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

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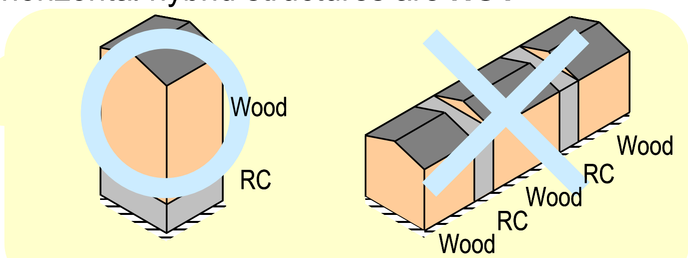
1. Background

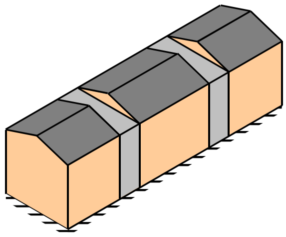
- **Wood structures** have been built mainly as small detached houses so far. But large buildings are also expected to be built by wood because of environmental issue.
- **Hybrid structure** has advantages to enhance the seismic resistance.
- **Design handbook** for wood hybrid structures were published. However, horizontal hybrid structures are **NOT** covered.

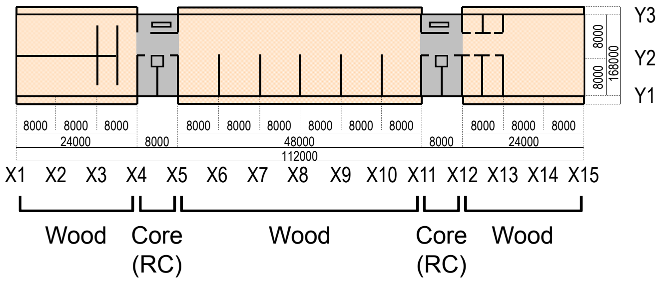
Design hand book



Vertical hybrid structure   Horizontal hybrid structure

2. A Prototype of Horizontal Hybrid Structure of Wood and RC



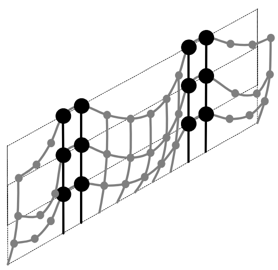


3-story school building
Floor area＝5,532m^2
Height＝13.4m

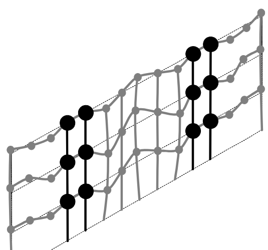
Wood : Glued-laminated timber's framing and plywood sheathing walls and floor diaphragms

RC core : RC frame with shear walls

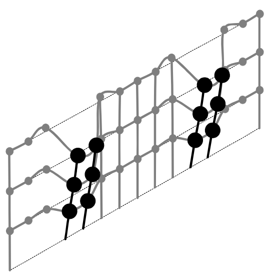
Architectural Institute of Japan (2012), “Technical Issues and resolutions of Large Wood Building” (in Japanese), Material of AIJ annual meeting 2012



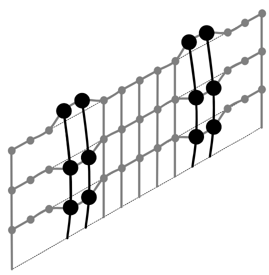
Wood part dominant 1st mode



Wood part dominant 2nd mode

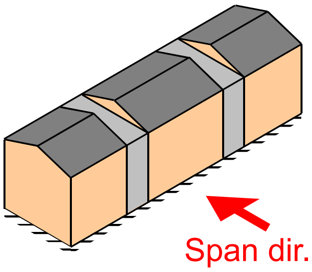


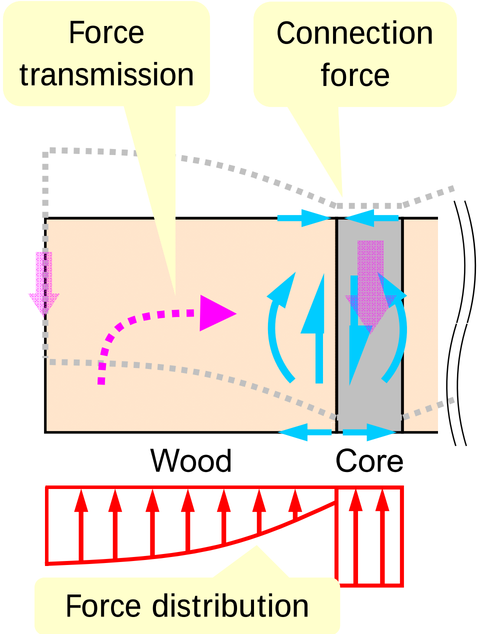
Core part dominant 1st mode



Core part dominant 2nd mode

3. Characteristics of Seismic





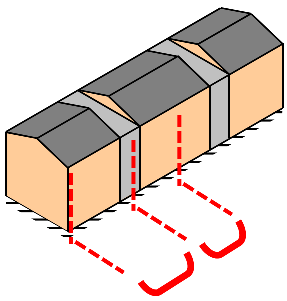
- Difference of weight and stiffness between wood parts and RC parts
- Deformation of floor diaphragm in wood parts

4. Objective

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

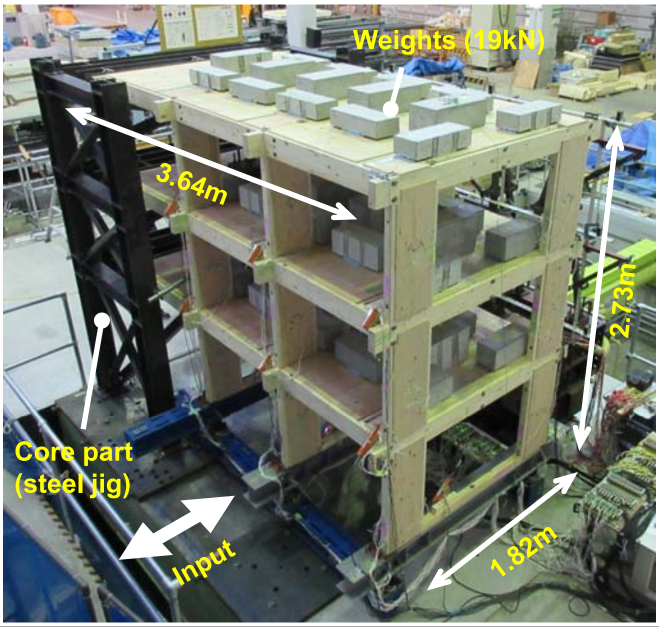
Then ***simplified modeling method*** by two-dimensional continuous model is introduced, and the applicability is discussed.

5. Setup of Shaking Table Test

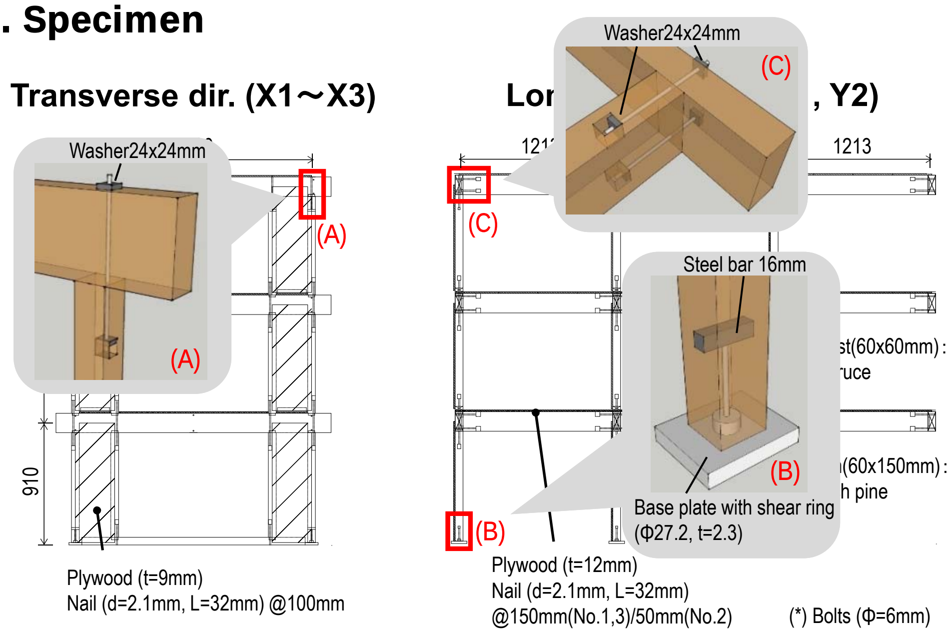


One-sided core

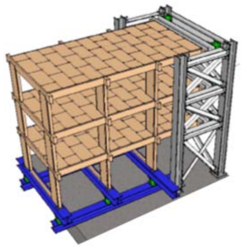
- **Wood part**
  → One third scaled model
- **Core part**
  → Steel jigs



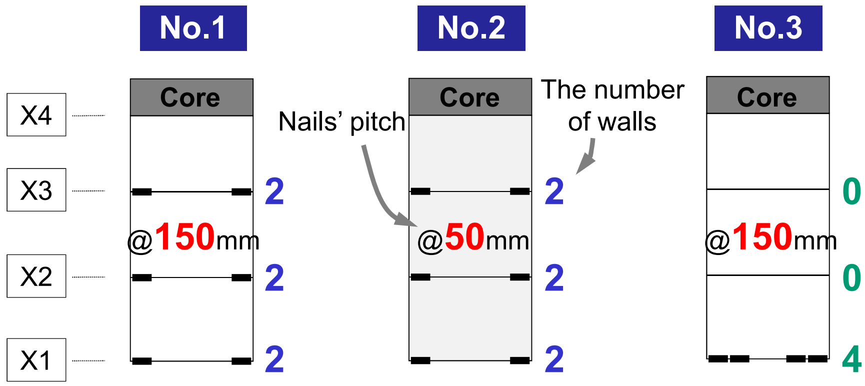
6. Specimen



7. List of Specimens



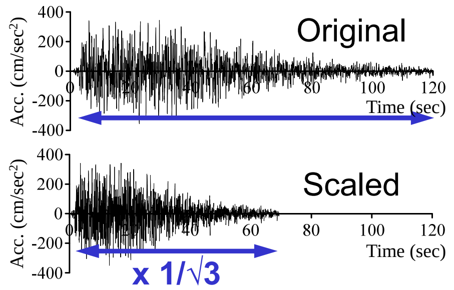
Parameters are
- ***arrangement of shear walls***
- ***nails' pitch*** of floor diaphragm (in-plane stiffness)

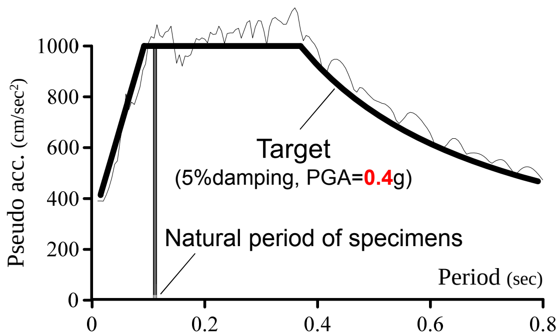


8. Input motion

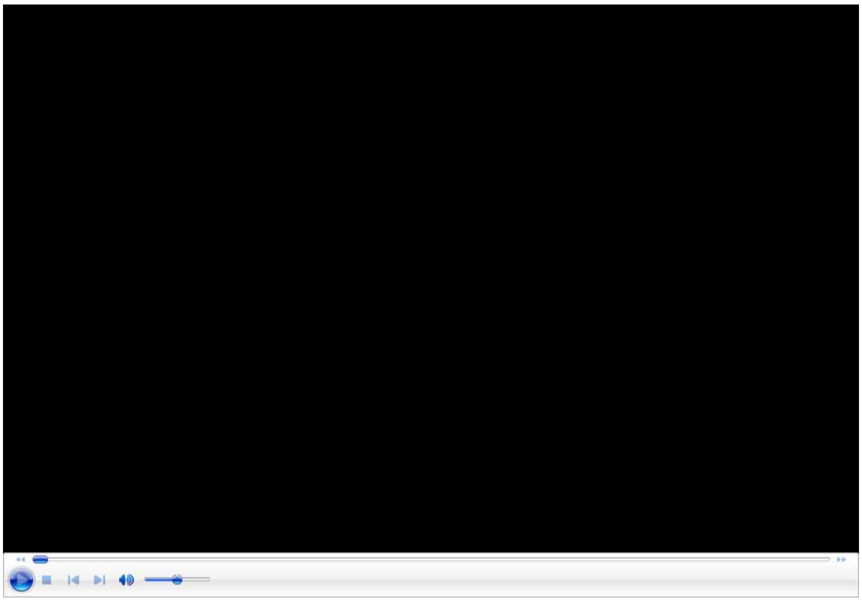
	Motion	PGA
1	WN	0.05g
2	EQ	0.1g
3	WN	0.05g
4	EQ	0.2g
5	WN	0.05g
6	EQ	0.4g
7	WN	0.05g
8	EQ	0.6g
9	WN	0.05g
10	EQ	0.8g
11	WN	0.05g

WN : White Noise
EQ : Artificial Earthquake

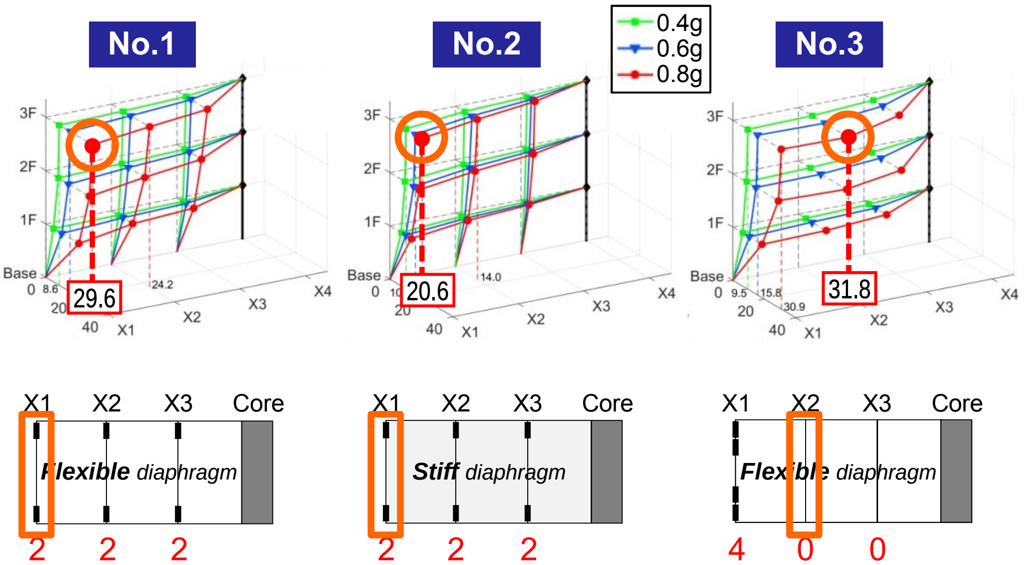




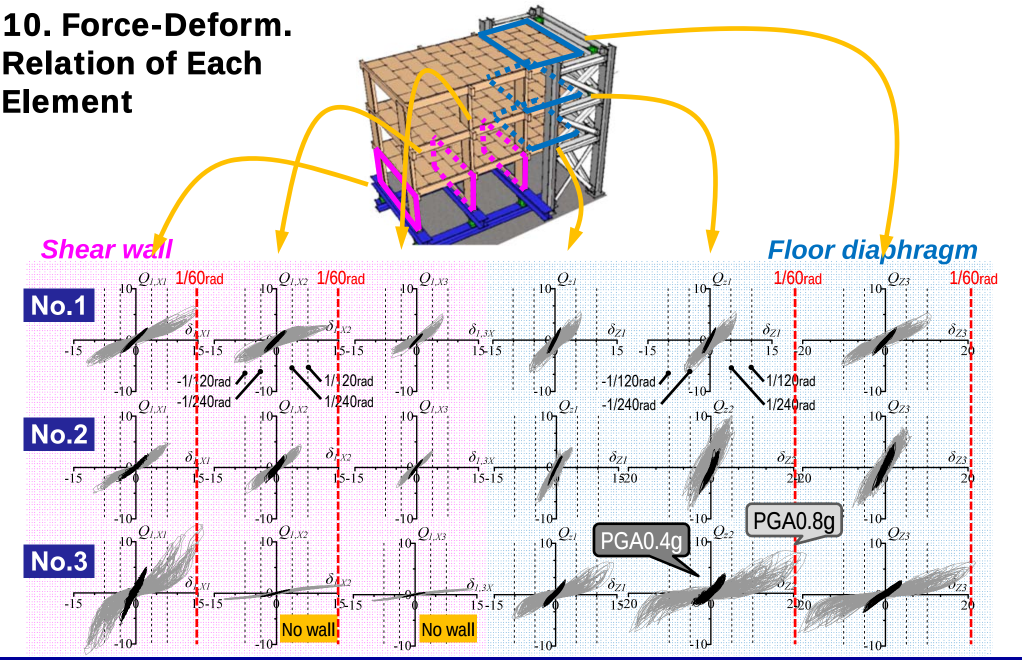
Specimen No.1, PGA=0.8g, Time scale x √3 (original scale)



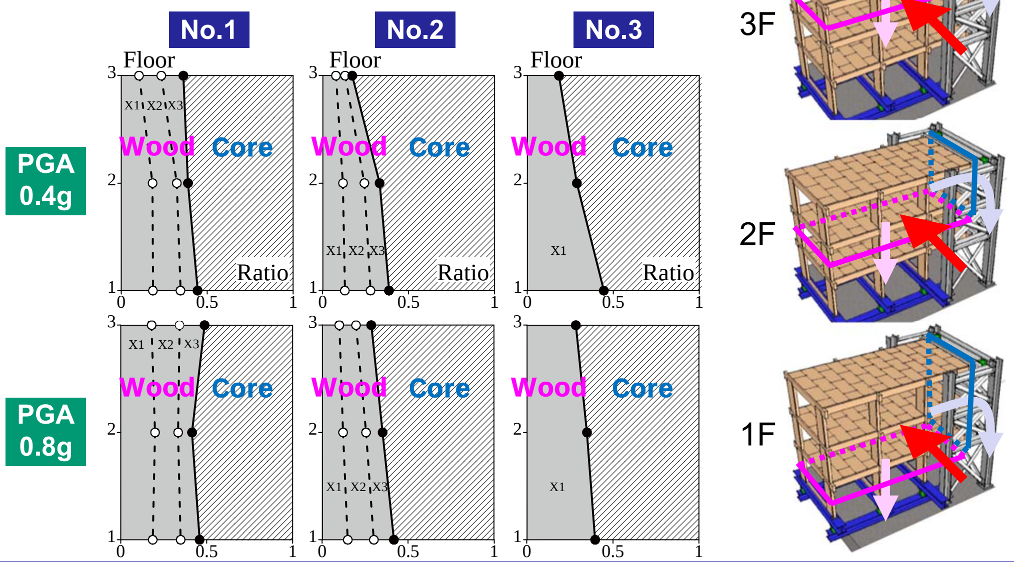
9. Maximum Displacement Distribution



10. Force-Deform. Relation of Each Element



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

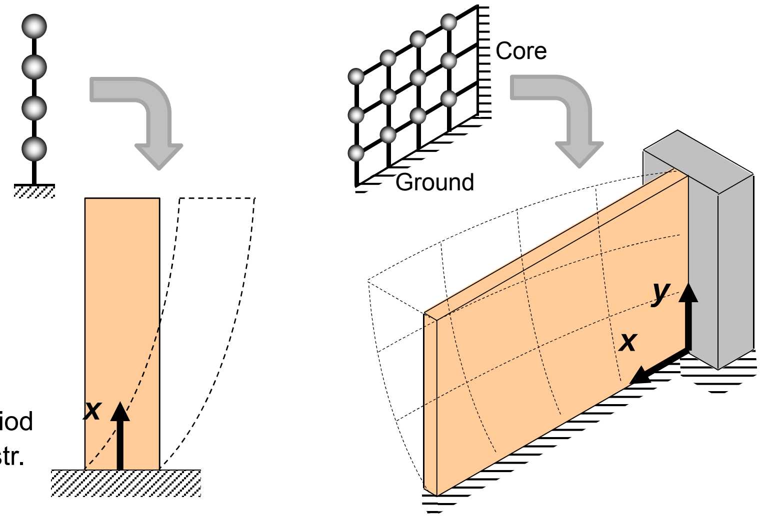


12. Idea of Modeling Method

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

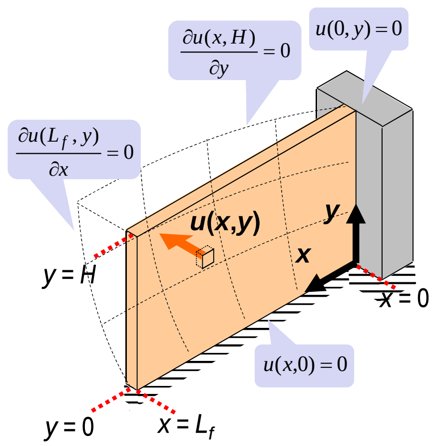
$$\rho\frac{\partial^2 u}{\partial t^2}=G_x\frac{\partial^2 u}{\partial x^2}+G_y\frac{\partial^2 u}{\partial y^2}$$

Equation of wave motion

Get eigen function considering boundary condition

$$\phi_{mn}(x,y)=\sin\frac{(2m-1)\pi x}{2L_f}\sin\frac{(2n-1)\pi y}{2H}$$

$$\omega_{mn}=\sqrt{\left(\frac{(2m-1)\pi}{2L_f}\right)^2\frac{G_x}{\rho}+\left(\frac{(2n-1)\pi}{2H}\right)^2\frac{G_y}{\rho}}$$



Please see
Yoshihiro Yamazaki and Hiroyasu Sakata, 2016, "Simplified Modeling Method and Seismic Force Evaluation of Building Structures Involving Stiff Cores: Study on dynamic behavior of wooden horizontal hybrid structure Part1(in Japanese)", *Journal of structural and construction engineering*, Architectural Institute of Japan, No.720, pp.291-301

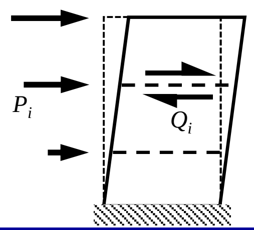
14. Comparison of Vertical Shear Coefficient

$$A_i' = \begin{cases} \dfrac{1}{\alpha_i}\dfrac{\alpha_i'}{\alpha_1'}\sqrt{\dfrac{3-2\alpha_i'}{3-2\alpha_1'}} & \text{(Combination of all modes)} \\[2ex] \dfrac{1}{\alpha_i}\dfrac{\sin(\pi\alpha_i'/2)}{\sin(\pi\alpha_1'/2)} & \text{(Only the 1st mode)} \end{cases}$$

$$\alpha_i' = \begin{cases} \left(\sum_{j=i}^{N-1} W_j + W_N R_N\right) \Big/ \left(\sum_{j=1}^{N-1} W_j + W_N R_N + 0.5W_1\right) & (i \neq N) \\[2ex] \left(W_N R_N\right) \Big/ \left(\sum_{j=1}^{N-1} W_j + W_N R_N + 0.5W_1\right) & (i = N) \end{cases}$$

$$R_N = \left(\sqrt{\frac{k_{f,N-1}/W_{N-1}}{k_{f,N}/W_N}\cdot\beta} + 1\right) \Big/ \left(\sqrt{\beta}+1\right) \qquad \beta = \frac{G_y L_f^2}{G_x H^2}$$

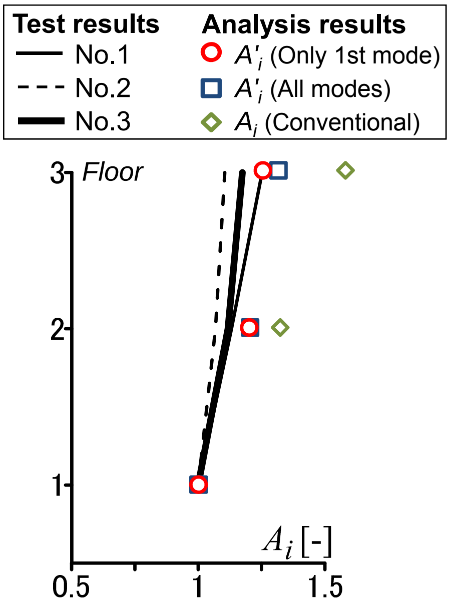
Seismic force



$\sum_{j=i}^{N} W_j$ Weight above i-th floor

Vertical shear coefficient

$$A_i = Q_i / \sum_{j=i}^{N} W_j \, A_1 \quad (i \geq 2)$$



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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We would like to express our gratitude to them.

Thank you for your kind attention