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國家實驗研究院

傾斜滑動支承之振動台試驗

Experimental Study of Sloped Sliding-type Bearing

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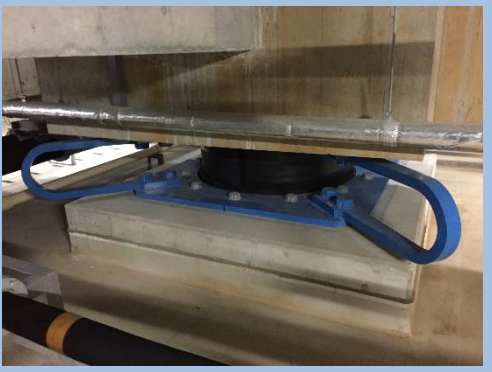
報告人：**楊卓諺**

Outline

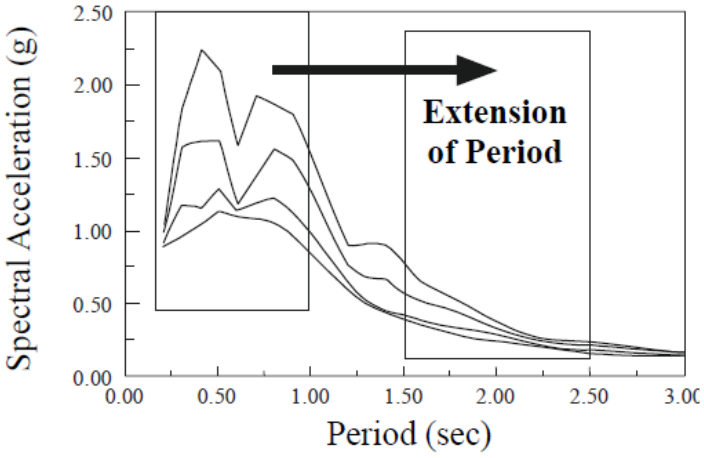
- **Background and Motivation**
- **Equation of Motion**
- **Experimental verification**
- **Conclusion**

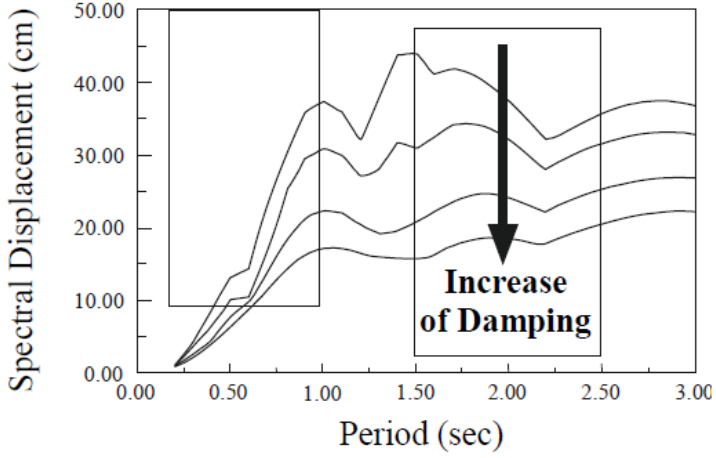
Background and Motivation

-Isolation Technique




- **Structural period can be elongated by the isolation system**
- **Reduce the seismic force transmitting to the superstructure**





Background and Motivation

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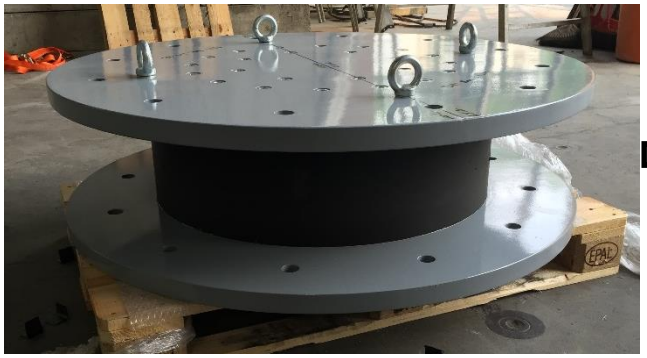
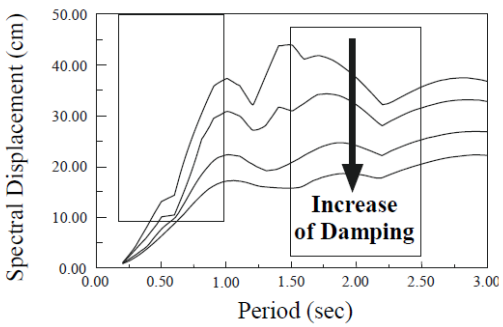
-Isolation Design Principles

- Sufficient vertical stiffness to support vertical load.
- Sufficient flexibility to extend the structural period.
- Energy dissipation mechanism to confine isolator displacement.
- Re-centering capability.



Provide energy dissipation mechanism



Background and Motivation

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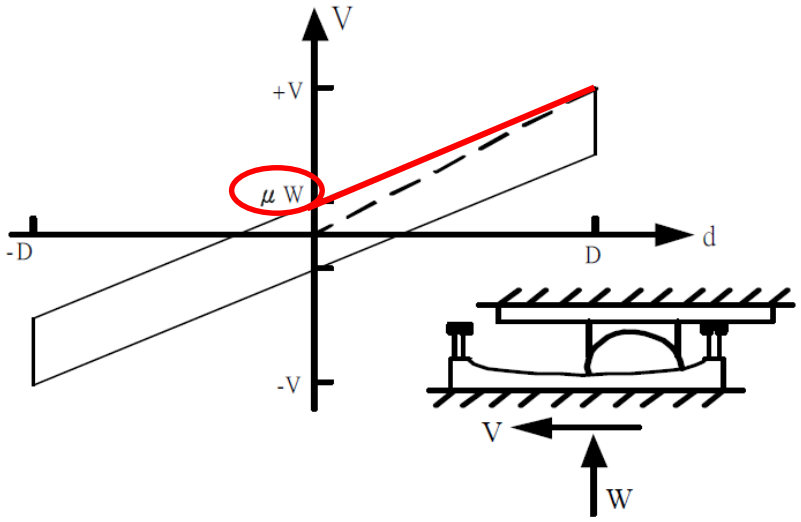
-Sliding Isolation Bearing

Energy dissipation mechanism : frictional force.

The frictional force will take great influence to the characteristic strength.

Shear force: frictional force and restoring force.



Force-Displacement Hysteretic Loop

Background and Motivation

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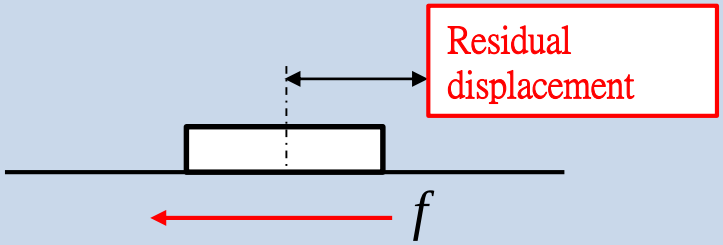
-Sliding Isolation Bearing

Pure Friction System(PFS):

Flat sliding surface.

No specific isolation period.

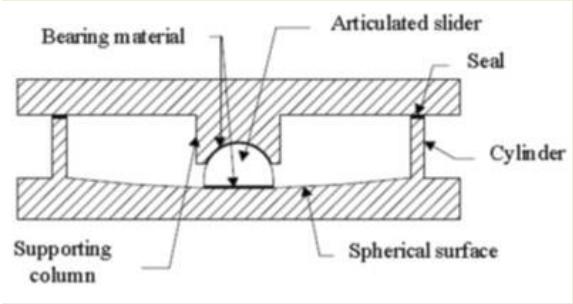


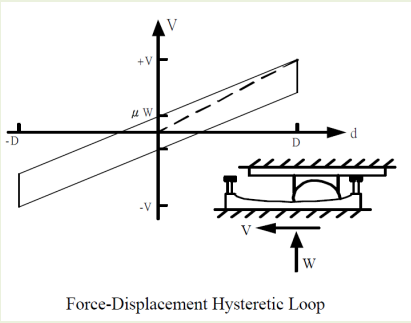
Advantage: insensitive to the earthquake amplitude and frequency content.

Disadvantage: no re-centering

Friction Pendulum System(FPS):

Spherical sliding surface.





Force-Displacement Hysteretic Loop

$$T = 2\pi\sqrt{\frac{R}{g}}$$

Advantage: displacement control, re-centering capability.

Disadvantage: Specific period (resonance)

Background and Motivation

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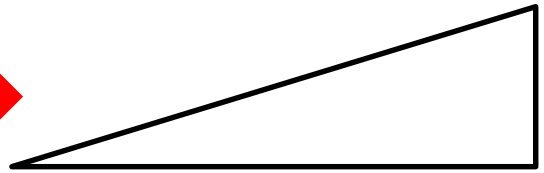
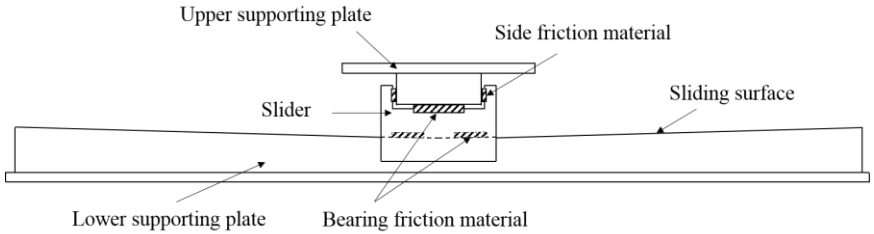
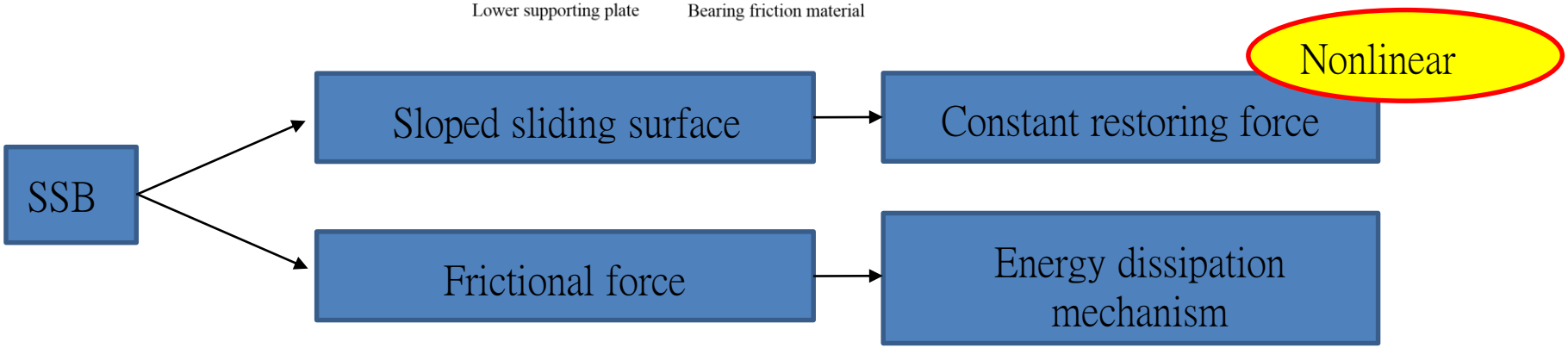
-Sliding Isolation Bearing

Altering the geometry of the sliding surface



New Isolation Technique:Sloped Sliding-type Bearing(SSB)





Equation of Motion

-Basic Assumption

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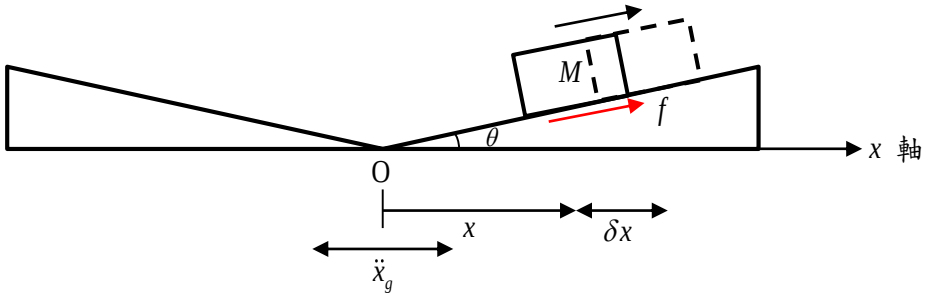
- Basic assumption

(1) neglect pounding effect.

(2) neglect the contribution of EQ to normal force.

(3) neglect vertical reaction projected by the horizontal EQ.

Equation of Motion



$$\vec{X} = \left(x_g + x\right)\hat{i} + \tan\theta \cdot |x|\,\hat{j}$$

$$\vec{V} = \left(\dot{x}_g + \dot{x}\right)\hat{i} + \left(\tan\theta \cdot \mathrm{sgn}(x) \cdot \dot{x}\right)\hat{j}$$

$$\vec{A} = \left(\ddot{x}_g + \ddot{x}\right)\hat{i} + \left(\tan\theta \cdot \mathrm{sgn}(x) \cdot \ddot{x}\right)\hat{j}$$

By Lagrange's equation of motion and Hamilton's principle, the equation of motion can be written as:

$$M\left(1+\tan^2\theta \cdot \mathrm{sgn}(x)^2\right)\ddot{x} + Mg\tan\theta \cdot \mathrm{sgn}(x) = f\sec\theta - M\ddot{x}_g$$

Equation of Motion
-Hysteresis Loop

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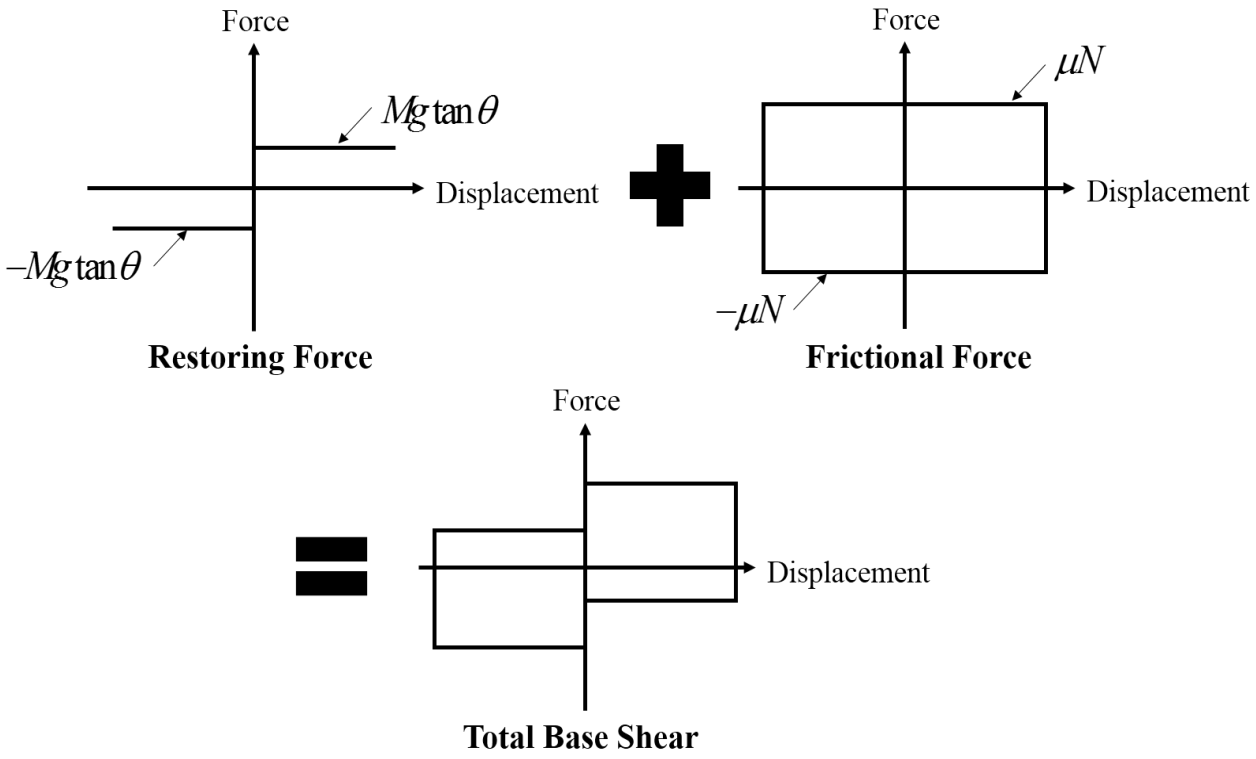
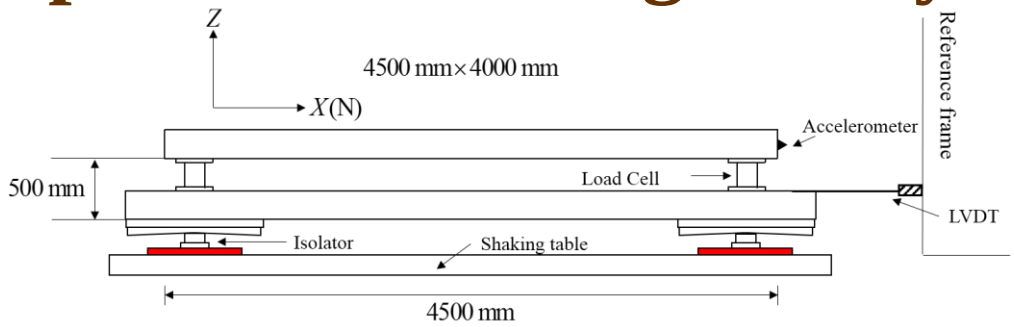
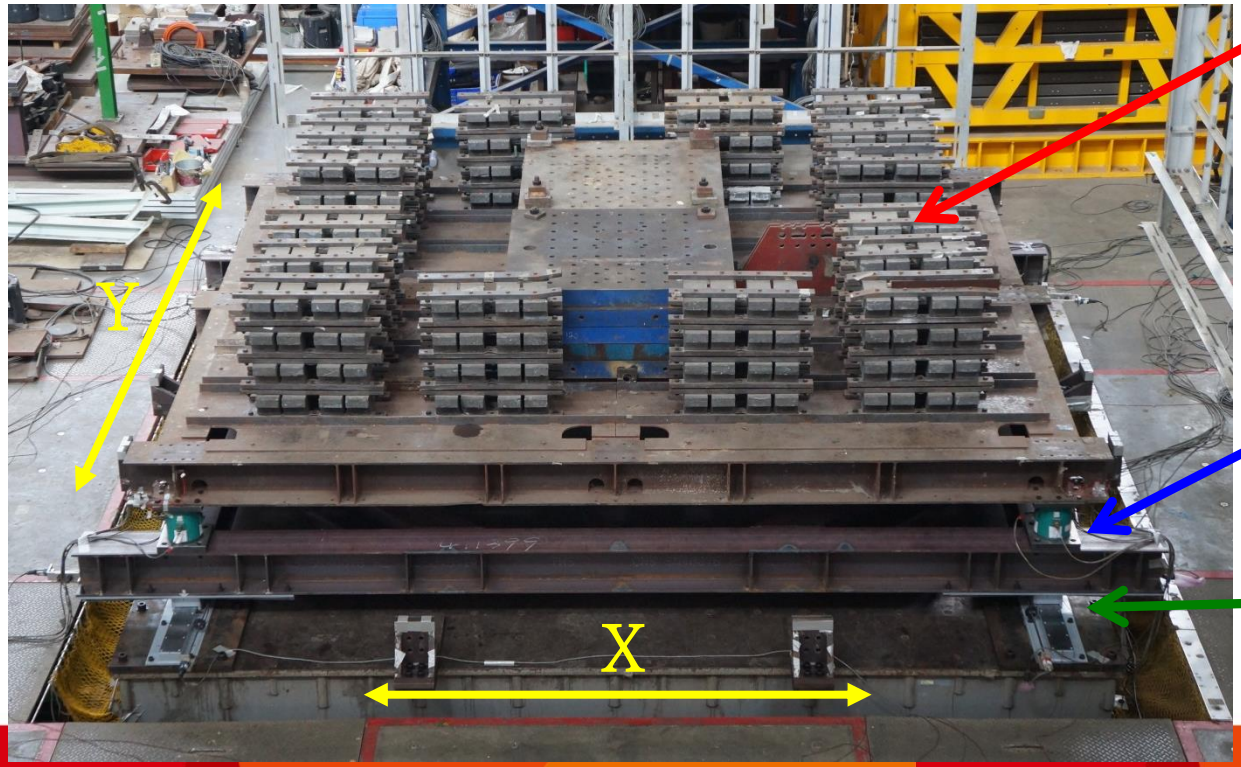
- **Coulomb friction model**



Experimental Study- *Shaking Table Experiment*

- **Superstructure: Rigid body**



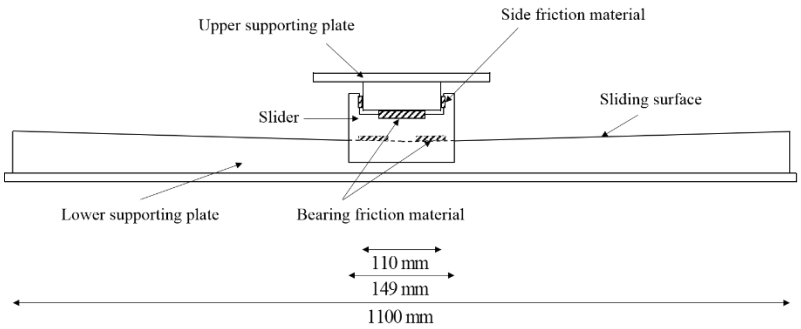


Total weight: 34.08 tf

Load cell × 4

SSB isolator × 4

Experimental Study - *Design Parameters*



Sloped Sliding-Type Bearing	
Inclination angle	1.5°
Design displacement	450 (mm)
Design vertical load(Long term)	10 (tf)
Design friction coefficient	0.06

Experimental Study - *Seismic excitations*

- **Taiwan：**
  - **Chi-Chi (集集地震，MCE人造歷時)**
    - **TAP095、TCU082、KAU054**
  - **Meinong (美濃地震，原始記錄)**
- **Japan：**
  - **Kobe (神戶)**
  - **Kokuji (告示波)**
  - **Haga (芳賀)**
  - **Kumamoto (熊本)**
- **Other：**
  - **El Centro**

X、Y、XY

Earthquake	Direction	Intensity (%)		PGA (g)		
		X	Y	X	Y	Z
El Centro (Original)	X	100	-	0.373	0.034	0.041
	Y	-	100	0.050	0.217	0.042
	XY	100	100	0.367	0.224	0.065
El Centro (50 kine)	X	100	-	0.313	0.062	0.047
	Y	-	100	0.049	0.521	0.057
	XY	100	100	0.315	0.515	0.073
Kokuji	X	100	-	0.426	0.031	0.063
	Y	-	100	0.044	0.364	0.079
	XY	100	100	0.519	0.335	0.075
Kobe	X	100	-	0.835	0.049	0.074
	Y	-	100	0.063	0.649	0.076
	XY	100	100	0.838	0.632	0.085
Haga	X	100	-	1.247	0.066	0.103
	Y	-	100	0.061	0.799	0.112
	XY	100	100	1.270	0.794	0.112
Chi-Chi TCU082 (Spectrum Compatible)	X	100	-	0.372	0.028	0.053
	Y	-	100	0.041	0.343	0.073
	XY	100	100	0.382	0.323	0.074
Chi-Chi KAU054 (Spectrum Compatible)	X	100	-	0.370	0.042	0.042
	Y	-	100	0.047	0.312	0.058
	XY	100	100	0.374	0.284	0.066
Chi-Chi TAP095 (Spectrum Compatible)	X	100	-	0.317	0.032	0.041
	Y	-	100	0.047	0.297	0.074
	XY	100	100	0.346	0.301	0.066
Meinong	X	100	-	0.246	0.033	0.047
	Y	-	100	0.031	0.180	0.042
	XY	100	100	0.248	0.195	0.040
Kumamoto (Prior)	X	100	-	0.939	0.049	0.083
	Y	-	100	0.084	0.851	0.086
	XY	100	100	0.984	0.810	0.099
Kumamoto (Major)	X	100	-	1.207	0.041	0.076
	Y	-	100	0.057	0.726	0.073
	XY	100	100	1.109	0.698	0.077
Chi-Chi TCU082 (Original)	X	100	-	0.224	0.026	0.043
	Y	-	100	0.028	0.220	0.044
	XY	100	100	0.186	0.221	0.065

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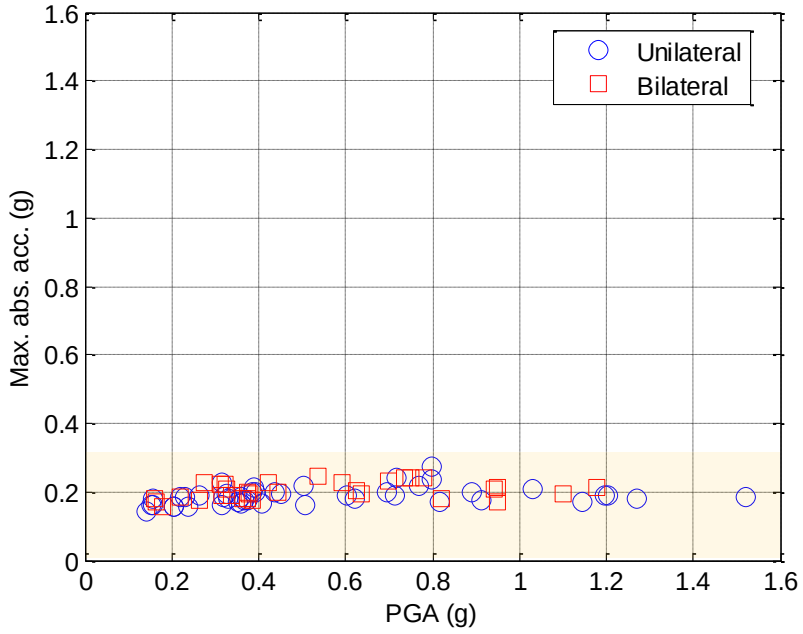
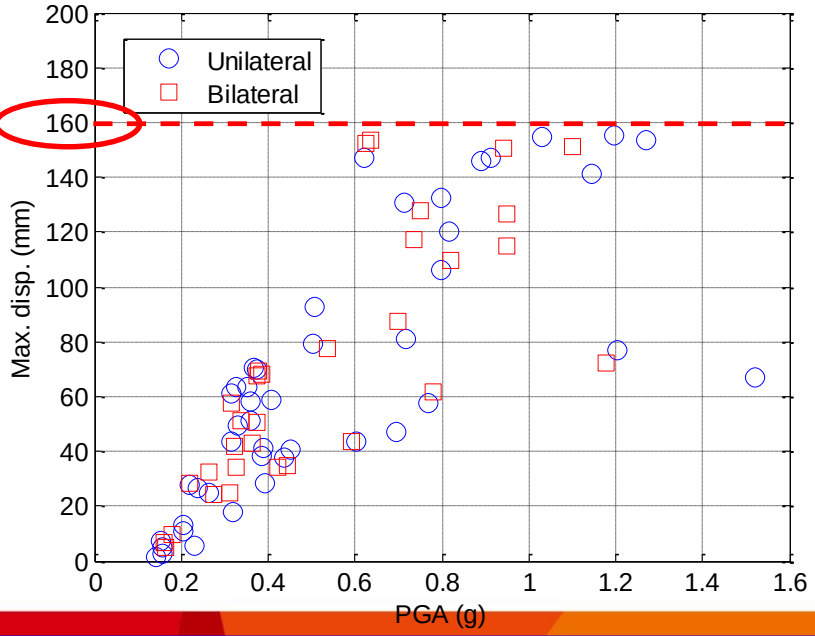
Experimental Study - *Test result*

- **Performance:**



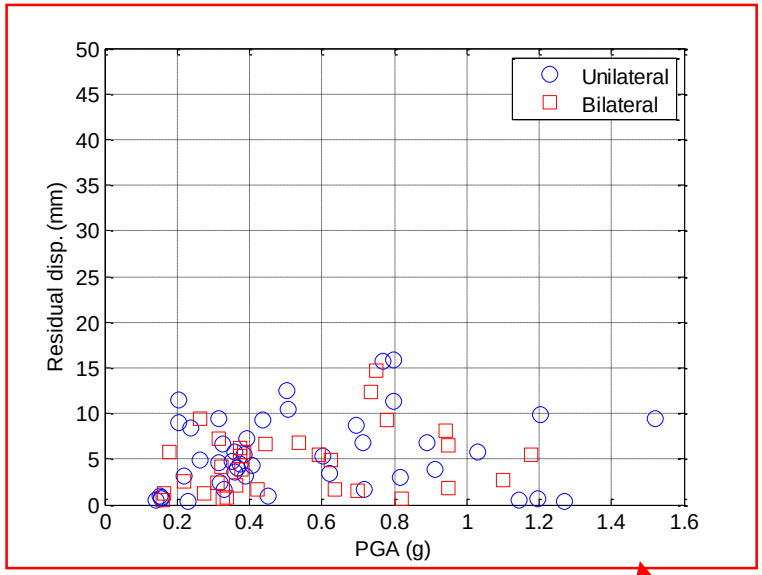
Effective and stable!

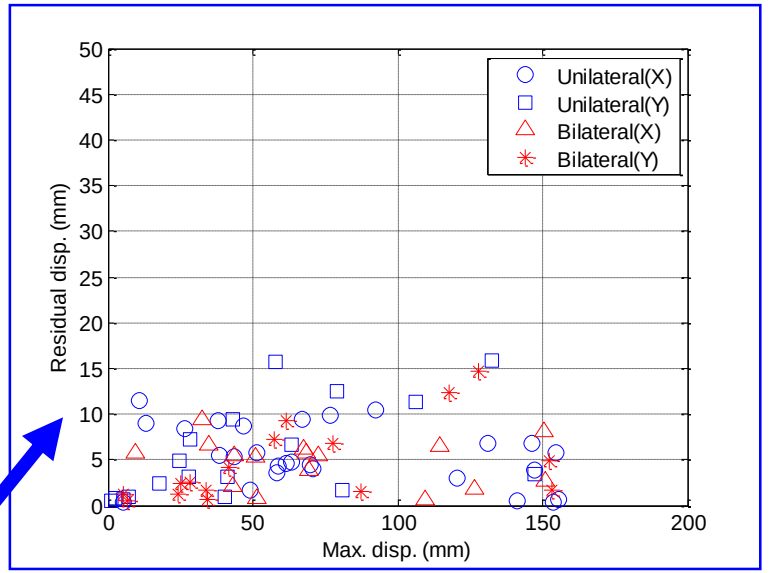
Displacement <16 cm

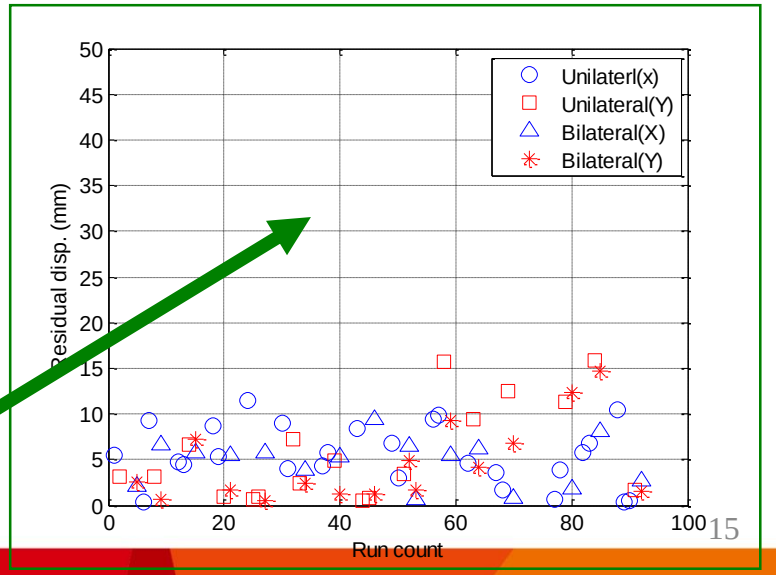


Experimental Study - *Test result*

- **Performance:**







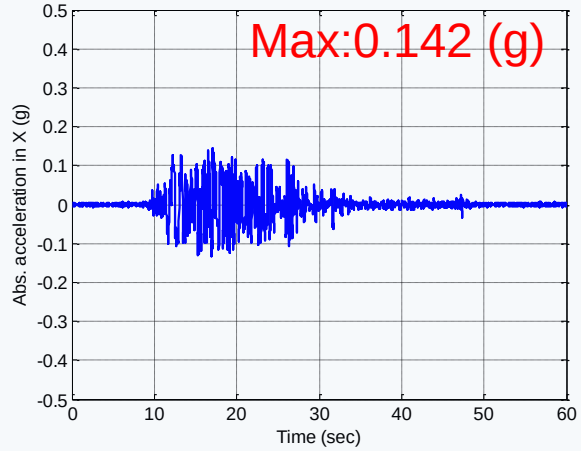
Residual disp. < 2 cm

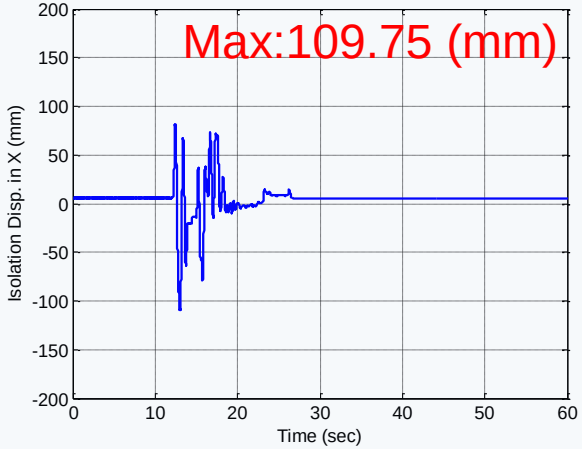
No relation between residual disp. and max. disp.

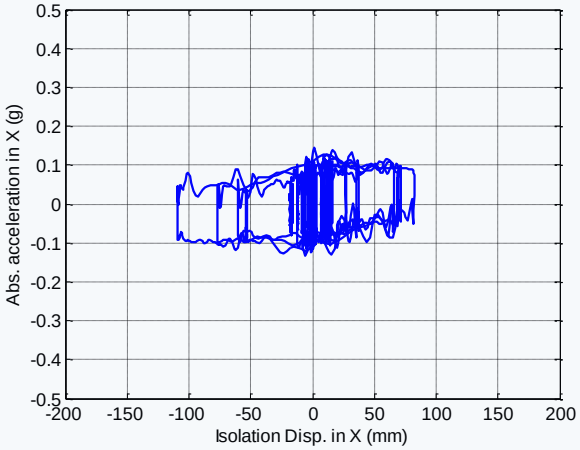
Residual disp. is no cumulative

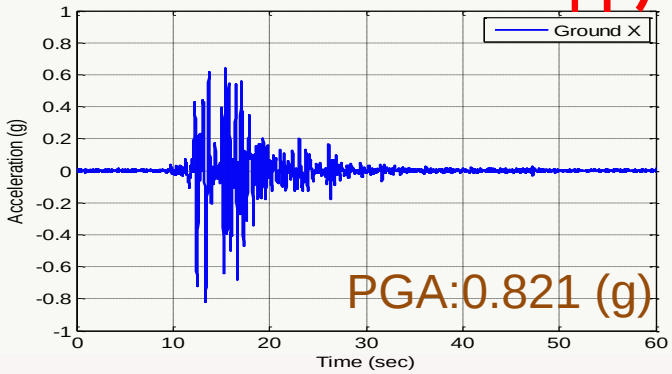
X-dir.

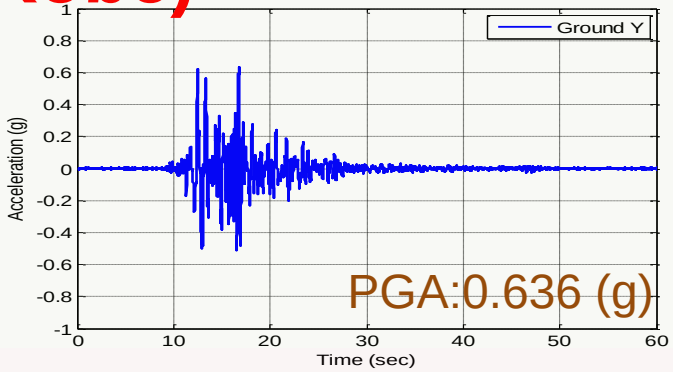
神戸(Kobe)



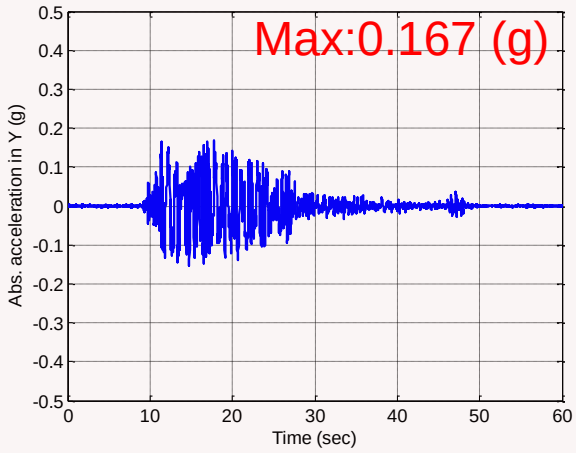


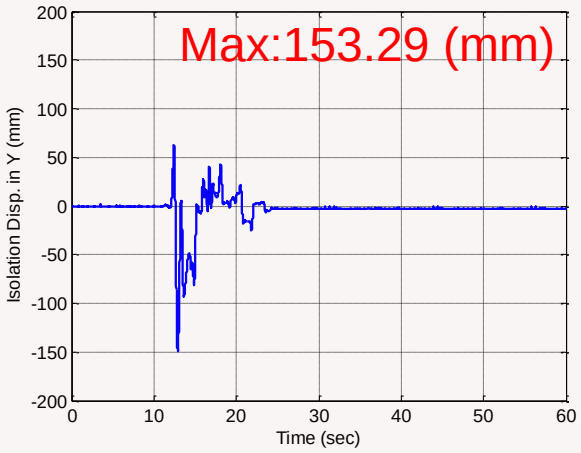


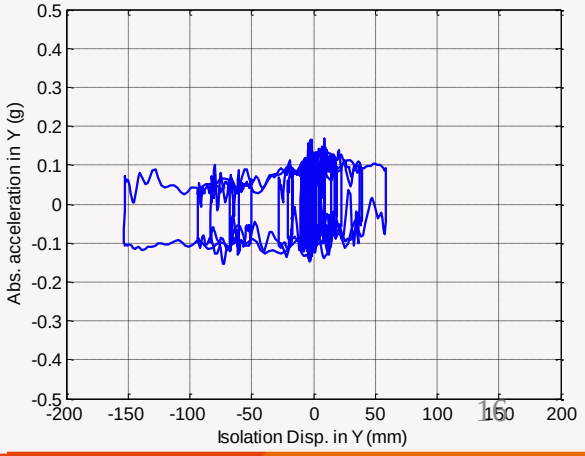




Y-dir.







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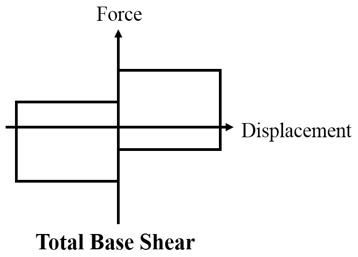
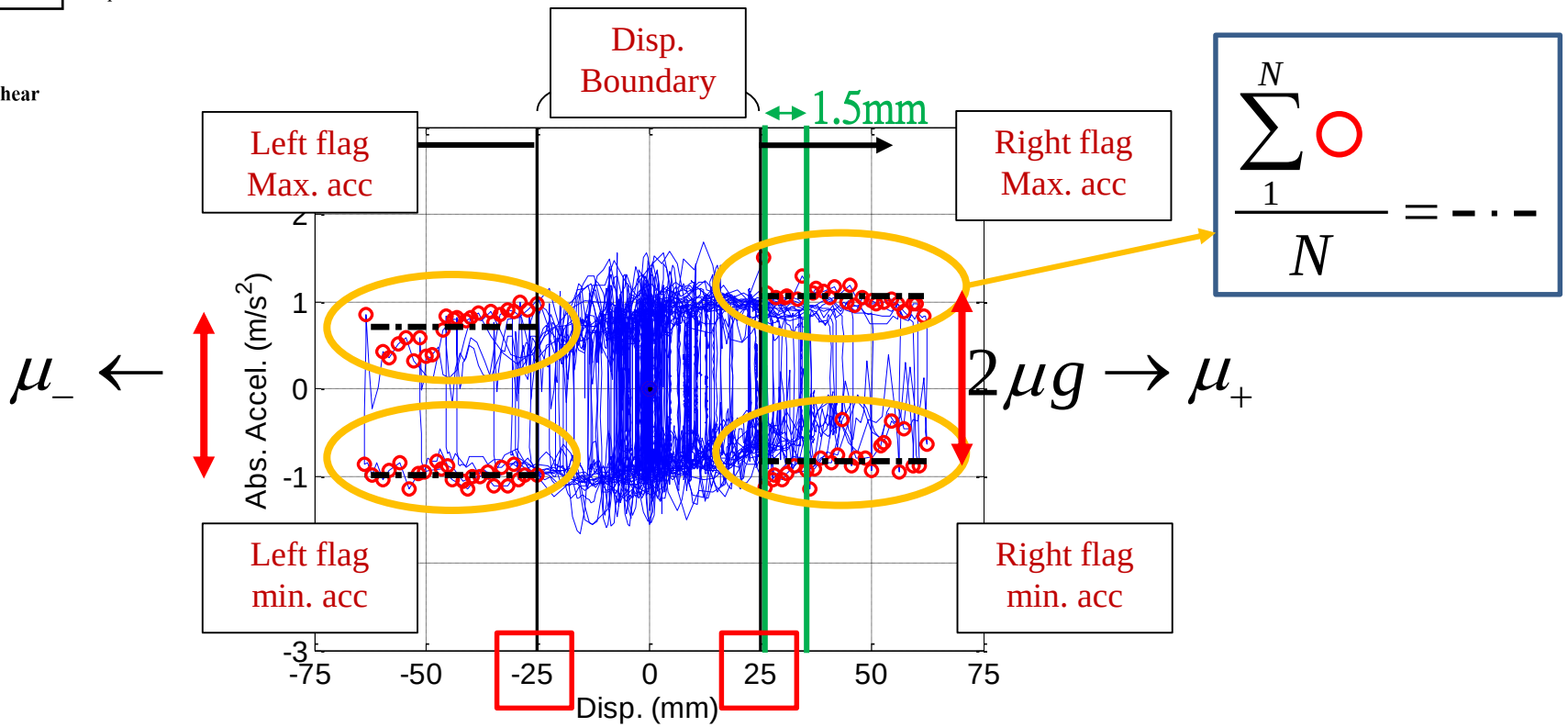
Experimental Study - *Test result*

神戸(Kobe, XY, 100%)

Experimental Study- *Identification of friction coefficient μ*



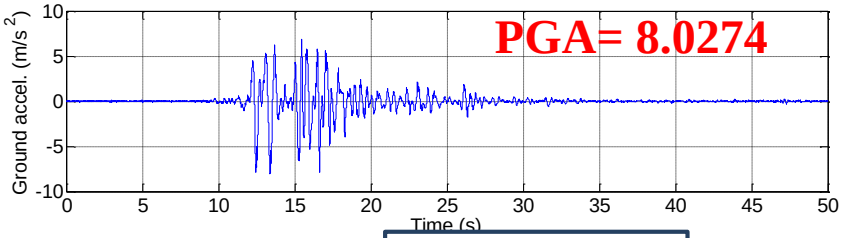
Design friction coefficient	0.06



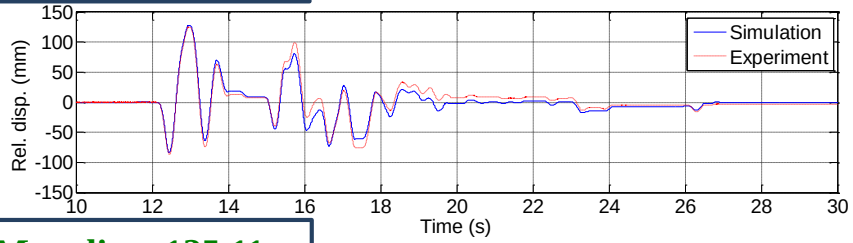
R.M.S. of all μ→ μ=0.0817

Experimental Study- *Resimulation Result*

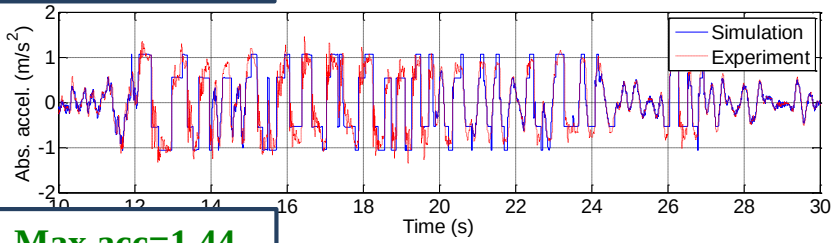
Kobe_X_100%



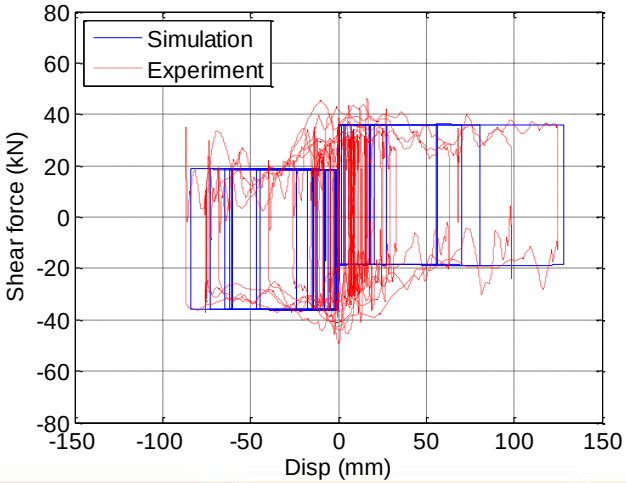
Max.disp=128.16



Max.acc=1.06



Max.disp=125.11

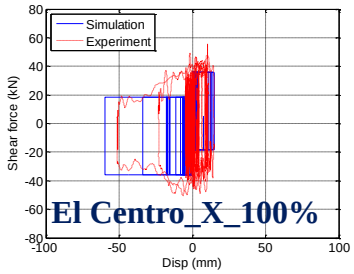


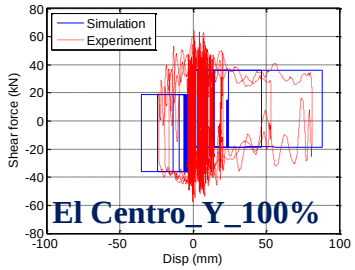
Max.acc=1.44

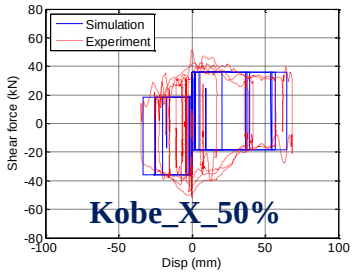
	Abs. Accel.(m/s^2)		Isolator Disp.(mm)	
	Peak Value	R.M.S.	Peak Value	R.M.S.
Simulation	1.06	0.343	128.16	14.65
Exp.	1.44	0.342	125.11	15.54
Error(%)	26.37	0.26	2.44	5.70

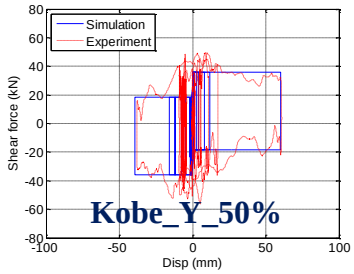
<10%

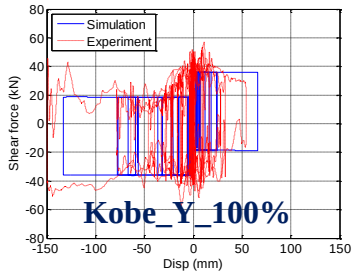
Experimental Study- *Resimulation Result*

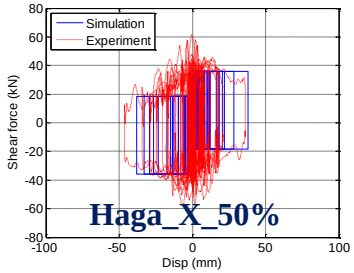


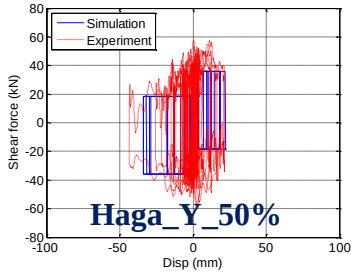


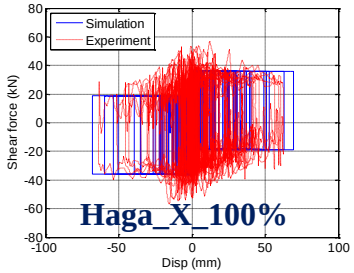


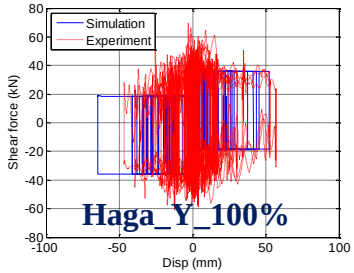


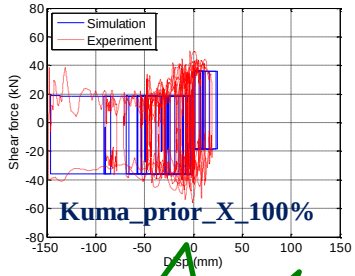


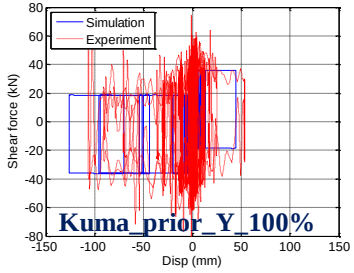


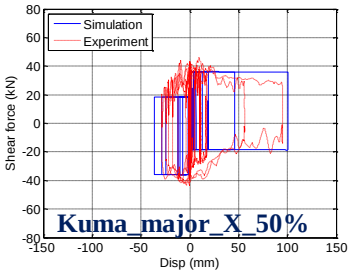


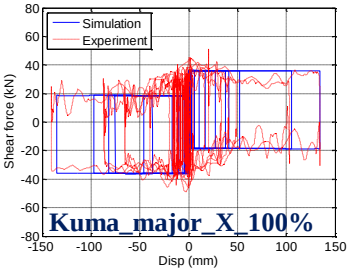


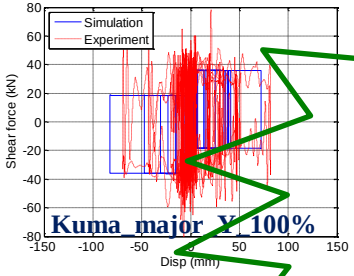












Match!

NARLabs

Conclusion

1. The Equation of motion was derived and experimentally verified.
2. The sloped sliding bearing is effective to reduce the seismic response of superstructure.
3. The maximum acceleration is controlled by slope and friction coefficient.
4. The range of residual displacement is acceptable.
5. The pounding effect is observed.

NARLabs

Thank you for listening~

Q&A