Seismic Pressures on Buried and Retaining Walls

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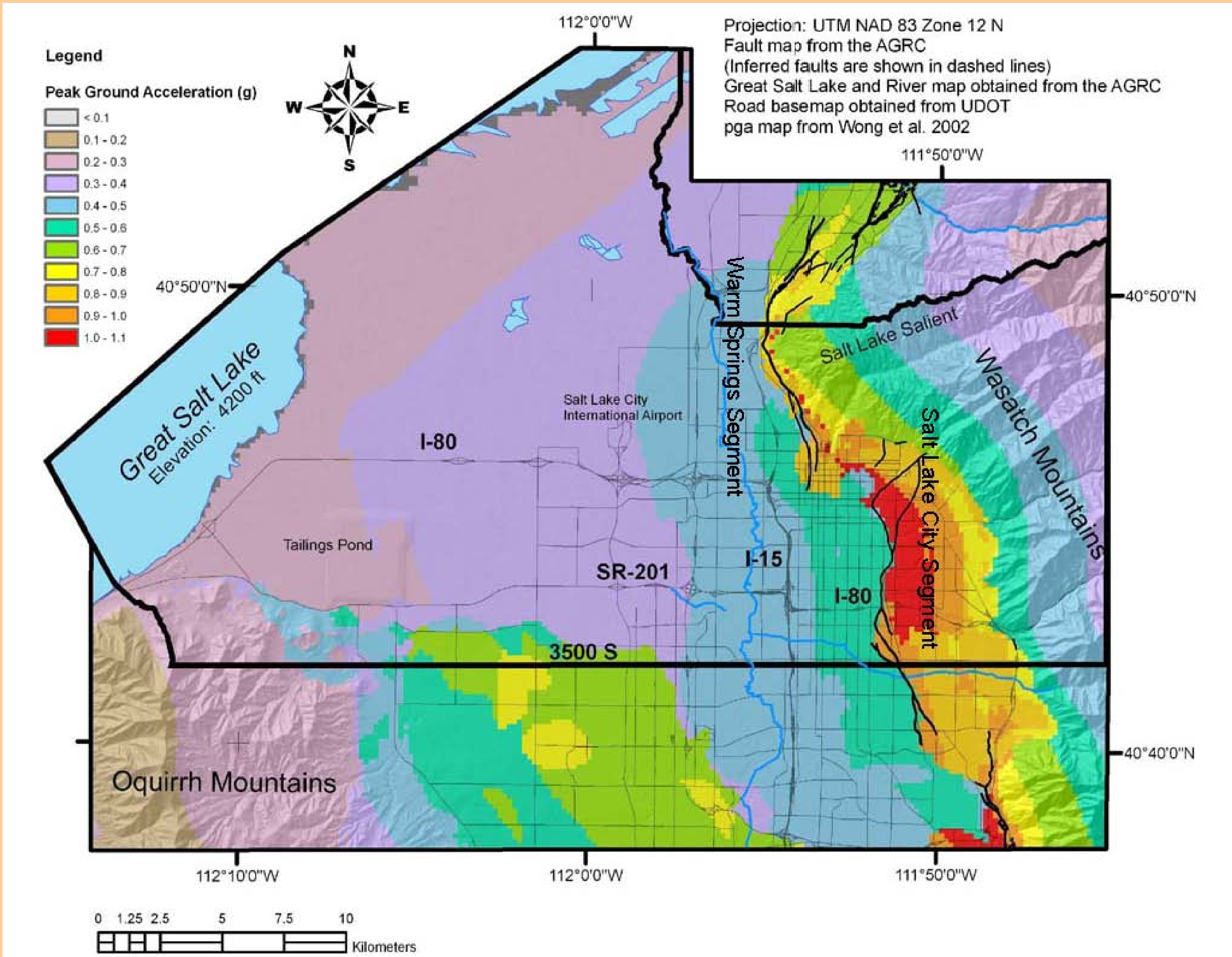
Objectives

- 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.**

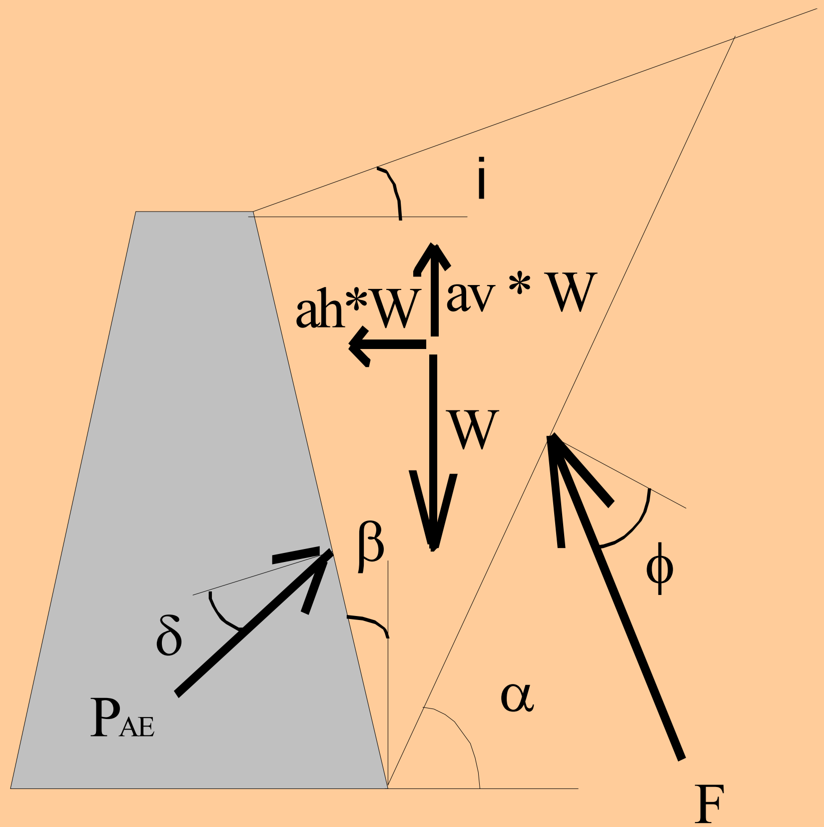
- **The M-O method**
  - **Based on Coulomb's theory of static soil pressure**
  - **Pseudostatic method**
  - **Valid for yielding walls**

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



$$Fh = ah * W$$
$$Fv = av * W$$

M-O Lateral Earth Pressure

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

Static Earth Pressure + Earthquake Pressure

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

Height of Resultant Force (h)

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

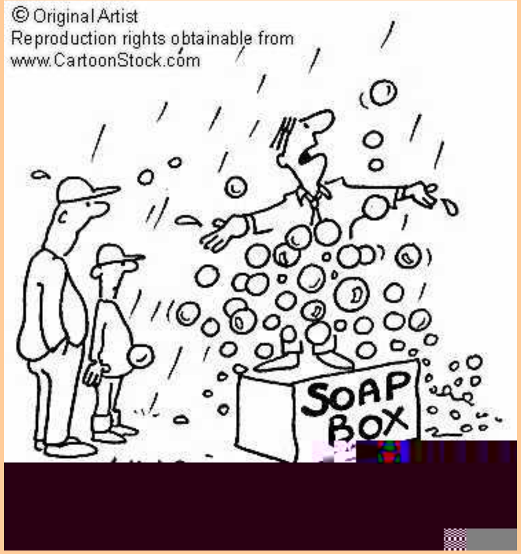
M-O Seismic Earth Pressure Coefficient

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.**

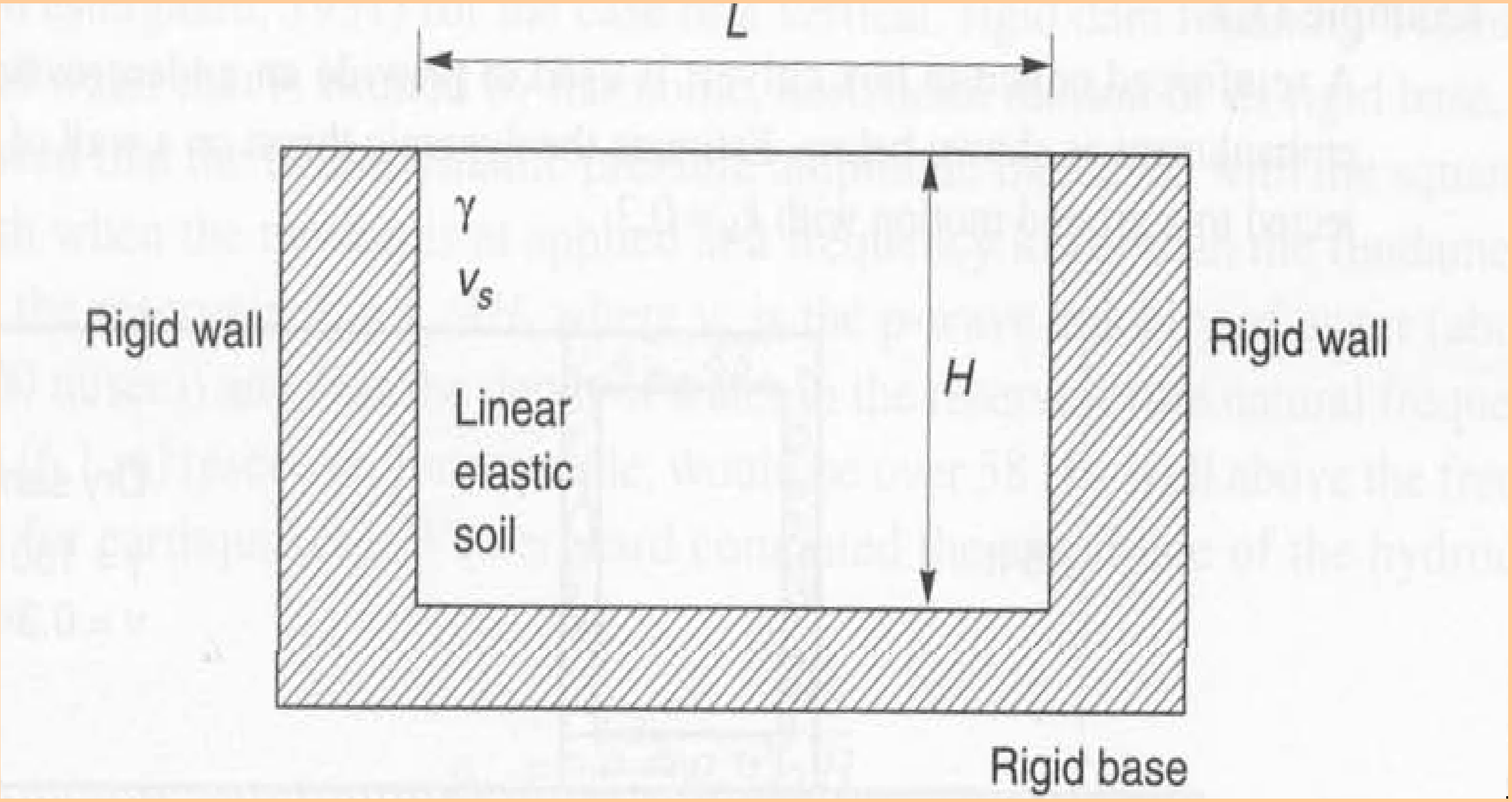


Seismic Lateral Earth Pressures
(Wood, 1973)

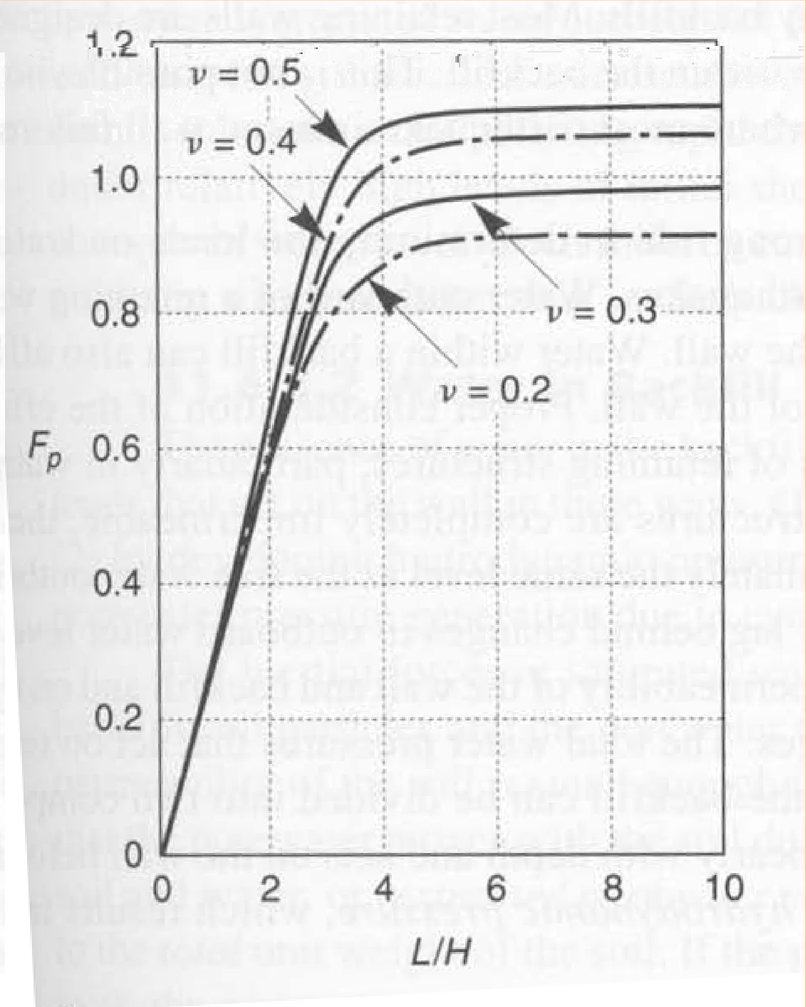
- **Wood developed a finite element solution for a non-yielding wall.**
- **While the solution is based on dynamic modal analysis (hence dynamic), the solution used in practice is a static solution based on horizontal body force of 1g acceleration.**
- **Need to know PGA, Poisson's ratio and density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

Seismic Lateral Earth Pressures

(Wood, 1973)



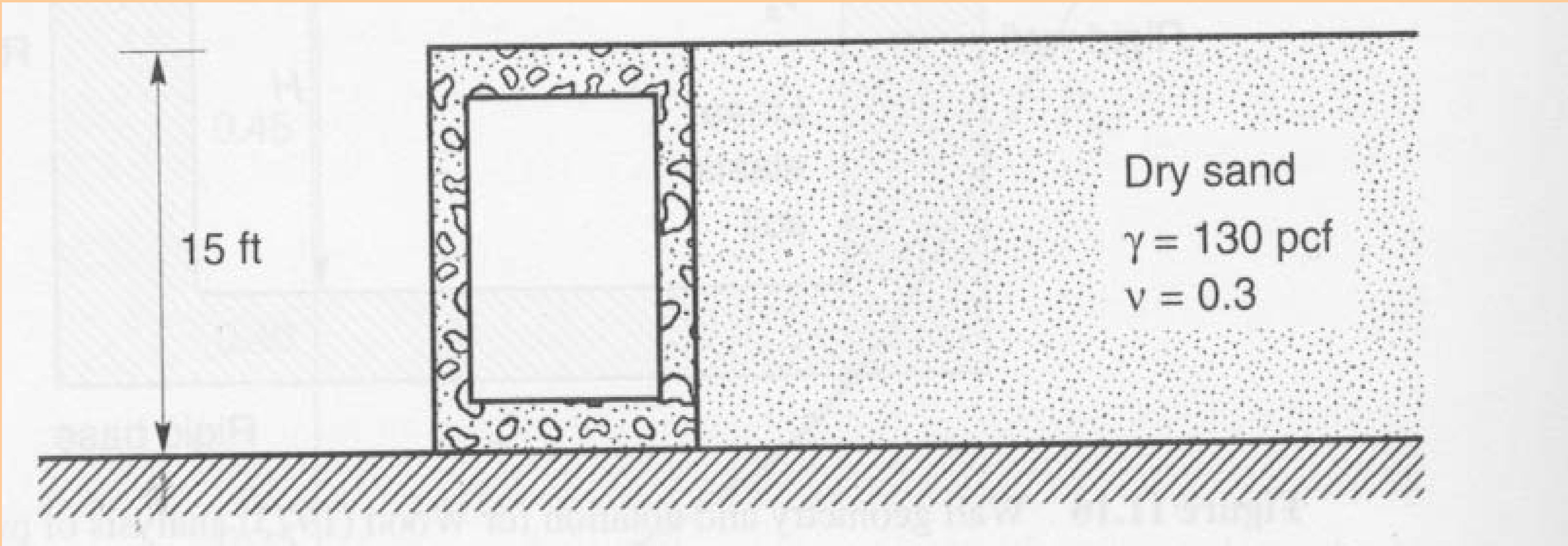
Seismic Lateral Earth Pressures
(Wood, 1973)



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

Seismic Lateral Earth Pressures

(Wood, 1973)



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

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).**

Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

THE UNIVERSITY OF UTAH

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)

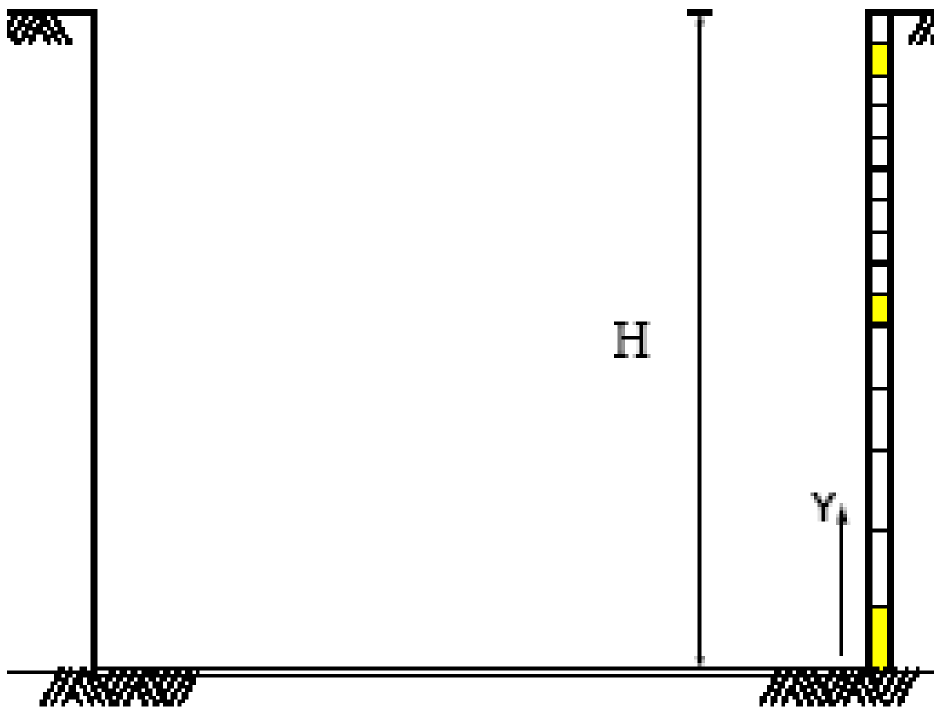
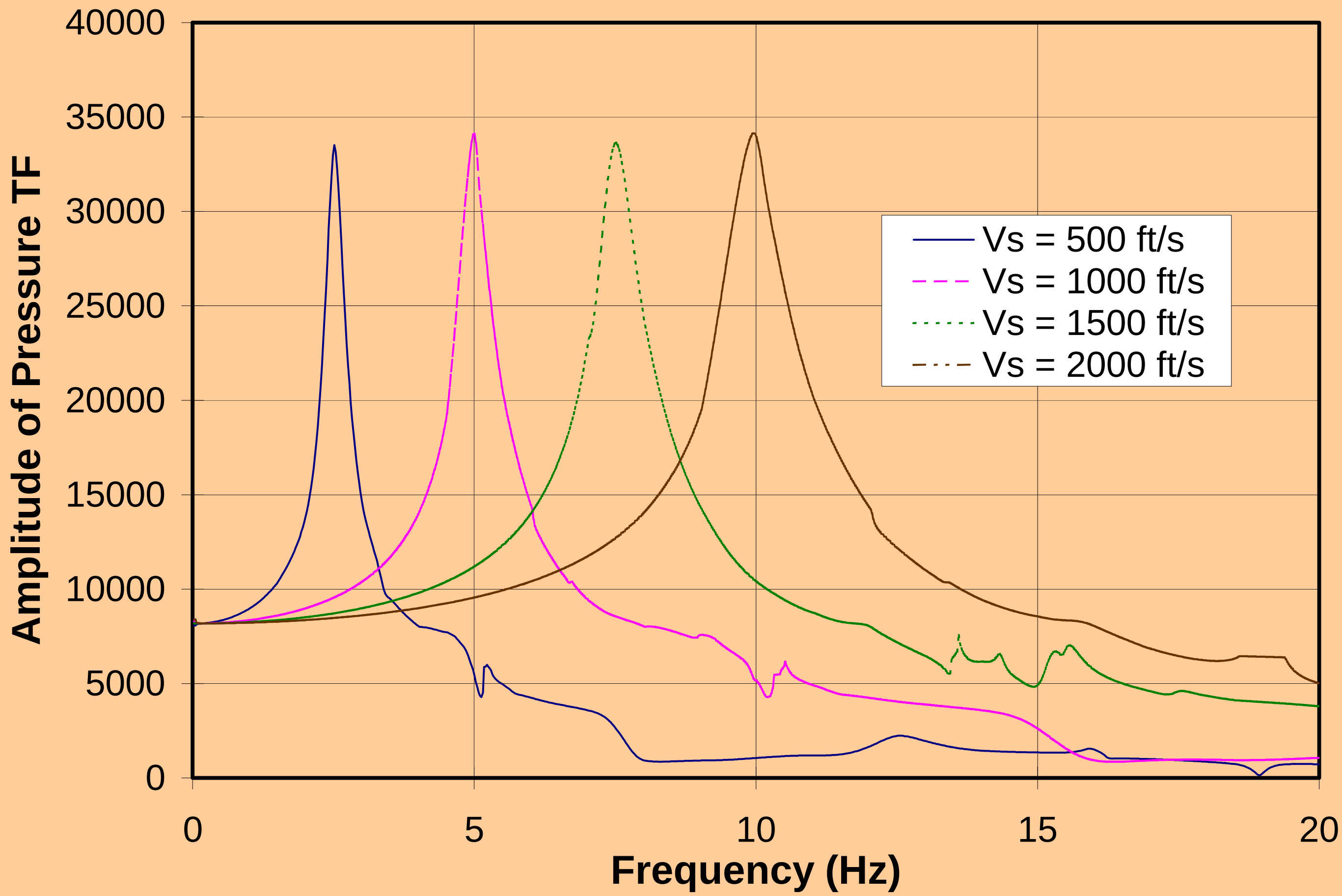


Fig. 1: A Typical SASSI Model of the Foundation

Seismic Lateral Earth Pressures
(Ostadan and White, 1997)

Transfer Functions



Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

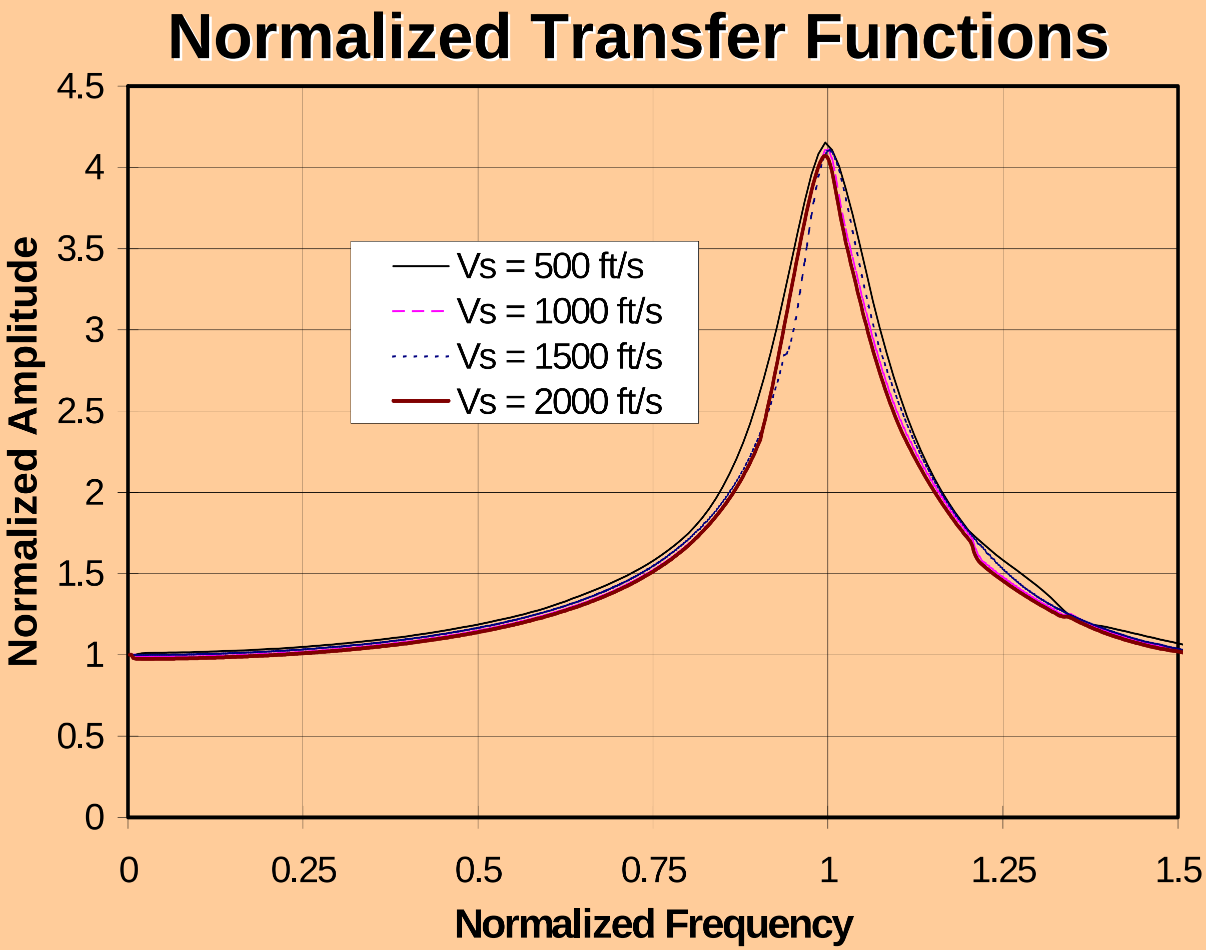
- **Careful examination of dynamic soil pressure response from a SSI solution shows that the pressure response is very similar to the response of a single degree-of-freedom (SDOF) system.**

- **Also, the natural frequency of the results can be normalized by the soil column frequency**

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

Seismic Lateral Earth Pressures

(Ostadan and White, 1997)



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)

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

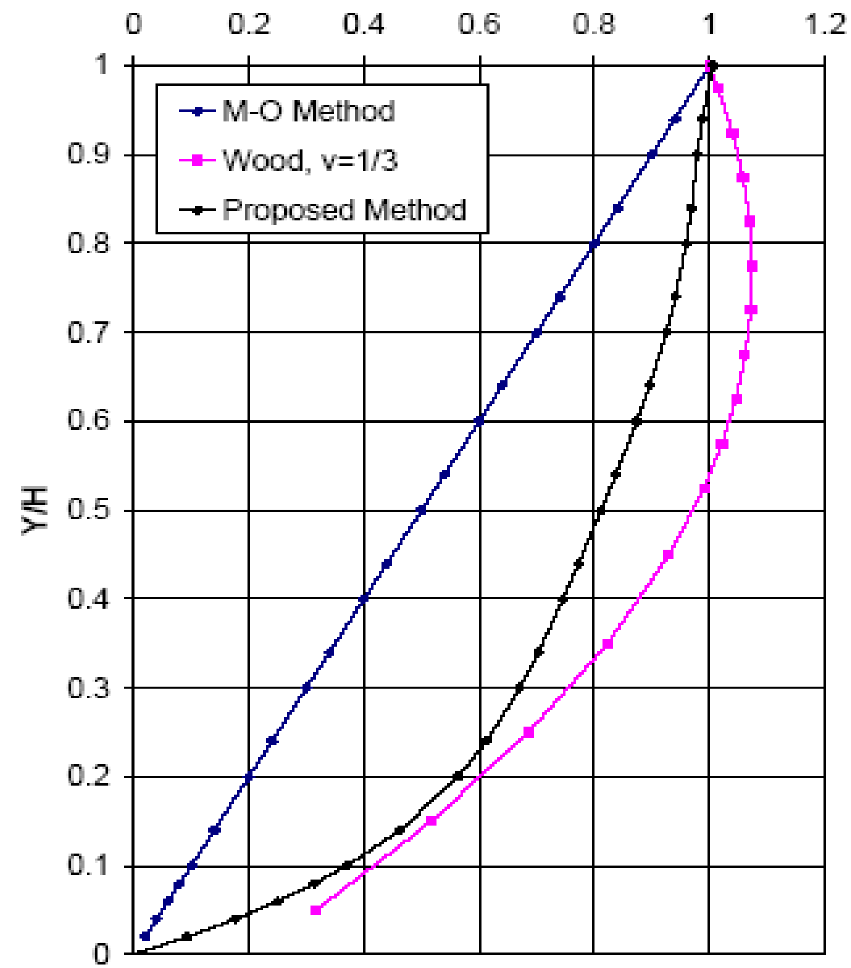


Fig. 4: Comparison of Normalized Pressure Profiles

Seismic Lateral Earth Pressures

(Ostadan and White, 1997)

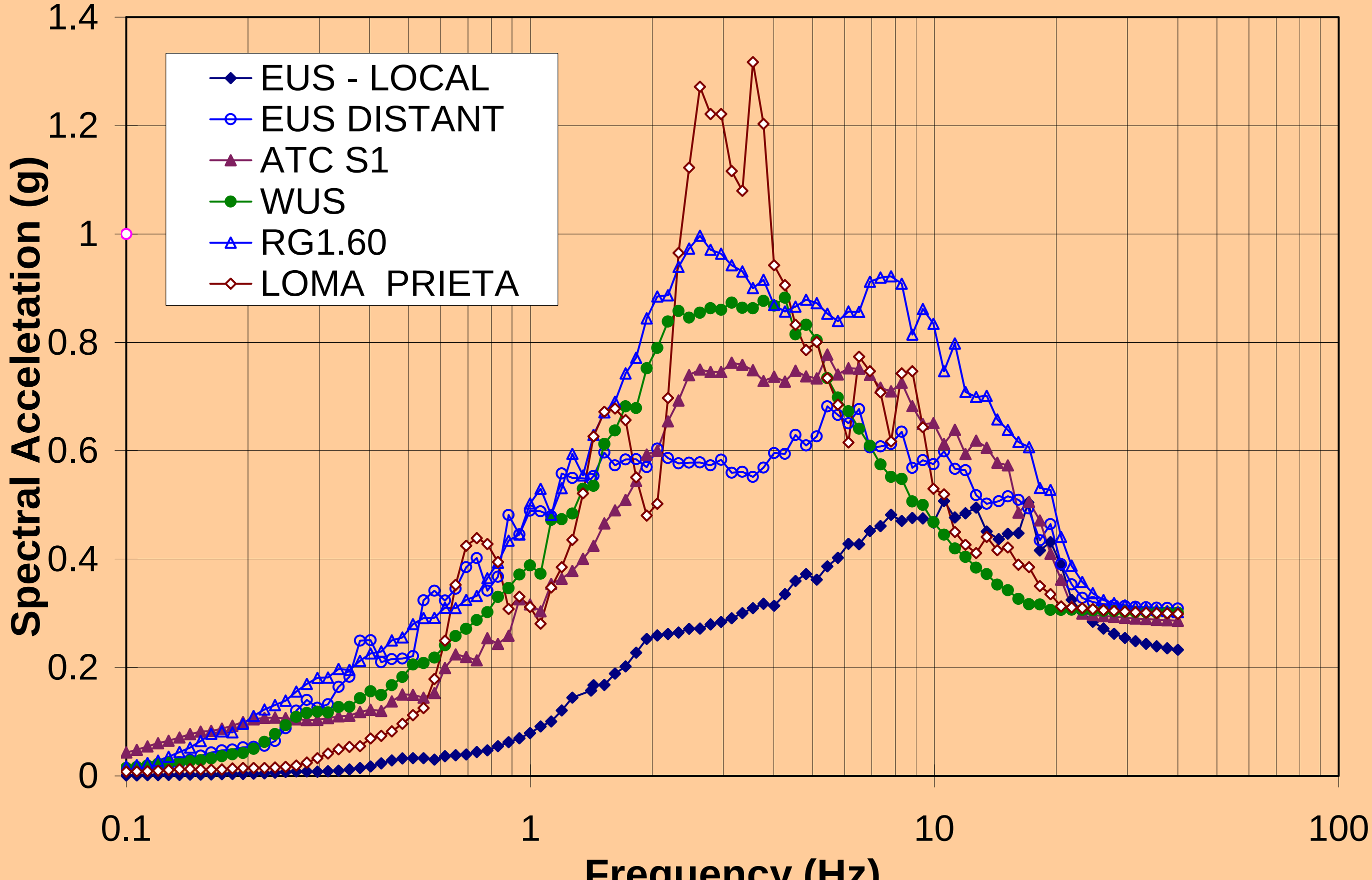
Observations from SSI analyses

- **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)

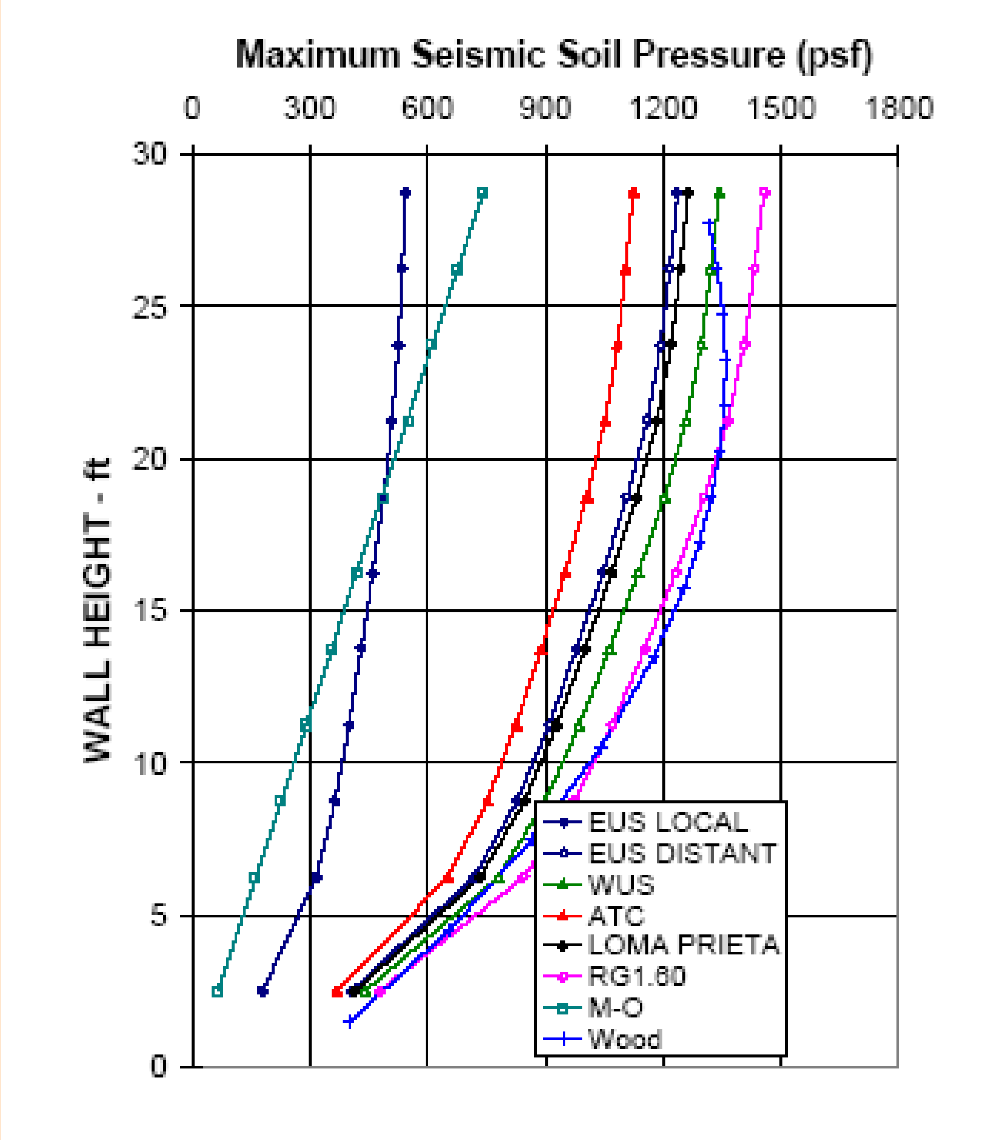
- The resulting force for each event was computed from the SSI analysis and the associated mass and damping were back calculated.

$$m = 0.50\ \rho\ H^2\ \Psi_\nu$$

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

- 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:**

$$m = 0.50\, \rho\, H^2\, \Psi_\nu$$

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.

$$F = m\,Sa_{\text{free field}} \text{ for } f_{soil}$$

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)