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Arts, Architecture and Technology

Structural Performance of Traditional Timber Structures in Japan against Seismic Load

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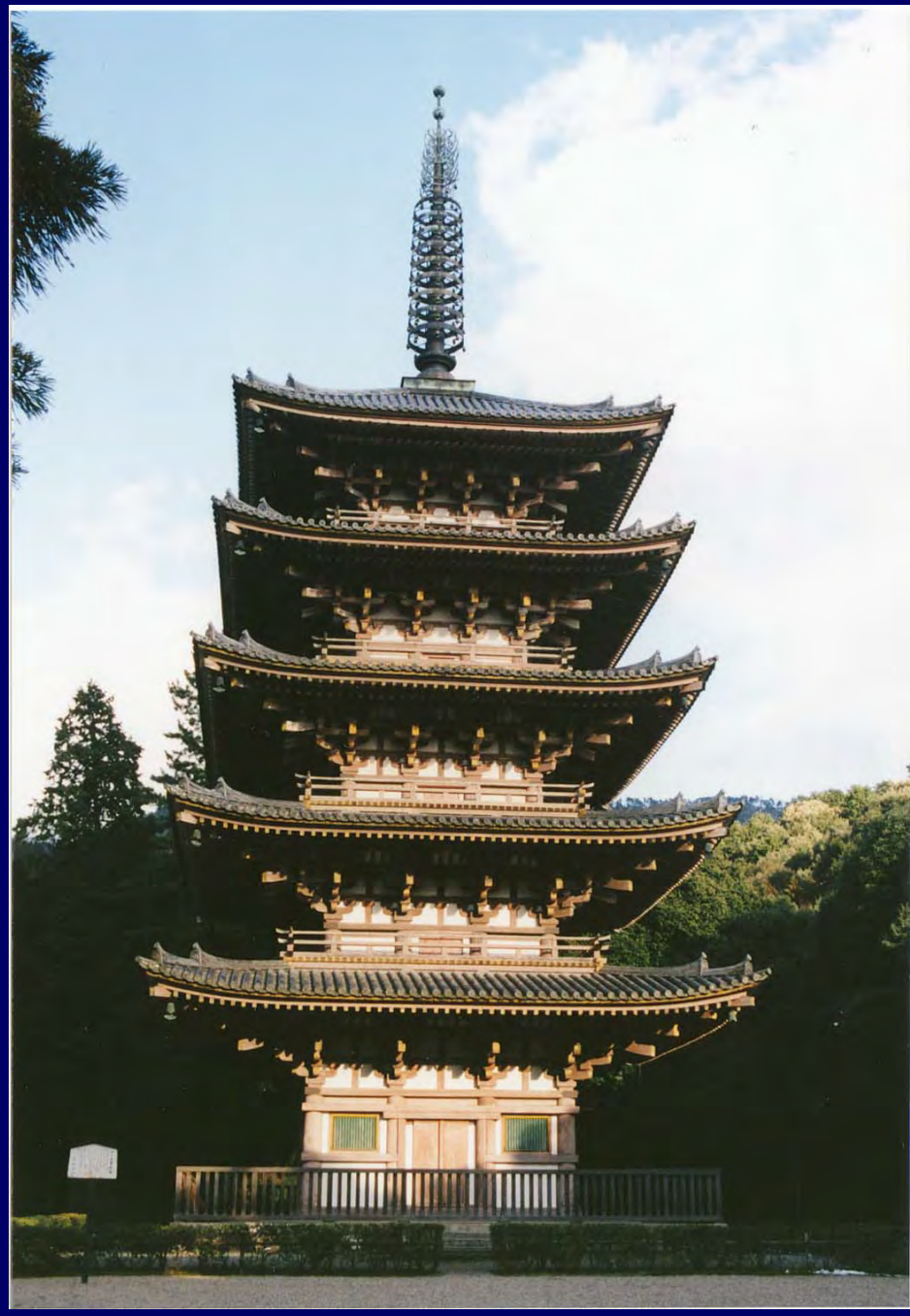
Introduction

- Natural Hazard
- Consideration to structural safety
  - Legal issues
  - Technical issues
- Examples on verification of traditional timber structures in Japan

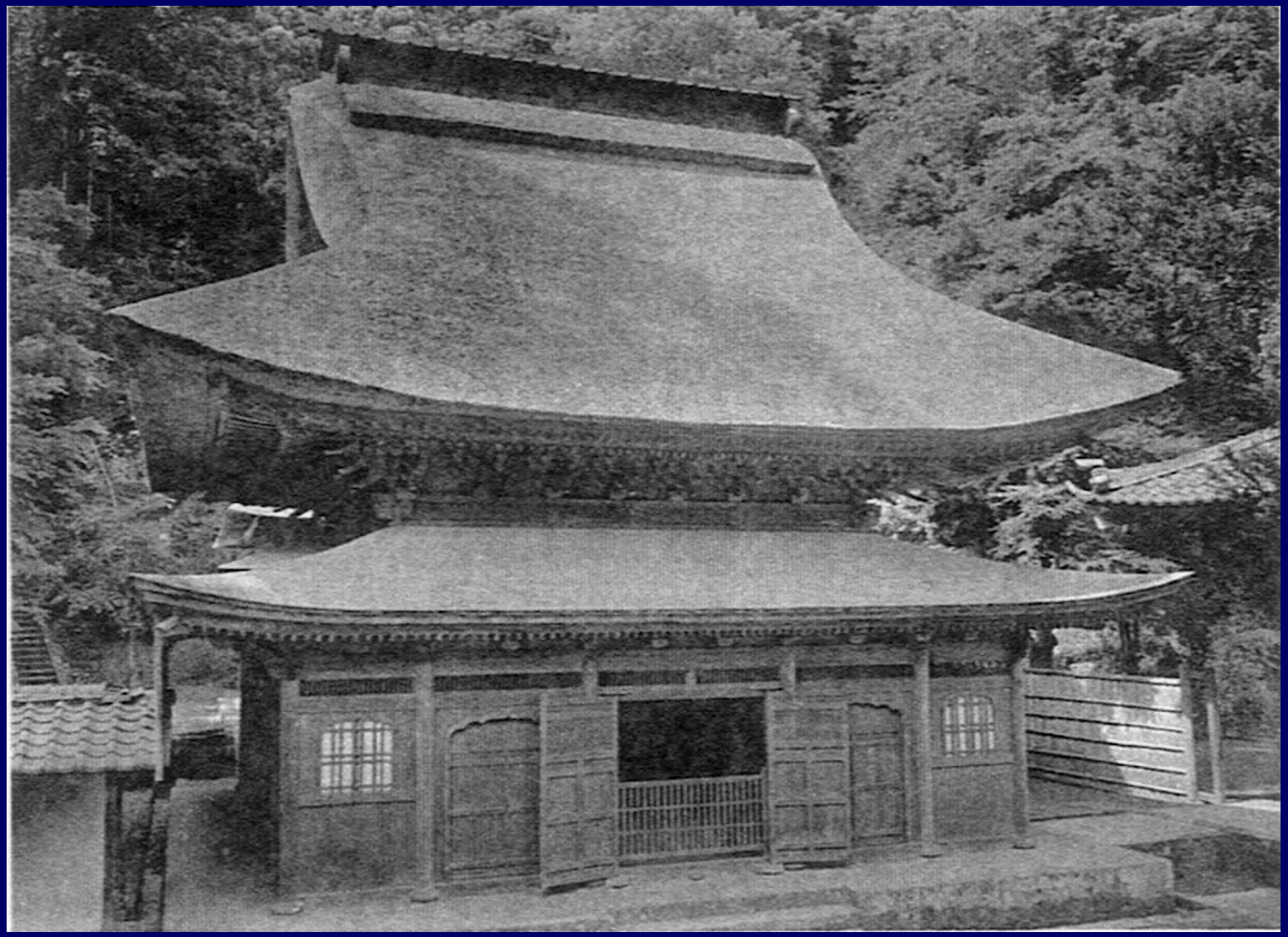


1948: Fukui Earthquake

2007 Noto Penisula Eq

1995 “Kobe” earthquake

2011 Tohoku earthquake



main hall (*Shariden*) of Engakuji 15c AD

Shariden of Engakuji
destroyed by the Kanto earthquake (1923)

Engaku-ji Shariden restored after the earthquake
(Photo by Prof. Sakamoto)

Legal Issues

- Legal provisions on architectural heritage in Japan
  - 1897: Law for the Preservation of Ancient Shrines and Temples
  - 1929: Law for the Protection of National Treasures
  - 1950: Law for the Protection of Cultural Properties

- Important cultural properties
  - 5,000 buildings
  - 90% timber structures
  - Repetitive repairment

Structural regulations of architectural heritage

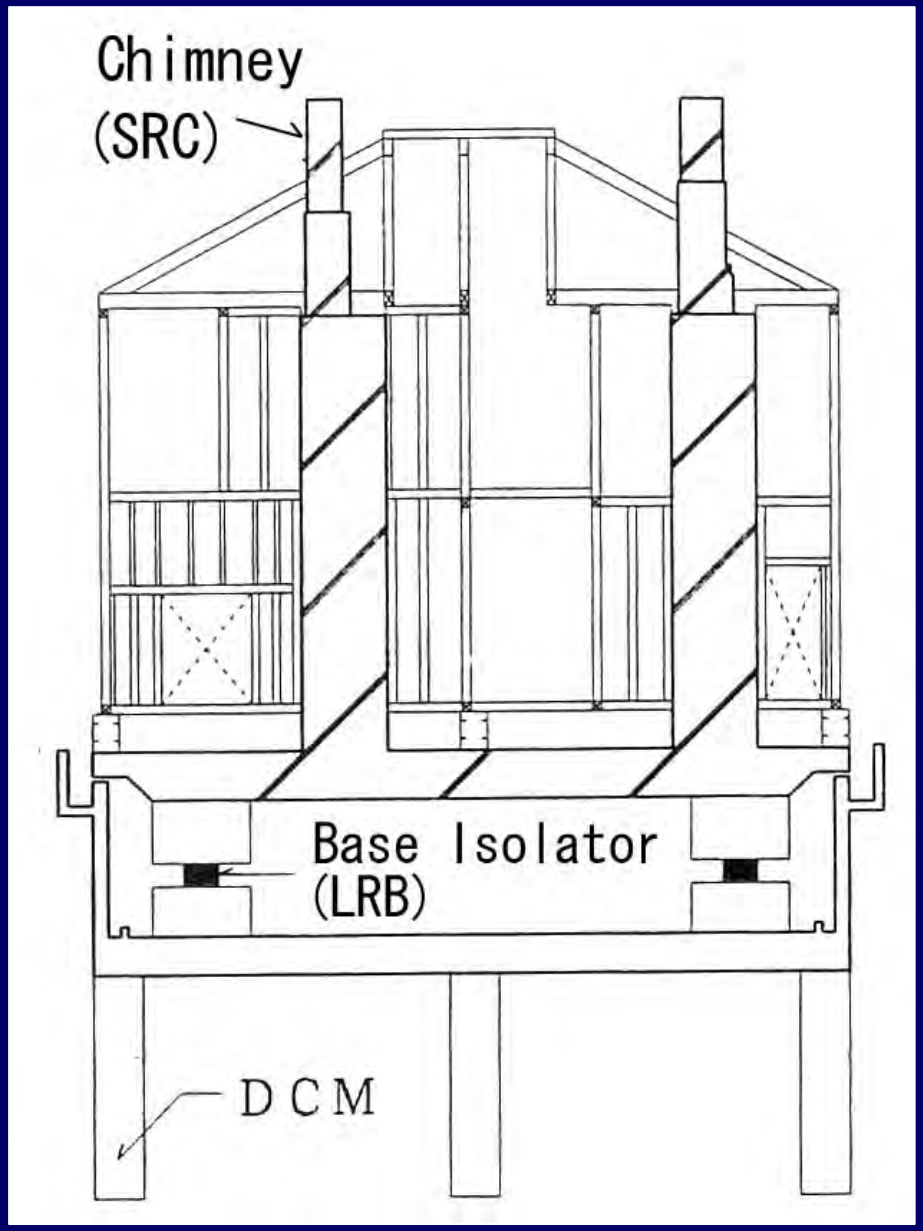
- Not regulated by the Building Standard Law
  - Enacted in 1950

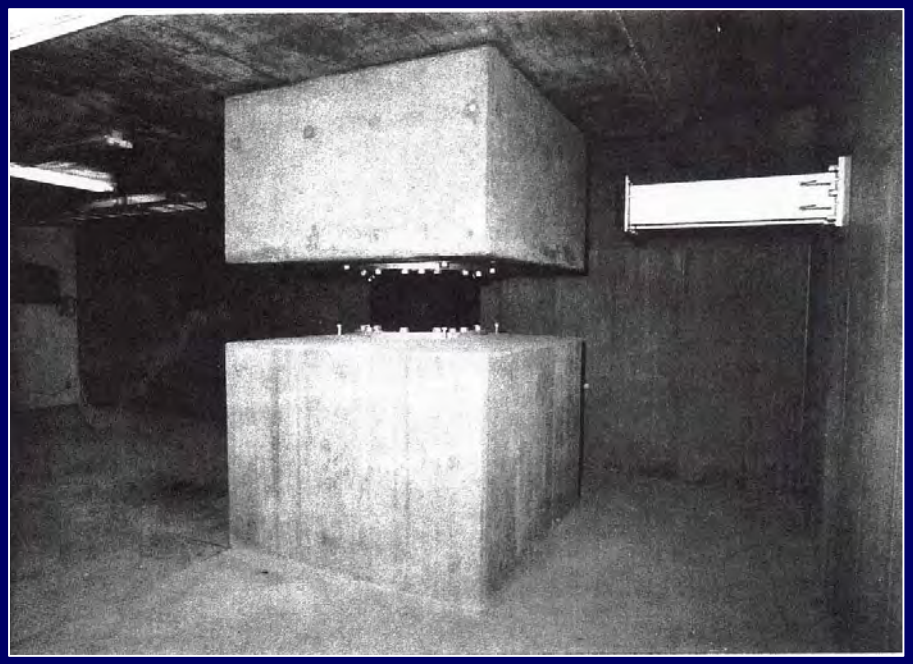
- Law for the Protection of Cultural Properties
  - No mandatory requirement on structural safety
  - Unauthorized alterations: basically prohibited

1995 Hyogoken Nanbu Eq (M7.2) 240,000 houses destroyed 6,433 died

- Former Trading House on Lot.15 （1881）

Former Trading House on Lot.15 destroyed by the 1995 Hyogoken nanbu earthquake (Kobe)





Lead Rubber Bering

RC Mat Slab (360ton)

Building structure (480ton)

Effect of reinforcement (Co0.2)

Before 1/60rad.

After 1/800rad.

- Former Trading House on Lot.15 （1881）
- After damage repair 1998

After 1995 Kobe earthquake

- Structural analysis as well as reinforcement is commonly operated to historical architecture
  - Long term vertical load, seismic, wind

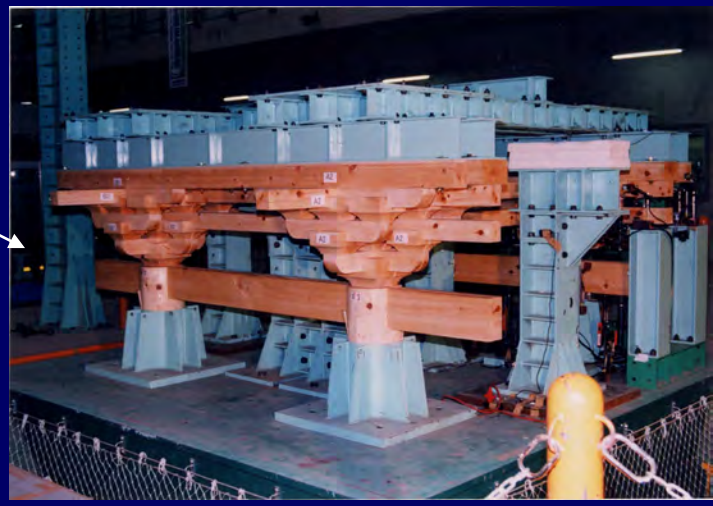
- Reinforcement technology
  - Innovative: vibration control
  - Conventional: plywood, metal fastners, etc.

- Research on the structural aspects of traditional timber structures (seismic load)

Verification of the Structural Performance of Traditional Timber Structures

Experiment of Elements

Static and/or Dynamic Test



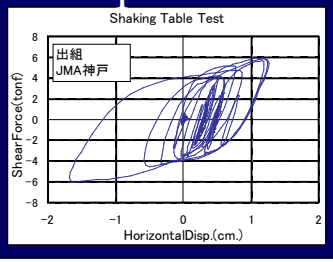
Analysis

Comparison

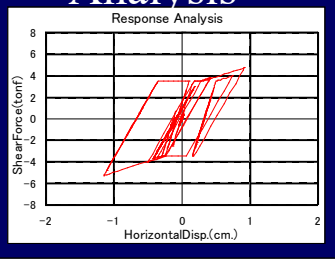
Structural modeling

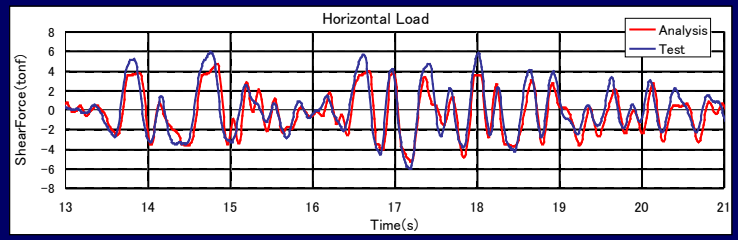
Static and/or Dynamic Analysis

Experiment



Analysis



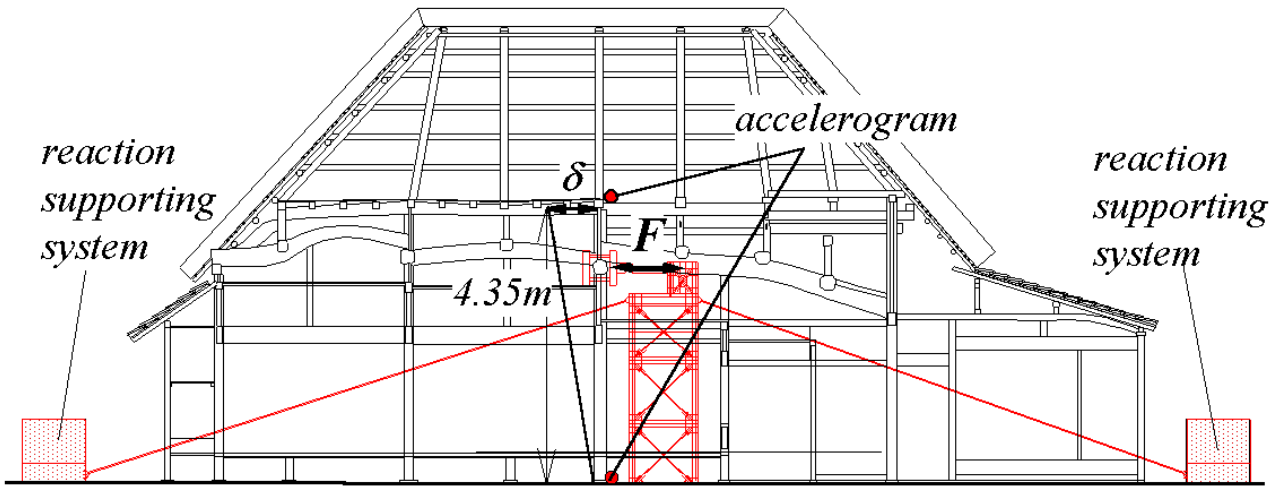


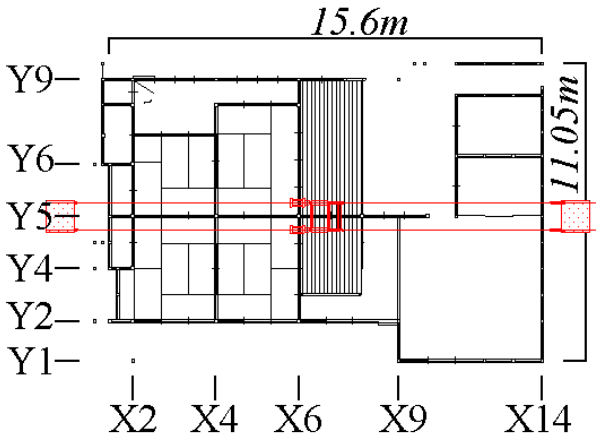
Analysis of the Combined elements

Earthquake Response Monitoring

- Earthquake response monitoring since 2002
- Tsu Kanon Pagoda built in 2001
- Approximately 300 acceleration records

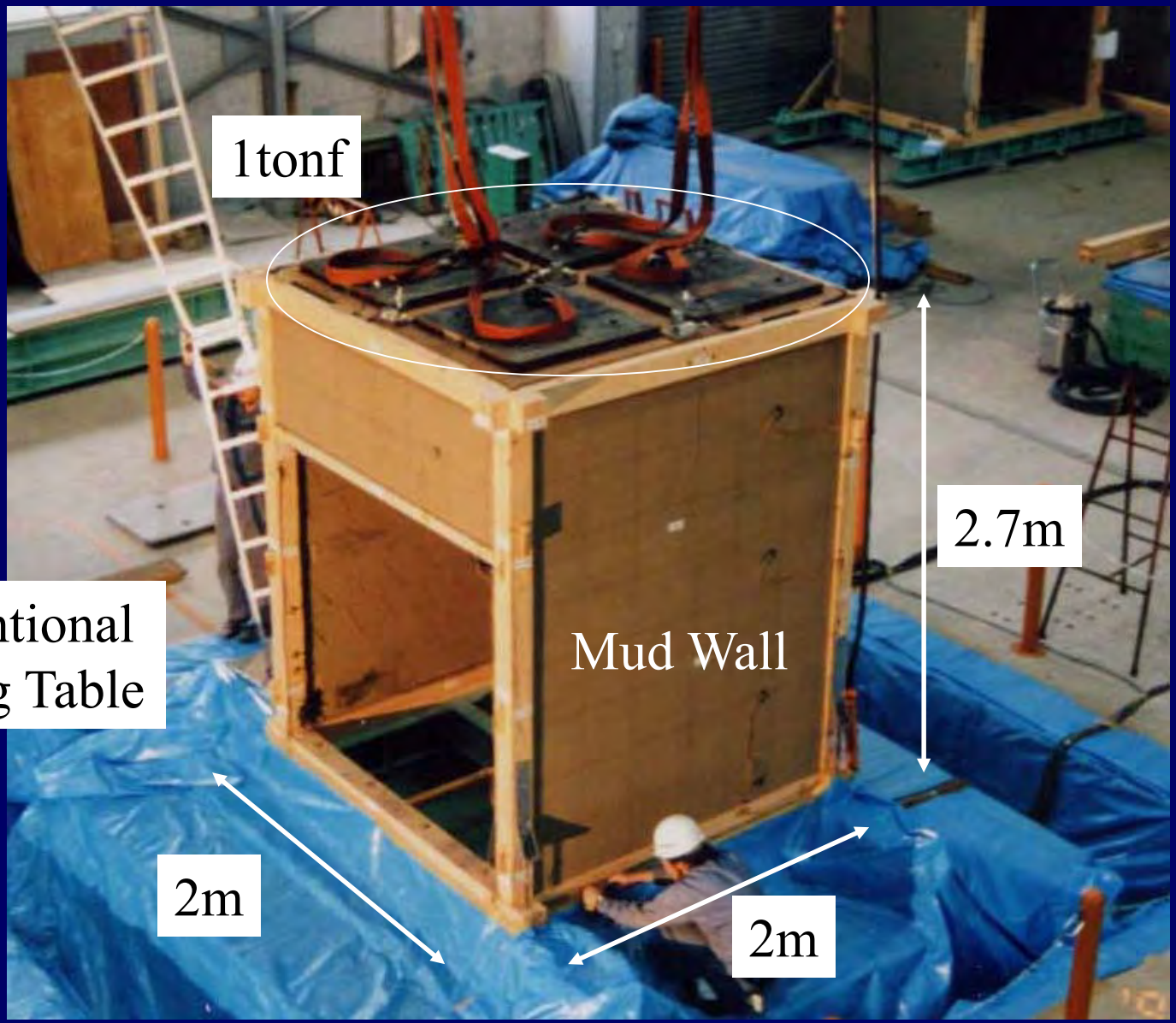
Experiment on total structure





Static loading test on existing house, 2000

Experiments on Structural elements



3 dimentional
Shaking Table

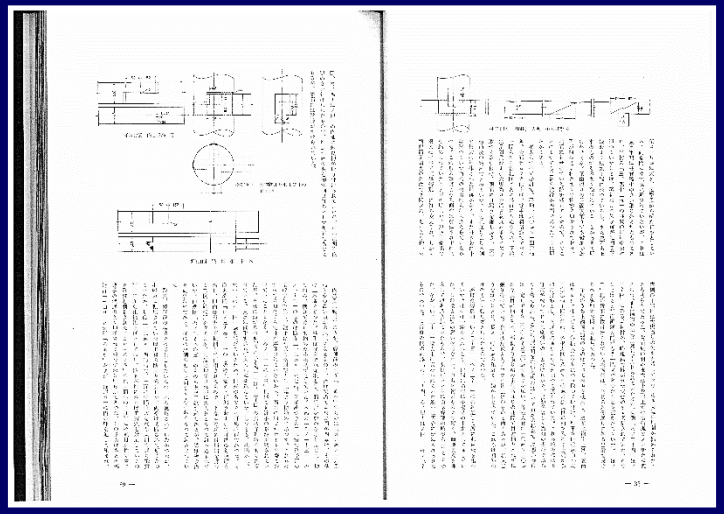
Shaking Table Test of Traditional Walls

Fujita,Sakamoto 1996

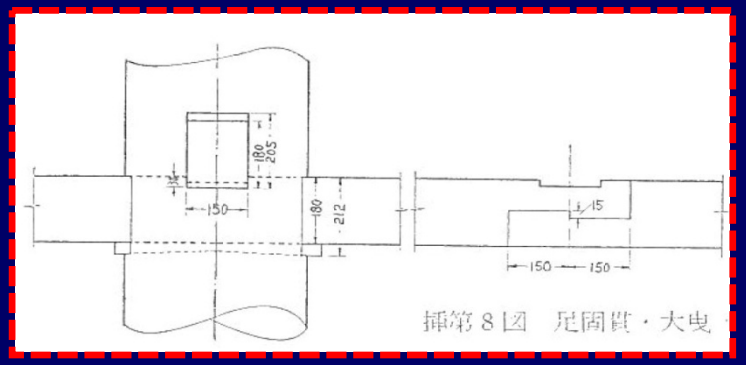
Literature Survey on the detail

136 Buddhist temple halls built after 12thc in Kyoto, Nara

50 Undergone total or partial repair work



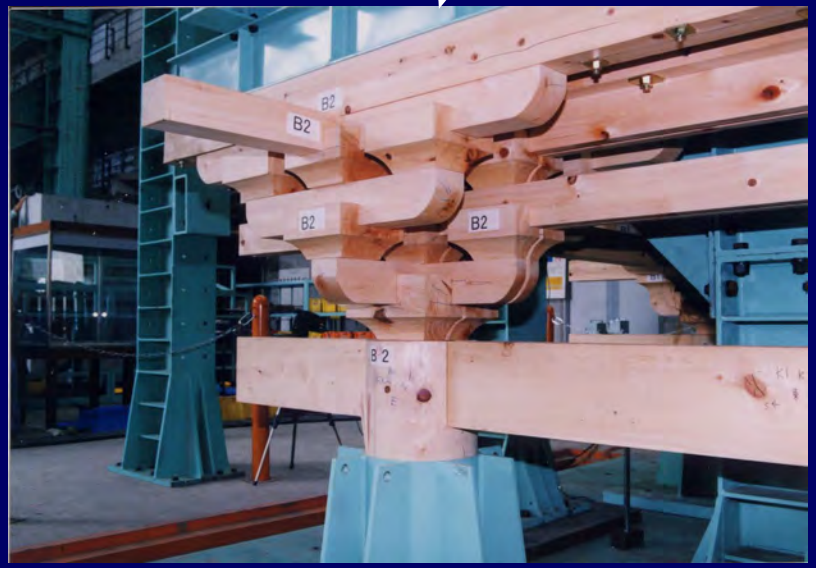
48 Written documental reports



25 Buildings with information on column and penetrating beam joint

Horizontal load resisting elements

Shear wall (mud wall)



Bracket complex

Frame with moment resisting joints

Horizontal load resisting elements of traditional timber structures

Tofuku-ji Temple Gate 15c

- Shear wall
- Joint
- Column
- Bracket complex

- Material
  - Timber, mud, bamboo

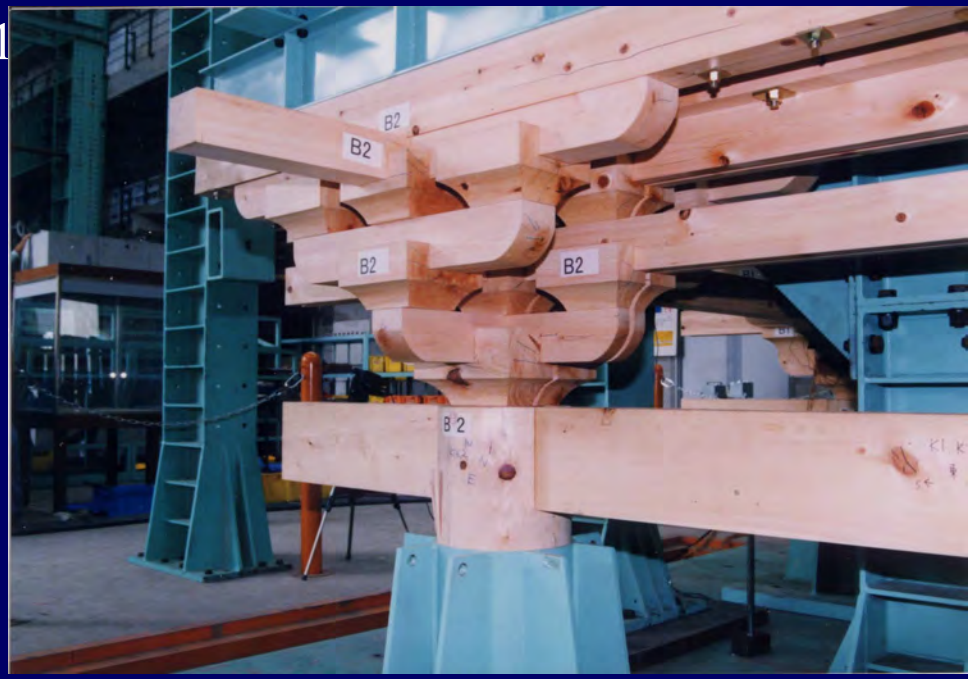
Structural elements: unique
Material: natural

→ Various
Non-engineered

Outline of research on bracket complex

- Example of experiment and analysis on structural element
- Simulation of the effect on total structure

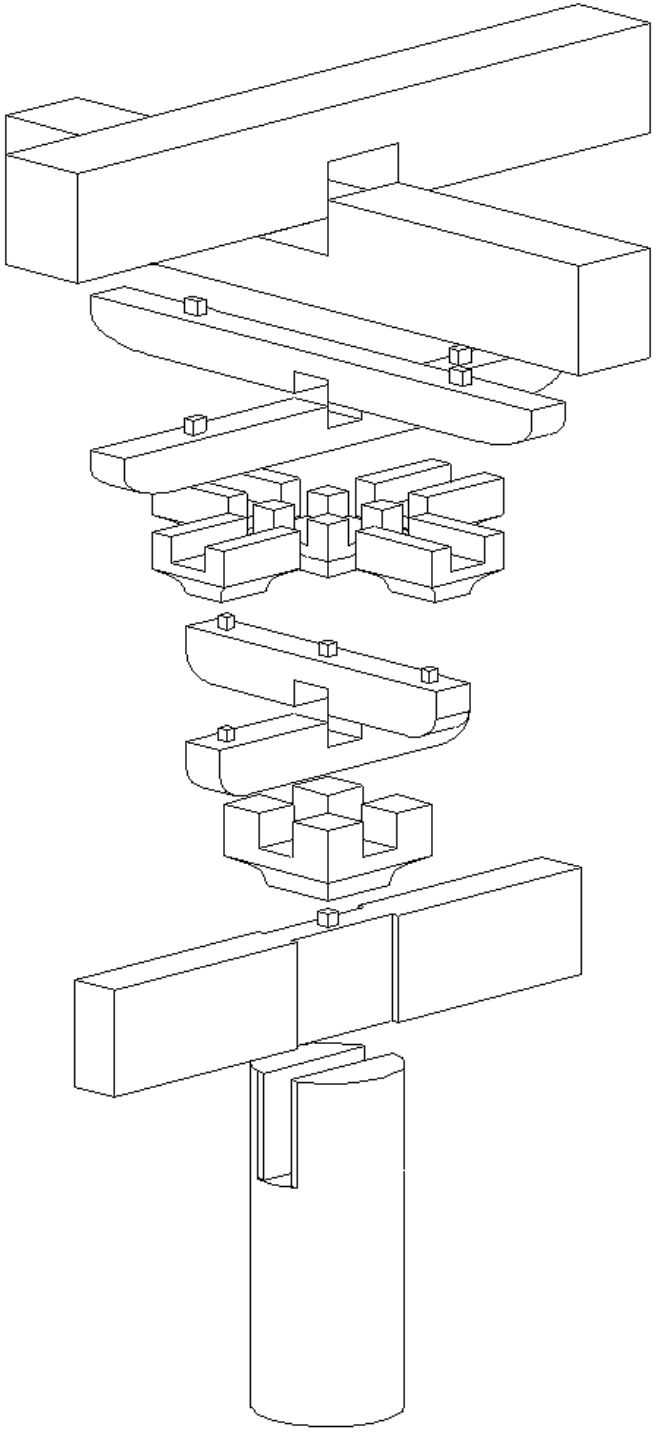
- Literature survey (97-)
- Static loading test (97-98, 2001
- Shaking table test (97-98)
- Dynamic loading test (2003)
- Structural Modeling (98-)
- Earthquake response analysis(99-)



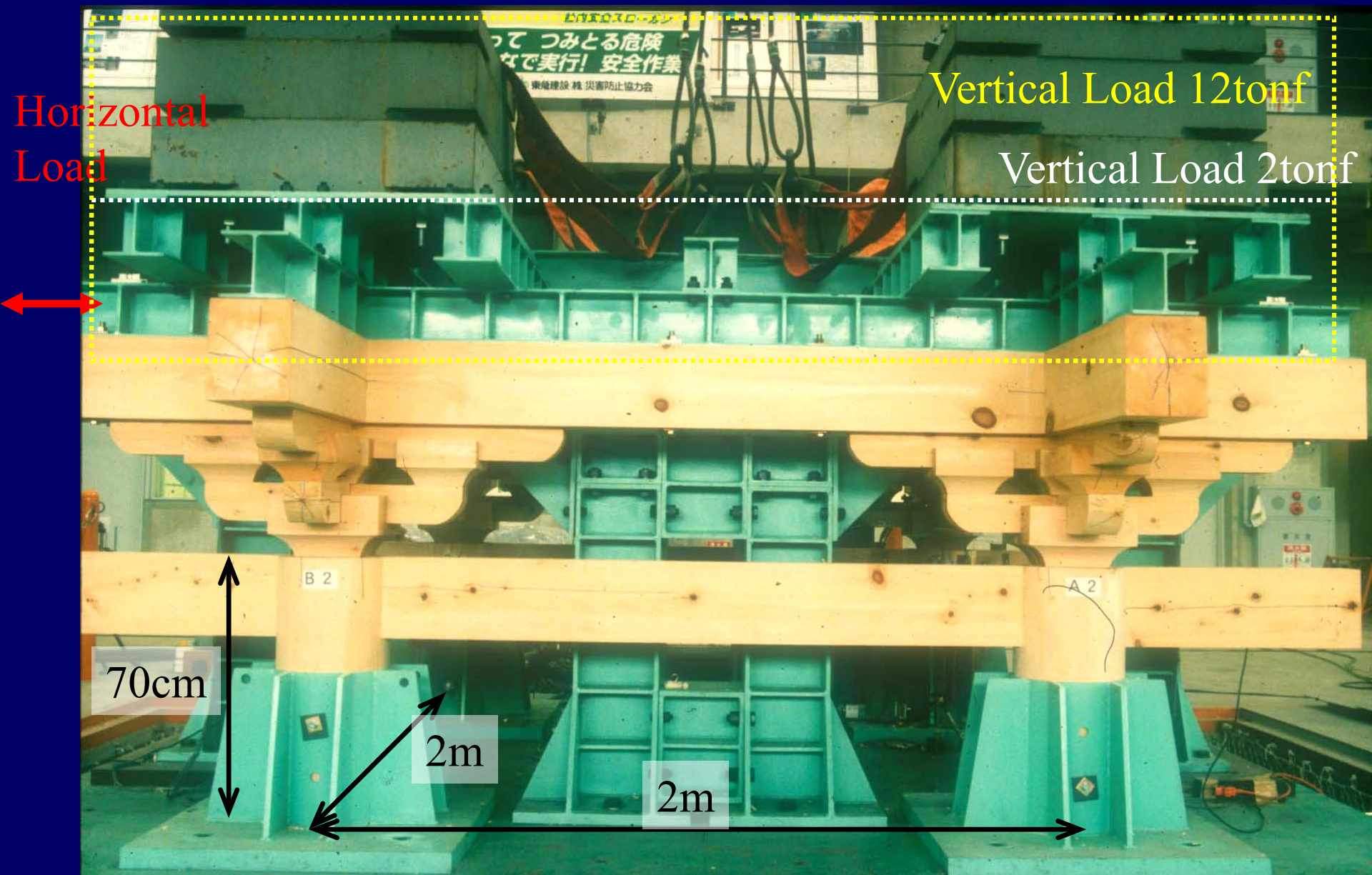
Description of Bracket Complex

Piled (stacked) blocks of timber elements

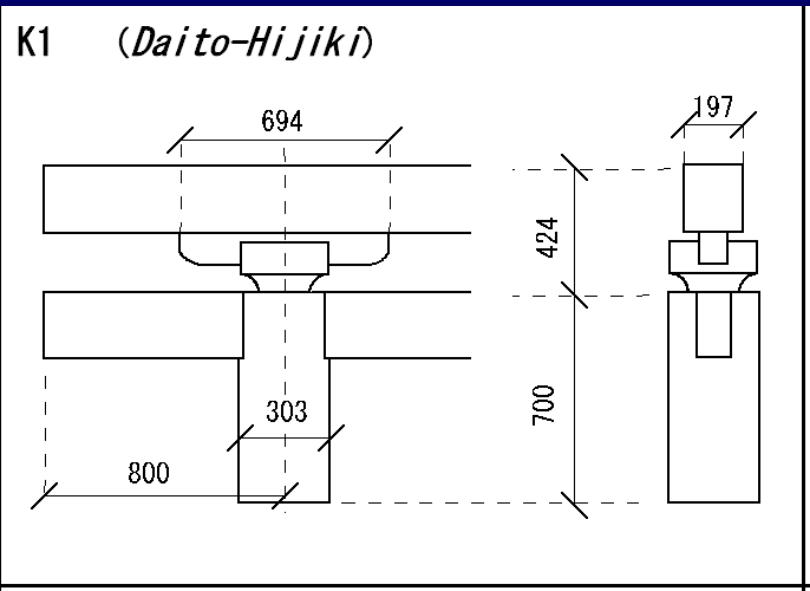
Connection: timber dowel
wood work joints
friction

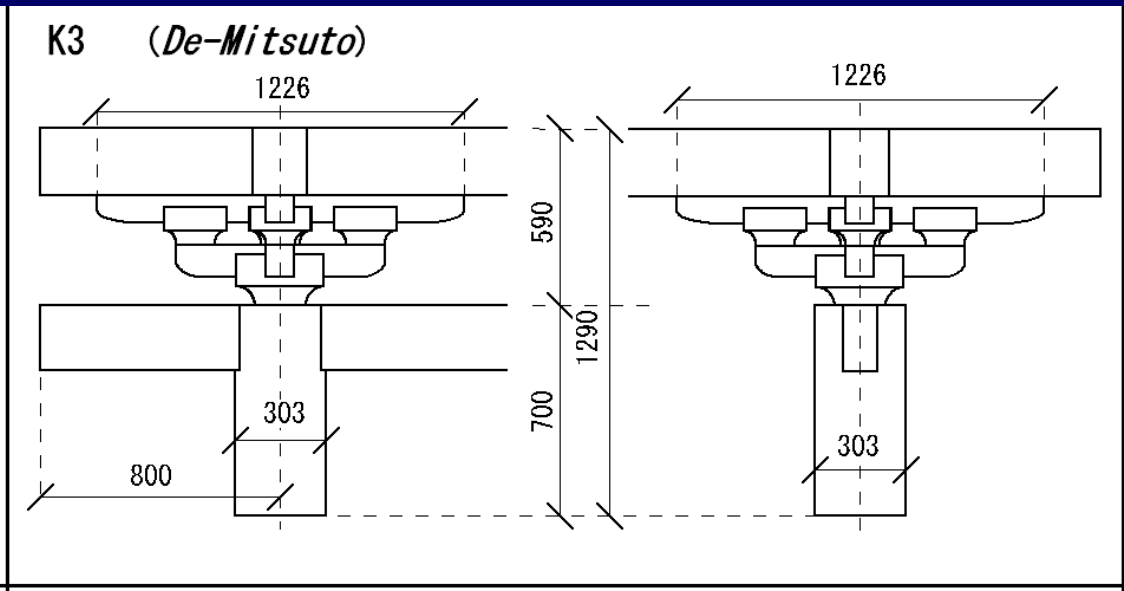


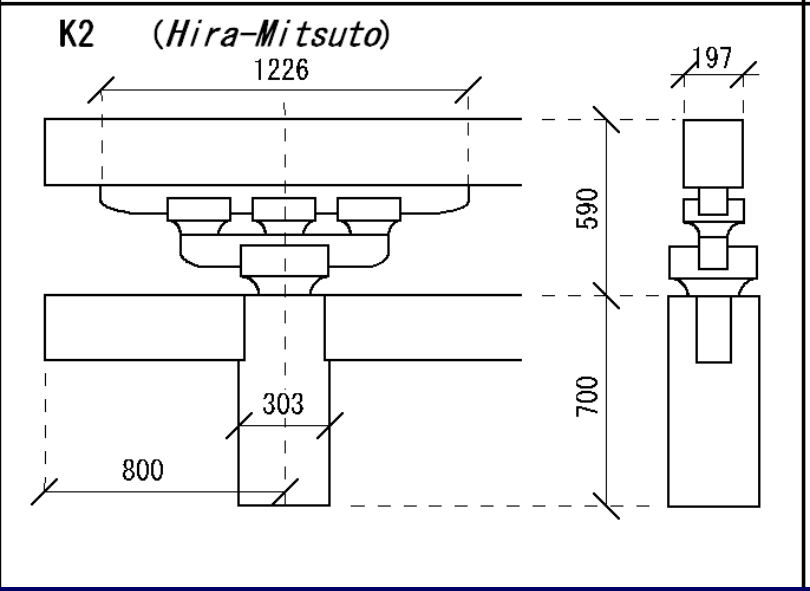
Method of Experiment

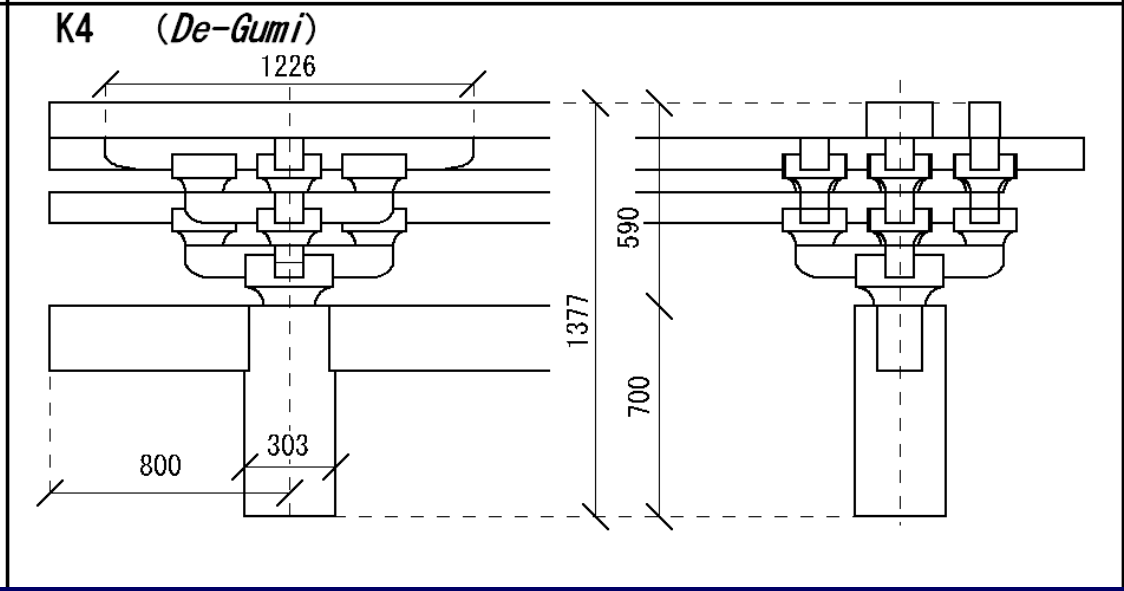


Specimen



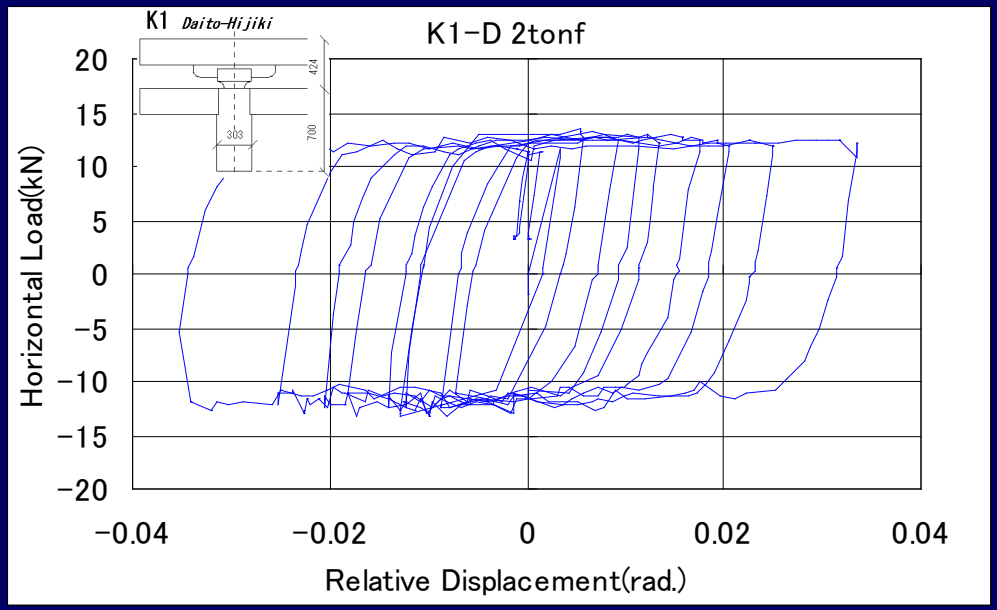


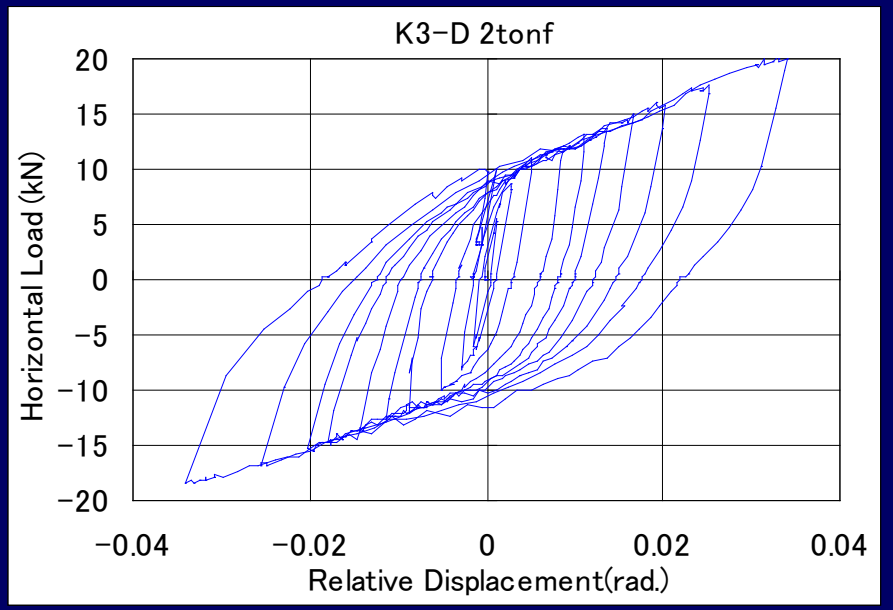


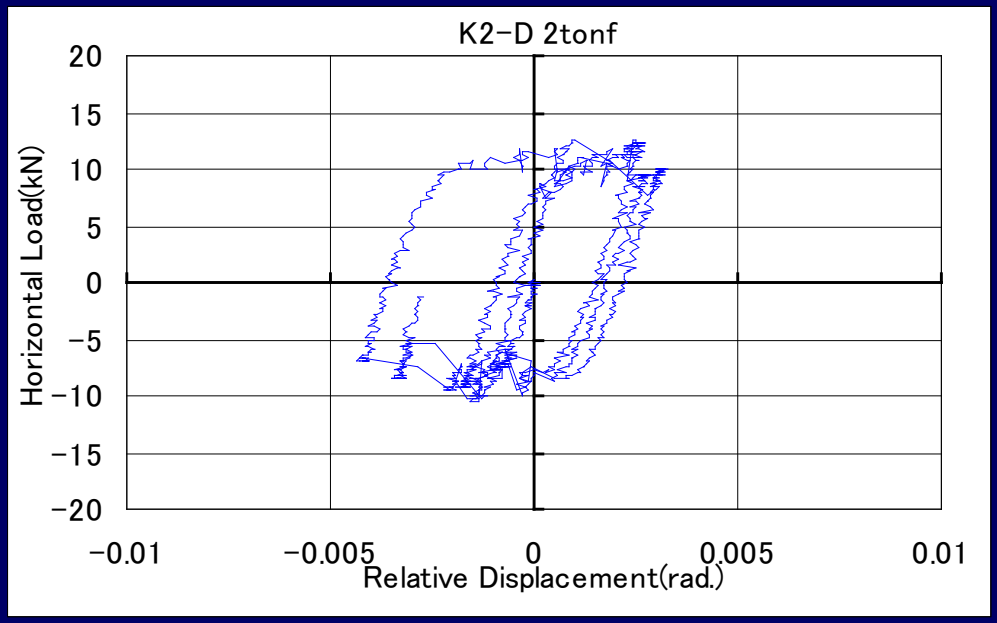


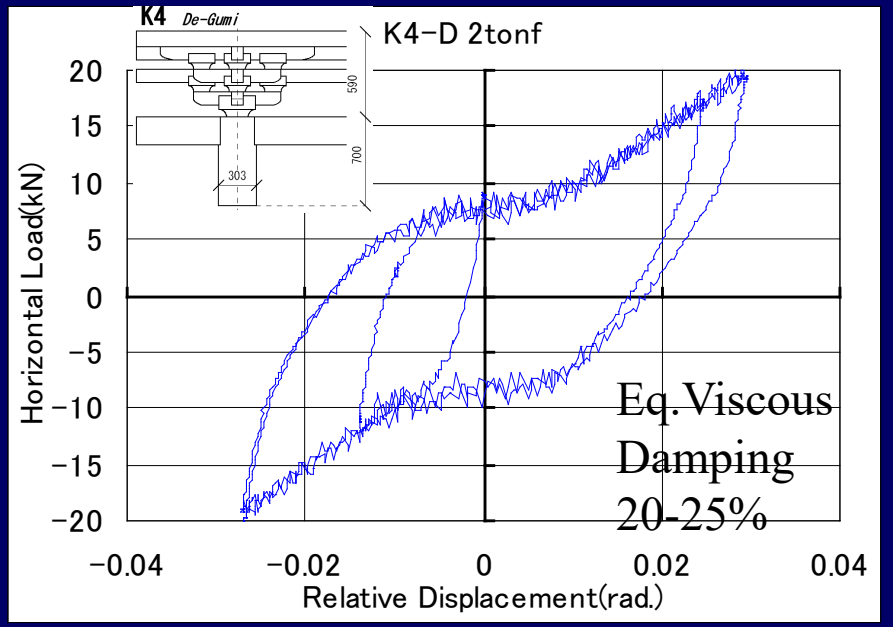
Full scale models of 4 types of fundamental bracket complex

Results of Static Loading Test

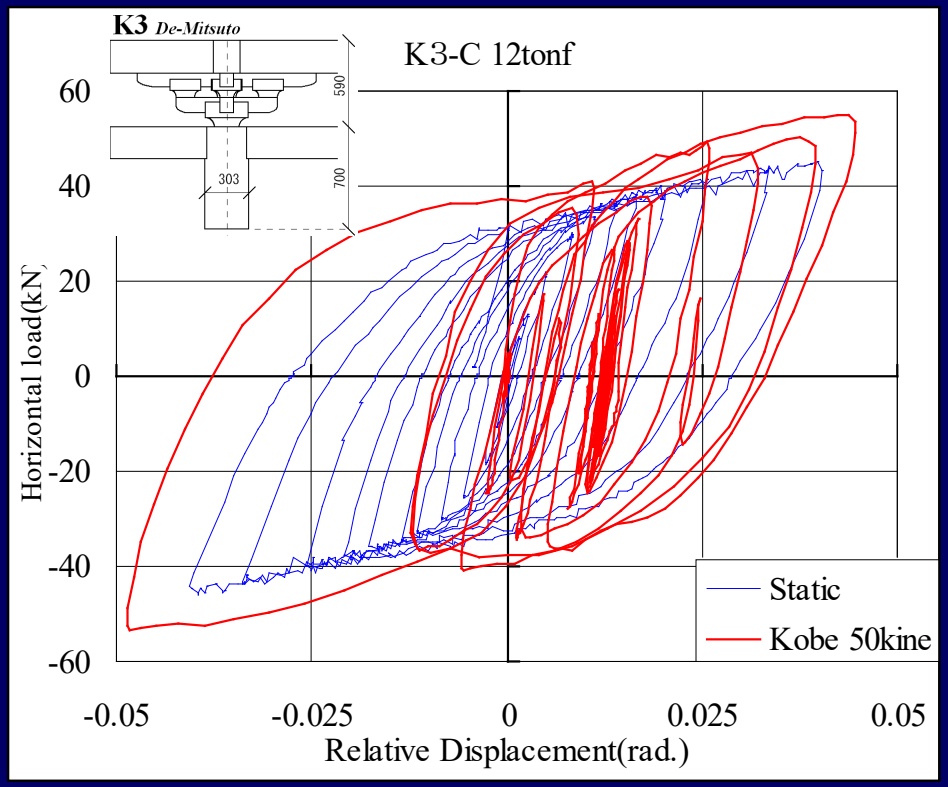


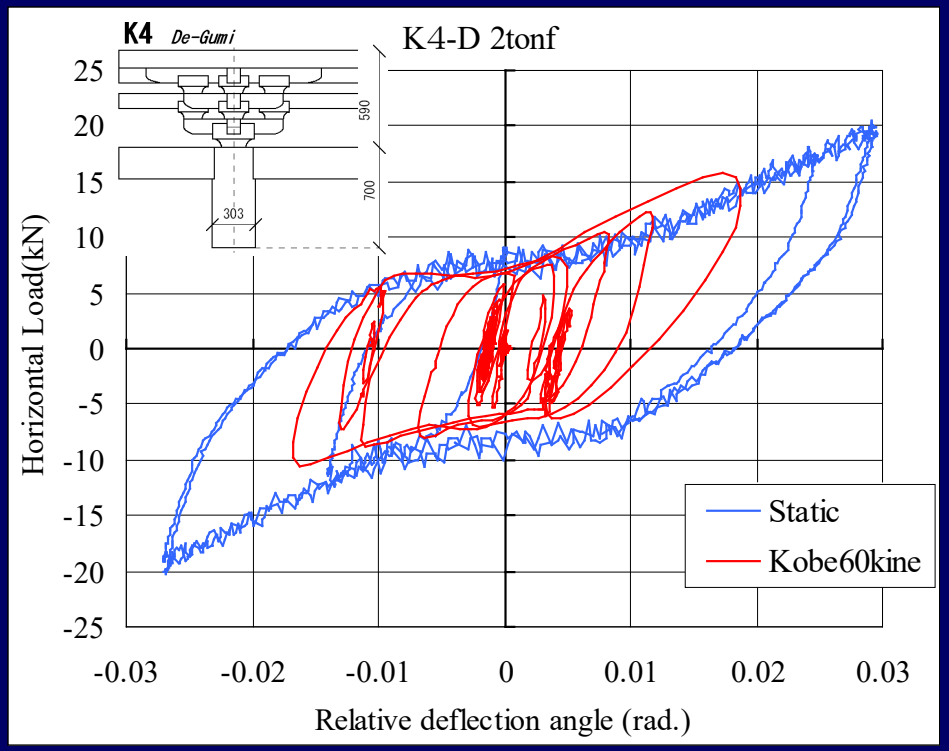






Performance of bracket complex by Static- Dynamic tests



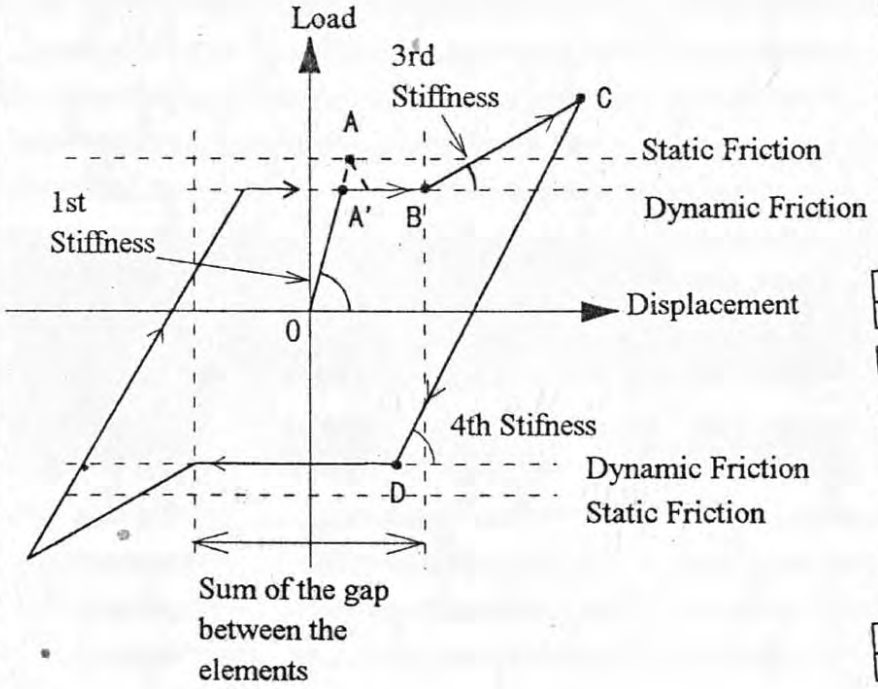


Large energy dissipation by sliding and crushing of timber

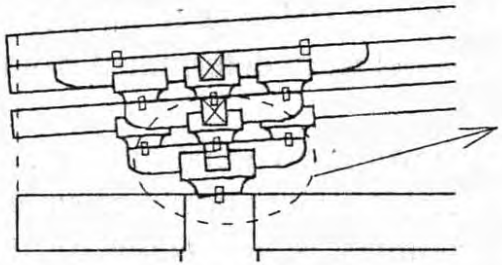
Stiffness degradation can not be seen by multiple cyclic loading

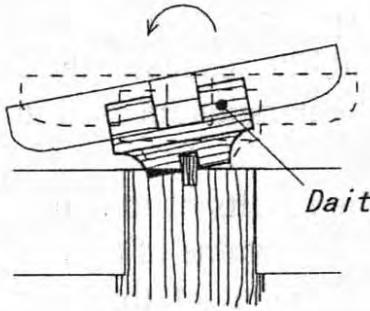
Consistency in the deformation characteristic

Displacement Characteristic

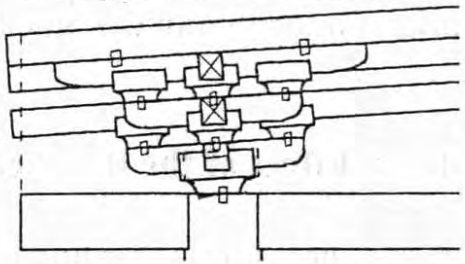


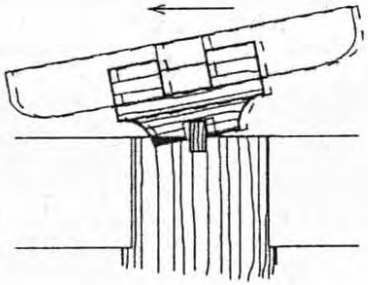
O - A'
Rotation of *Daito*



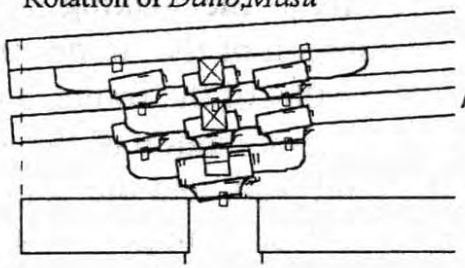


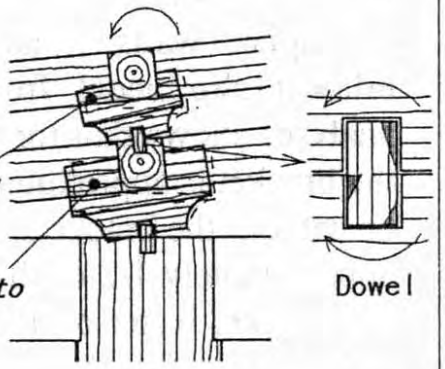
A' - B
Sliding between the elements



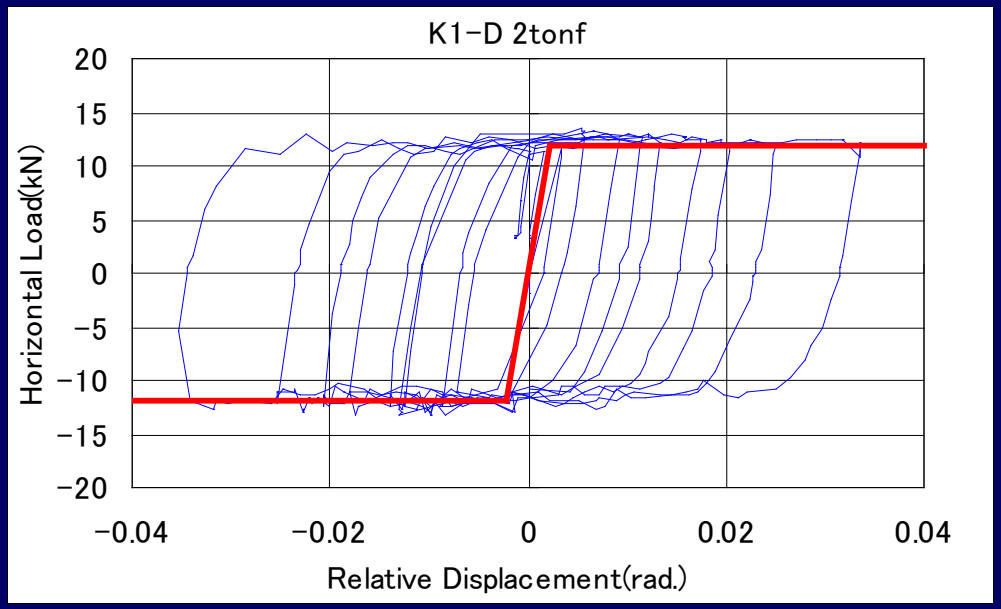


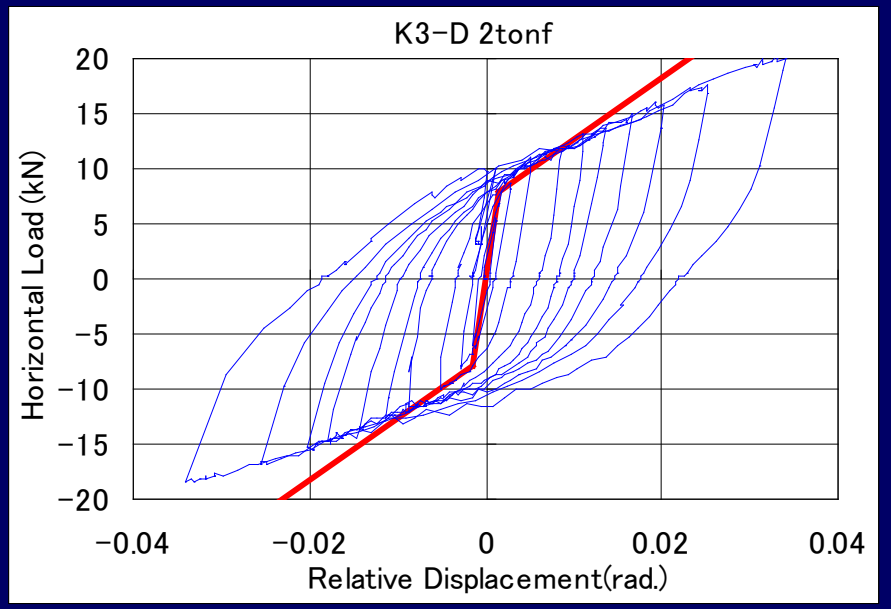
B - C
Rotation of *Daito,Masu*

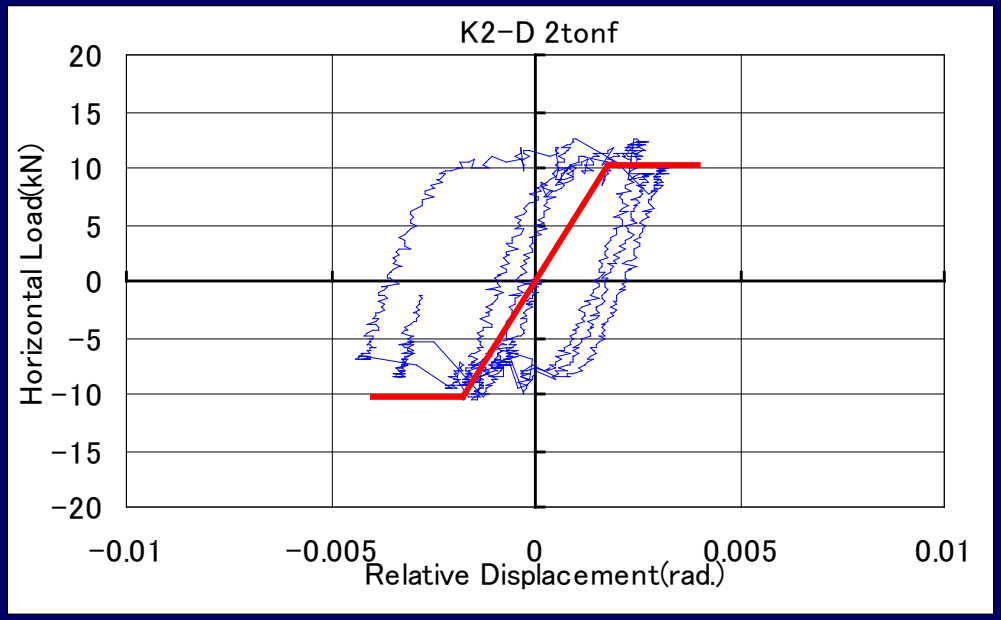


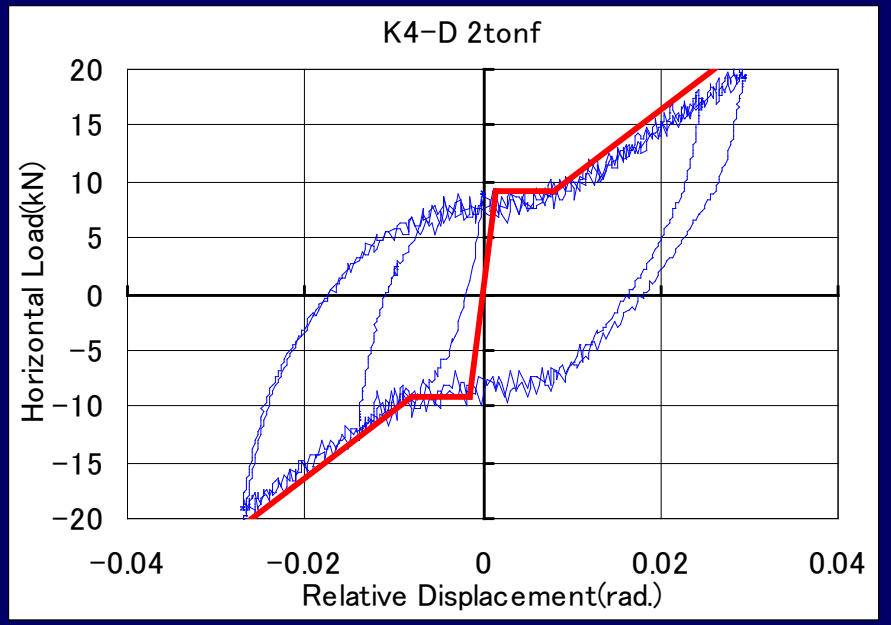


Theoretical Stiffness

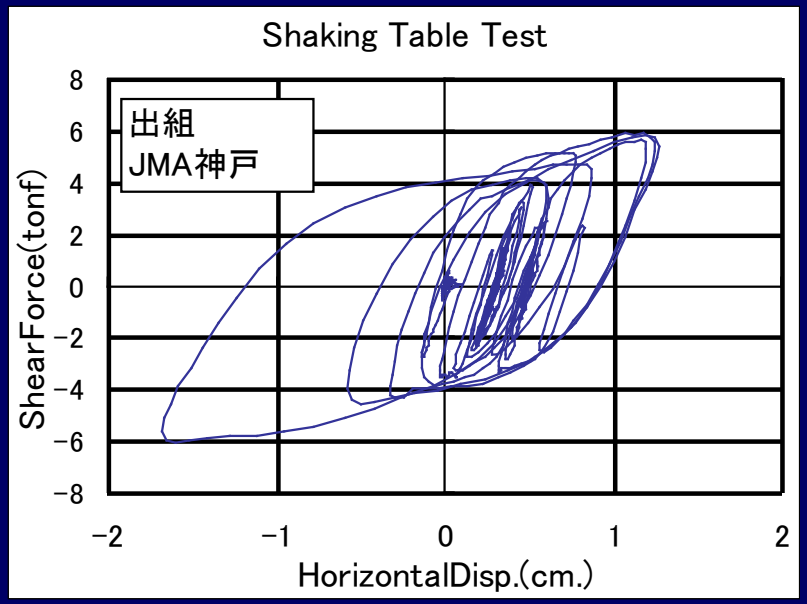


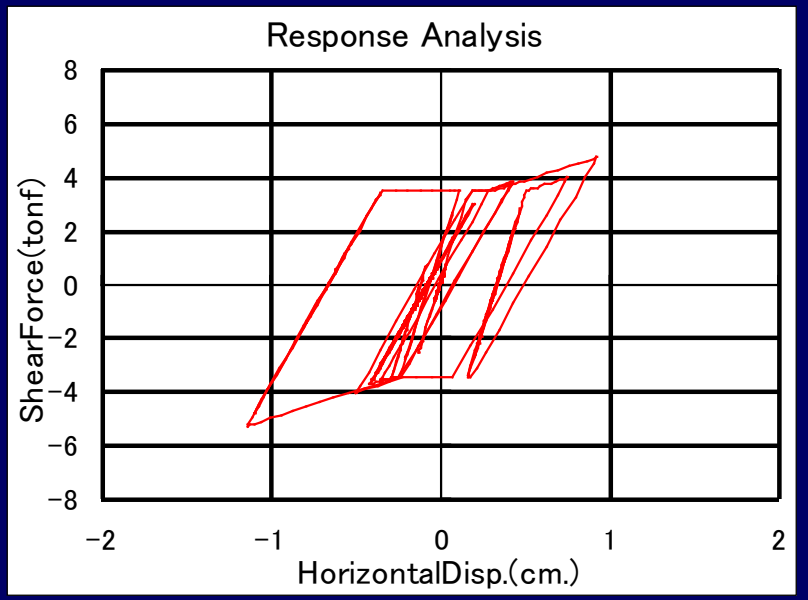


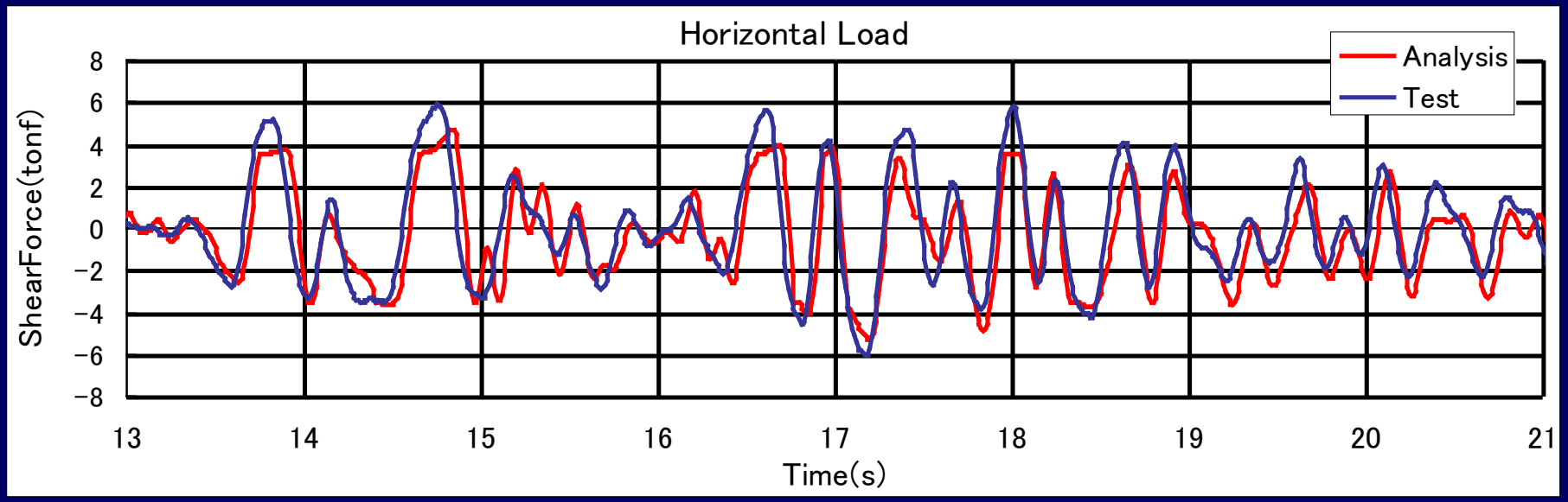




Non-linear analysis and shaking table test

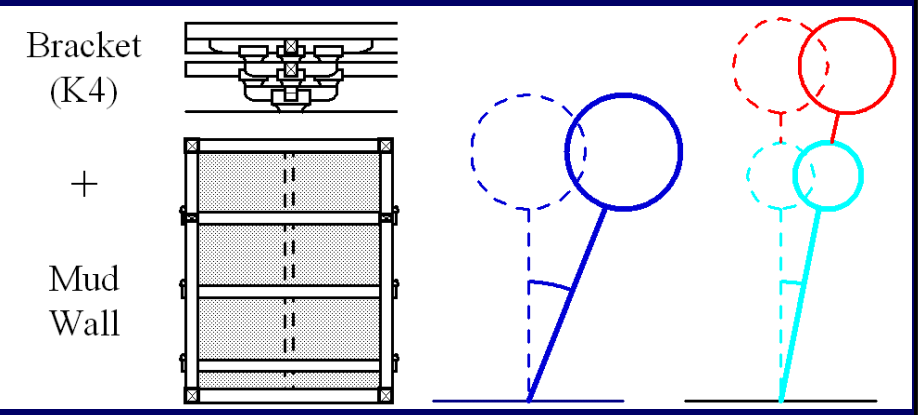


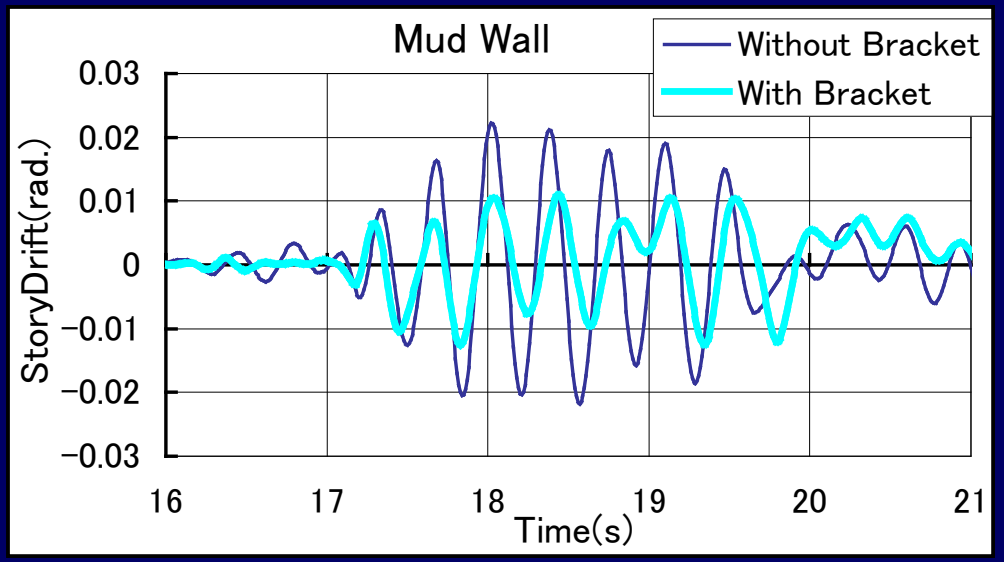


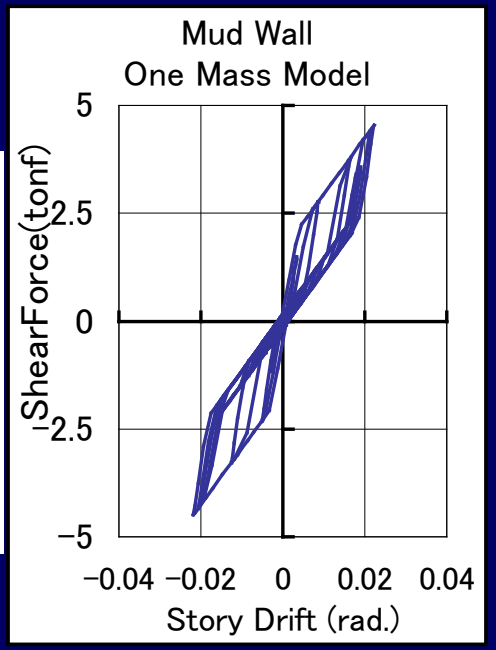


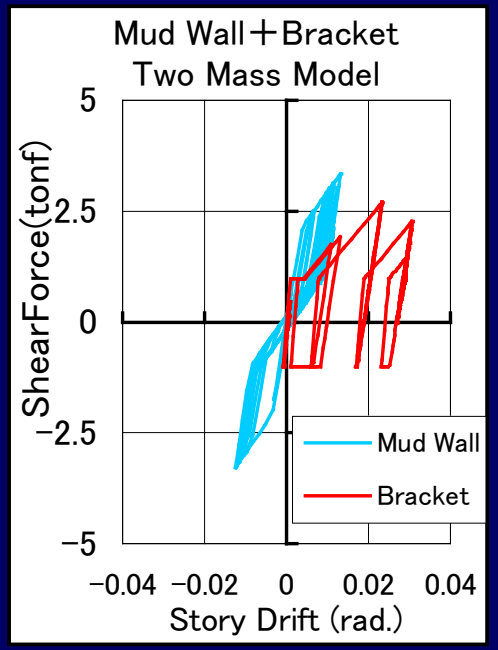
Simulated Effect on Total Structure

- Deformation of the structure can be expected to reduce by using the bracket
- If the stiffness is close



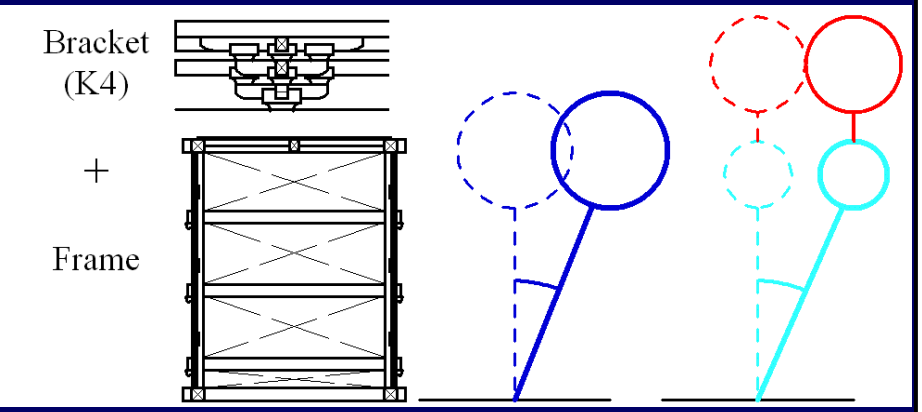


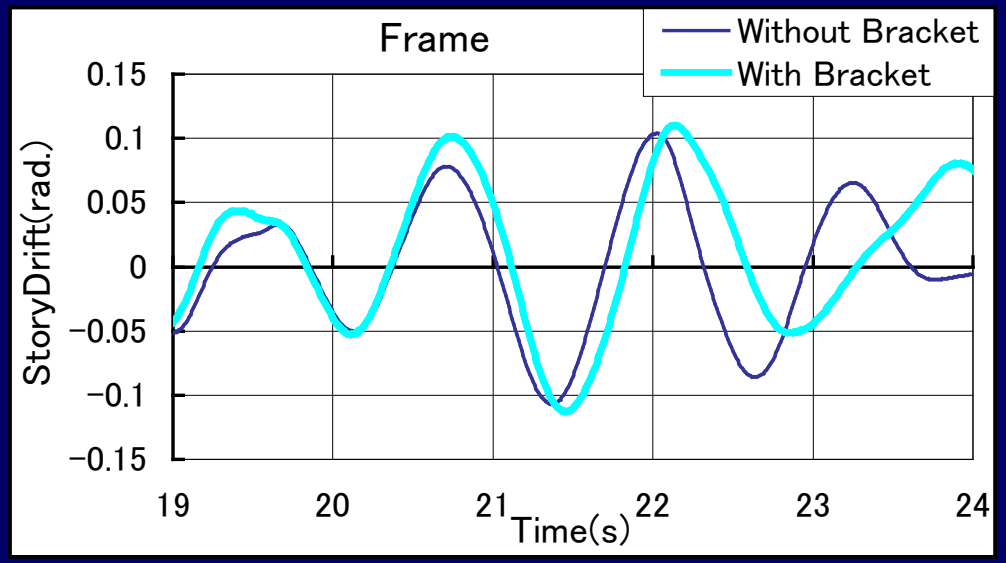


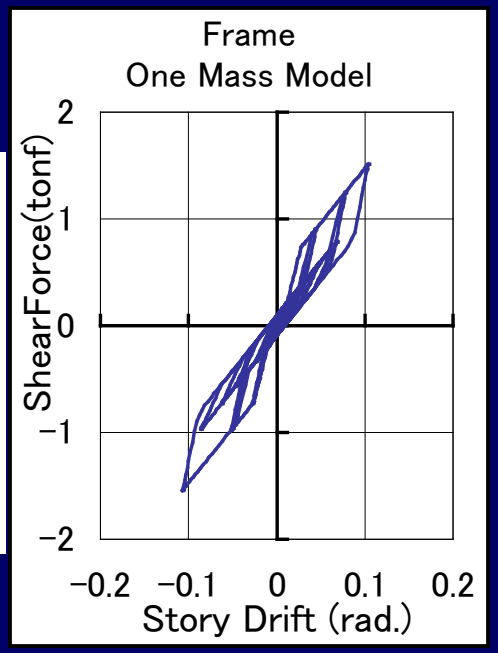


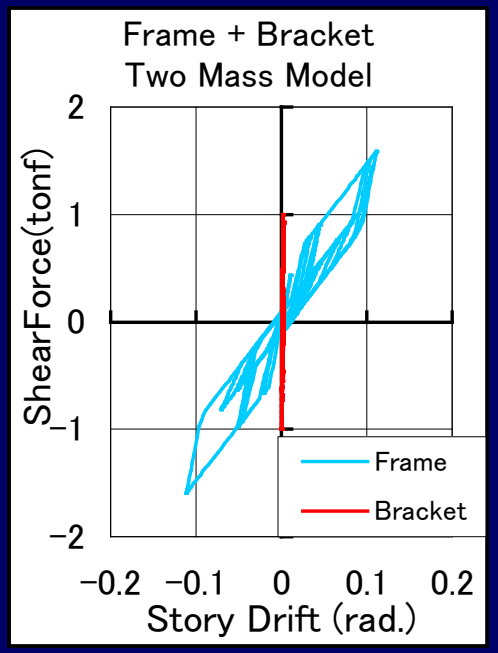
Simulated Effect on Total Structure

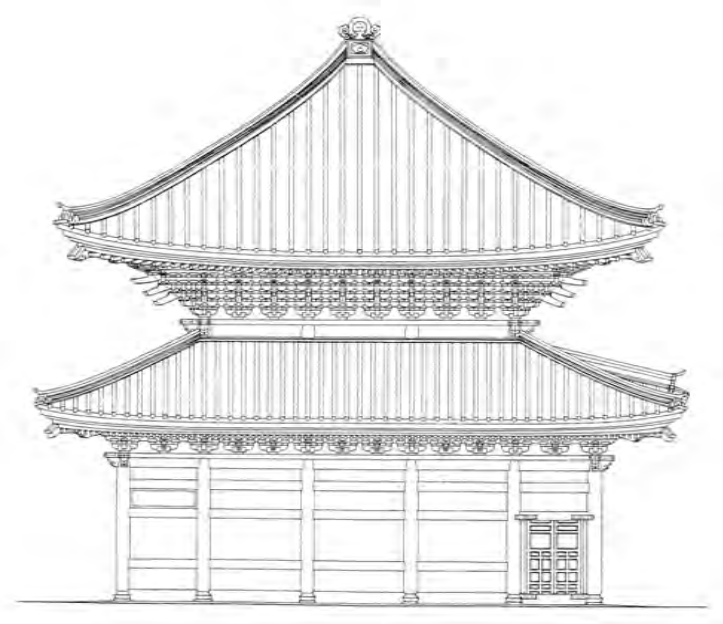
- If the stiffness of bracket is too large in comparison with the frame
- Brackets act only as dead load

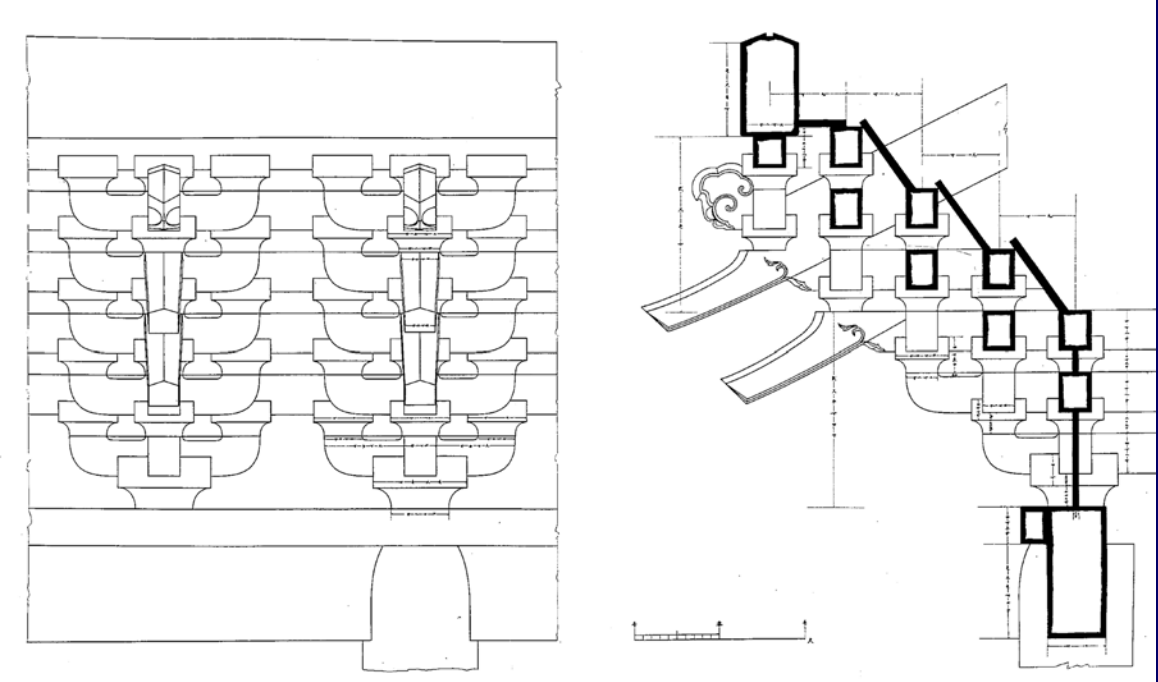


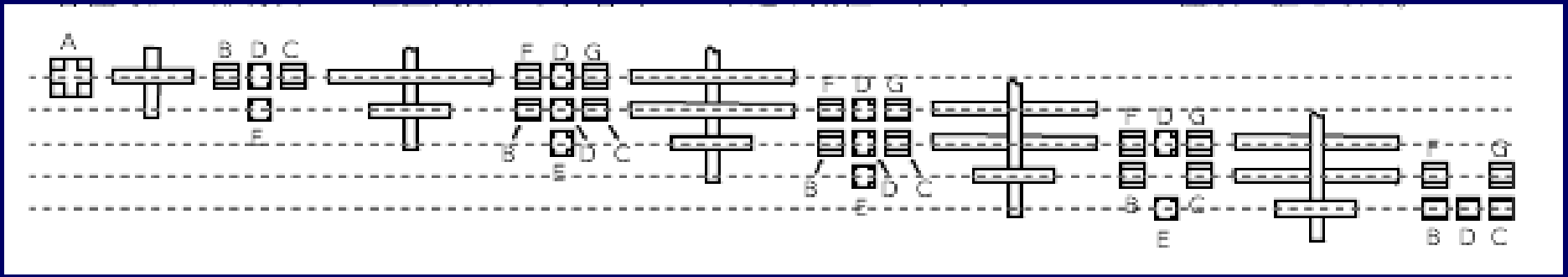








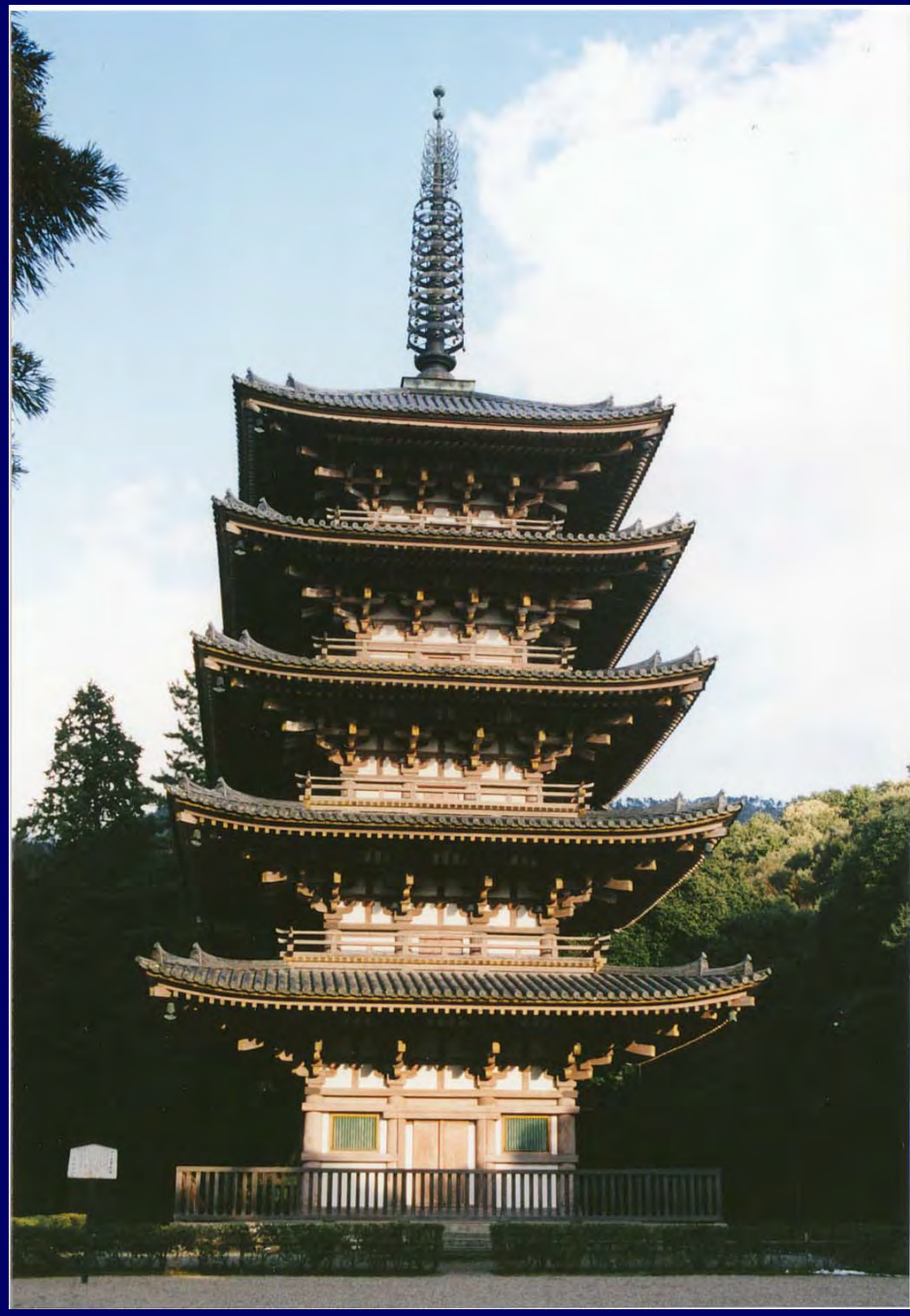




Bracket complex of the main Hall in Kencho-ji temple

Concluding remarks

- Today consideration to structural safety is essential to utilize historic architecture
- Verification of structural performance of traditional timber structures in Japan



Thank You!

The research introduced in this presentation was supported by many people and institutions.

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