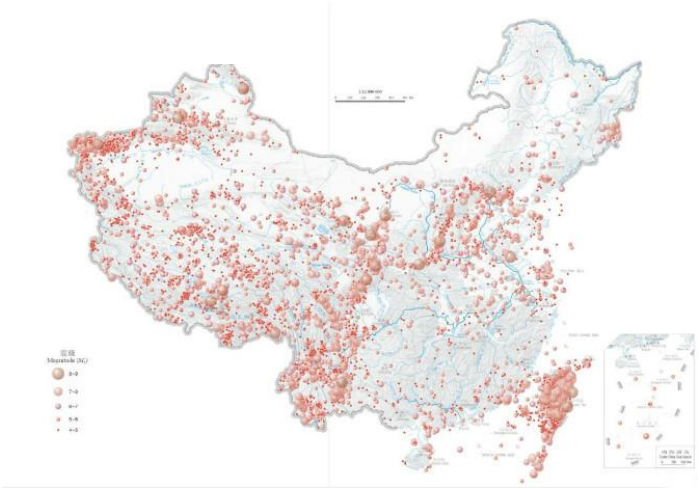
Huazhong University of Science and Technology

School of Civil Engineering and Mechanics

Probabilistic seismic hazard assessment for the pseudo-negative stiffness control of a steel base-isolated building: A comparative study with bilinear isolation scheme



Earthquake Epicenter Distribution of China

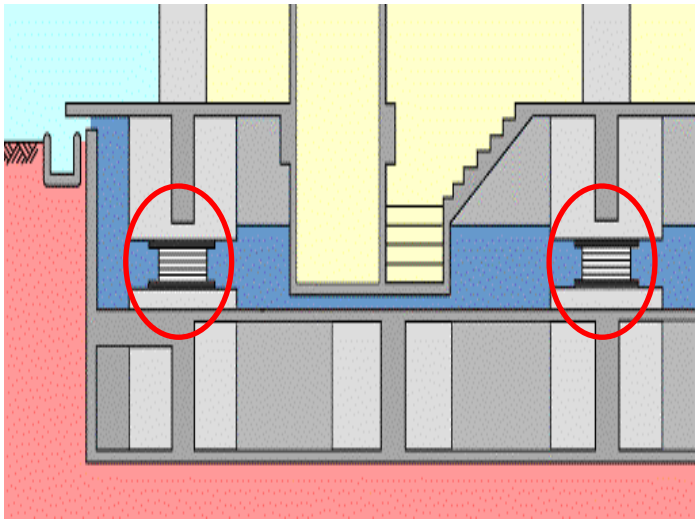
Wei Gong， 龚微， PhD Candidate,

Huazhong University of Science and Technology

Email: ivykung@foxmail.com

1037, LuoYu Road, Wuhan, China,430074

Background | Objective | Method | Conclusion



Flexibility

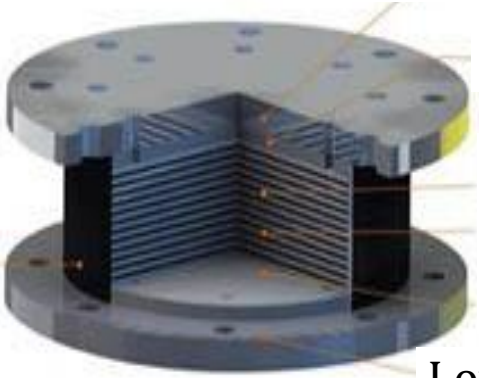
Superstructure demands

Base movement

Near-fault ground motion

Extensive earthquake

Upper connection plate



Upper cover plate

Internal rubber

Internal steel plate

Lower cover plate

Lower connection plate



New device brings new problem!

Background | Objective | Method | Conclusion

Structure control

passive

Reduce isolation effectiveness in superstructure response control

Isolation safety

Isolation effective



active

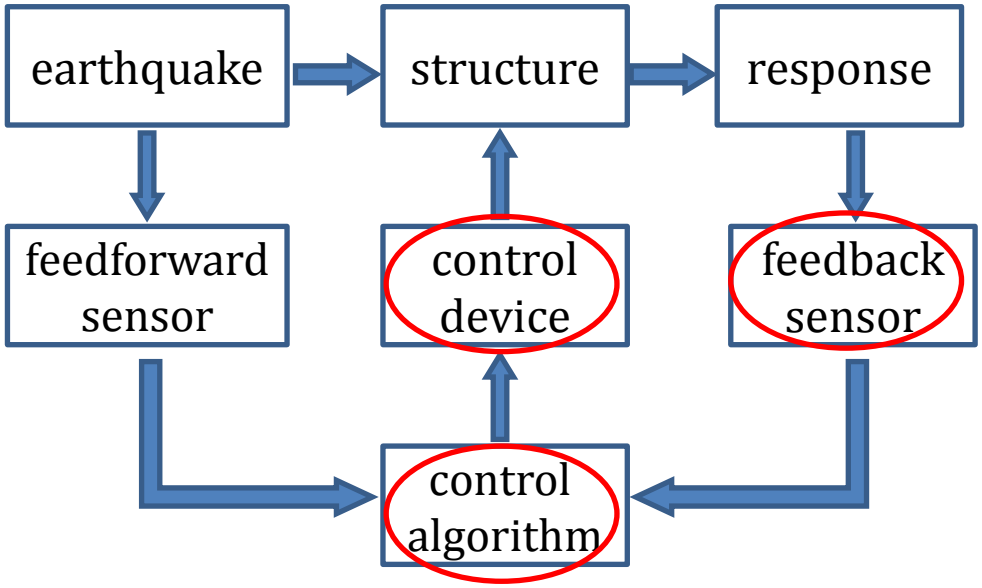
Require large power supply and doubtable reliability

Semi-active

Effectiveness + reliability + adaptability



Background | Objective | Method | Conclusion



Is there a semi-active control algorithm simple?



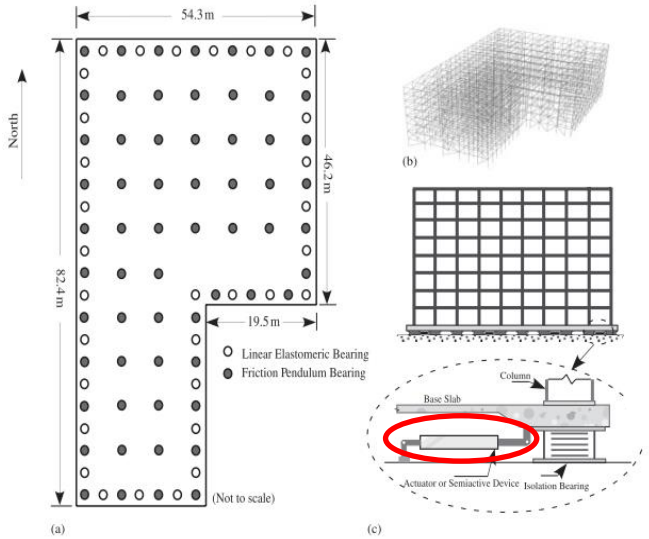
Conventional semi-active control algorithm:

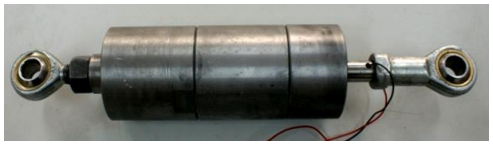
clipped-optimal control
maximum energy dissipation
modulated homogeneous friction
fuzzy logic-based control
Lyapunov control algorithm

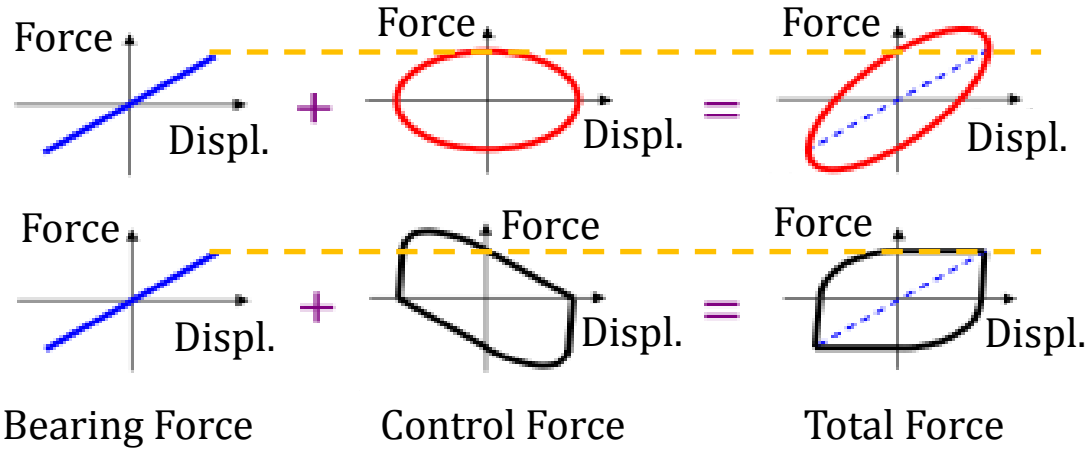
Complex ⇒ complicated computational process; massive sensing networks

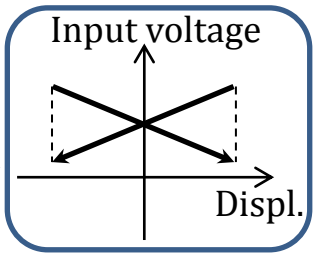
Background | Objective | Method | Conclusion

pseudo-negative stiffness (PNS) control









- reduced force transmission to the superstructure
- high damping ratio

53.4%

1、Low energy source requirement
2、high control force

Effectiveness; Safety; Simplicity

base shear | base displ. | func. of displ

Background | Objective | Method | Conclusion

PNS control

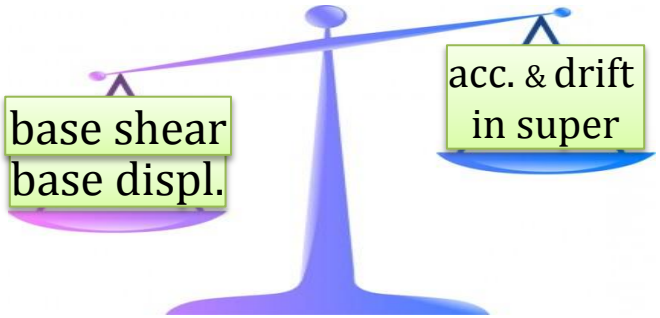
Less base shear → Force to super. ↓

Large damping → Base displ. ↓

real effective

Less acc. & drift in super.

A low base shear is not a guarantee of an real effective isolation system because the high modes, which carry both the floor acceleration and inter-storey drift, are almost orthogonal to the base shear. (Kelly, 1999)





Can we get both?

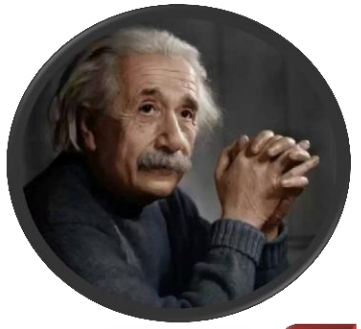
Background | Objective | Method | Conclusion

socio-economic

variability in seismic intensity

Ideal isolation control principle

Response quantities can't be always reduced simultaneously for a specific control strategy.



Basic concept : different *seismic intensity* different *control objective*

frequent earthquake → improve the structural functionality → acc. and drift in super.

extreme earthquake → improve the structural safety → isolator displacement

reduce the overall economic loss

Ideal isolation control principle solves the conflict between iso. effectiveness and iso. safety.

Background | **Objective** | Method | Conclusion

Modified PNS control
MPNS

Propose

evaluate

Ideal isolation control principle

difficulty

Deterministic

Probabilistic

Probabilistic seismic risk assessment



Benchmark base-isolated building

MPNS, PNS and passive damping control

Part 1: Modified pseudo-negative stiffness (MPNS) control

Control object:

energy dissipation capacity

- loosen the restriction on isolator displacement for **low-to-moderate** seismic intensity
- prevent the relative movement of isolators for **high** seismic intensity

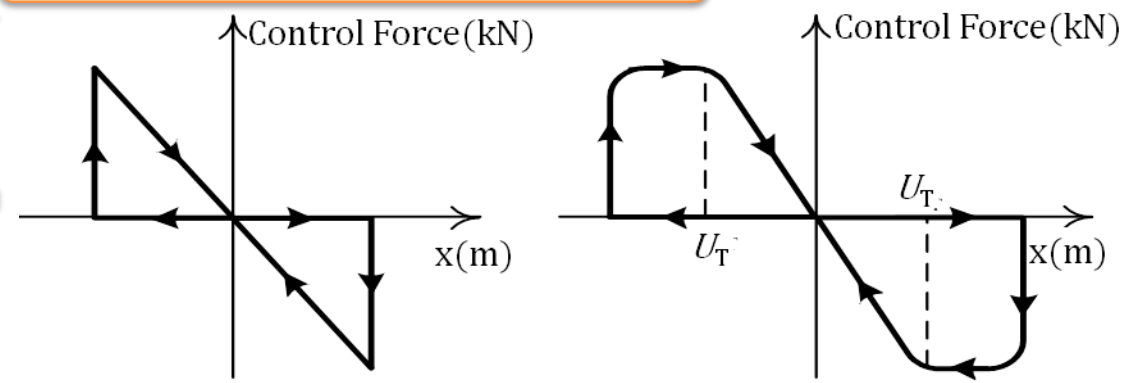
increasing the control force

passive energy dissipation fashion

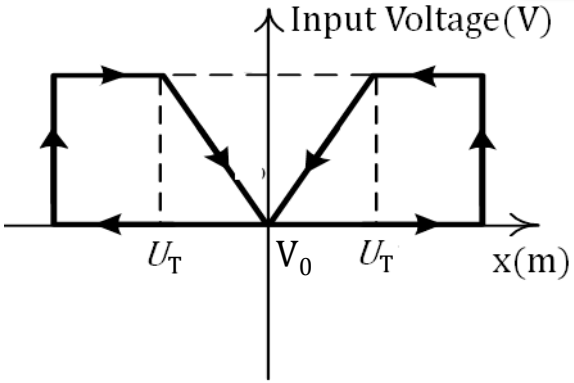
V_0=1

k_{pns}=5

U_T=0.2



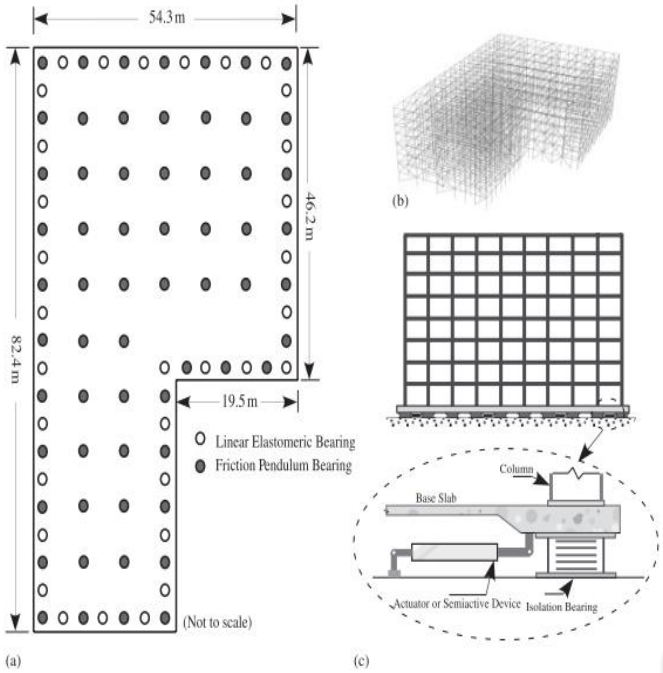
Force-displacement sketch of MPNS



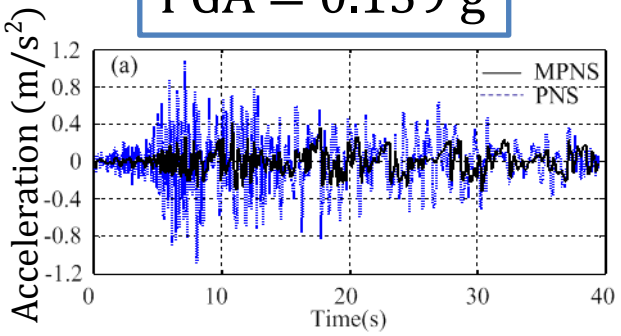
Implemented by MRD

Part 2: Deterministic assessment of MPNS control

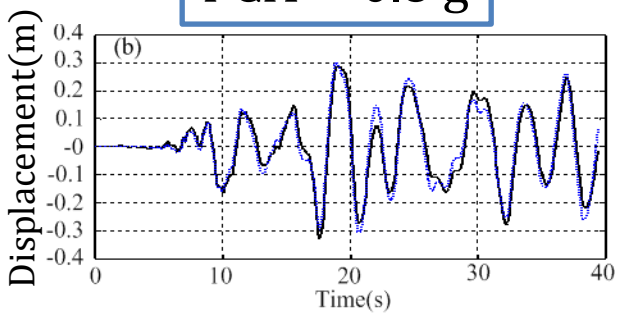
Seismic input : El Centro x-direction

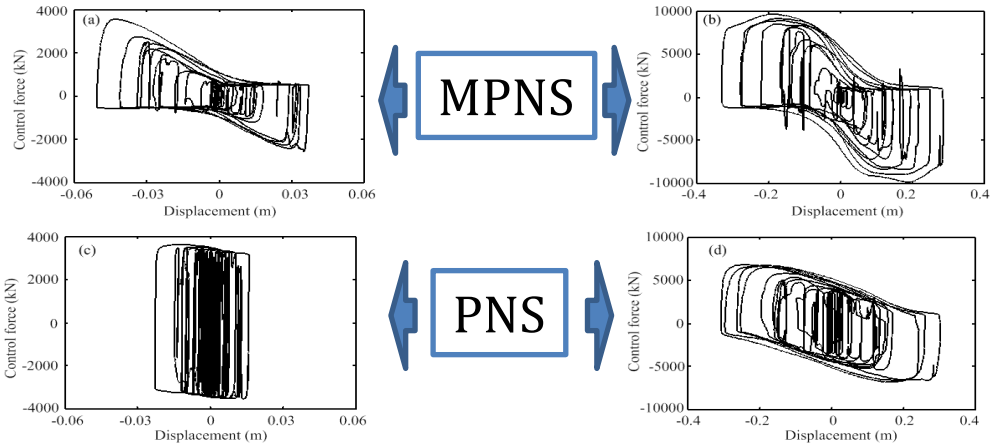


PGA = 0.139 g



PGA = 0.8 g





MPNS

PNS

Larger iso. displ. for MPNS

Larger contr. force for MPNS

Part 3: Probabilistic seismic hazard/risk assessment (PSHA) of MPNS control

Definition :

estimate probabilities of exceeding various damage states for a certain damage measure

Merit :

- consider various ground motions with different ***frequency contents*** and ***intensities***
- descript structural performances in probabilistic format

explicit

scientifically complete

Damage Measure (DM) : θ_{max} a_{max} U_{bmax} → **EDP**

Damage State	Slight (LS1)	Moderate (LS2)	Extensive (LS3)	Collapse (LS4)
Inter-storey drift ratio	0.1%	0.2%	0.7%	1.5%
Story acceleration(g)	0.05	0.1	0.2	0.4
Bearing displacement (m)	0.1D (0.06)	0.2D (0.12)	0.45D (0.27)	min(0.55D,3Tr) (0.33)

Background | Objective | **Method** | Conclusion

Part 3: Probabilistic seismic hazard/risk assessment (PSHA) of MPNS control

Site Hazard → Nonlinear IDA → Probabilistic Seismic Fragility → Structure Hazard

$$\ln(\lambda(im)) = \frac{\alpha}{\ln(im) - \ln(im_{asy})} + \ln(\lambda_{asy})$$

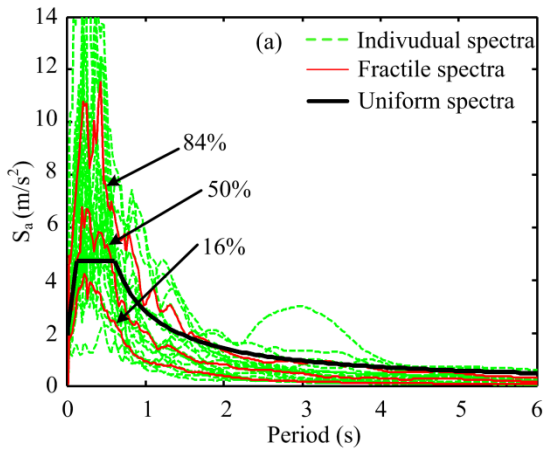
Scale up with **IM**

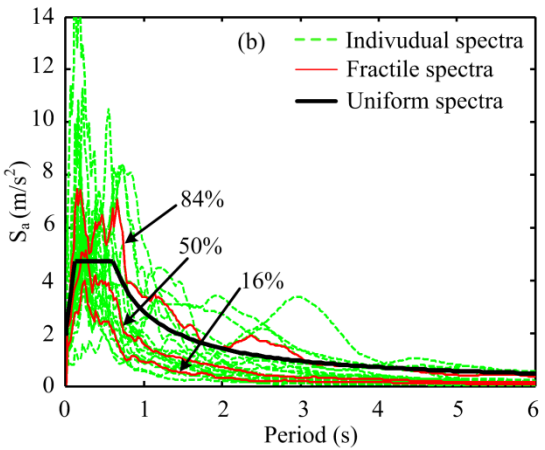
$$\dot{P}(DS_i|im) = n_i/N$$

$$P(DS_i \mid im) = \Phi\left[\frac{\ln(im) - \eta_{im}}{\xi_{im}^2}\right]$$

$$\lambda(DS_i) = \sum P(DS_i \mid im)\left|\frac{d\lambda(im)}{dim}\right|$$

$$P_{50}(DS_i) = 1 - \exp(\lambda(DS_i) \times 50)$$

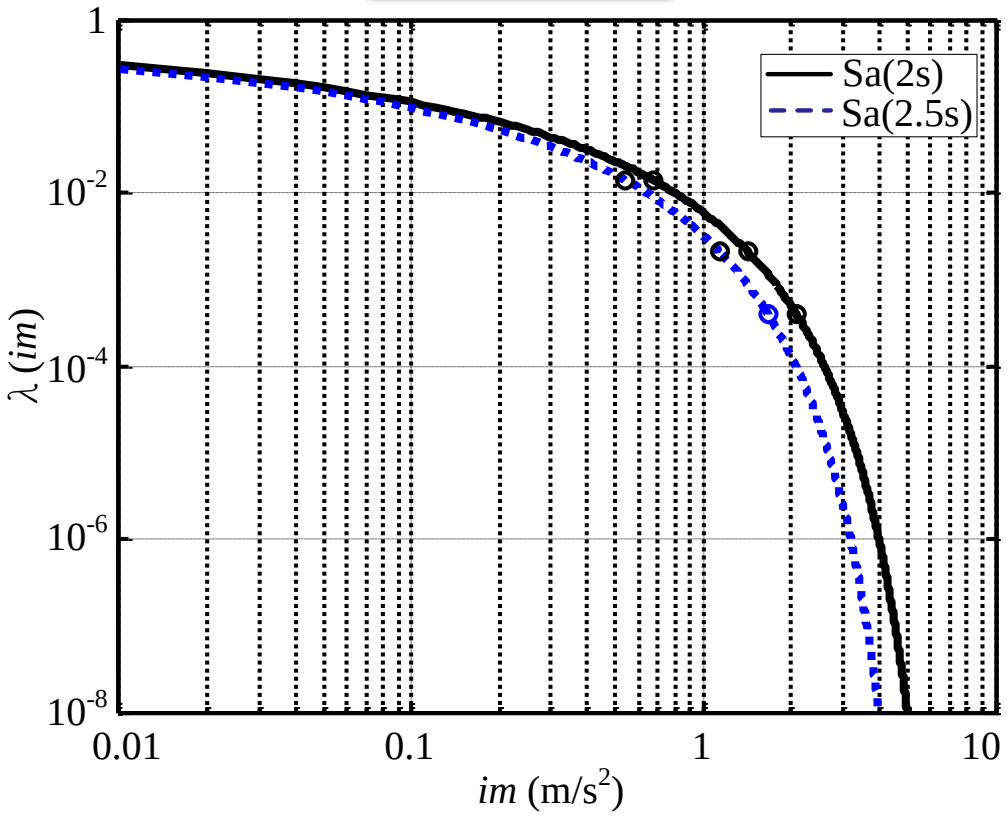




$Sa(T_1)$ → **IM**

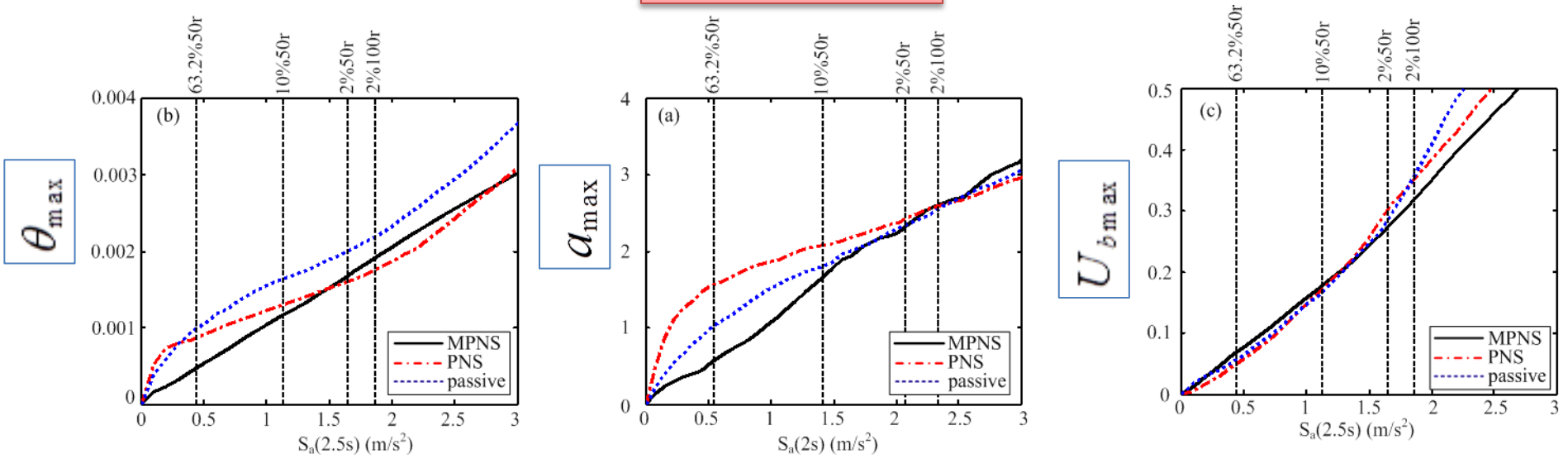
Part 3: Probabilistic seismic hazard/risk assessment (PSHA) of MPNS control

Site Hazard



Part 3: Probabilistic seismic hazard/risk assessment (PSHA) of MPNS control

Nonlinear IDA

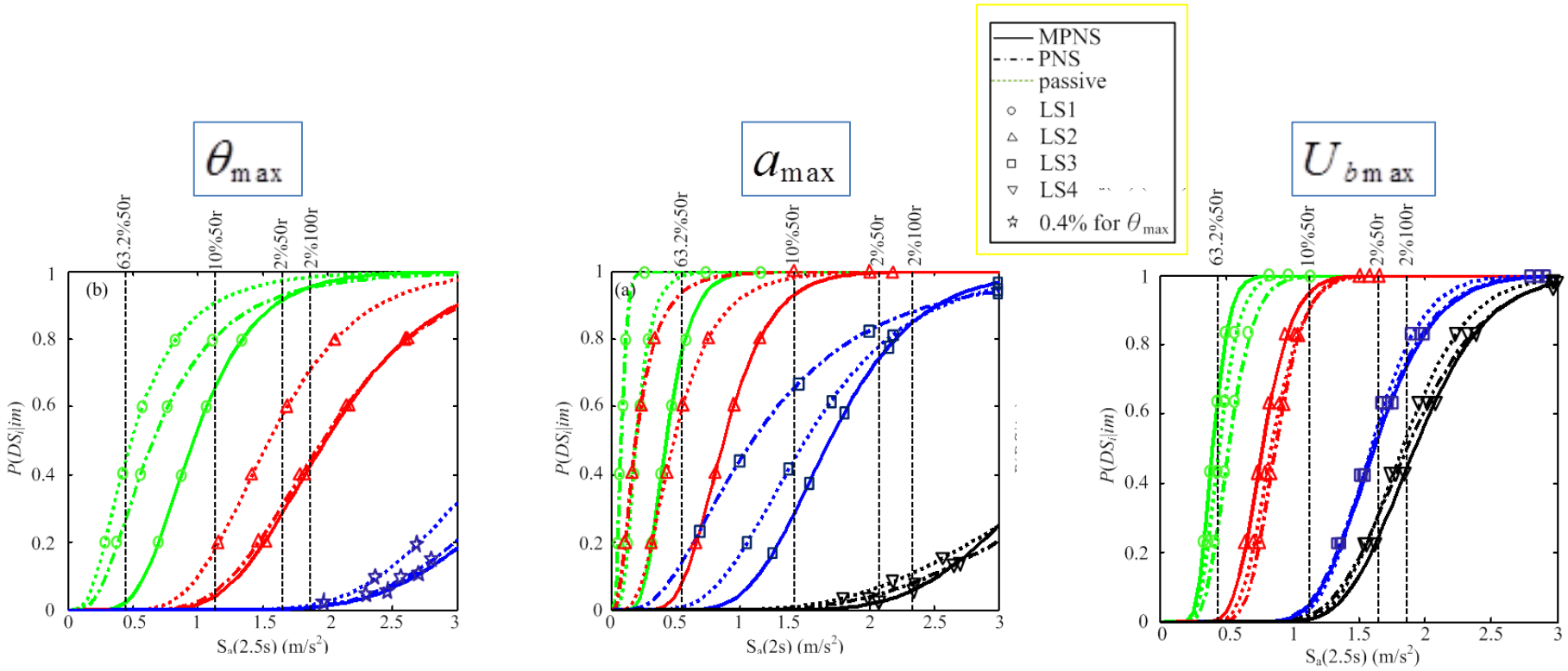


$$\frac{\text{PNS-MPNS}}{\text{PNS}}$$

	63.2%50r	10%50r	2%50r	2%100r
θ_{max}	47%	11%	/	/
a_{max}	64%	20%	/	/
U_{bmax}	/	/	9%	9%

Part 3: Probabilistic seismic hazard/risk assessment (PSHA) of MPNS control

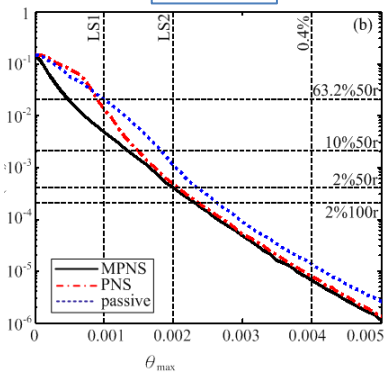
Probabilistic Seismic Fragility



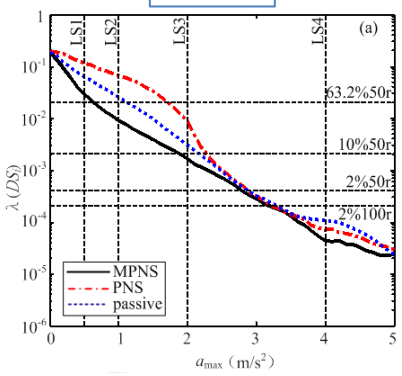
Part 3: Probabilistic seismic hazard/risk assessment (PSHA) of MPNS control

Structure Hazard

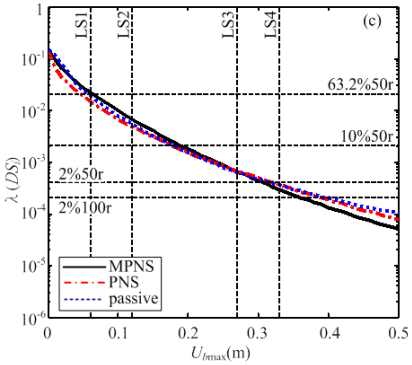
θ_{max}



a_{max}



U_{bmax}



probabilities of exceeding DMs per 50 years

EDP	Control scheme	PE in 50 years (10^{-2})			
		>LS1	>LS2	>LS3	>LS4
θ_{max}	MPNS	**21.0**	**2.0**	0.0	0.0
	PNS	**48.1**	**2.3**	0.0	0.0
	BIS	**63.2**	**5.4**	0.1	0.0
a_{max}	MPNS	**76.1**	**36.7**	8.0	0.2
	PNS	**99.7**	**96.3**	35.0	0.4
	BIS	**95.9**	**72.6**	13.9	0.5
U_{bmax}	MPNS	66.1	27.9	**3.1**	**1.4**
	PNS	52.1	21.3	**3.3**	**1.8**
	BIS	60.4	23.5	**3.1**	**1.8**

- A MPNS control scheme is proposed based on the 'ideal isolation control principle.'
- The effect of the MPNS control is investigated within a probabilistic performance-based seismic engineering framework in terms of structural functionality and safety.
- MPNS control exhibits an enhanced ideal isolation control capacity for improving structural functionality to a substantial extent for low seismic intensities and for enhancing structural safety from collapse.

Thank you ~

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