



# Seismic Pressures on Buried and Retaining Walls

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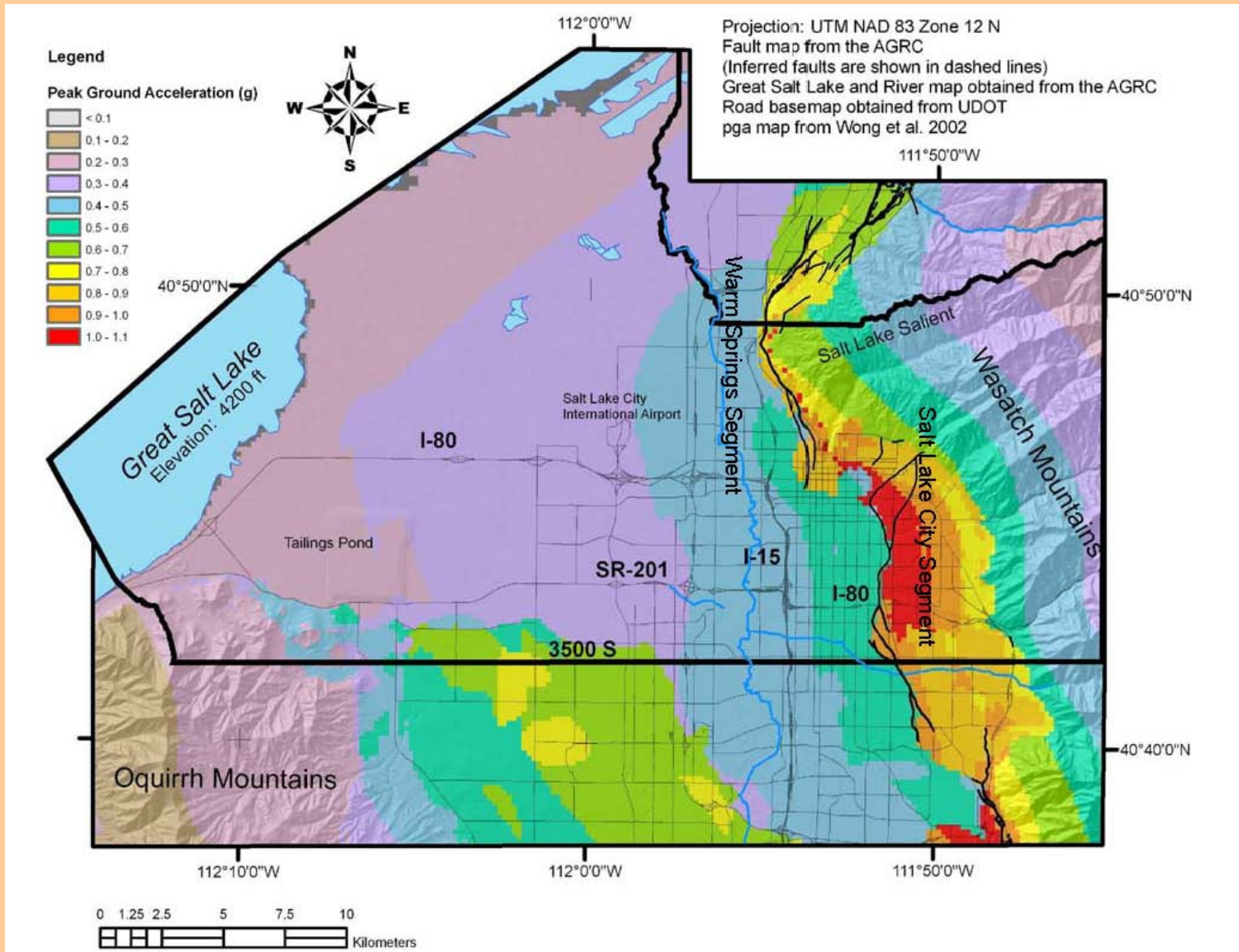
Bechtel, San Francisco



# **Objectives**

- **Earth pressures under seismic loading**
  - **Yielding Walls**
  - **Non-Yielding Walls**
  
- **Compaction Induced Stress (Matt Francis, URS)**
  
- **Reduction of Lateral Earth Pressures (Matt Francis, URS)**
  
- **Panel**
  - **Bill Gordon**
  - **Joergen Pilz**
  - **Matt Francis**
  - **Steven Bartlett**

# Near Fault Seismicity



# *Types of Walls*

- **Gravity**
- **Cantilever**
- **Braced**
- **Tieback**
- **Soil Reinforced**
- **Rigid Walls (Basement Walls)**

# *Seismic Behavior of Walls*

- **Yielding Walls**
  - Can the wall move sufficiently enough to develop the active earth pressure state?
    - **Modes of yielding**
      - Translation (sliding)
      - Rotation
      - Flexible (MSE)
- **Non-Yielding Walls**
  - Basement walls are non-yielding walls
    - Do not develop the active earth pressure state

## ***Mononobe-Okabe (M-O) Method***

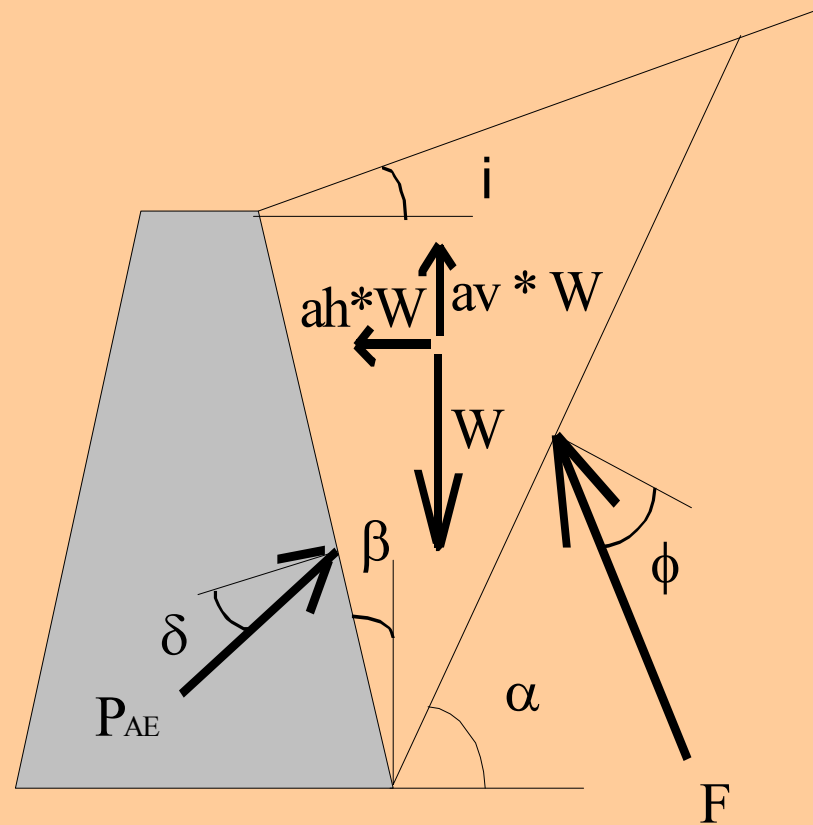
- **Effect of ground motion on retaining walls was recognized by Okabe (1924) and Mononobe (1929) following the great Kanto earthquake of 1923.**
- **The M-O method**
  - **Based on Coulomb's theory of static soil pressure**
  - **Pseudostatic method**
  - **Valid for yielding walls**

## ***Mononobe-Okabe (M-O) Method***

- **F. E. analyses by Pitilakis (1987) found good agreement between F. E. analyses results and Mononobe-Okabe theory and observed behavior, and that the M-O theory is satisfactory for design purposes if the wall movement was about 0.5 percent of the height of the wall.**

**0.05 x 20 ft = 0.1 ft deflection required for M-O method to be valid**

# M-O Lateral Earth Pressure



$$F_h = a_h * W$$

$$F_v = a_v * W$$



## ***M-O Lateral Earth Pressure***

$$P_{\Delta E} = P_A + \Delta P_{\Delta E}$$

**Static Earth Pressure + Earthquake Pressure**

$$P_{\Delta E} = 1/2 \gamma H^2 (1-a_v) K_{\Delta E}$$

**Height of Resultant Force (h)**

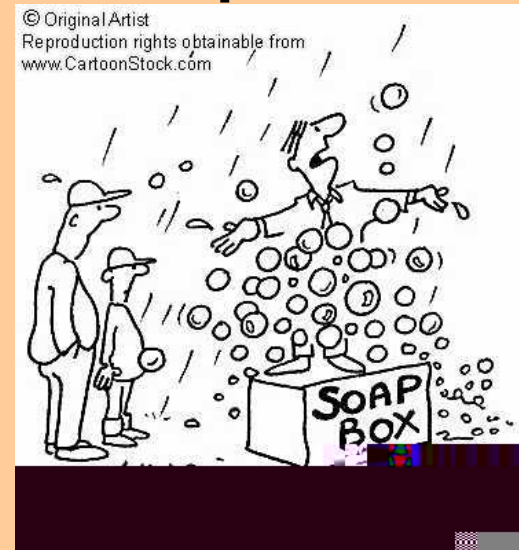
$$h = (P_A H / 3 + \Delta P_{\Delta E} (0.6) H) / P_{\Delta E}$$

# ***M-O Seismic Earth Pressure Coefficient***

where:  $\theta = \tan^{-1} (a$

## *M-O Summary*

- In spite of much better understanding of soil-structure interaction effects and many criticisms of the M-O method, the M-O method is widely used for building walls.
- In this regard, the M-O method is one the most abused methods in the geotechnical practice.



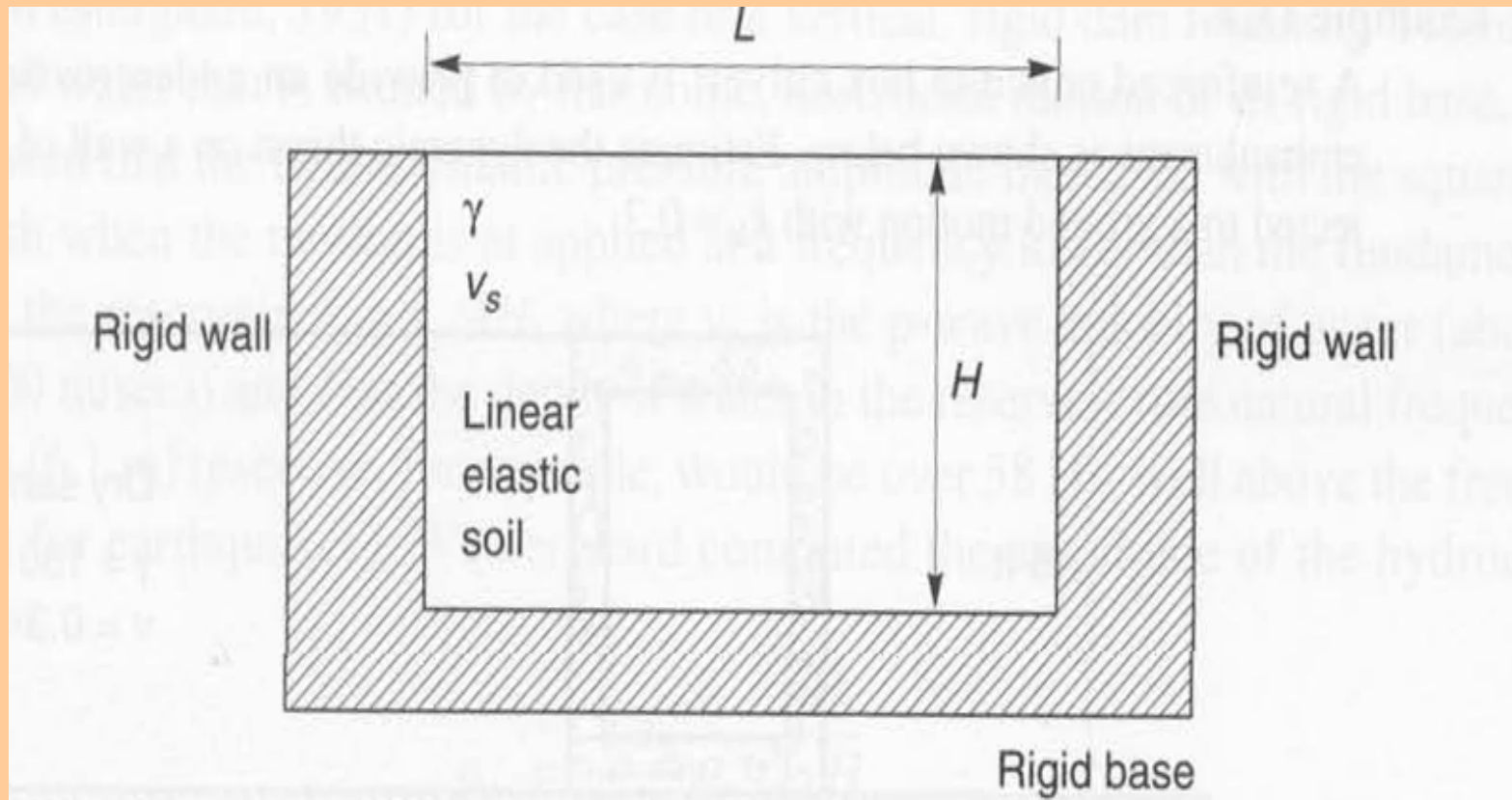
# ***Seismic Lateral Earth Pressures***

*(Wood, 1973)*

- **Wood developed a finite element solution for a non-yielding wall.**
- **While the solution is based on dynamic modal analysis (hence dynamic), the solution used in practice is a static solution based on horizontal body force of 1g acceleration.**
- **Need to know PGA, Poisson's ratio and density of the soil to get the pressure.**

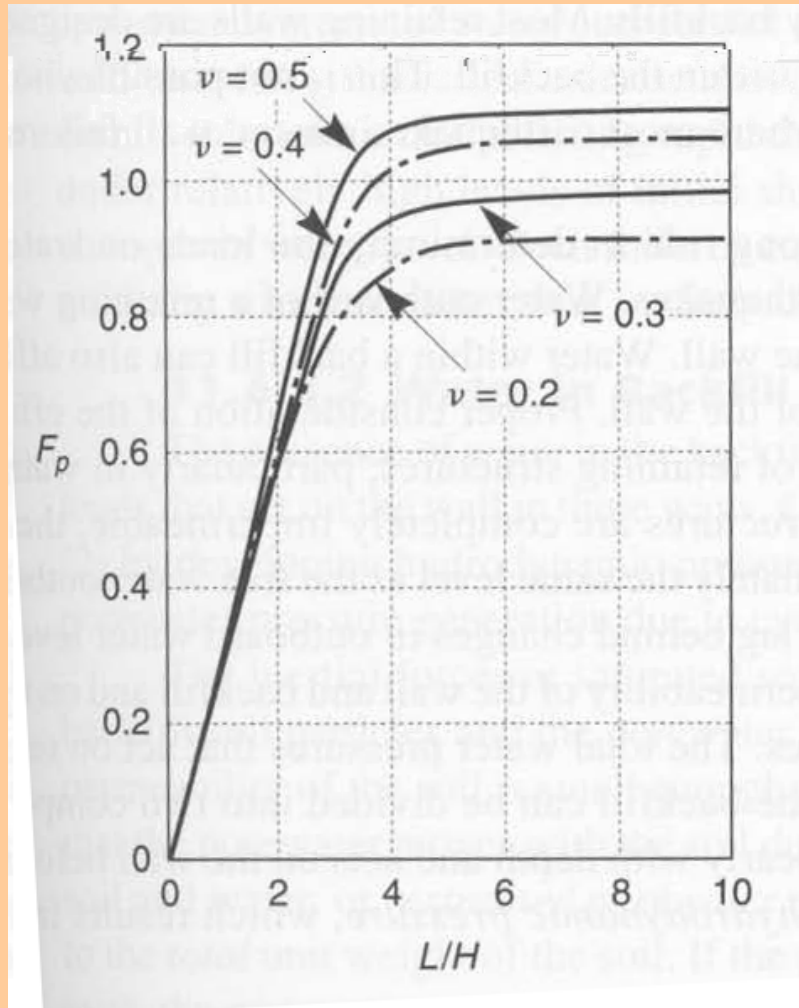
# Seismic Lateral Earth Pressures

(Wood, 1973)



# Seismic Lateral Earth Pressures

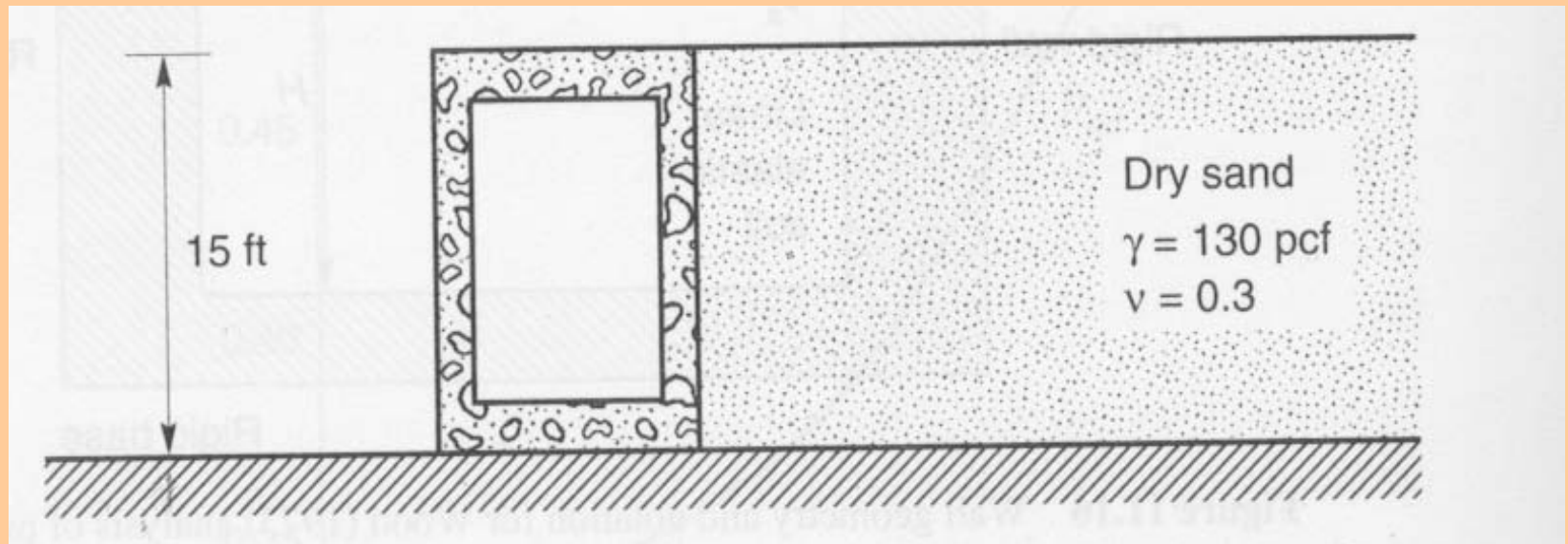
(Wood, 1973)



$$\Delta P_{eq} = \gamma H^2 (a_h/g) F_p$$

# Seismic Lateral Earth Pressures

(Wood, 1973)



$$\Delta P_{eq} = \gamma H^2 \frac{a_h}{g} F_p = (130 \text{ pcf})(15 \text{ ft})^2 \frac{0.2 g}{g} (1.0) = 5850 \text{ lb/ft}$$

# ***Seismic Lateral Earth Pressures***

## ***Recent Experiments and Observations***

- **In recent years recorded data from many underground structures have been examined.**
- **Lotung 1/4-scale model, in Lotung, Taiwan (1987).**
  - The studies show that seismic soil pressure is:
    - affected by the long period part of the ground motion
    - function of relative motion between the soil and the structure (soil-structure interaction)
    - amplified near the resonant frequency of the backfill
    - a function of soil nonlinearity
- **Many recent observations from Japan confirmed the above findings**



# Seismic Lateral Earth Pressures

## Recent Experiments and Observations

- Lotung 1/4-scale model, in Lotung, Taiwan (1987).

A photo of the Lotung LSST site



# ***Seismic Lateral Earth Pressures***

*(Ostadan and White, 1997)*

## **Assumptions and Method**

- **Assume the building basemat is founded on rock.**
- **Input ground motion at basemat elevation.**
  
- **The walls of the building are effectively rigid.**
- **30 foot-embedment considered**
  
- **5 percent material damping of soil**
- **Poisson's ratio of soil = 1/3**
  
- **Kinematic SSI is considered.**
- **Inertial SSI is not considered.**
  
- **The solution is derived from SSI analyses using SASSI.**

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

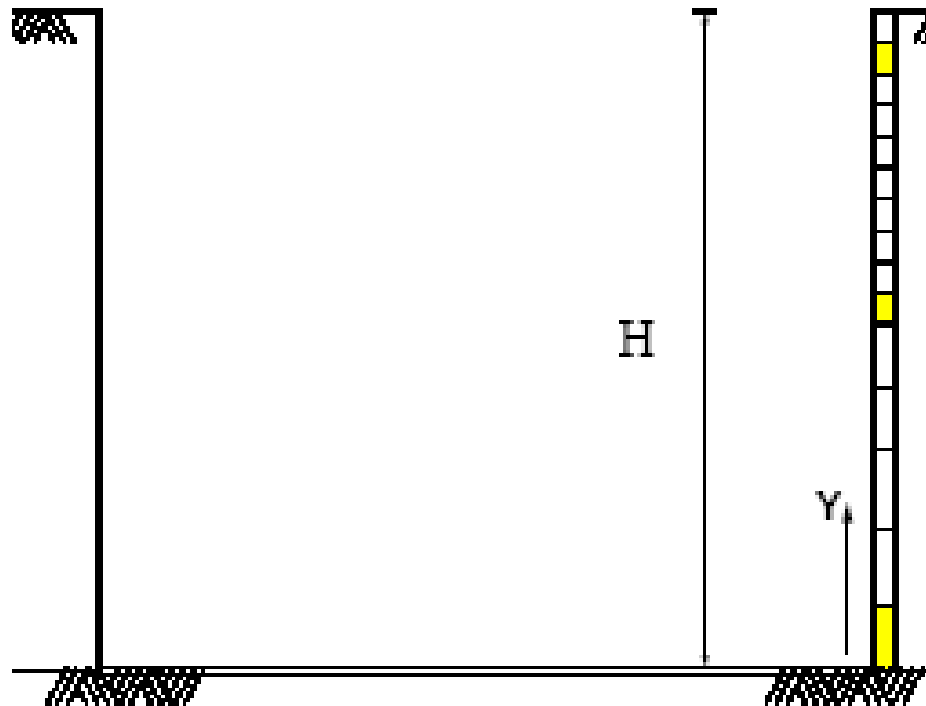
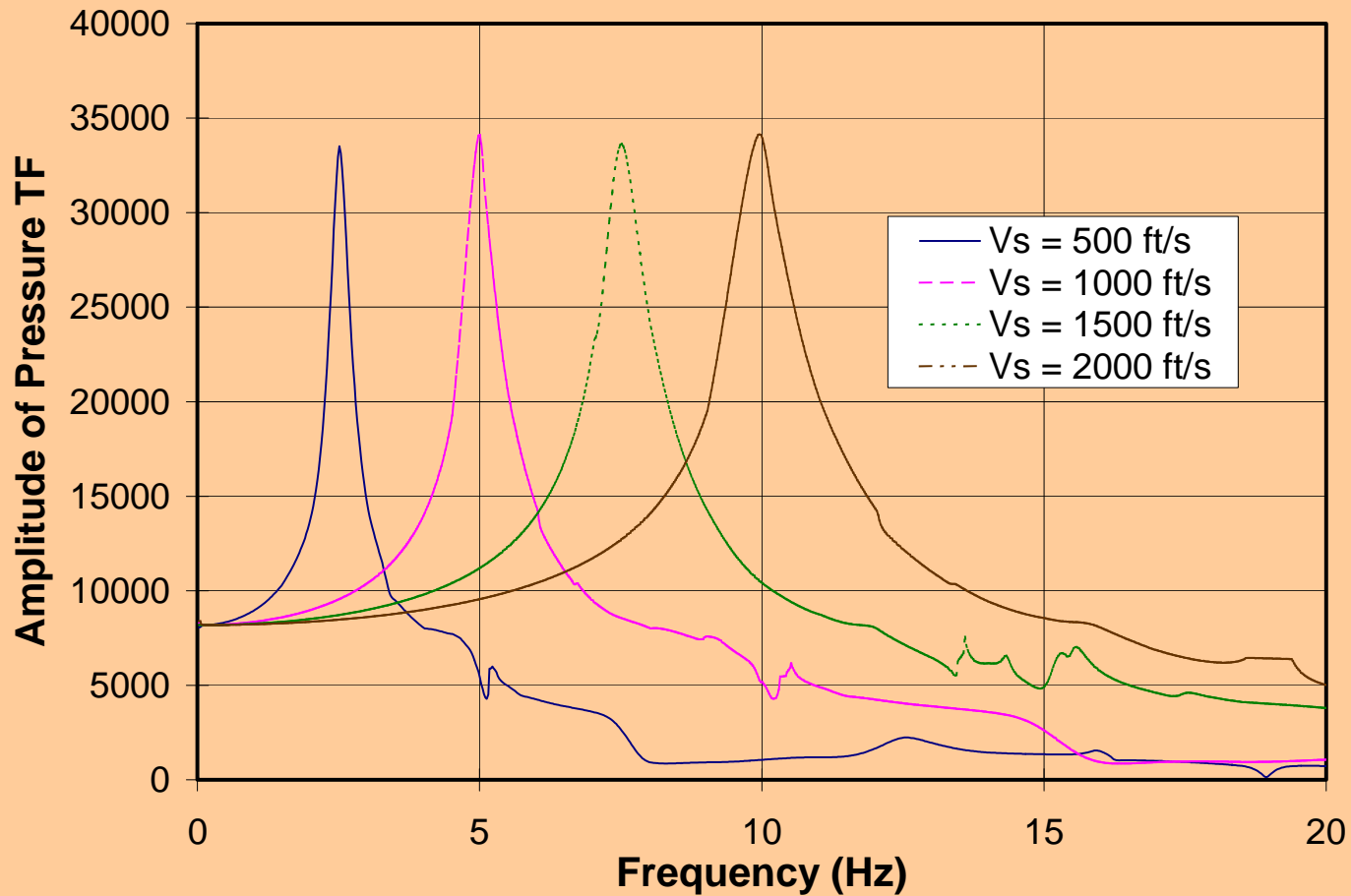


Fig. 1: A Typical SASSI Model of the Foundation

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

## Transfer Functions



# ***Seismic Lateral Earth Pressures***

*(Ostadan and White, 1997)*

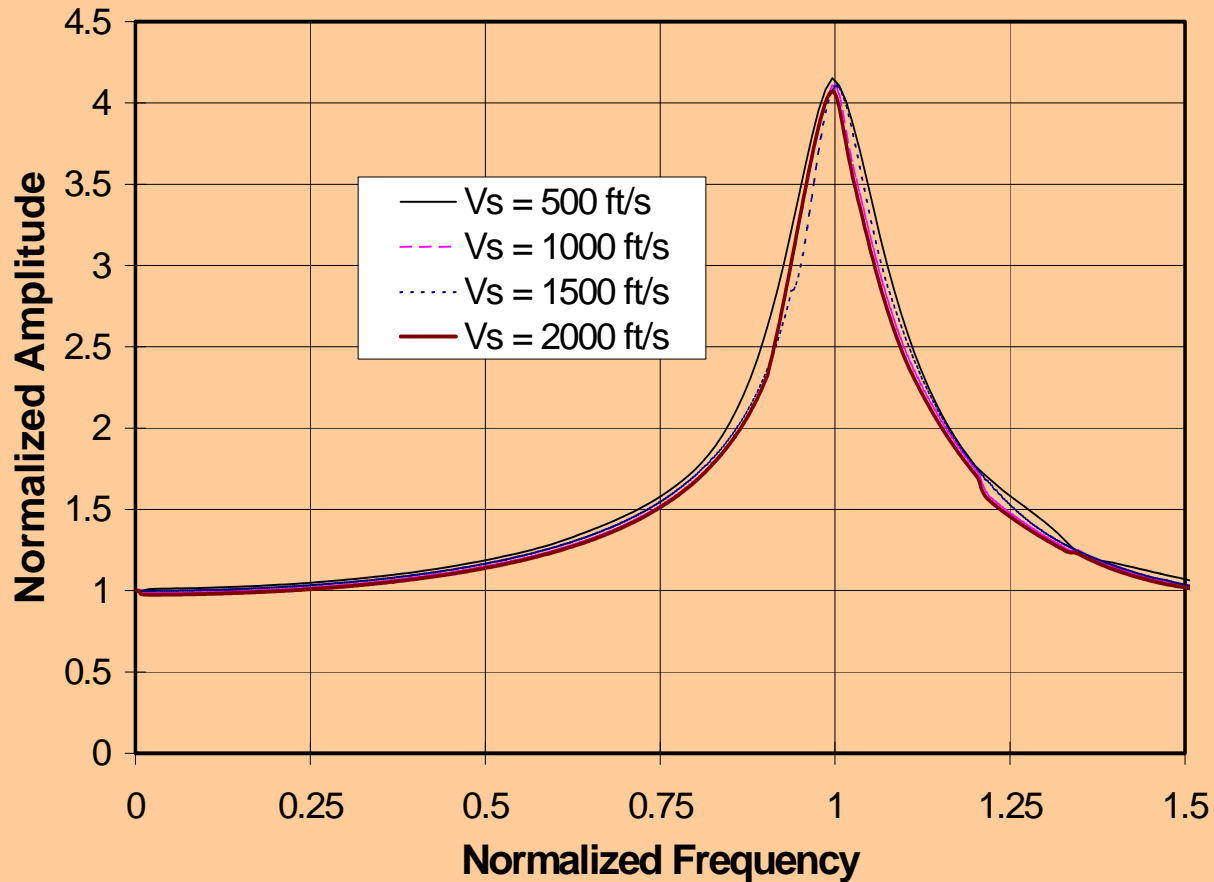
- **Careful examination of dynamic soil pressure response from a SSI solution shows that the pressure response is very similar to the response of a single degree-of-freedom (SDOF) system.**
- **Also, the natural frequency of the results can be normalized by the soil column frequency**

$$f_{\text{soil column}} = V_s / (4 \times H)$$

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

## Normalized Transfer Functions



A/A @ low frequency

(TF) amplitude which is the ratio of the amplitude of the seismic soil pressure to the amplitude of the input motion (1g harmonic acceleration) in the free-field for each

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

## Normalized Pressure Profile

(normalized to max. pressure at surface)

$$p(y) = -.0015 + 5.05y - 15.84y^2 + 28.25y^3 - 24.59y^4 + 8.14y^5 \quad (3)$$

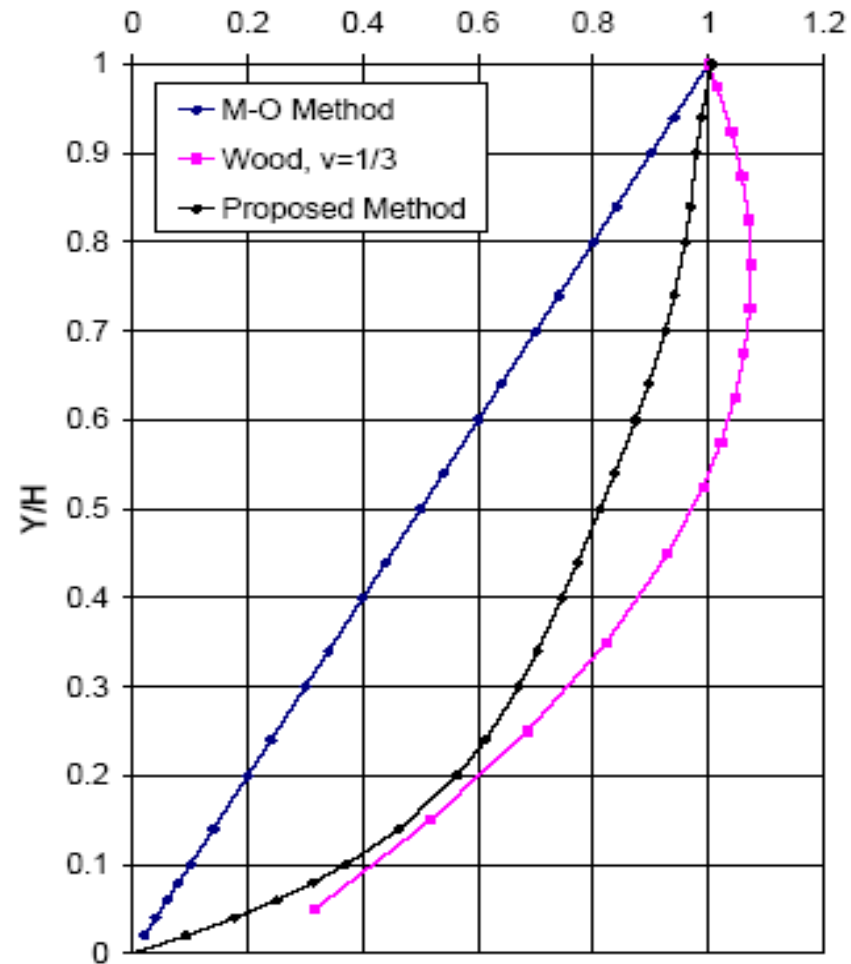


Fig. 4: Comparison of Normalized Pressure Profiles

# ***Seismic Lateral Earth Pressures***

*(Ostadan and White, 1997)*

## **Observations from SSI analyses**

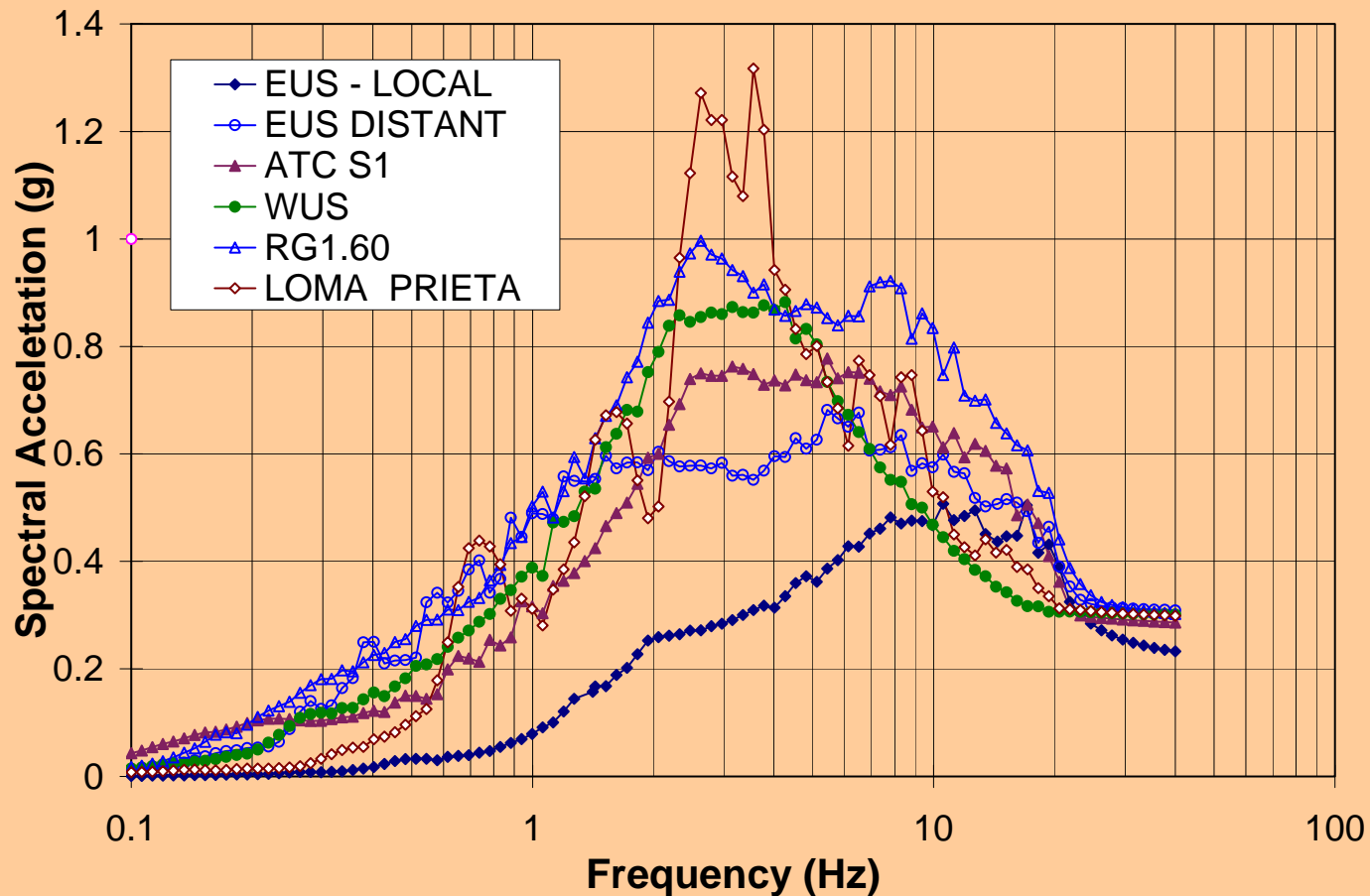
- **Response of system was controlled by stiffness at long period, damping at resonance and inertia at short period, similar to a SDOF system.**
- **The pressure amplitude and its distribution was obtained from the low frequency solution of the response.**



# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

- To estimate the damping and the total force, the soil-wall system was subjected to 6 different input motions.



# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

- The resulting force for each event was computed from the SSI analysis and the associated mass and damping were back calculated.

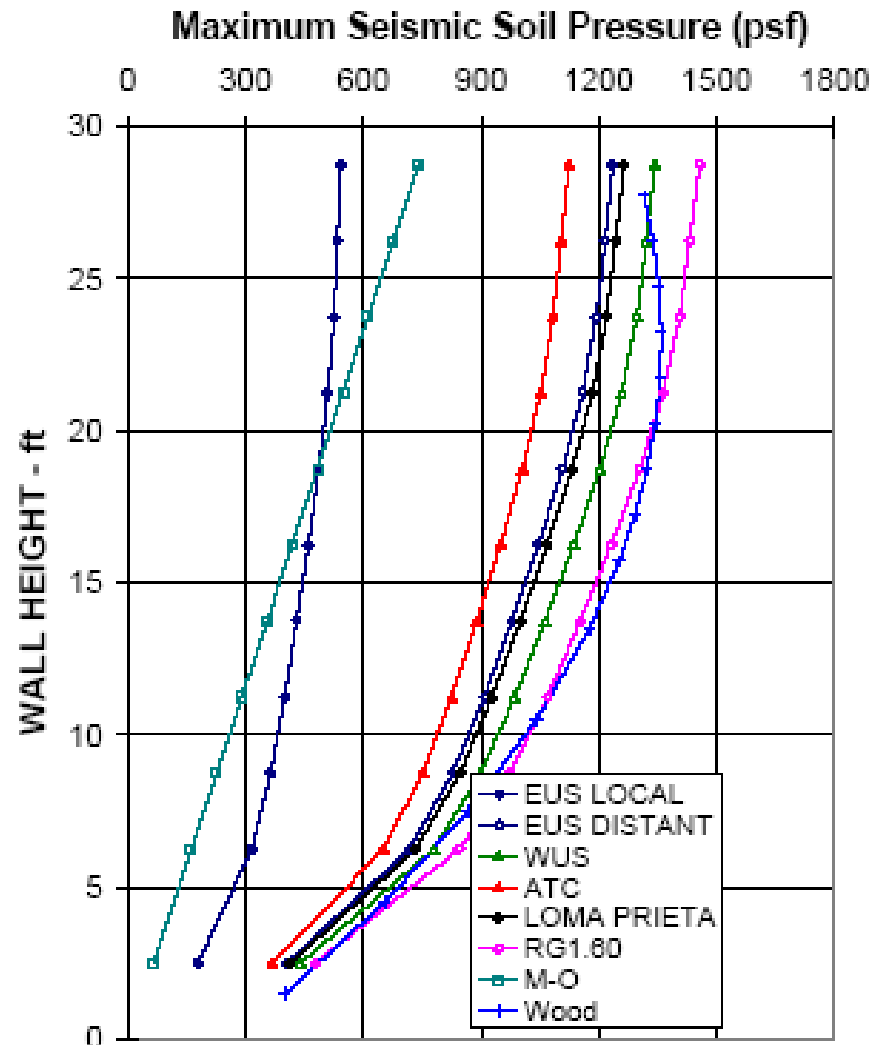
$$m = 0.50 \rho H^2 \Psi_v$$

$$\Psi_v = \frac{2}{\sqrt{(1-\nu)(2-\nu)}}$$

- The maximum amplification of the pressure response is controlled by the radiation damping due to continuity of the soil behind the wall.
- The damping associated with the response is about 30% due to high level of radiation damping.

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)



# ***Seismic Lateral Earth Pressures***

*(Ostadan and White, 1997)*

## **COMPUTATIONAL STEPS**

- 1. Perform seismic ground response analysis (using SHAKE) and obtain the acceleration response spectrum at the basemat level in the free-field at 30% damping.**
- 2. Obtain the total mass using:**

$$m = 0.50 \rho H^2 \Psi_v$$

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

3. Obtain the seismic lateral force by multiplying the mass from Step 2 by the spectral amplitude of the free-field response (Step 1) at the soil column frequency.

$$F = m S a_{\text{free field}} \text{ for } f_{\text{soil}}$$

# Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

4. Calculate the max. lateral earth pressure (ground surface) by dividing the results for step 3 by the area under the normal soil pressure curve (area = 0.744 H)
5. Calculate the lateral pressure distribution verses depth by multiply the max. lateral earth pressure by the  $p(y)$  function below.

$$p(y) = - .0015 + 5.05y - 15.84y^2 + 28.25y^3 \\ - 24.59y^4 + 8.14y^5$$

where  $y$  is the normalized height ( $Y/H$ ) measured from the base of the wall.

# ***Seismic Lateral Earth Pressures***

*(Ostadan and White, 1997)*

- **The method was verified by comparing the results of the simple computational steps with the direct solution from SASSI.**
- **The verification included 4 different wall heights, 6 different input time histories and 4 different soil properties.**
- **The method is very simple and only involves free-field (e.g. SHAKE) analysis and a number of hand computational steps.**
- **The method has been adopted by building code (NEHRP 2000) and will be included in the next version of ASCE 4-98.**
- **The Ostadan-White method is by no means a complete solution to the seismic soil pressure problem. It is merely a step forward at this time.**

# Seismic Lateral Earth Pressures

(Mitigation Strategies)

