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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 Peninsula 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
- Structural modeling
- Static and/or Dynamic Analysis

Comparison
- 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

Shaking Table Test of Traditional Walls

Fujita, Sakamoto 1996
Literature Survey on the detail

136 Buddhist temple halls built after 12th c 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

- Shear wall
- Joint
- Column
- Bracket complex

- Material
  - Timber, mud, bamboo

Structural elements: unique
Material: natural

Various
Non-engineered

Tofuku-ji Temple Gate 15c
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

Vertical Load 12 tonf

Vertical Load 2 tonf

Horizontal Load

70cm

2m

2m
Specimen

Full scale models of 4 types of fundamental bracket complex
Results of Static Loading Test

Graphs showing the relationship between horizontal load (kN) and relative displacement (rad.) for K1-D 2tonf, K2-D 2tonf, K3-D 2tonf, and K4-D 2tonf. The graphs display hysteresis loops indicating the dynamic behavior of the structures under static loading.

The text "Eq. Viscous Damping 20-25%" is also present, indicating the damping characteristics observed in the test results.
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

Displacement

Load

Sum of the gap between the elements

1st Stiffness

2nd Stiffness

3rd Stiffness

4th Stiffness

Static Friction

Dynamic Friction

Static Friction
Theoretical Stiffness

K1-D 2tonf

K3-D 2tonf

K2-D 2tonf

K4-D 2tonf

Horizontal Load (kN)

Relative Displacement (rad.)
Non-linear analysis and shaking table test

Shaking Table Test

Response Analysis

Horizontal Load

Analysis
Test
Simulated Effect on Total Structure

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

![Graphs and diagrams illustrating the effect of a bracket on structure deformation and shear force.](image-url)
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!

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