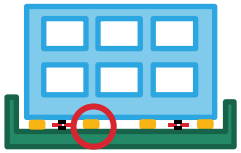
↓

Diameter of Rubber Bearing
Adoption of Slider

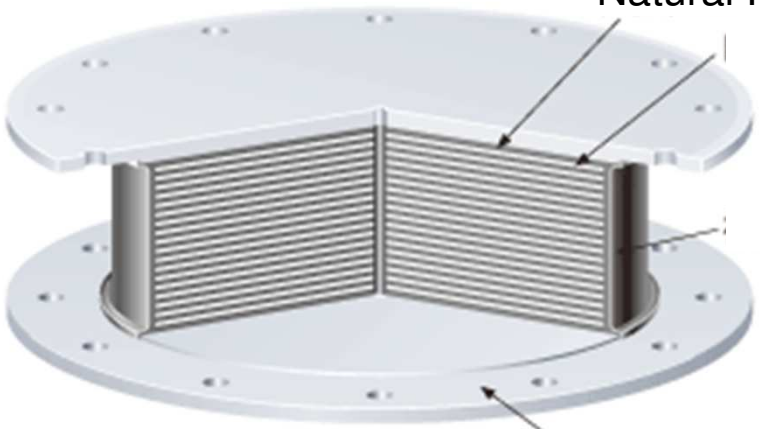
↓

Arrangement of Dampers

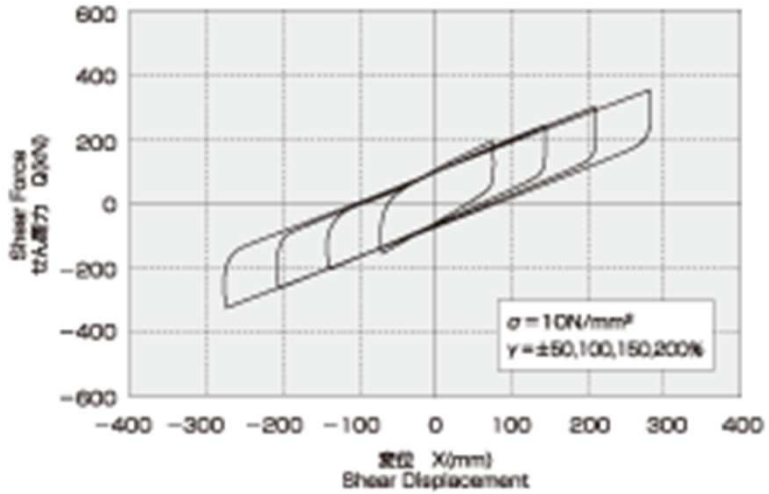
③ Selection of Isolation Device

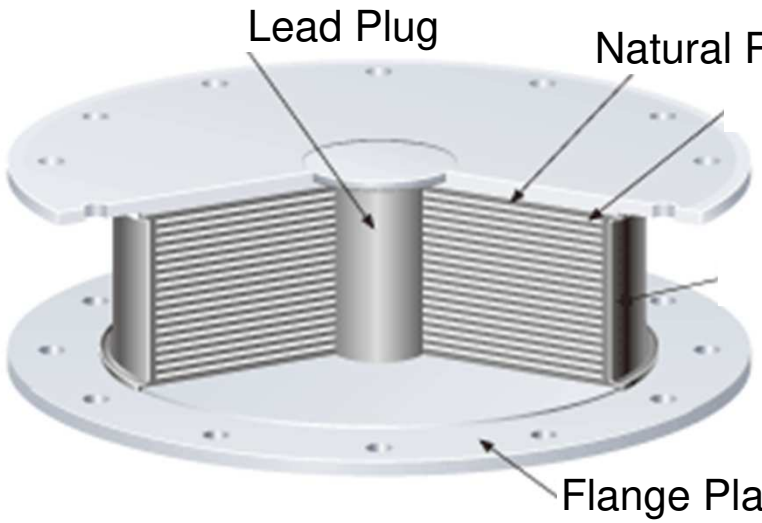


- Rubber Bearing -



Hysteresis Curve of Lead Rubber Bearing

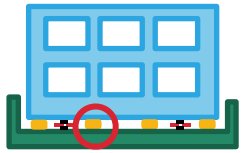


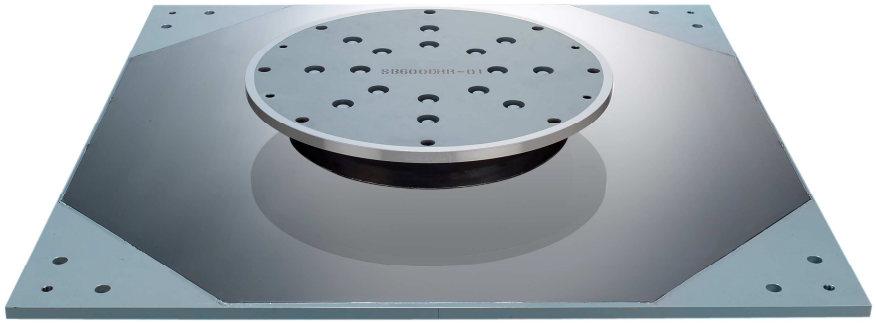


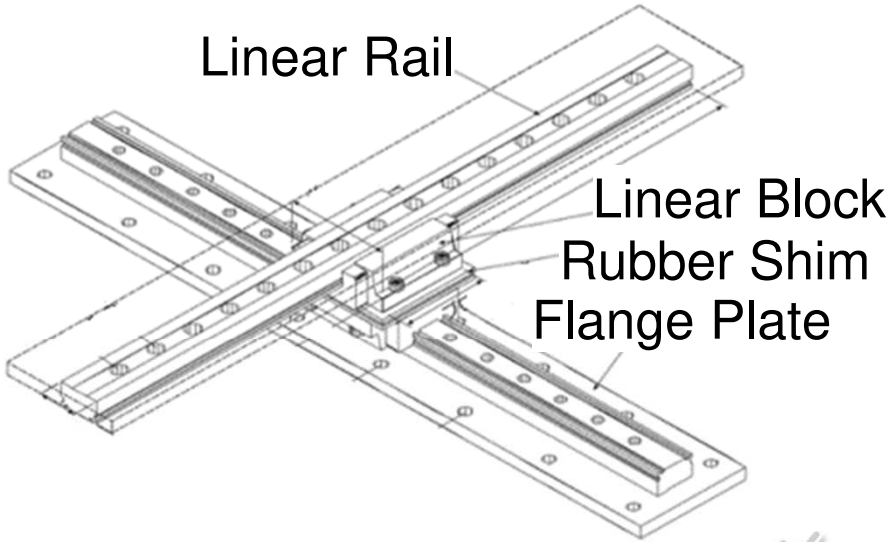
http://www.bridgestone.co.jp/, http://www.swcc.co.jp/

③ Selection of Isolation Device

- Slider -



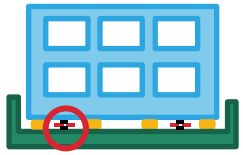


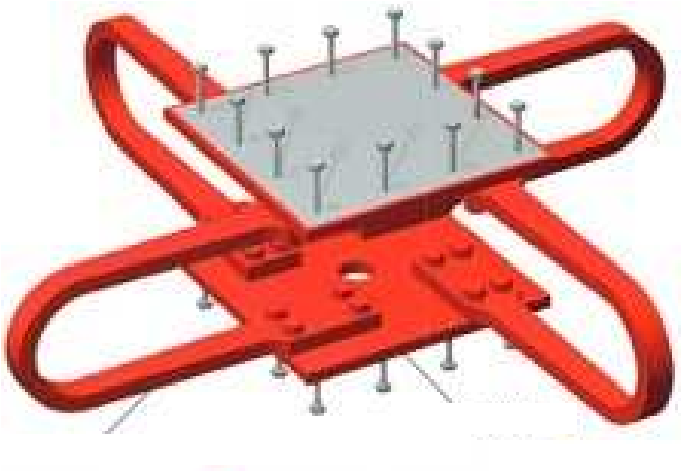


http://www.swcc.co.jp/, http://www.adc21.com/

③ Selection of Isolation Device

- Damper -





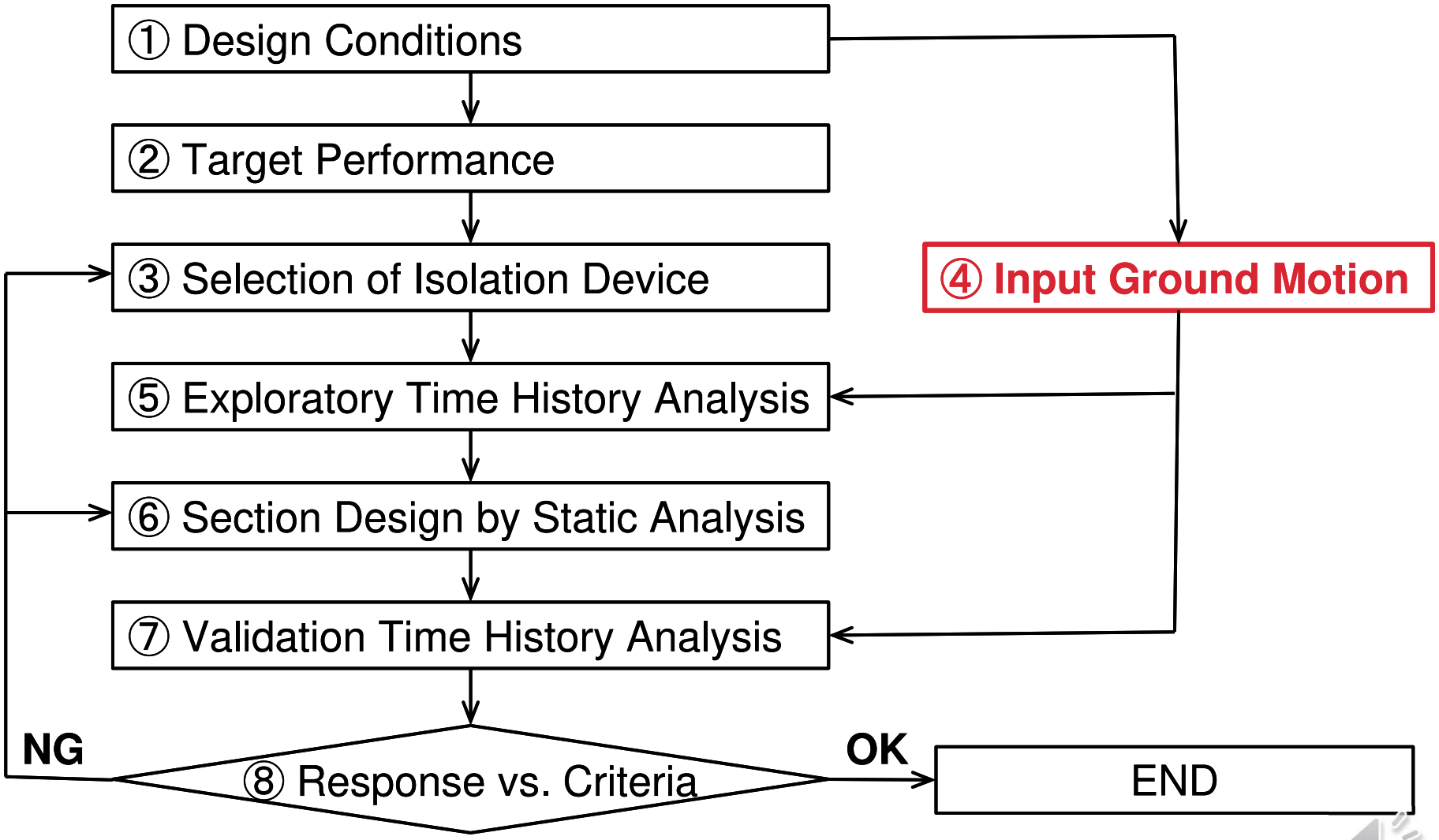
Steel Damper

Lead Damper

Fluid Damper

https://www.nsec-steelstructures.jp/, http://www.sumitomo-siporex.co.jp/, https://www.kyb-ksm.co.jp/

Typical Structural Design Flow



④ Input Ground Motion

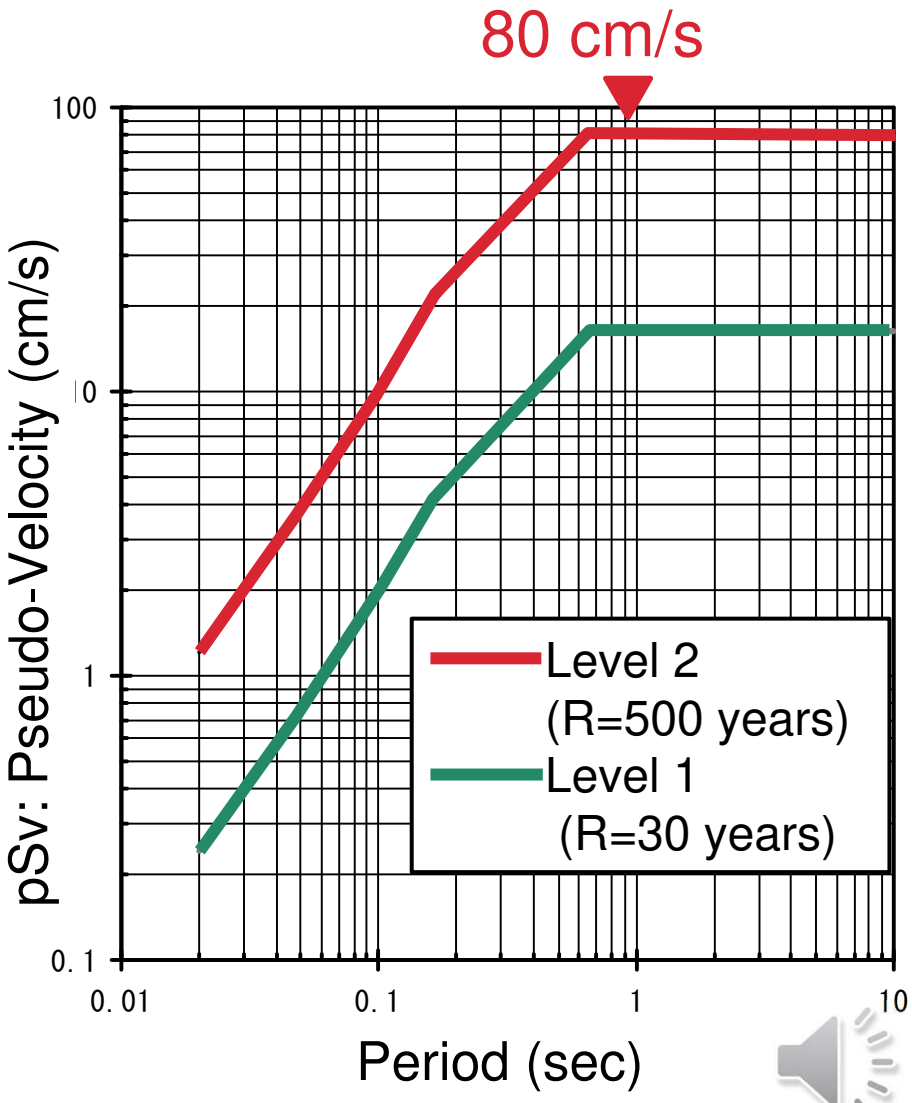
1 Kokuji Wave (Notification Wave)

Japanese building law provides design pseudo-velocity response spectra.

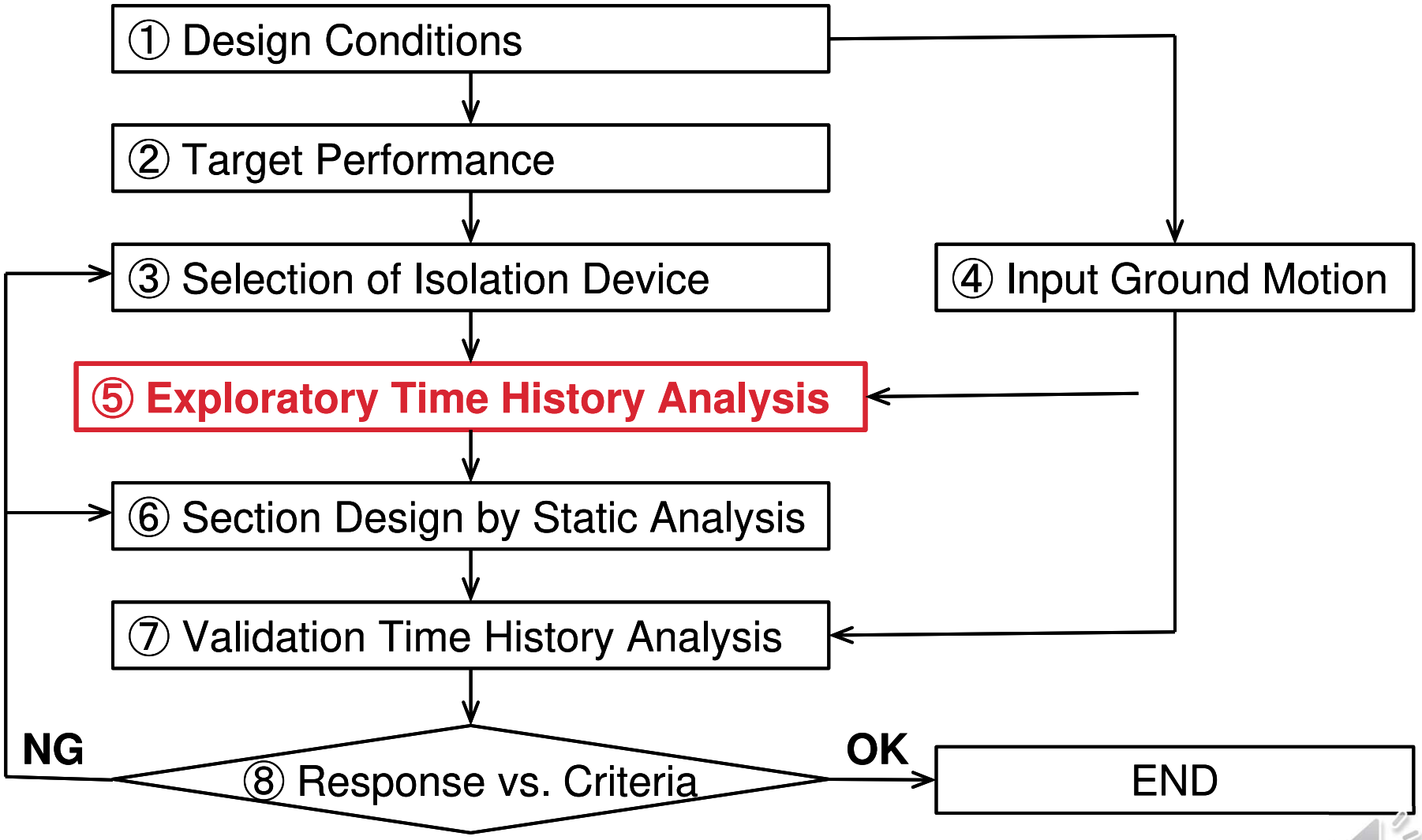
The green line is for Level 1 earthquake and red line is for Level 2 earthquake.

The maximum pseudo-velocity considered is 80 cm/s for Level 2.

More than 3 ground motions with different phase spectra should be considered for each of Level 1 and Level 2.

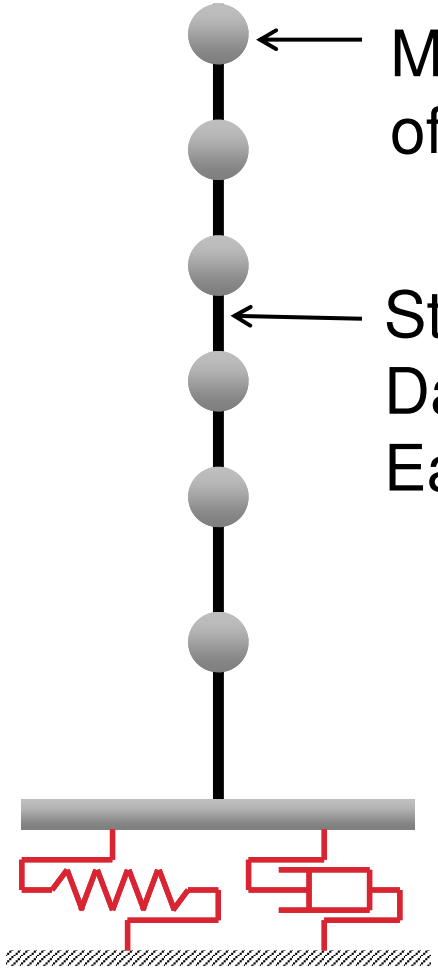


Typical Structural Design Flow

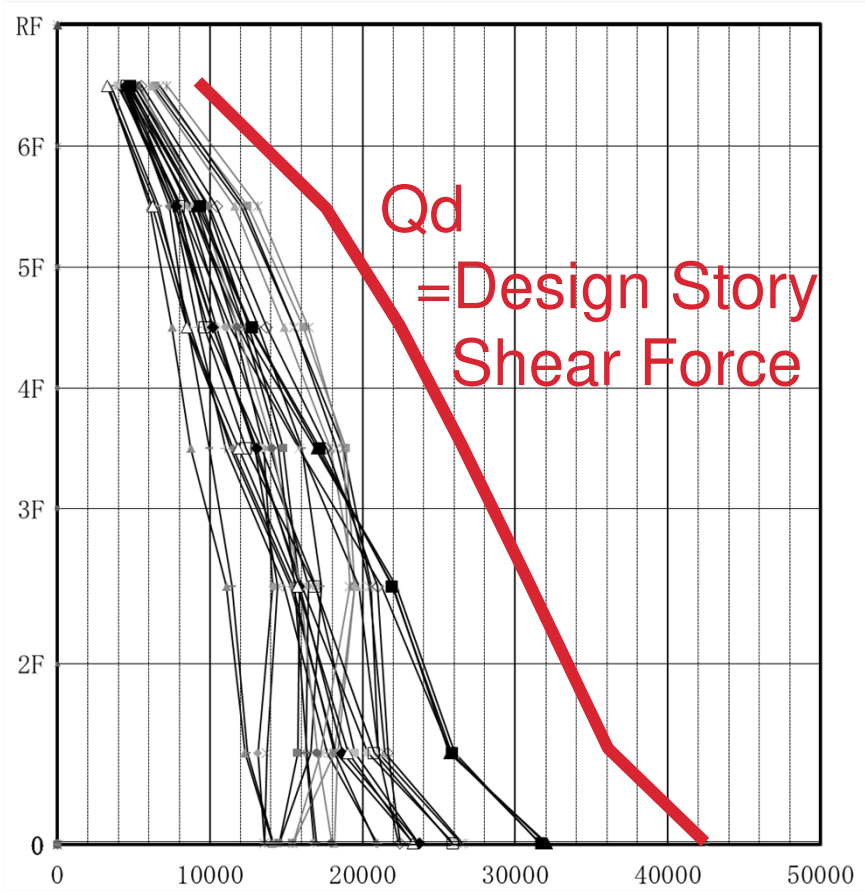


⑤ Exploratory Time History Analysis

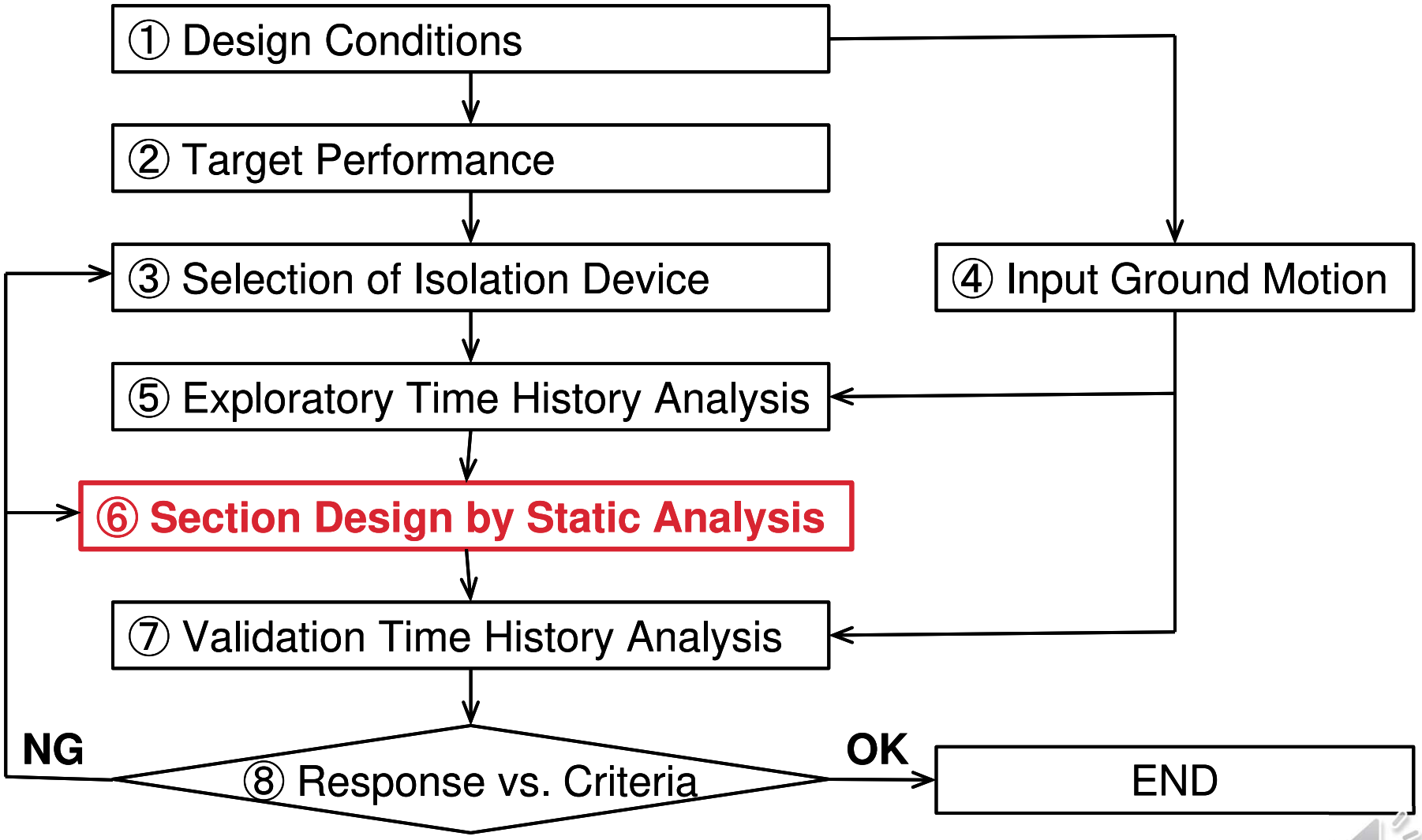
Determination of Story Shear Force



Stick Model

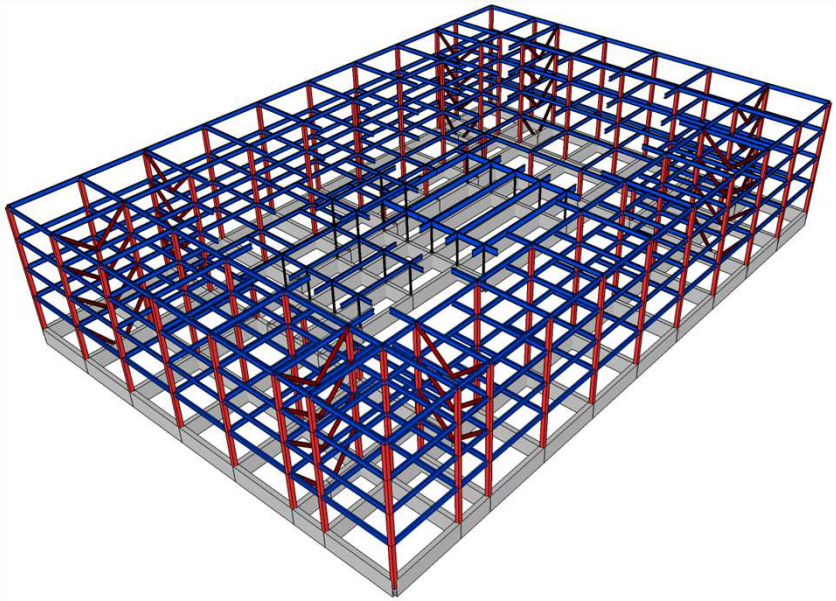


Typical Structural Design Flow



⑥ Section Design by Static Analysis

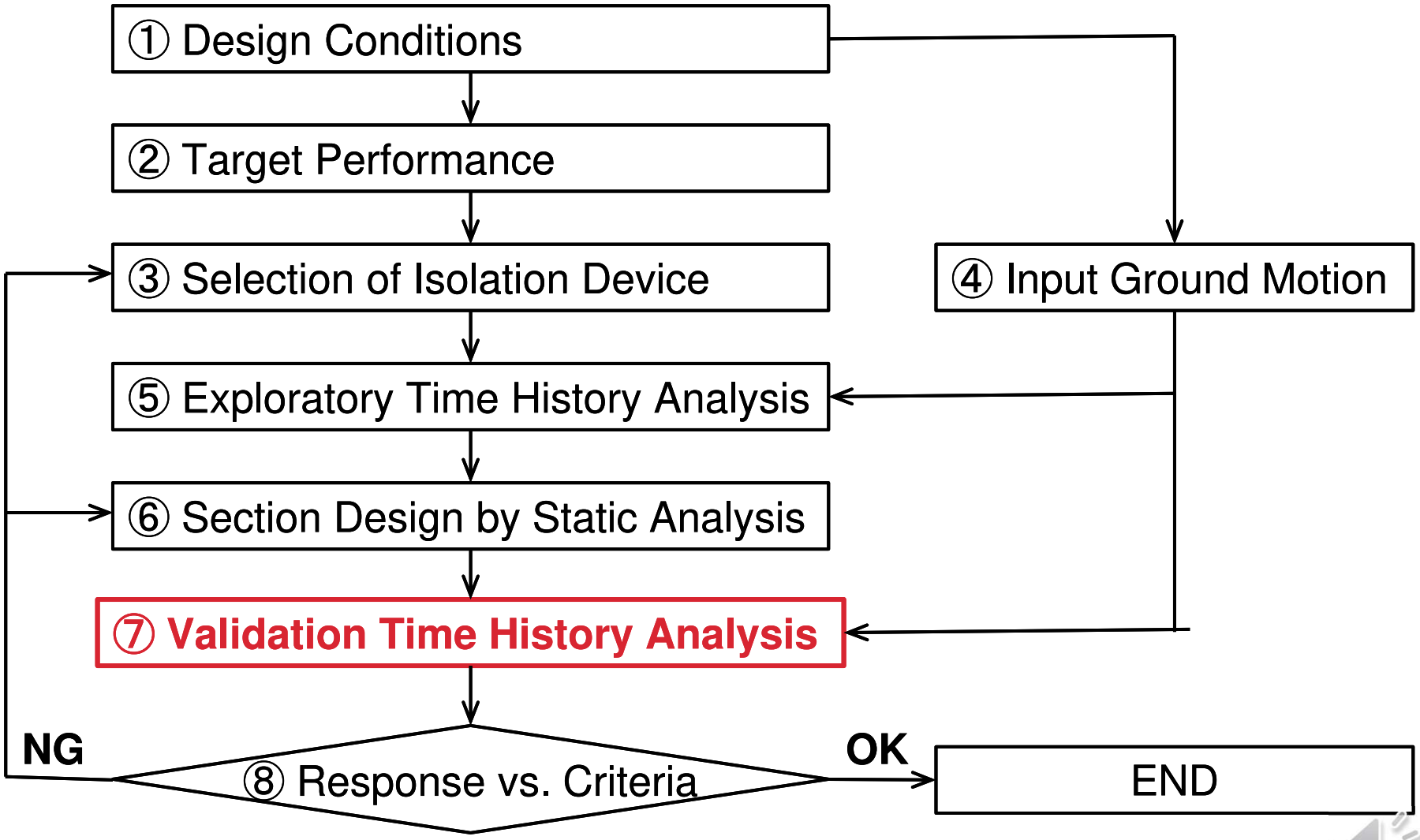
The established seismic load is applied in a 3D static analysis model.



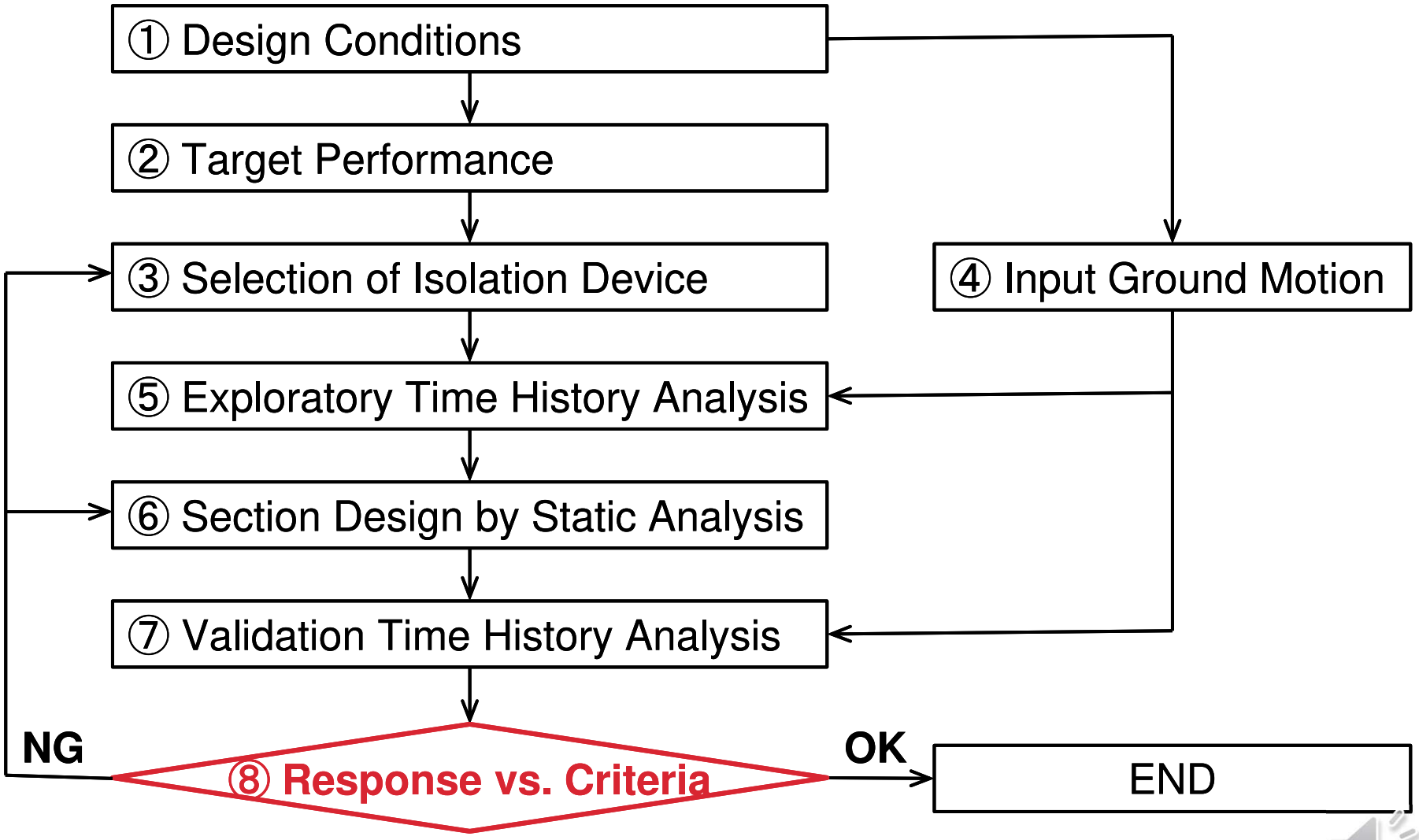
3D Static Analysis Model

Design Force Diagram

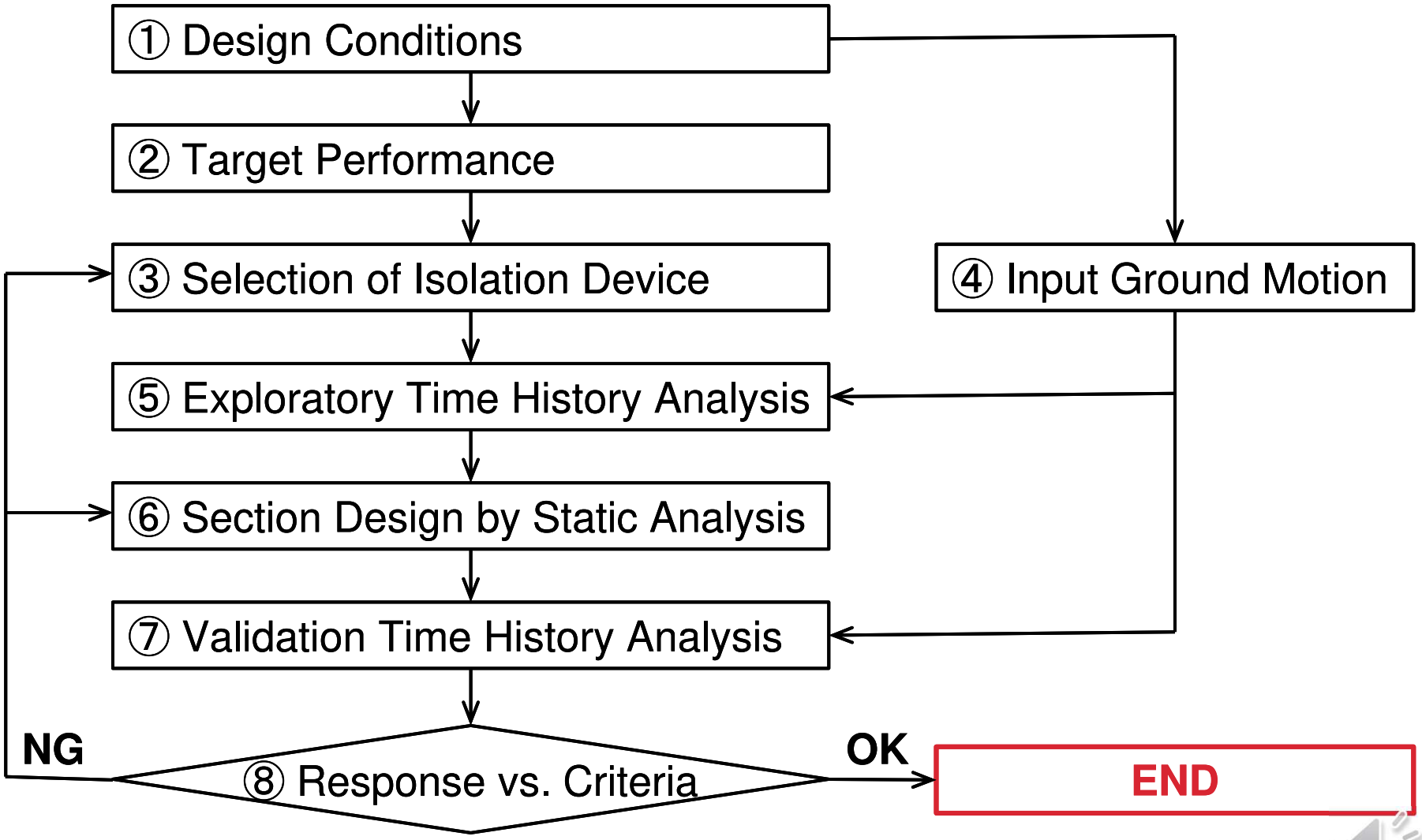
Typical Structural Design Flow



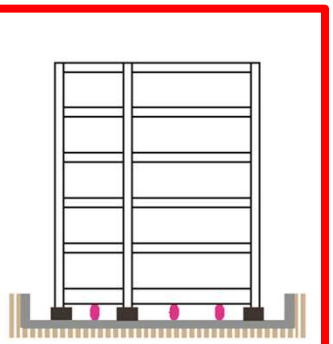
Typical Structural Design Flow



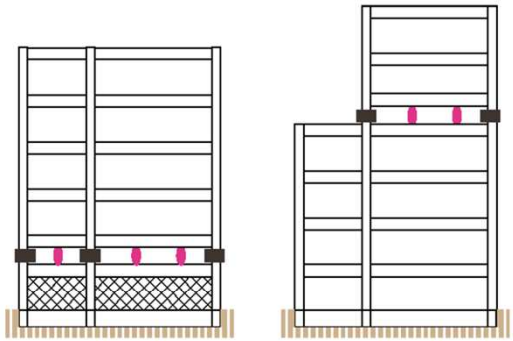
Typical Structural Design Flow



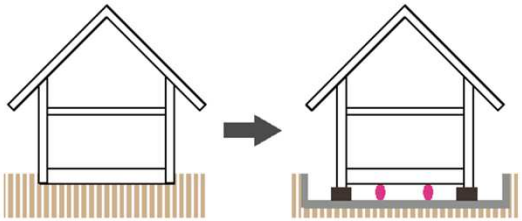
3 Examples of Seismic Isolation Design



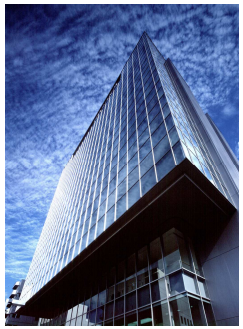
Base isolation

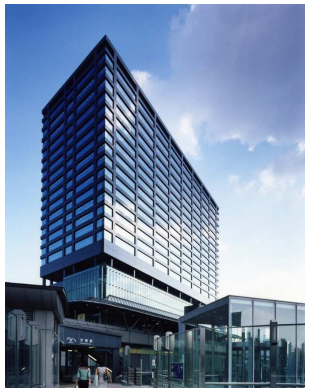


Middle floor isolation



Seismic retrofiting for existing building





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日建設計

Kochi City Hall
[High Seismic Risk]

Kochi City Hall

Occupancy : Municipality Office

Floor Area : 33,000m²

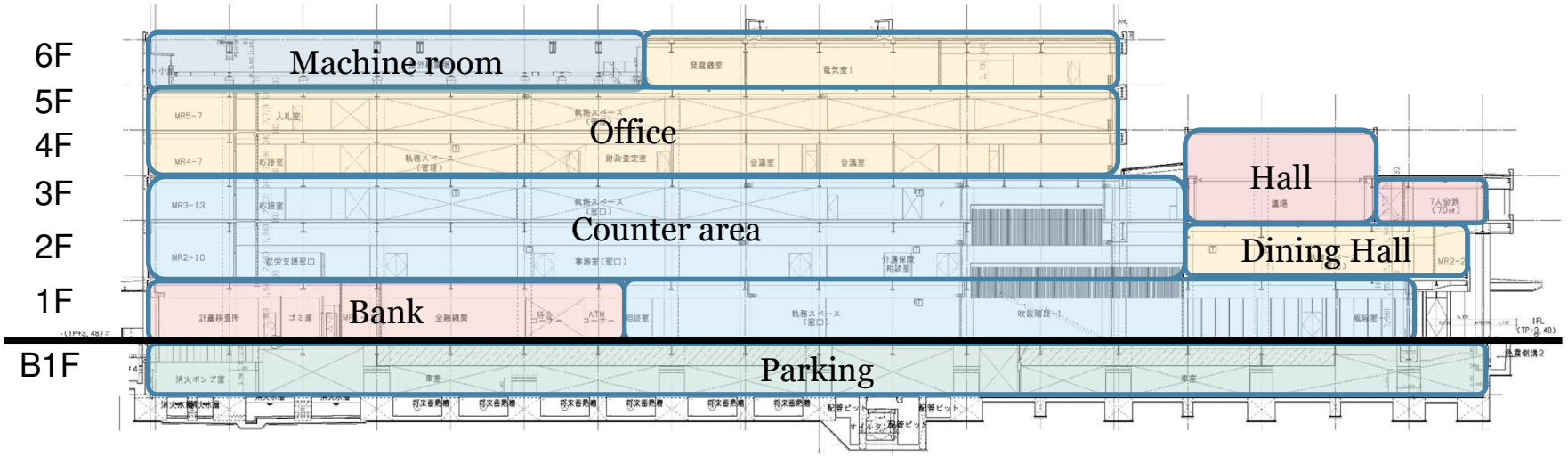
Max. Height : 27.0m

Storeys : B1F/6F

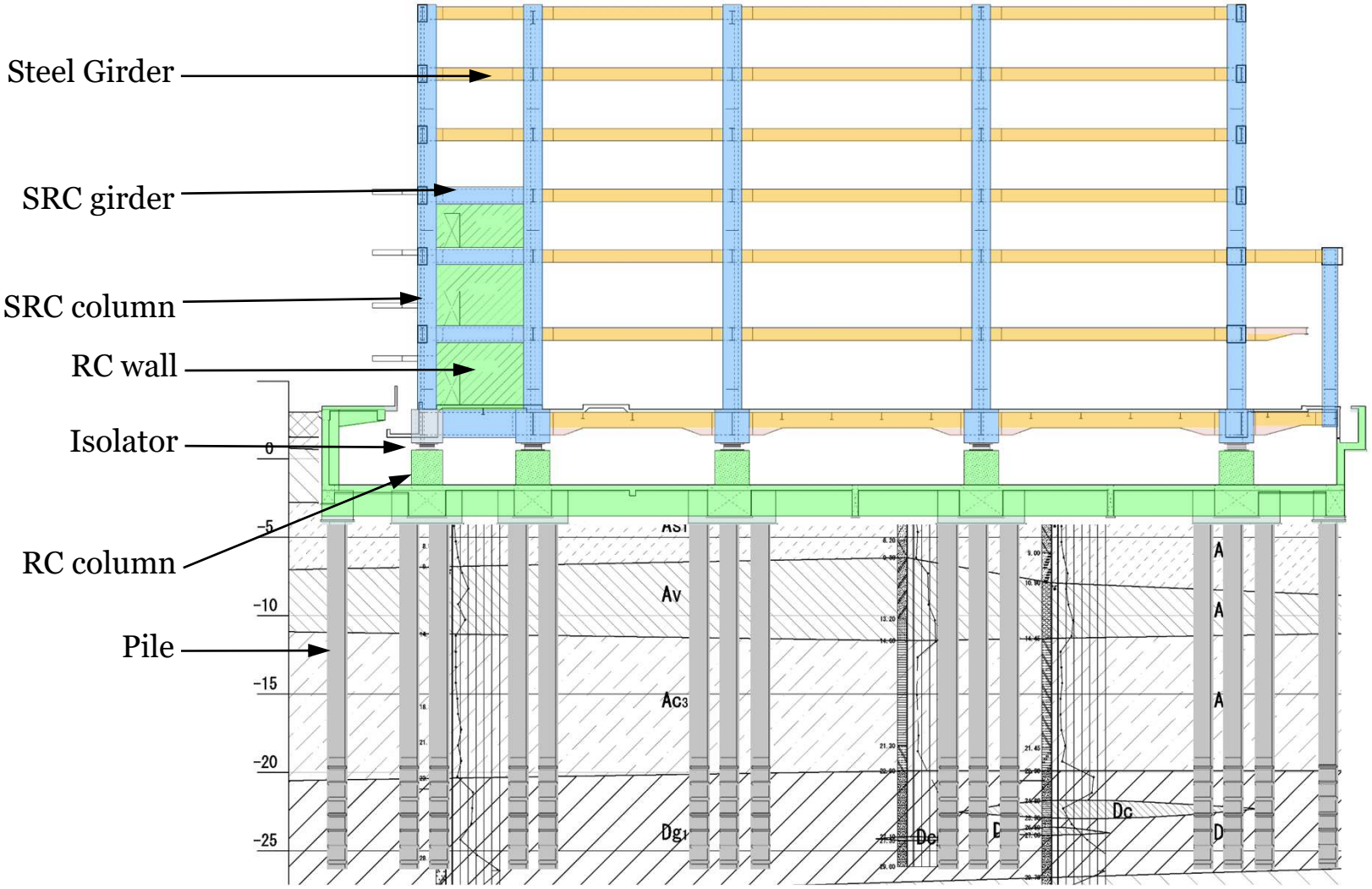
Old City Hall

Kochi City Hall

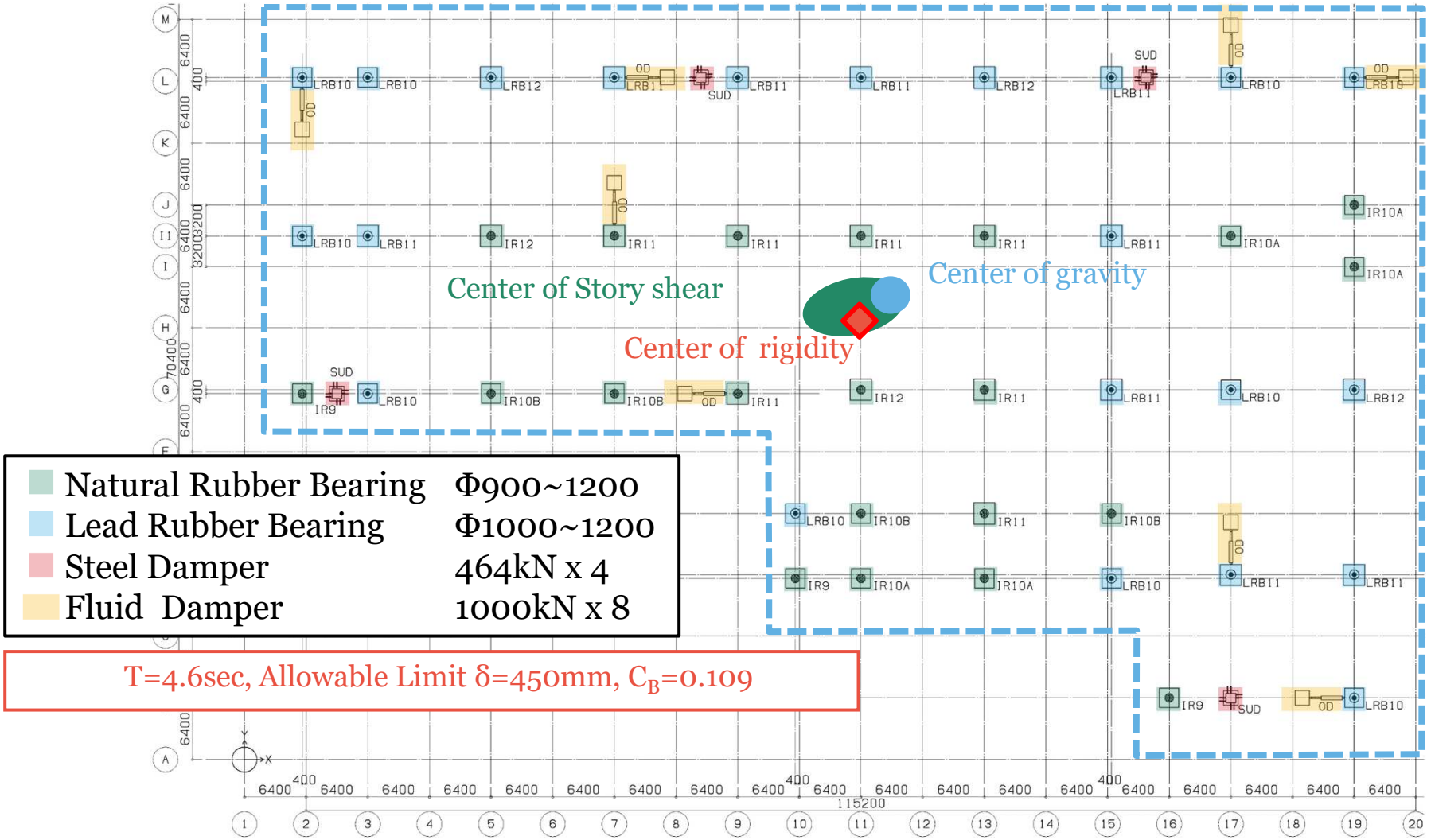
Structural Challenge:
The site is located at the assumed hypocenter of NANKAI Trough earthquake which might be M9 class. Mega earthquake and Tsunami should be considered in the design.



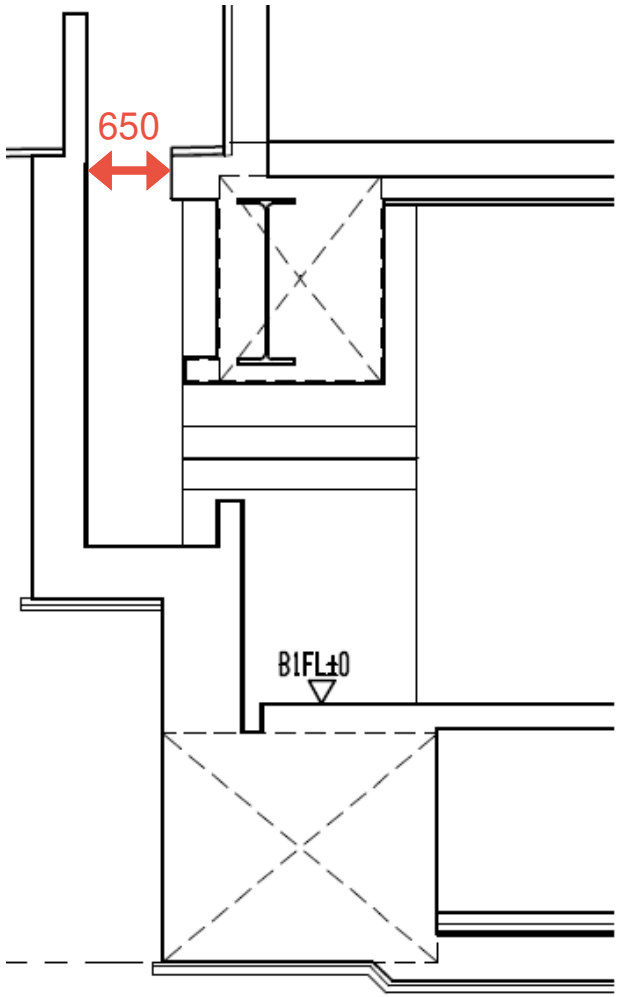
Kochi City Hall



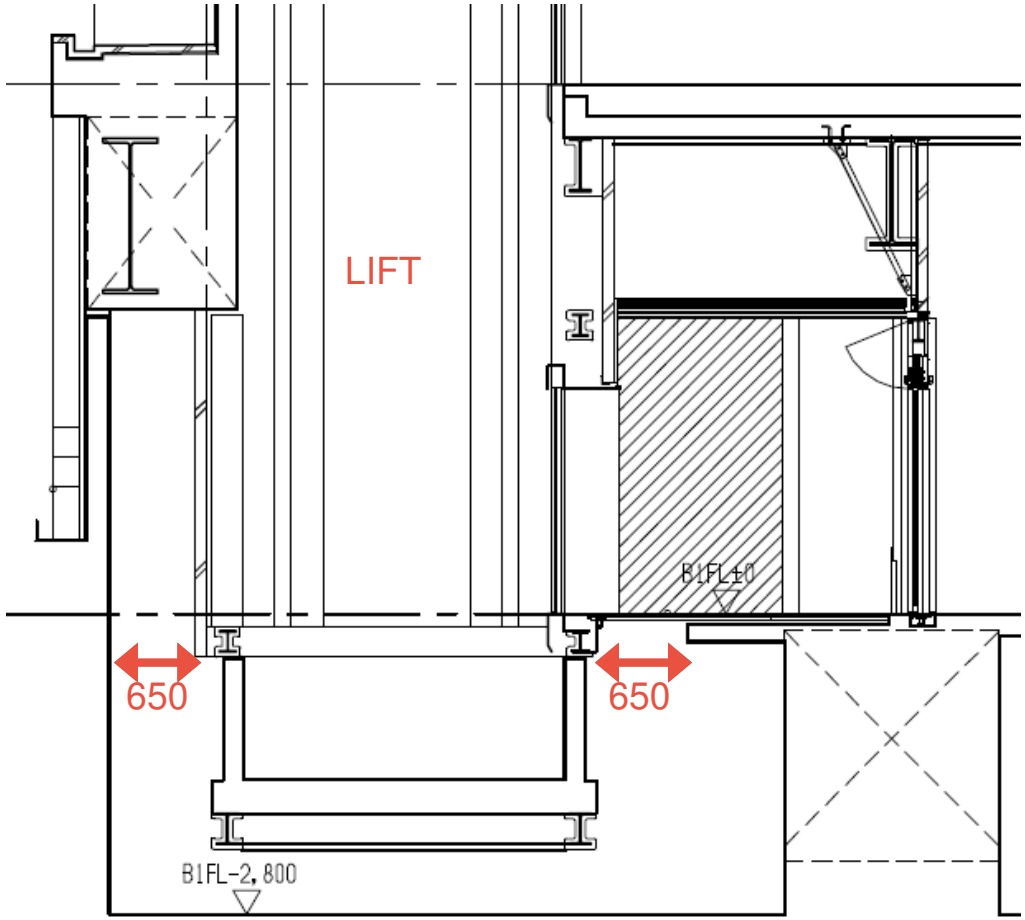
Kochi City Hall



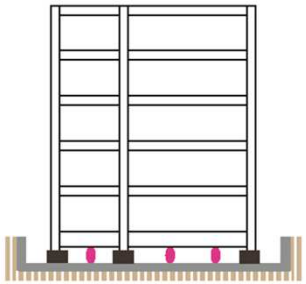
Kochi City Hall



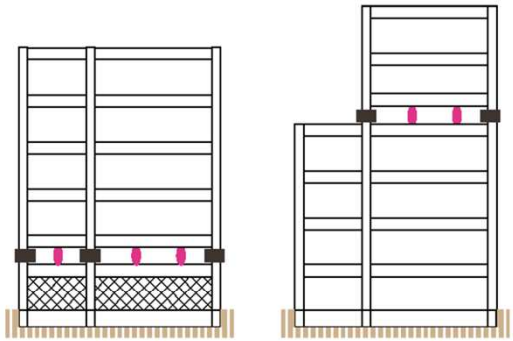
Clearance to Retaining Wall



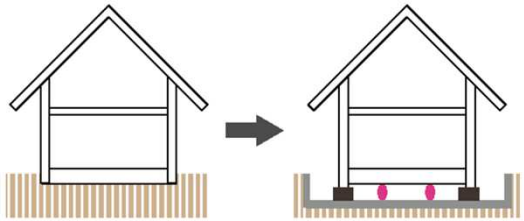
Clearance around Lift Pit



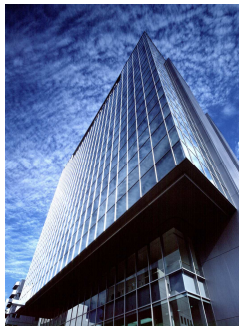
Base isolation

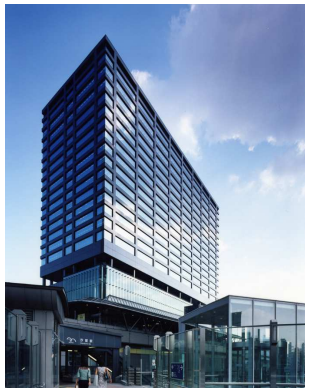


Middle floor isolation



Seismic retrofiting for existing building





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NIKKEN SEKKEI LTD

Nagano Government Office
[Seismic Retrofit]

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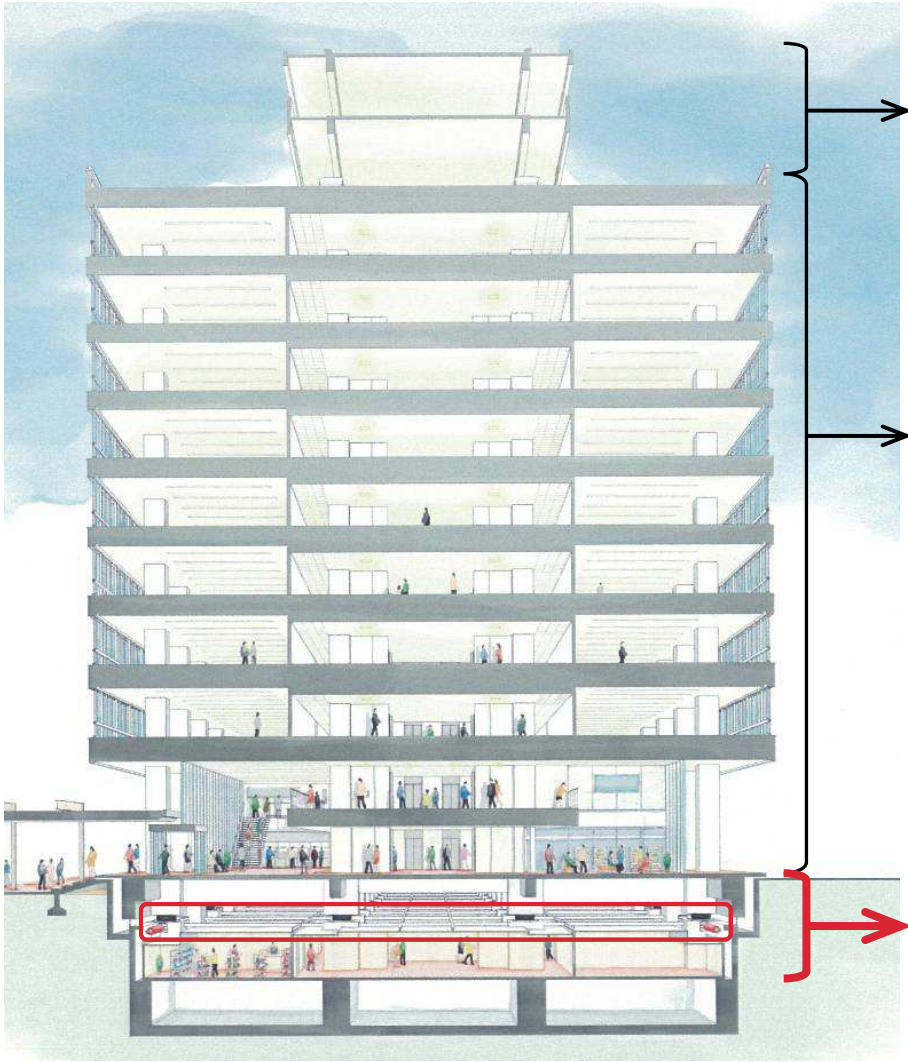
日建設計

Nagano Government Office

Occupancy : Municipality Office
Floor Area : 35,964.36m^2
Max. Height : 39.12m
Storeys : B1F/10F
Completion : 1967 (original)
2014 (retrofit)

Nagano Government Office

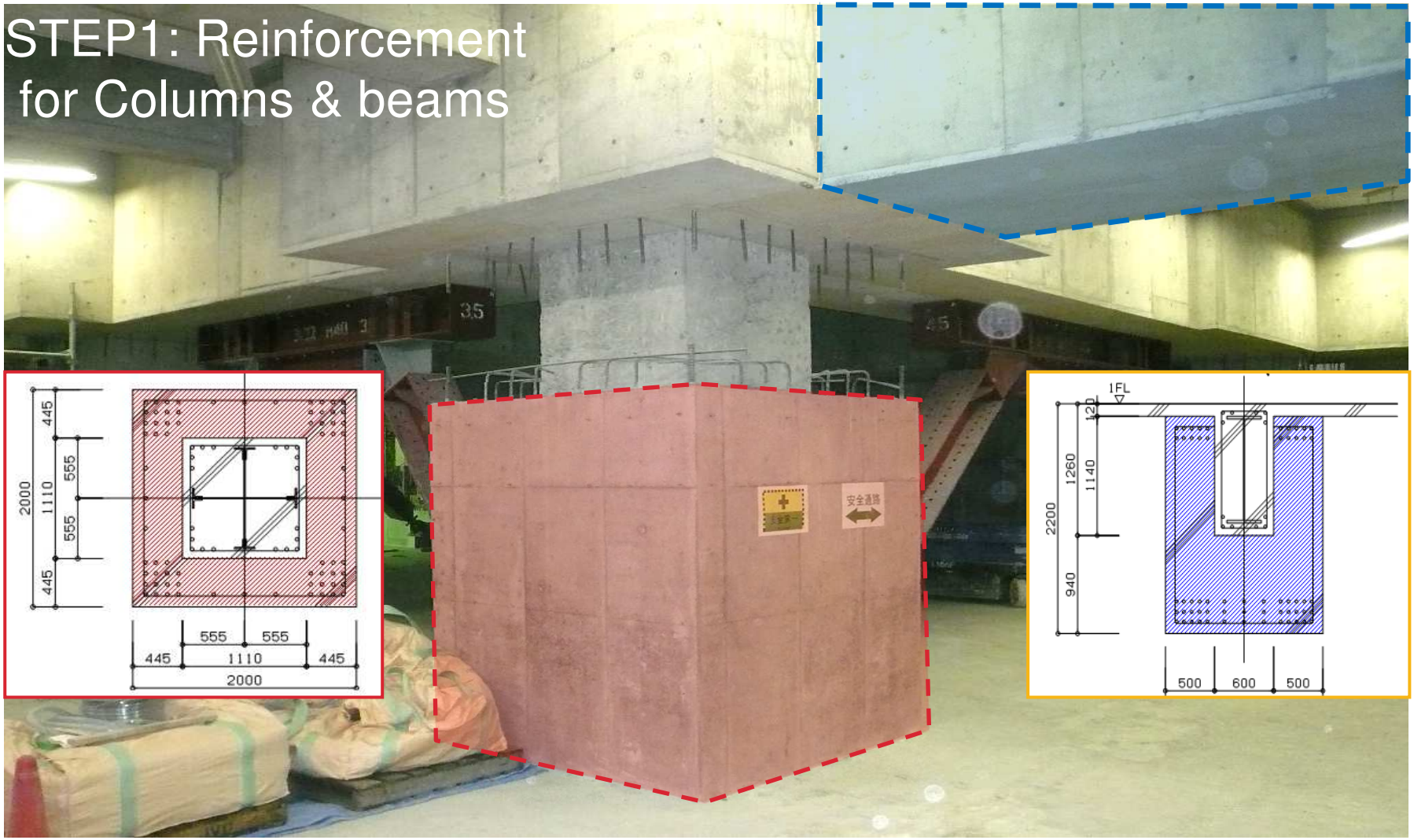


Penthouse: Minor modification
- Seismic gaps are installed to improve the seismic performance.

Above GF: No modification.
- The operation of municipality office shall be continued during the retrofit construction work.

Below GF: Major retrofit area
- Seismic isolators are to be installed at the mid of columns of B1F.
- Columns and beams are to be reinforced so as to resist the induced force by the isolation layer drift.
- No operation during the retrofit work.

Nagano Government Office



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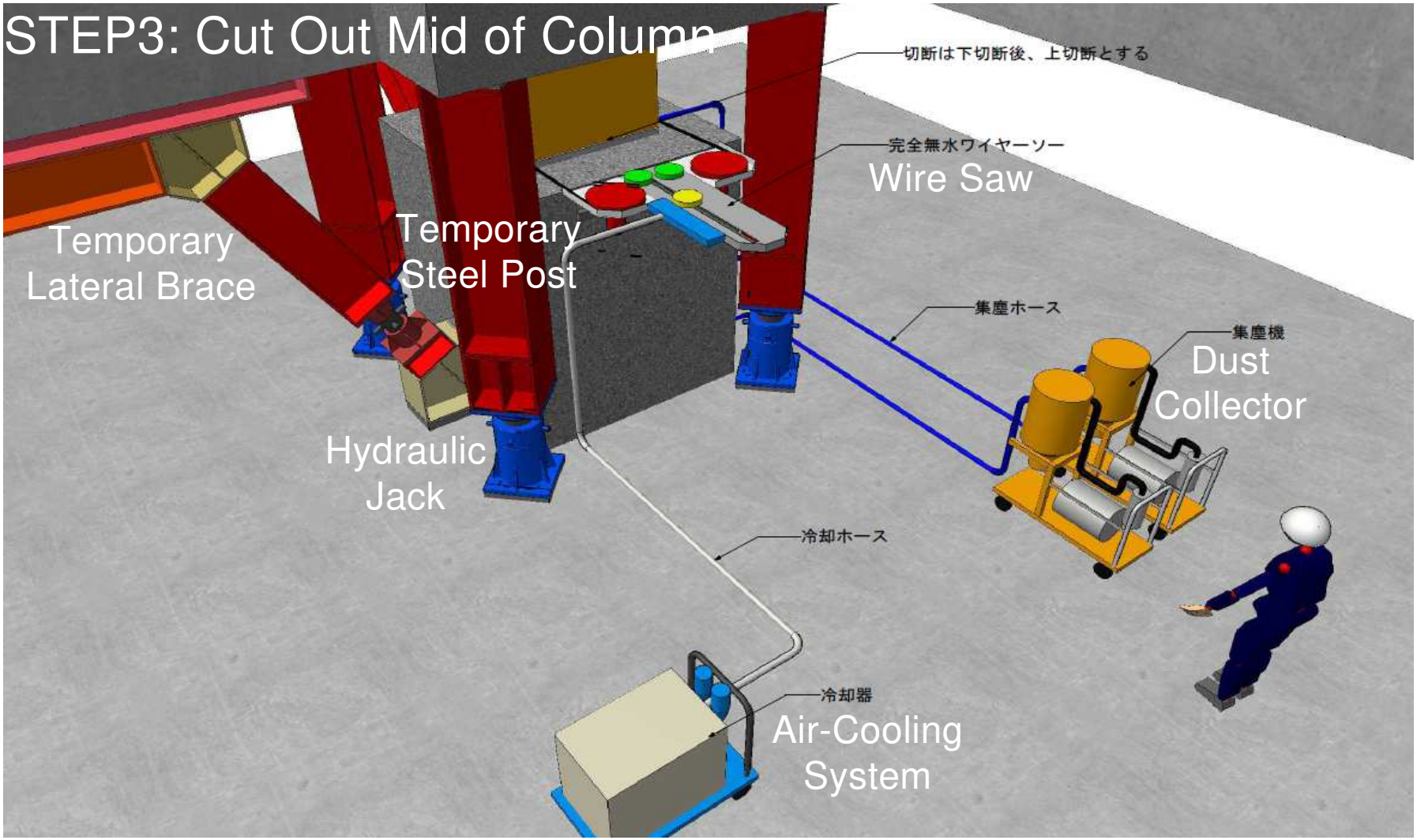
Nagano Government Office

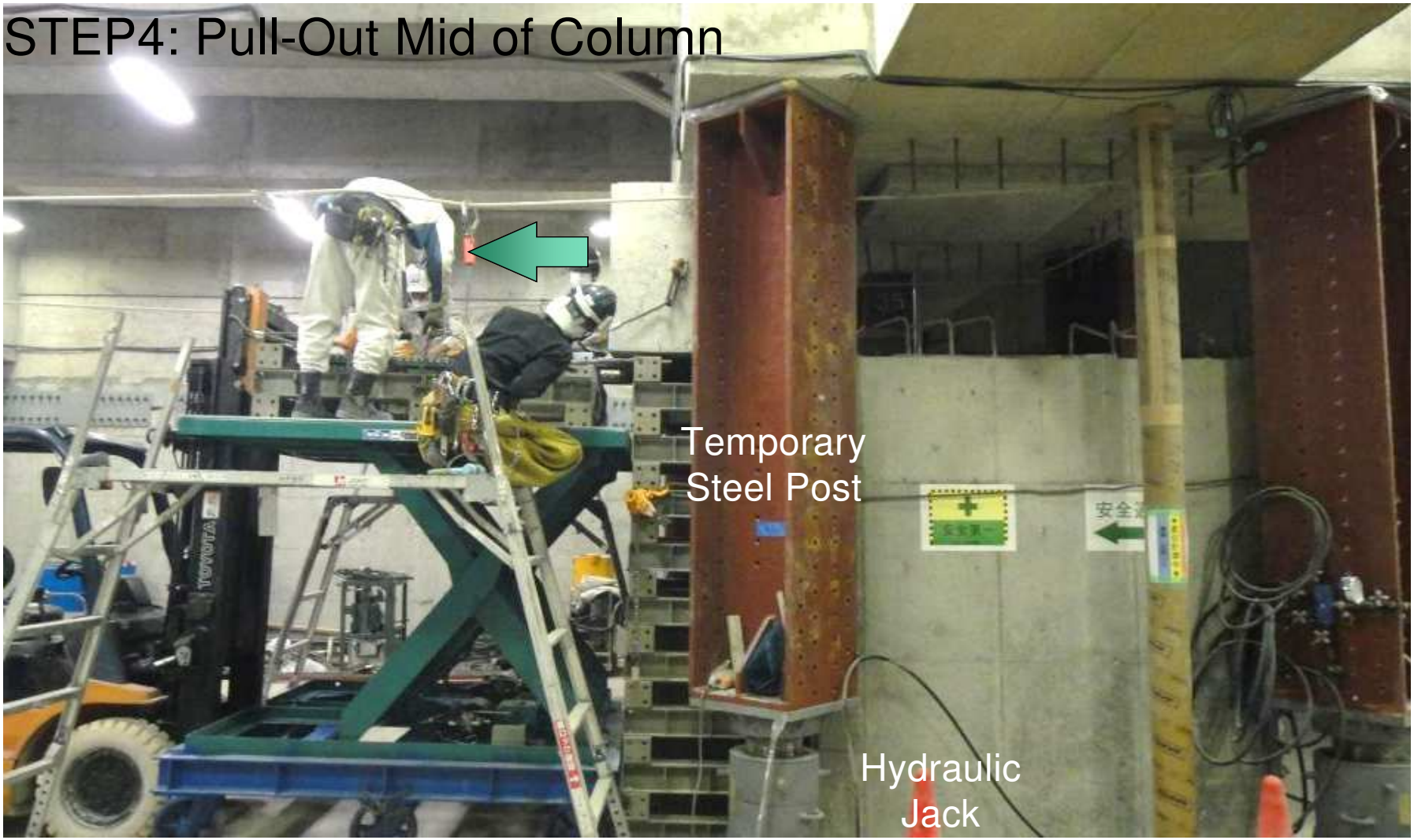
Nagano Government Office



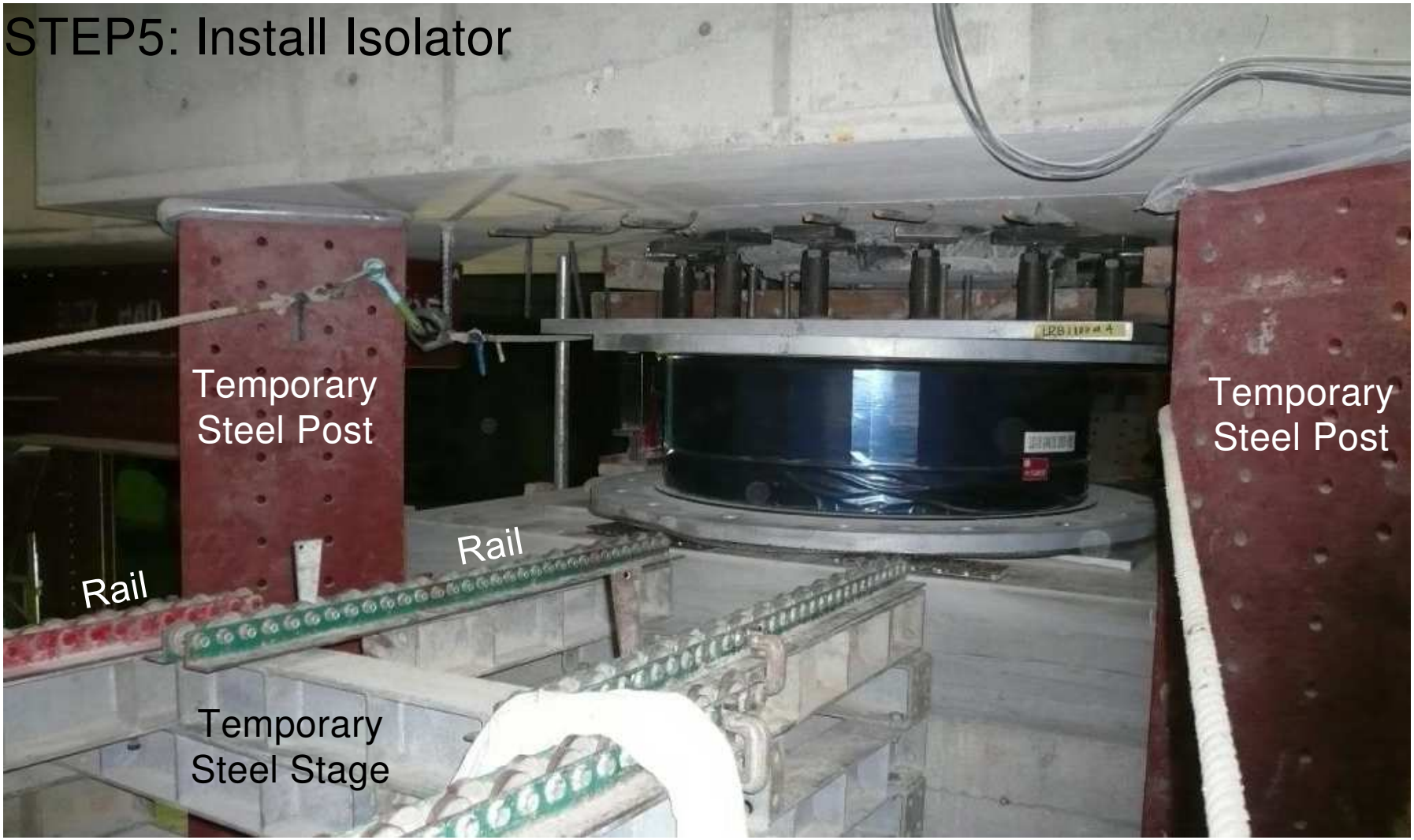
Nagano Government Office

STEP3: Cut Out Mid of Column

Nagano Government Office



Nagano Government Office



Nagano Government Office

STEP6: Jack-Down & Removal Temporary Structure

4 Examples of Construction, Operation & Management for Isolated Structures

Construction for Isolation Device

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Construction for Isolation Device

Inspection and replacement of Isolation Device

Isolated buildings need to be inspected periodically.
In general, inspections are conducted after construction is completed,
5 years later, 10 years later, and then every 10 years after that ,in Japan.

Main inspection Items

Isolation Device

- Vertical support performance
- Horizontal displacement performance
- Damping Performance
- Fire resistance performance

Seismic isolation layer and perimeter of the building

- Check that there is nothing to obstruct the deformation of the building.
  （ex. equipment piping , planting , etc）

Inspection and replacement of Isolation Device

The access for replacement should be considered when designing the building. A machine hatch about 3m × 3m is required.

Summary

1 Building Performance Design

2 Design Method of Seismic Isolation Structure in Japan

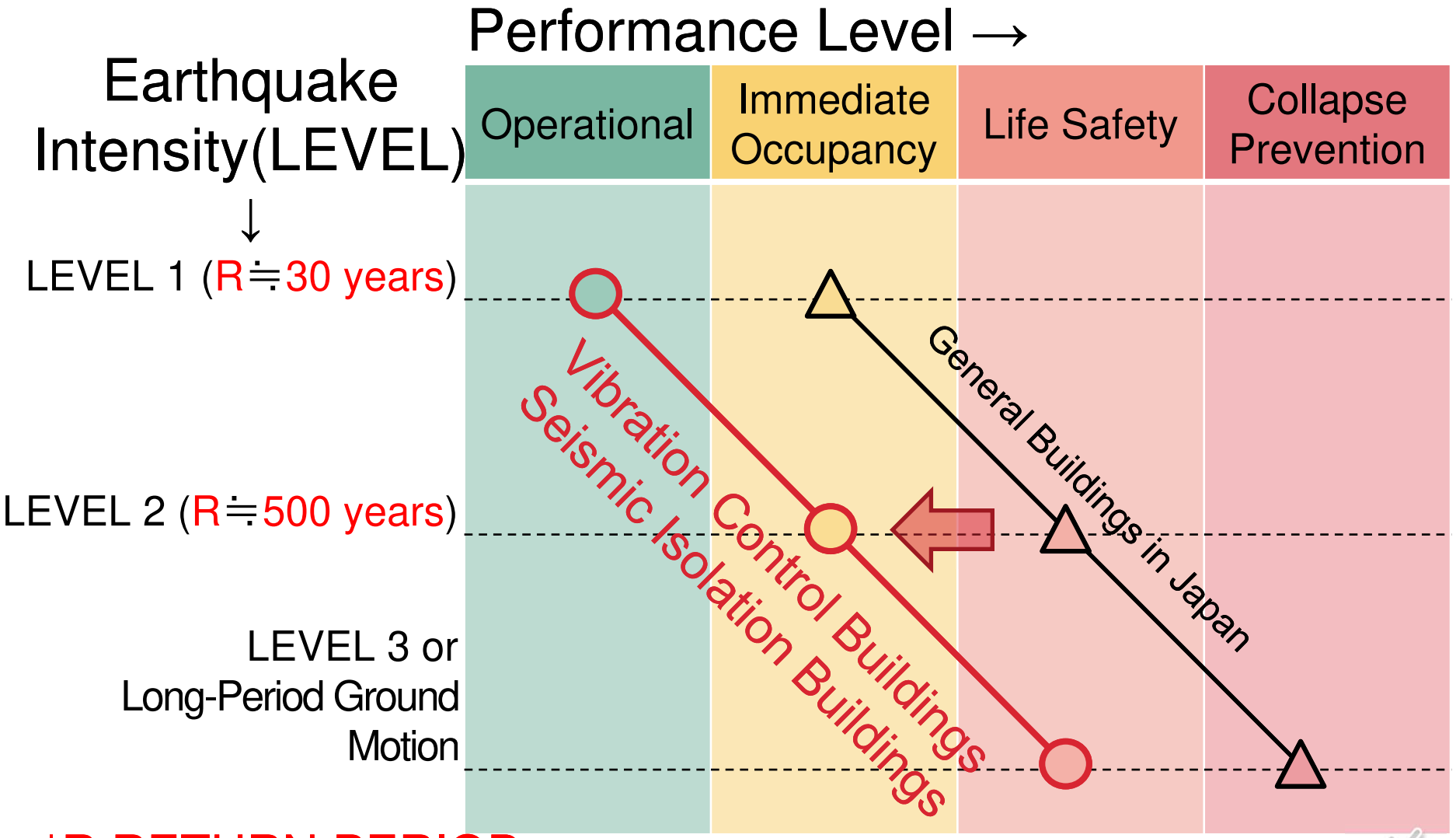
3 Example of Seismic Isolation Design

4 Examples of Construction, Operation & Management for Isolated Structures

I thank all of you for your kind attention.

END

Building Performance Level



*R:RETURN PERIOD

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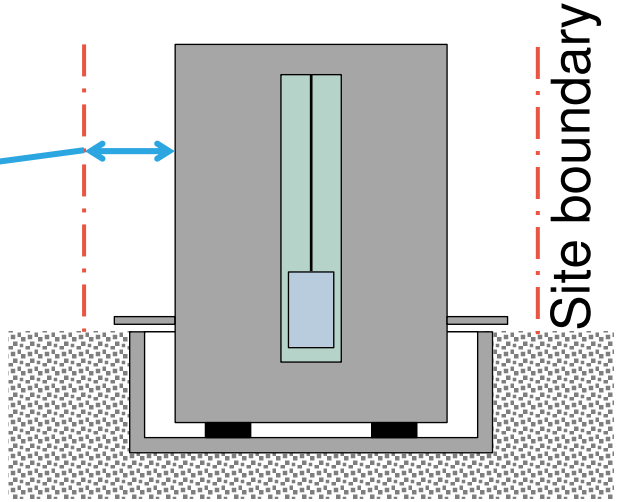
① Design Conditions : Isolation Layer Position

Base Isolation

Large Clearance
(approx. 2.0m)



Mid-story Isolation

Small Clearance
(approx. 0.6m)

Clearance for
Lift Shaft