Prospects and challenges in future timber engineering research
- Japanese experience -

Motoi Yasumura

Todaiji Daibutsuden (8th century, renovated in 1709): largest existing wooden building in Japan


M Yasumura


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Major earthquakes 1978-2011

Year	Earthquake	Magnitude	Fatality/lost (person)	Number of damaged houses (unit)		
				Complete	Partial	Slight
1978	Miyagiken-oki	7.4	28	1,183	5,574	-----
1983	Nihonkai-chubu	7.7	104	934	2,115	3,258
1984	Naganoken-seibu	6.8	29	14	73	565
1995	Hyogo-ken nanbu	7.3	6,433/3	104,906	144,274	263,702
2000	Tottori-ken seibu	7.3	0	394	2,494	14,134
2003	Miyagi-ken hokubu	6.4	0	1,115	3,078	9,266
2003	Tokachi-oki	8	0/2	60	81	1,292
2004	Niigata-ken chuetsu	6.8	40	2,619	8,536	77,838
2007	Noto-hanto	6.9	1	649	1,655	24,959
2007	Niigata Chuetsu-oki	6.8	14	1,082	1,987	25,102
2008	Iwate-Miyagi	7.2	17/6	30	146	---
2011	Tohoku -Pacific Ocean	9.0	14,728/ 10,808	83,586	31,747	273,114

Damage of RC buildings(1995 Kobe)

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Damage of wood houses(1995 Kobe)

Damage of wood houses(1995 Kobe)

Damage of wood houses(1995 Kobe)

Steel or wood?

Damage of buildings (2011 Tohoku)

Damage by Tsunami(2011 Tohoku)

Damage by Tsunami(2011 Tohoku)

Damage of wooden house (2011 Tohoku)

Design of timber structures

- Prescriptive design

  Total floor area
  $\leqq 500 m^2$

  less than three stories

  Prescription described in Building Standard Law,

  Enforcement Order,

  Notifications

- Structural calculation

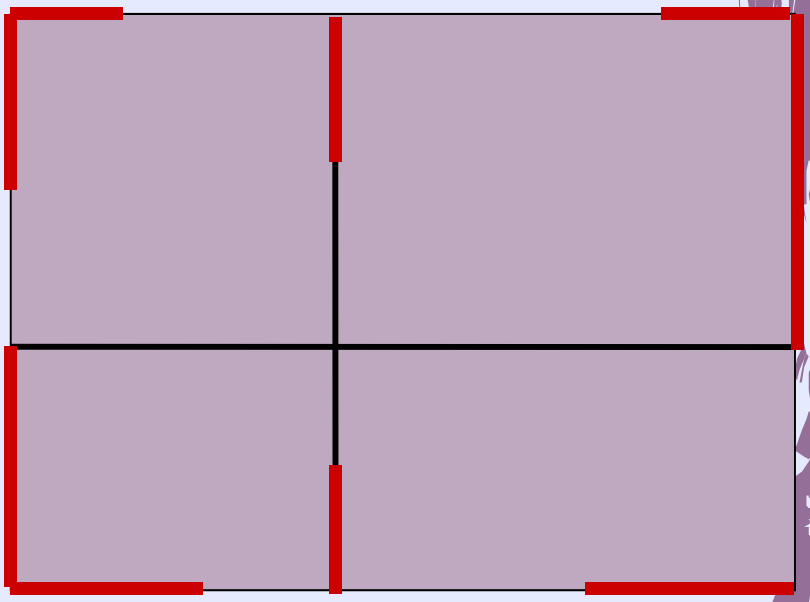
  - allowable stress design
  - Horizontal load-carrying capacity calculation (seismic)
  - limit capacity design (seismic, wind and snow)

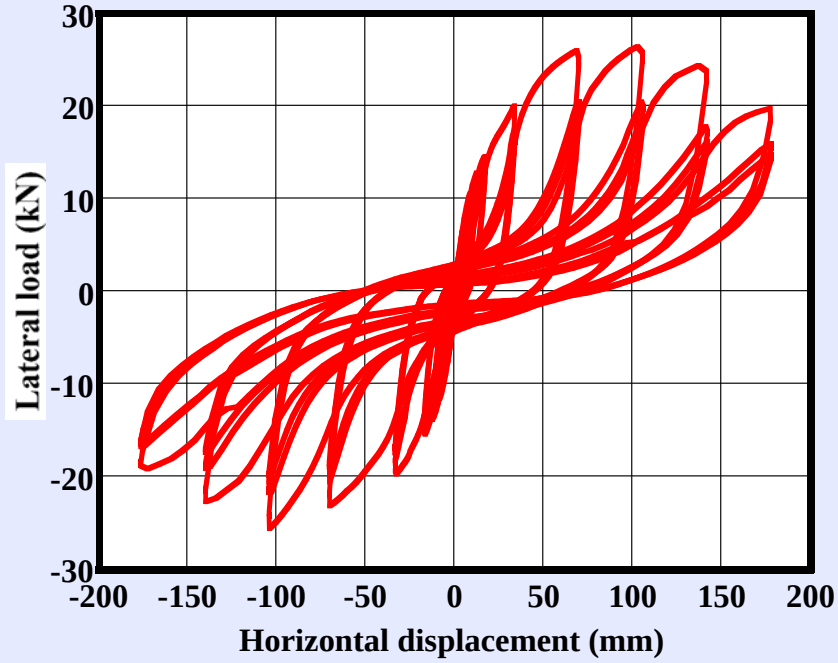
Prescriptive design
- Simplified method-

Effective length of shear walls
=sum of the wall coefficient x
wall length

Effective length of shear walls
> Required wall length x Area

For example:
Required wall length = 0.33m/m^2
in the case of the 1st story of two
story building

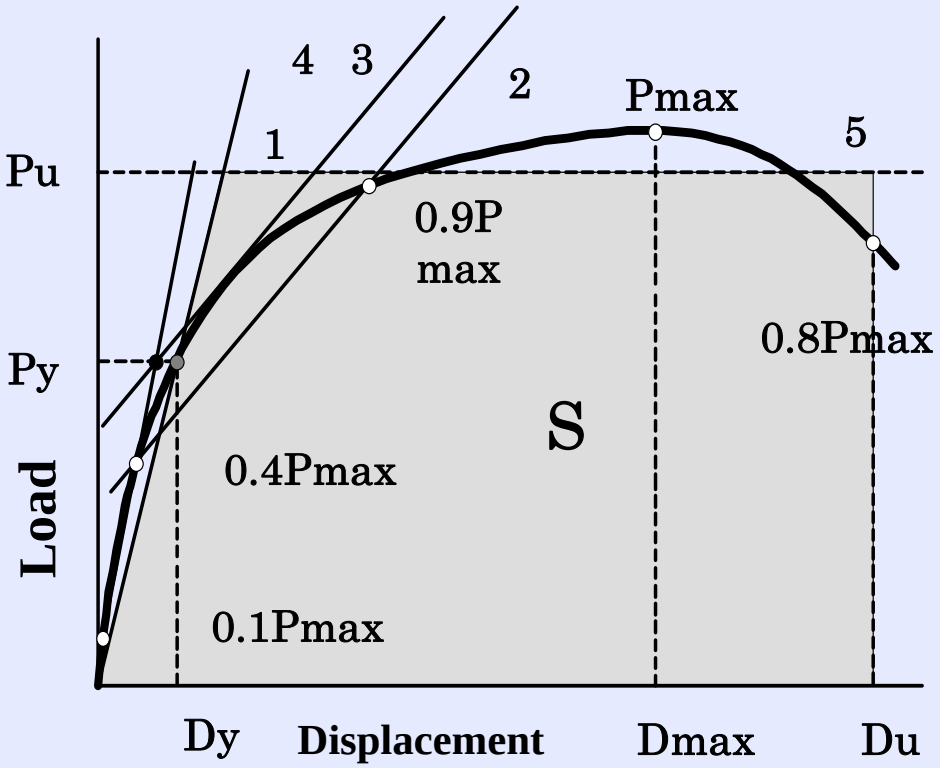




Wall coefficient is obtained by racking tests of shear walls

Full restraints are required to ensure full capacity of shear wall

Evaluation of wall Coefficient



$$W.C. = \frac{P_a}{1960 \times wall\ length}$$

$$P_a = \min. \begin{Bmatrix} P_y \\ P_{1/120} \\ 2/3\, P_{\max} \\ 0.2 P_u \sqrt{2\mu - 1} \end{Bmatrix}$$

Allowable stress design (moderate earthquake)

- Stress ≦ allowable stress (Co = 0.2)
- Story drift ≦ H/200 (H/120)
- Eccentricity ratio (Re) ≦ 0.15 (0.3)
- Stiffness ratio ≧ 0.6

＋

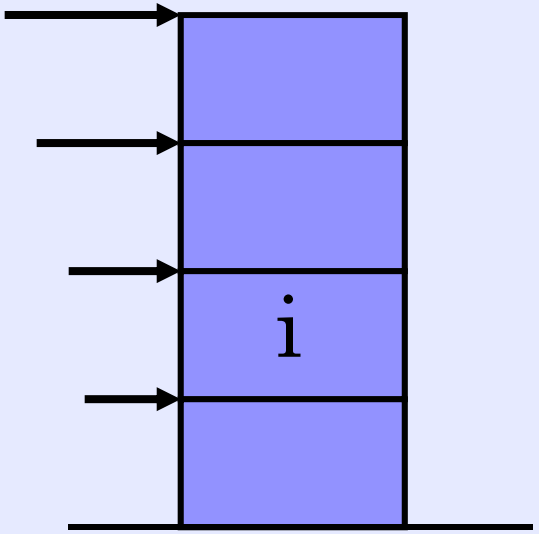
Requirements on structural methods

Horizontal load-carrying capacity (severe earthquake)

$$Q_i = C_i \cdot \sum W_i$$

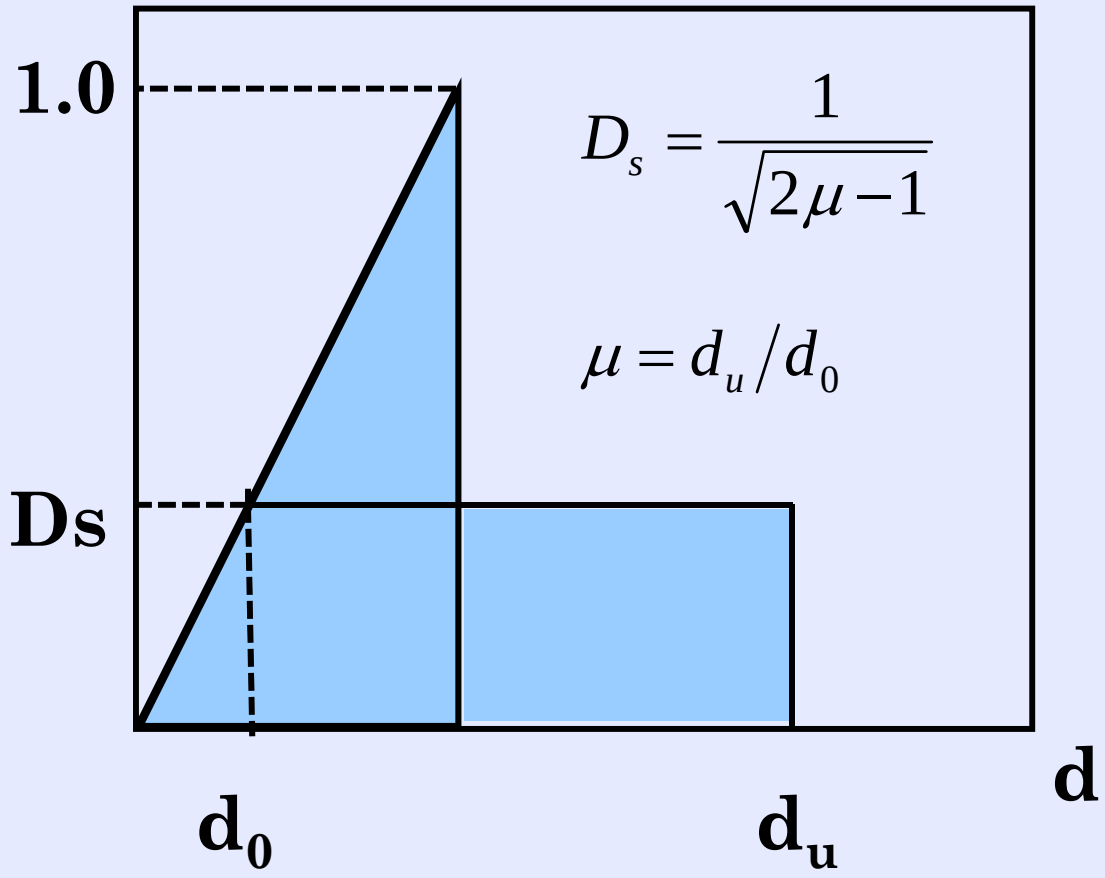
$$C_i = C_0 \cdot Z \cdot R_t \cdot A_i \cdot F_{es} \cdot D_s$$

$$C_0 = 1.0$$

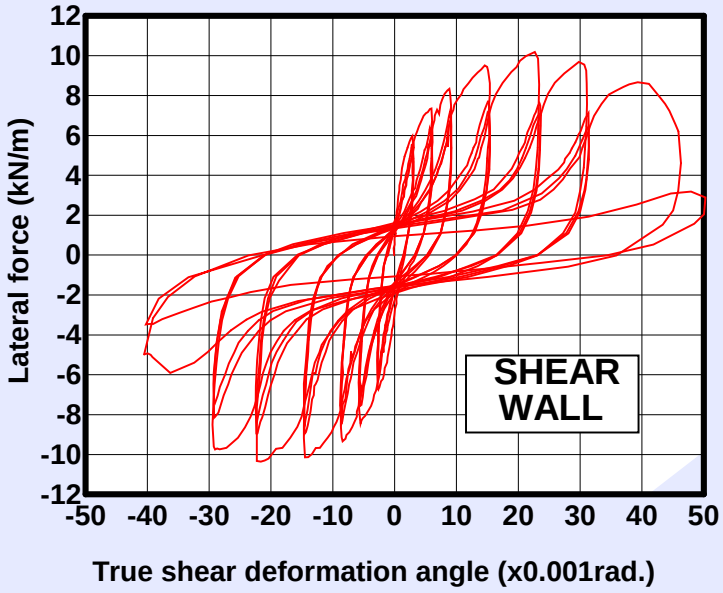


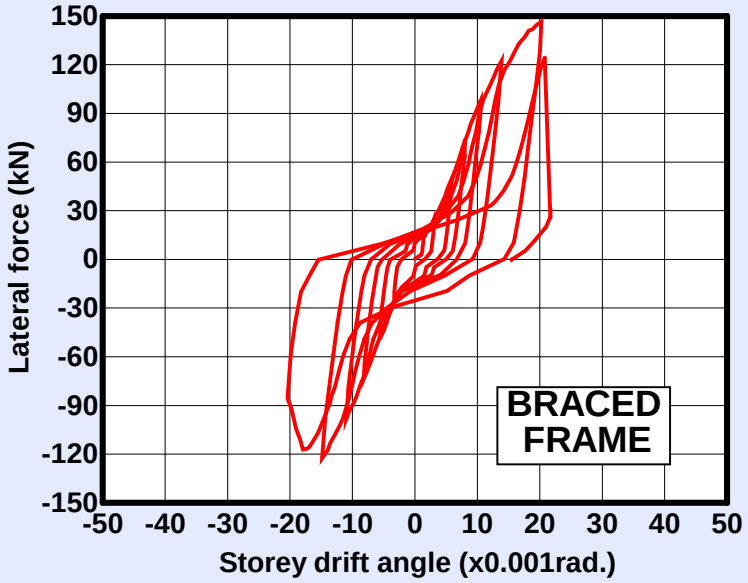
$$Q \geqq Qi$$

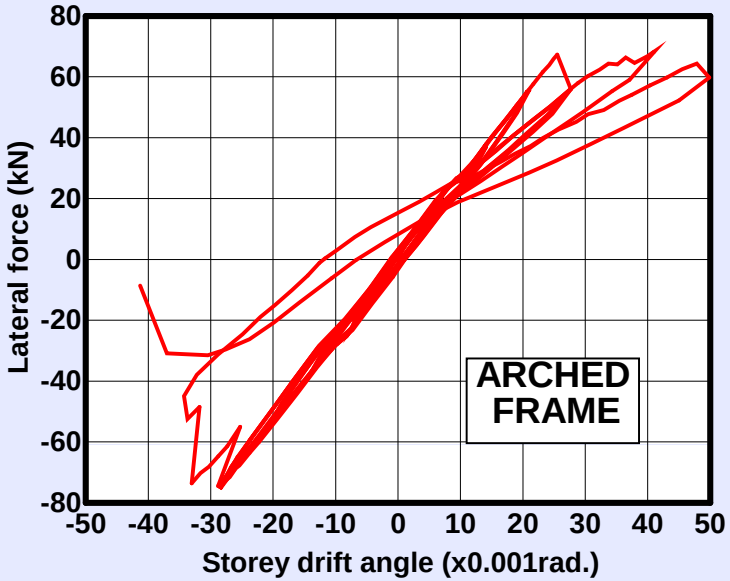
Structural behavior factor (Ds)

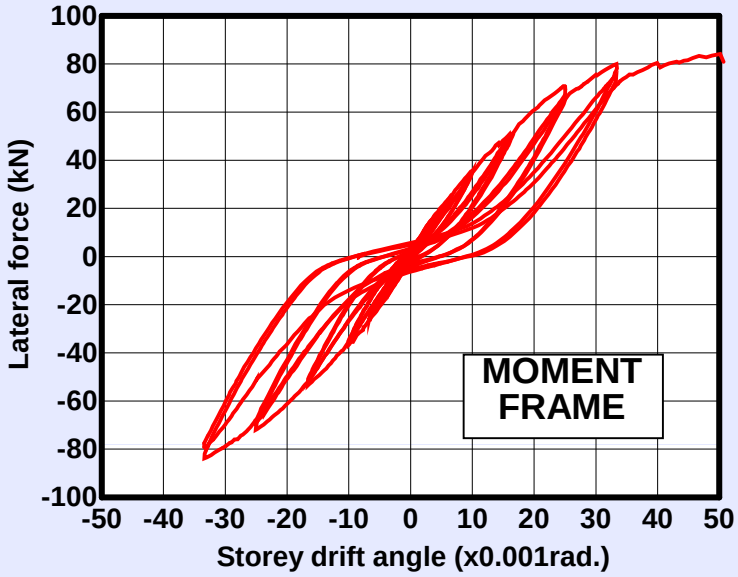


Ductility of timber structures

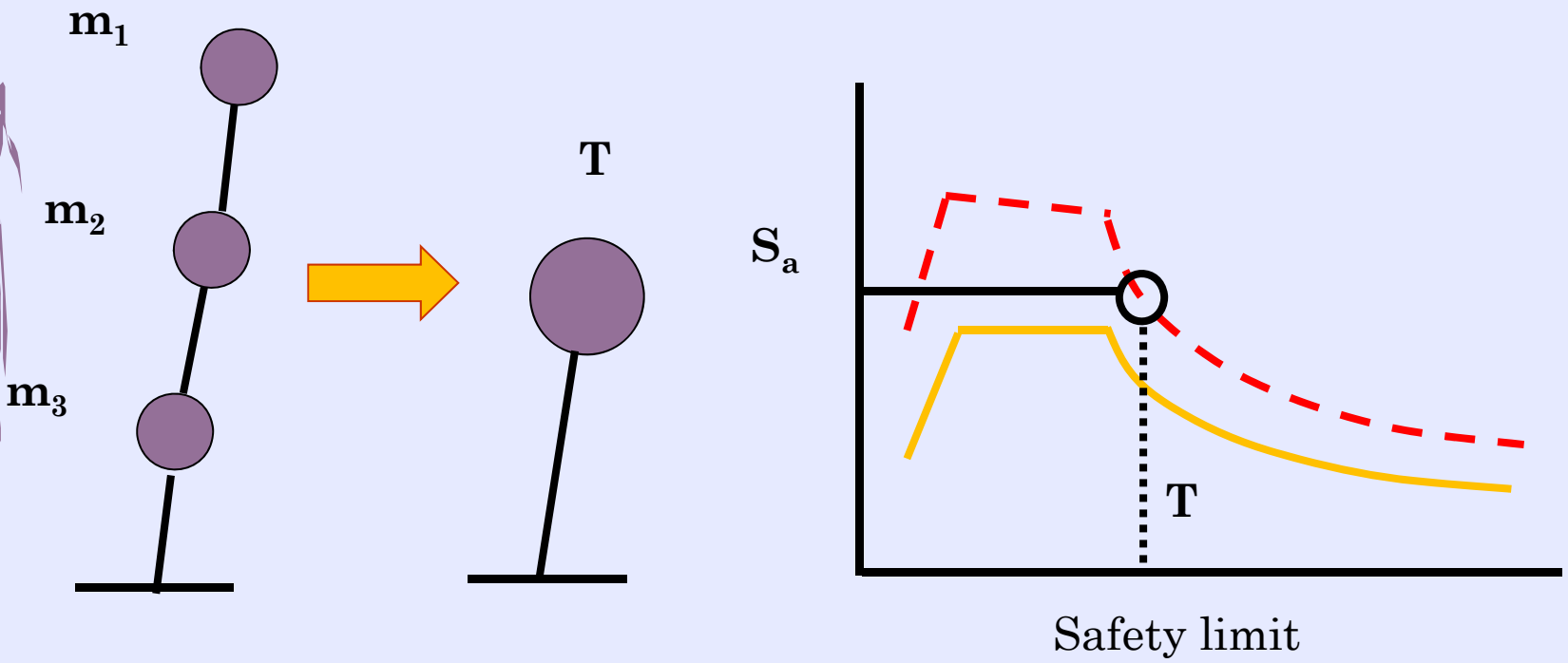






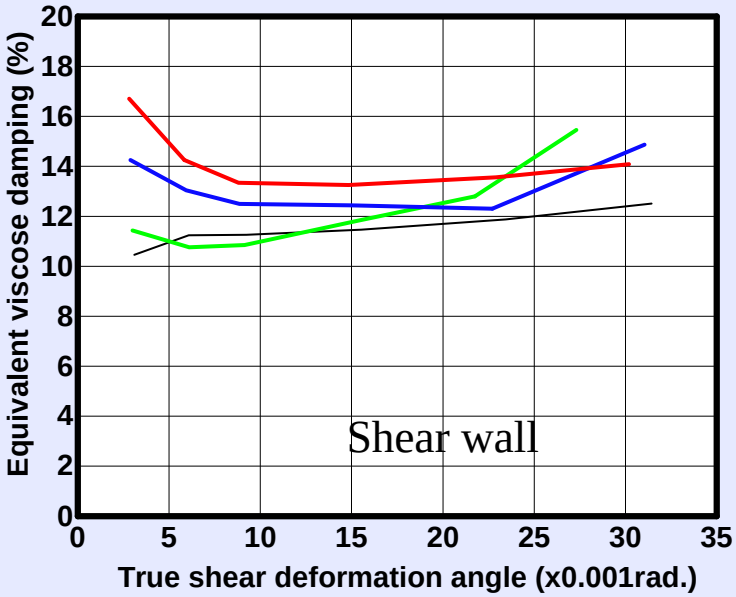


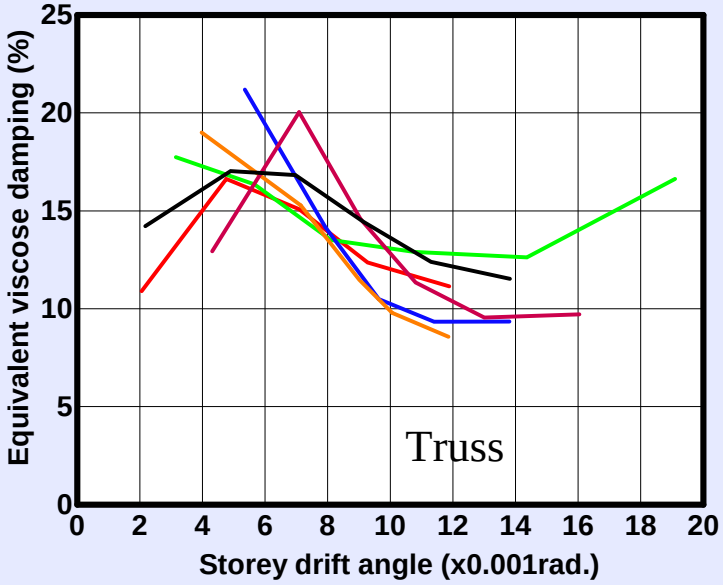
Capacity spectrum design (Limit capacity design)

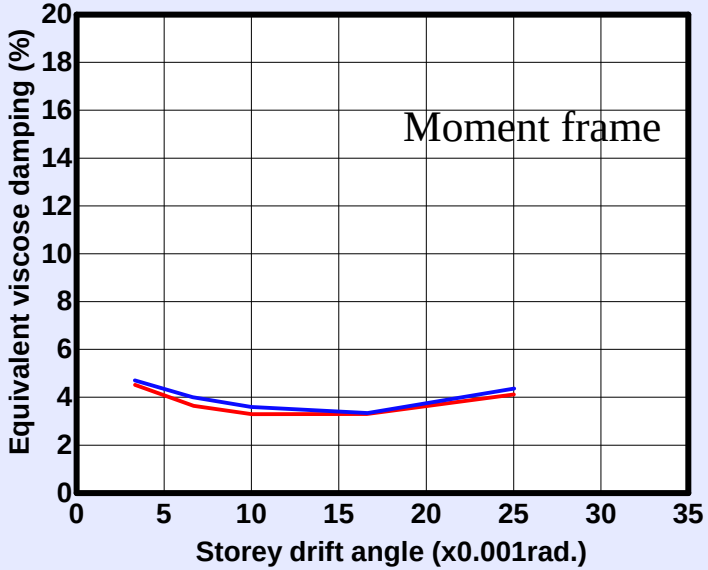


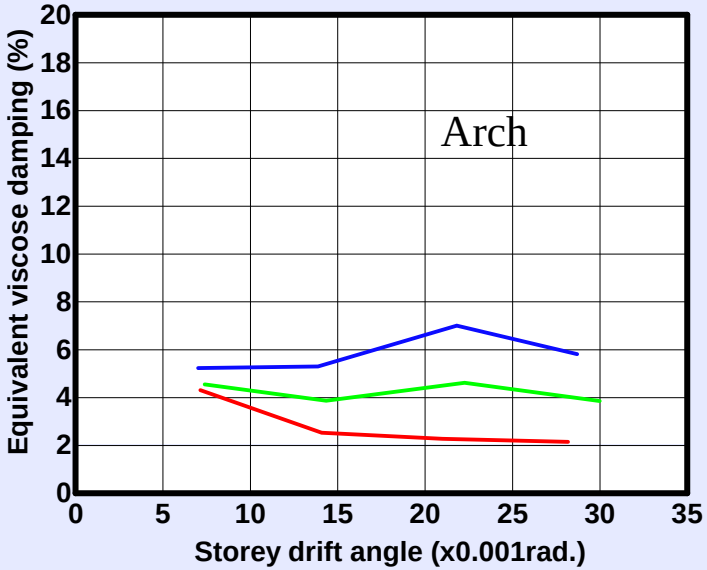
$$Q_i = B_i F_h Z G_s S_a \sum m_i$$

Equivalent damping









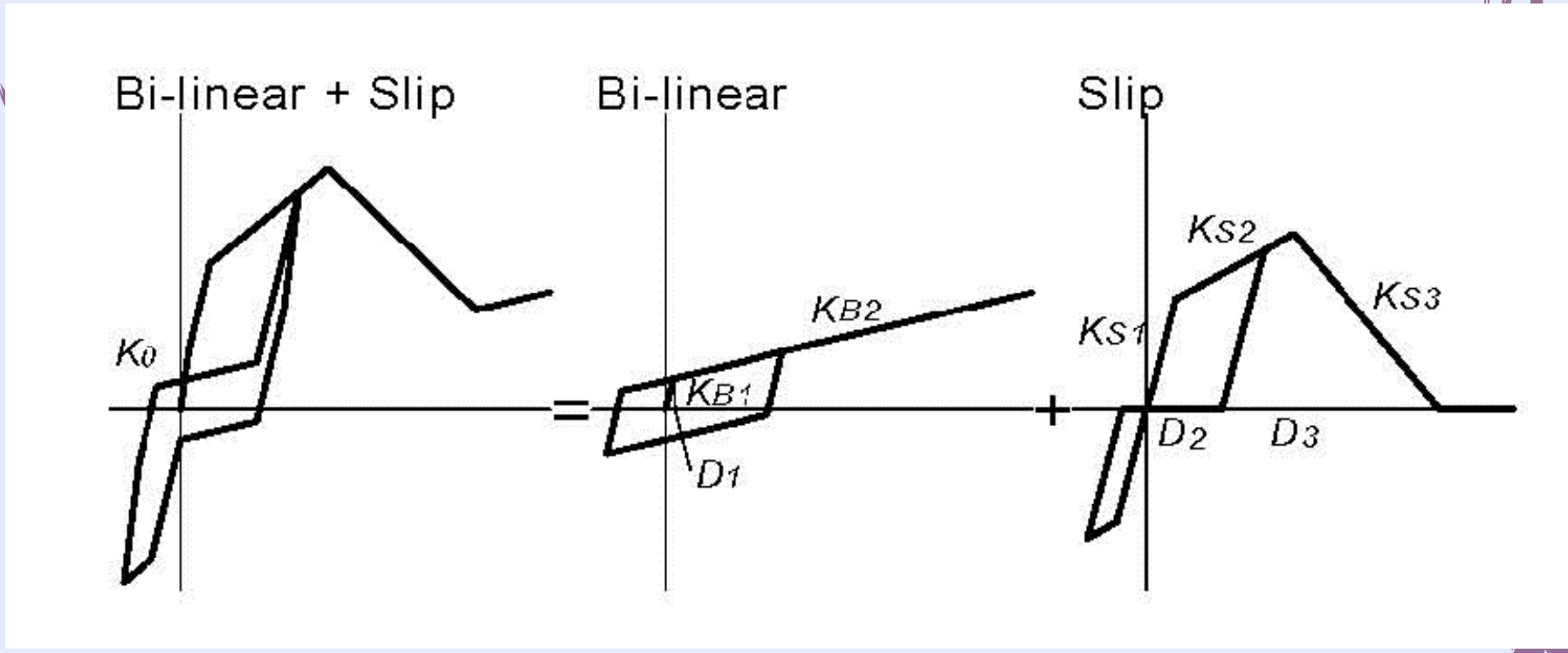
Time history response analysis

- Input earthquake ground motions
  - observed ground motion
  - simulated seismic motion following the spectrum stipulated in Building code or at the construction site
- Input ground motion level (level 1, level 2)
  level 1 (return period of 50-100 years)
  level 2 (return period of 500 years)

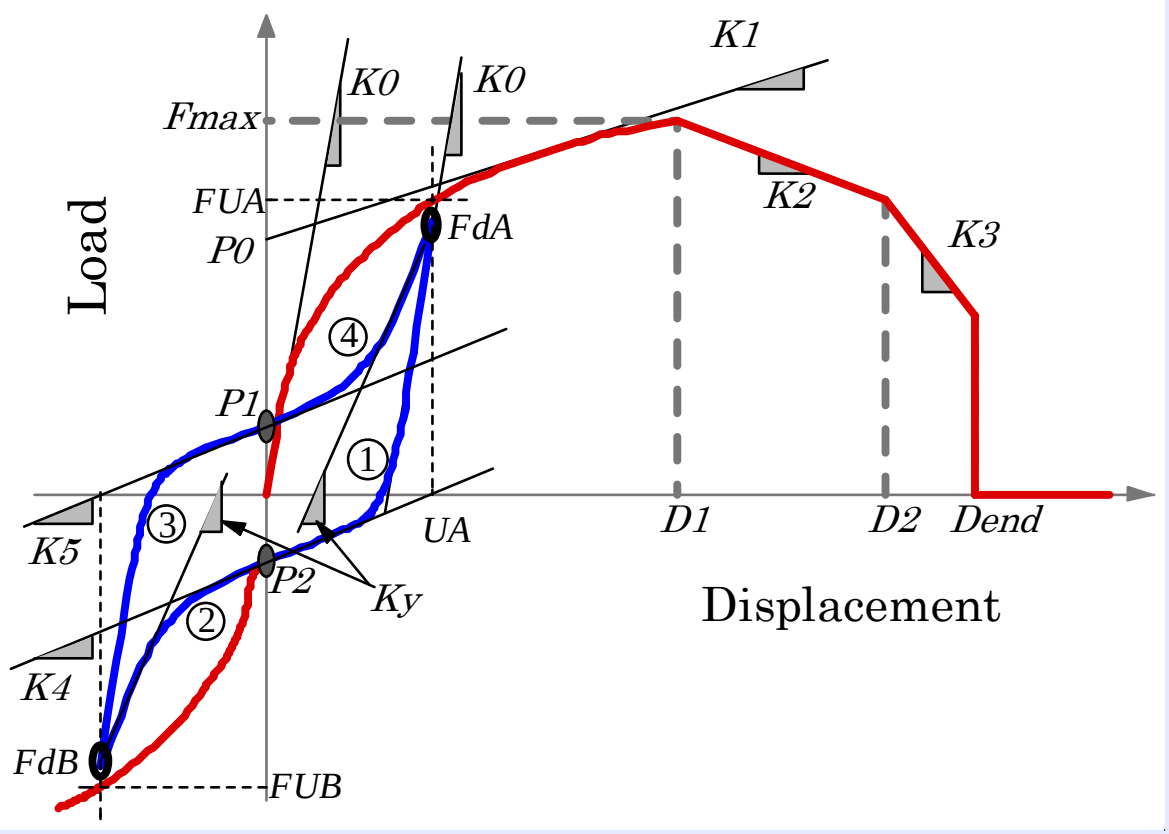
Modeling of timber structure

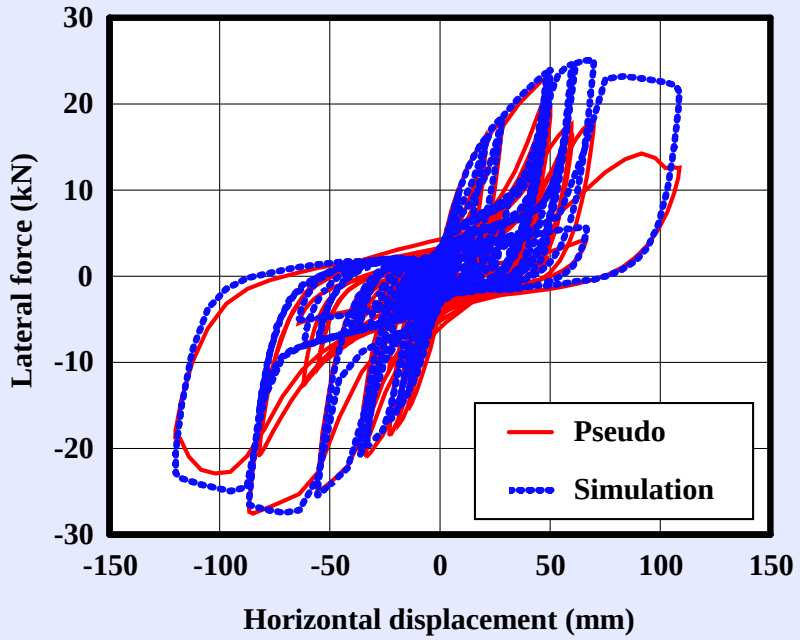
- Joints dissipate seismic energy while wooden members remain elastic
- Modeling of hysteretic properties of joints or seismic resistant assembly
- SDOF damped mass-spring system
- Finite Element Method
- Distinct Element Method
- Micro-macro model

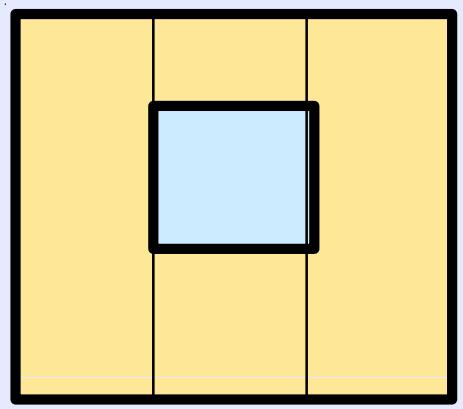
Hysteresis model for joints, shear walls, etc.

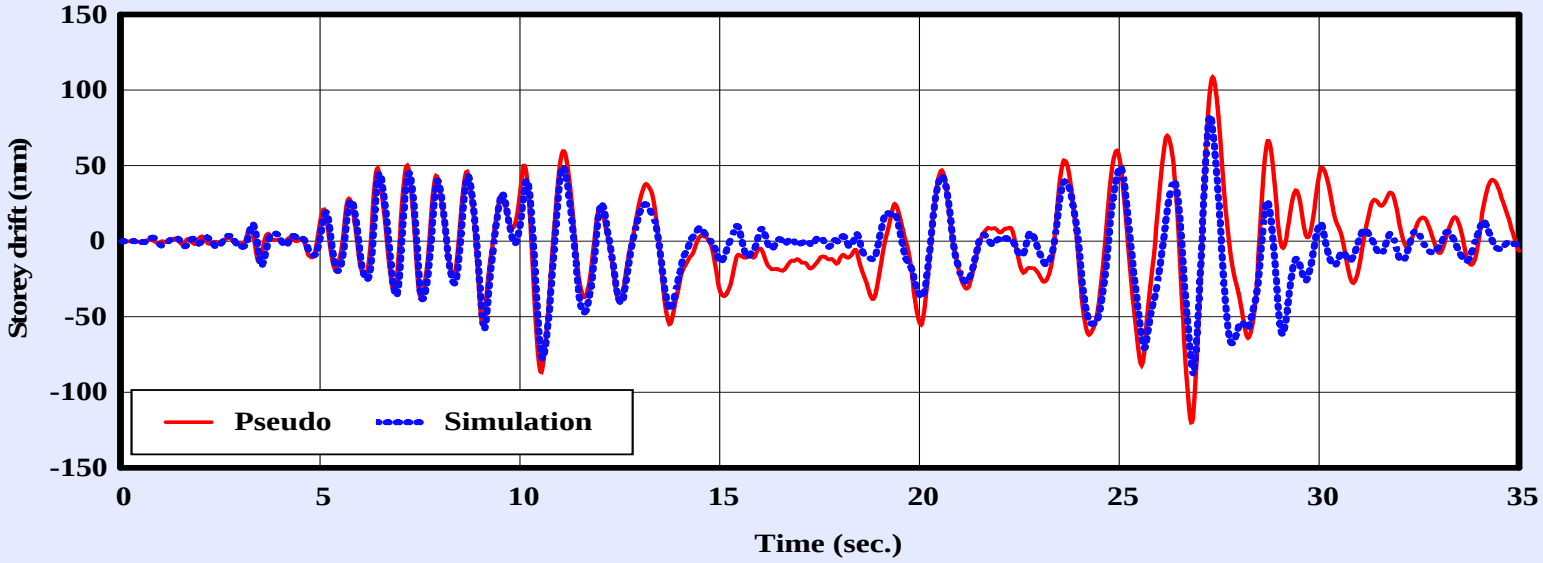


LMT model


K1
K0
K0
Fmax
FUA
P0
FdA
K2
K3
Load
④
P1
①
③
K5
UA
D1
D2
Dend
P2
Ky
Displacement
②
K4
FdB
FUB


Lateral force (kN)
30
20
10
0
-10
-20
-30
-150
-100
-50
0
50
100
150
Horizontal displacement (mm)
Pseudo
Simulation

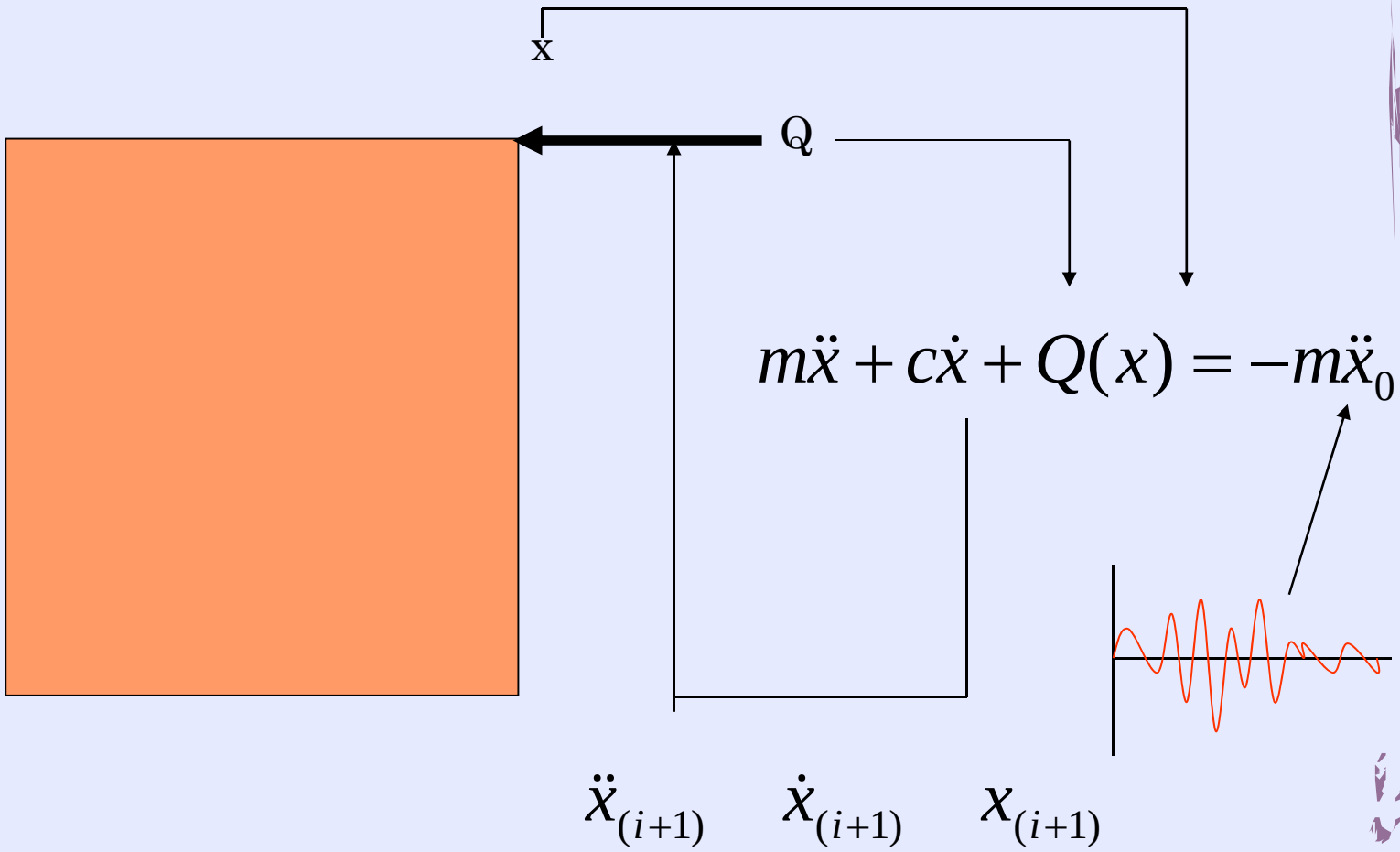


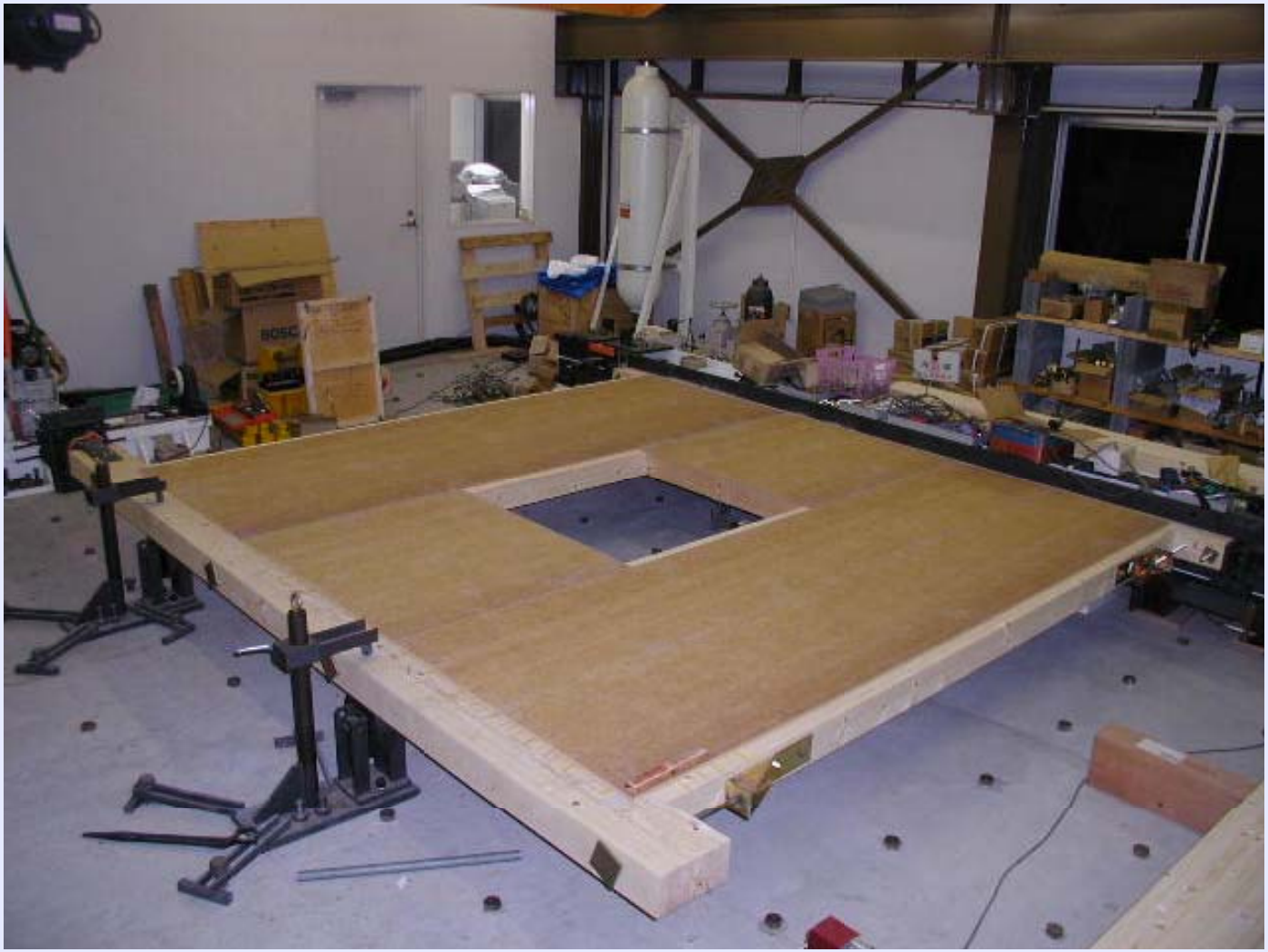

Storey drift (mm)
150
100
50
0
-50
-100
-150
0
5
10
15
20
25
30
35
Time (sec.)
Pseudo
Simulation

Validation of model

- Pseudo-dynamic test
- Shaking table test

What is Pseudo-dynamic test?

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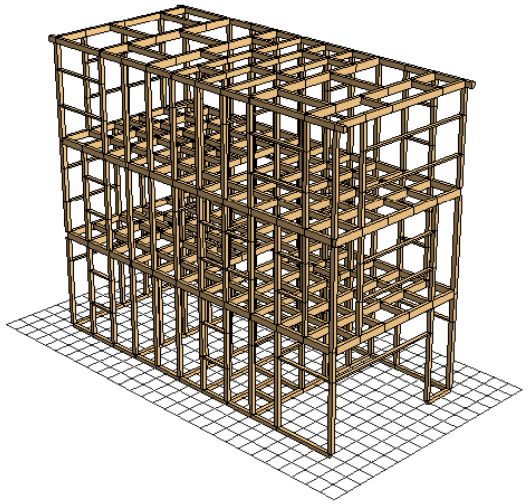
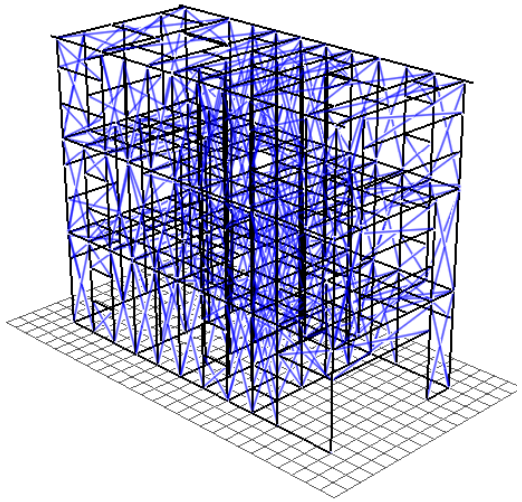
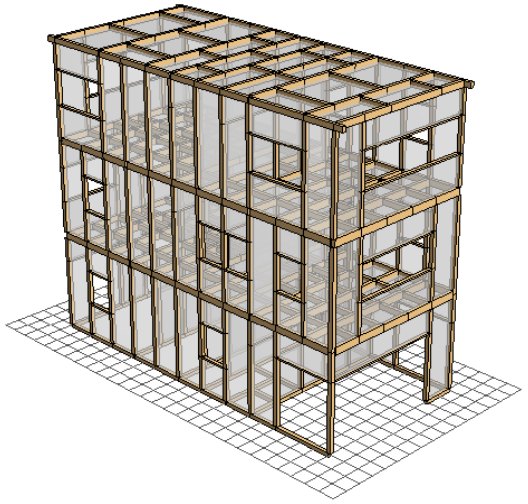
Is deterministic approach correct?

Analysis by Distinct Element Method







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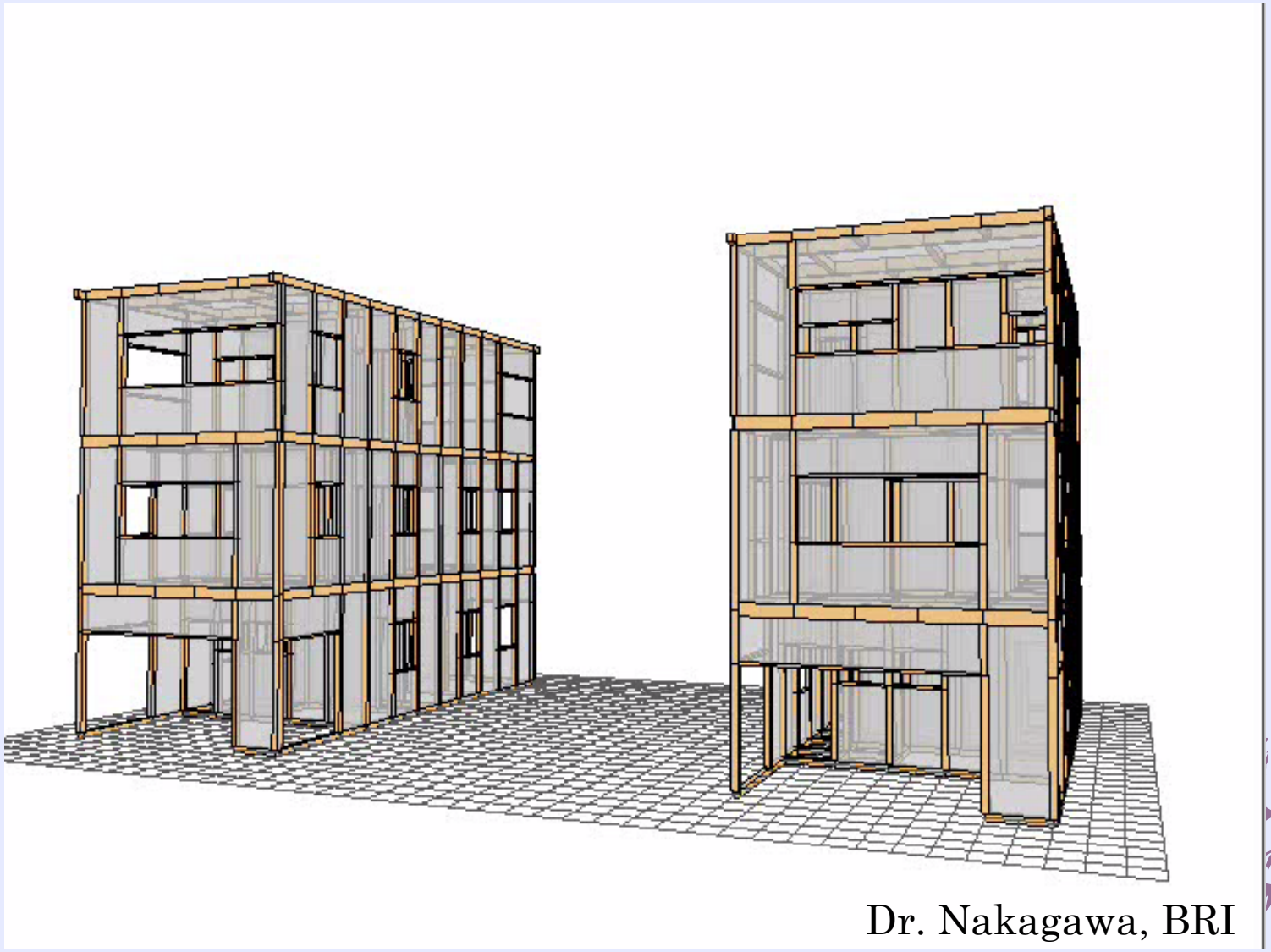
Calculation before the test



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Conclusions

- How can we determine Ds (q) values for new types of timber structures?
- Probabilistic approach will be necessary to determine the failure mode.
- We need the data base on the reversed cyclic loading test results for joints and seismic resistant assemblies.

Thank you for your attention!