# Vertical Ground Motion Effects on High-Rise Buildings

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# WHY NOT VERTICAL GM?

1. Lower Energy Content Compared to Horizontal Components

2. A Large Safety Factor Against Gravity Loads Used in Design

# WHAT TRIGGERS RESEARCHER'S INTEREST?

**Northridge Earthquake**

- **January 17th, 1994**
- **California, USA**
- **Peak Vertical GM: 1.18g**
- **Peak V/H Ratio: 1.79**

**(Usually Assumed to be 2/3 in Design Code)**

# A LOT OF STRUCTURAL FAILURES

- **High Mode Response**
- **Abrupt Changes of Stiffness and Strength in Elevation**
- **Lack of Capacity in High Storey**

- **Brittle Failure by Direct Compression**
- **Reduction of Shear and Flexural Strength and Ductility**

# SITE EVIDENCE OF VERTICAL GROUND MOTION

Symmetrical compressive column failure in a residential building.

Photograph courtesy of Earthquake Engineering Research Institute

# SITE EVIDENCE OF VERTICAL GROUND MOTION

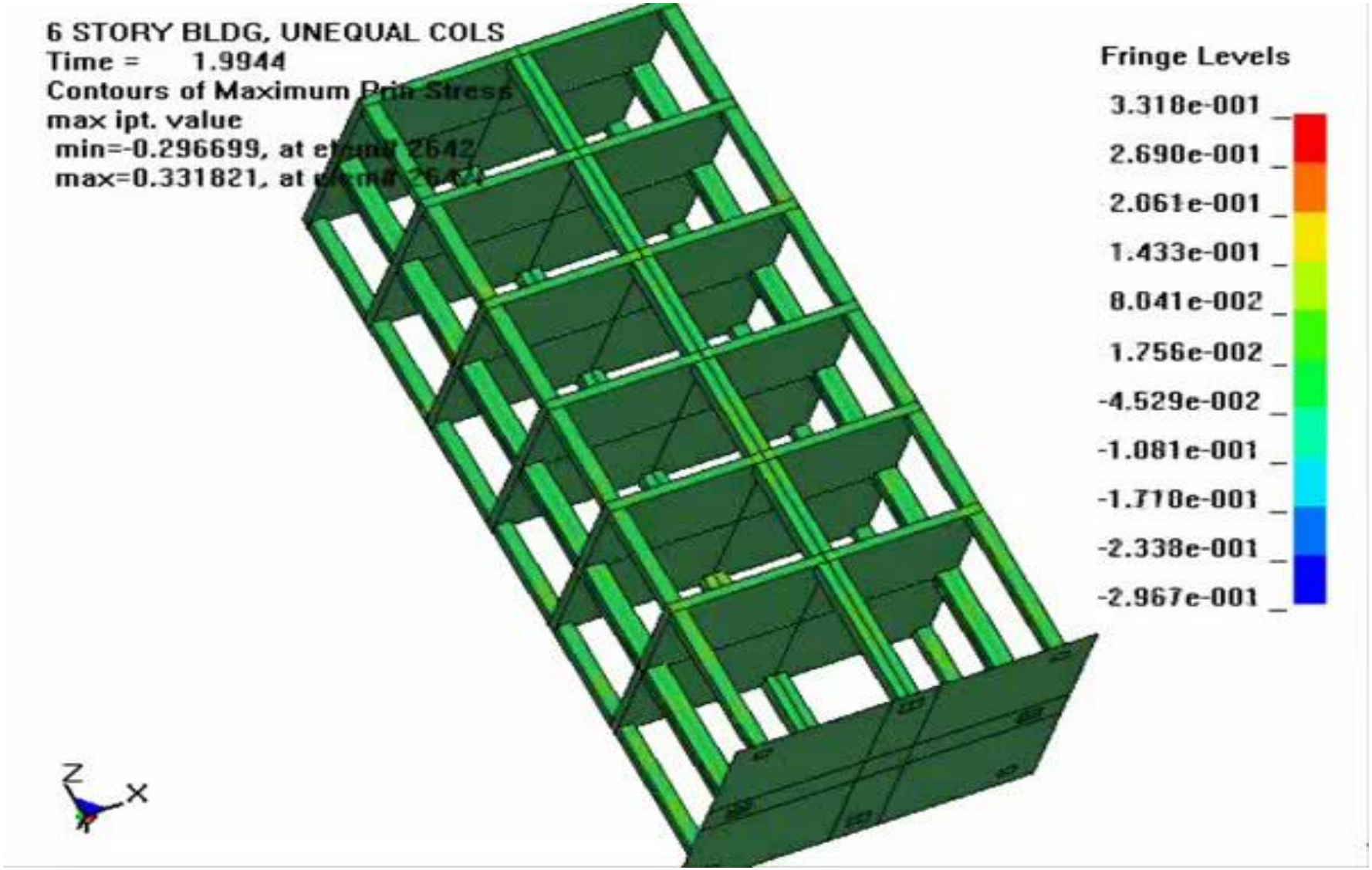
Brittle failure of the second floor of a building.

Photograph courtesy of Earthquake Engineering Research Institute

# SITE EVIDENCE OF VERTICAL GROUND MOTION

Punching shear failure of upper floor in a Mall.

Photograph courtesy of Earthquake Engineering Research Institute




Video by Dr. Gregory Szuladzinski,
https://www.youtube.com/watch?v=DhM4HjceMfk

# GM CHARACTERISTICS

Horizontal P-Wave
Longer Period
Lower Frequency Content
Higher Overall Energy Content

Vertical S-Wave
Shorter Period
Higher Frequency Content
Lower Overall Energy Content

# FACTORS AFFECTING VERTICAL GROUND MOTIONS

**Strong Function of:**

- **Oscillator Period**
- **Source-to-Site Distance**
- **Local Soil Condition**

**Weak Function of:**

- **Earthquake Magnitude**
- **Type of Faulting**

**Niazi,M and Y. Bozognia . “Behavior of Vetical Ground Motion Parameters in the Near Field.”**

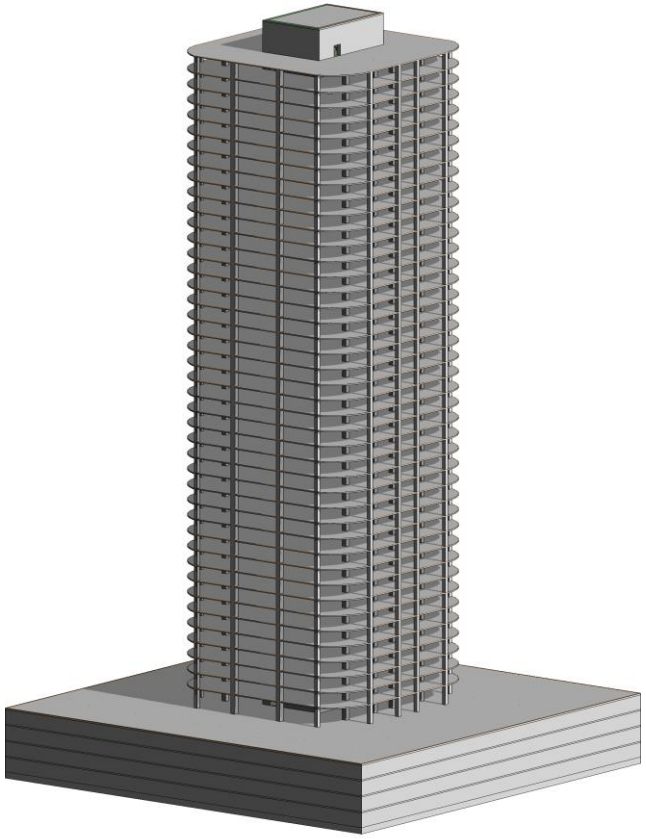
# VERTICAL GM IN DESIGN CODE

*"The vertical component of ground motion may be defined by scaling corresponding horizontal accelerations by a factor of two-thirds. Alternative factors may be used when substantiated by site-specific data. Where the Near-Source Factor, $N_a$, is greater than 1.0, site-specific vertical response spectra shall be used in lieu of the factor of two-thirds."*

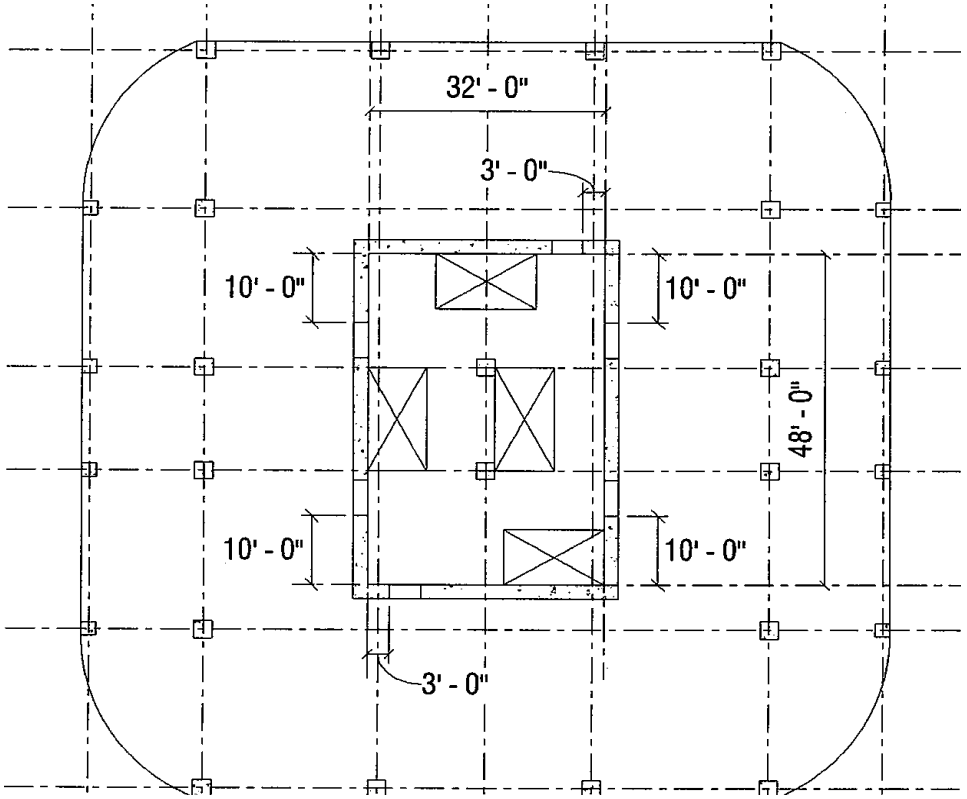
The Near-Source Factor $N_a$ is specified in Table 16-S of UBC-97 and is greater than 1.0 for the following cases:

- Seismic Source Type A when the closest distance to a known seismic source is < 10 km
- Seismic Source Type B when the closest distance to a known seismic source is < 5 km

# ANALYTICAL STUDY OF A 42-STOREY BUILDING IN LOS ANGELES

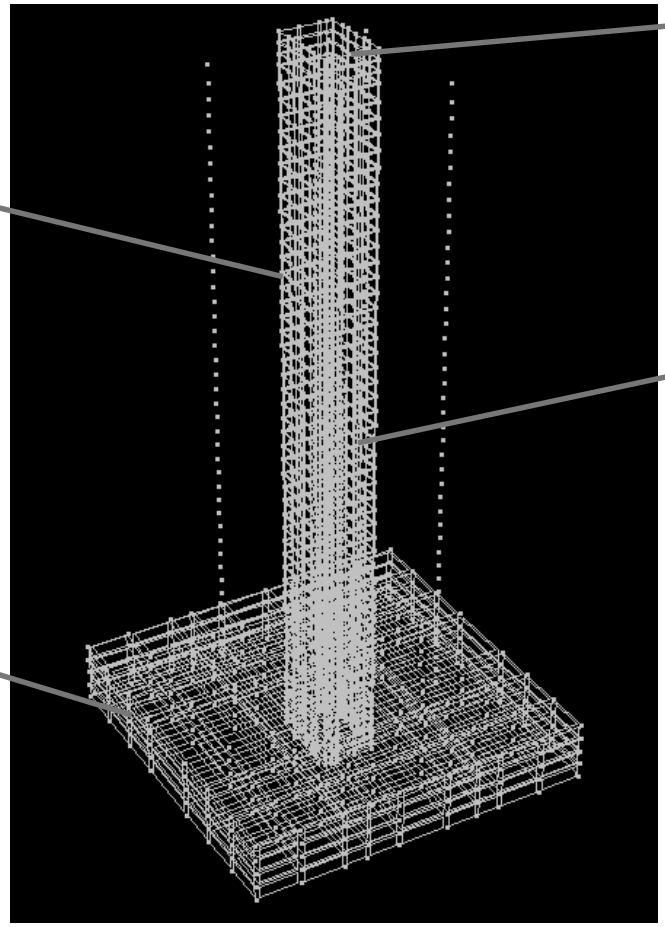


Isotropic View




Plan View

# ANALYTICAL MODEL OF A 42-STOREY BUILDING IN LOS ANGELES



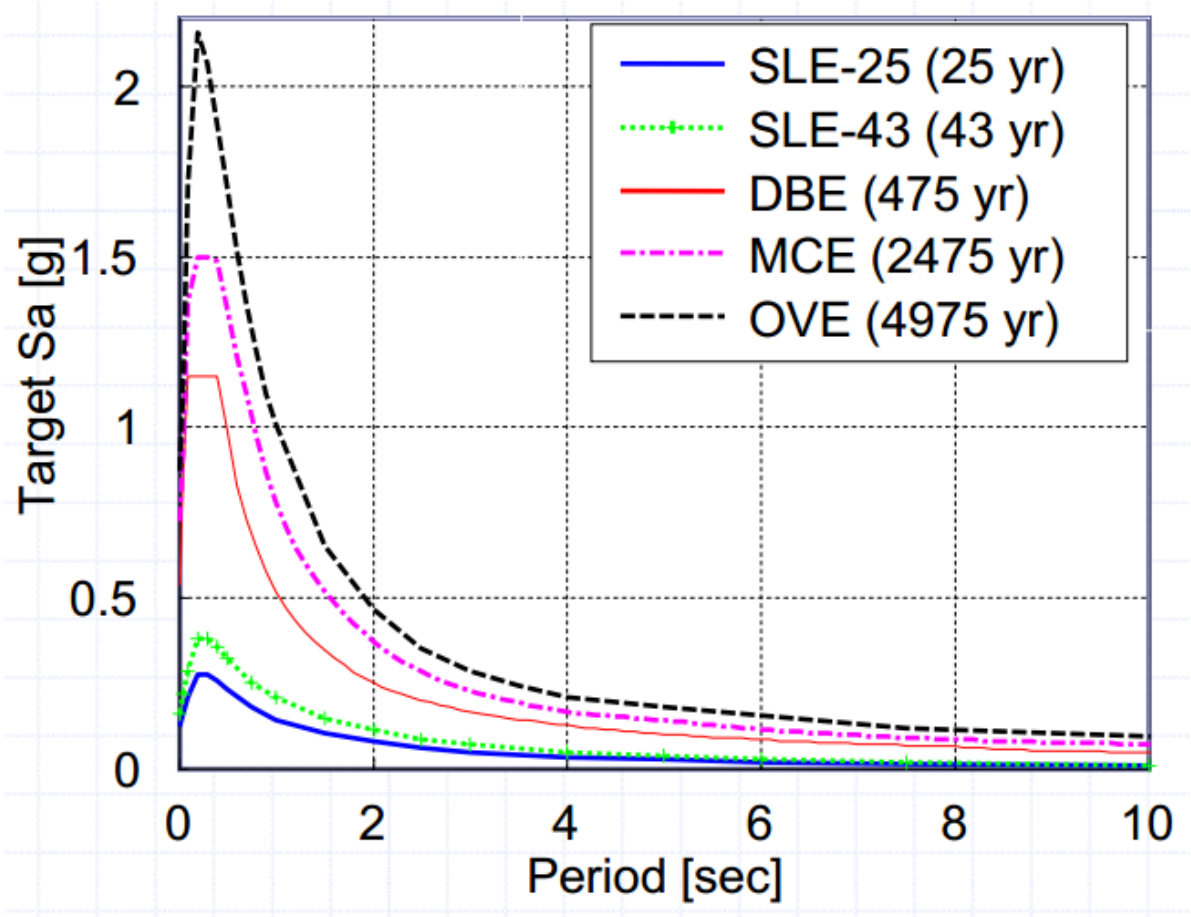
Mass (Tributary Area)

Nonlinear Coupling Wall

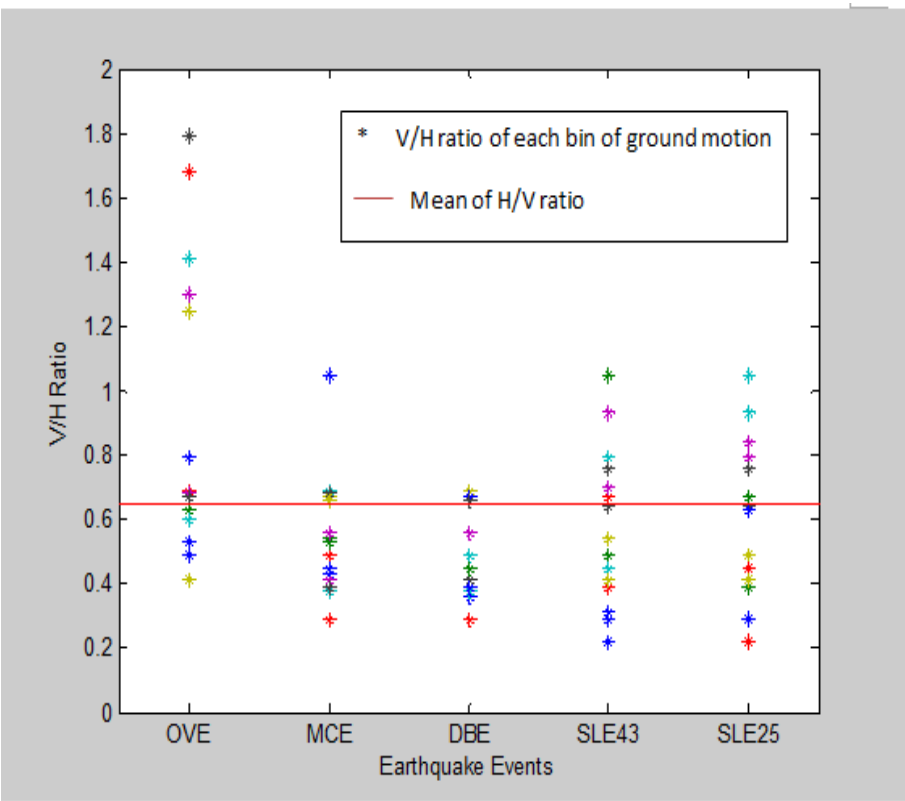
Core Wall: Nolinear Fiber Section

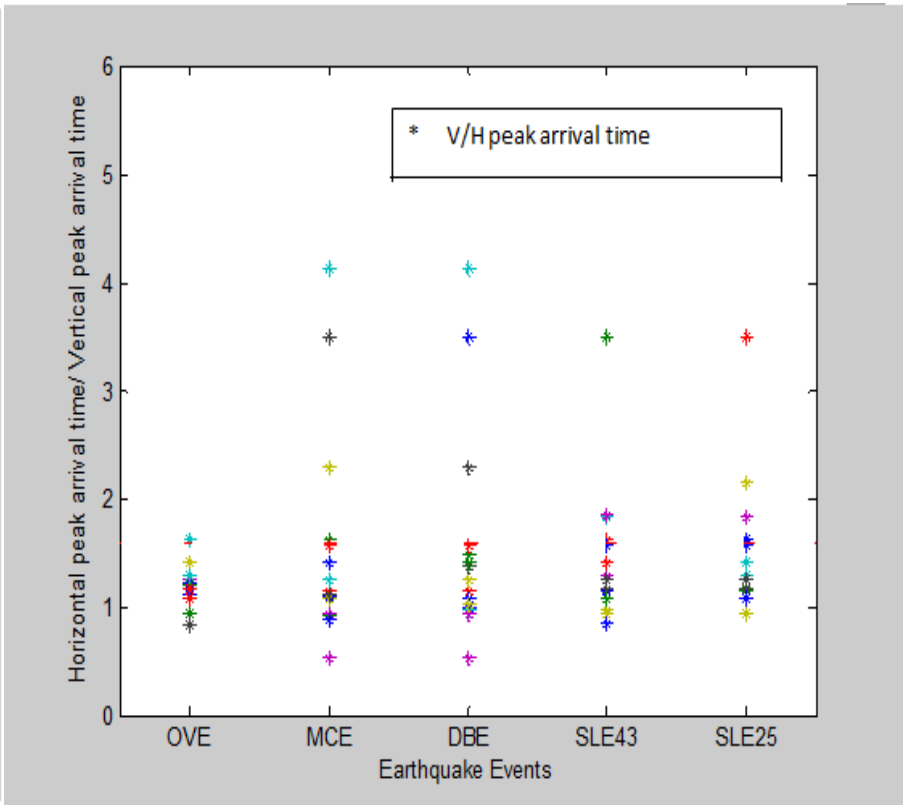
Basement Wall: Elastic Shear Wall Element

# GROUND MOTIONS SPECTRUM

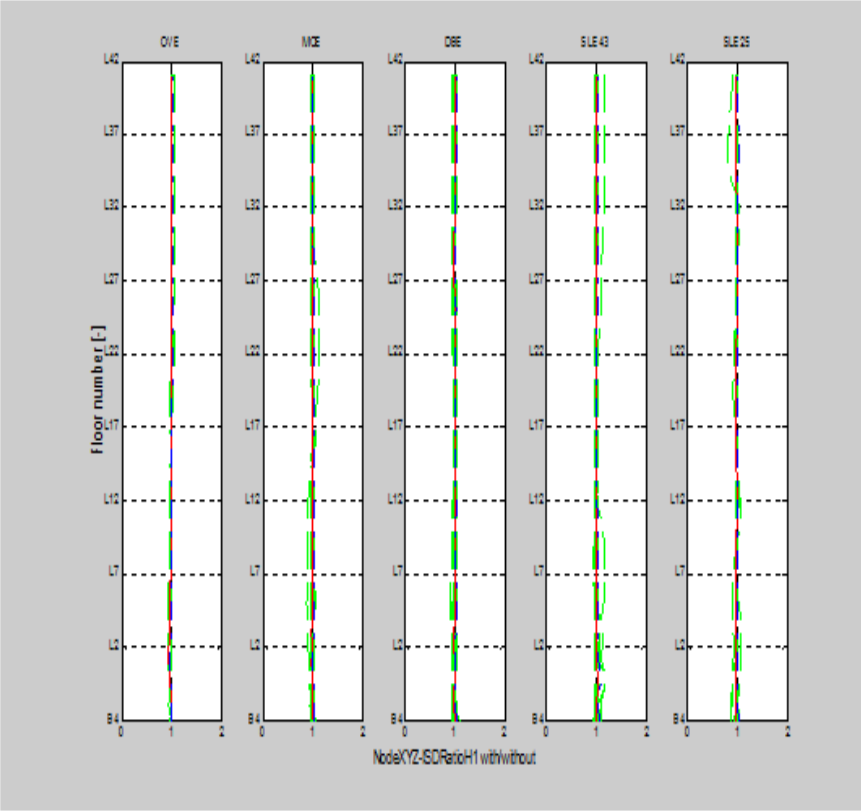


# V/H AND ARRIVAL TIME

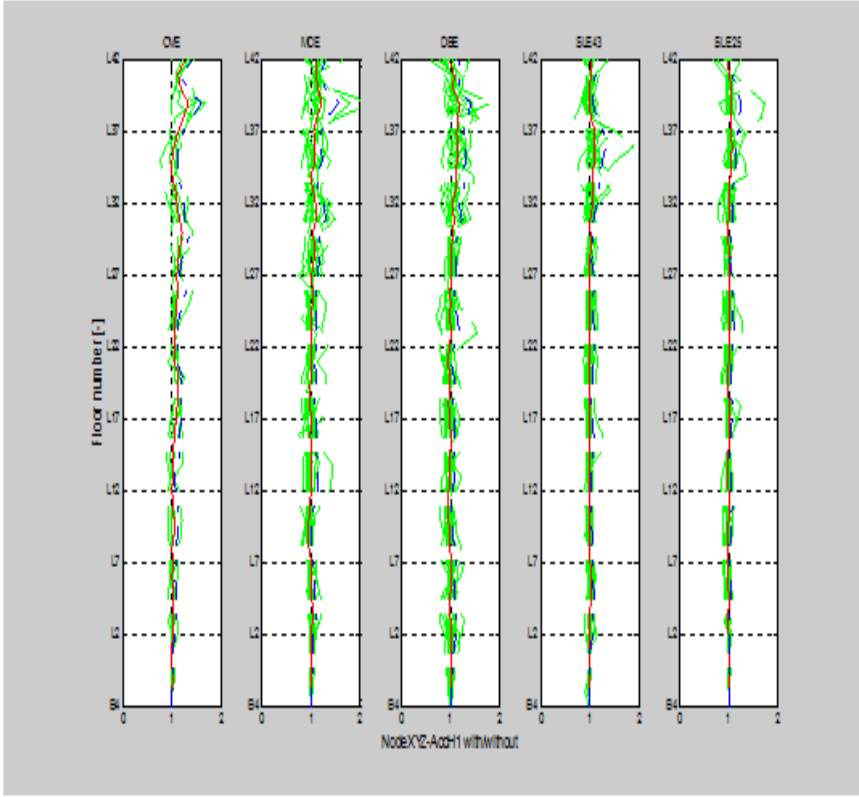


# STRUCTURAL RESPONSE

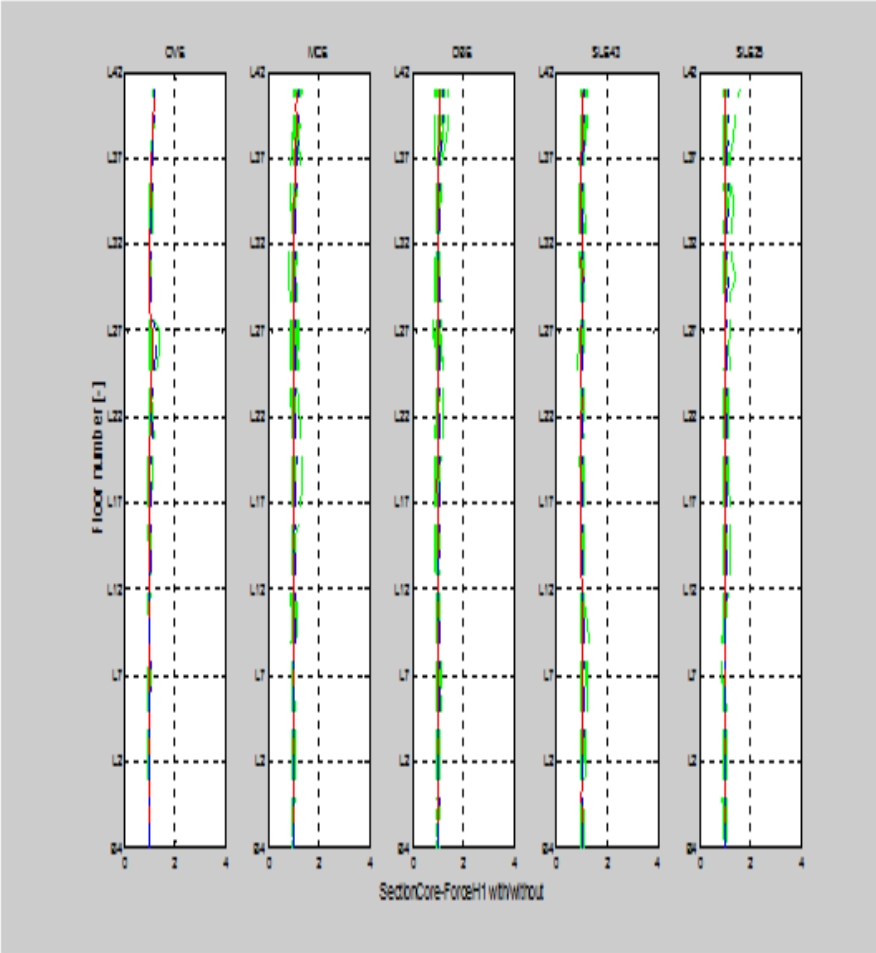



Ratio of the maximum inter-story drift ratio in H1 direction

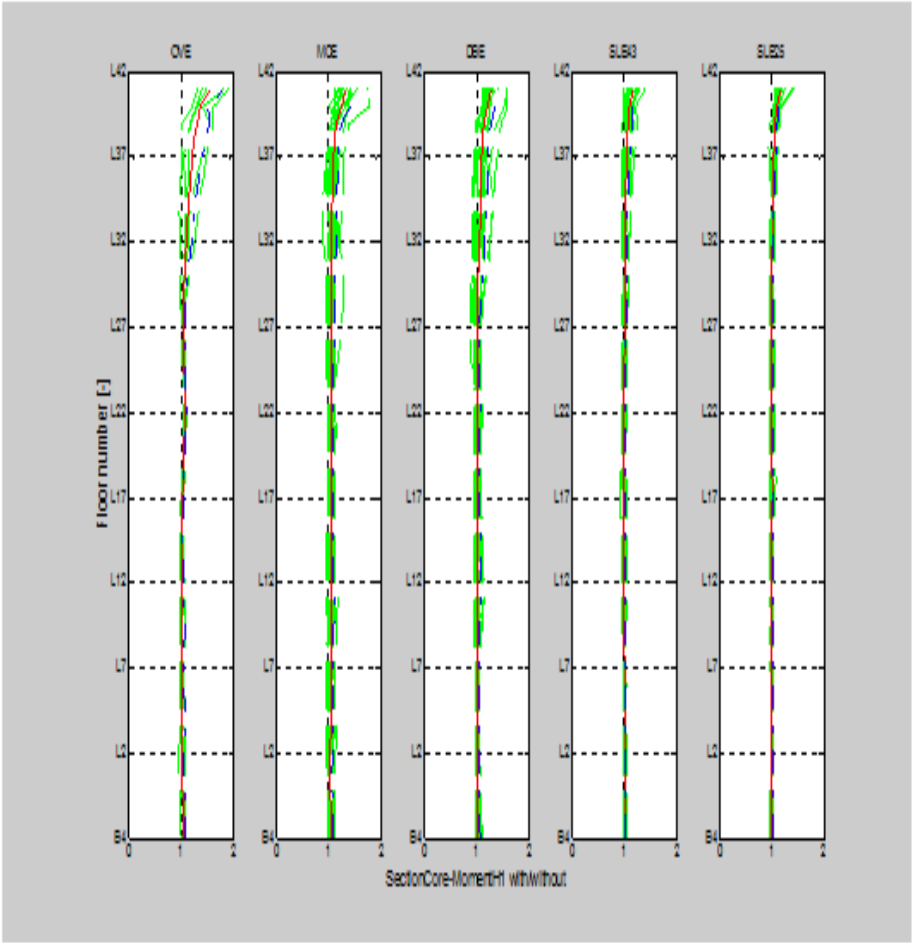



Ratio of the maximum floor acceleration in H1 direction

# STRUCTURAL RESPONSE

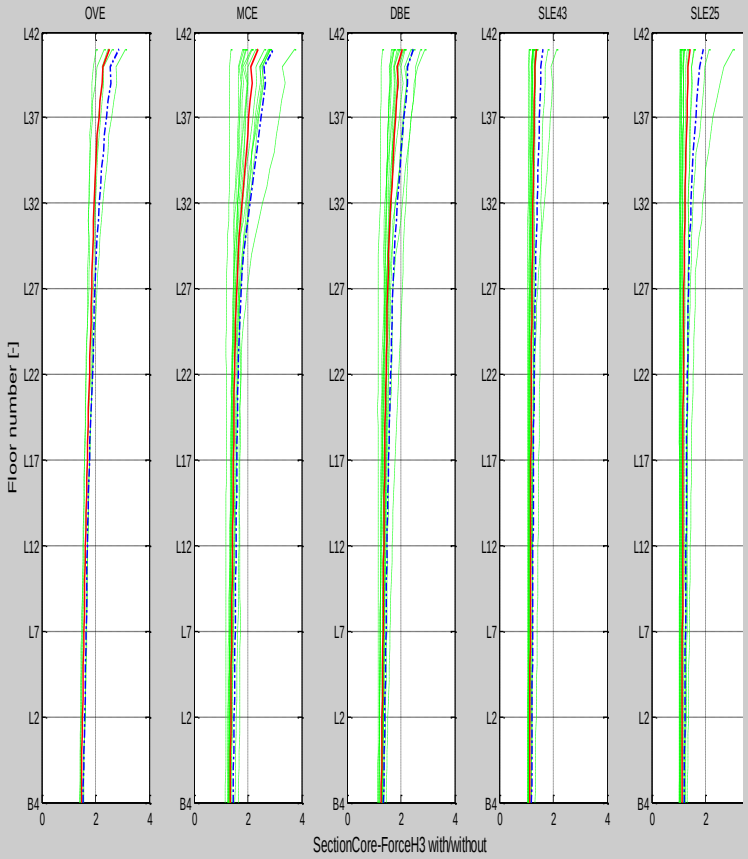


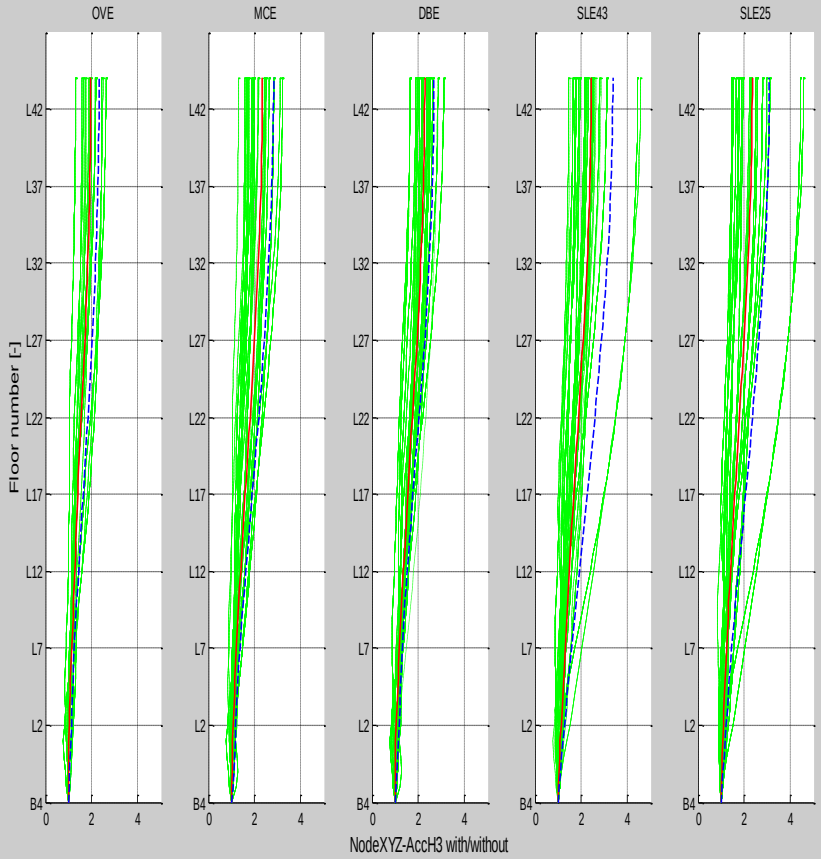

Ratio of the maximum shear force in the core wall in the H1 direction



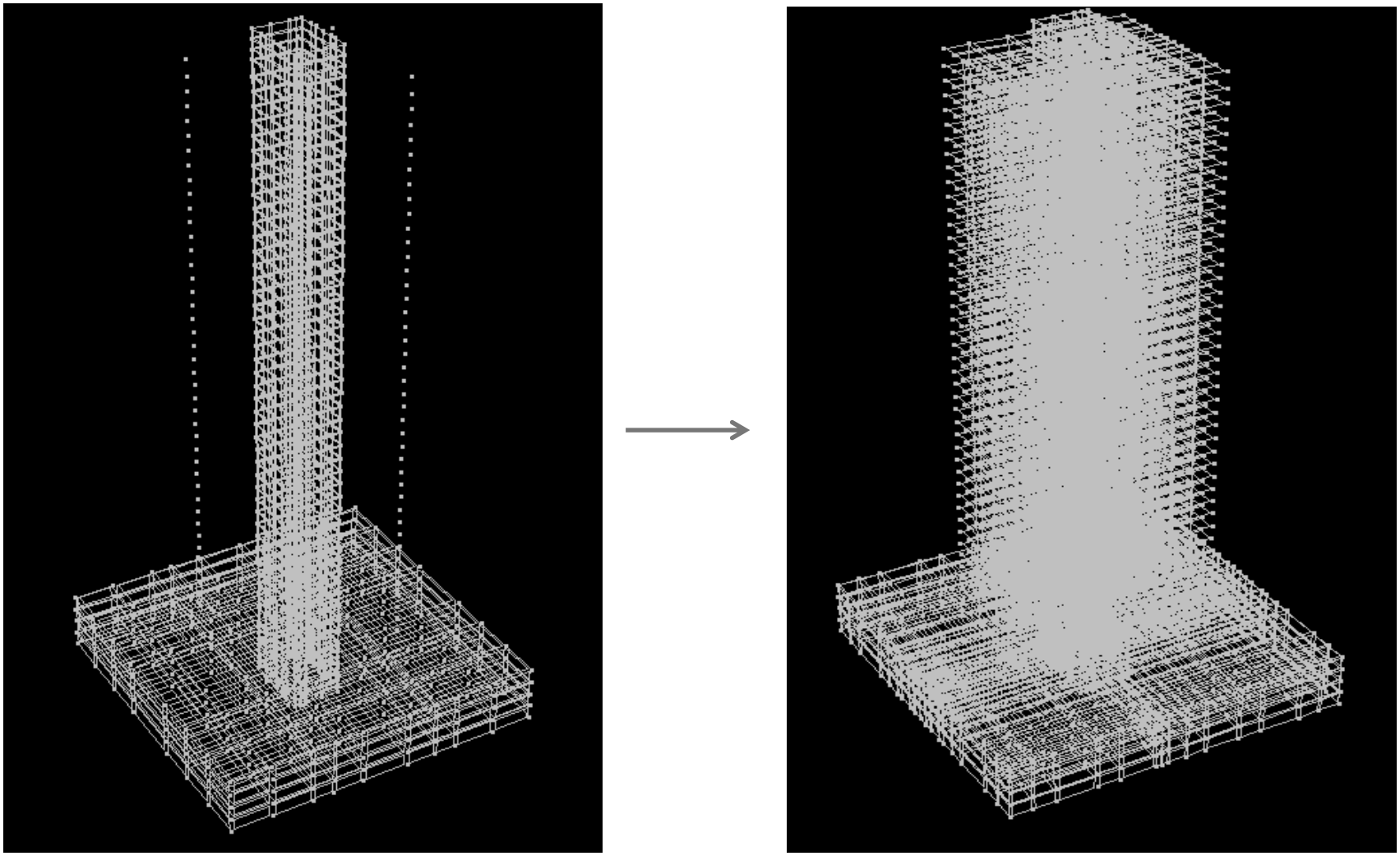

Ratio of the maximum moment in the core wall in the H1 direction

# STRUCTURAL RESPONSE

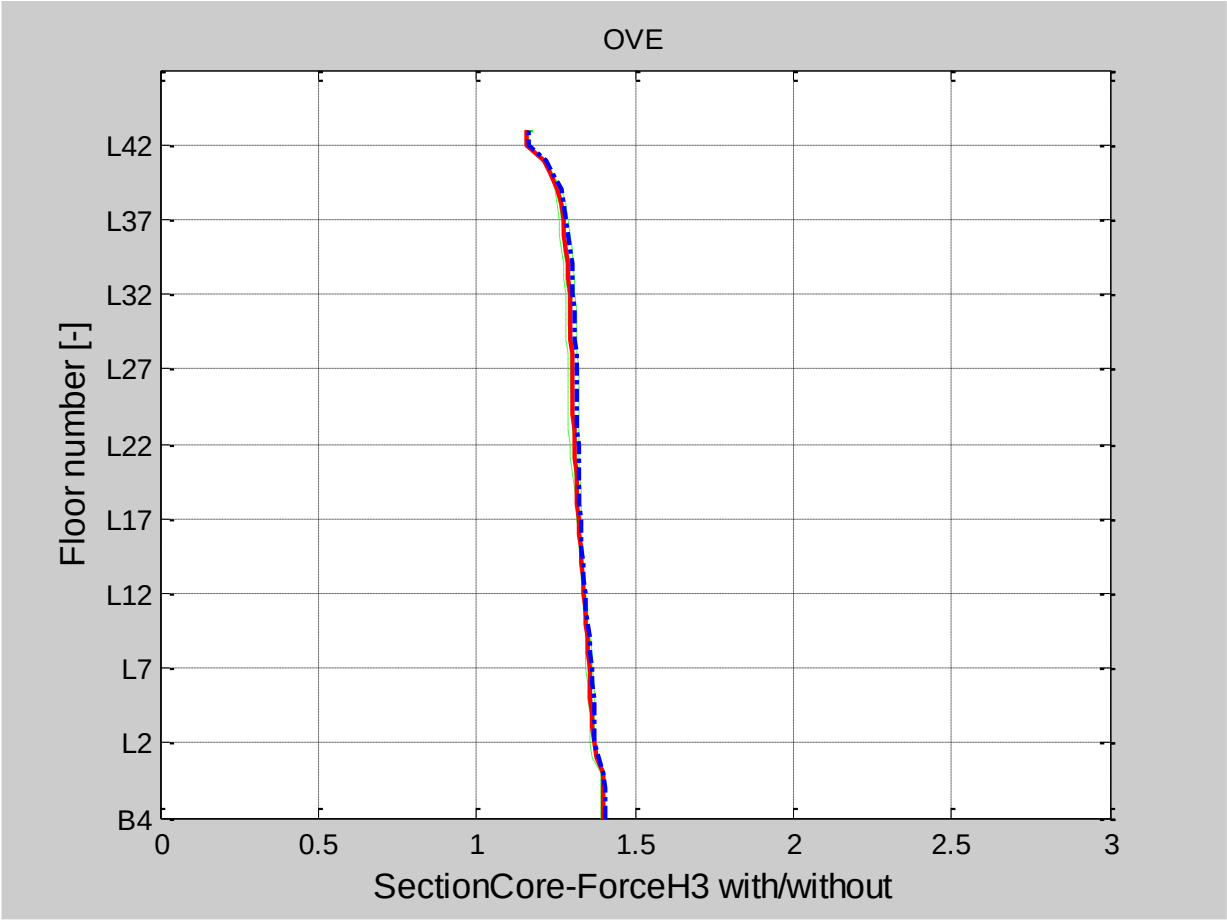


# ANALYTICAL MODEL WITH THE DIAPHRAGM SYSTEM



# AXIAL FORCE IN THE CORE WALL



# CONCLUSION AND RECOMMENDATIONS

**Problems:**

- **Axial force increases in structural components.**
- **Potential shear and moment capacity reduction.**
- **Ductility reduction.**

**Two simplified methods to more accurately scale vertical spectrum:**

1. **Shift the horizontal spectrum to shorter periods and reduce its amplitude to approximate the vertical spectrum.**
2. **Use V/H scaling factor.**

Bozorgnia, Campbell, and Niazi (2006). “Vertical Ground Motion: Characteristics, Relationship with Horizontal Component, and Building-Code Implications.

# Thank You!

## Questions?