Vertical Ground Motion Effects on High-Rise Buildings

Sophia Zhou
University of British Columbia
August 19, 2013
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 17\textsuperscript{th}, 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
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. Bozoglia. “Behavior of Vertical Ground Motion Parameters in the Near Field.”
“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

Nonlinear Coupling Wall

Basement Wall: Elastic Shear Wall Element

Mass (Tributary Area)

Core Wall: Nonlinear Fiber Section
V/H AND ARRIVAL TIME

* V/H ratio of each bin of ground motion
* Mean of H/V ratio

* V/H peak arrival time

Earthquake Events:
- OVE
- MCE
- DBE
- SLE43
- SLE25
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.

Thank You!

Questions?