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Effect of Bilateral Excitation on the Seismic Performance of Reinforced Concrete Bridge Columns

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Extensive damage of columns in the 1995 Kobe earthquake

Backgrounds

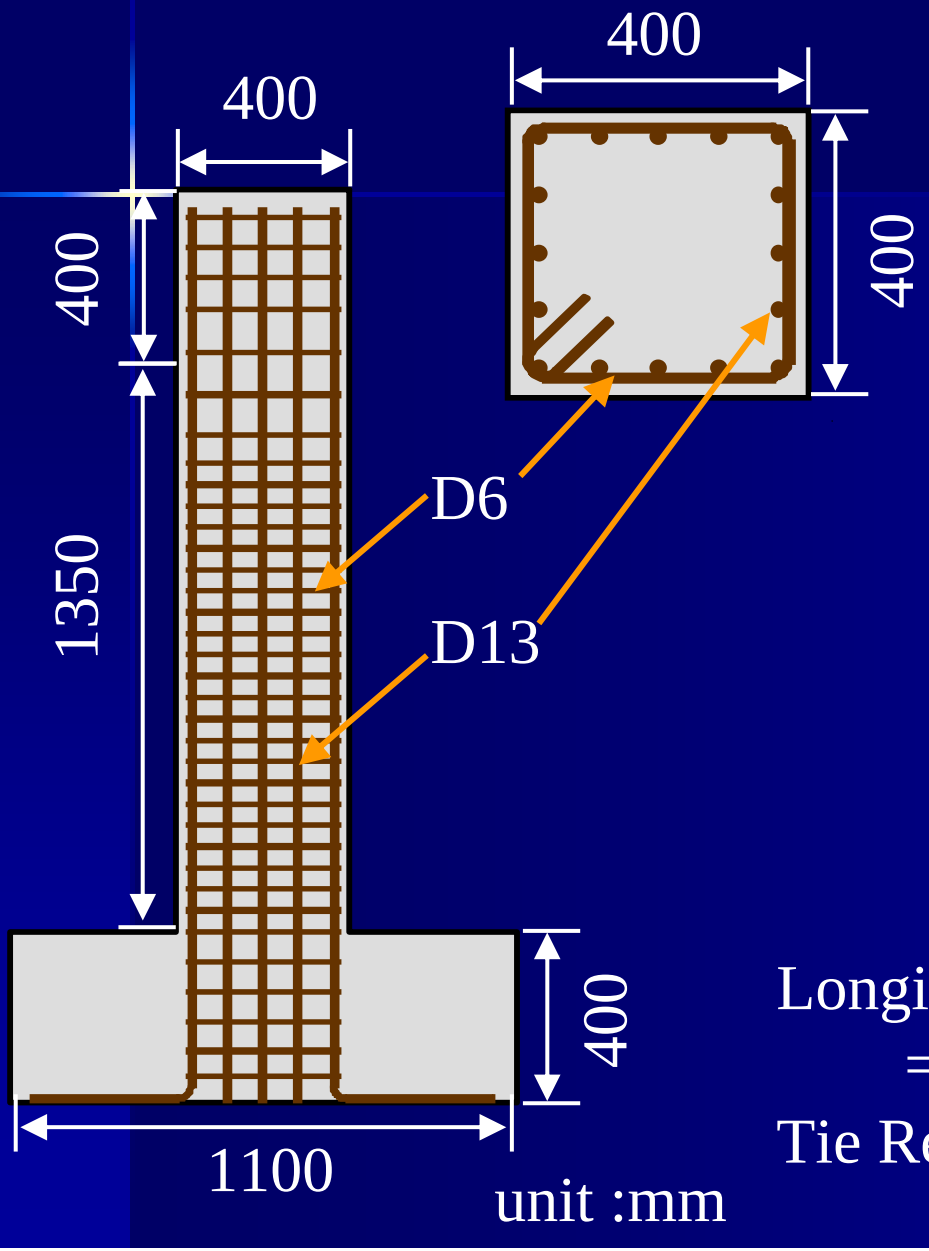
In Current Japanese Seismic Design

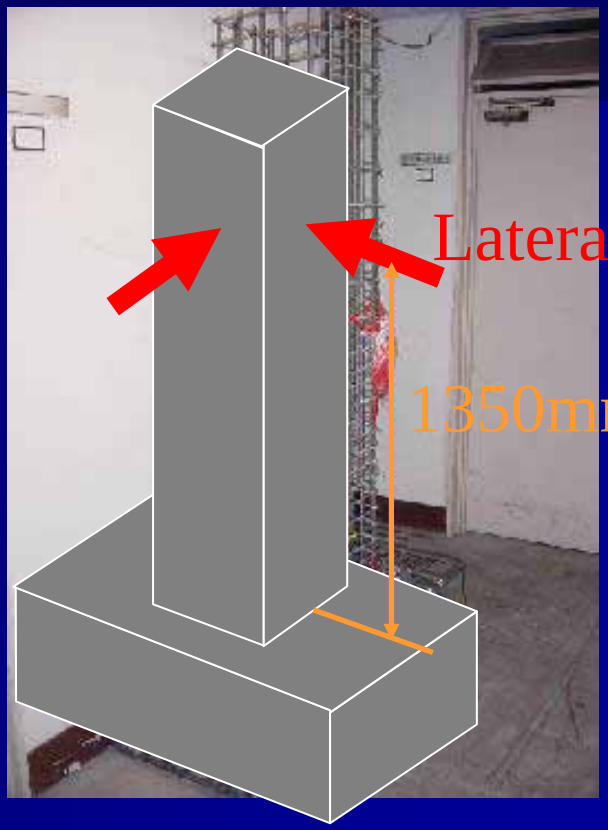
- ✓Bridge columns are designed independently in longitudinal and transverse directions.
- ✓Seismic performance of bridge columns has been decided based on an unilateral cyclic loading test.

Under a real earthquake …

Columns are subjected to bilateral seismic excitation.

Model Columns

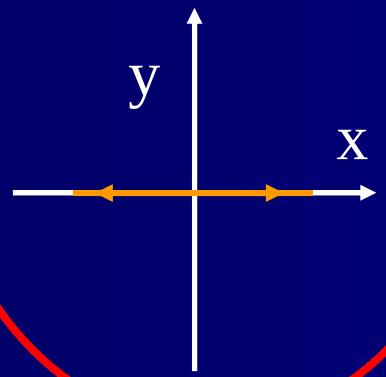




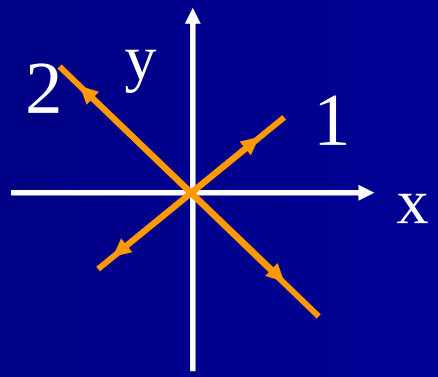
Longitudinal Reinforcement Ratio
=1.27%
Tie Reinforcement Ratio=0.79%

Loading Orbits in the Cyclic Loading Test

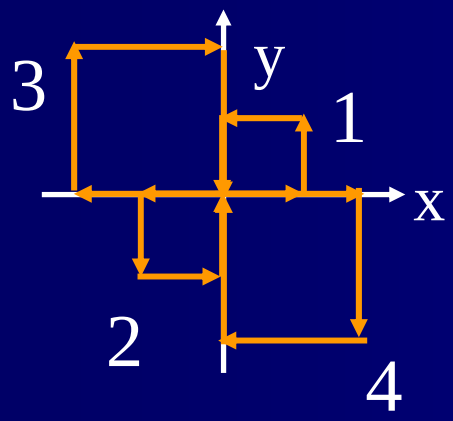
Unilateral



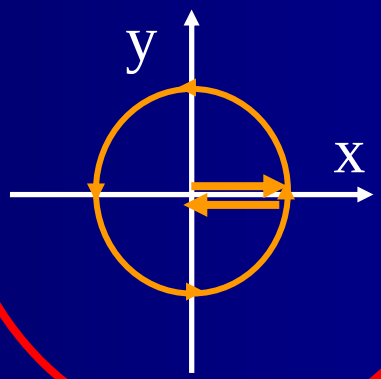
Diagonal



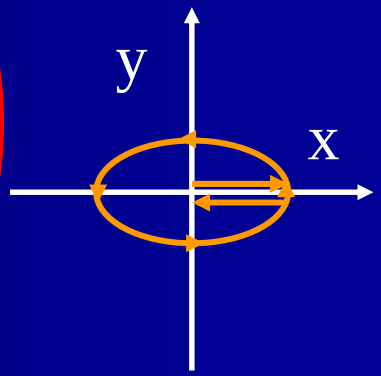
Square



Circular



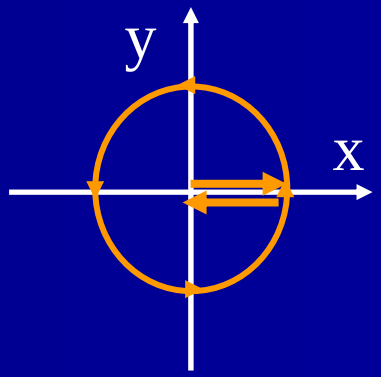
Ellipse



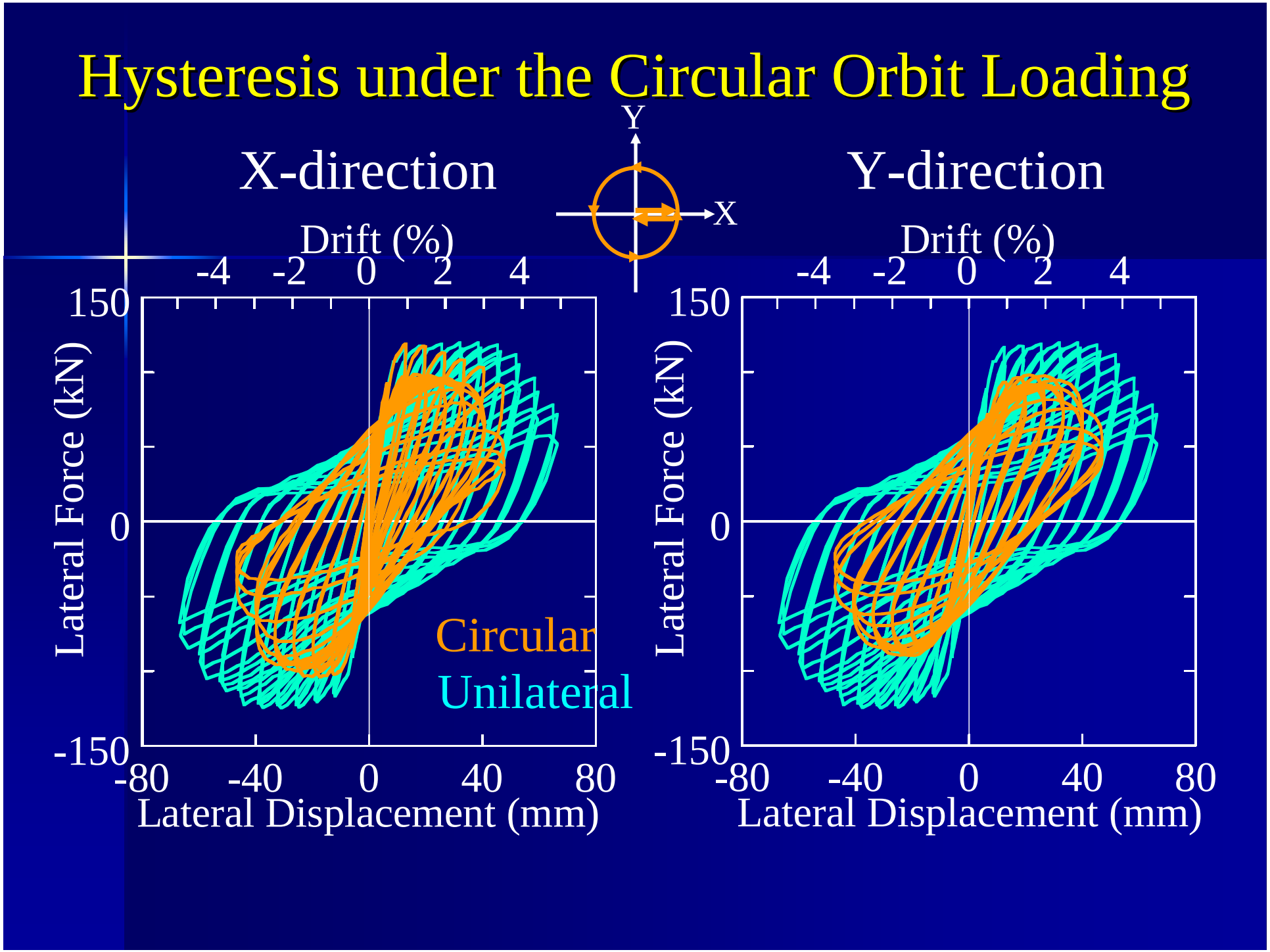
Performance under Circular Orbit Loading

3.5% Drift

Circular

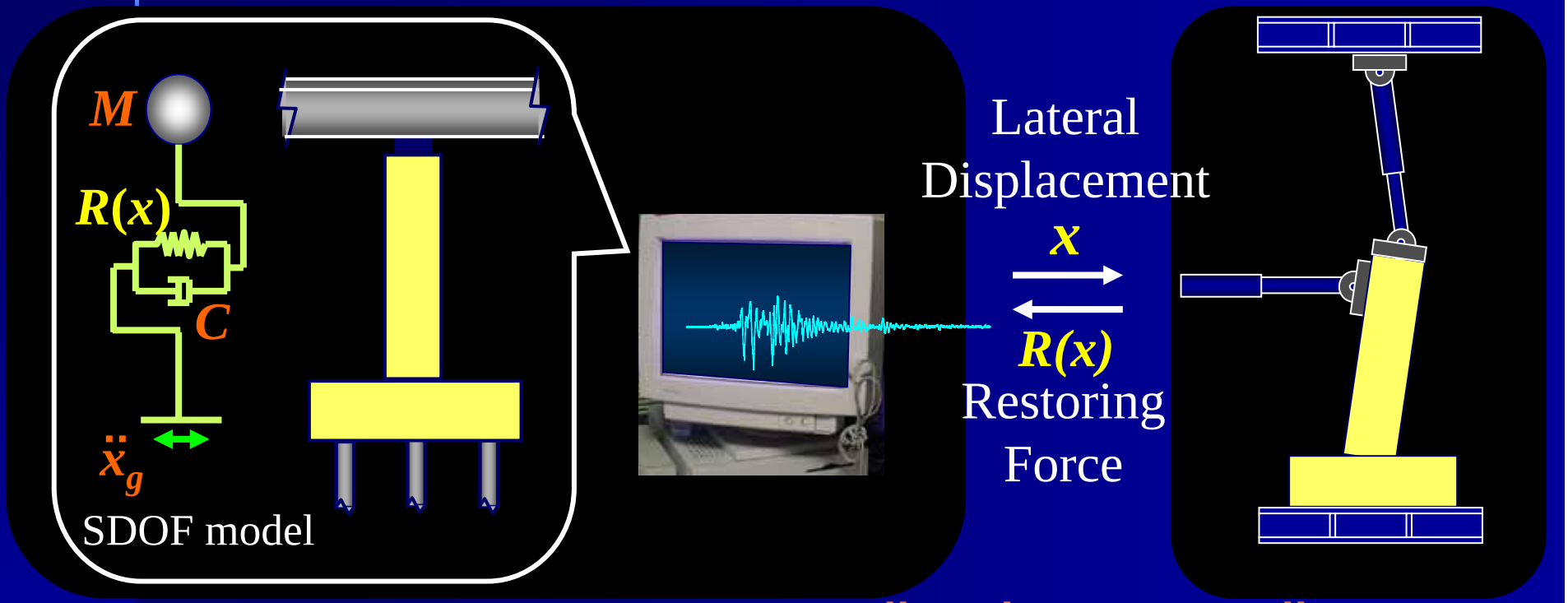


Hysteresis under the Circular Orbit Loading



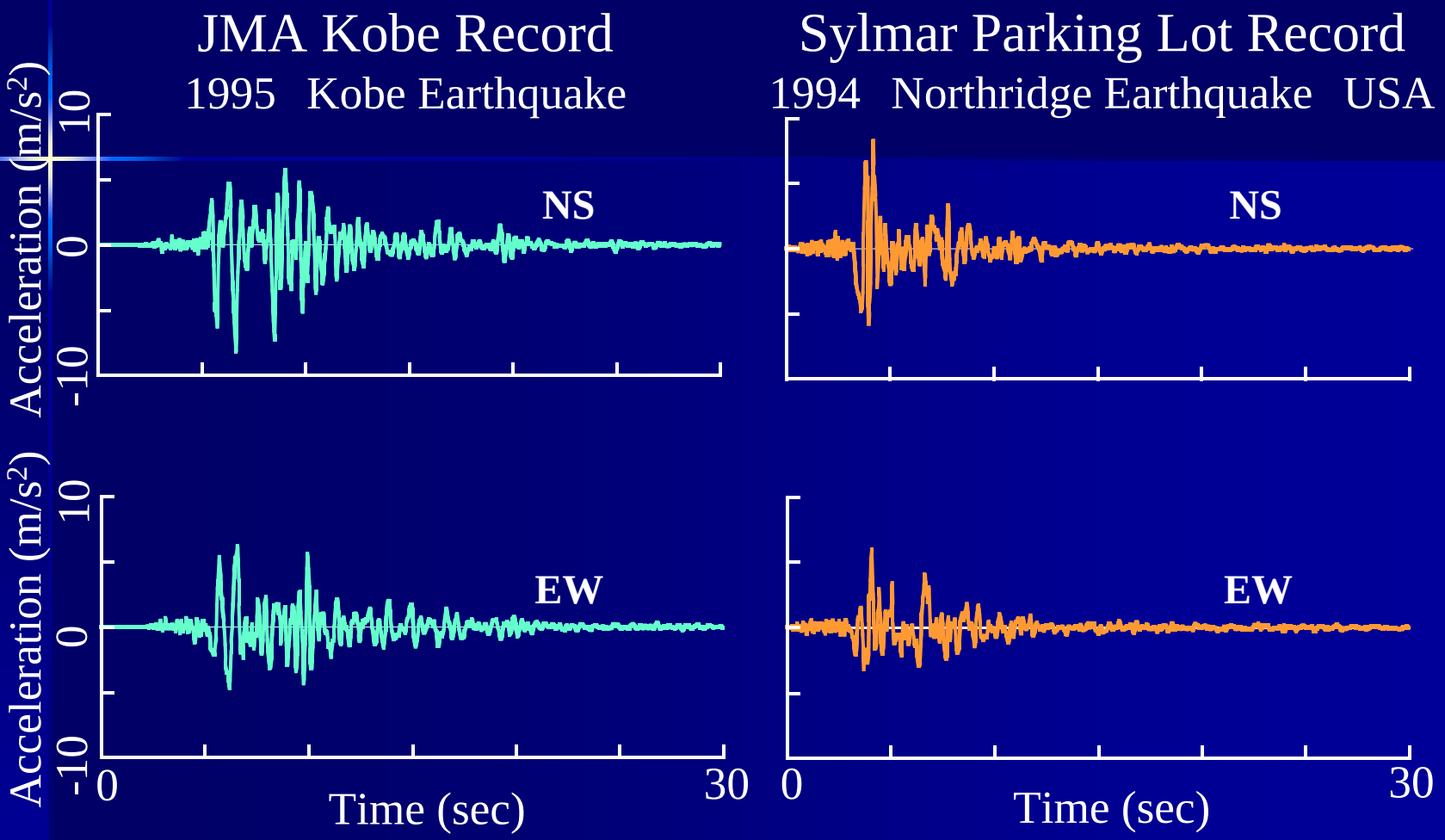
Hybrid Loading Test

Method for reproducing behavior of bridge column under the earthquake experimentally



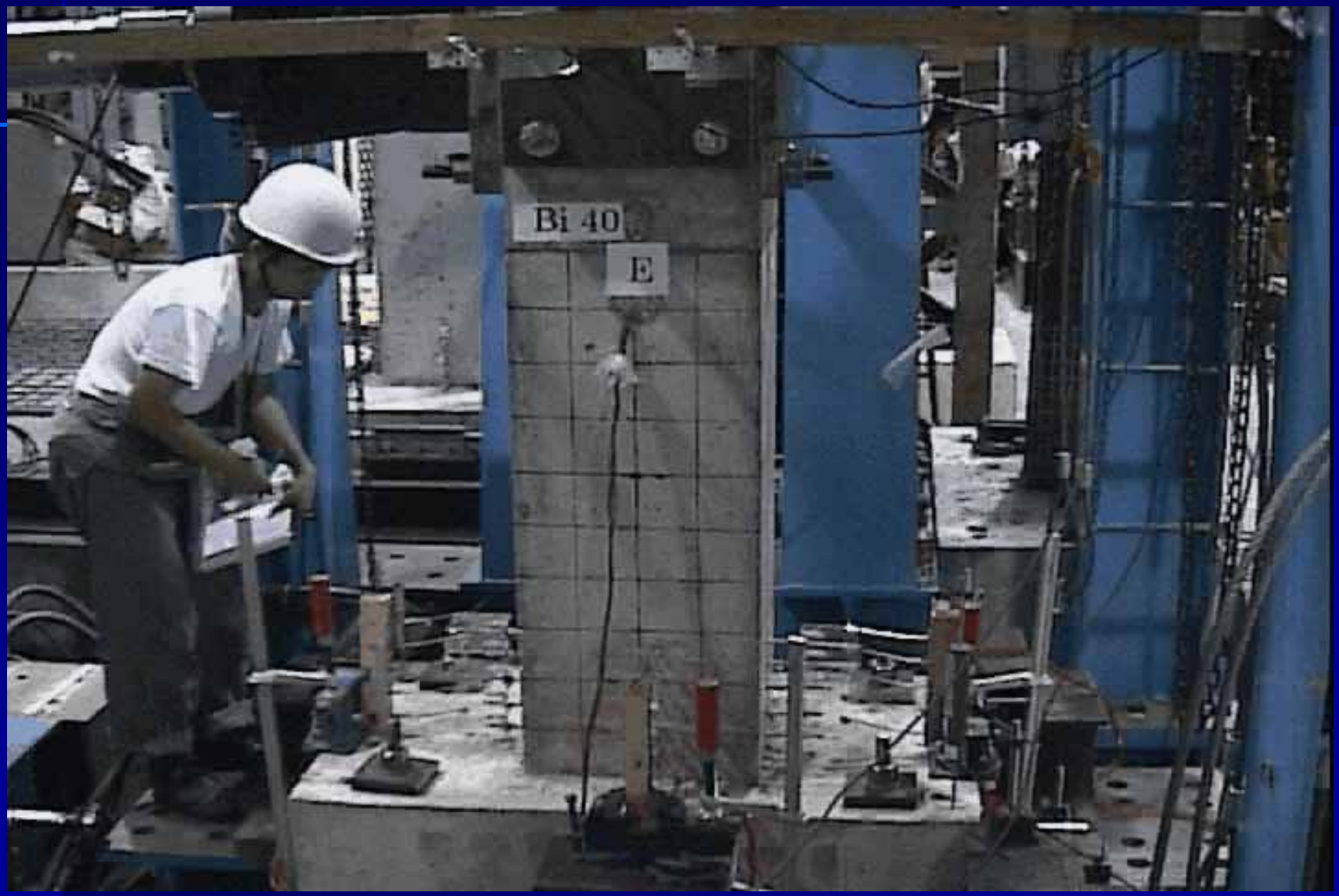
$$M\ddot{x}+C\dot{x}+R(x)=-M\ddot{x}_g$$

Input Ground Motions



In the experiments, the acceleration amplitude was reduced to 30%-50% of the original.

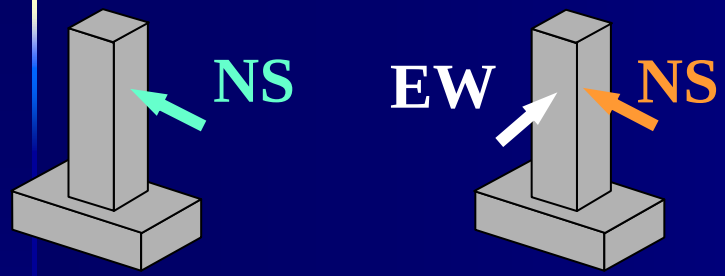
Bilateral Excitation, Kobe 40%

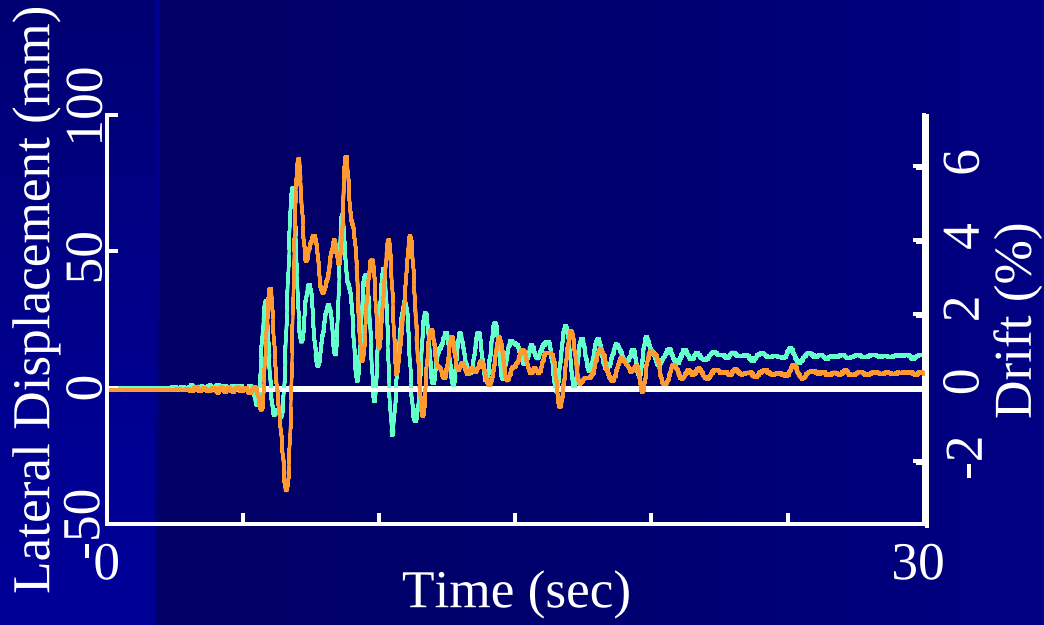


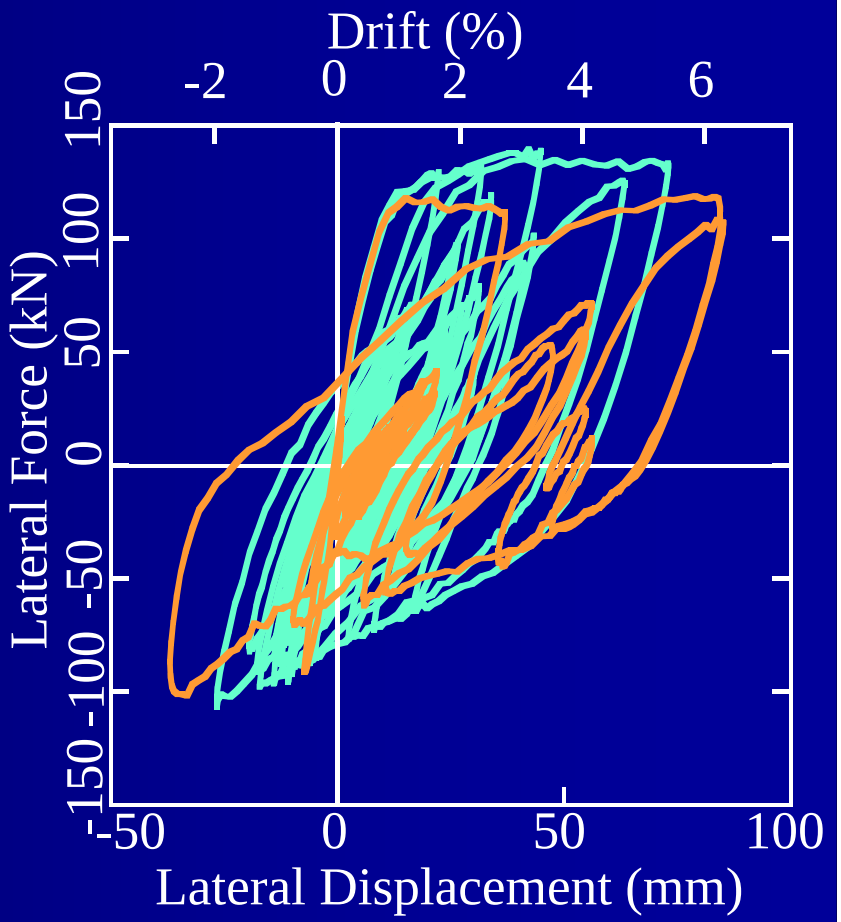
Effect of Bilateral Excitation

Kobe 40%

Unilateral Bilateral



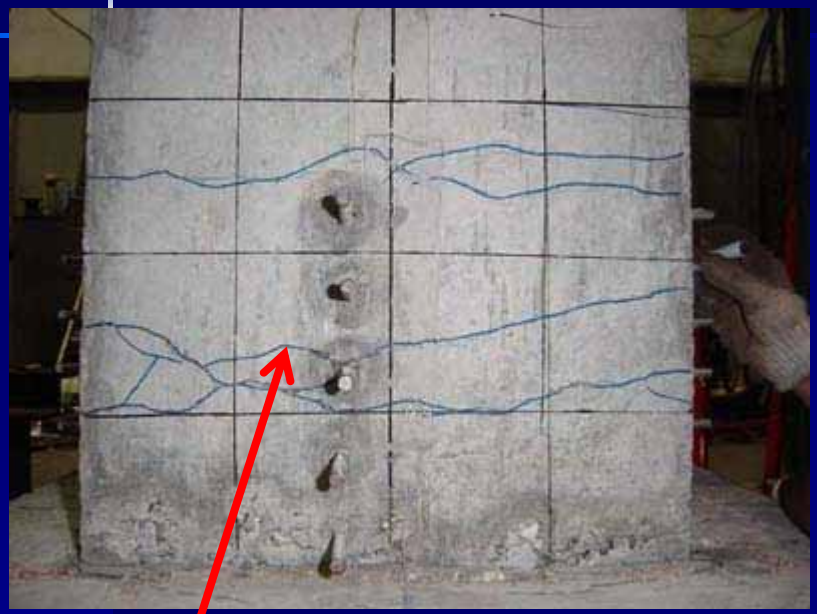




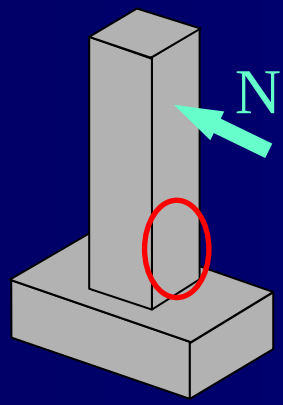
Effect of Bilateral Excitation

Kobe 40%

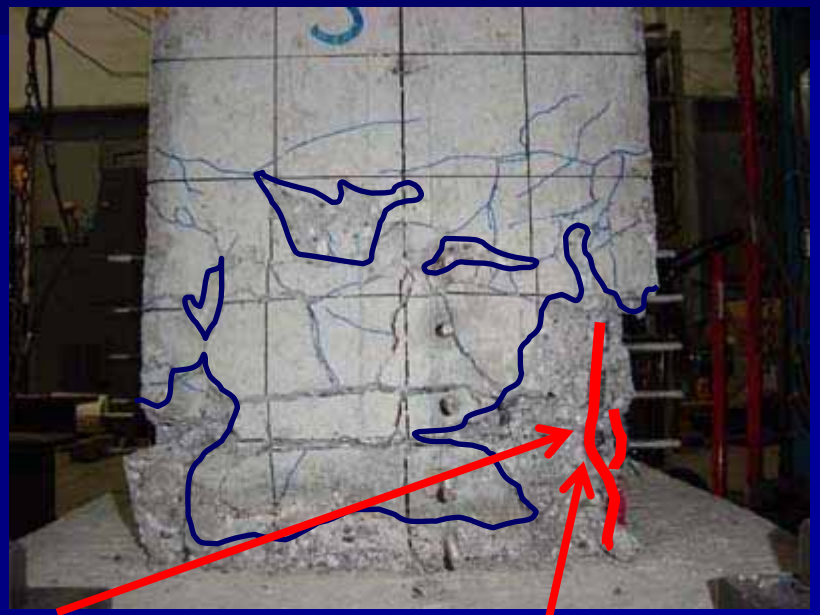
Unilateral



Cracks

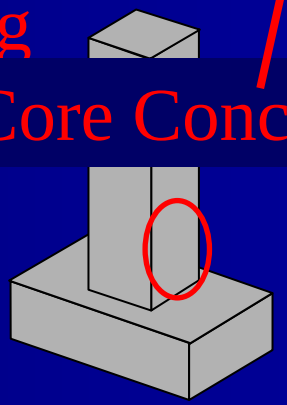


Bilateral



Local Buckling

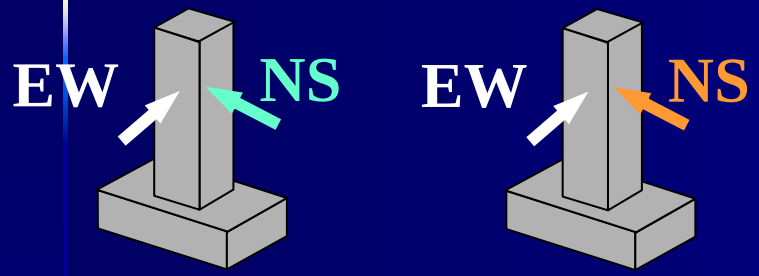
Damage of Core Concrete

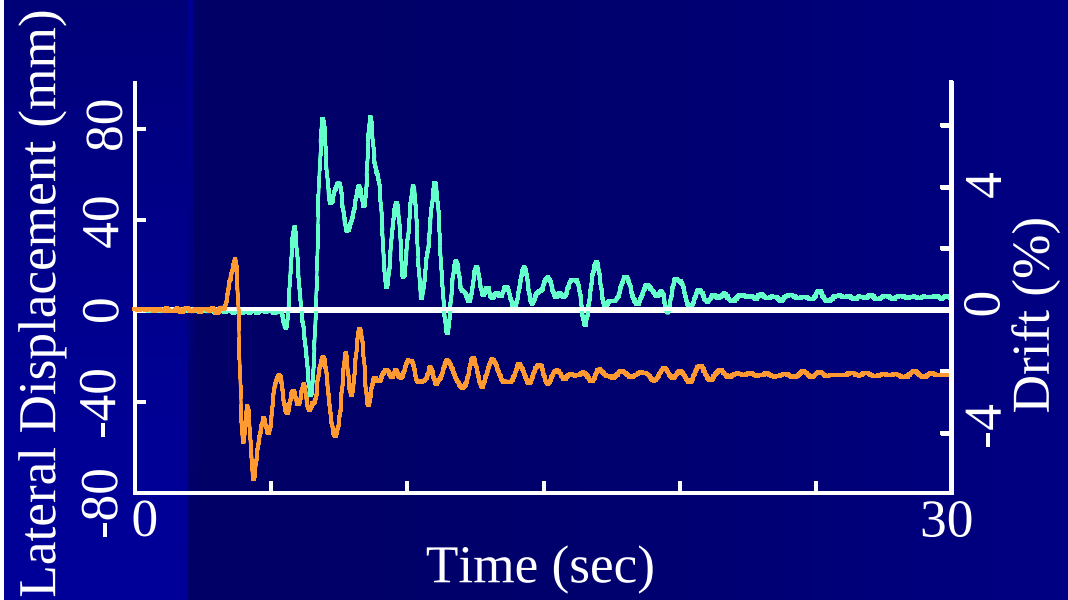


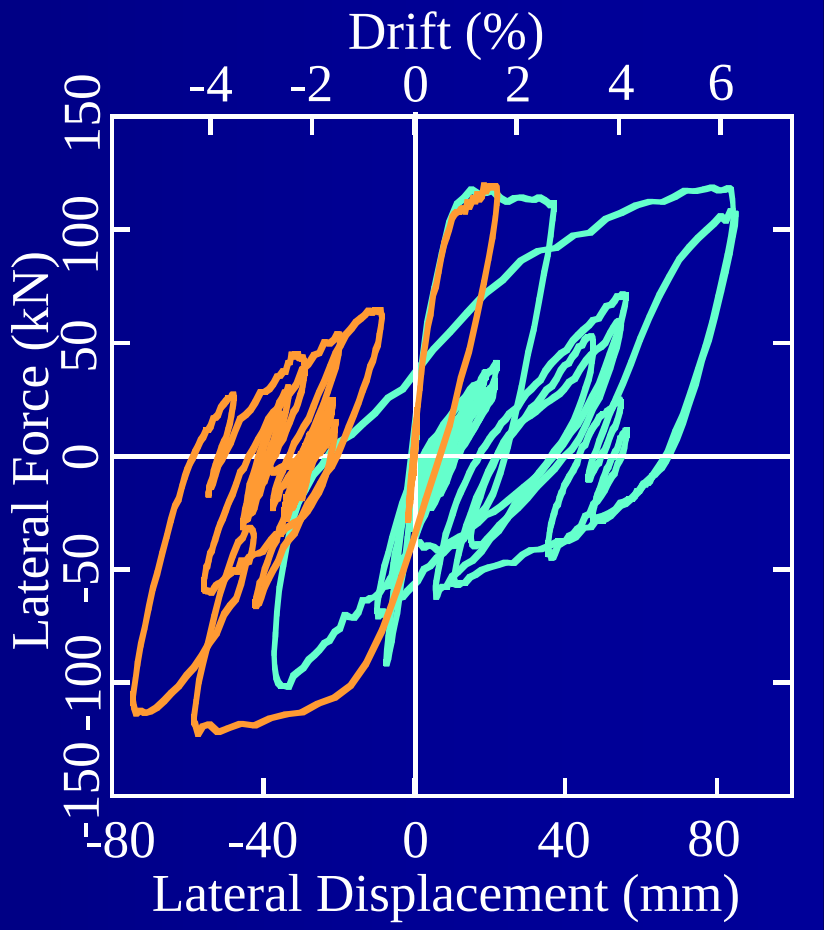
Bilateral Excitation, Sylmar 50%

Effect by the Difference in Input Ground Motion

Kobe Sylmar

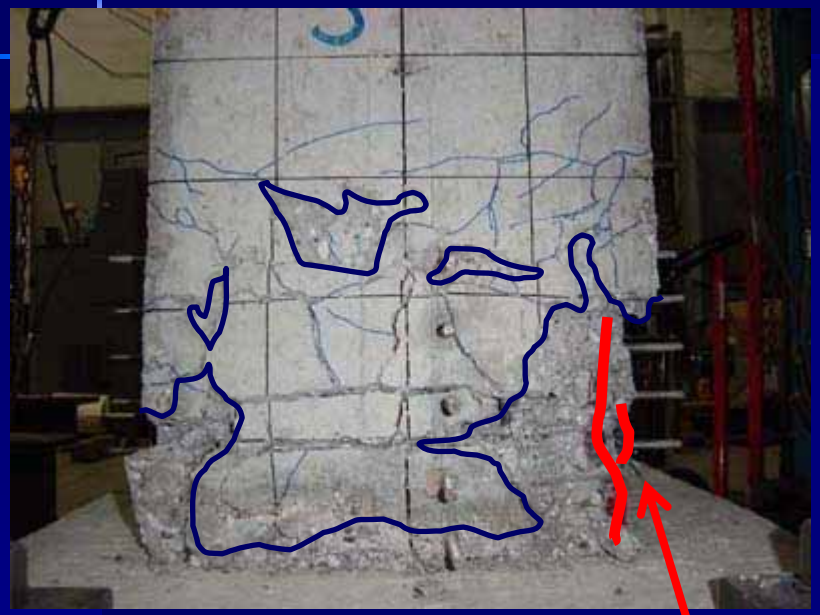




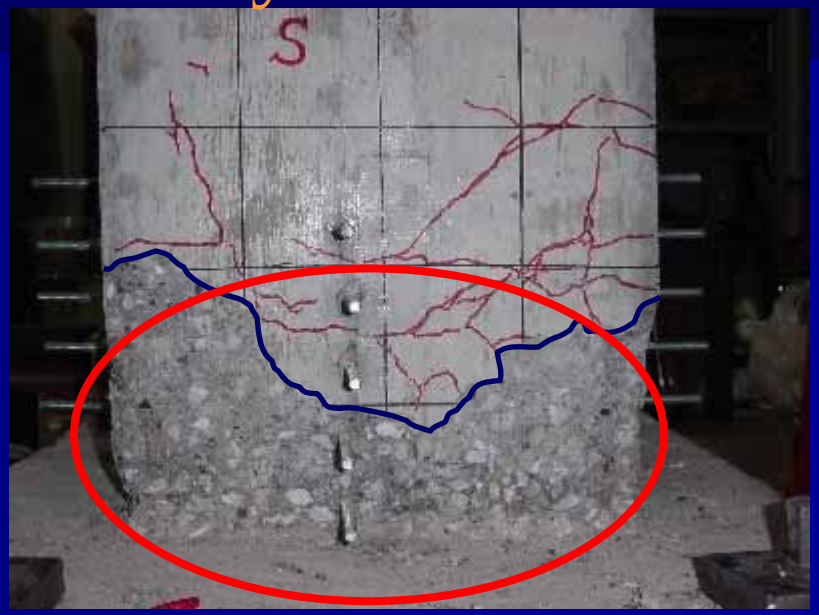


Failure Modes under Bilateral Excitation

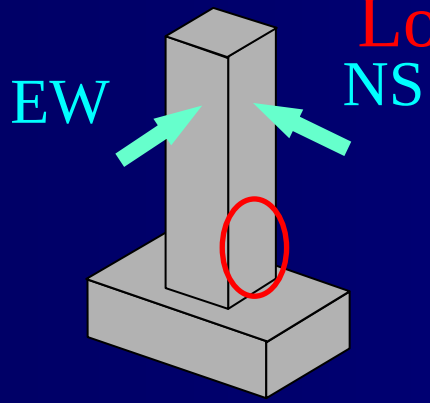
Kobe 40%

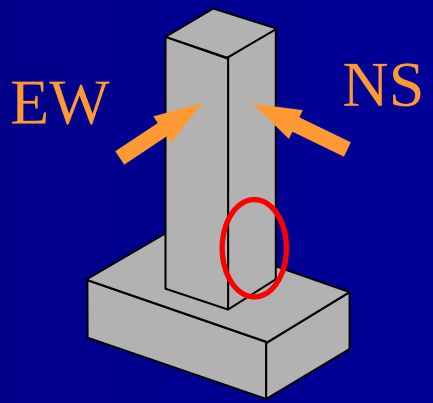


Sylmar 50%

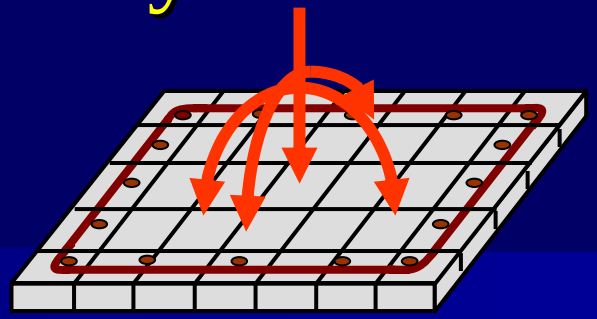


Local Buckling





Fiber Element Analysis



Lateral Force

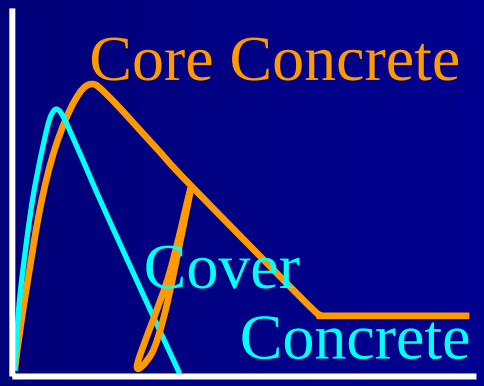
1350mm

Fiber Element

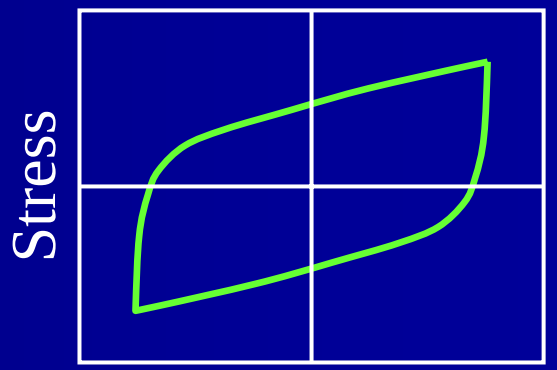
Plastic Hinge

Elastic Rotating Spring

Concrete



Reinforce bar

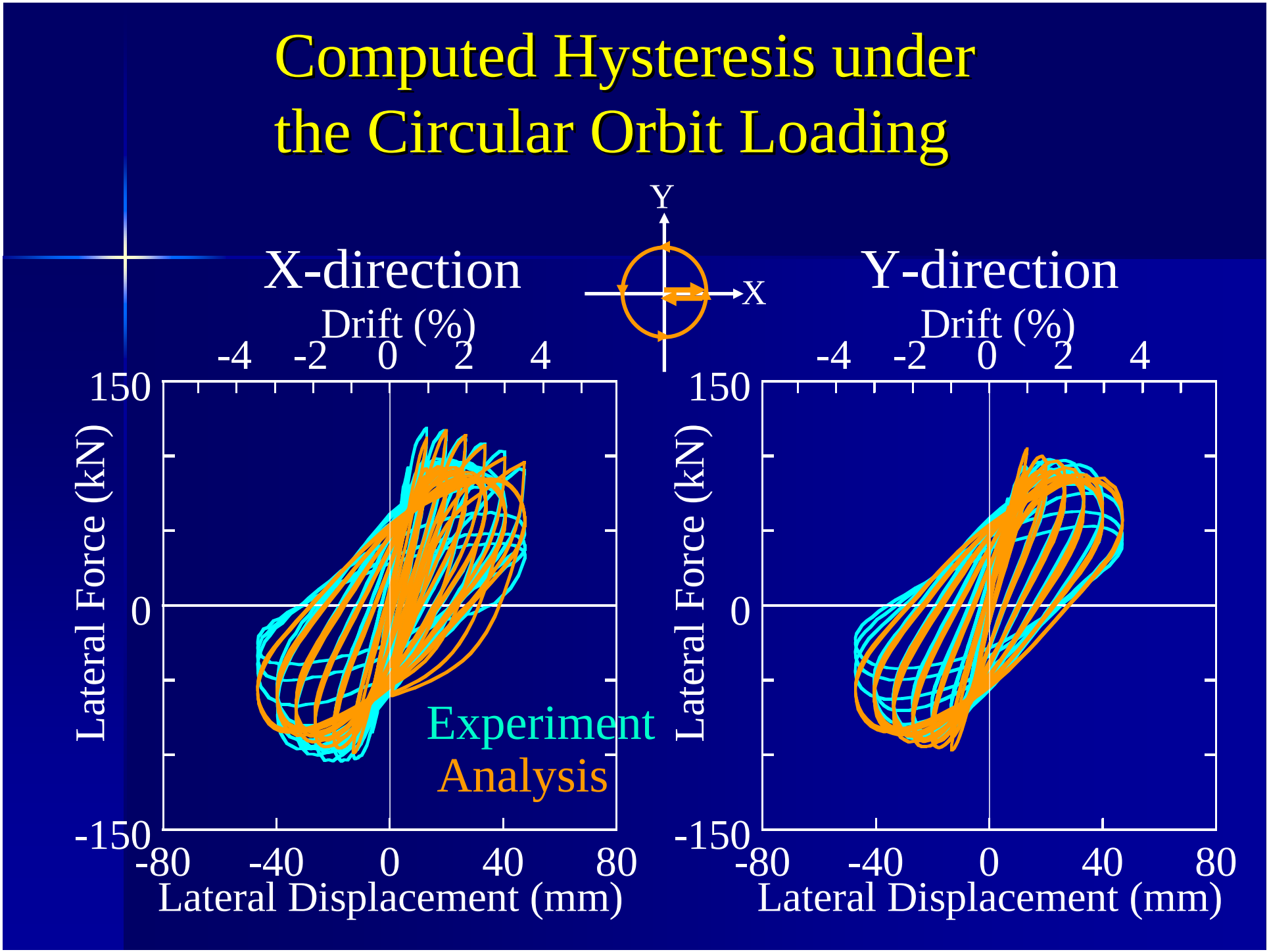


Hoshikuma, Kawashima et al (1997)

Sakai and Kawashima (2000)

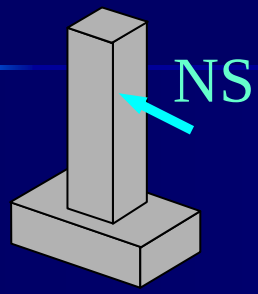
Menegotto and Pinto (1973)

Computed Hysteresis under the Circular Orbit Loading



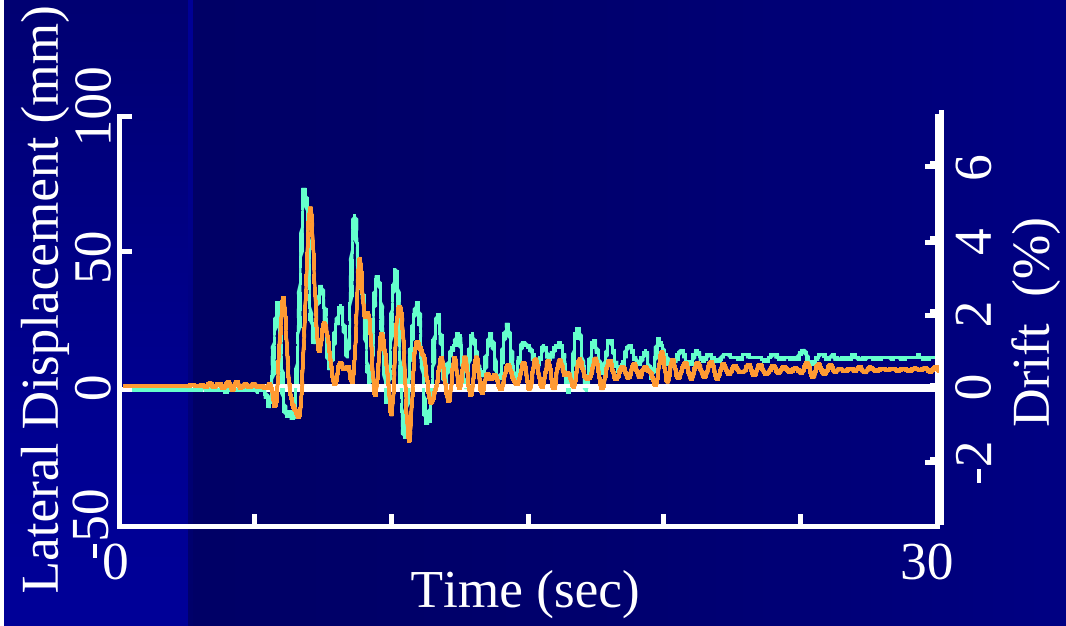
Fiber Element Analysis

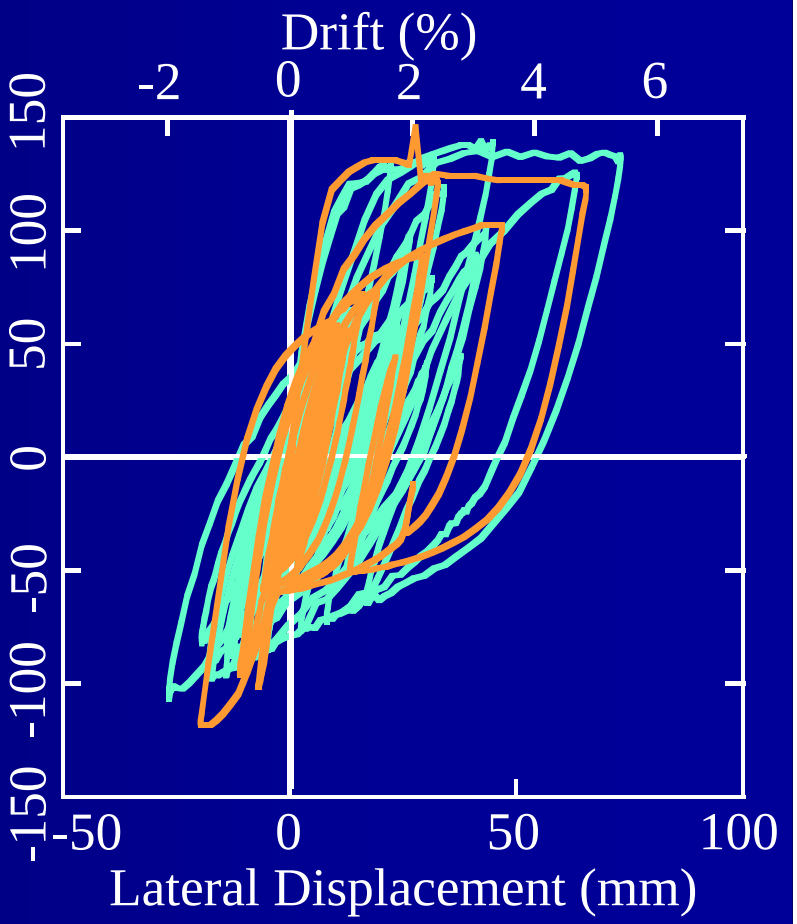
Unilateral Excitation, Kobe 40%



Experiment

Analysis

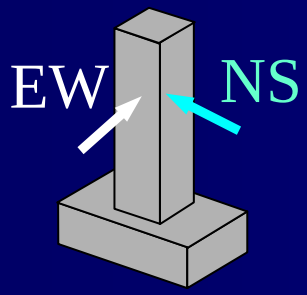




Fiber Element Analysis

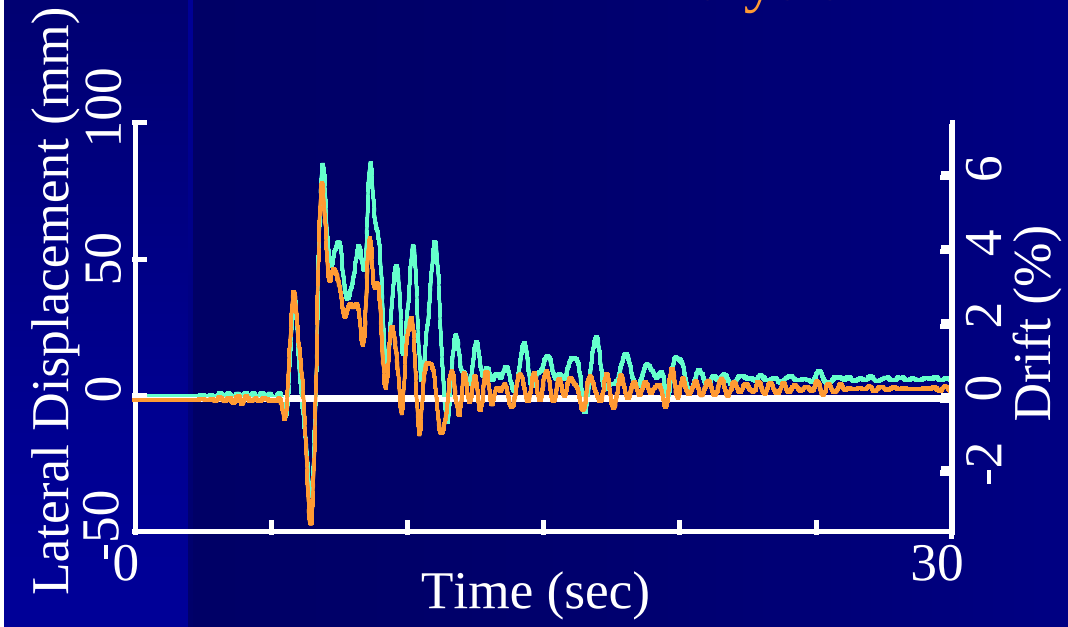
Bilateral Excitation, Kobe 40%

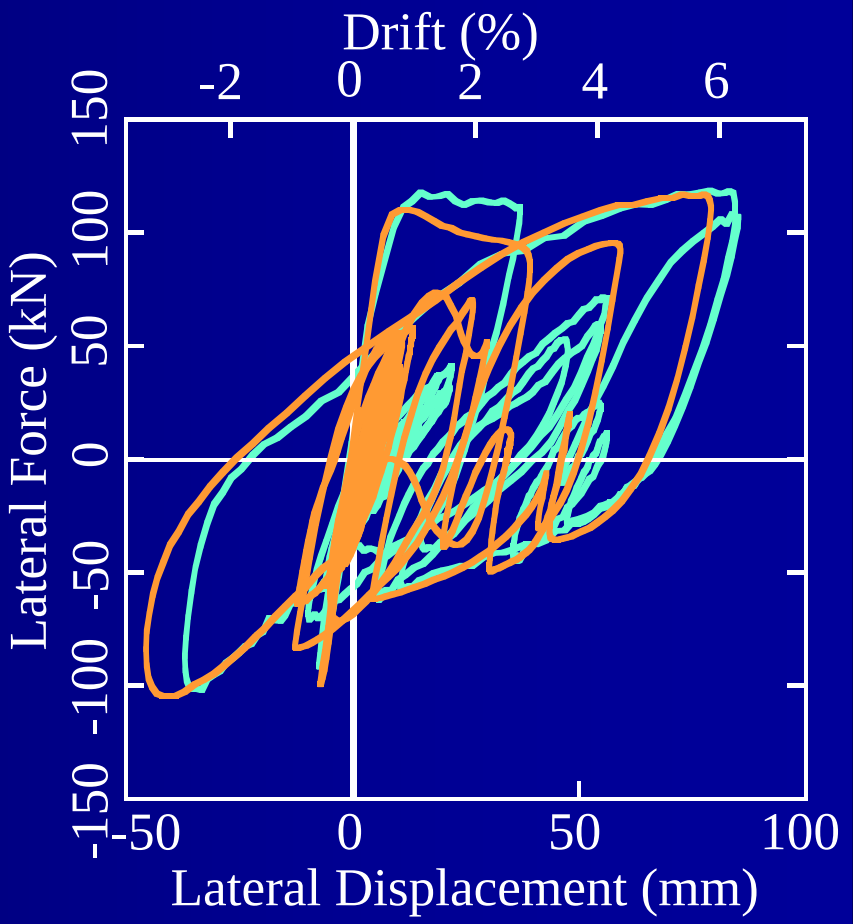
NS Component



Experiment

Analysis

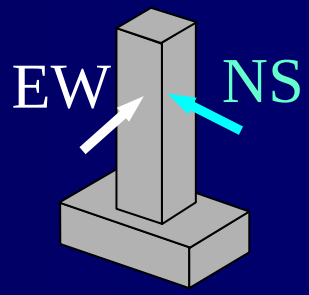




Fiber Element Analysis

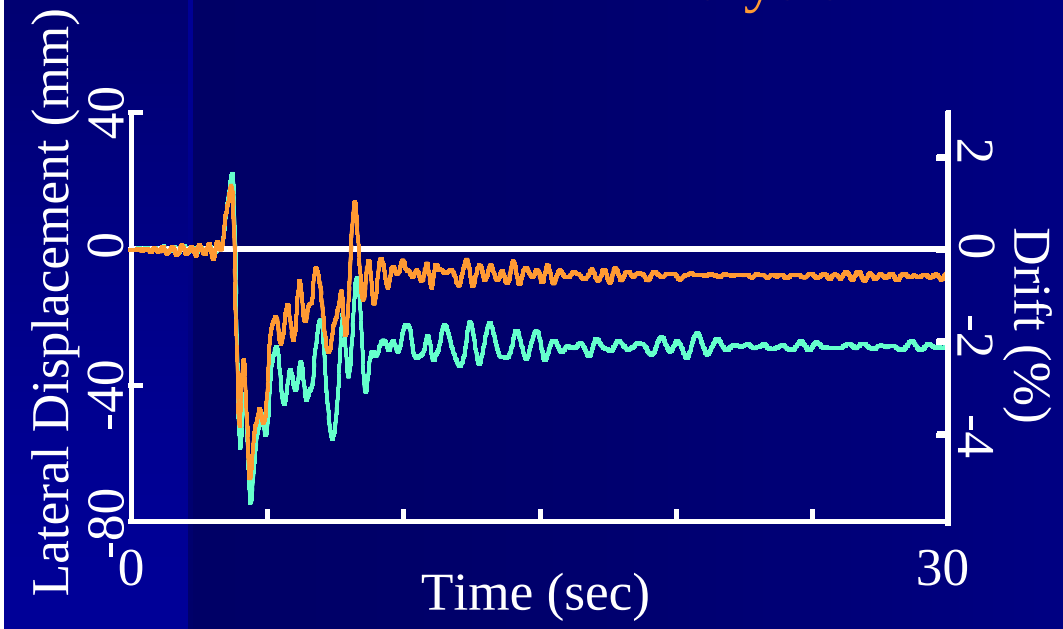
Bilateral Excitation, Sylmar 50%

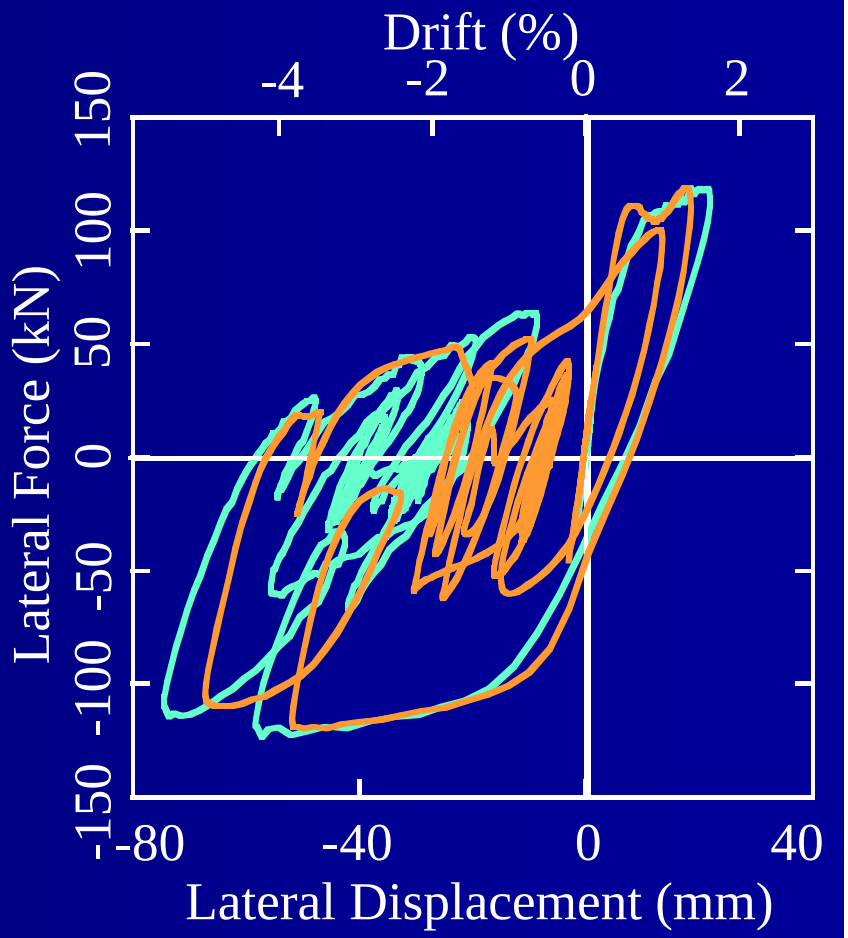
NS Component



Experiment

Analysis





Conclusions

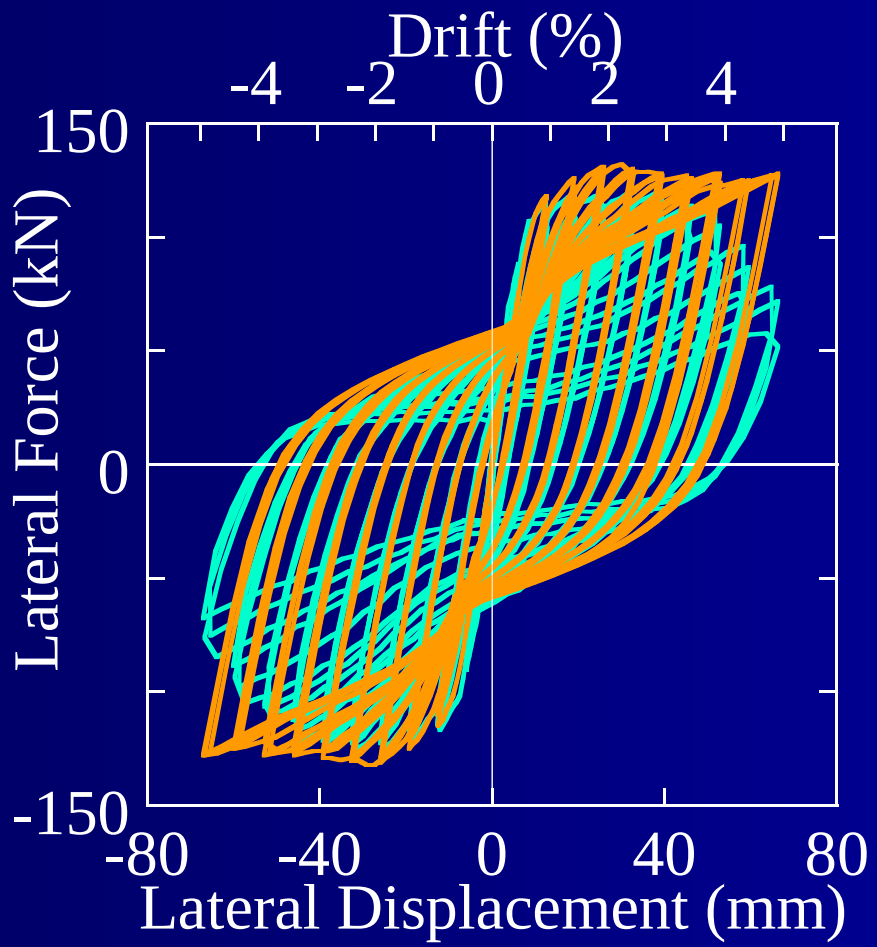
- The flexural strength and ductility capacity of the column under the bilateral loading is smaller than those under the unilateral loading
- The above results in larger response displacement of the columns under the bilateral excitation than the unilateral excitation in the hybrid loading test.
- Fiber element analysis correlates the general trends of the column responses. However, correlation on the residual drift is poor.

Thank you for your kind attention.

Effect of Bilateral Excitation on the Capacity of RC Bridge

- More important in bridges than buildings because of the lesser degree of static indeterminate
- Possibly overestimating the strength and ductility capacities of bridge columns
- Always encounter this effect in skewed and curved bridges
- More realistic evaluation is required to meet the performance goals in the performance-base seismic design

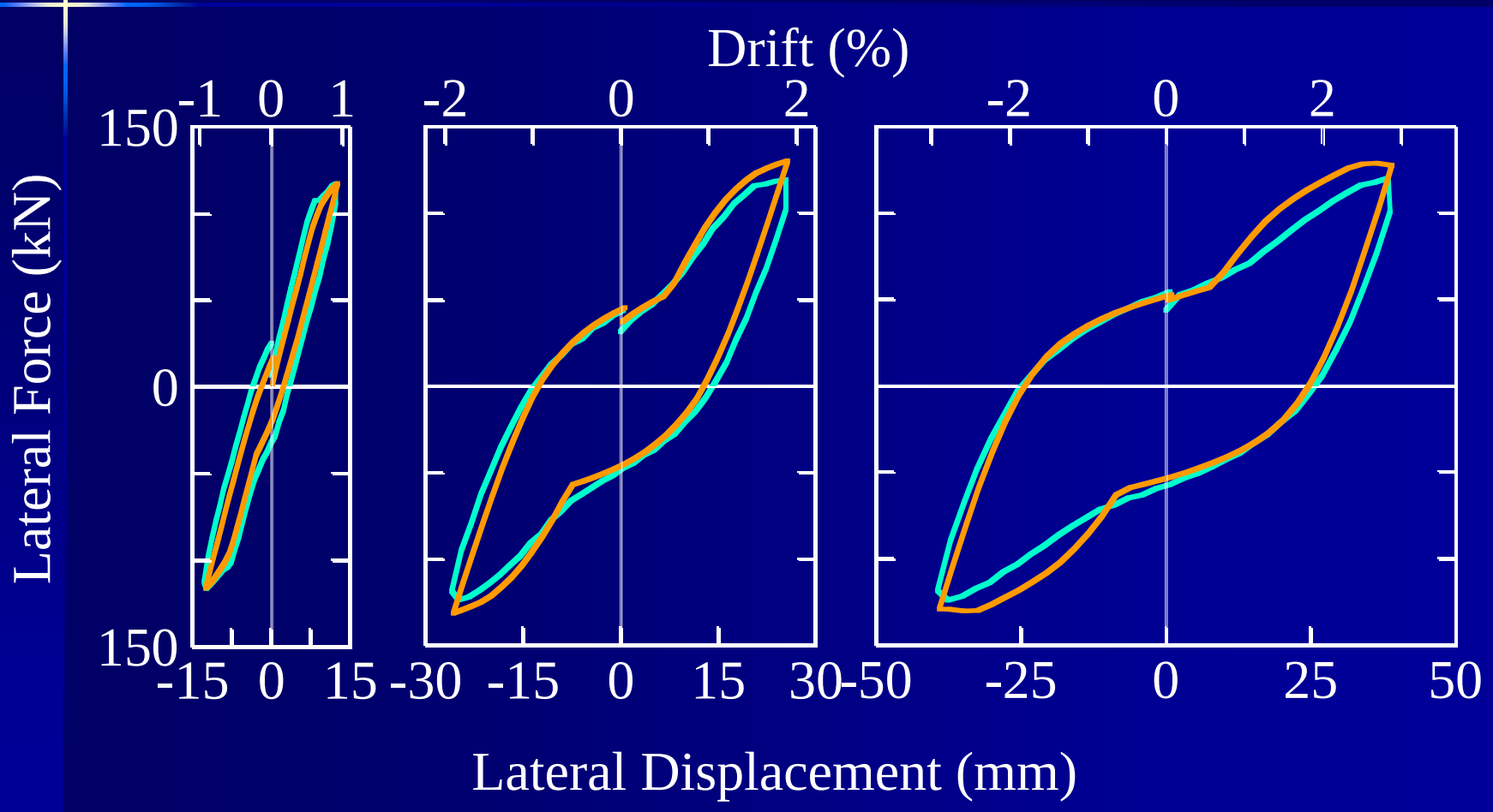
Computed Hysteresis under the Unilateral Loading



Experiment

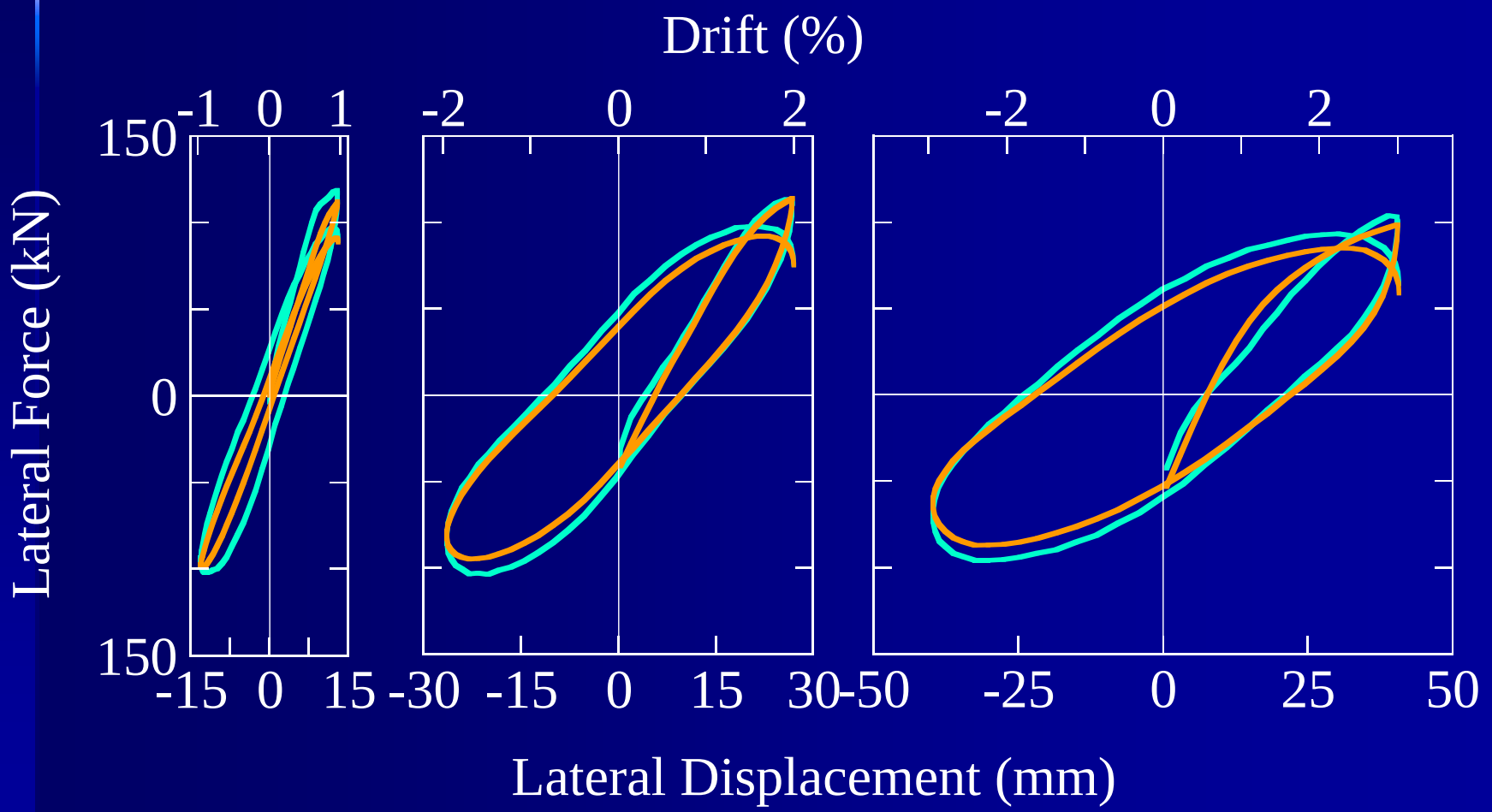
Analysis

Computed Hysteresis under the Unilateral Loading



Computed Hysteresis under the Circular Orbit Loading

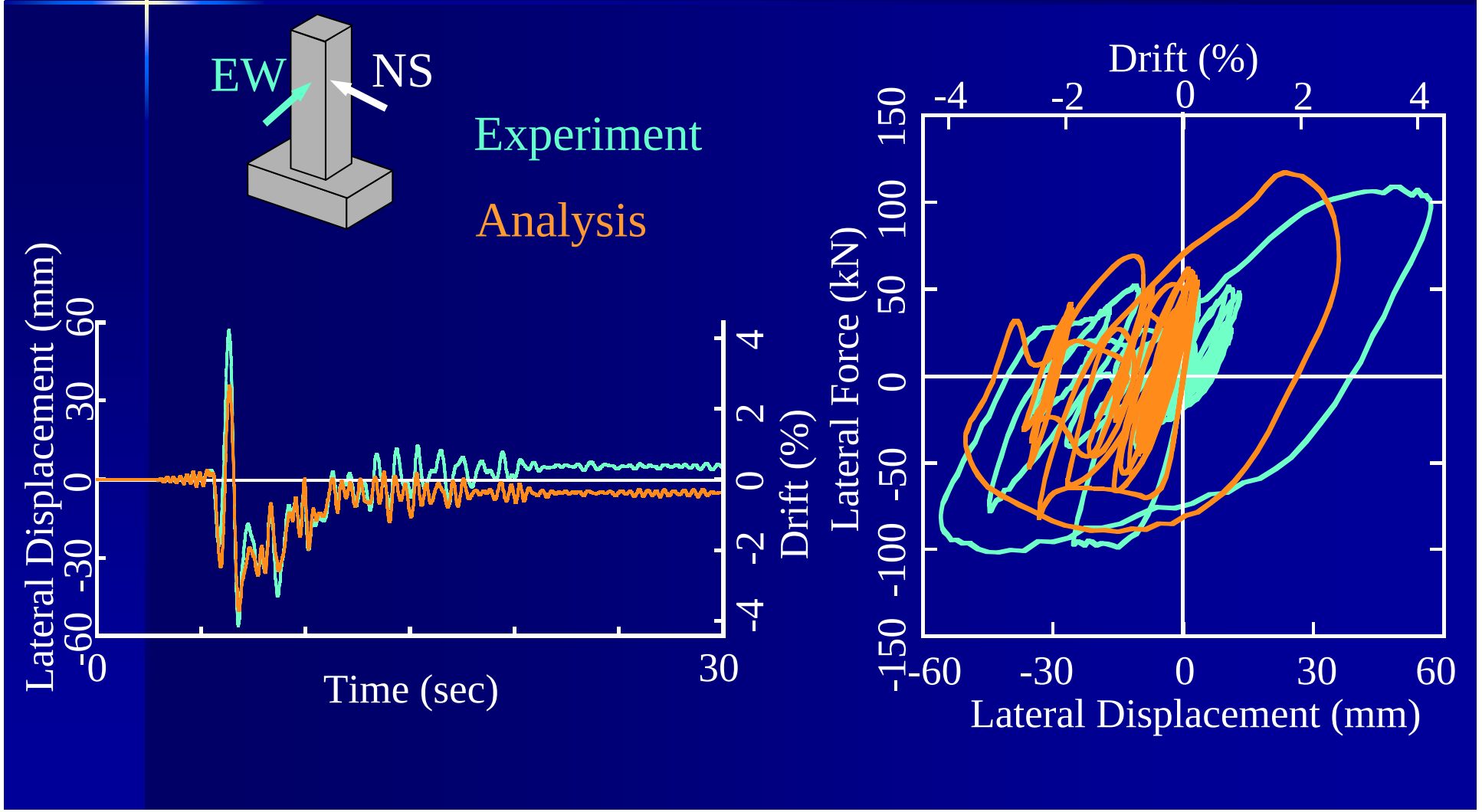
Experiment Analysis



Fiber Element Analysis

Bilateral Excitation, Kobe 40%

EW Component



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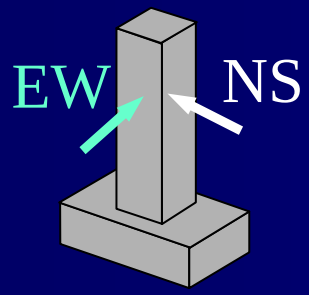
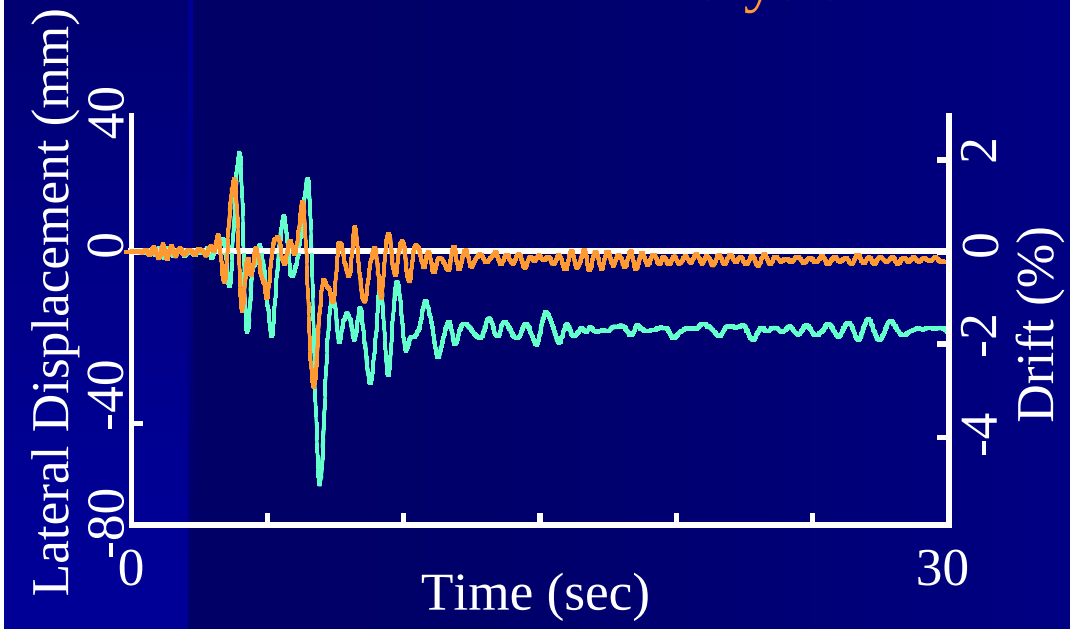
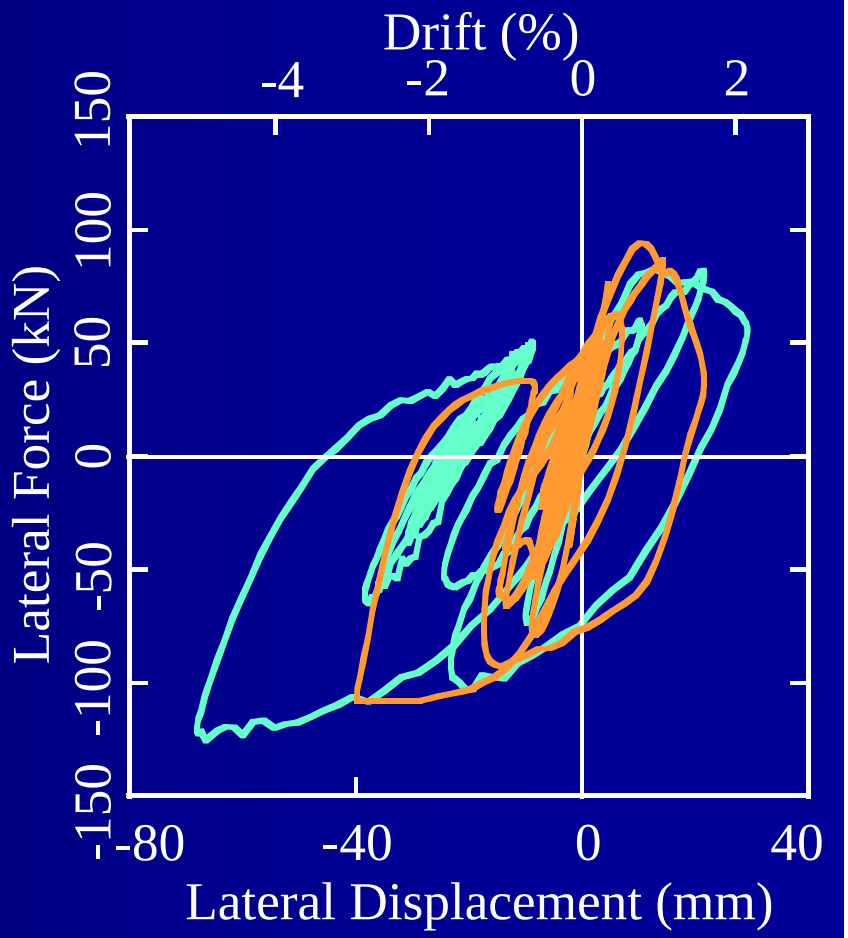


Experiment

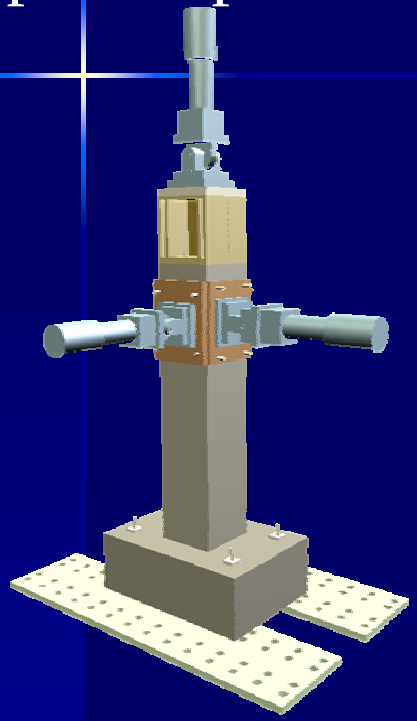
Analysis

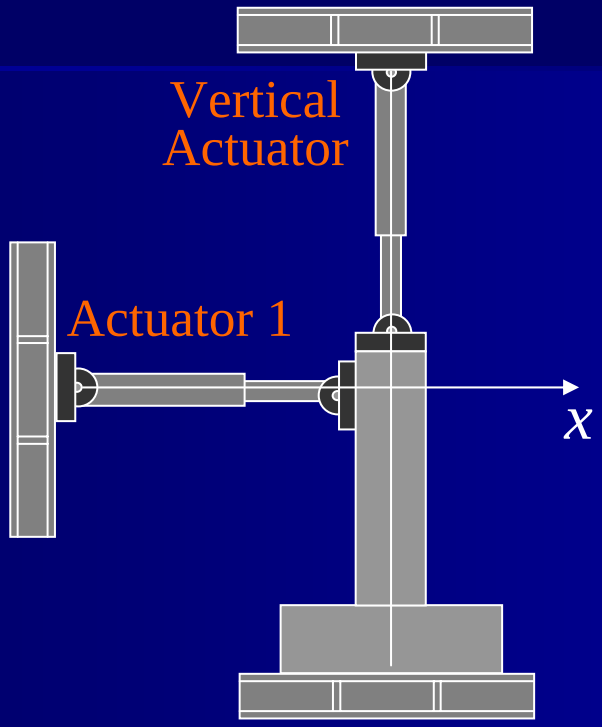


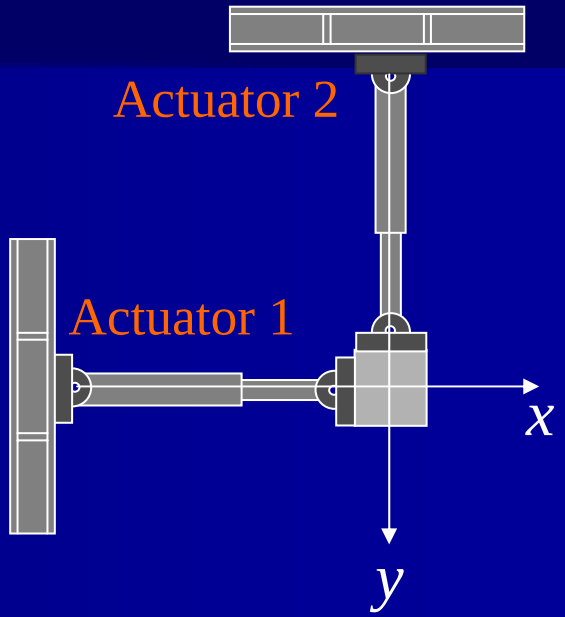


P-delta Effect by Actuators

The error in measuring strength of stability of bridge pier experimentally







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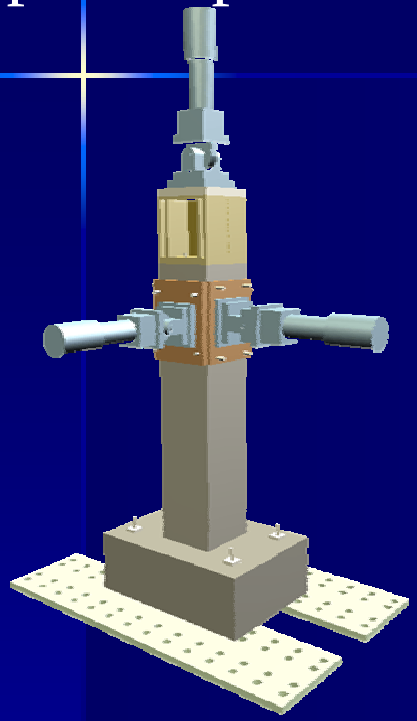
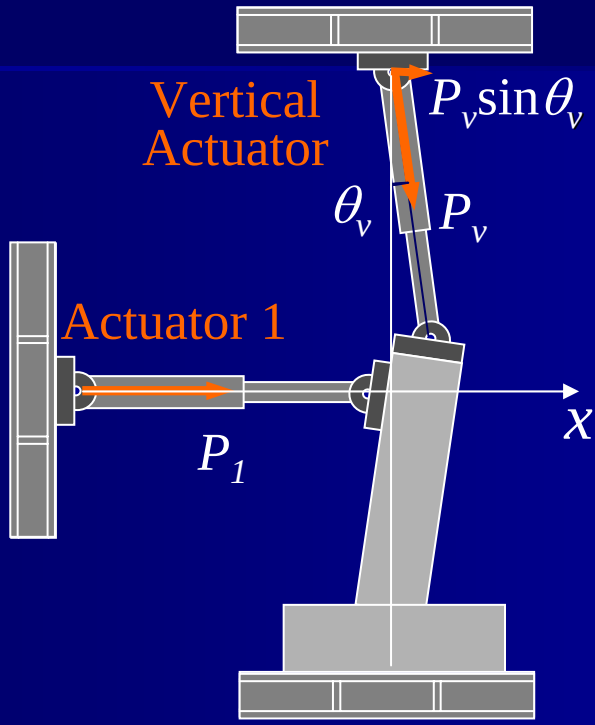
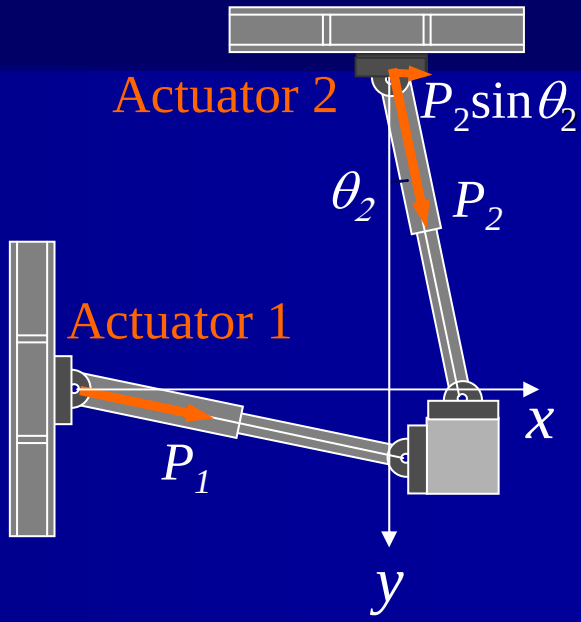




P–Δ effect
by vertical Actuator



P–Δ effect
by horizontal Actuator