Development of Modal Hysteretic Model for the Seismic Response Analysis of Tall Buildings with RC Shear Walls

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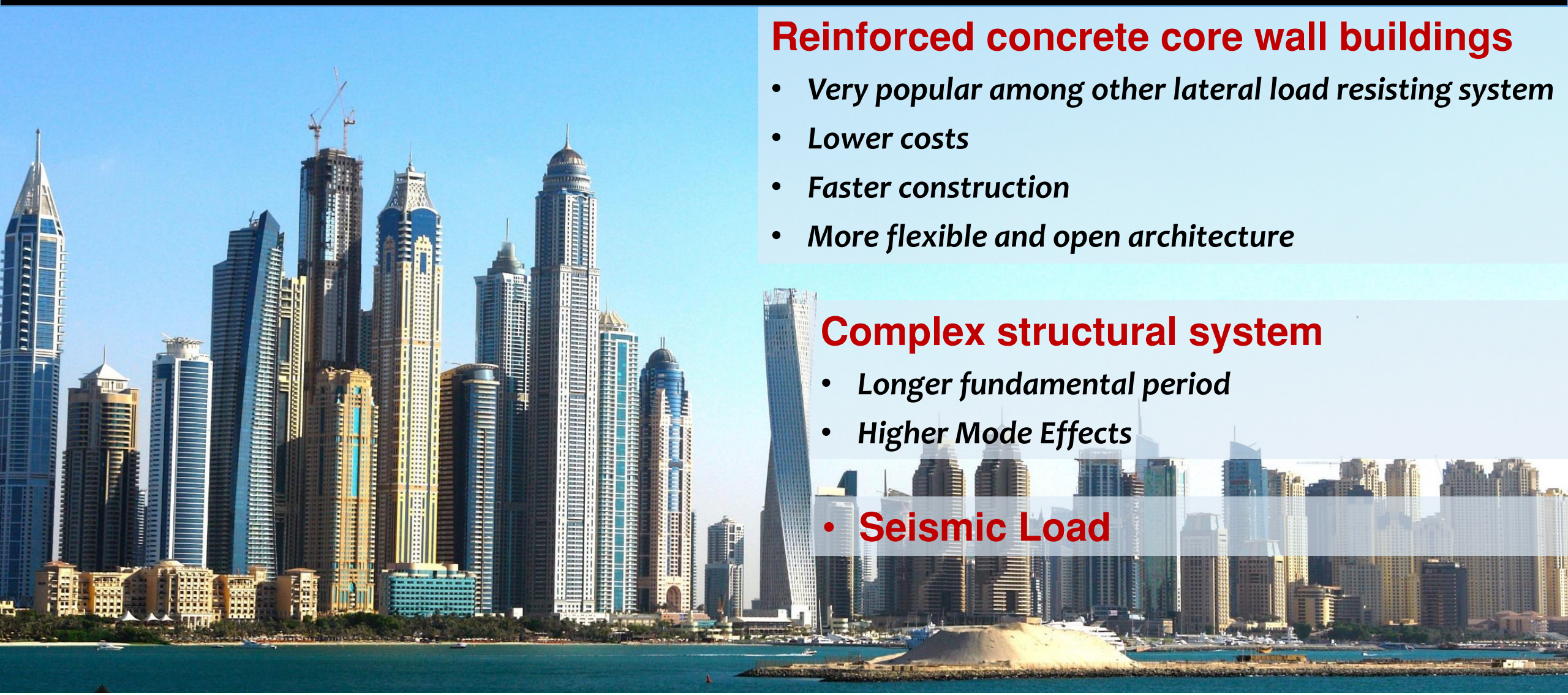
Introduction



Reinforced concrete core wall buildings

- *Very popular among other lateral load resisting system*
- *Lower costs*
- *Faster construction*
- *More flexible and open architecture*

Complex structural system

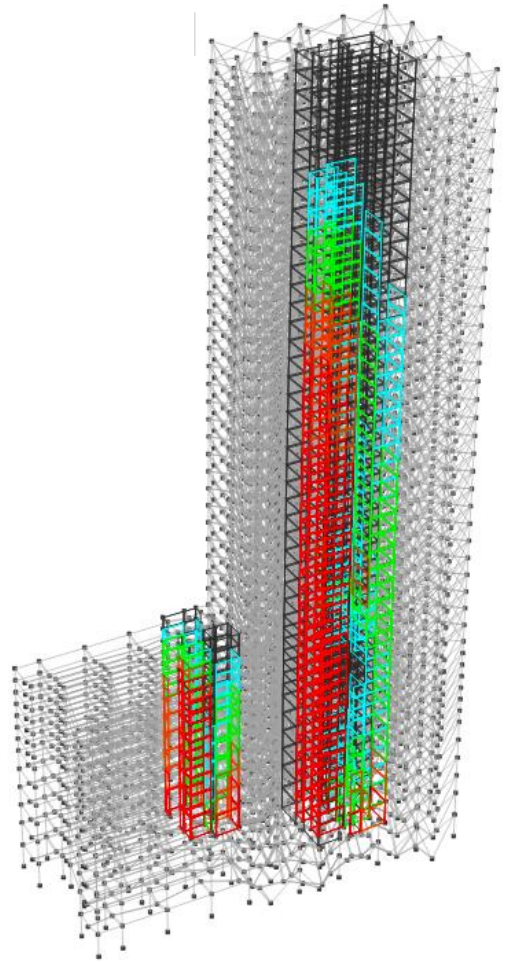
- *Longer fundamental period*
- *Higher Mode Effects*

- **Seismic Load**

Seismic Analysis Procedures

Non-Linear Response History Analysis (NLRHA)

- *Most reliable and accurate*
- *Required long computational time, expensive*
- *Require high expertise to interpret analysis results and implement them for design*
- *Difficult to gain physical understanding of complex nonlinear dynamic response*



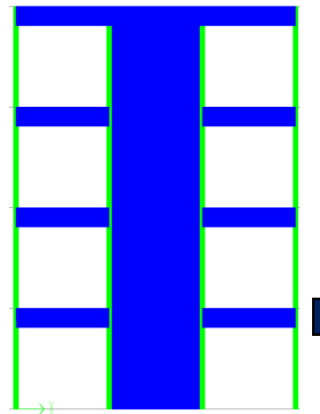
Uncoupled Modal Response History Analysis (UMRHA)

- *Developed by Chopra and Goel (2002)*
- *Extended version of the "Classical Modal Analysis" procedure*
- *Each vibration mode behaves like SDOF system and can be expressed as,*

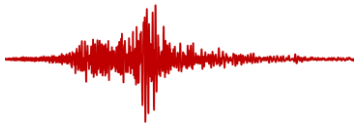
$$\ddot{D}_n + 2\xi_n\omega_n\dot{D}_n + \frac{F_{sn}(D_n, \dot{D}_n)}{L_n} = -\ddot{u}_g(t)$$

- *Total response is determined by combining response of all significant modes*
- *Assumes that 'vibration modes' still exist even for the nonlinear responses*
- *Assumes principle of superposition remain valid for inelastic responses.*

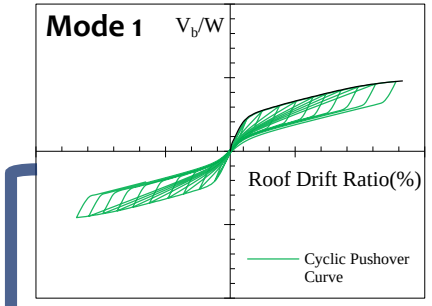
Uncoupled Modal Response History Analysis (UMRHA)

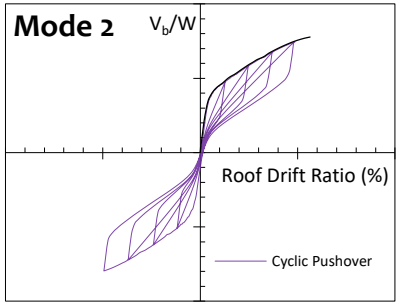


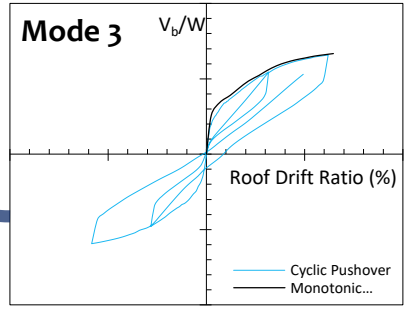
Nonlinear Structure



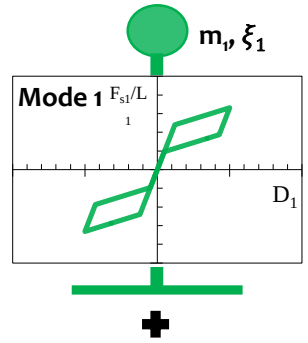
Detailed 3D Nonlinear Response Analysis (NLRHA)

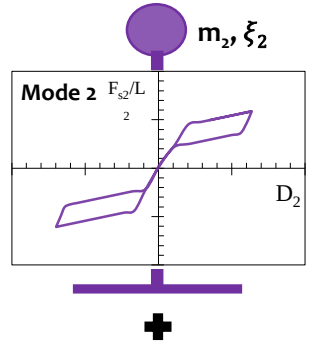


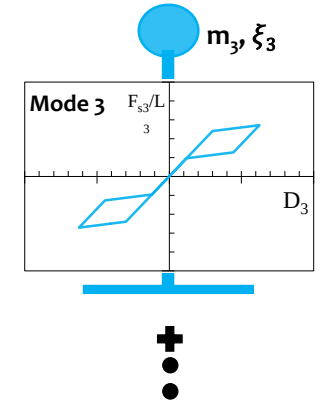




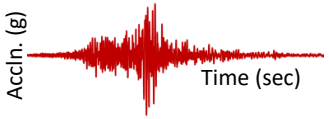
Modal Pushover Curves

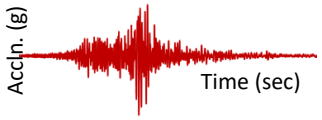


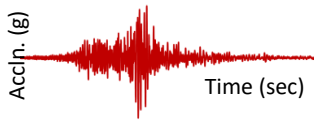


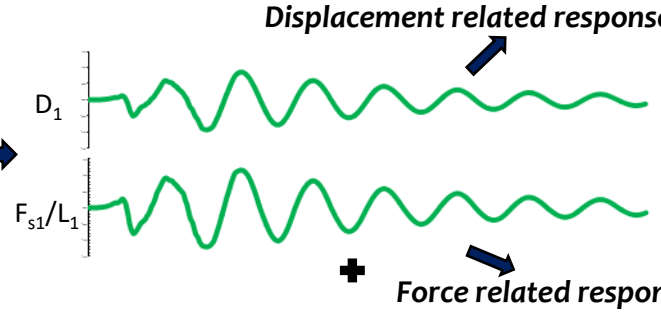


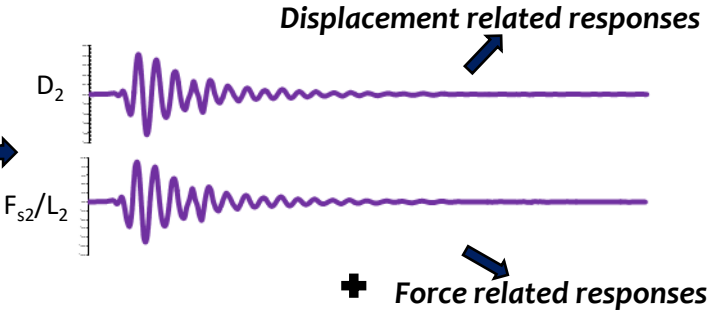
Idealized SDOF systems

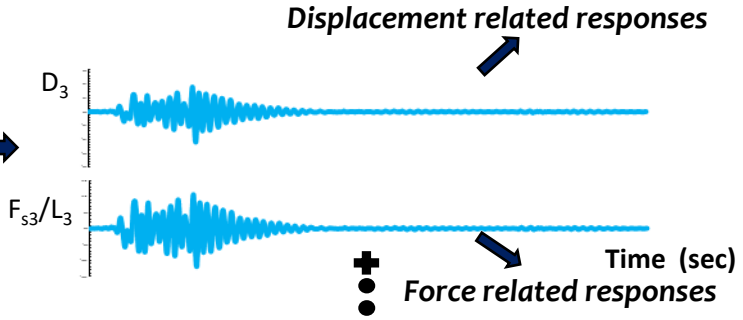






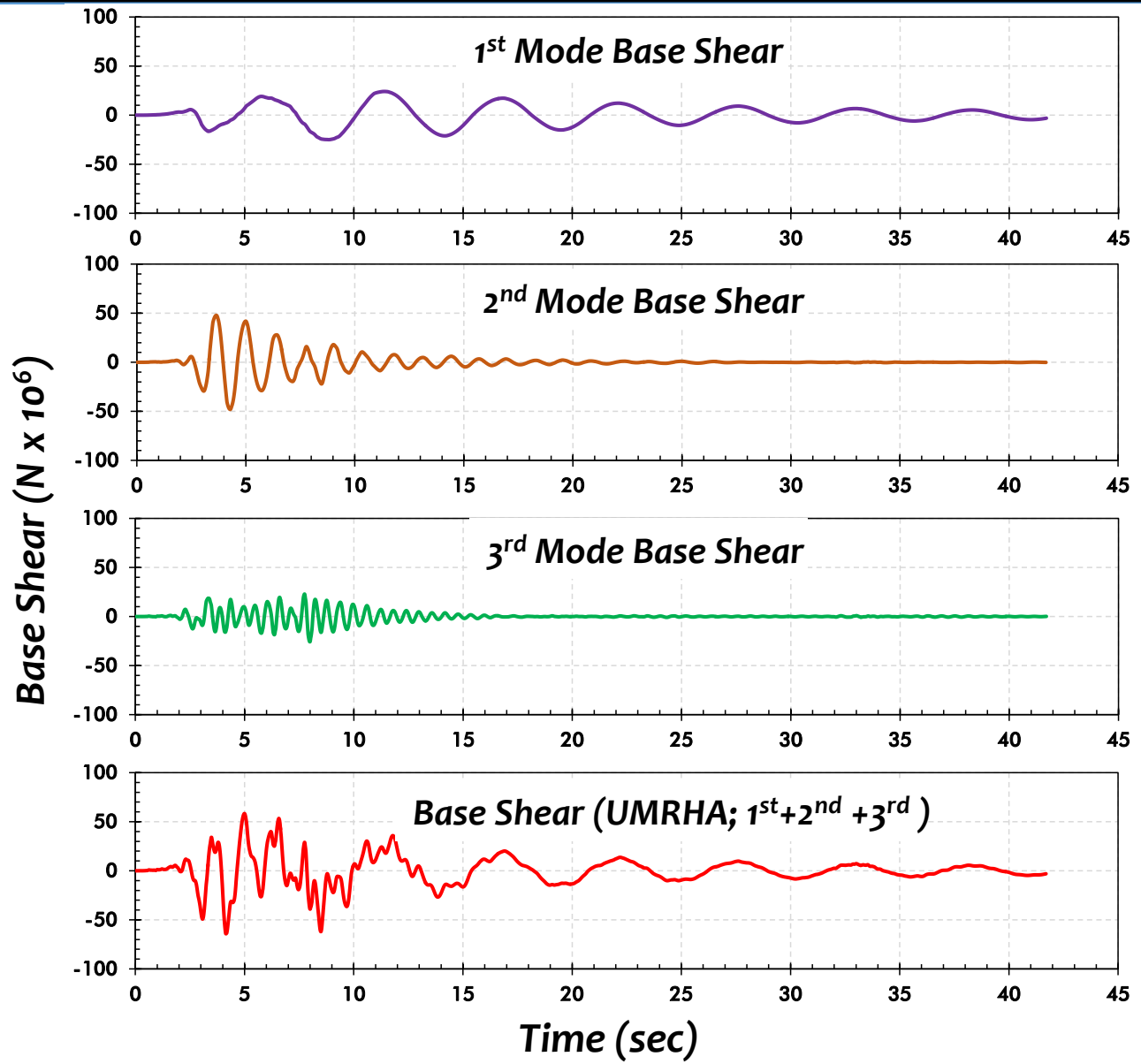


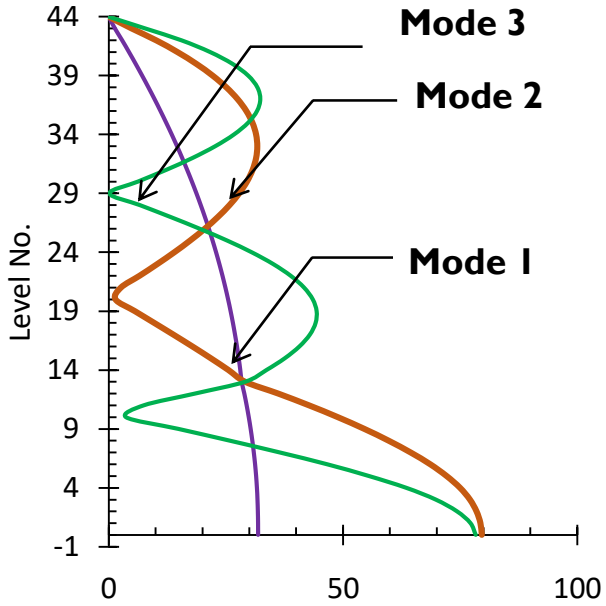




Individual modal responses

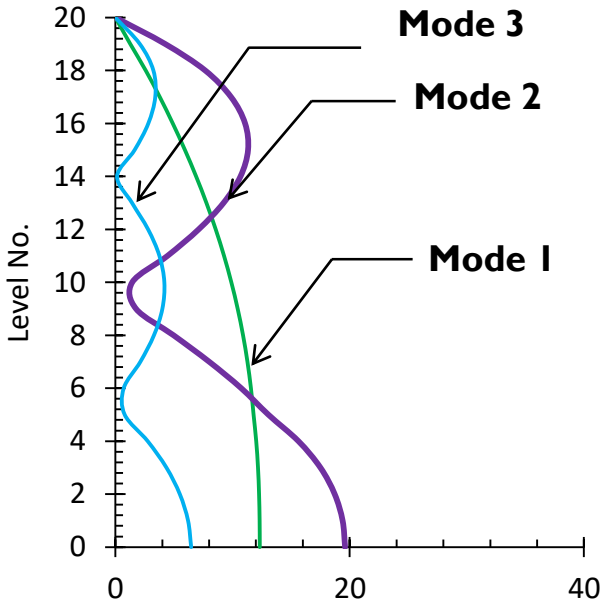
Uncoupled Modal Response History Analysis (UMRHA)





Why UMRHA ?

- *Reliable and reasonably accurate*
- *Required less computational time comparing to NLRHA*
- *Modal decomposition allows physical understanding of complex nonlinear dynamic responses of tall buildings*
- *Allows engineers to develop effective strategies to improve the seismic performance of tall buildings*



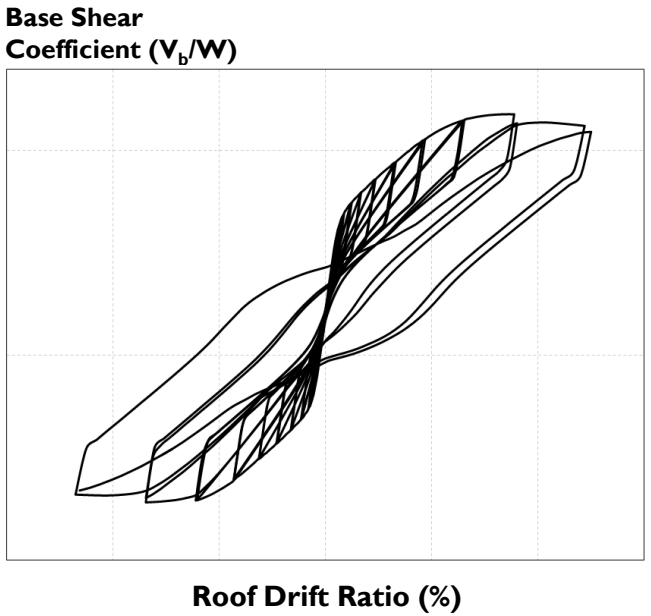
Time required for analysis & data processing for each building
NLRHA: 35 hours
UMRHA: 30 minutes

Uncoupled Modal Response History Analysis (UMRHA)

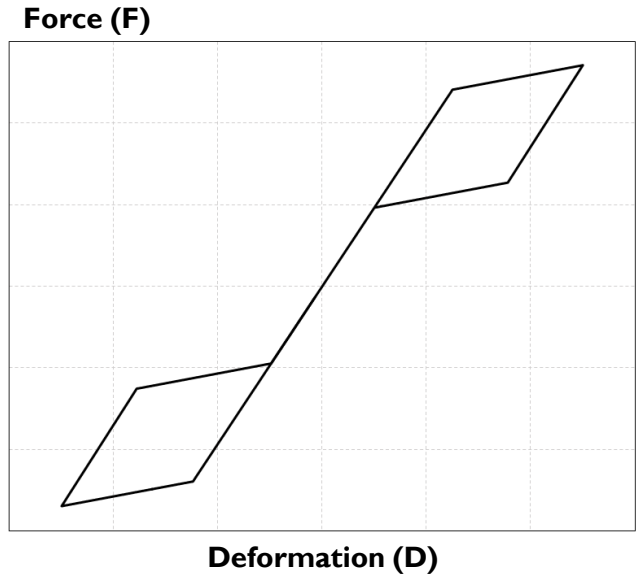
Accuracy of UMRHA ?

- *Mainly depends on how accurately the nonlinearity of modal system is represented*

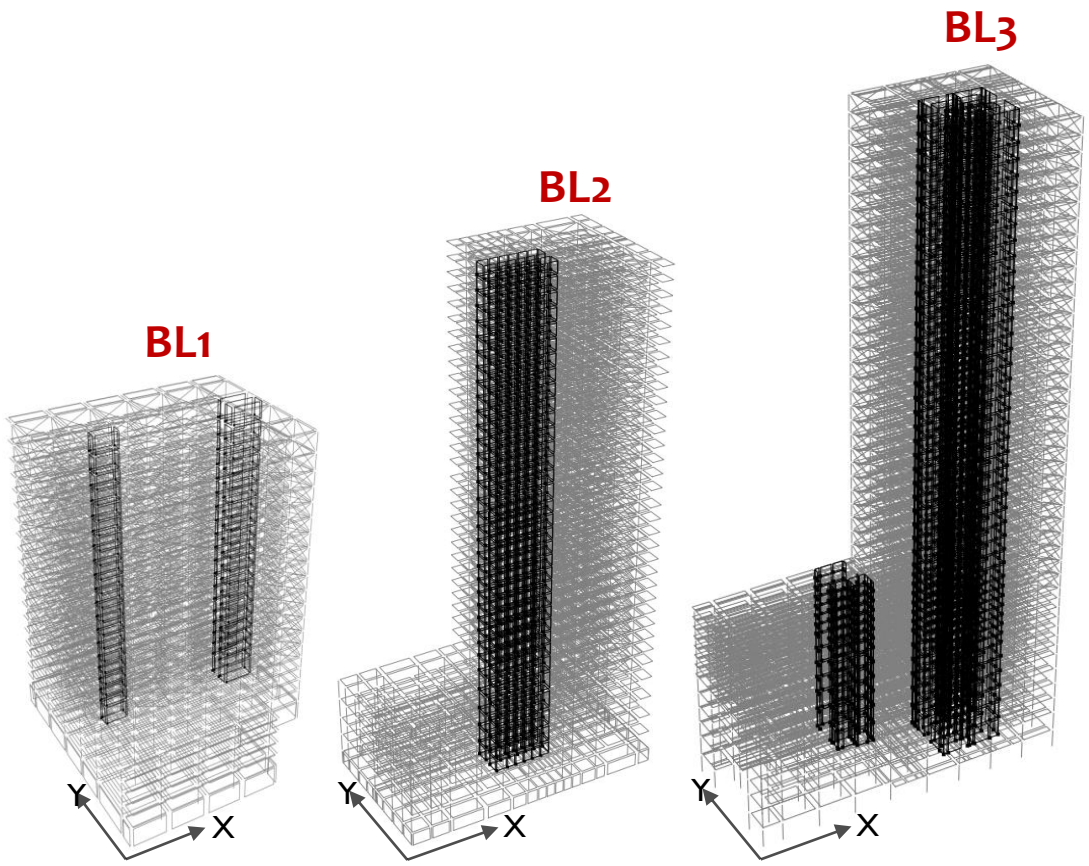
Modal Pushover Curve



Mathematical Hysteresis Model

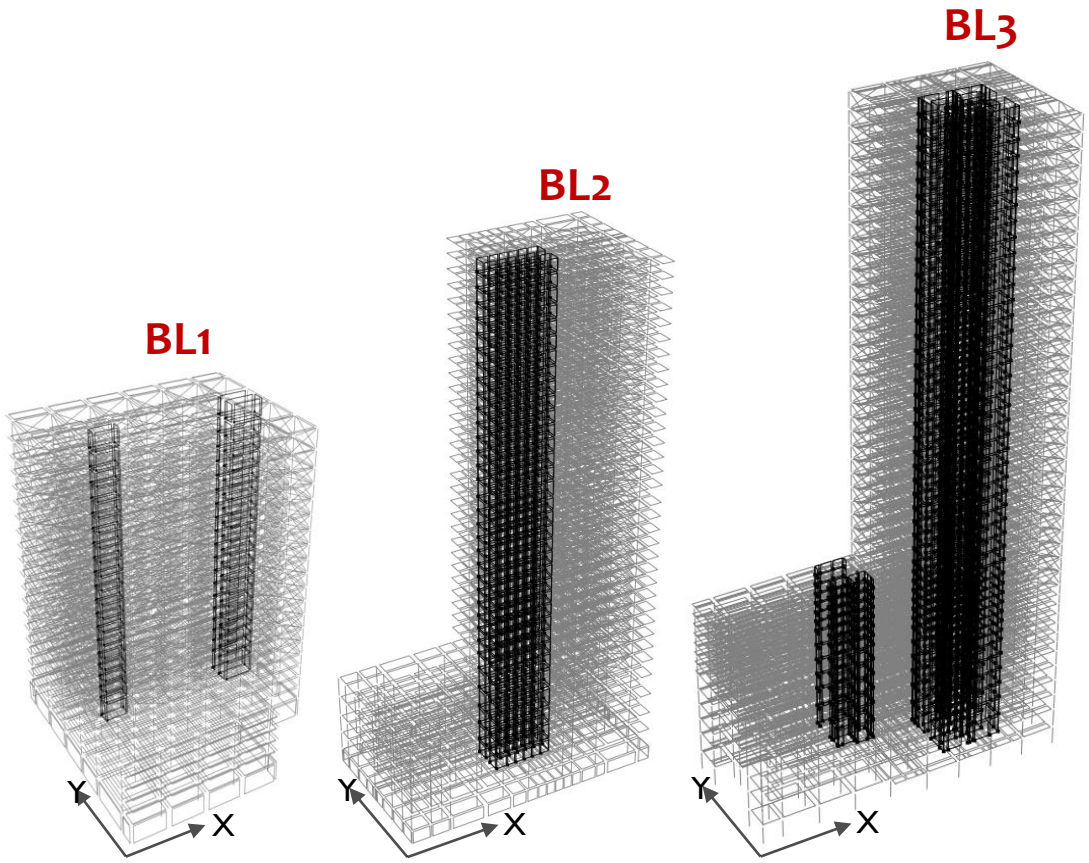


Three Case Study Buildings



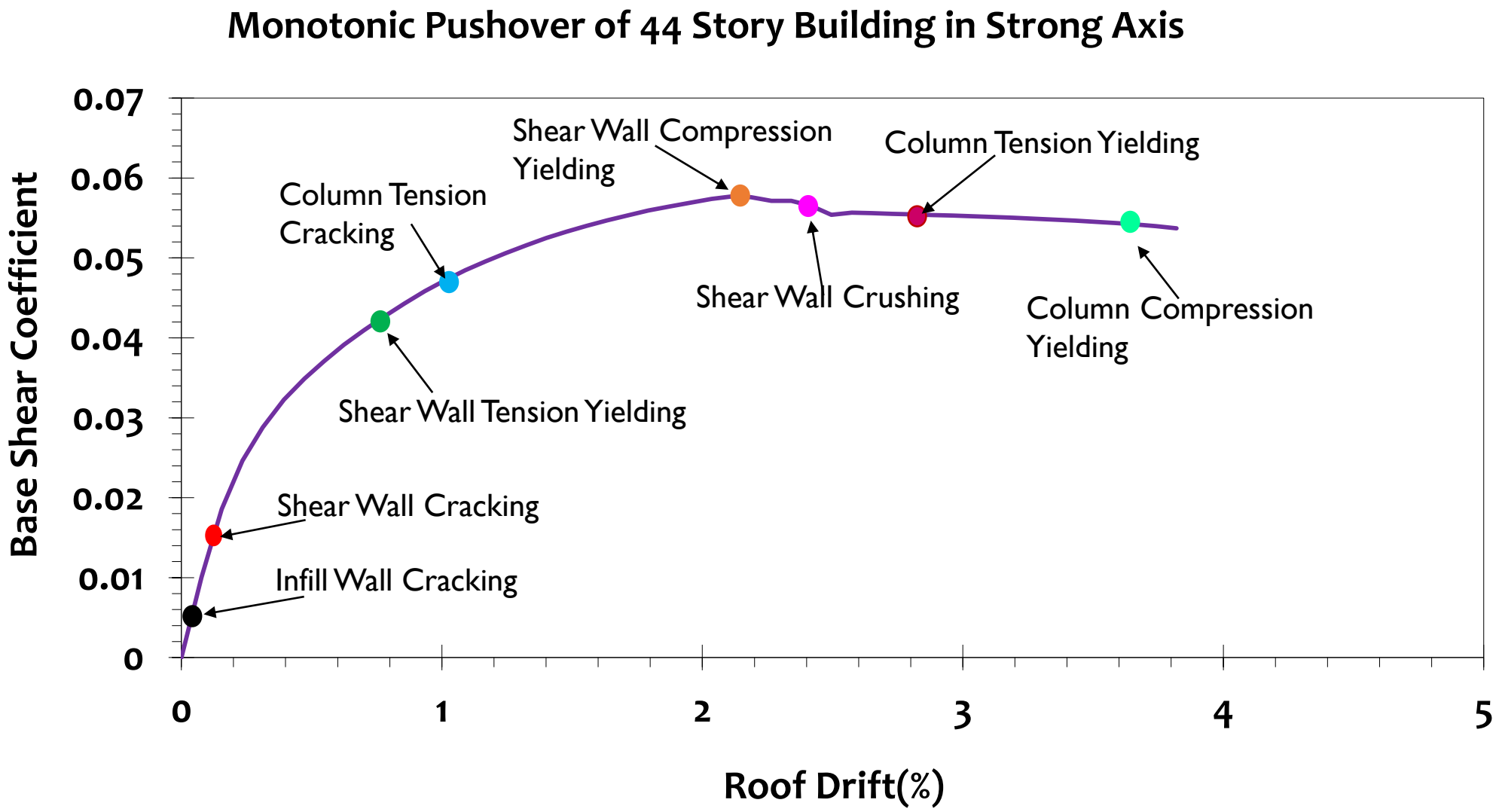
- Located in Bangkok
- Designed for wind loads
- Representation of the typical RC shear buildings
- Full 3D Nonlinear Model in Perform-3D
- Modal cyclic and monotonic pushover analysis

Three Case Study Buildings



- Gravity load resisting system is RC slab-column frame
- RC shear walls and cores for lateral load
- Masonry infill walls and mat foundation resisting on piles.
- Multiple Vertical Line Element model (MVLEM) for shear wall modeling.
- Mander's unconfined trilinear stress strain model was used to model concrete fibers and for steel fibers a non-degrading type bilinear hysteretic model including strain hardening
- Lumped fiber modeling was used for RC columns with steel and concrete fibers at both ends with elastic frame in between.
- Concrete slabs were modeled by elastic thin shell elements.
- Equivalent struts according to FEMA 356 guidelines were used to model masonry infill wall.
- Modal damping = 2.5% (Najam and Warnitchai, 2016).

First Mode Pushover Response of 44 Story Building in Strong Direction



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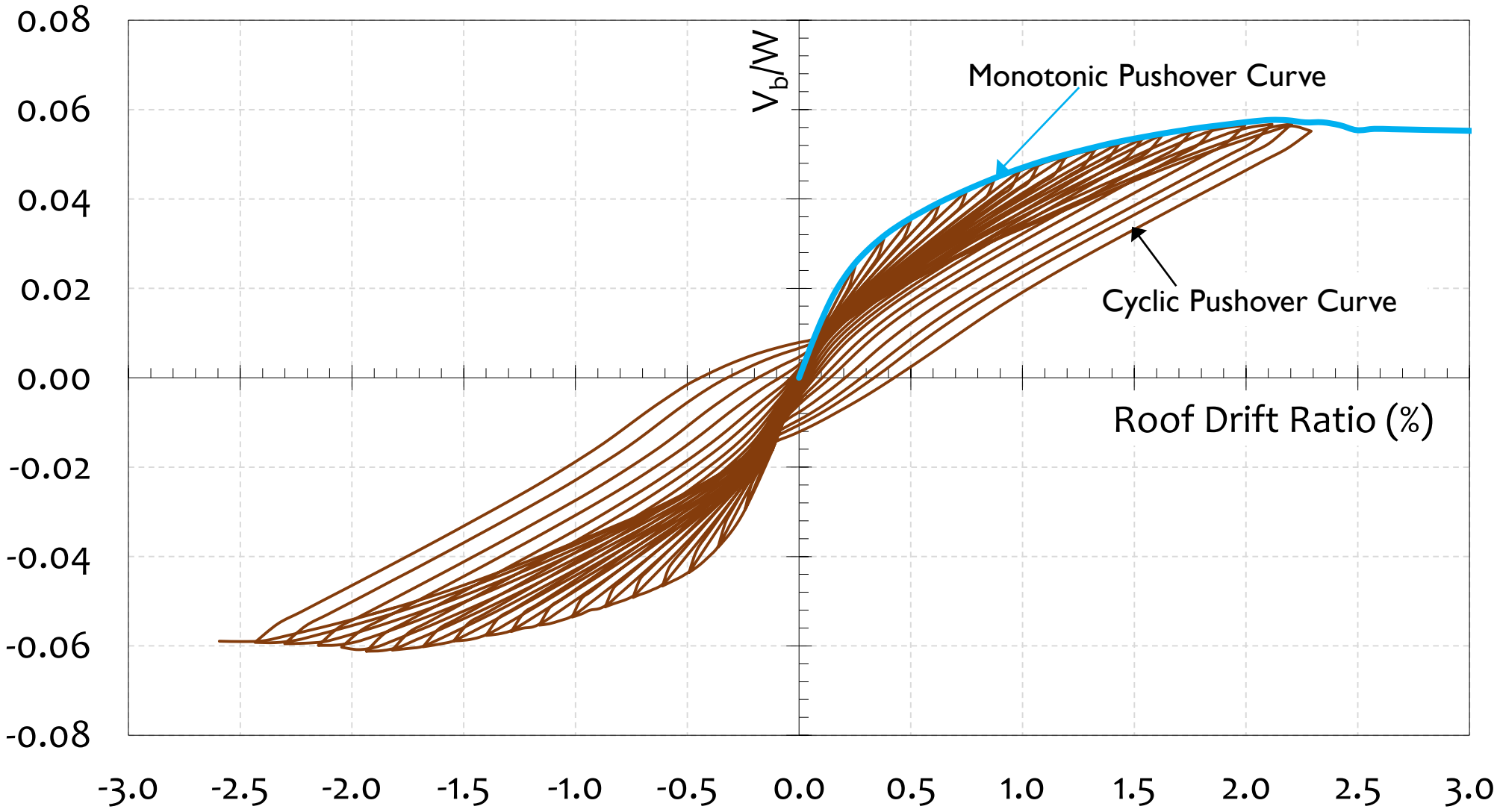
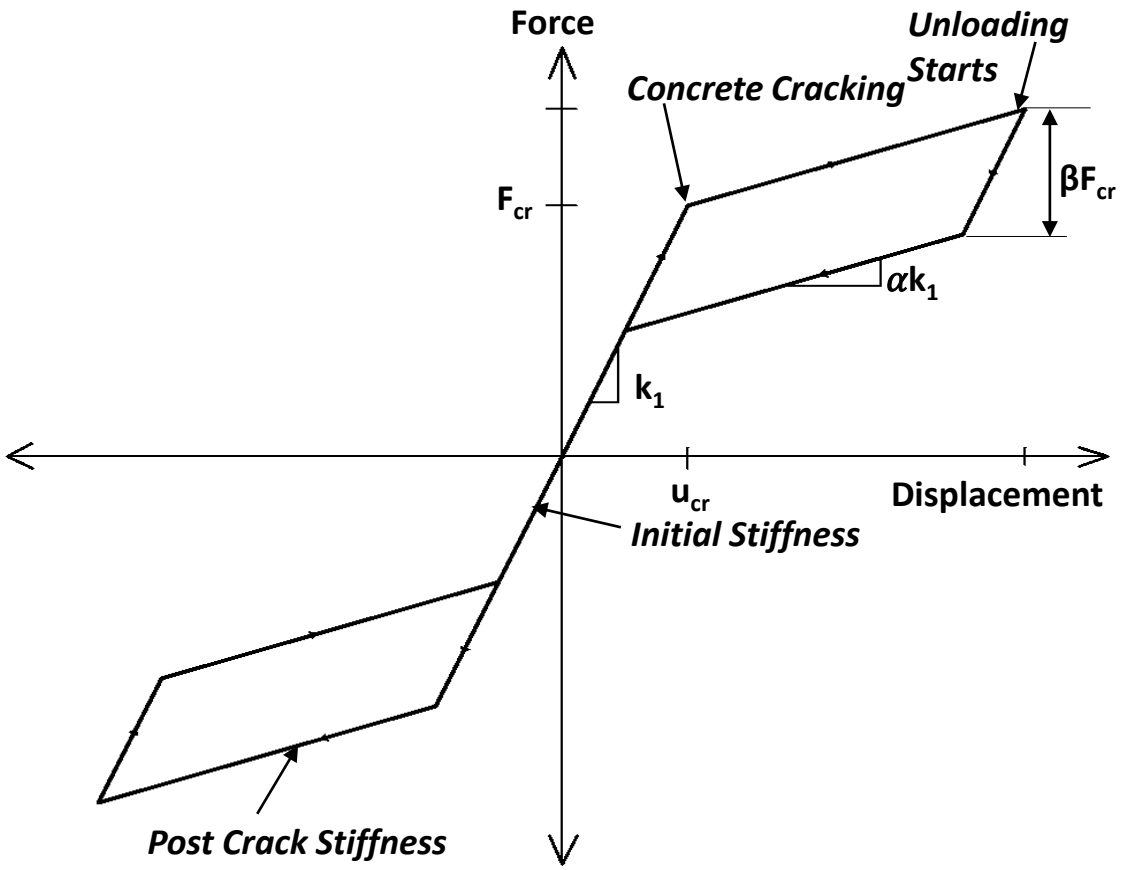


Idealized Hysteretic Model

Flag Shape Model



For Flag Shape Model

- F_{cr} is crack force
- K_I is a initial stiffness
- α is post crack stiffness ratio , and
- β is Flag depth (force reduction factor)

- ❖ ***Simplified Model***
- ❖ ***Doesn't have cyclic stiffness degradation***
- ❖ ***Model may not be applicable after yield and can not predict the residual deformation***
- ❖ ***Munir & Warnitchai, 2012, Warnitchai et.al., 2016 have used this model on their study***

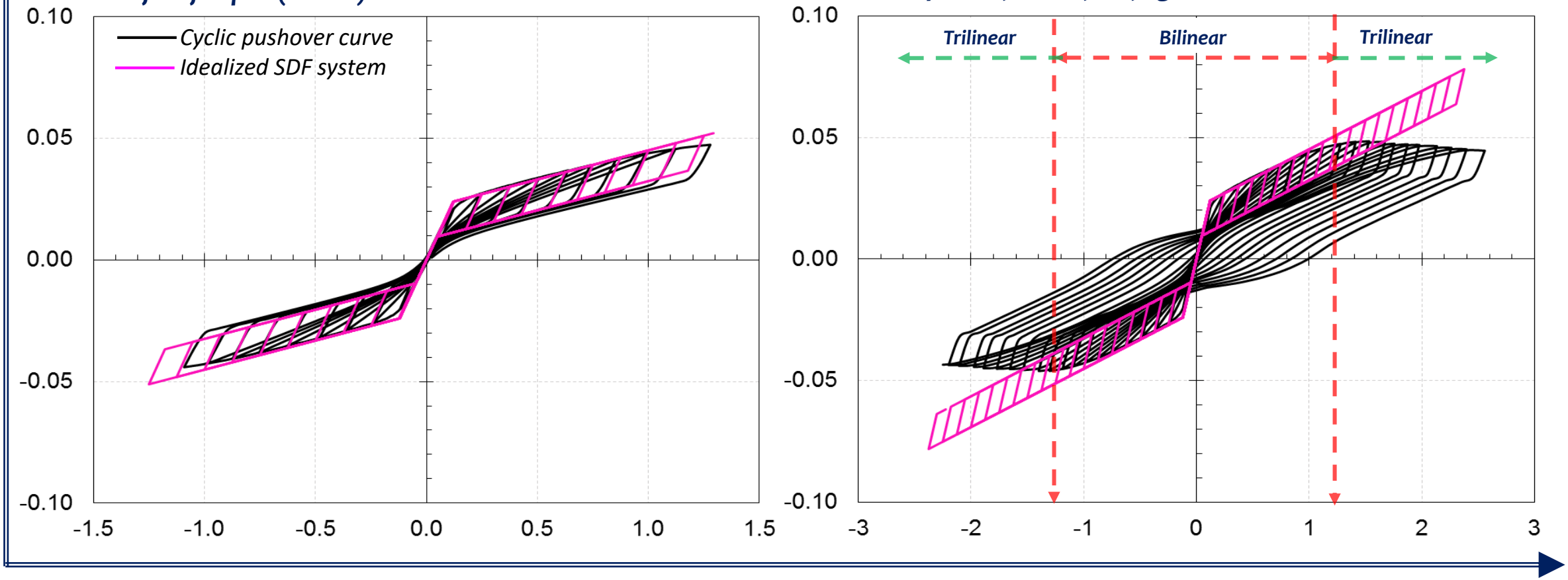
Comparison of Actual Pushover Curve and Flag Shape Hysteretic

Base Shear Coefficient (V_b/W)

First Mode Pushover Response of 19 Story Building in Strong Direction

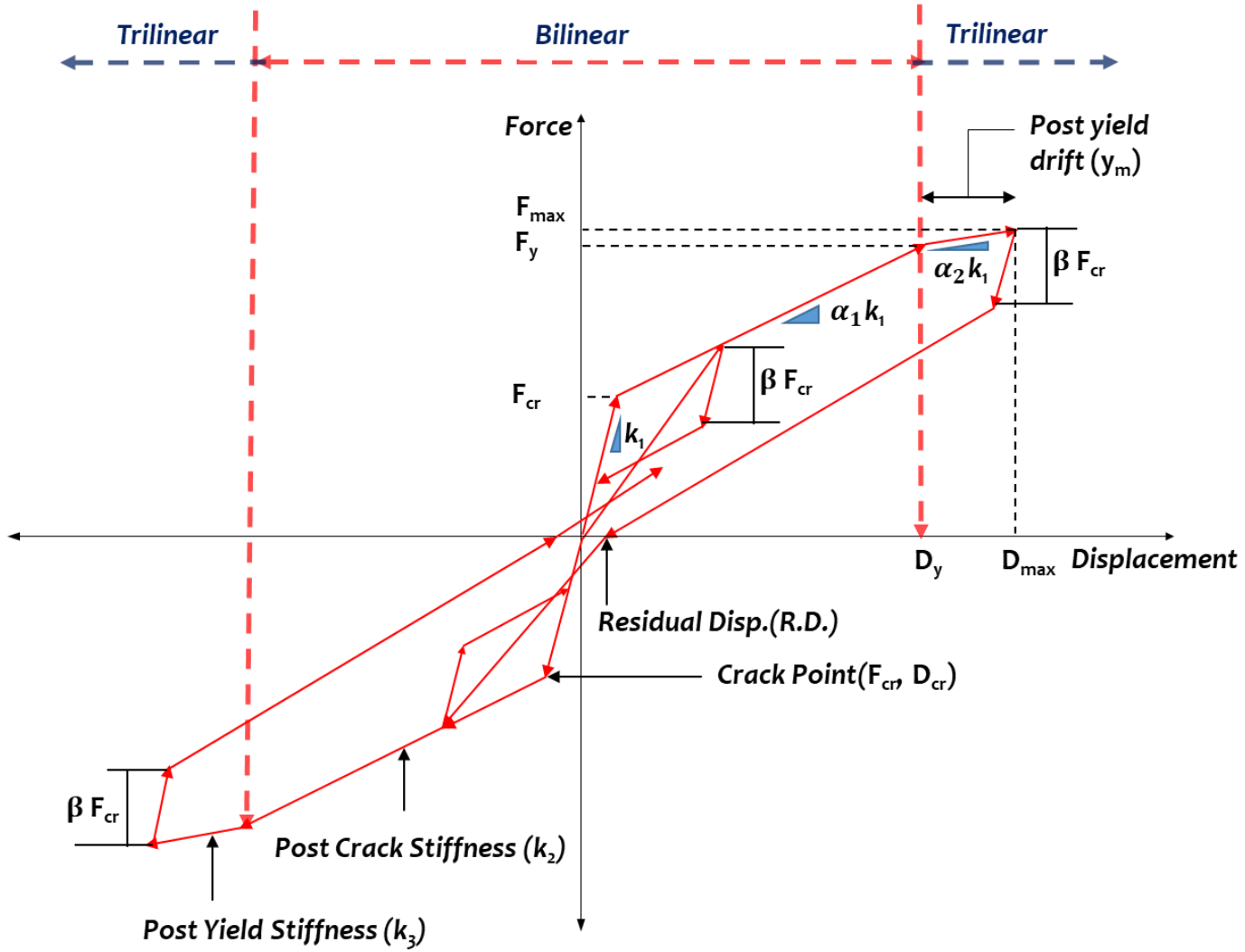
❖ *Flag Shape Model can predict the hysteretic response for roof drift upto (1.0-1.2)%*

❖ *Flag Shape Model cannot predict the hysteretic response for roof drift greater than 1.0-1.2%*



Roof Drift Ratio (%)

Modified Flag Shape Hysteretic Model

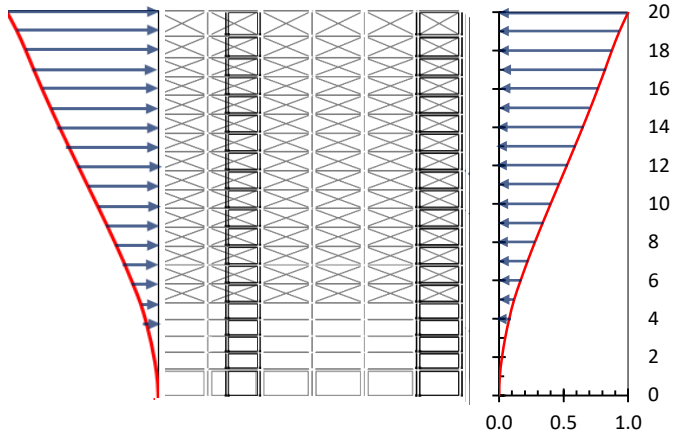


k_1 - Initial stiffness
α_1 - Post crack stiffness ratio
α_2 - Post yield stiffness ratio
β - Flag Depth

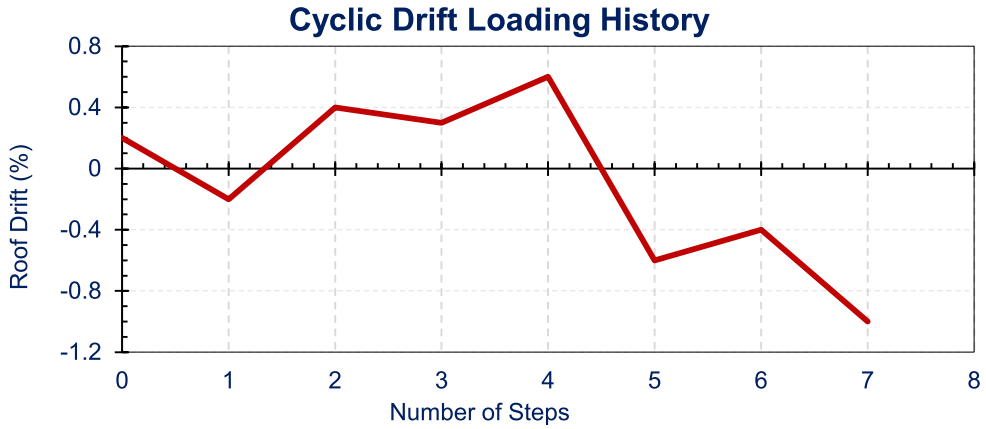
- *Trilinear Backbone*
- *Has Stiffness Degradation*
- *Peak oriented*
- *Residual displacement*

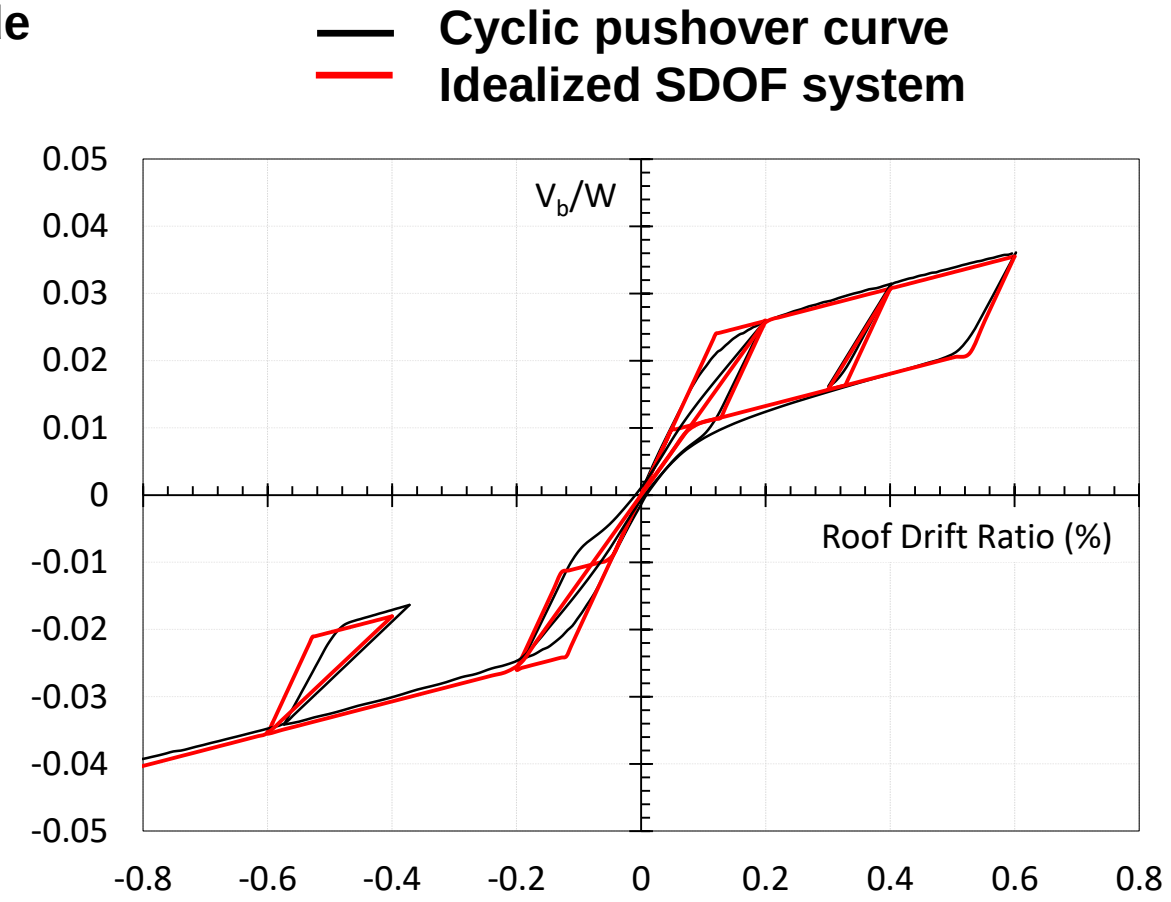
Identifying Hysteretic Rule

Push to specified roof drift in proportion to mode shape



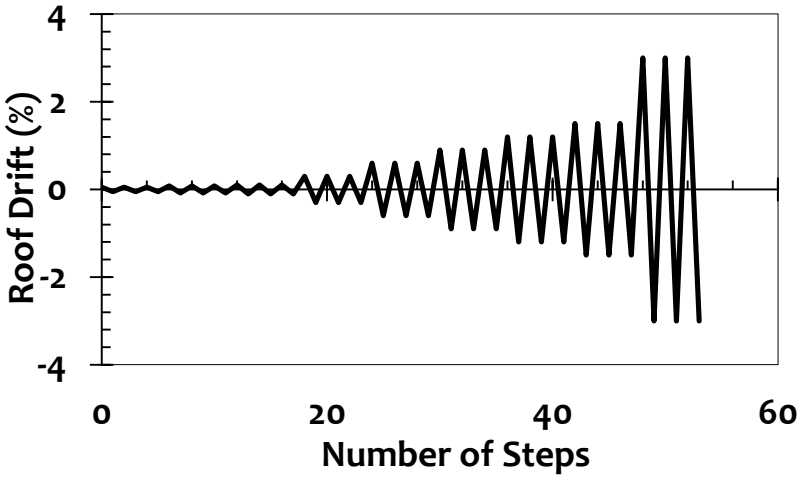
Nonlinear 3D model of building



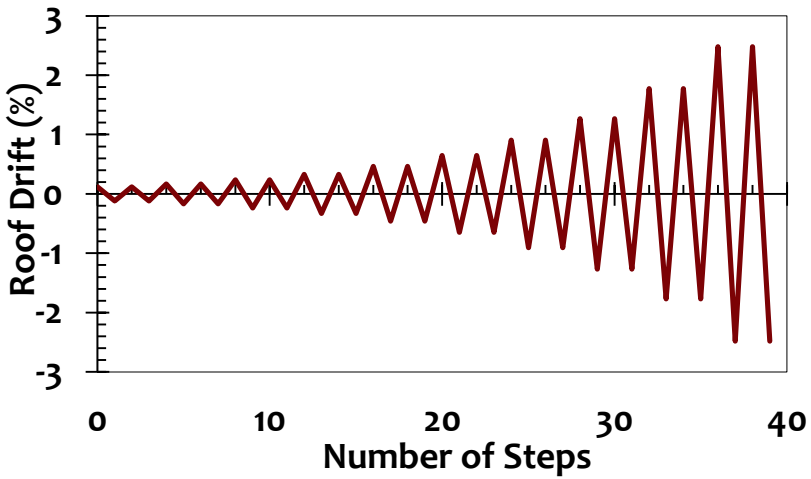


Loading Protocols Used

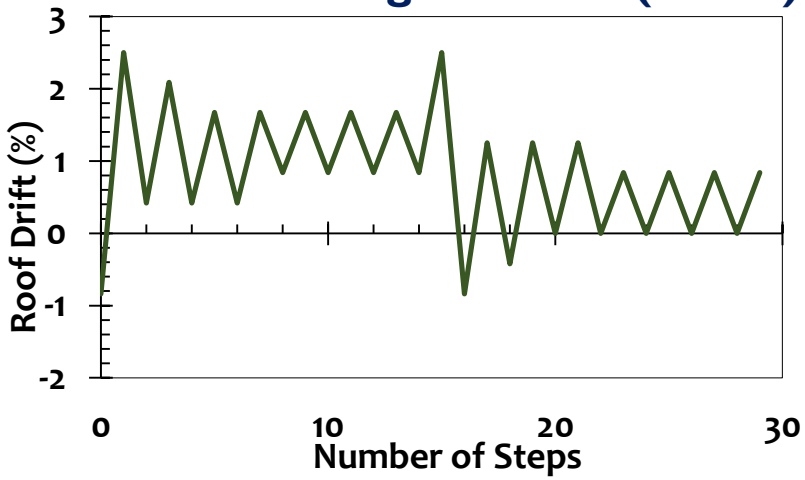
ATC-24



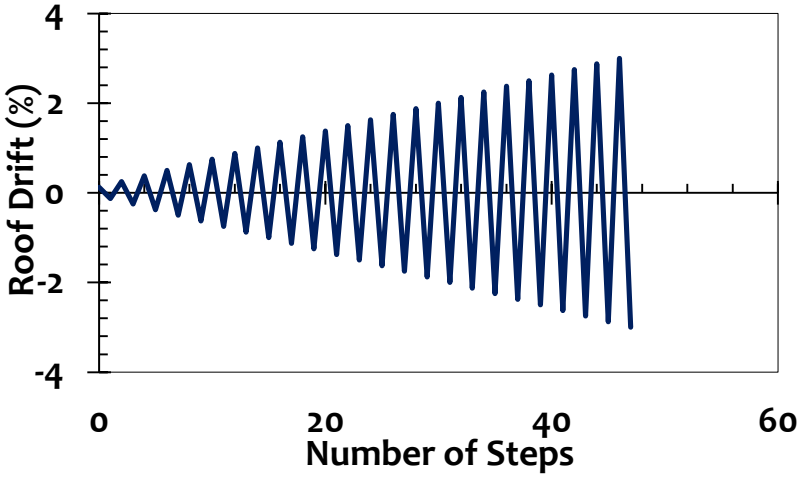
FEMA-461



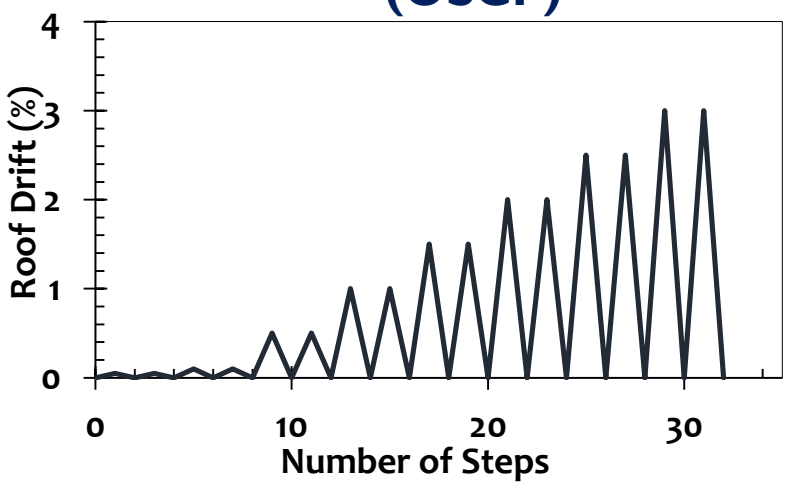
Near Fault Loading Protocol (NFLP)



Conventional Pushover Loading



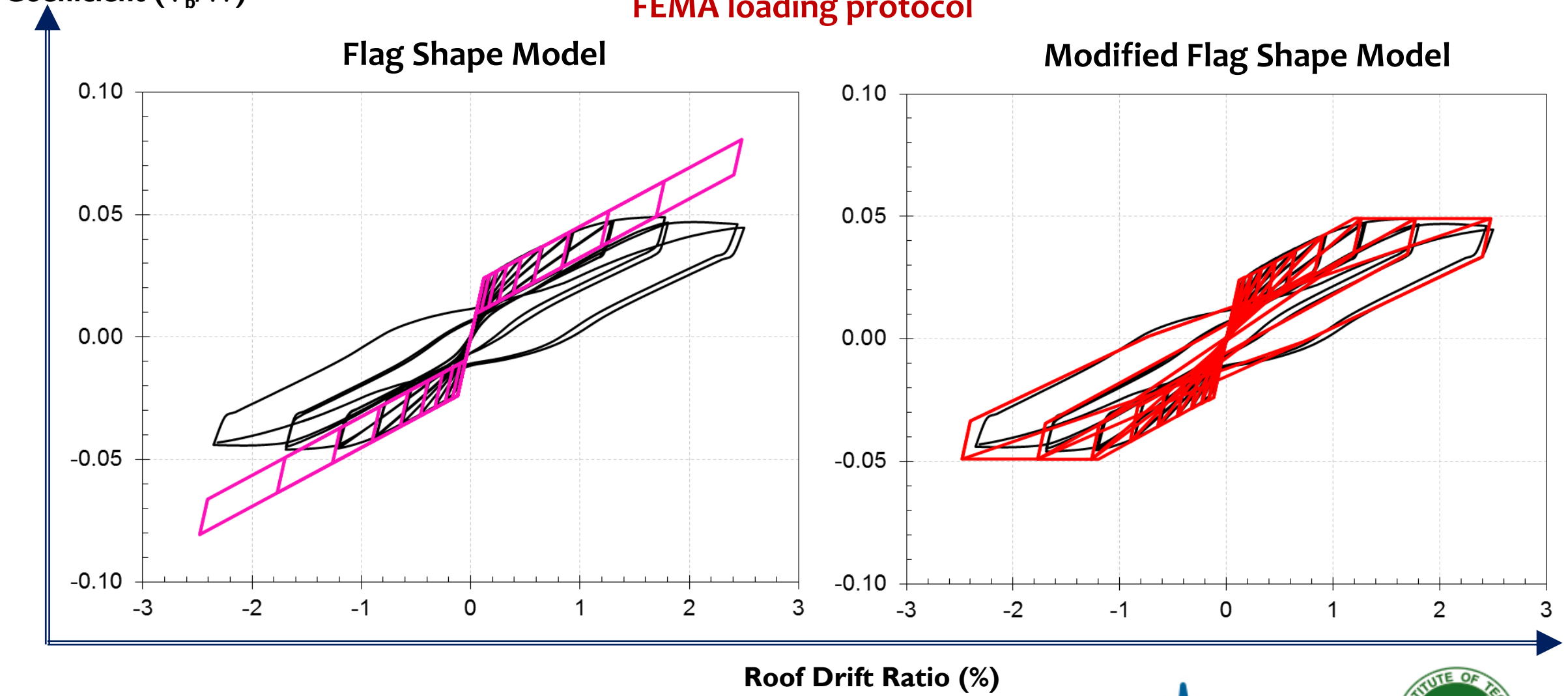
One Sided Cyclic Pushover Loading (OSCP)



Comparison of Pushover Curve

First Mode Pushover Response of 19 Story Building in Strong Direction

FEMA loading protocol



Comparison of Pushover Curve

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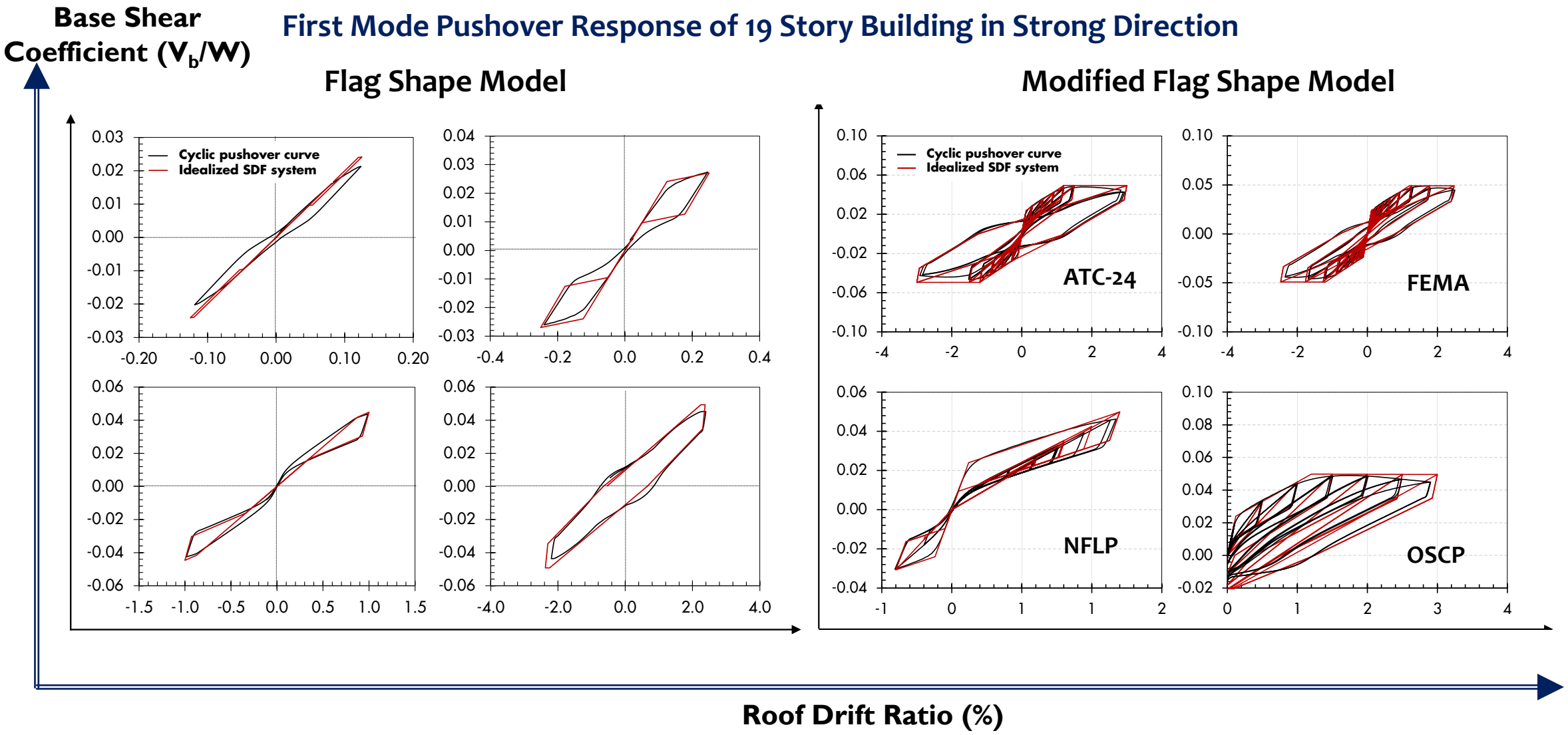
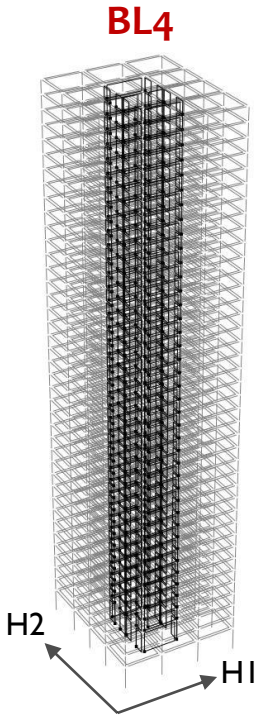
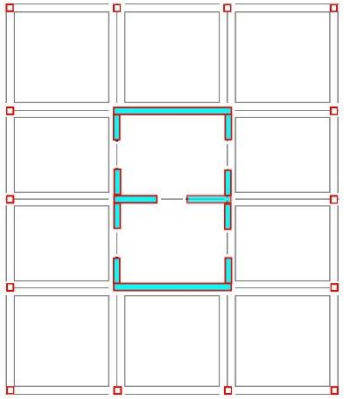


Case study Building and Ground Motions

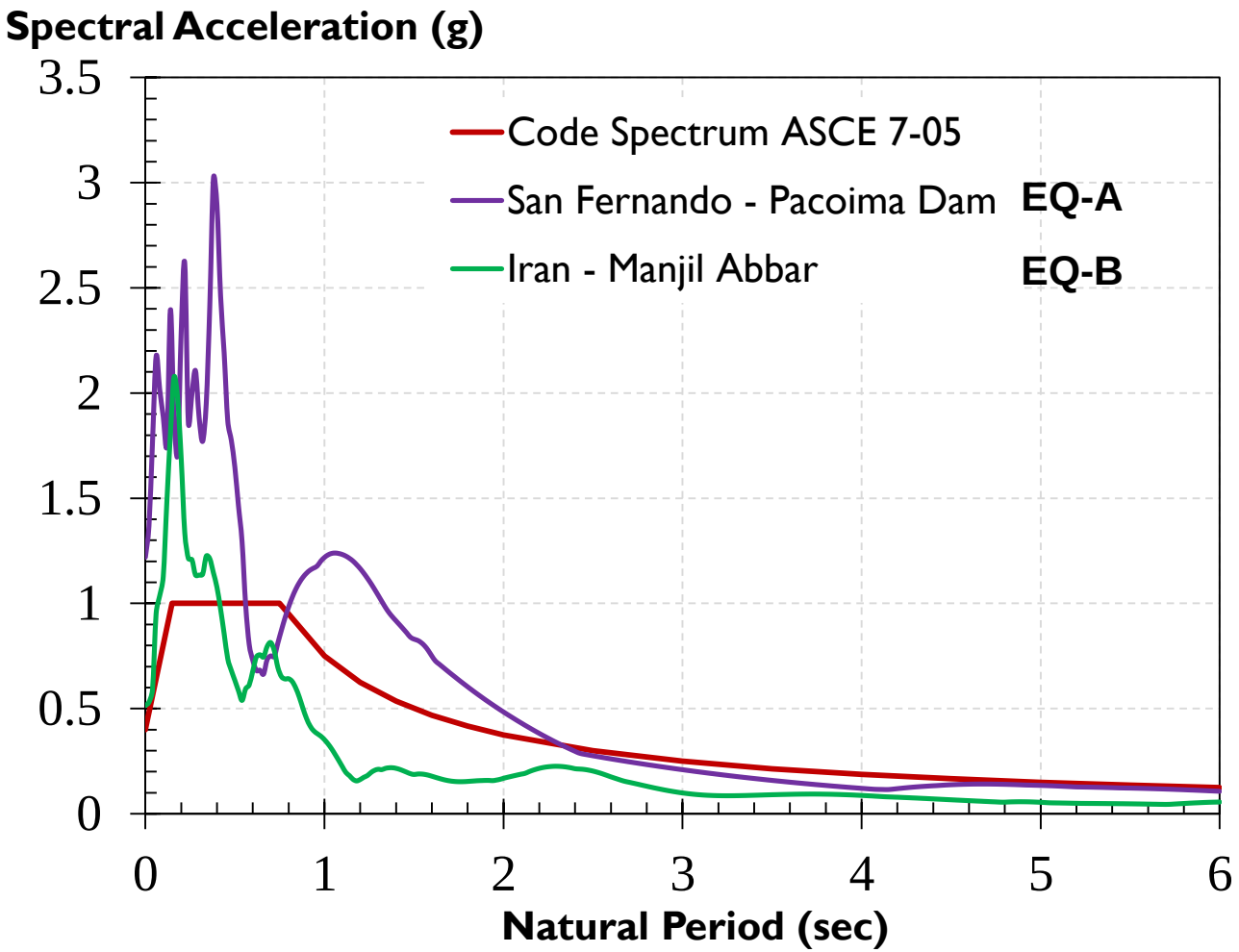
40-story shear wall Building



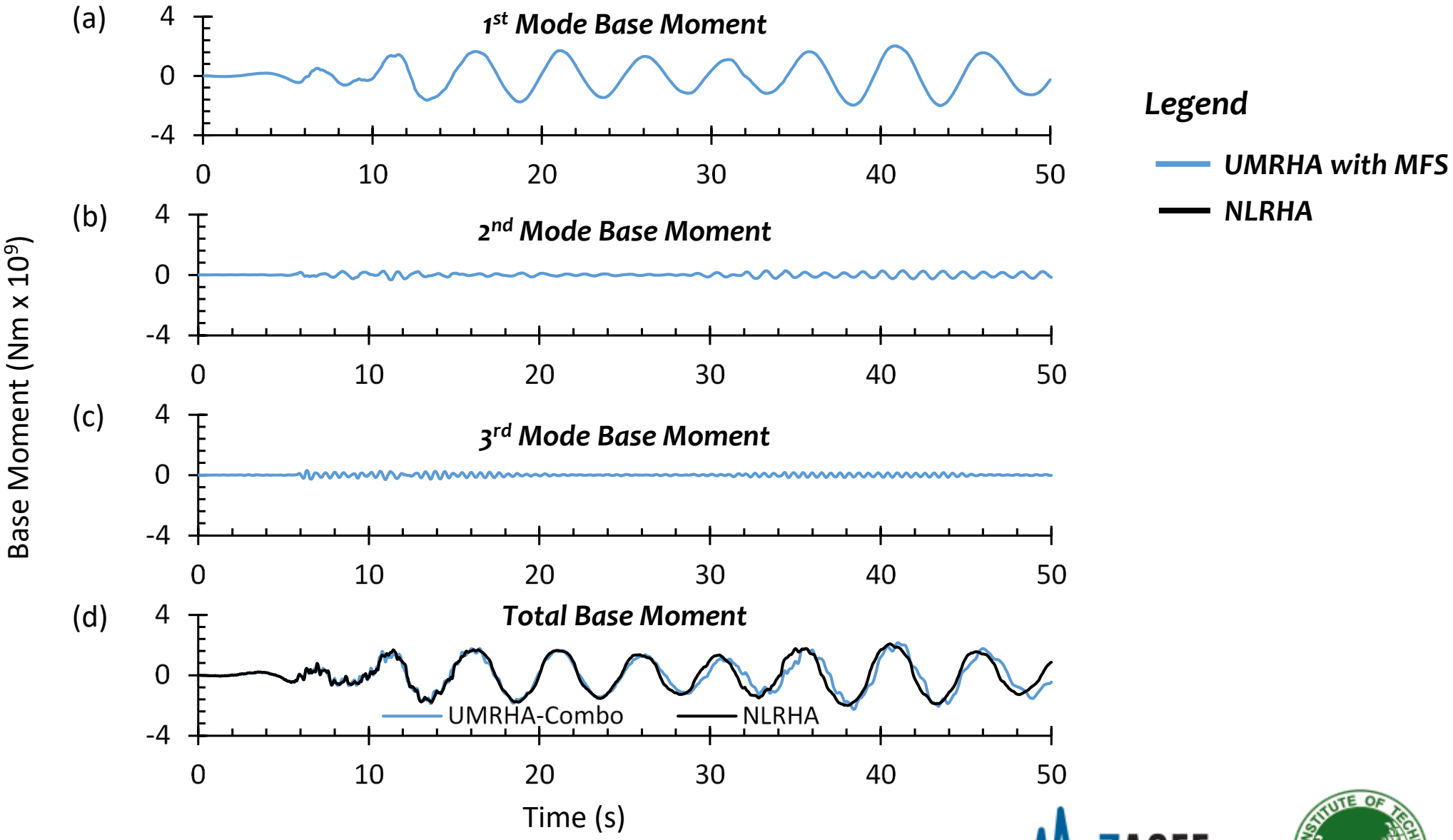


Plan View

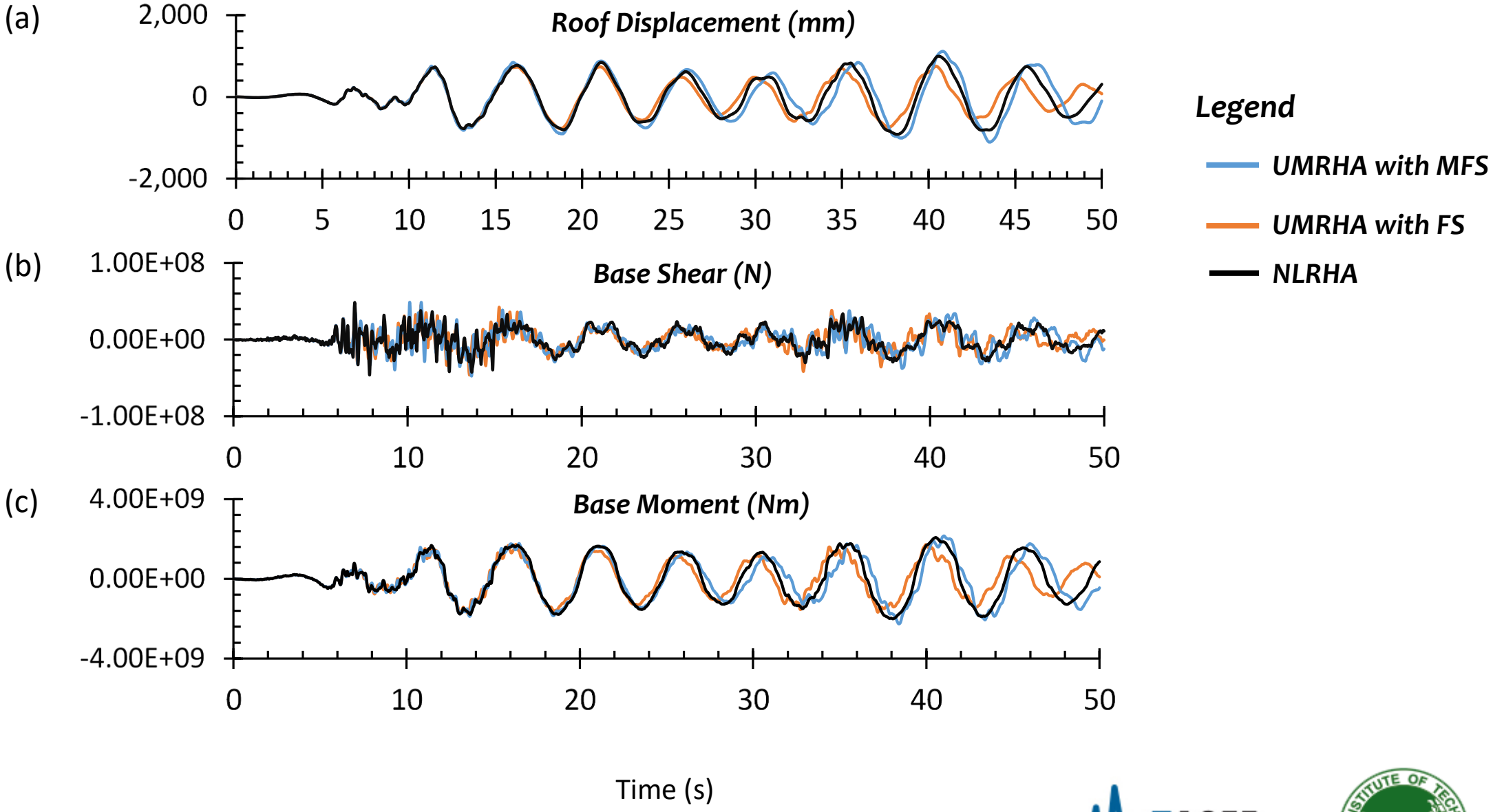
- Gravity load resisting system - RC slab-column frame
- Lateral load resisting system - RC Shear wall



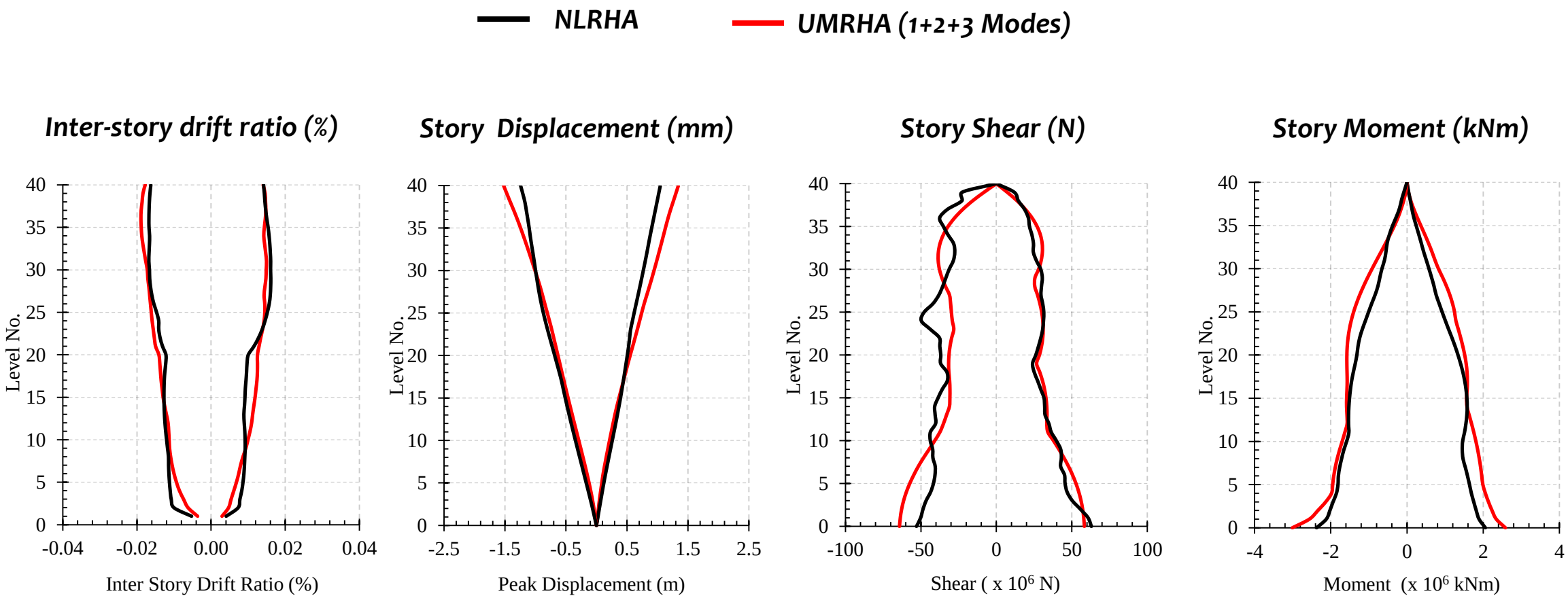
Modal Decomposition of Base Moment: BL4 and EQ-B



Comparison of UMRHA Responses vs NLRHA : BL4 and EQ-B



Comparison of UMRHA Responses vs NLRHA : BL4 and EQ-A



Conclusions

Based on four case study buildings, five loading protocols and two selected ground motions, following conclusions are drawn:

- ***New hysteresis model "Modified Flag Shape Model" is developed and validated for tall buildings with RC shear walls and is able to predict the modal behavior with reasonable accuracy***

- ***UMRHA provides good demand prediction before structure yield with FS hysteresis idealization as well as MFS hysteresis idealization.***

- ***UMRHA is proved to predict demands accurately for strong ground motion with Modified Flag Shape hysteresis.***

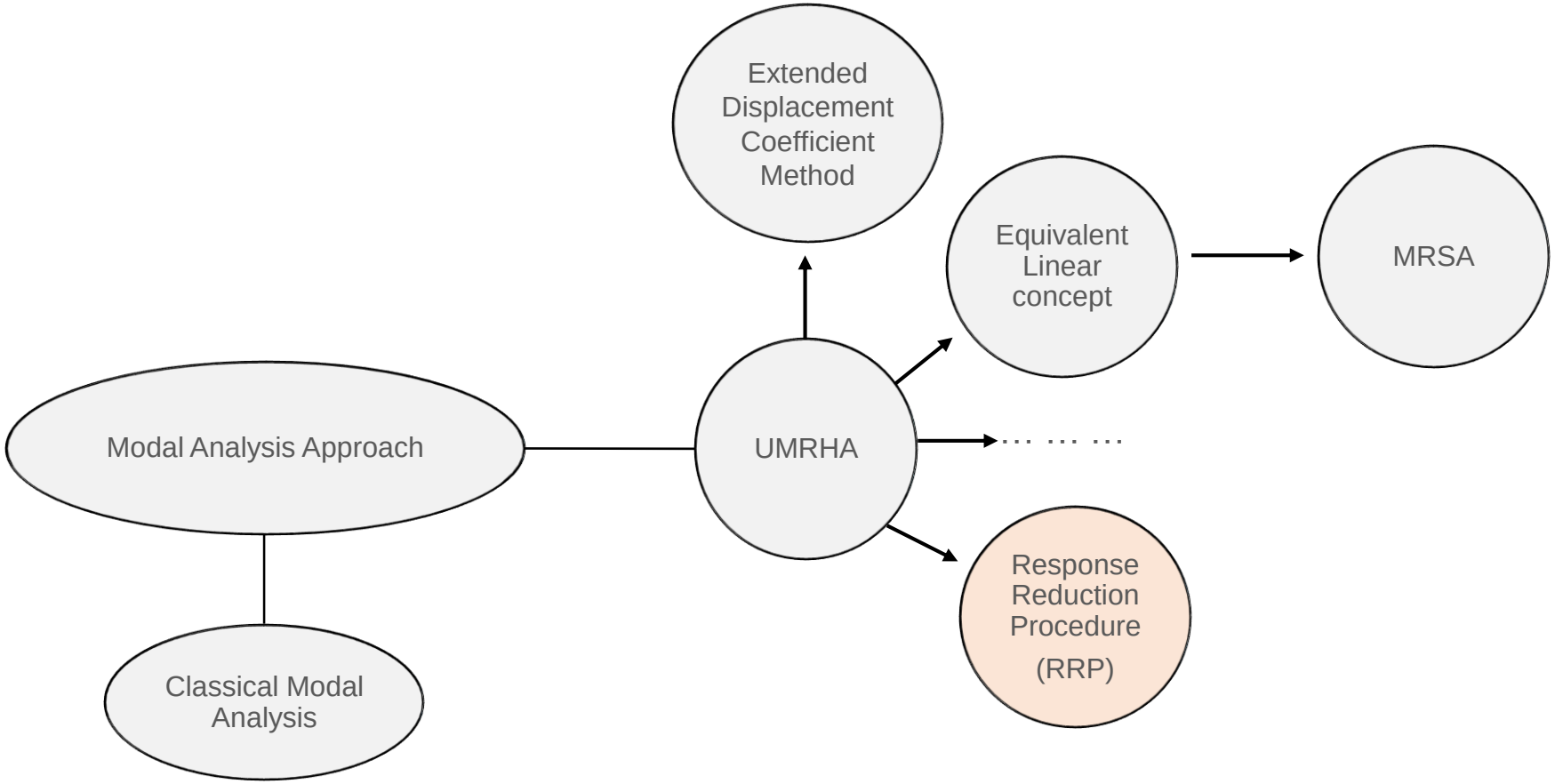
- ***Conventional Flag Shape hysteresis idealization, on the other hand, show less accurate demand prediction after significant yielding of the structure.***

- ***The required computational effort is very low compared to that of NLRHA***

Future Research

FUTURE STUDY

- ***Develop equivalent linear model for modified flag shape model***



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Thank you for your Kind Attention

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