Response Modification of Urban Infrastructure
都市施設の免震設計

(3) Chapter 2 Seismic Damage of Bridges due to Ground Vibration (Part 2)
(3) 2章　地震動による橋梁の地震被害(Part 2)

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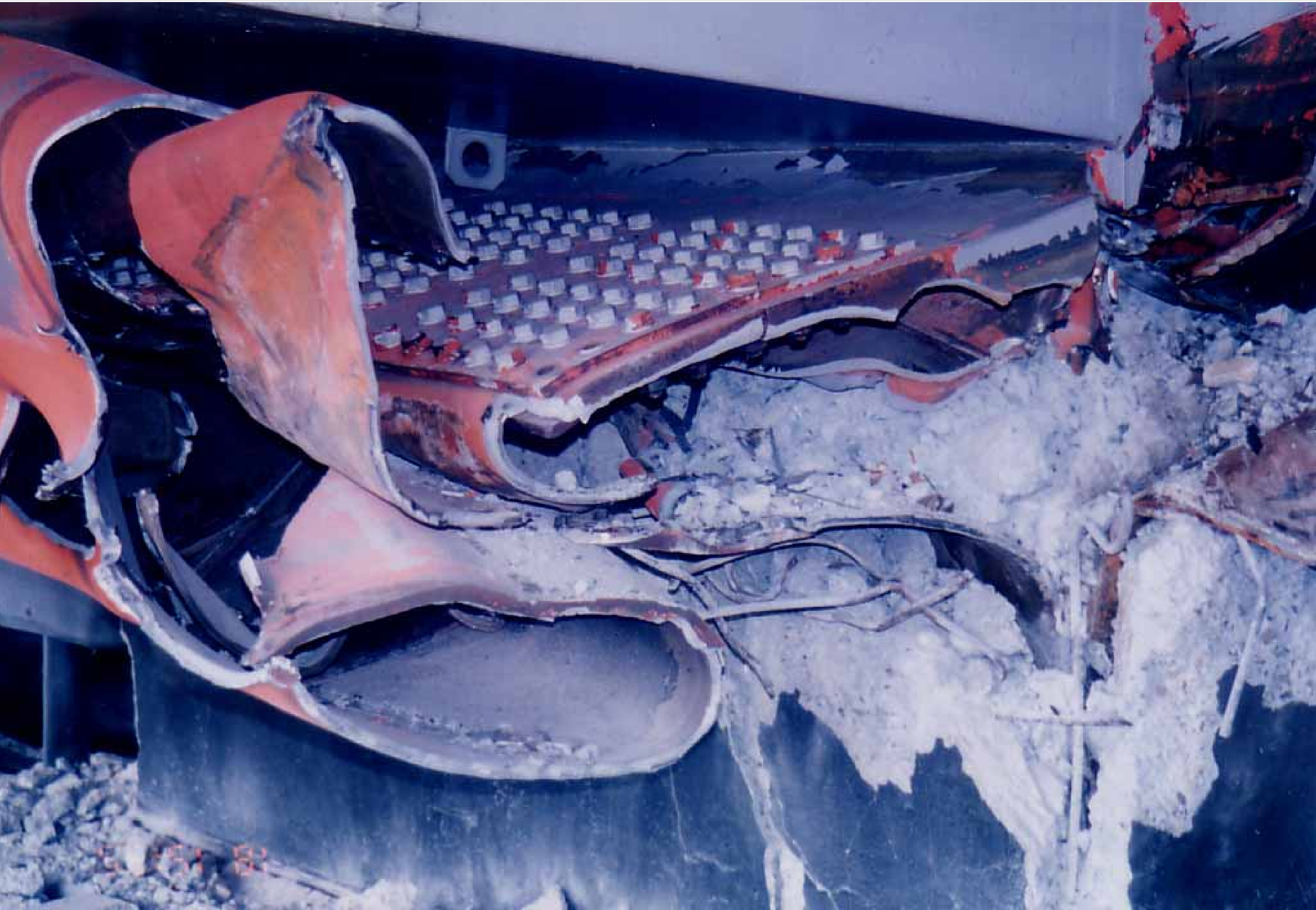
2) Shear Failure of RC Columns

Shear Failure　せん断破壊

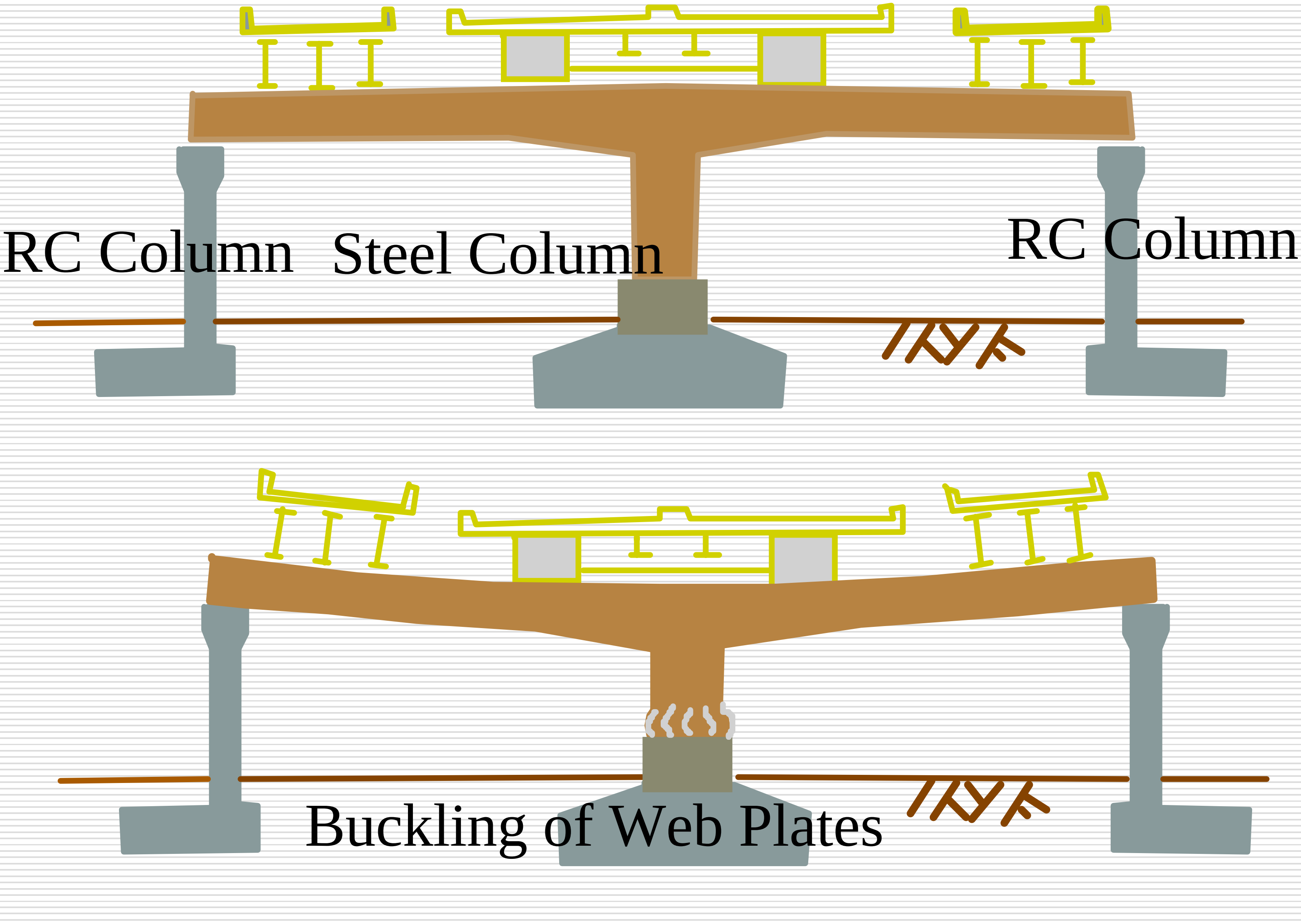
Shear Failure
せん断破壊

3) Failure of Steel Piers

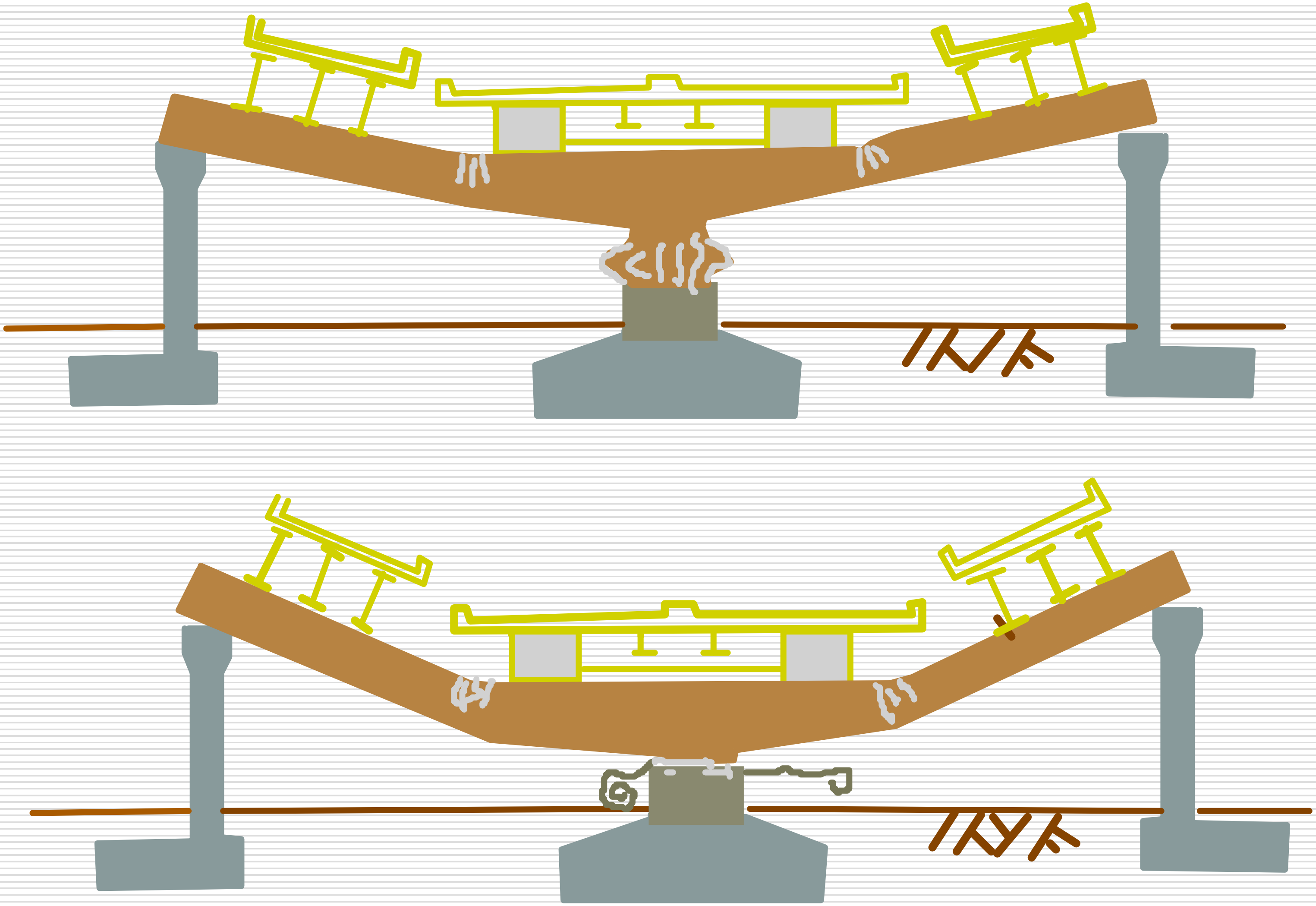
World First Damage on Steel Piers



Progress of Failure of Steel Columns



Progress of Failure of Steel Columns (continued)



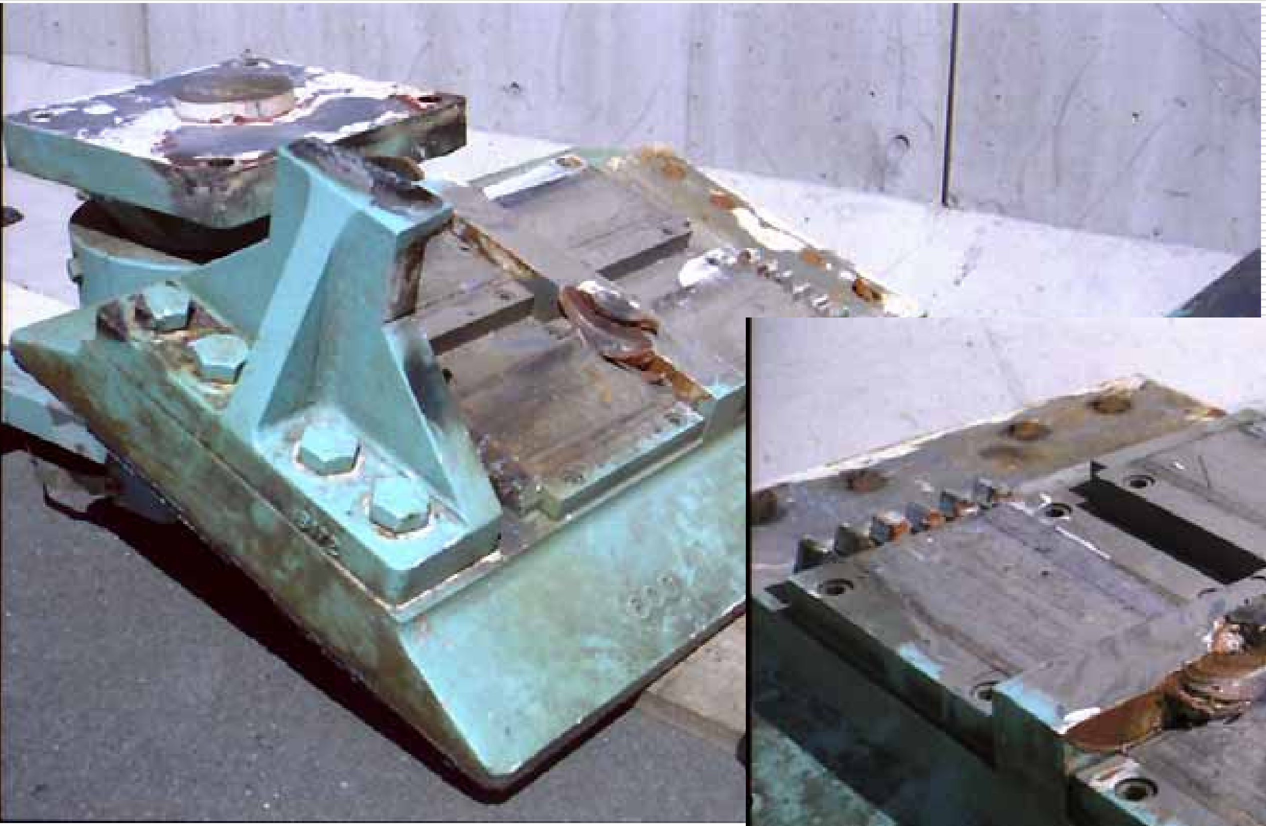
4) Damage of Foundations

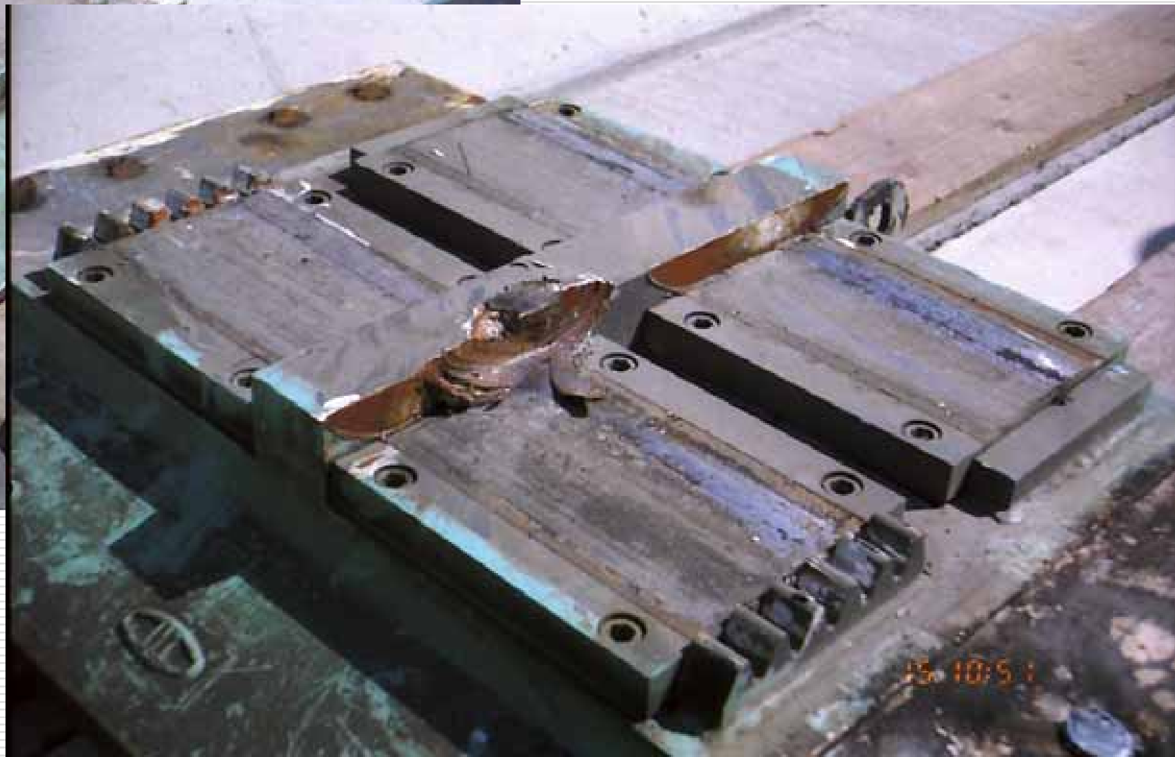
Damage of foundations was less, but not none

5) Extensive Damage of Bearings

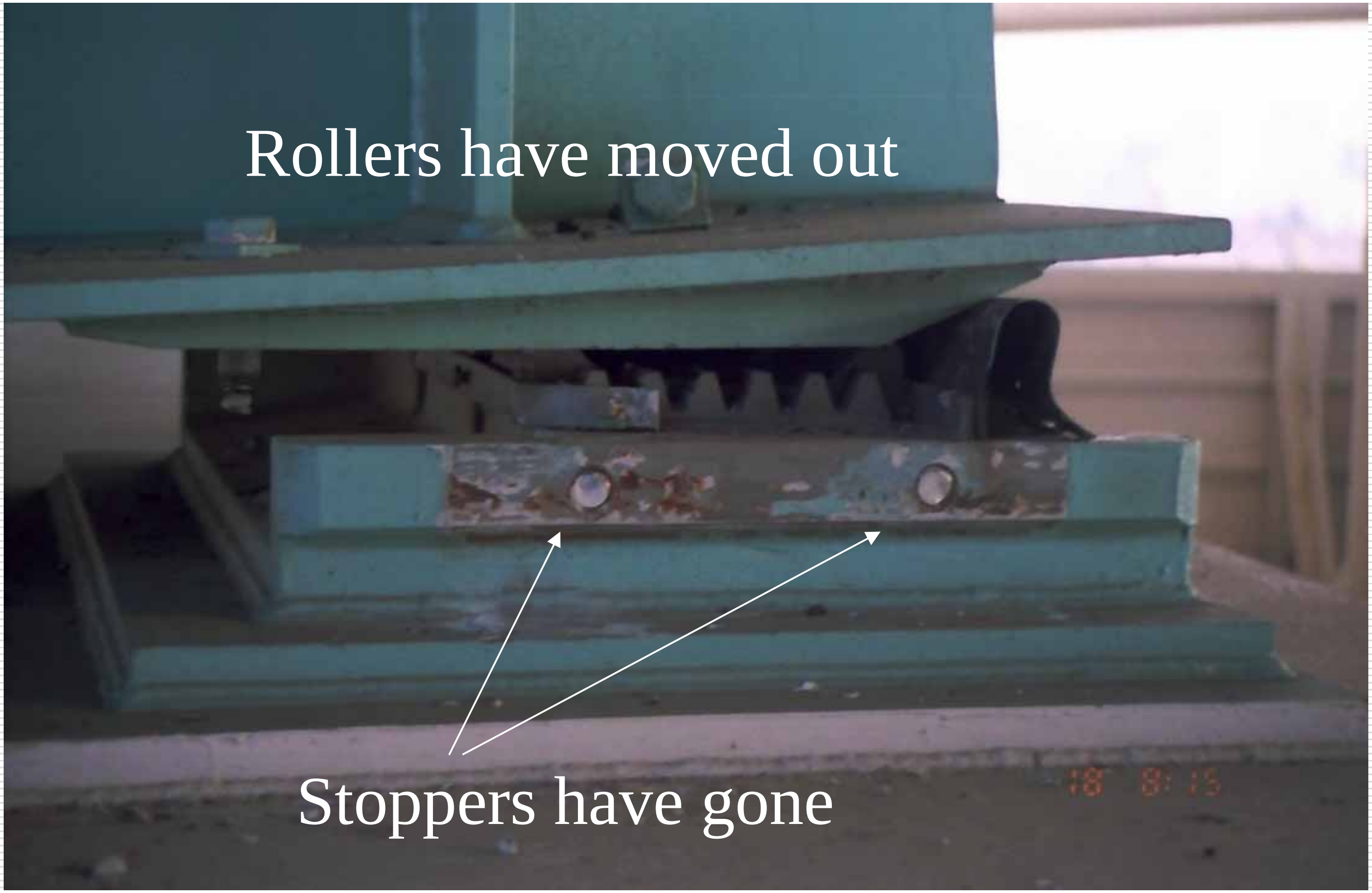
Extensive Damage of Bearings & Unseating Prevention Devices

Vulnerable Steel Pin Bearings (Fixed bearings) & Roller Bearings (Movable Bearings) (ピン支承、ローラー支承)





Vulnerable Steel Roller Bearings　(Movable bearings) (ローラー支承、可動支承)



Failure of Steel Bearings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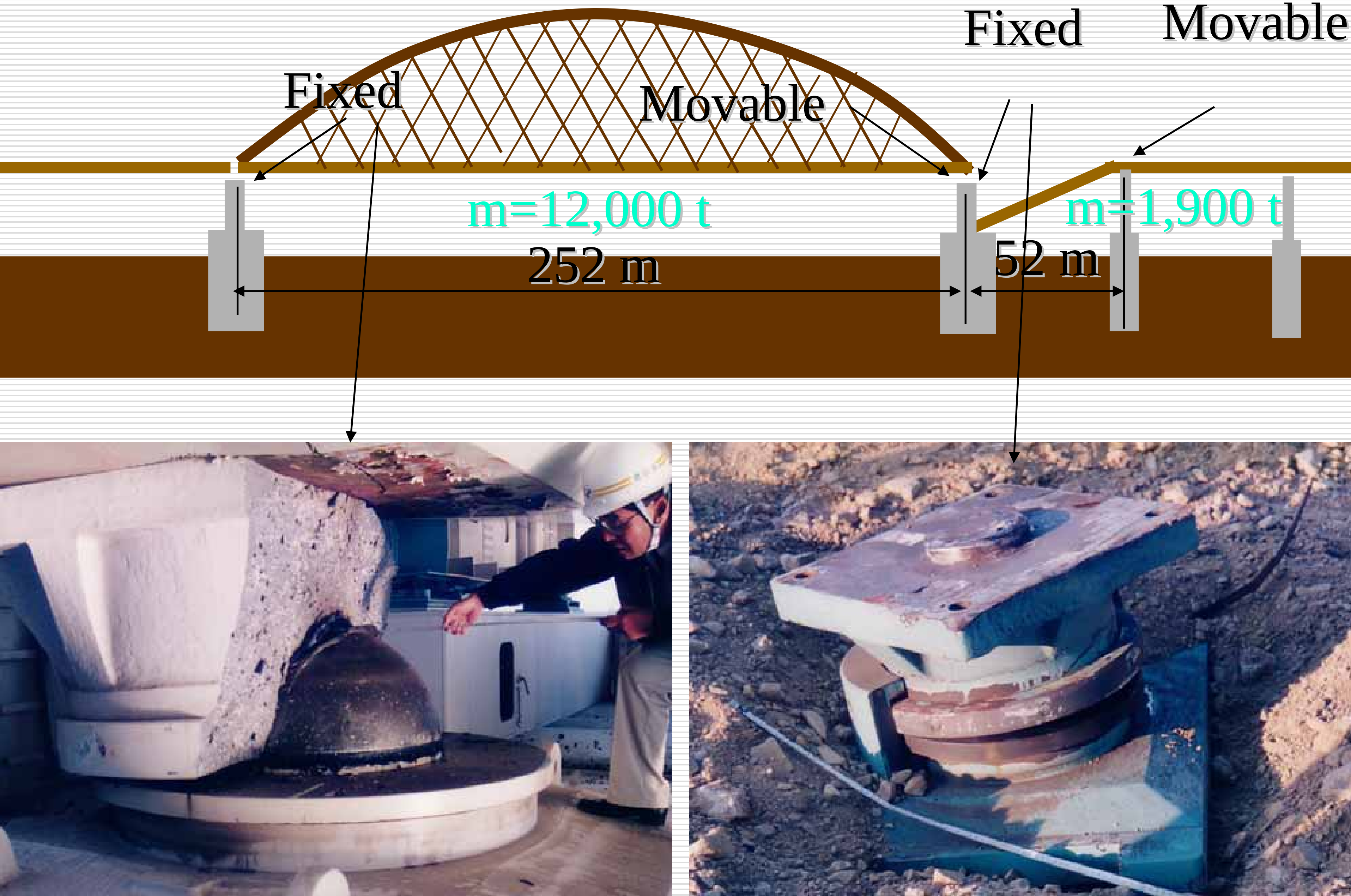
Collapse of an Approaching Span



Change of Design Practice of Bearings after 1995 Kobe Earthquake

- Damage of bearings (steel bearings) was an issue of discussion at every time when a damaging earthquake occurred.

- However there was always an argument that bearing a fuse to restrict extensive damage of the substructures. As a consequence, only minor upgrading was conducted to bearings.

- However it was so obvious after the 1995 Kobe earthquake that bearing was not a fuse for restricting damage of substructures, but it was one of the main factors resulting in the extensive damage.

Consequence of the 1995 Kobe Earthquake (cont.)

- It was recommended in the 1995 & 1996 codes that elastomeric bearings (**積層ゴム支承**) including LRB (**鉛プラグ入り積層ゴム支承**) and HDR (**高減衰積層ゴム支承**) should be used.
- Steel bearings have the following deficiencies:
  - ✓Insufficient strength and weak for shock
  - ✓Structures with insufficient lateral and vertical capacity
  - ✓Insufficient length of movement
- As a consequence, about 98% of the total bearing was steel bearing before 1995, but 90% is now elastomeric bearings.

6) Damage of Unseating Prevention Devices

Damage of Unseating Prevention Devices

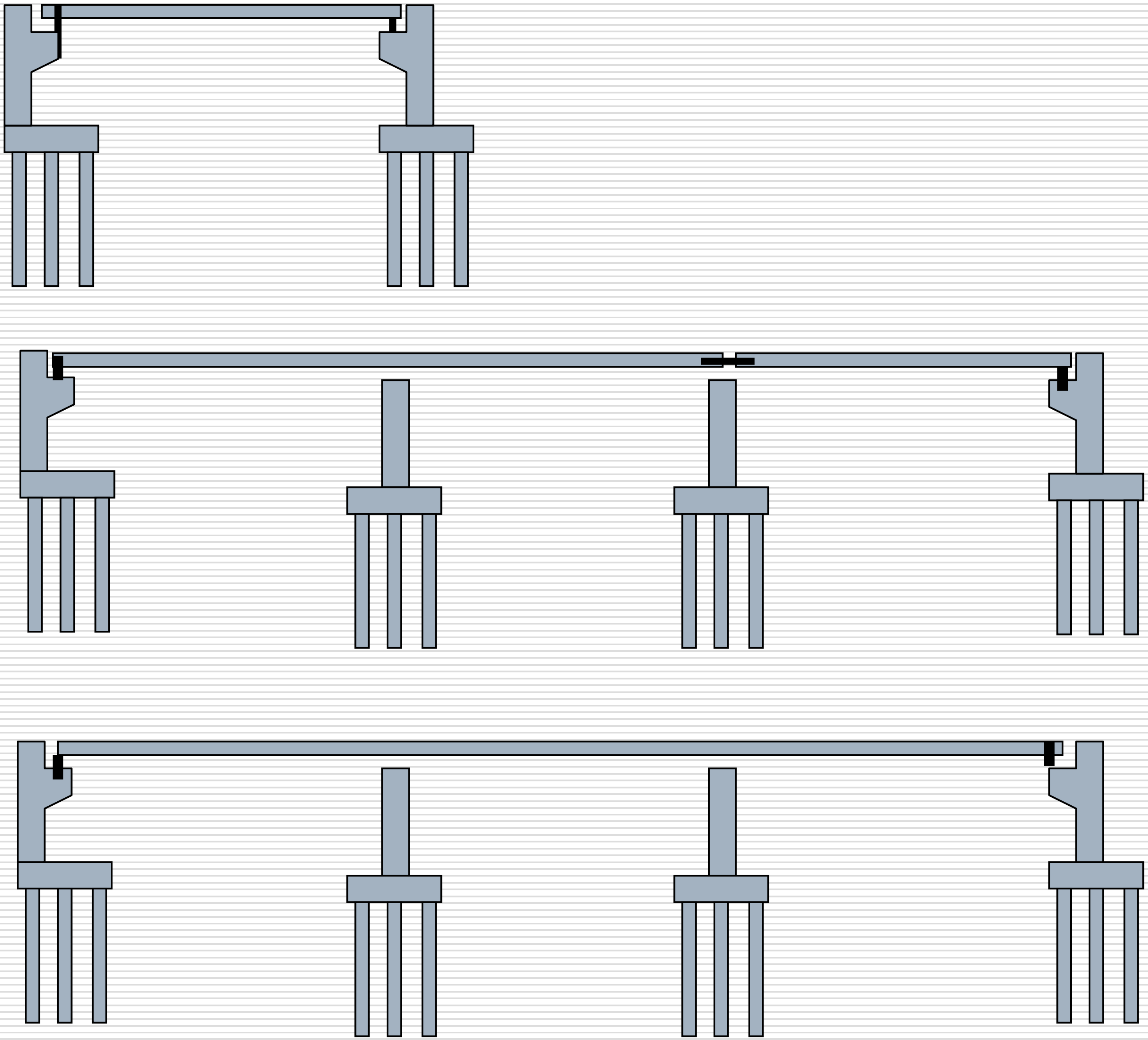
Damage of Unseating Prevention Devices

Design Force of Unseating Prevention Devices was Increased after the 1995 Kobe Earthquake

As we studied in 2.2.2., three measures are implemented as “unseating prevention devices.”

- Provide sufficient seat support length SE
- Device connecting a girder to a substructure
- Device connecting adjacent girders

Design Force of Unseating Prevention Devices was Increased after the 1995 Kobe Earthquake



Lateral Force Demand of Unseating Prevention Devices

$$F_i = k_h R_i$$

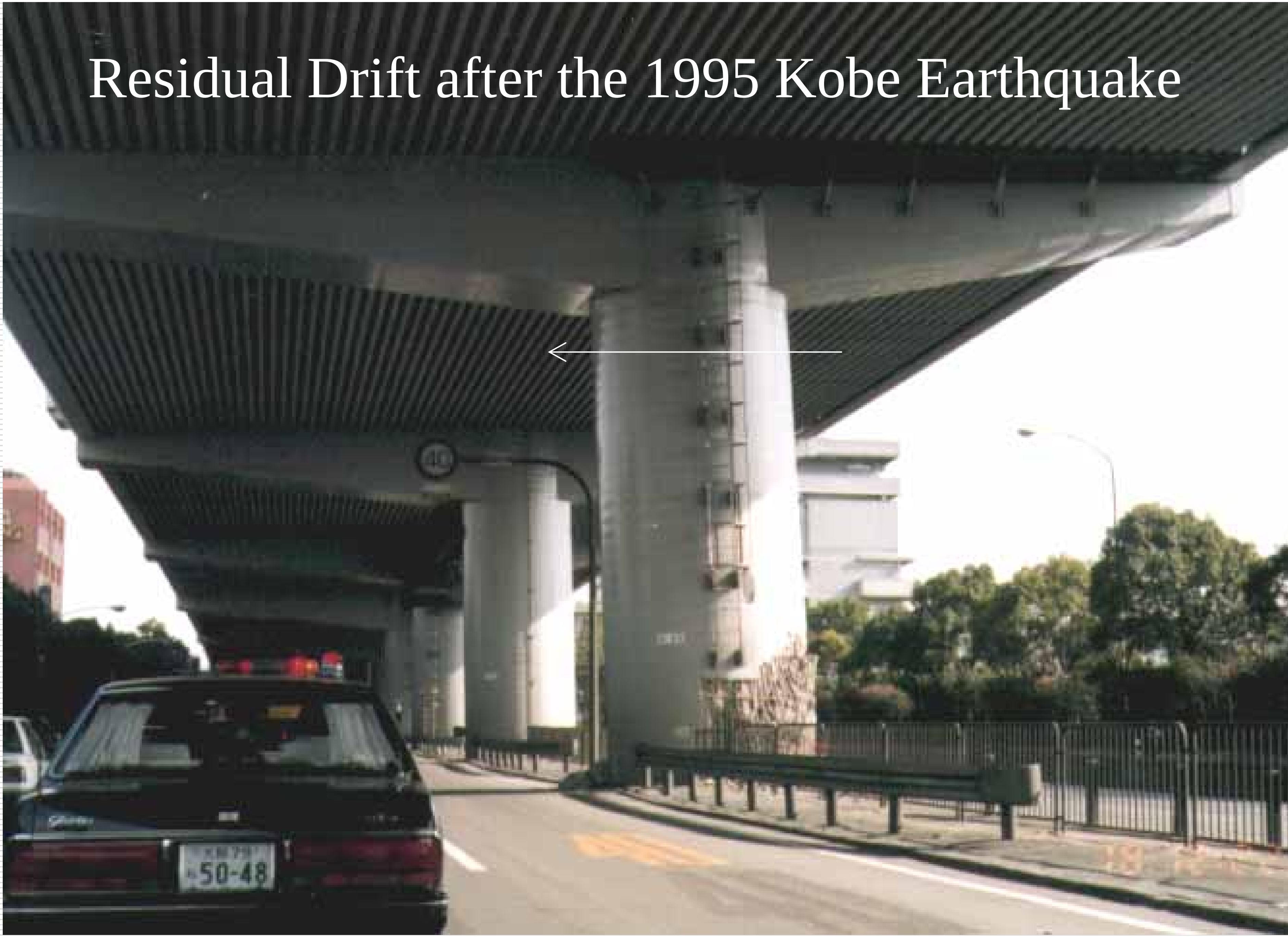
where,

F_i: Lateral Force Demand of the i-th Device
R_i: Reaction force due to dead load at the i-th support
K_h: seismic coefficient

- k_h was increased from 0.2 to 1.0 after the 1995 Kobe earthquake.
- However this is an emergency measures. There are many unknowns, so there needs more thorough research on the force demand of unseating prevention devices.

7) Residual Tilt of Columns

Residual Drift after the 1995 Kobe Earthquake



First Provision to Residual Tilt of Piers(残留変位)

- A new provision was introduced for limiting residual tilt of columns after the 1995 Kobe earthquake. This was the first provision for the residual tilt.

- Residual displacement response spectra were used to formulate the provision as:

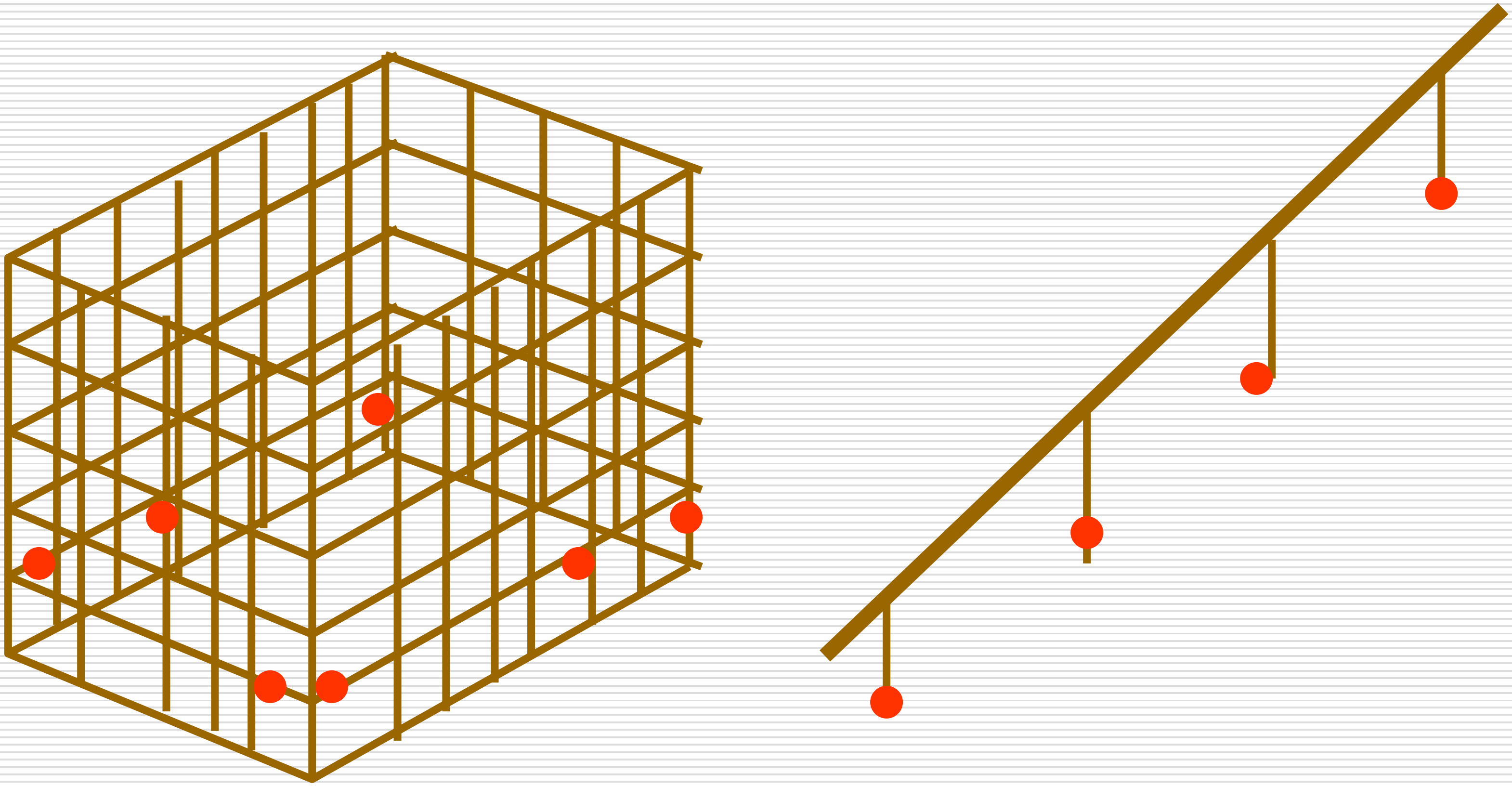
$$u_R < u_{Ra}$$ ← Design residual displacement

$$u_R = c_R \cdot u_{R\max} = c_R(\mu_r - 1)(1 - r)u_y$$

$$u_{Ra} = \frac{1}{100}H$$ ← Column height

Residual Drift

Much Less Static Indeterminacy in Bridges than Buildings



Plastic Hinges

2.3.3 Summary of the 1995 Kobe Earthquake

- What were the lessons?

Experience of the 1995 Kobe Earthquake

Past damage occurred at foundations & Piers/Columns

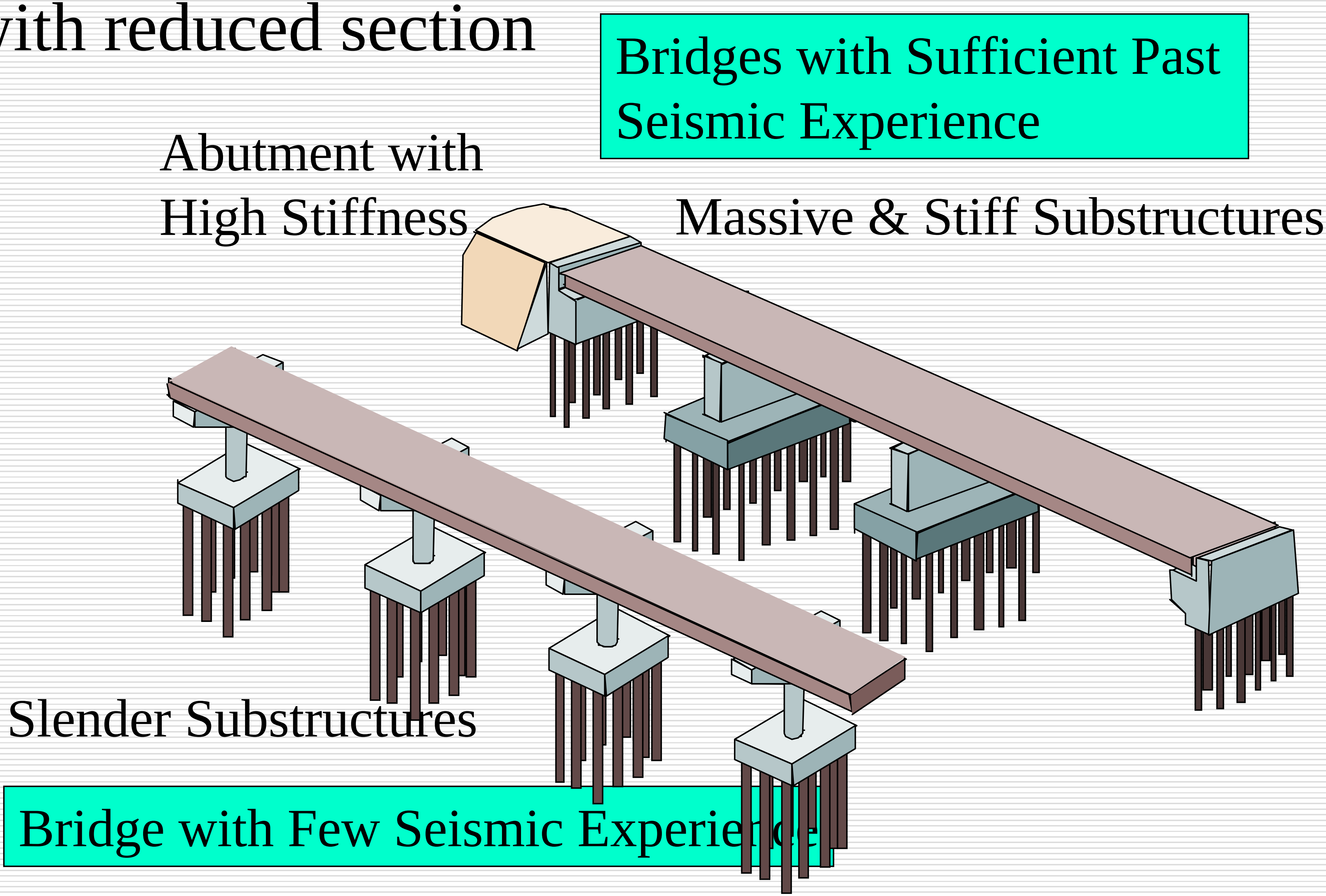
→ Construction of Massive & Stiff Foundations & Piers with Large Sections

↓ Restrictions of Space under Bridges

Construction of Slender RC and Steel Columns

Extended the Past Design Practice to Slender RC and Steel Columns

New experience on the damage of columns with reduced section



Two Major Factors which Developed The Extensive Damage in Bridges during 1995 Kobe Earthquake

- Destructive near field ground motions
- Insufficient strength & ductility capacity of columns, bearings and unseating prevention devices.

Importance to have good insight on the damage & bridge behavior under extensive ground motions

- "Seeing" is "believing."
- We cannot generally trust that things what we have not yet seen happens.
- We should have a good insight on what could happen.

2.4 What are the research targets in the next 10 years?

What are the concern of the public to seismic damage of urban infrastructures?

An eyewitness of collapsing the 18 span continuous viaduct during the 1995 Kobe earthquake

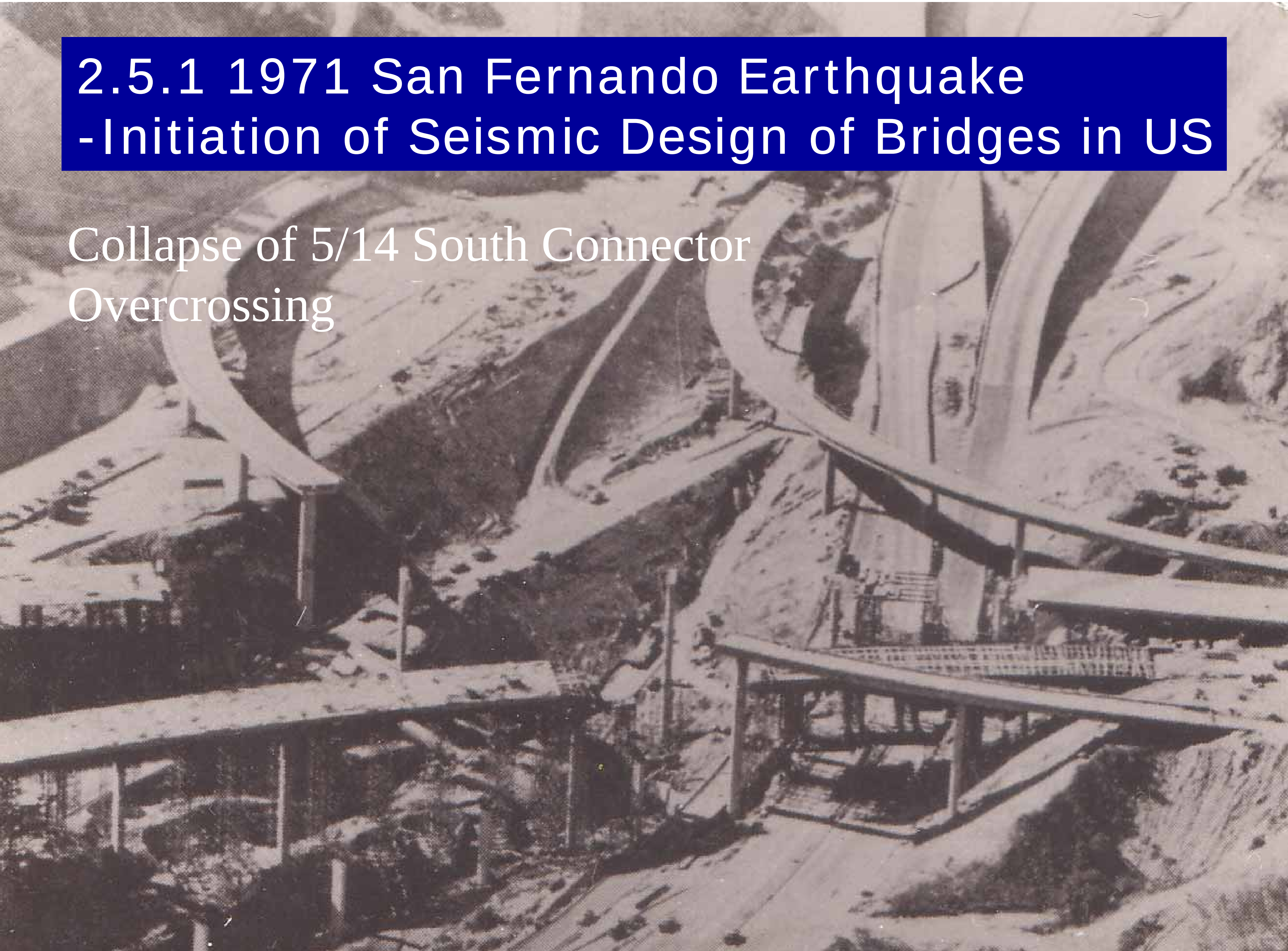
What are the research targets in the next 10 years?

- Are bridges safe as a system to ensure the safety of the users and the public in urban areas?
- What are the next type damage?
- Are the current seismic performance goal that bridge should not collapse during an extensive earthquake acceptable to the public?

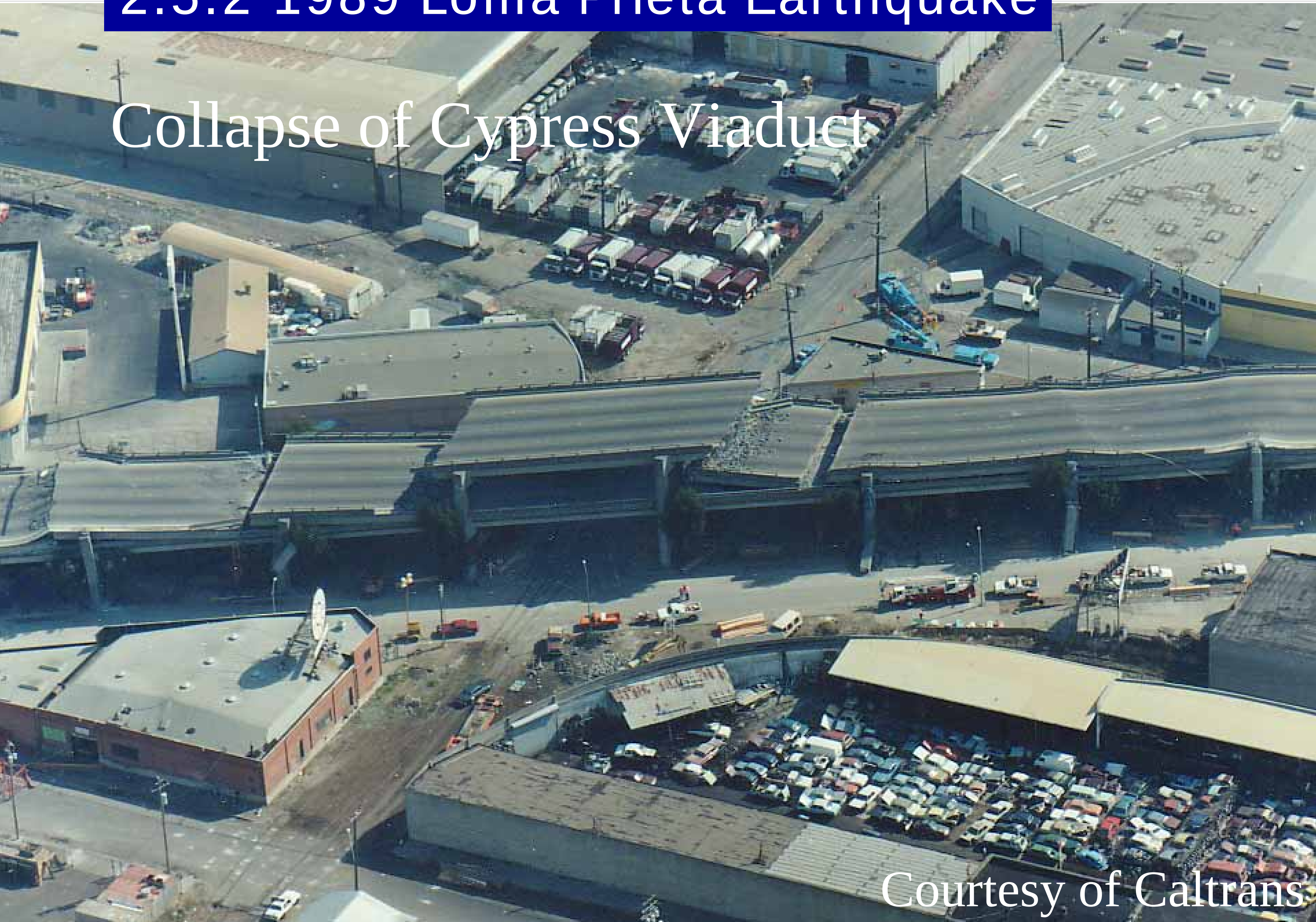
2.5 Seismic Damage of Bridges in USA

2.5.1 1971 San Fernando Earthquake -Initiation of Seismic Design of Bridges in US

Collapse of 5/14 South Connector Overcrossing



2.5.2 1989 Loma Prieta Earthquake



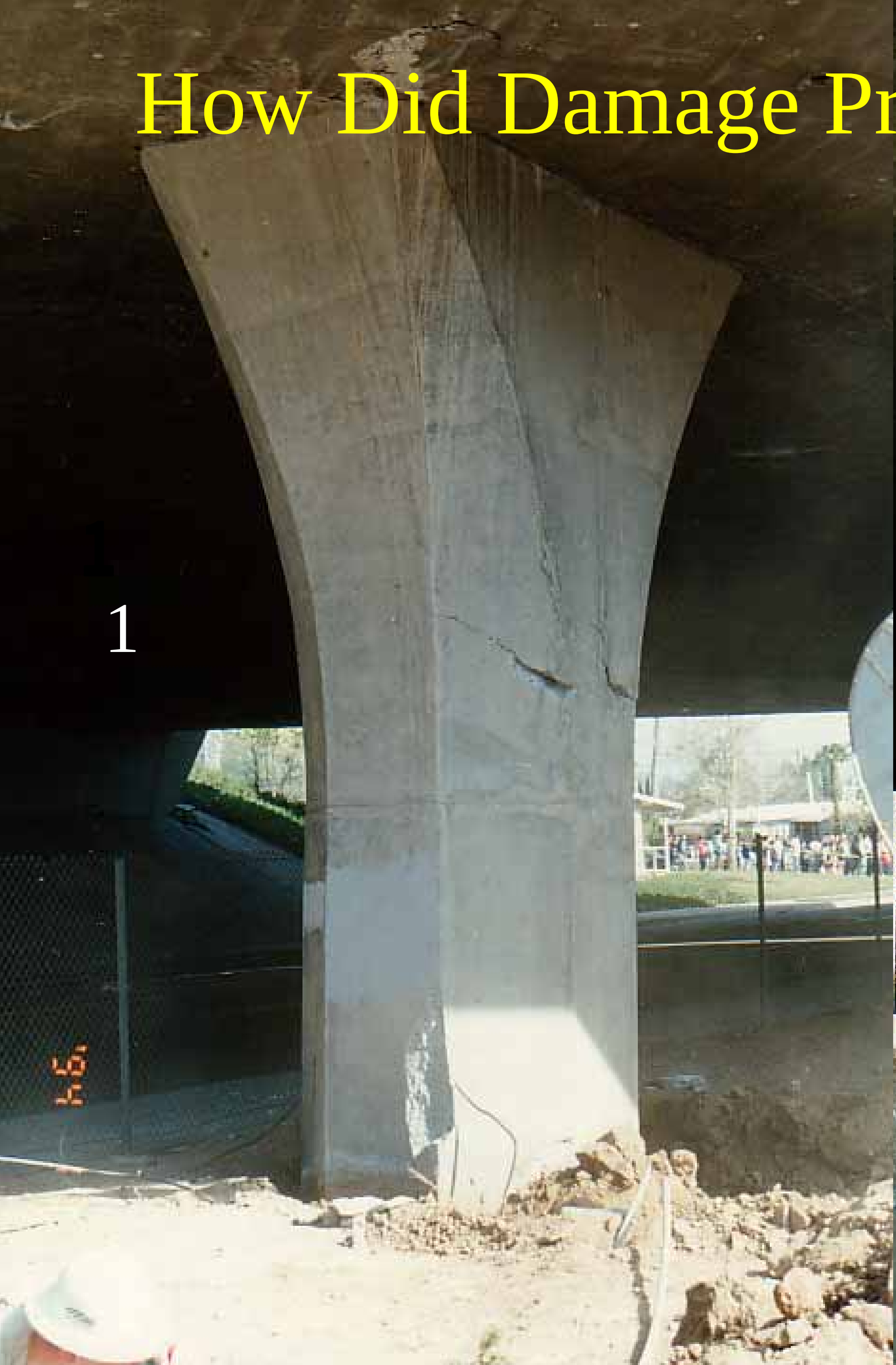
Collapse of Cypress Viaduct
1989 Loma Prieta Earthquake

Courtesy of Caltrans

2.5.3 1994 Northridge Earthquake

1989 Loma Prieta Earthquake

How Did Damage Progress?

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5

6

Pounding of Decks at Intermediate Hinge

2.6 Seismic Design History of Bridges in USA

1776	Independence
1830-1840	Gold Rush
1850	California became a part of US territory
1906	San Francisco Earthquake
1933	Long Beach Earthquake
	Field Act (0.1 Seismic coefficient for school buildings, and 0.02-0.05 seismic coefficient or other structures) & Riley Act
1936	Construction of San Francisco Oakland Bay Bridge
1957	Construction of Cypress Viaduct
1961	First Stipulation for Seismic Effects in AASHO
1961	First Stipulation for Seismic Effect in California Department of Transportation

History of Seismic Design of Bridges in USA (continued)

1971	San Fernando Earthquake
	Damage of bridges during 11 earthquakes with magnitude of 5.4-7.7 between 1933 and 1971 was only $100,000
1973	New Caltrans Seismic Design (Incorporated into AASHTO in 1975)
1981	New FHWA Seismic Design Code
1989	Loma Prieta EQ
1994	Northridge EQ

2.7 History of Seismic Design of Bridges in Japan

1923 Kanto EQ

1925 First Design Code for Bridges including Seismic Effects

1964 Design Specifications (2 pages)

k_h=0.2, k_v=0.1

1971 First Independent Seismic Design Specifications (30 pages)

Unseating prevention devices, Evaluation for liquefaction potential

1980 Design Specifications (50 pages)

Updated Evaluation for Liquefaction

History of Seismic Design of Bridges in Japan (continued)

1990 Design Specifications (100 pages)

Check for Ductility, Lateral Force for Multi-span Bridges, Standard Ground Motions for Dynamic Analysis

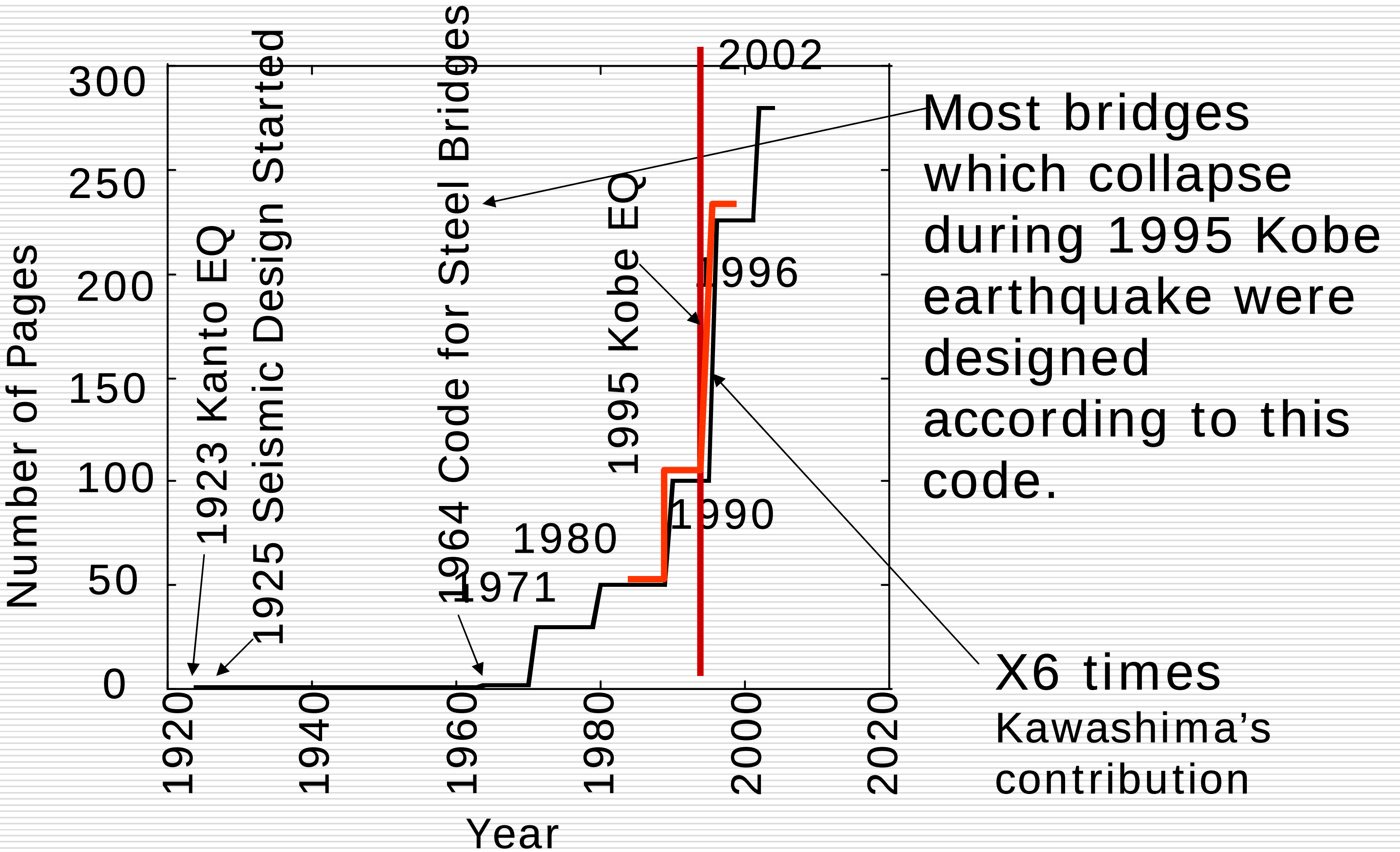
1995 Kobe EQ

1996 Design Specifications (200 pages)

Ductility Design, Near-Field Ground Motions

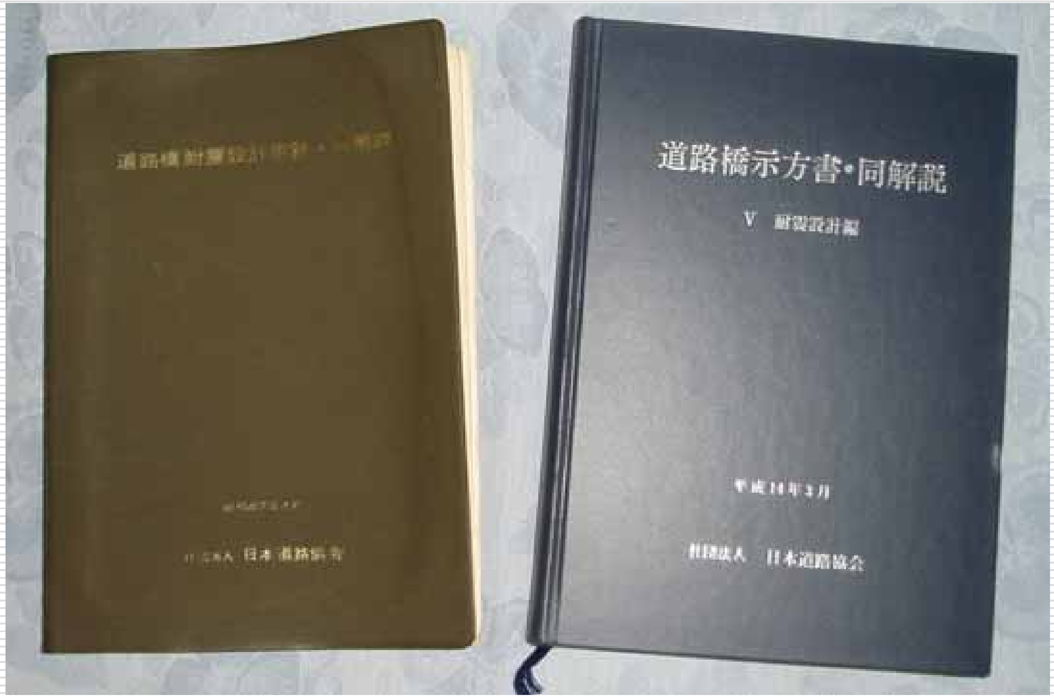
2002 Design Specifications (240 pages)

Number of Pages related to Seismic Design of Bridges in Japan



1971Code and the Latest Code (2002)

1971



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