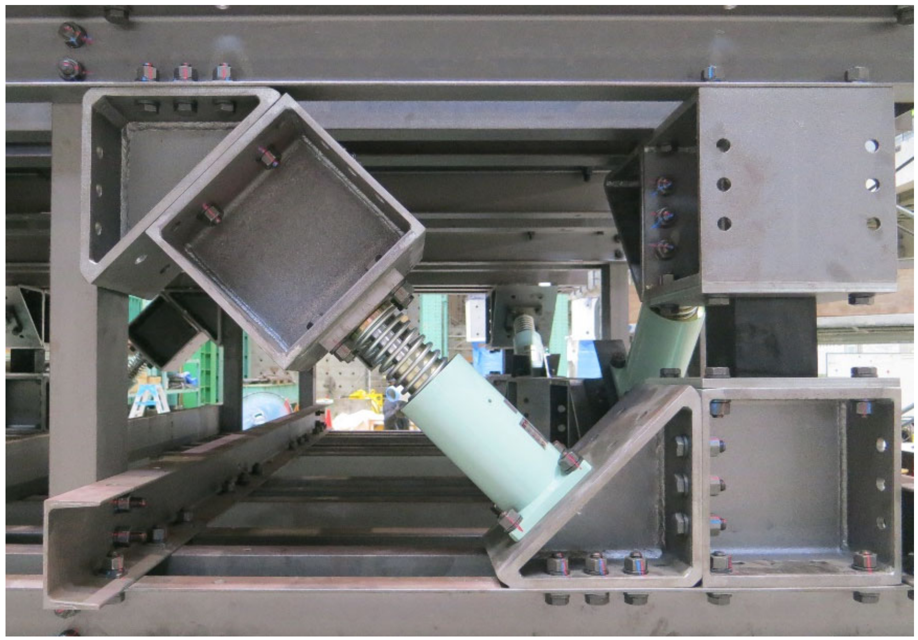
Partially Isolated Structure Dynamics under Random Excitation



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■ Back ground and Outline of the Research Project

１. Back ground and motivation of the research
→ Recognition of the small vibration control performance of many application projects with dampers

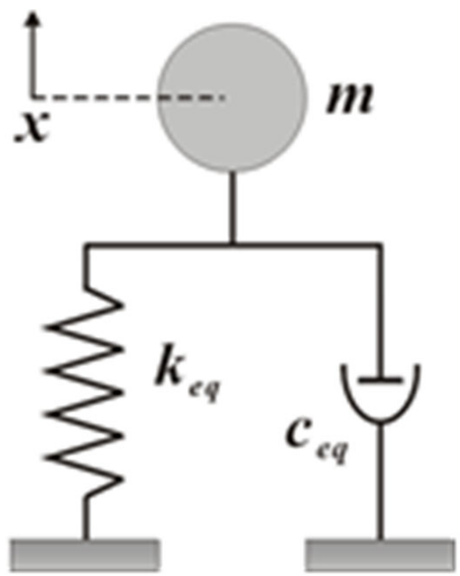
２. Theoretical study funded from 2011 to 2013 by Japan Society for Promotion of Science
→ The second order dynamic equation does not properly explain the damping performance

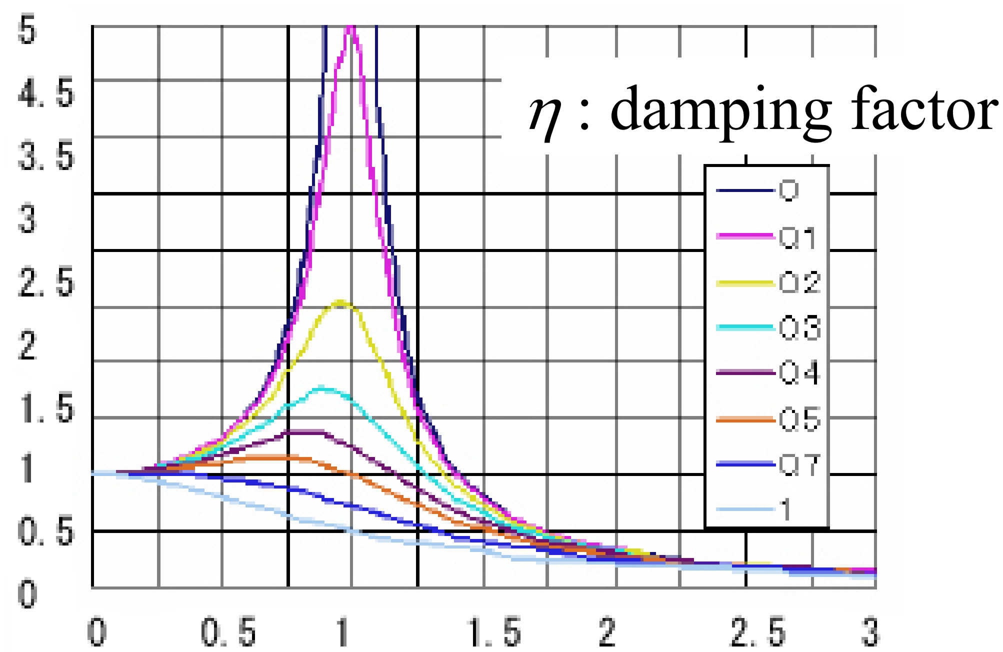
３. Research project currently funded by Tokyu Construction Co.
→ Shaking table tests of a frame structure with dampers and laminated rubber bearings

Part A

Why passive dampers do not work well ?

■ Because the model in the text book is insufficient.





ω : natural frequency

Second order dynamic model

Resonance curve

■ Weak point of the conventional dynamic model

○ As we increase the damping coefficient, the structure’s stiffness becomes large as a result.
The natural frequency of a system with high stiffness naturally becomes higher, which is our common sense.

○ The formula from the second order dynamic model tells us the natural frequency is given by

$$\omega = \omega_0\sqrt{1 - \eta^2}$$

which is against our common sense.

■ Why this happen ?

○ Eigenvalue of the second order differential equation can explain exactly two physical phenomena.

One: The amplitude does not influence the natural period.

Two: The amplitude decreases as the time goes on.

○ There is at least one more to explain….

Three: As the damping factor increases, the stiffness of the system increases.
As a result, the mode frequency becomes higher.

■ Why this happen ?

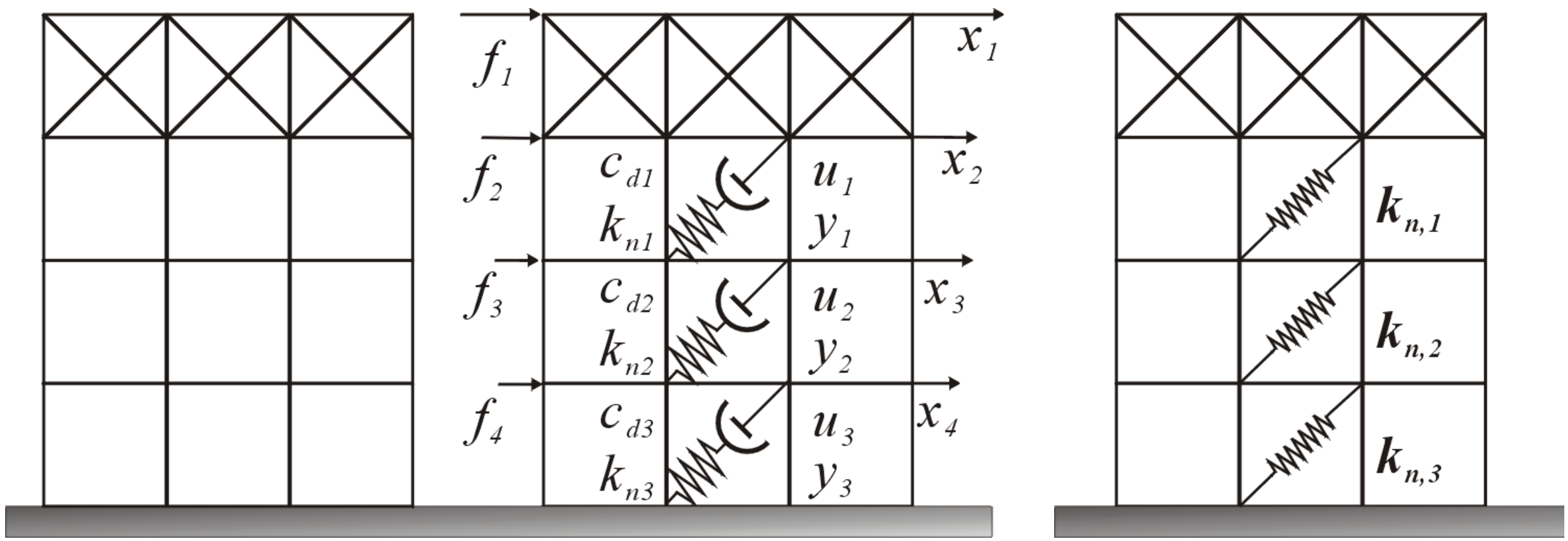
○ Eigenvalue of the third order differential equation can explain three physical phenomena at one time.

One: The amplitude does not influence the natural period.

Two: The amplitude decreases as the time goes on.

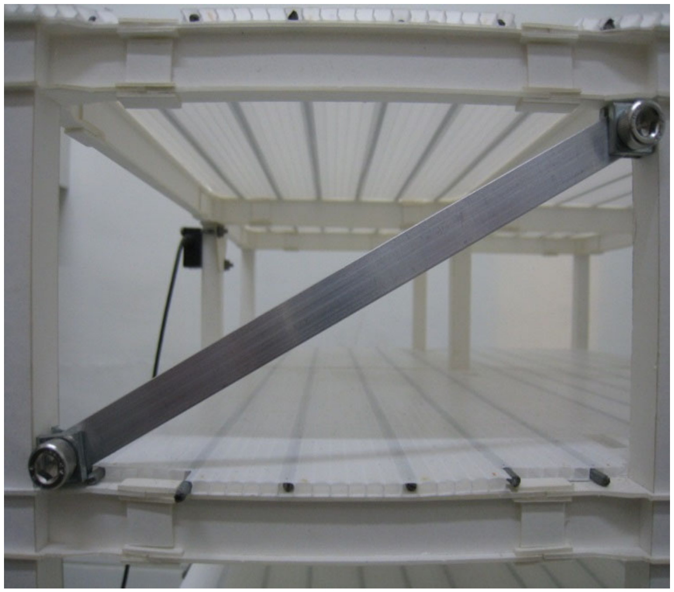
Three: As the damping coefficient increases, the mode frequency becomes higher.

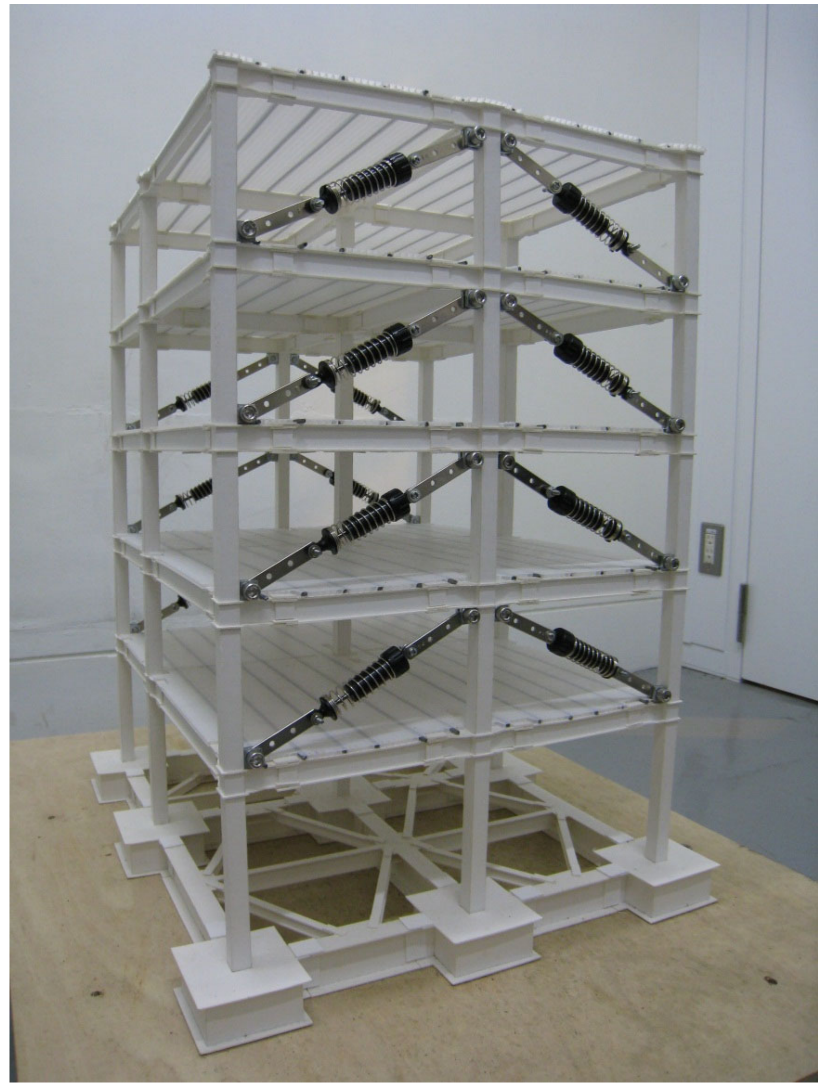
■ Third order differential equation model



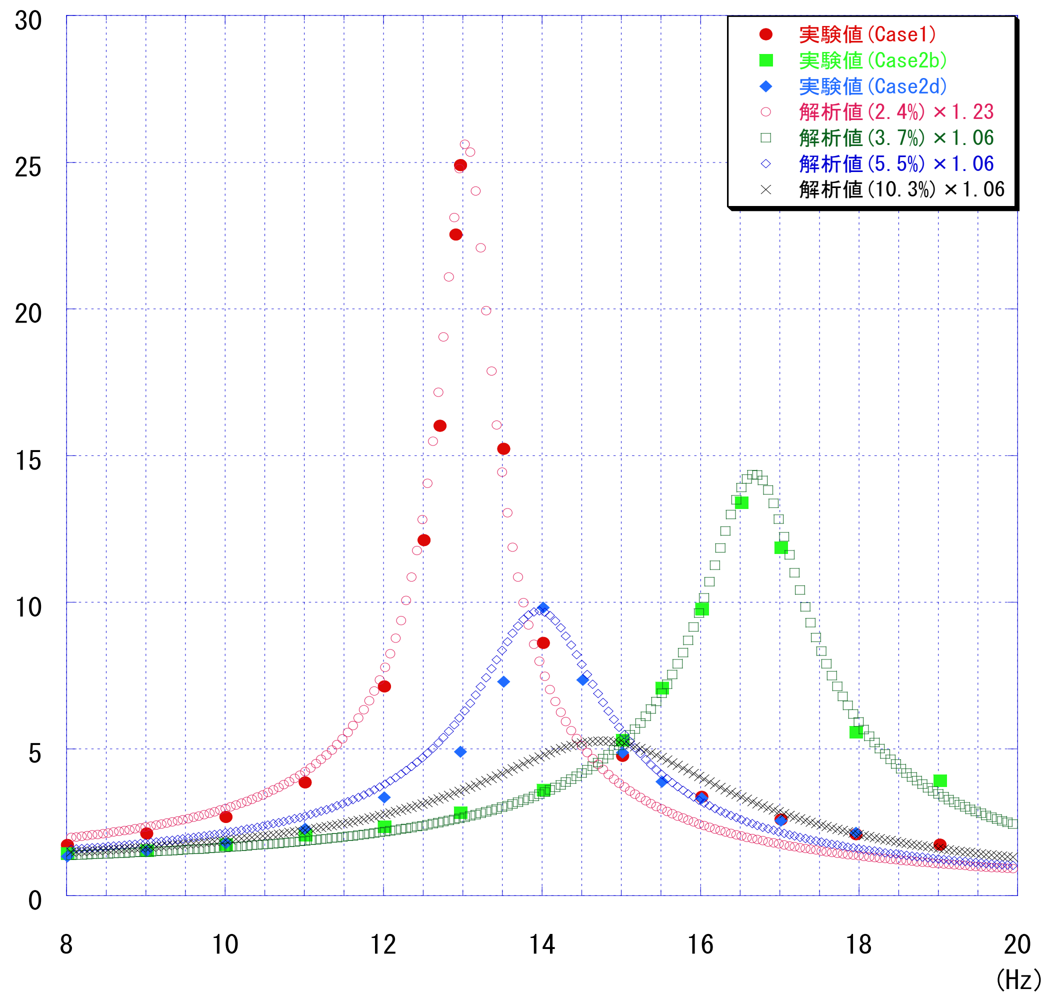
ωo	<	ωeq	<	$\omega \infty$
$Cd = 0.0$	<	$Copt$	<	$Cd = \infty$
$\eta = 0.0$	<	ηmax	>	$\eta = 0.0$

■ Small model test under random excitation





◇ Test result from a small model on the shaking table



Part A

Conclusion

It is impossible to achieve damping factor more than 5 % by means of implementing damping devices into a relatively large building structure.

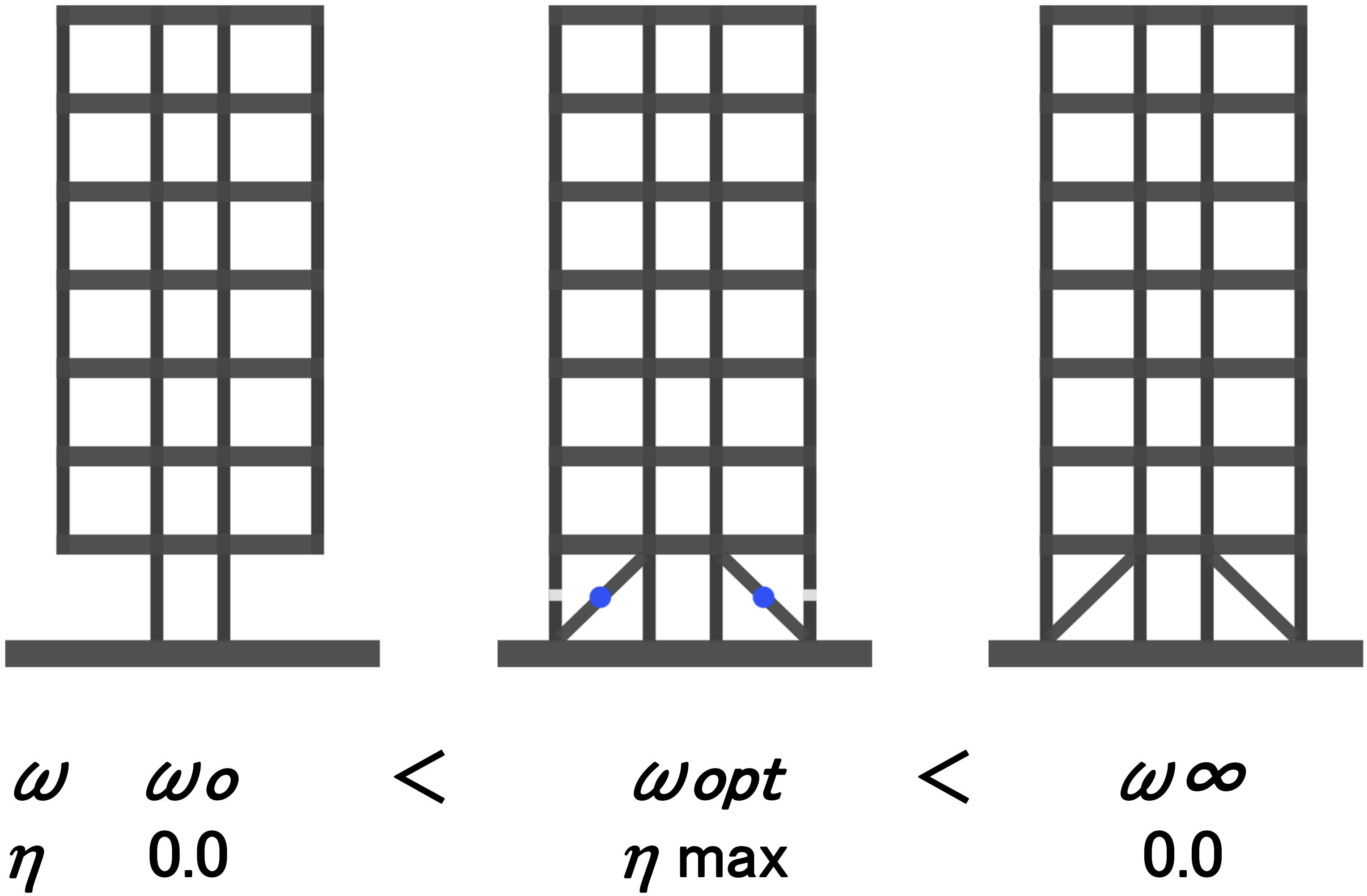
Part B

How can we achieve high damping performance ?

Solution

If we want to improve damping performance, we should increase the stiffness of the structure by installing damping devices.

■ Study of damper location



■ Study of damper installation

○ The third order differential equation tells us..

If you wish to get high damping performance,
you should implement not only damping devices
but also structure members at the same time.

Because you can not increase damping factor independently,
in other words the damping factor is related to stiffness.

■ Evaluation of damping factor and natural frequency

- Stiffness augmentation

$$\beta = \frac{\omega_\infty^{\ 2} - \omega_o^{\ 2}}{\omega_o^{\ 2}}$$

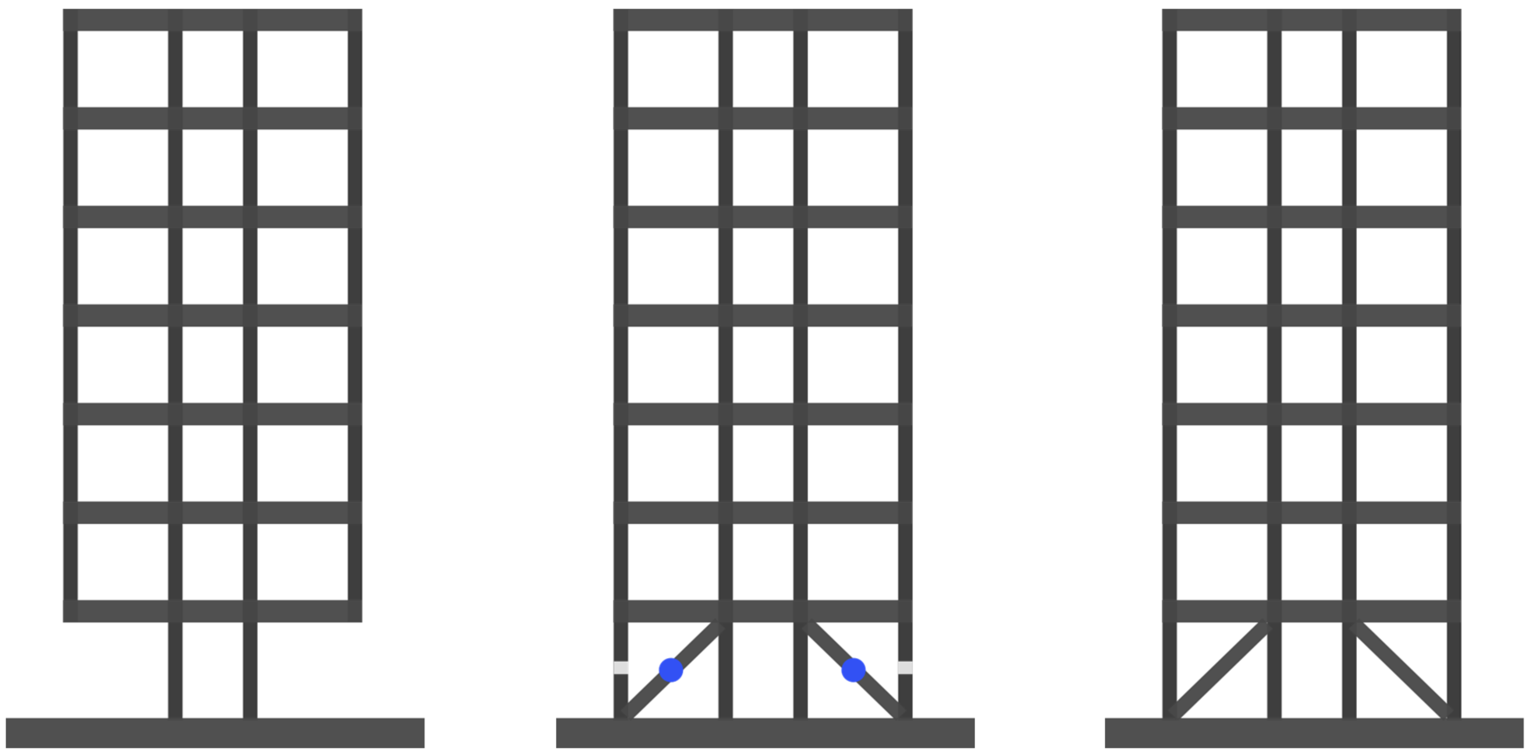
- Upper boundary of damping factor

$$\eta_{eq} = \frac{\beta}{2+\beta}\sqrt{\frac{1}{2(2+\beta)}}$$

- Frequency of the partially isolated structure

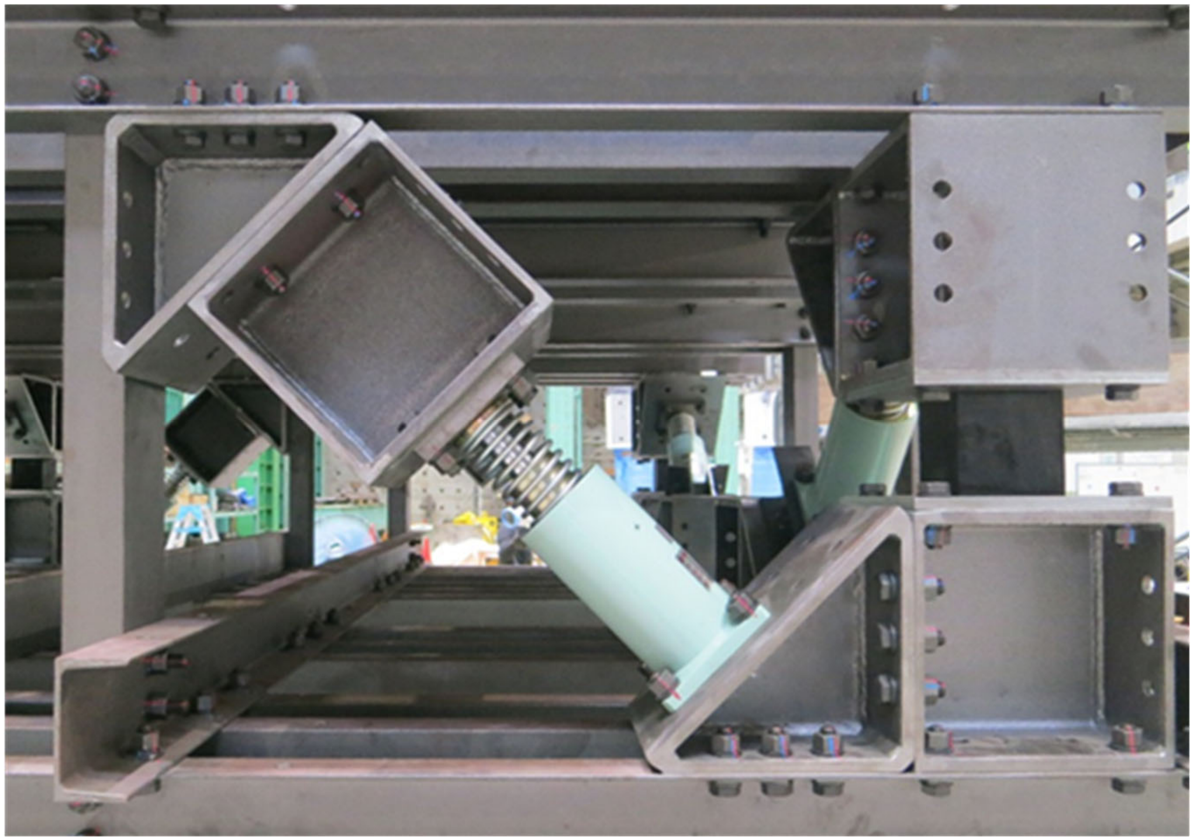
$$\omega_{eq} = \sqrt{\frac{\omega_o^{\ 2} + \omega_\infty^{\ 2}}{2}}$$

■ Evaluation of damping factor and natural frequency



ω	ω_o	$<$	ω_{opt}	$<$	ω_∞
η	0.0		η max		0.0

■ Configuration of damper and rubber bearing



■ Steel frame model

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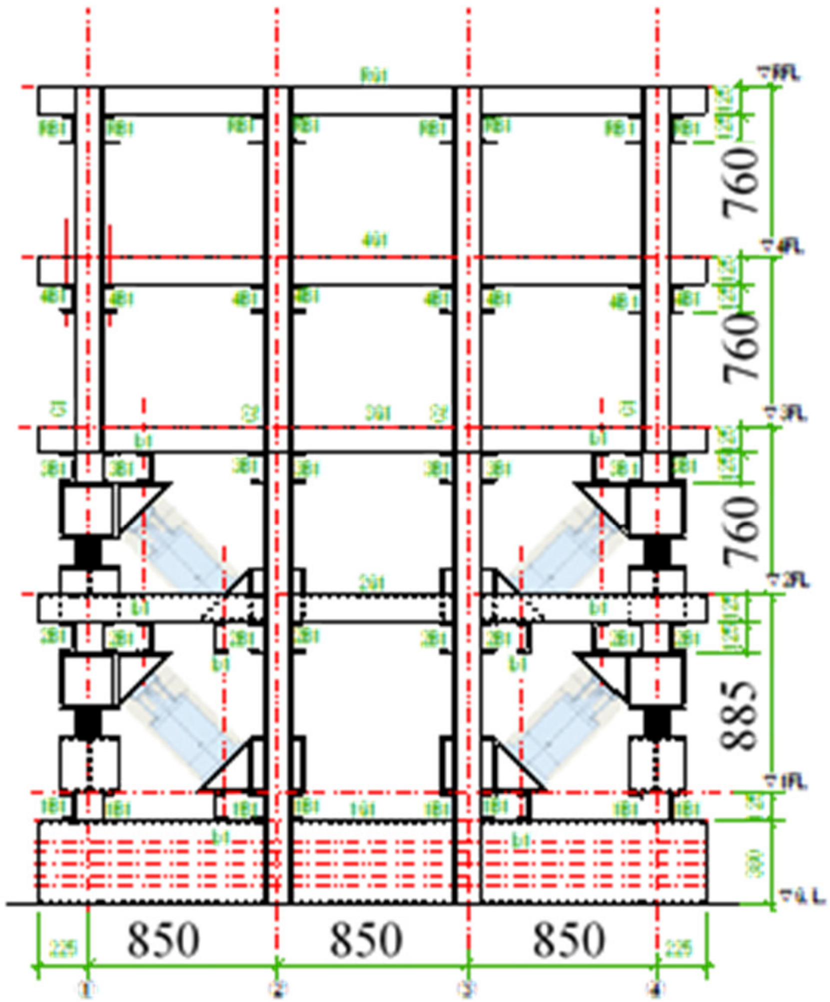
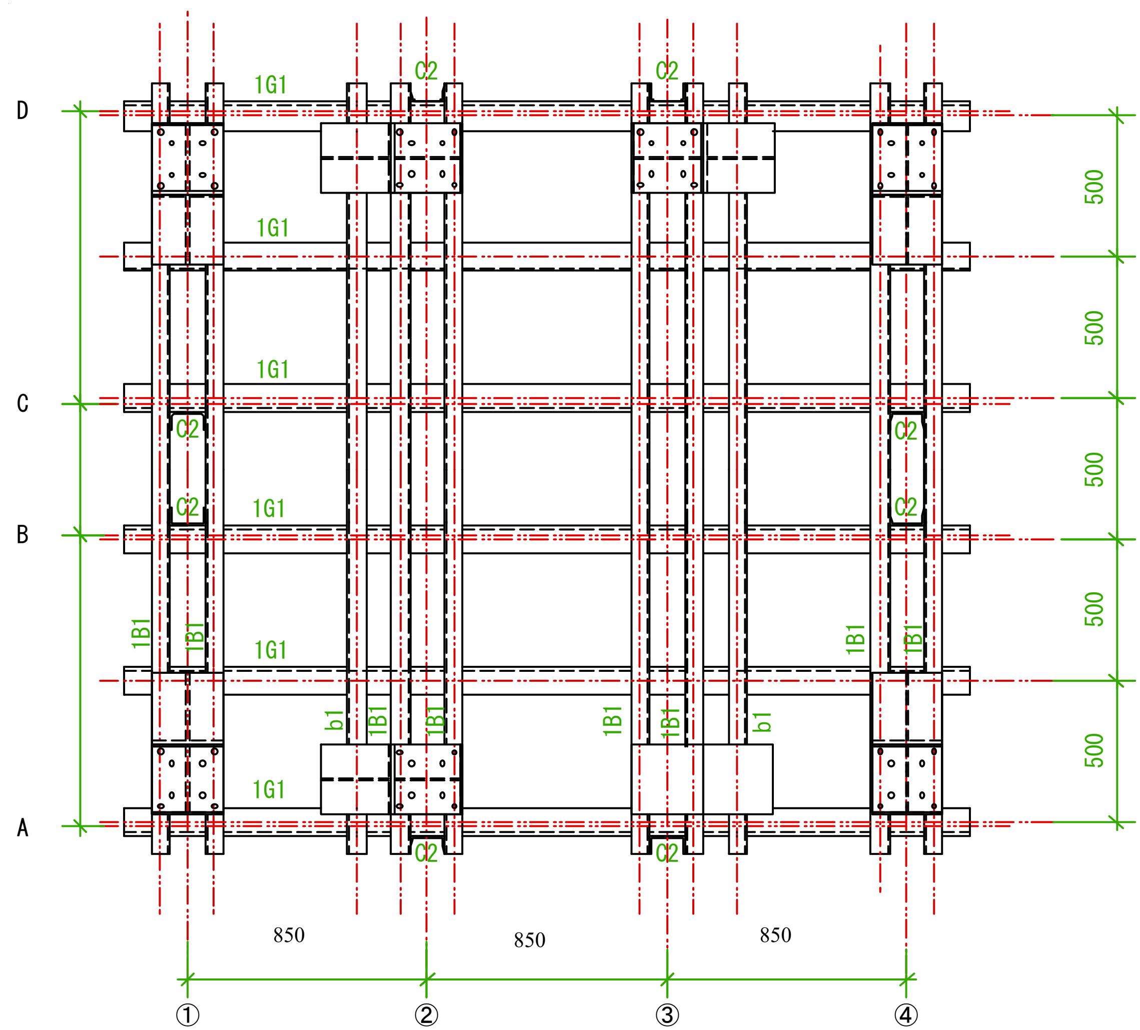
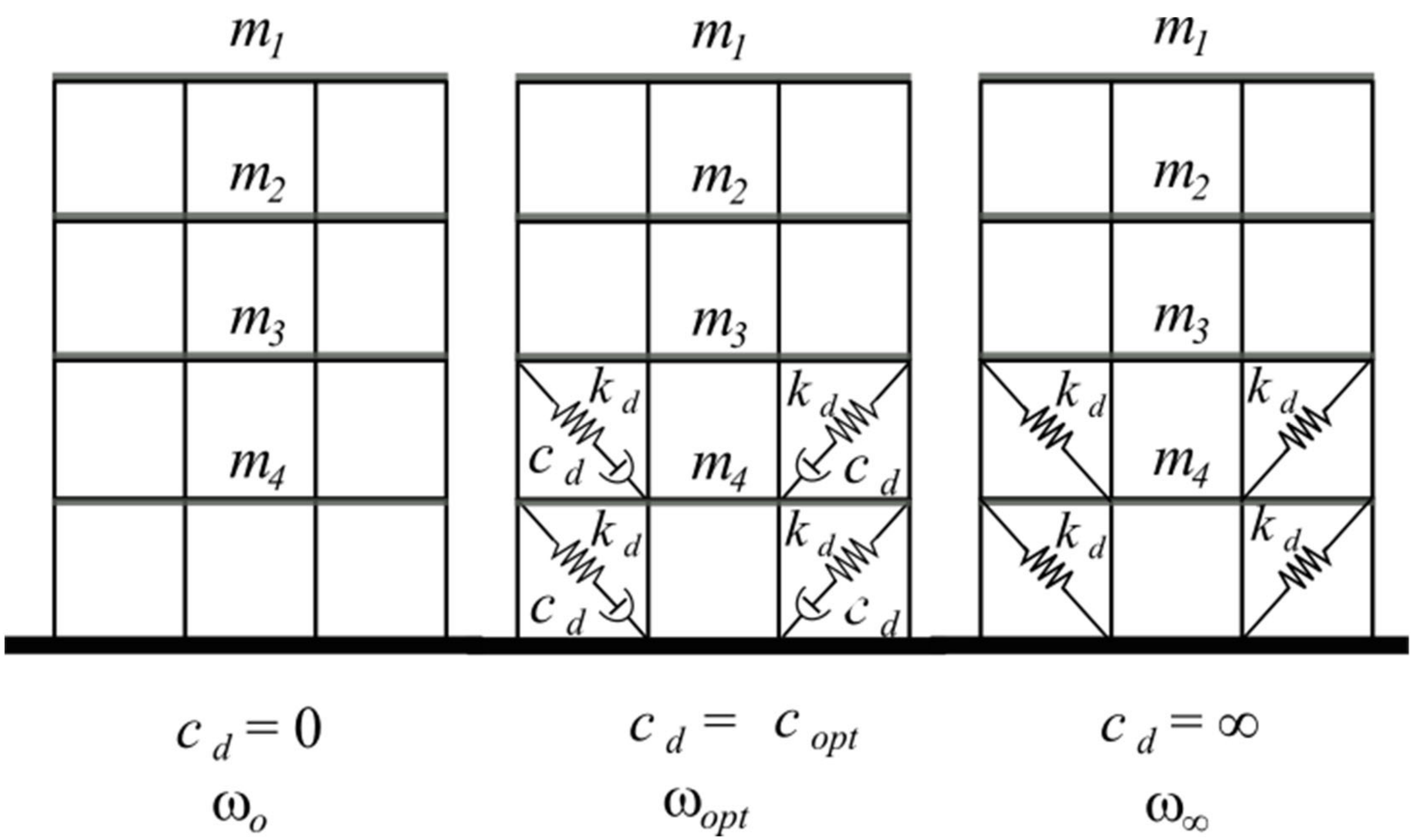


■ Ground floor of the steel model

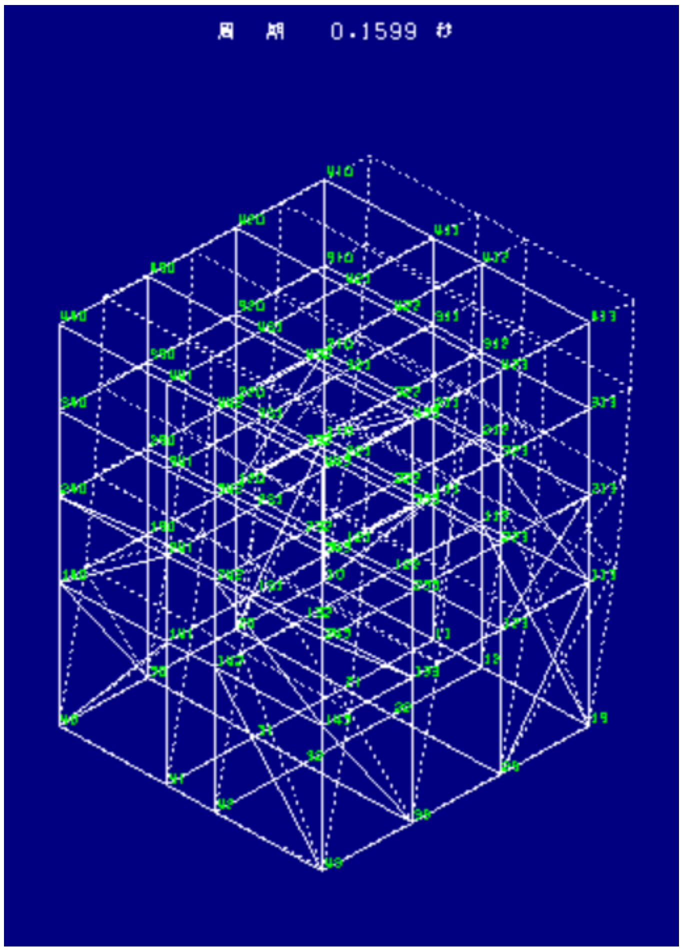


■ Steel frame model

■ Damping performance evaluation



The result of real eigenvalue analysis



X direction

If Cd = 0 , then

ωo = 30. 3 rad/sec

If Cd = ∞, then

$\omega\infty$ = 39. 3 rad/sec

Y direction

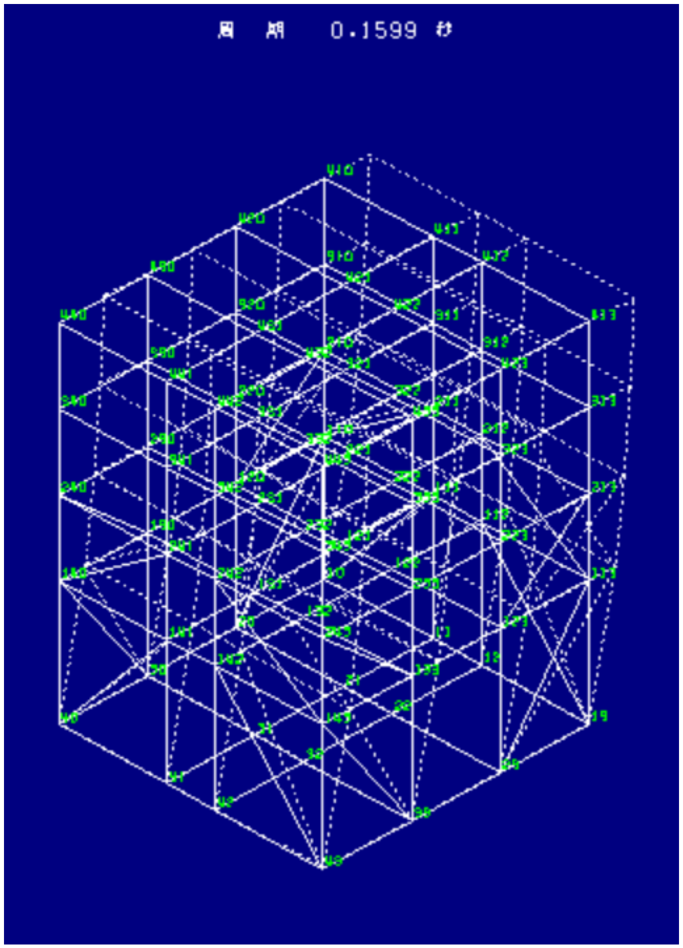
If Cd = 0 , then

ωo = 29. 5 rad/sec

If Cd = ∞ , then

$\omega\infty$ = 37. 6 rad/sec

- Eigenvalue analysis for both directions



- X direction damping factor

$\beta = 0.682$

$\eta = 0.110$

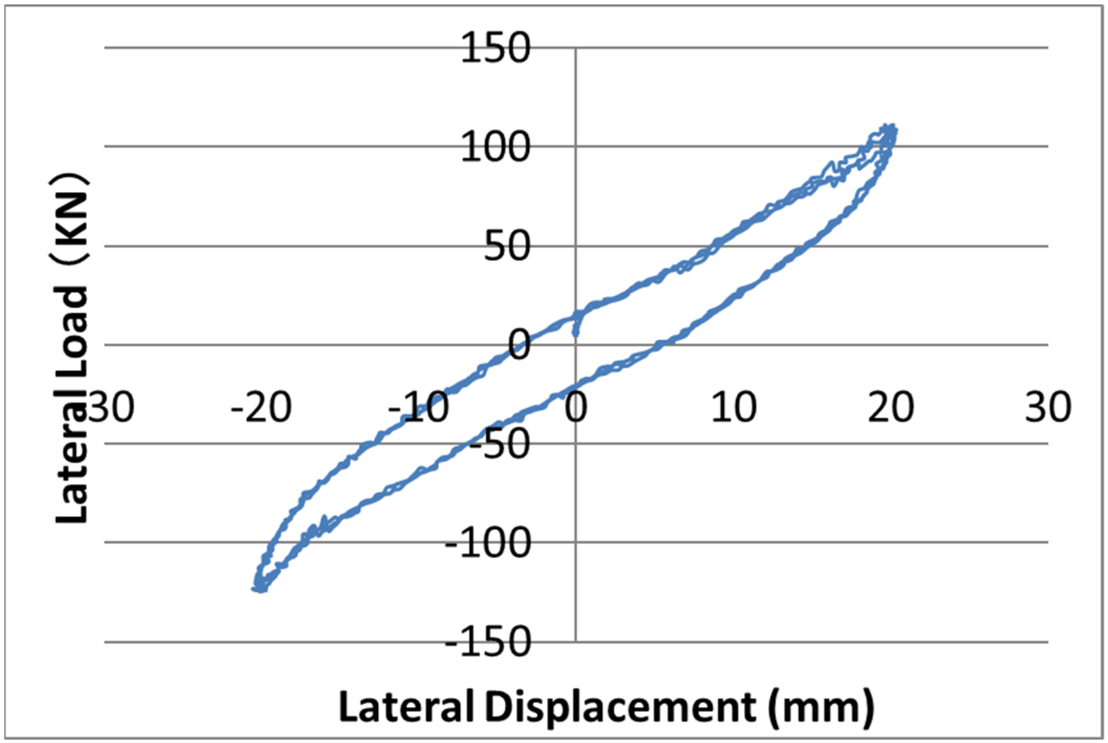
- Y direction damping factor

$\beta = 0.624$

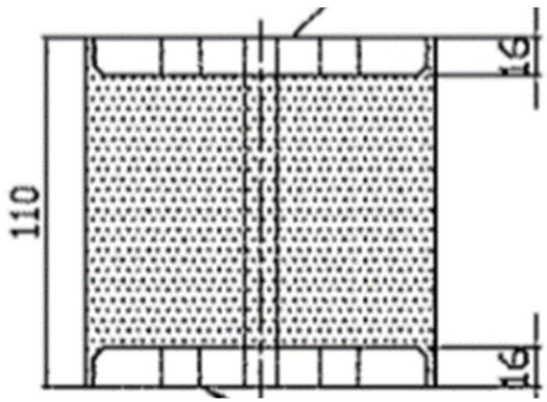
$\eta = 0.100$

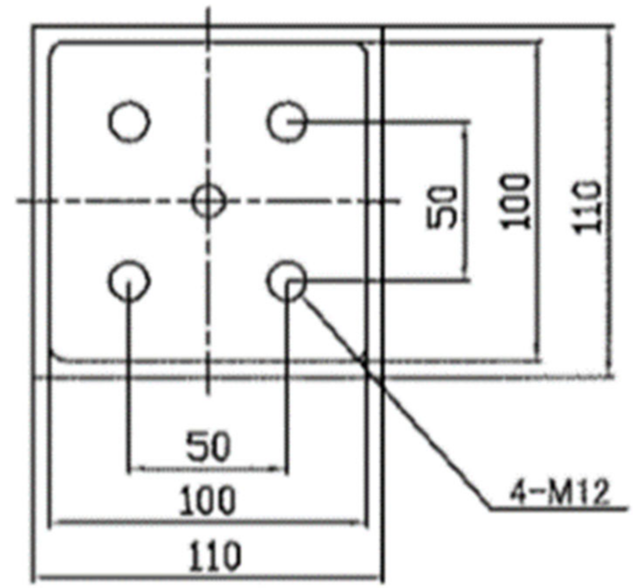
Set up of the laminated rubber bearing

Laminated rubber bearing load-displacement property

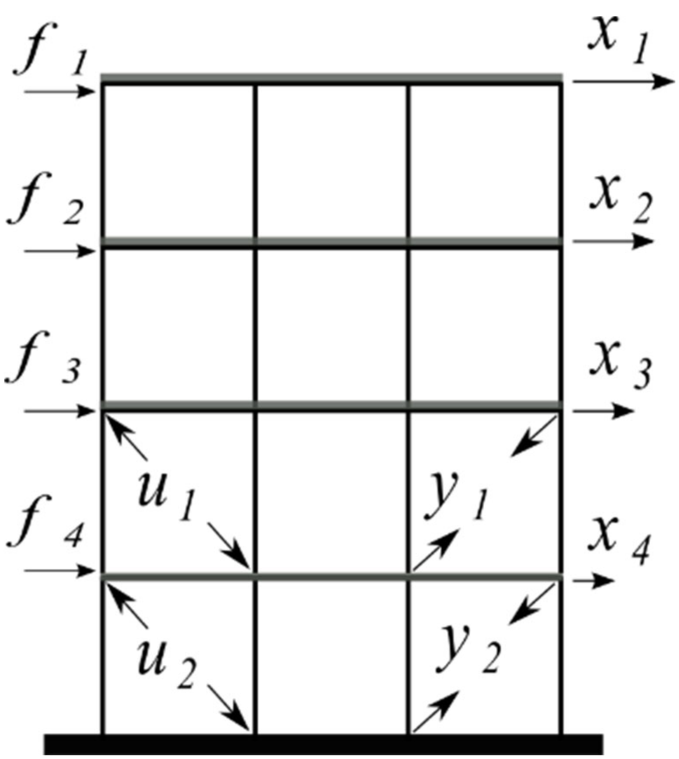


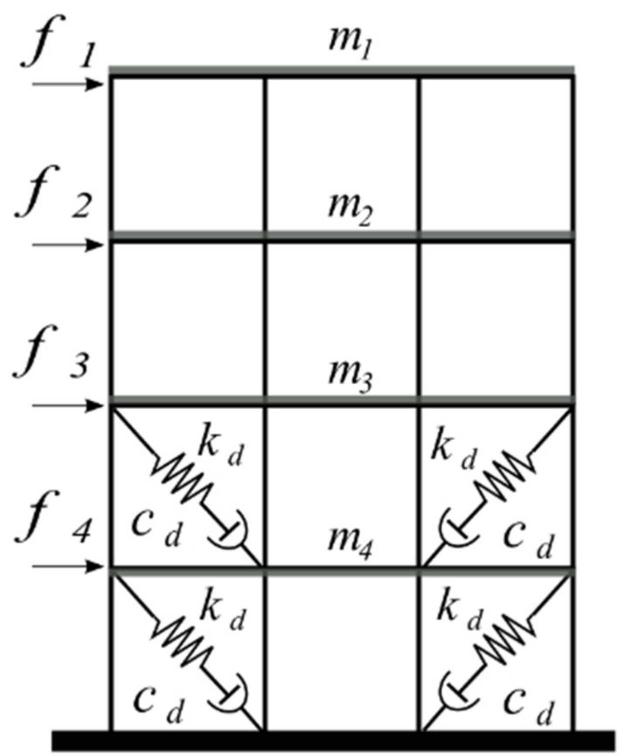
Configuration the laminated rubber bearing





System equation of the frame matrix





System equation of the frame matrix

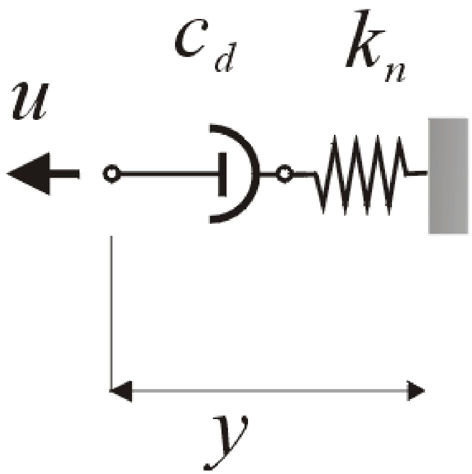
$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ y_1 \\ y_2 \end{bmatrix} = \begin{pmatrix} 0.361 & 0.325 & 0.284 & 0.217 & 0.0470 & 0.1600 \\ 0.325 & 0.316 & 0.282 & 0.216 & 0.0470 & 0.1590 \\ 0.284 & 0.282 & 0.272 & 0.214 & 0.0420 & 0.1580 \\ 0.217 & 0.216 & 0.214 & 0.187 & 0.0190 & 0.1320 \\ 0.047 & 0.047 & 0.042 & 0.019 & 0.0188 & 0.0147 \\ 0.160 & 0.159 & 0.158 & 0.132 & 0.0147 & 00992 \end{pmatrix} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ u_1 \\ u_2 \end{bmatrix}$$

[*mm/KN*]

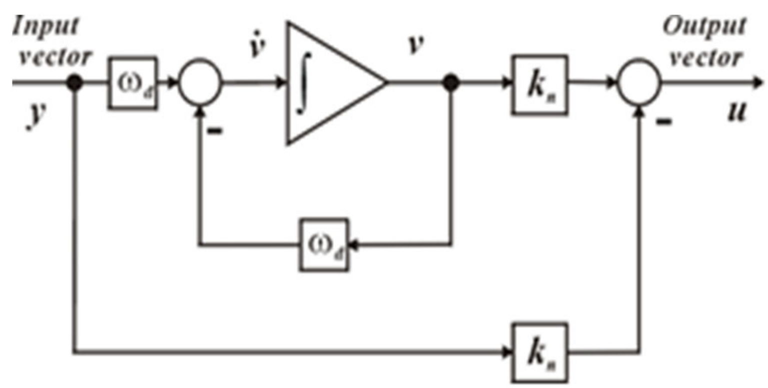
$$\begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ m_4 \end{bmatrix} = \begin{pmatrix} 875 \\ 1063 \\ 1063 \\ 313 \end{pmatrix}$$

[*kg*]

■ The damper dynamics

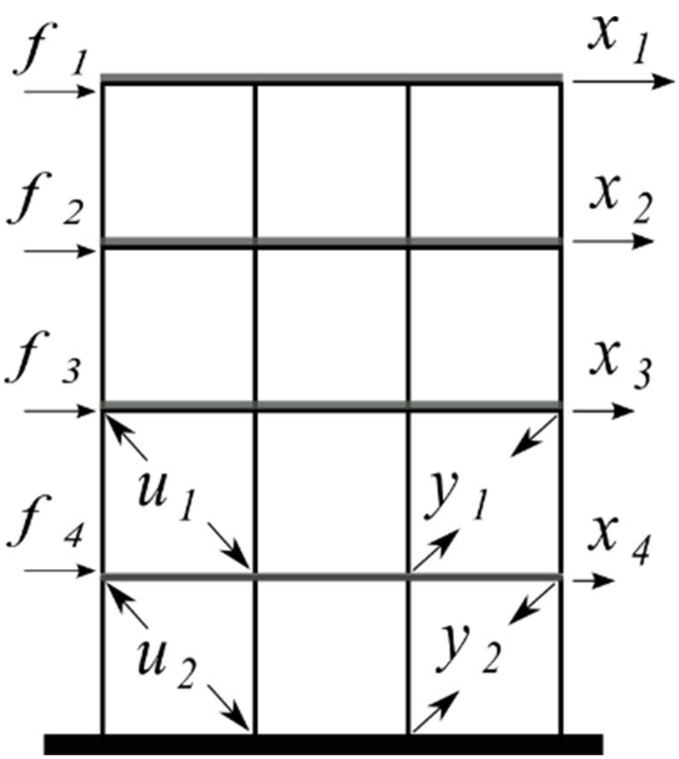


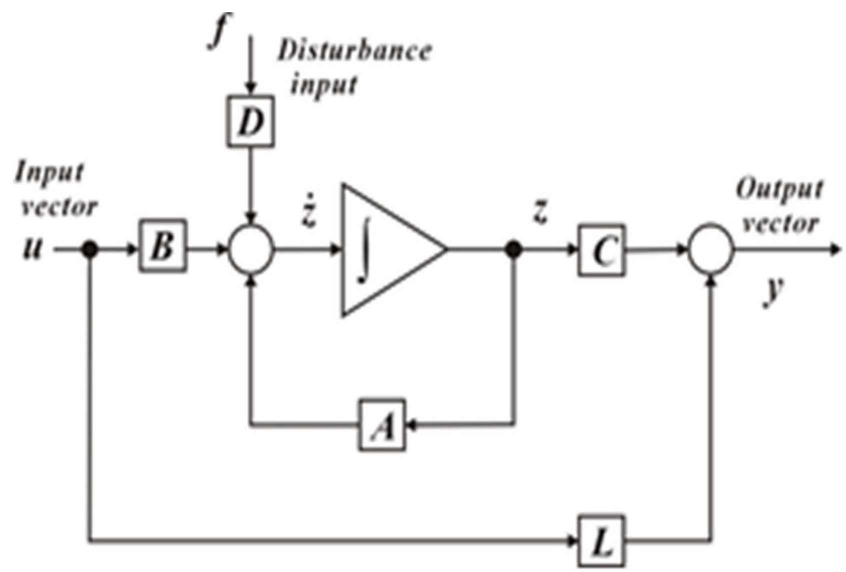
$$\begin{cases} \dot{v} + \omega_d v = \omega_d y \\ u = k_n v - k_n y \end{cases}$$



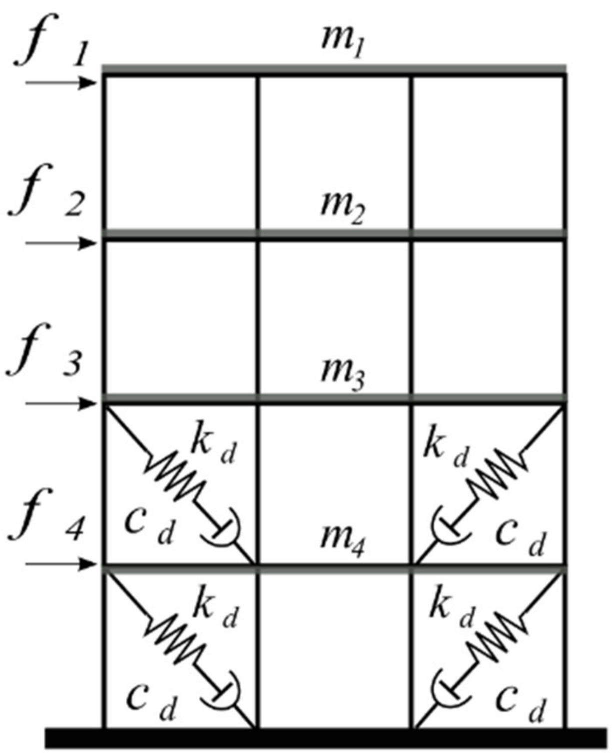
$$\omega_d = \frac{k_n}{c_d}$$

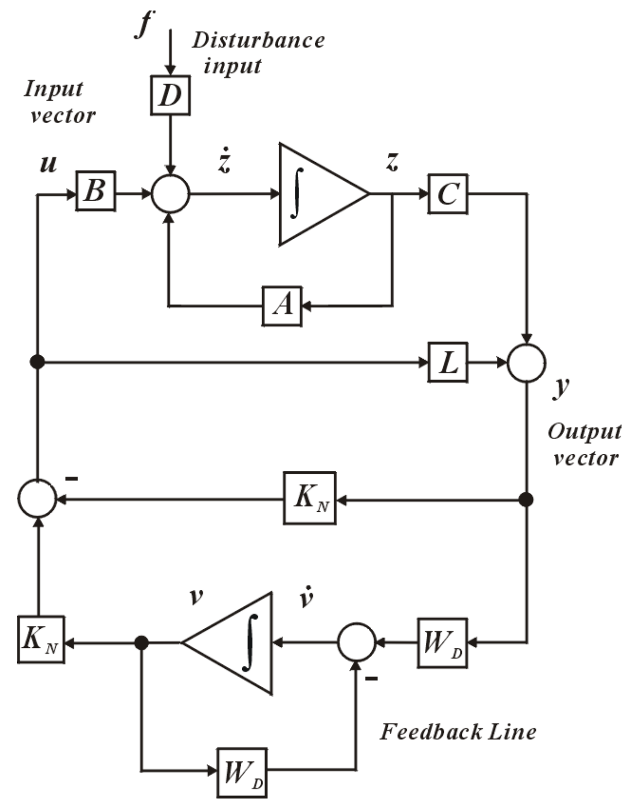
- The structure dynamics



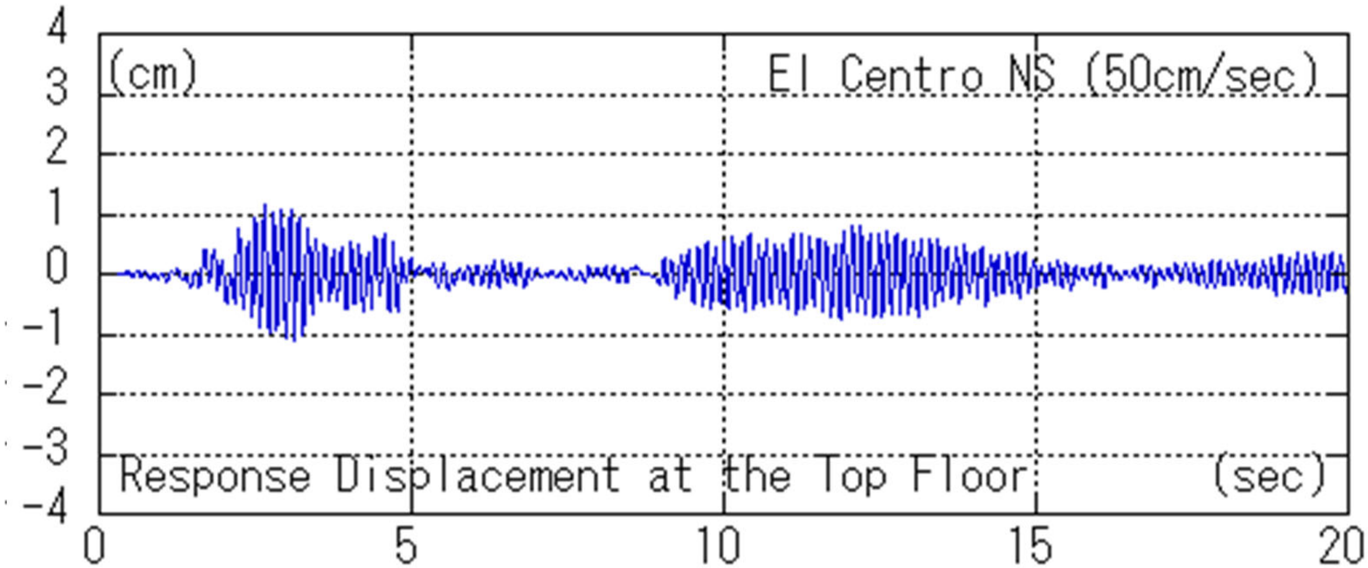


Comprehensive model based on feedback control





■ Response displacement at Top floor with dampers



With damper coefficient 100KNsec/mm

CONCLUSIONS

1. The third order differential equation is necessary for damping evaluation in the design phase.

2. Damping factor can only be increased by implementing structure member at the appropriate location.

3. The damping factor can be easily evaluated by stiffness augmentation, which can be easily calculated by real eigenvalue analysis.

4. The theoretical prediction has been verified by a quarter size model on the shaking table test.

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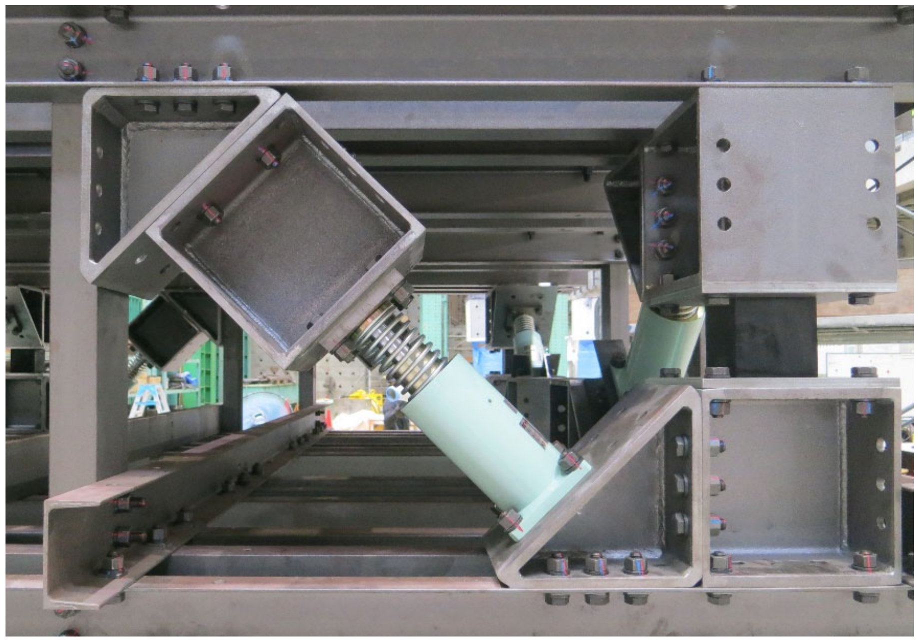

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