Appendix 8

Section 8 *Smart Structural System Large Scale Shaking Test*

presented by M.Teshigawara

Smart Structural System

Large Scale Shaking Test

1. Introduction
2. Objectives
3. Specimen
4. Shaking Tests
5. Summary

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What is S.S.S.?

1. Function of Sensing、Processing、Actuating
2. Auto Adaptive to Provide Safety and Function Effectively

1. Improvement of Structural Performance
2. Performance Based Maintenance and Sustainable Structure

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Objectives of Large Scale Shaking Test

- Verification of Structural Control
  - Rocking system
  - Semi-Active Base Isolation System with M/R Damper
  - Semi-Active Structural Control with M/R Damper
- Verification of Smart Sensors and Damage Identification
  - System Identification for Damage detection
  - Smart sensors

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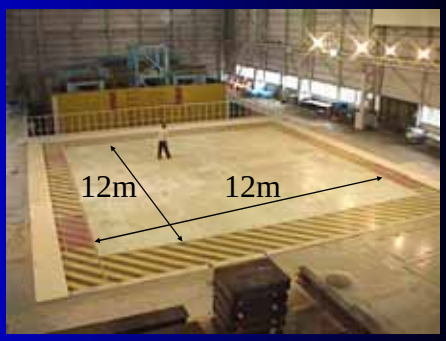
Shakeing Table and Schedule

- Shaking Table
  - National Research Institute for Earth Science and Disaster Prevention (NIED), Science and Technology Agency, Tsukuba, Japan



Schedule

February-April, 2002

July-August, 2002 (if necessary)

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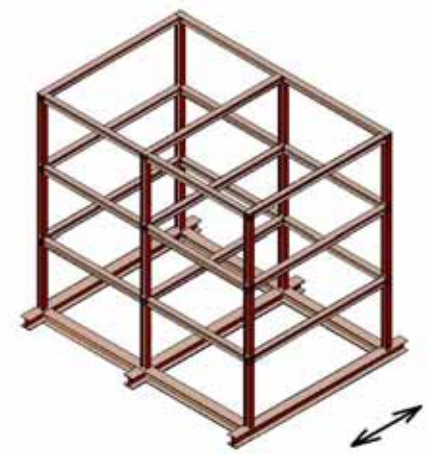
Frame



Shaking

- **Members**
  - C：H148×100×6×9
  - B：H150×150×7×10
- **Mass**
  - W3=4.65(t)
  - W2=4.76(t)
  - W1=4.76(t)
- **Span**
  - 3m×1span (Loading Di.)
  - 2m×2spans (Trans. Di.)
- **Story Height**
  - 1.8(m) each story
- **Natural Period**
  - 0.490(s)
- **Elastic Limit**
  - Story Drift=26.9(mm)
  - Base Shear=111.7 (kN)

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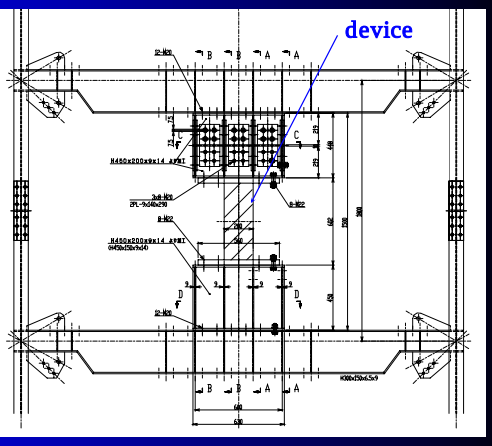
Test Specimen

Appearance Photo of Test Specimen



Installation Figure of Damage Device

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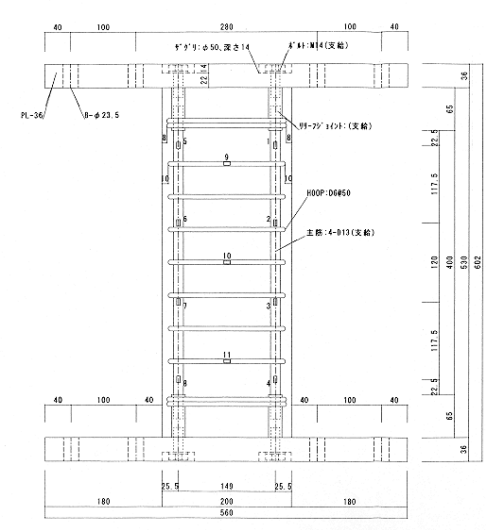
Column for Damage



Size of Cross Section	100×200(mm)
Height	400(mm)
Specified Design Strength	50(N/mm2)
Main Reinforcement	4−D13 (SD245)
HOOP	□−D6@50
Material of Cement System	Polyethylene Fiber + Steel Cord

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Measurement of load

- Q (RC Column) =Q (Total) −Q (Frame)
  - Shear force of Frame from strain of steel columns

    → Calibration test of simple beam
- Verification by shaking Test

  → Shaking test of Open Frame

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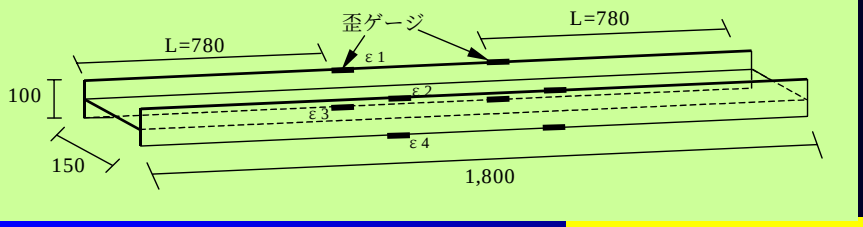
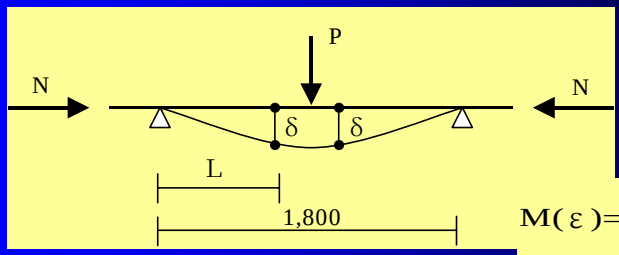
Simple Beam Test



H150×100×9×6.5(SN490)



$$M(\varepsilon)=\frac{P}{2}L+N\cdot\delta$$

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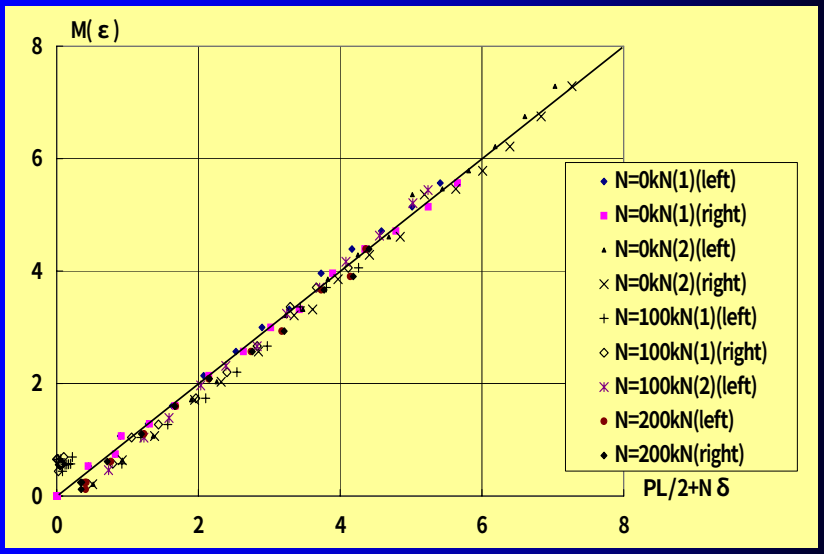
Load vs. Measurements



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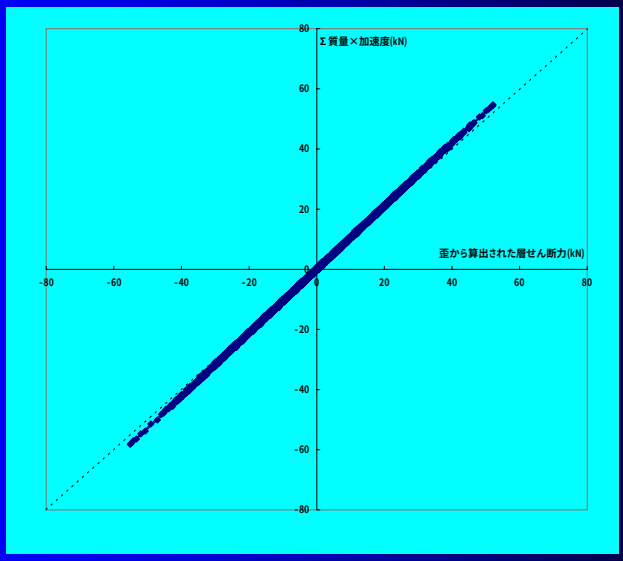
Results from Open Frame Test



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Damage Detection

Input Motion

No.	Input wave	Target Level
1	BCJ wave	2.5cm/sec
2	El Centro 1940 NS	5cm/sec
3	El Centro 1940 NS	10cm/sec
4	El Centro 1940 NS	15cm/sec
5	BCJ wave	20cm/sec
6	El Centro 1940 NS	30cm/sec
7	El Centro 1940 NS	40cm/sec
8	El Centro 1940 NS	50cm/sec
9	El Centro 1940 NS	60cm/sec

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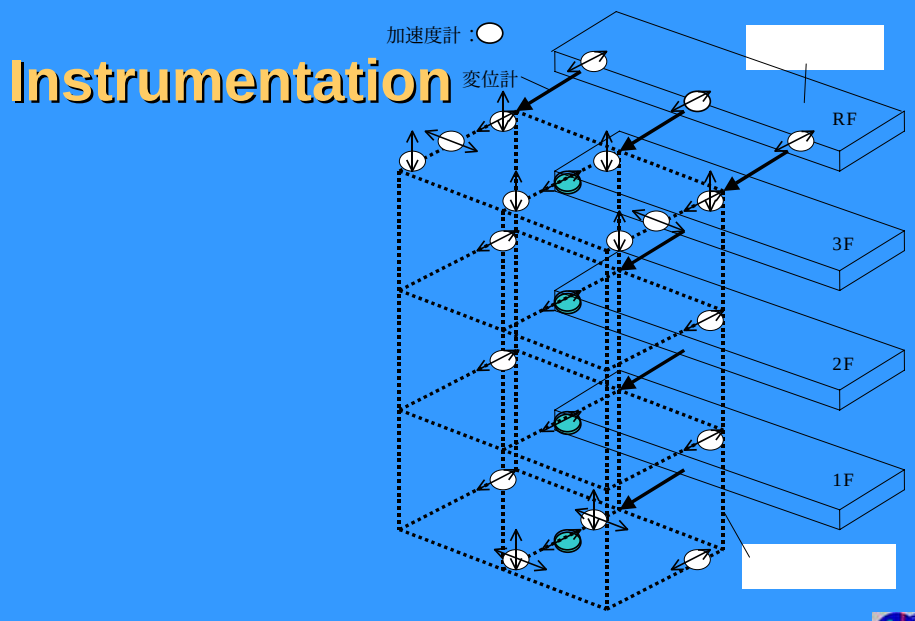
Instrumentation



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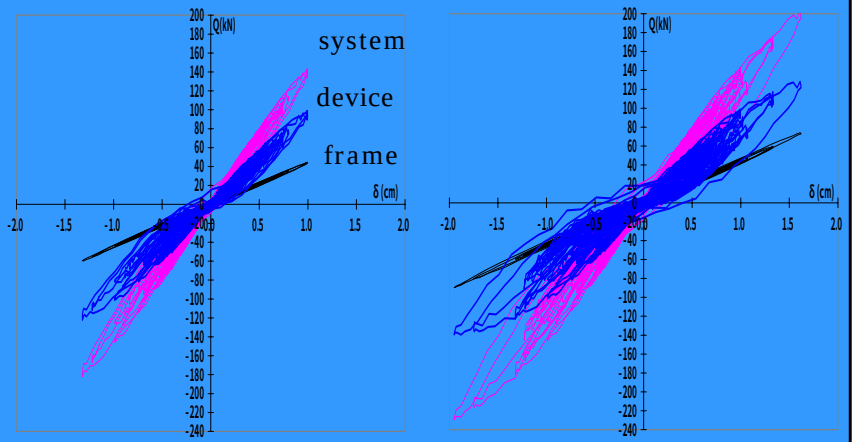
Shear vs. Drift ③



El Centro 50cm/sec　　El Centro 60cm/sec

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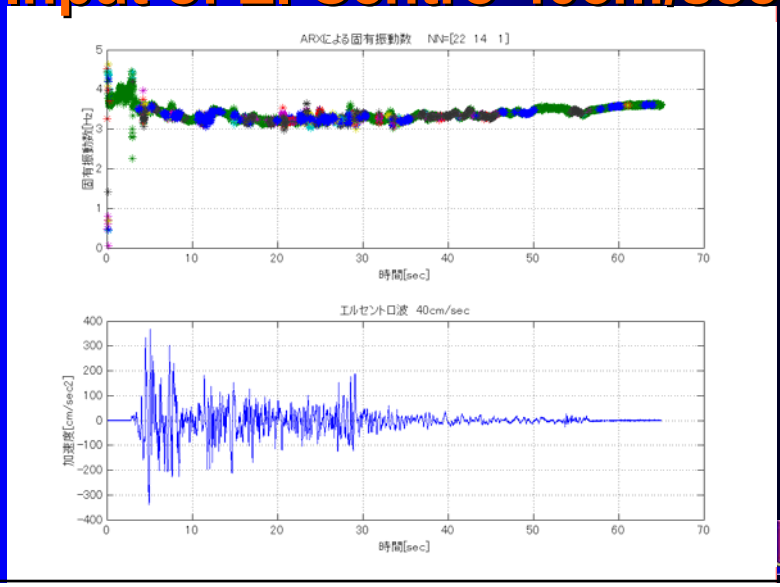
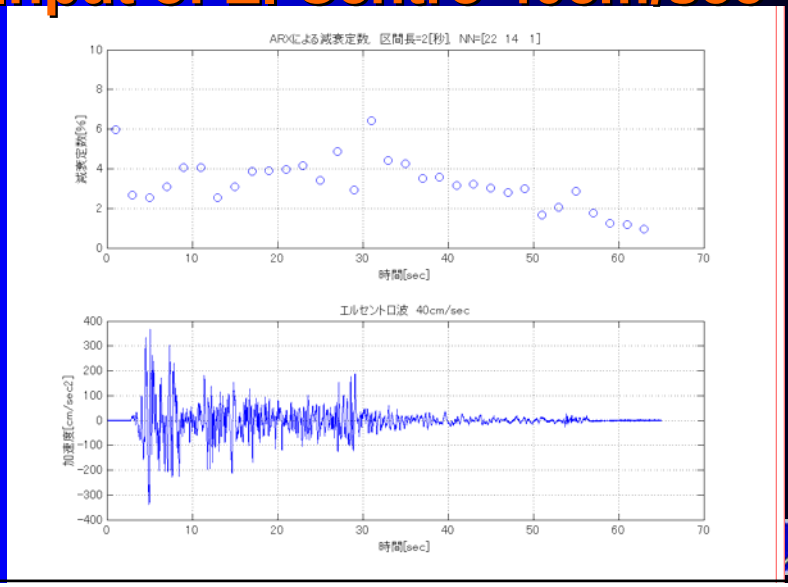
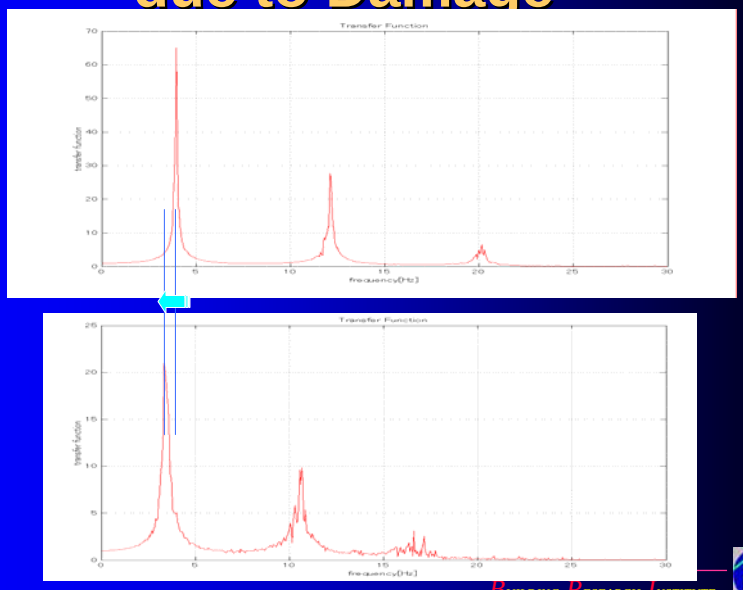
Change of Natural Period at Input of El Centro 40cm/sec



Change of Damping Coefficient at Input of El Centro 40cm/sec



Change of Transfer Function due to Damage



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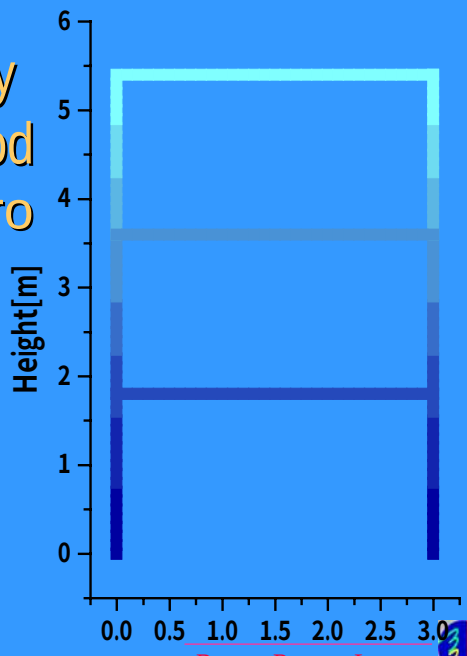
Damage Identification by Flexibility Method (after El Centro 40cm/sec)

Dark color indicates damage parts



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Structural Control by M/R Damper

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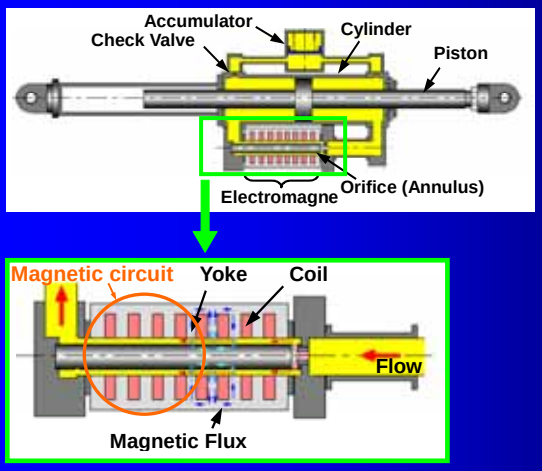
Design of Magneto-Rheological damper

Structure



Design Specifications

Max.Force		40kN
Stroke		±295mm
Cylinder Bore		φ90mm
Orifice	Section	Outer diameter φ48mm
		Gap 3.0mm
	Length	420mm
Electromagnet	Inductance	37.4mH×3
	Resistance	12Ω×3
	Max.Current	3A
MR fluid		Bando: # 230

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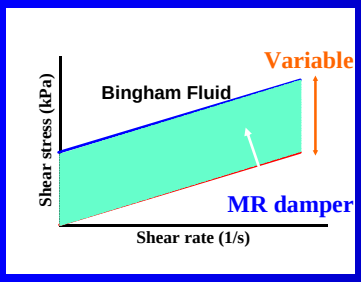
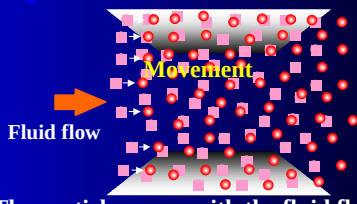
Conceptualism of MR fluid



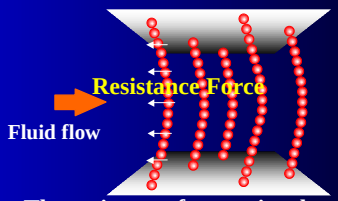
[Characteristic of Bingham Fluid]

No Magnetic field



The particle moves with the fluid flow

Magnetic field Action



The resistance force arises by the combination of the particle

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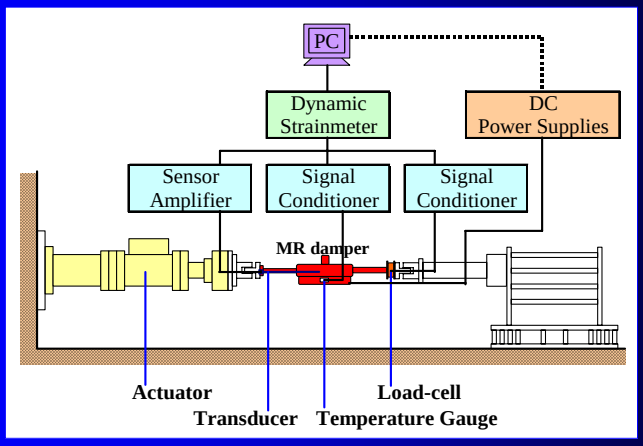
Experimental Setup for MR damper



Dynamic loading test

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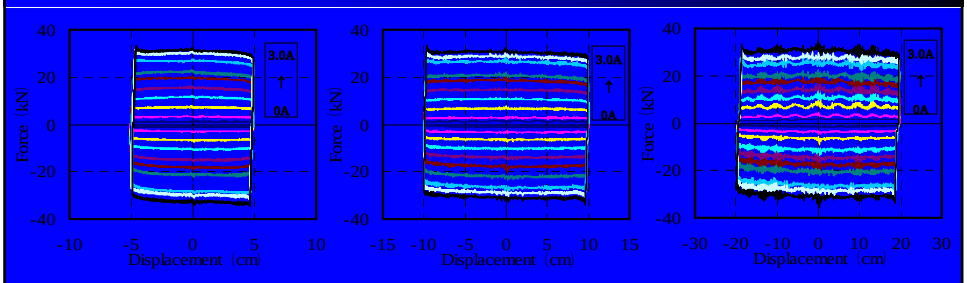
Dynamic loading test (Sinusoidal wave)



0.1Hz, 5cm, 3.14cm/s **0.1Hz, 10cm, 6.28cm/s** **0.1Hz, 20cm, 12.56cm/s**

Experimental Results

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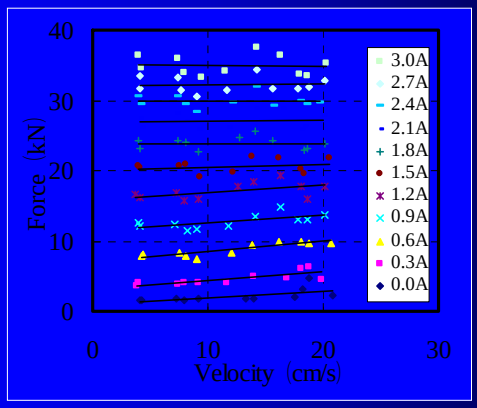
Force – Piston velocity Relationship



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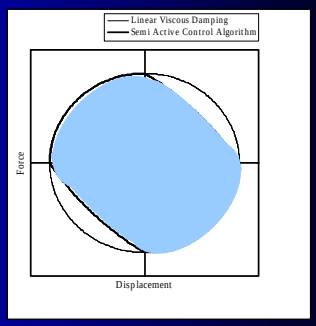
Control algorithm

$$F = \begin{cases} \mathrm{sgn}(\dot{u})k\left(\sqrt{\left(\frac{\lambda_{opt}\dot{u}}{\omega}\right)^2 + u^2} - |u|\right) & (u\dot{u} \geq 0) \\ k\frac{\lambda_{opt}\dot{u}}{\omega} & (u\dot{u} < 0) \end{cases}$$

F :MRダンパーの制御力
k :免震層の剛性
$u, \dot{u}$:免震層の変位,速度
$\mathrm{sgn}(\dot{u})$:免震層速度の符号
ω ：免震構造物を１質点とした場合の円振動数
λ_{opt} :制御定数(今回は 0.7)



制御の履歴ループ

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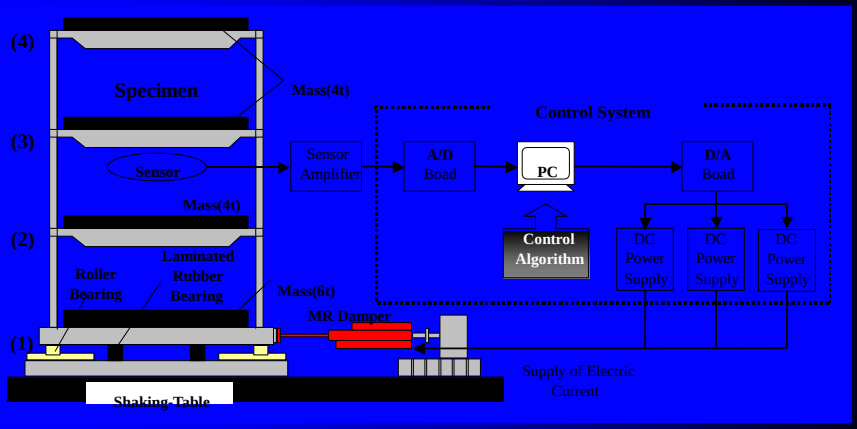
Control system



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Outline of base-isolated test frame

↑base-isolated test frame

Parameters test frame →

Input Wave

- Sweep sinusoidal wave
- White noise
- Elcentro (1940) NS
- Hachinohe (1968) NS
- JMA Kobe (1995) NS
- Taft (1952) EW

} 50cm/s

Member	Column	H150×100×6×9
	Beam	H150×150×7×10 (H300×150×6.5×9)
Material		SM490
Mass (ton)	3rd story	4.67
	2nd story	4.78
	1st story	4.78
	Base isolated layer	5.87
Stiffness (kN/cm)	3rd story	27.60
	2nd story	28.42
	1st story	35.37

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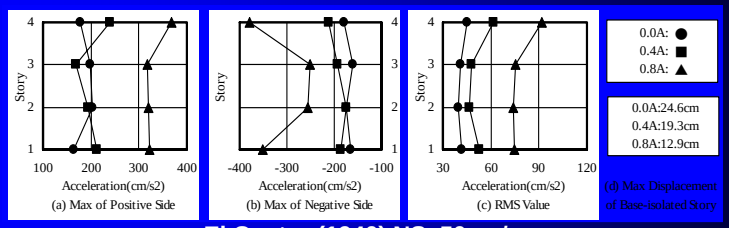
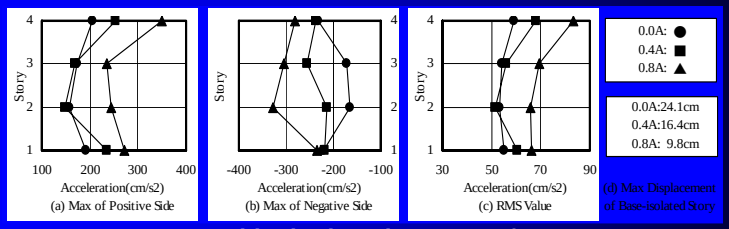
Experimental results (Constant Current)



El Centro (1940) NS 50cm/s



Hachinohe (1968) NS 50cm/s

Constant Electric Current 0A, 0.4A, 0.8A

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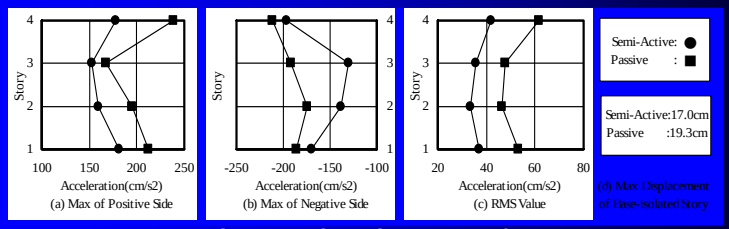
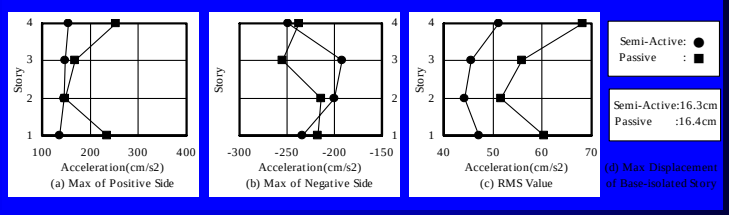
Experimental results (Semi-active control)



El Centro (1940) NS 50cm/s



Hachinohe (1968) NS 50cm/s

Passive (0.4A-constant current) - Semi-active control

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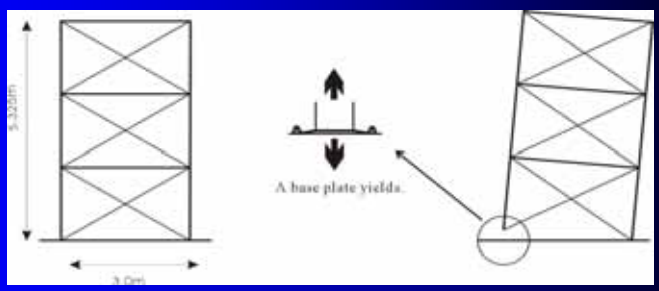
Rocking System with Base Plate Yielding Type

System Concept

- Up-Lift with yielding of base plate before yielding of super structure



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Test Specimen

- Height：5.325 m (1.725 m + 1.8 m + 1.8 m)
- Span：3.0 m
- Aspect ratio：1.775

(PC-bar Brace are installed)

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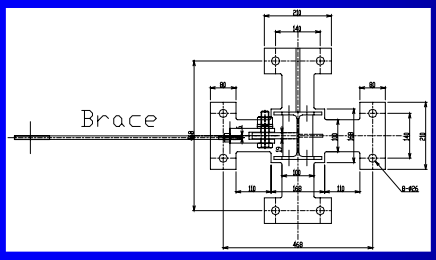
Base Plate



PL-6mm & 9mm, 2 & 4 fins for PL-9mm

Model name	JIS	Yield Point (N/mm2)
BP6	SS400	329.85
BP9, BP9-2	SS400	292.11

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Input Motion

- 1940 El Centro NS,
- Time interval is reduced by $1/\sqrt{2}$

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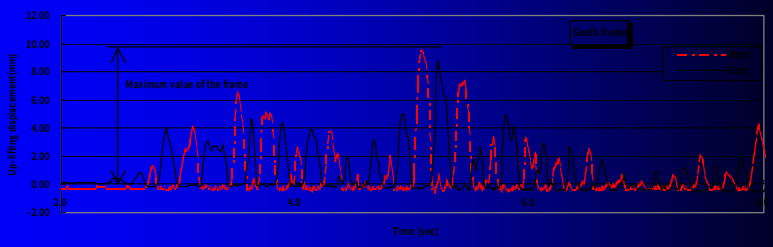
Test Result（1）

- Up-Lift Deformation



BP-2 model、MPA=5.84 m/sec^2

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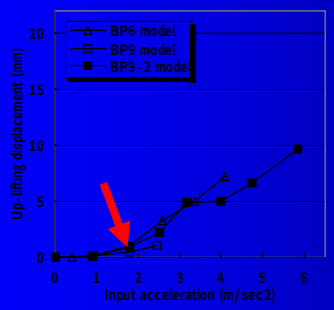
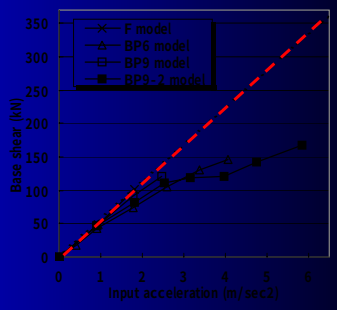
Test Result (2)

- Base Shear & Up-Lift Deformation



Up-Lift



Base Shear

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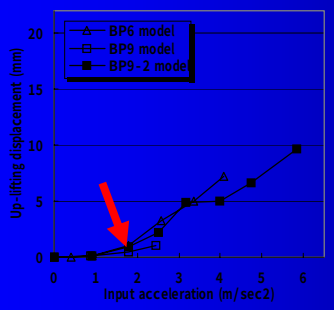
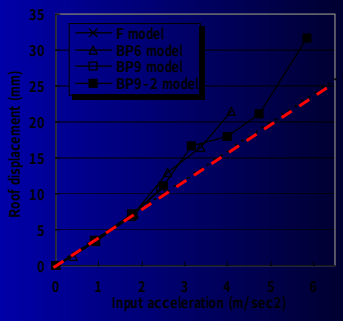
Test Result (3)

- Up-Lift & Top Deformation



Up-Lift



Top

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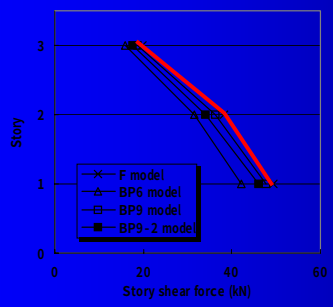
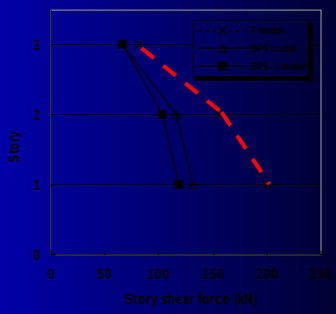
Test Result (4)

- Story Shear





MPA=0.9 m/sec^2 MPA=3.5 m/sec^2

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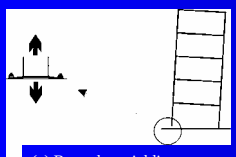
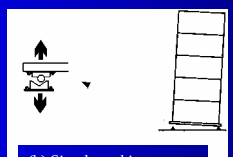
Reference

- 2001.5.16～6.28
- Aspect Ratio 2.5


(a) Base plate yielding system


(b) Simple rocking system

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