

# **SEISMIC PERFORMANCE OF MID-RISE LIGHT WOOD FRAME BUILDING CONNECTED TO A STIFF CORE**

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# Hybrid Building System

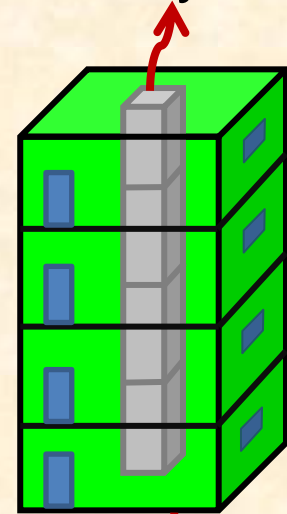
- Low-rise LWFS up to 4 storeys:

**Separated**

- Mid-rise LWFS up to 6 storeys:

**Combined**

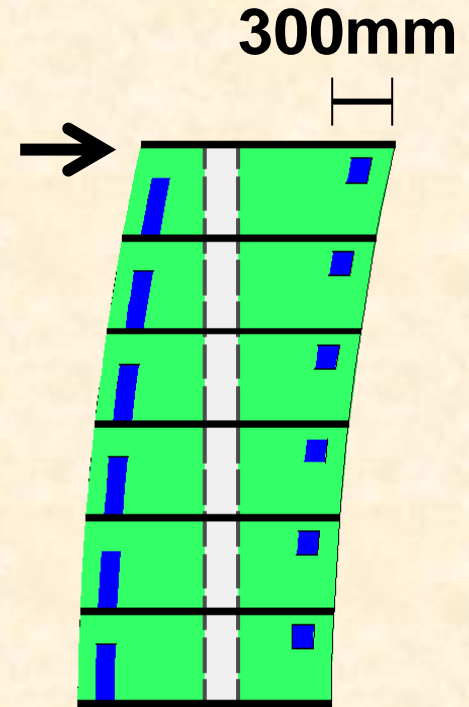
Reinforced  
masonry core



Light wood frame  
structure (LWFS)

# Hybrid Building System

- Low-rise LWFS up to 4 storeys:  
Separated
- Mid-rise LWFS up to 6 storeys:  
Combined



# Seismic Force Modification Factor $R$

	$R_d$	$R_o$	$R = R_d \times R_o$
LWFS	3.0	1.7	5.1
Masonry	2.0	1.5	3.0

$R_d$ : Ductility related

$R_o$ : Over-strength related

**Hybrid building: ?**

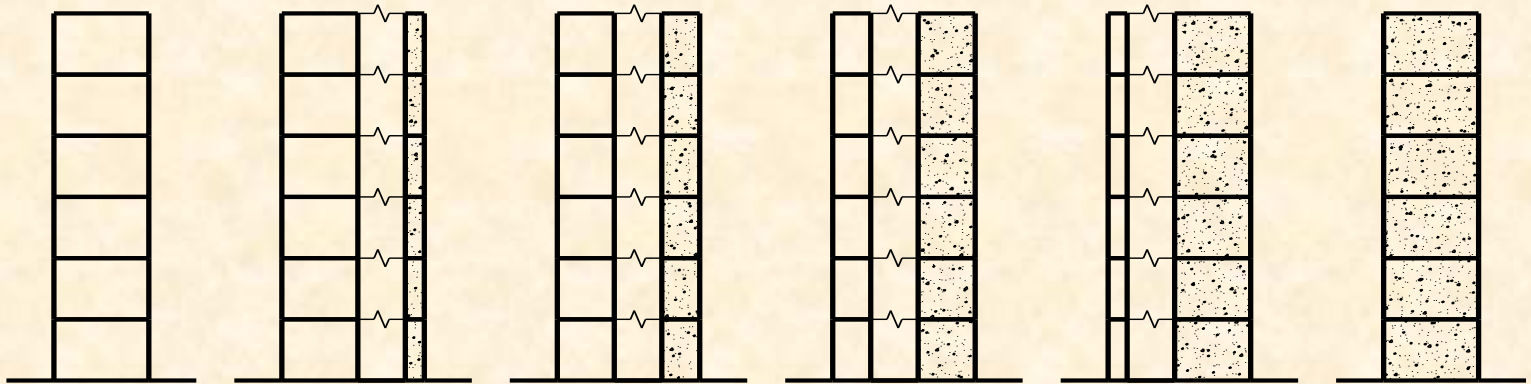
- To quantify the  $R$  ( $R_d$ ,  $R_o$ ) value of hybrid building system
- How the  $R$  ( $R_d$ ,  $R_o$ ) value are influenced by a series of parameters

# Design of Multi-storey Hybrid Buildings

- Location: Vancouver
- Six resistance ratio of masonry to hybrid building:  $\alpha$
- Three design methods: D1, D2 and D3
- Building height: 4, 6 and 8 storeys
- Ductility of connection: limited and moderate
- Ductility of masonry: limited and moderate

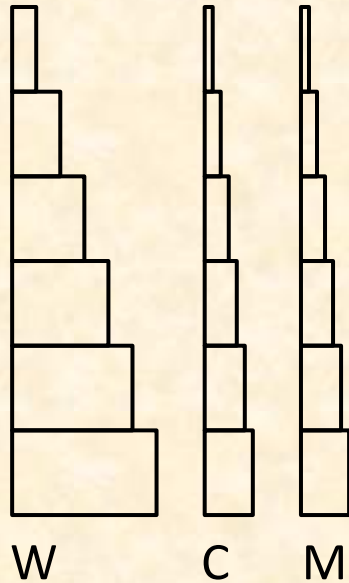
# Resistance Ratio of Masonry to Hybrid Building $\alpha$

$$R_{initial} = (R_w - R_m) (1 - \alpha) + R_m$$

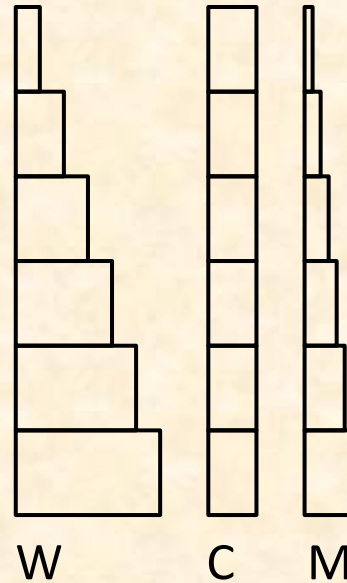


	Wood	Hybrid1	Hybrid2	Hybrid3	Hybrid4	Masonry
$\alpha$	0	0.2	0.4	0.6	0.8	1
$R$	5.1	4.68	4.26	3.84	3.42	3

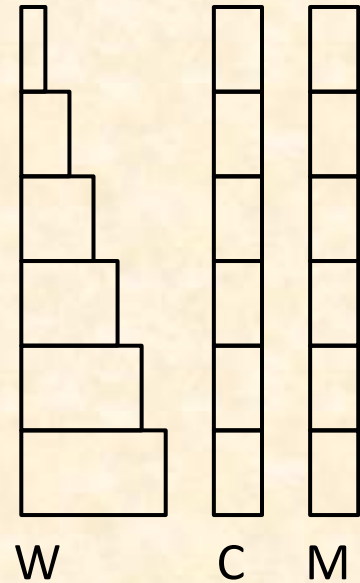
# Design Storey Base Shear



D1



D2

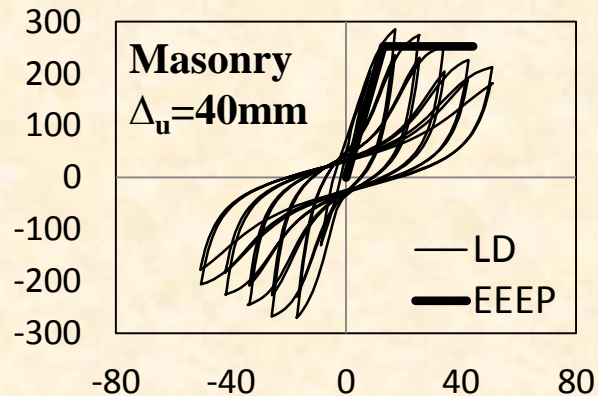
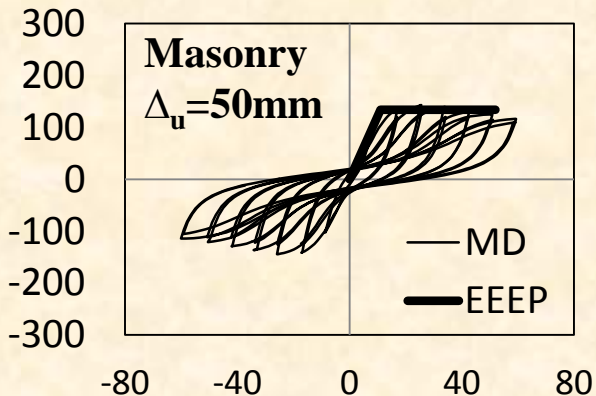
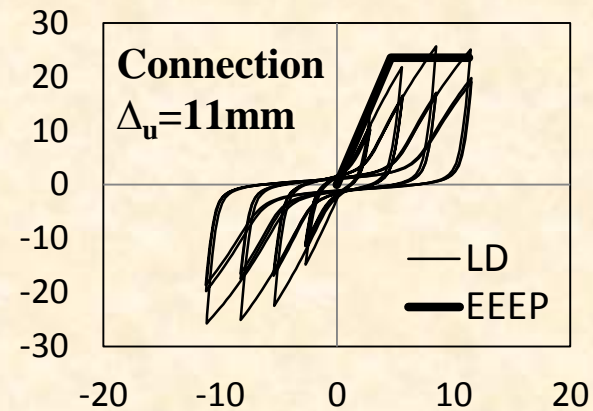
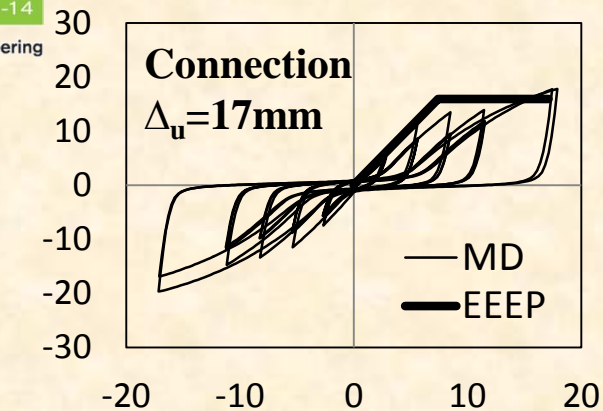


D3



# Ductility of connection and masonry core

Load(kN)

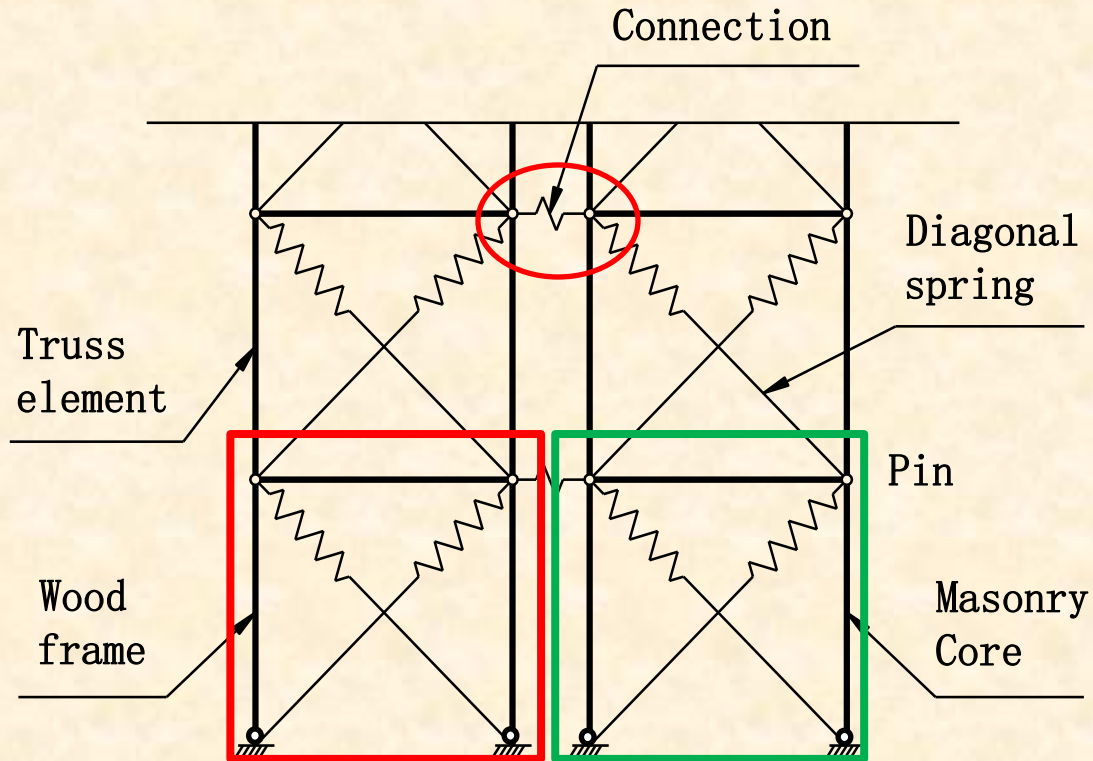


Displacement (mm)

# 67 Buildings cases

4W	4H1D1	4H2D1	4H3D1	4H4D1	4M
	4H1D2	4H2D2	4H3D2	4H4D2	
	4H1D3	4H2D3	4H3D3	4H4D3	
6W	6H1D1	6H2D1	6H3D1	6H4D1	6M
	6H1D2	6H2D2	6H3D2	6H4D2	
	6H1D3	6H2D3	6H3D3	6H4D3	
6W	6H1D1Lc	6H2D1Lc	6H3D1Lc	6H4D1Lc	6M
	6H1D2Lc	6H2D2Lc	6H3D2Lc	6H4D2Lc	
	6H1D3Lc	6H2D3Lc	6H3D3Lc	6H4D3Lc	
6W	6H1D1Lm	6H2D1Lm	6H3D1Lm	6H4D1Lm	6MLm
	6H1D2Lm	6H2D2Lm	6H3D2Lm	6H4D2Lm	
	6H1D3Lm	6H2D3Lm	6H3D3Lm	6H4D3Lm	
8W	8H1D1	8H2D1	8H3D1	8H4D1	8M
	8H1D2	8H2D2	8H3D2	8H4D2	
	8H1D3	8H2D3	8H3D3	8H4D3	

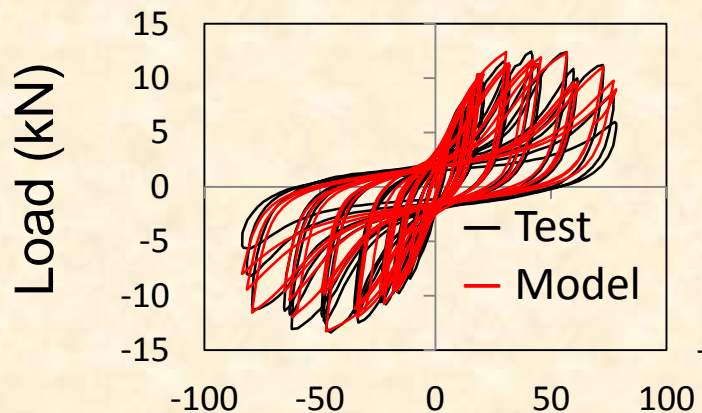
# Two-dimensional modeling approach



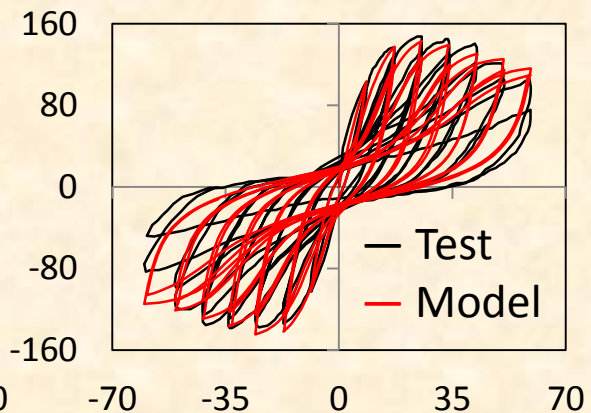
Bouc-Wen-Baber-Noori (BWBN) model

# Hysteresis loops

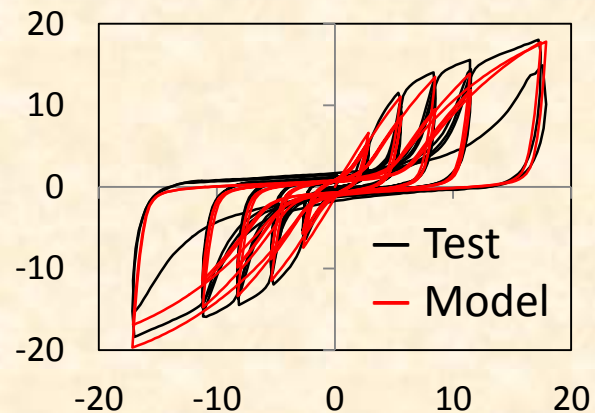
1m × 2.8m wood wall



1m × 2.8m masonry wall

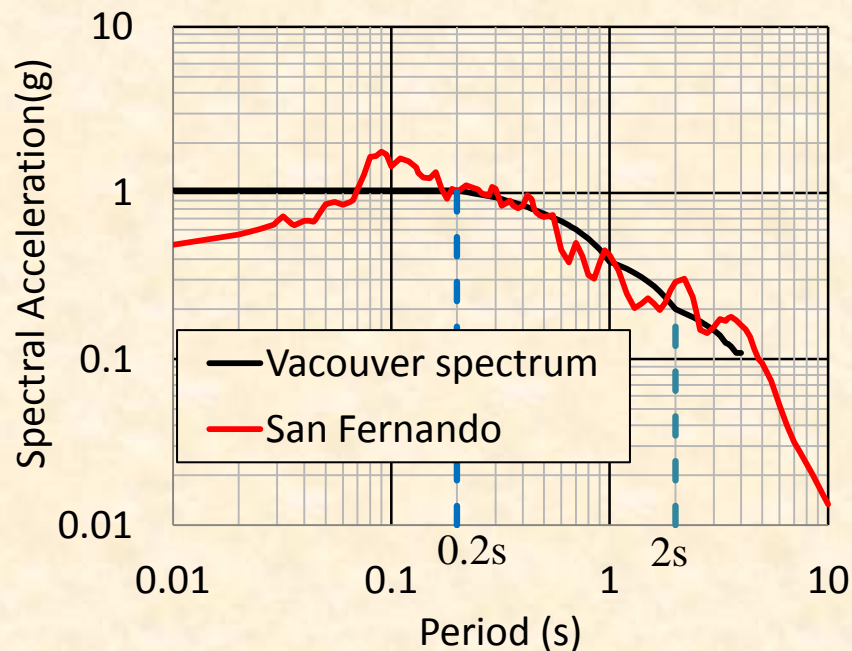


12.5mm bolt connection

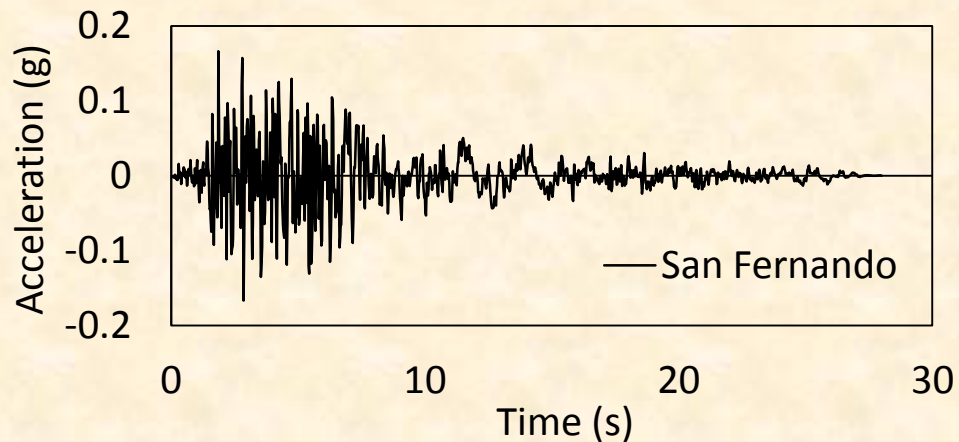


Displacement (mm)

# Earthquake load



Scaling interval:  
0.05 times of design level

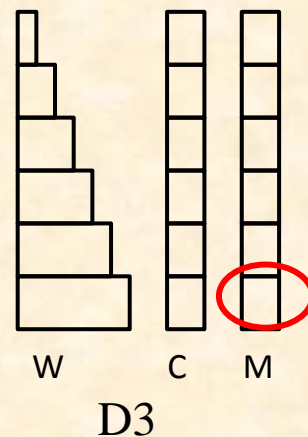
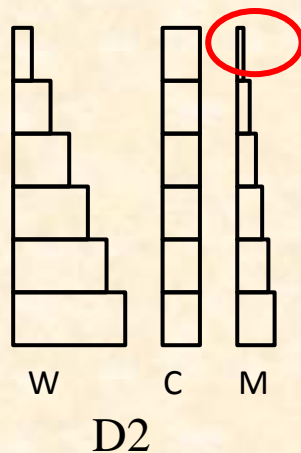
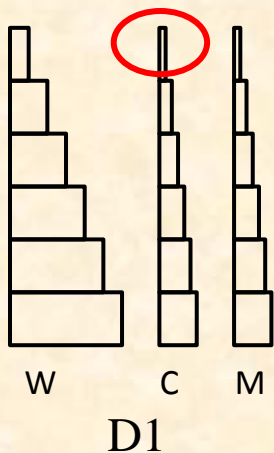


# Results — Failure mode

Failure criteria	$\Delta_u$ (mm)	
Wood	70	
Masonry	50	40
Connection	17	11

Three design methods:

- No failure happens at wood structure
- D1: connection on top storey
- D2: masonry core on top storey
- D3: masonry core on bottom storey



## $R$ ( $R_d$ , $R_o$ ) value of hybrid building

$$R = R_{initial} \times S \quad R_o = \frac{V_m}{V_d} \quad R_d = \frac{R}{R_o}$$

$R_{initial}$ : initial design assumption of  $R$  value

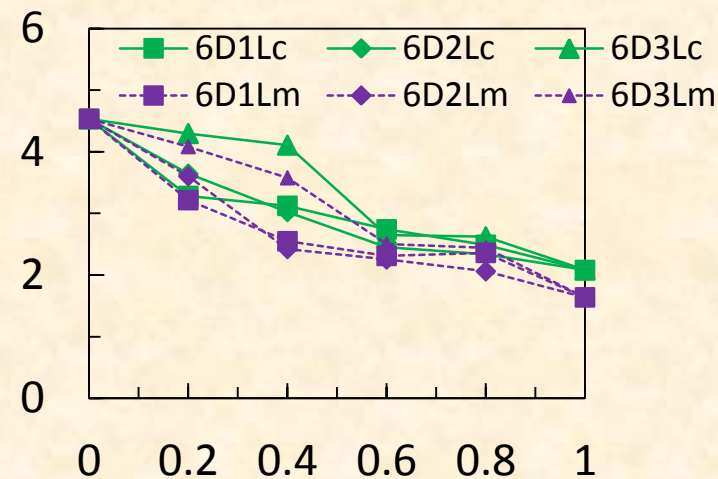
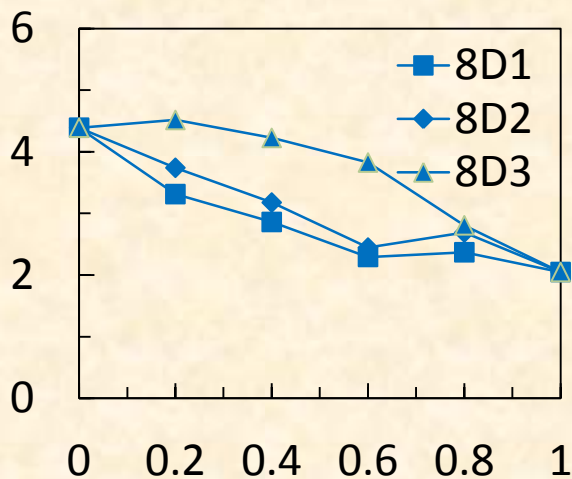
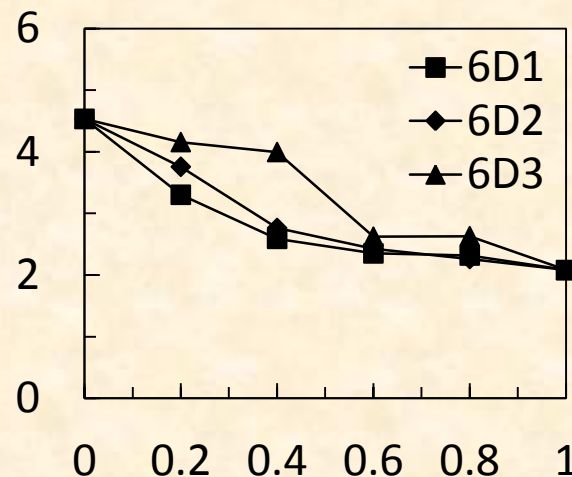
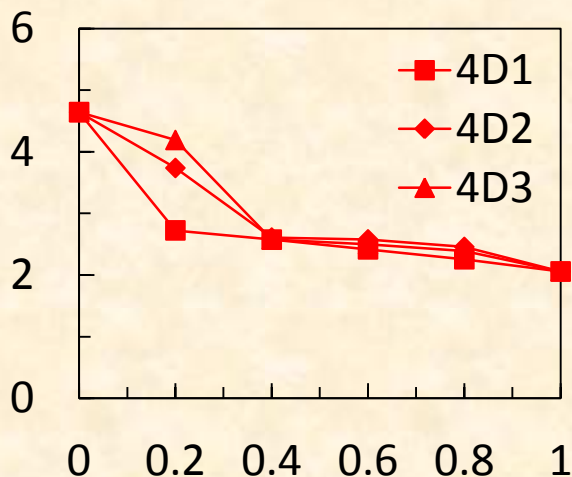
$V_m$ : maximum base shear

$V_d$ : design base shear

$S$ : ground motion scaling factor until failure

# Results

$R_d$



Resistance ratio ( $\alpha$ )



# Empirical equation of $R_d$

$$R_{dH} = (R_{dw} - R_{dm}) (1 - \alpha)^{\beta/N} + R_{dm}$$

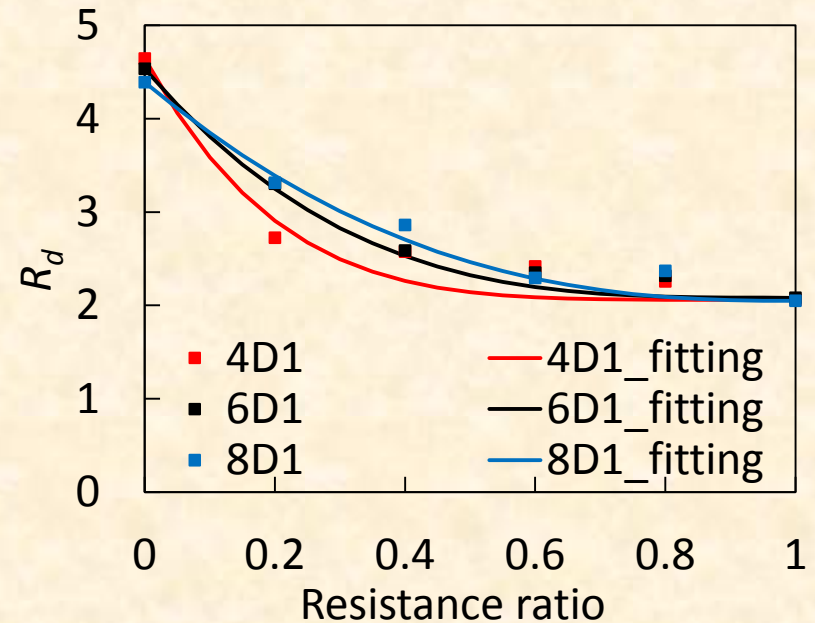
$R_{dH}$ :  $R_d$  of hybrid building

$R_{dw}$ :  $R_d$  of wood structure

$R_{dm}$ :  $R_d$  of masonry structure

$\alpha$ : resistance ratio

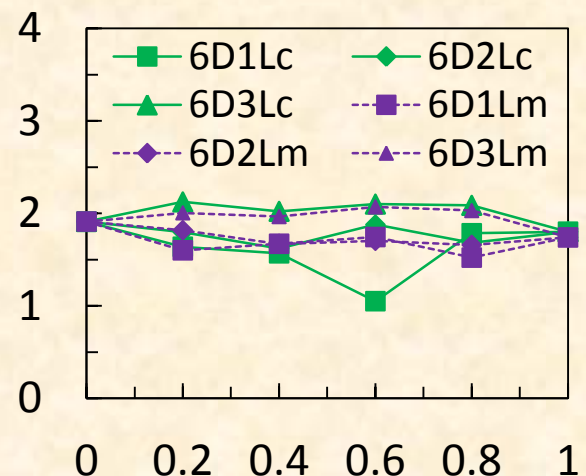
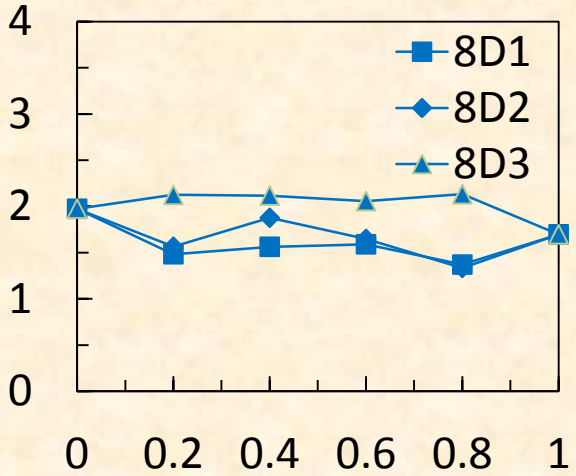
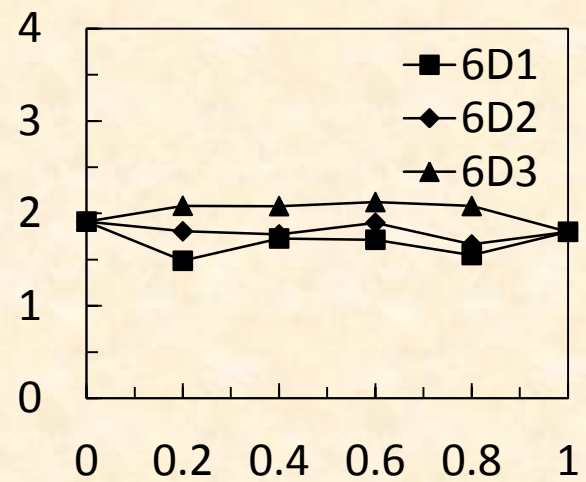
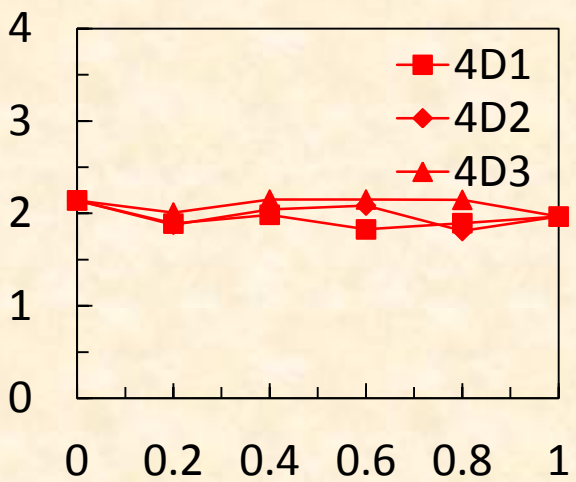
$N$ : storey number



	Design1	Design2	Design3
$\beta$	20	15	10

# Results

$R_0$



Resistance ratio ( $\alpha$ )

# Empirical equation of $R_o$

$$R_{oH} = (R_{ow} + R_{om})/2$$

$R_{oH}$ :  $R_o$  of hybrid building

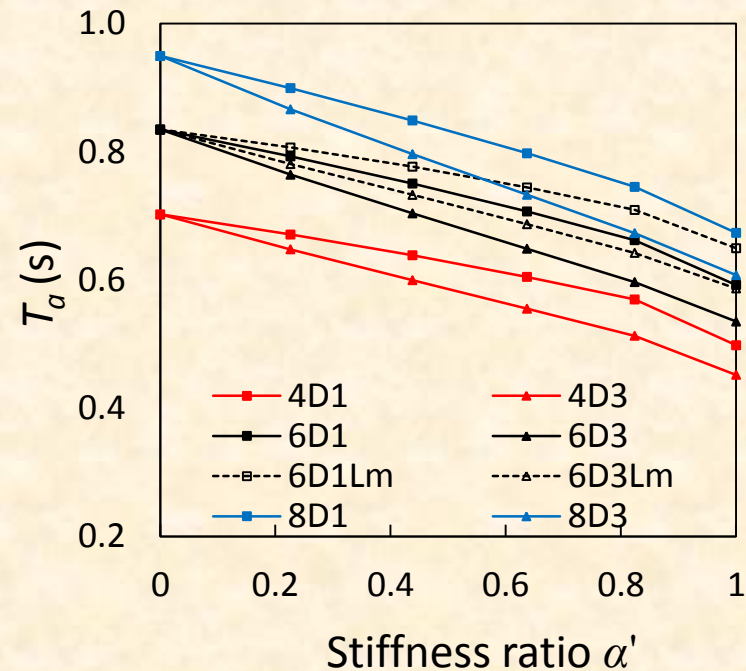
$R_{ow}$ :  $R_o$  of wood structure, 1.7

$R_{om}$ :  $R_o$  of masonry structure, 1.5

$R_o$	Design1	Design2	Design3
4-storey	2.0	2.0	2.1
6-storey	1.7	1.8	2.0
6-storeyLc	1.6	1.8	2.0
6-storeyLm	1.7	1.8	2.0
8-storey	1.6	1.7	2.0

# Fundamental period $T_a$ : 0.498s~0.950s

	W	H1	H2	H3	H4	M
4D1		0.67	0.64	0.60	0.57	
4D2	0.70	0.67	0.63	0.59	0.56	0.50
4D3		0.65	0.60	0.56	0.51	0.45
6D1		0.79	0.75	0.71	0.66	
6D2	0.83	0.79	0.74	0.70	0.65	0.59
6D3		0.76	0.70	0.65	0.60	0.54
6D1Lc		0.79	0.75	0.70	0.65	
6D2Lc	0.83	0.79	0.74	0.69	0.65	0.59
6D3Lc		0.76	0.70	0.65	0.59	0.54
6D1Lm		0.81	0.78	0.74	0.71	
6D2Lm	0.83	0.80	0.77	0.74	0.70	0.65
6D3Lm		0.78	0.73	0.69	0.64	0.59
8D1		0.90	0.85	0.80	0.75	
8D2	0.95	0.90	0.84	0.79	0.74	0.67
8D3		0.87	0.80	0.73	0.67	0.61



# Summary and conclusion

The  $R$  ( $R_d$ ,  $R_o$ ) of hybrid wood-masonry building can be larger than the lowest value of the two sub-system.

The  $R$  ( $R_d$ ,  $R_o$ ) value varies with changes of design method, resistance ratio of masonry core to hybrid building, building height and ductility level of connections and masonry core.

The failure mode of hybrid building depends on the relative stiffness and deformable ability of the wood, masonry and connections.

# Acknowledgements

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# The End Thanks