1. Background

- **Wood structures** have been built mainly as small detached houses so far. But large buildings are also expected to be built by wood because of environmental issue.

- **Hybrid structure** has advantages to enhance the seismic resistance.

- **Design handbook** for wood hybrid structures were published. However, horizontal hybrid structures are **NOT** covered.

Difficult!

Design hand book
2. A Prototype of Horizontal Hybrid Structure of Wood and RC

3-story school building
Floor area = 5,532m²
Height = 13.4m


Wood : Glued-laminated timber's framing and plywood sheathing walls and floor diaphragms
RC core : RC frame with shear walls
3. Characteristics of Seismic

- Difference of weight and stiffness between wood parts and RC parts
- Deformation of floor diaphragm in wood parts

4. Objective

The seismic performance of horizontal hybrid structure is demonstrated through *shaking table test* of scaled specimens.

Then *simplified modeling method* by two-dimensional continuous model is introduced, and the applicability is discussed.
5. Setup of Shaking Table Test

One-sided core
- Wood part
  → One third scaled model
- Core part
  → Steel jigs

6. Specimen

Transverse dir. (X1~X3)

Longitudinal dir. (Y1, Y2)

Plywood (t=9mm)
Nail (d=2.1mm, L=32mm) @100mm

Plywood (t=12mm)
Nail (d=2.1mm, L=32mm)
@150mm(No.1,3)/50mm(No.2)

(*) Bolts (Φ=6mm)
7. List of Specimens

Parameters are
- **arrangement of shear walls**
- **nails’ pitch** of floor diaphragm (in-plane stiffness)

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<table>
<thead>
<tr>
<th>No.</th>
<th>Core</th>
<th>Nails’ pitch</th>
<th>The number of walls</th>
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<tbody>
<tr>
<td>No.1</td>
<td>X4</td>
<td>150 mm</td>
<td>2</td>
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<td>X3</td>
<td></td>
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<tr>
<td></td>
<td>X2</td>
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<tr>
<td></td>
<td>X1</td>
<td></td>
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<tr>
<td>No.2</td>
<td>Core</td>
<td>50 mm</td>
<td>2</td>
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<td></td>
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</tr>
<tr>
<td>No.3</td>
<td>Core</td>
<td>150 mm</td>
<td>0</td>
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8. Input motion

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<tr>
<th>Motion</th>
<th>PGA</th>
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<tbody>
<tr>
<td>1</td>
<td>WN</td>
</tr>
<tr>
<td>2</td>
<td>EQ</td>
</tr>
<tr>
<td>3</td>
<td>WN</td>
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<tr>
<td>5</td>
<td>WN</td>
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<td>6</td>
<td>EQ</td>
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<tr>
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<td>WN</td>
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<td>EQ</td>
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<tr>
<td>9</td>
<td>WN</td>
</tr>
<tr>
<td>10</td>
<td>EQ</td>
</tr>
<tr>
<td>11</td>
<td>WN</td>
</tr>
</tbody>
</table>

WN: White Noise
EQ: Artificial Earthquake
Tokyo Institute of Technology, Yoshihiro Yamazaki

Study on Dynamic Behavior of Wooden Horizontal Hybrid Structure Involving Stiff Cores

Specimen No.1, PGA=0.8g, Time scale $x \sqrt{3}$ (original scale)

9. Maximum Displacement Distribution

No.1

No.2

No.3

Flexible diaphragm

Stiff diaphragm

$0.4g$ $0.6g$ $0.8g$

X1 X2 X3 Core X1 X2 X3 Core X1 X2 X3 Core

0

2 2 2

2 2 2

4 0 0

29.6 20.6 31.8
10. Force-Deform. Relation of Each Element

Shear wall

Floor diaphragm

No.1

No.2

No.3

11. Seismic Force Ratio Shared by Wood part and Core Part

PGA 0.4g

PGA 0.8g

No.1

No.2

No.3

3F

2F

1F
12. Idea of Modeling Method

Discretized model
(Lumped mass)

Continuous model
Useful to obtain
• fundamental period
• seismic force distr.

Uniform shear bar
(One-dimensional)

Uniform shear panel
(Two-dimensional)

13. Equation of Motion

Equation of wave motion
\[ \rho \frac{\partial^2 u}{\partial t^2} = G_x \frac{\partial^2 u}{\partial x^2} + G_y \frac{\partial^2 u}{\partial y^2} \]

Get eigen function considering boundary condition
\[ \phi_{mn}(x,y) = \sin \left( \frac{(2m-1)\pi x}{2L_f} \right) \sin \left( \frac{(2n-1)\pi y}{2H} \right) \]
\[ \omega_{mn} = \sqrt{ \left( \frac{(2m-1)\pi}{2L_f} \right)^2 \frac{G_x}{\rho} + \left( \frac{(2n-1)\pi}{2H} \right)^2 \frac{G_y}{\rho} } \]

Please see
14. Comparison of Vertical Shear Coefficient

Seismic force

$P_i$

Vertical shear coefficient

$A_i = Q_i / \sum_{j=1}^{N} |W_j| A_1$ (i ≥ 2)

Test results

Analysis results

- No.1 $A'_1$ (Only 1st mode)
- No.2 $A'_1$ (All modes)
- No.3 $A_i$ (Conventional)

15. Conclusions

Seismic behavior of wooden horizontal hybrid structure involving stiff cores was discussed.

1) 50 to 70% of seismic force acting on wood part was transmitted to core through floor diaphragms. The original intension of horizontal hybrid structure was realized. Therefore not only shear walls but floor diaphragms clearly contribute to seismic force resistance capacity.

2) Applicability of continuous model was discussed. It could improve accuracy of the vertical shear coefficient distribution compared to the conventional formula. The method can be applied to evaluate other dynamic properties.
Acknowledgment

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Thank you for your kind attention