AGU Annual Meeting, December 12, 2006,
Special Session S05 - Rotational Motions in Seismology

Rotational Ground Motions Radiated by Vibrating Structures

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Why are rotations important for Engineering?

- Represent **excitation** of structures **additional** to the three translations, which
  - contributes to the dynamic forces in their members, and
  - may lead to failure due to dynamic instability (when coupled with the gravity force).

Why else are rotations important?

- Represent **descriptors** of the response of a structure necessary for a complete description of their motion (motion at a point is completely described by 6 DOF).

- Rotations in structures can be large during strong earthquake shaking, when both the supporting soil and the structure undergo large deformations.

Why do we need to record rotations in structures?

- In absence of direct recordings, rotations in structures are estimated from recorded translations by pairs of sensors at a distance.
- But this is based on the assumption that the common support of the sensors (foundation mat or floor slabs) does not deform, which is just an idealization.
- The recordings of translation are contaminated by the rotational motions of the support of the sensors. Recording rotations independently is needed to correct the recordings of translations to get the “true” translations.

Why do we need to record rotations in structures? (cont.)

- Recording rotations independently can help measure the deformations of flexible foundation mats and floor slabs, and examine under which conditions the estimates of rotations from pairs of sensors are satisfactory for a particular problem.

Task force on Engineering Applications and Strong Ground Motion

Suggested priorities by Chair: Misha Trifunac

1. Prepare guidelines and recommendations for how and where to record rotational strong motions.
2. Promote establishment of several full-scale laboratories for measurement of rotational strong motions in buildings and on bridges, dams, and lifelines, as well as in the free field (near and far).
3. Develop data processing methods for processing 6DOF strong-motion records.
4. Develop software for synthetic generation of realistic rotational accelerograms, to facilitate engineering studies of the associated structural response.

Ground motions affect a structure by exciting it to vibrate.

Q: Does a structure influence the motion of the ground and how does that happen?

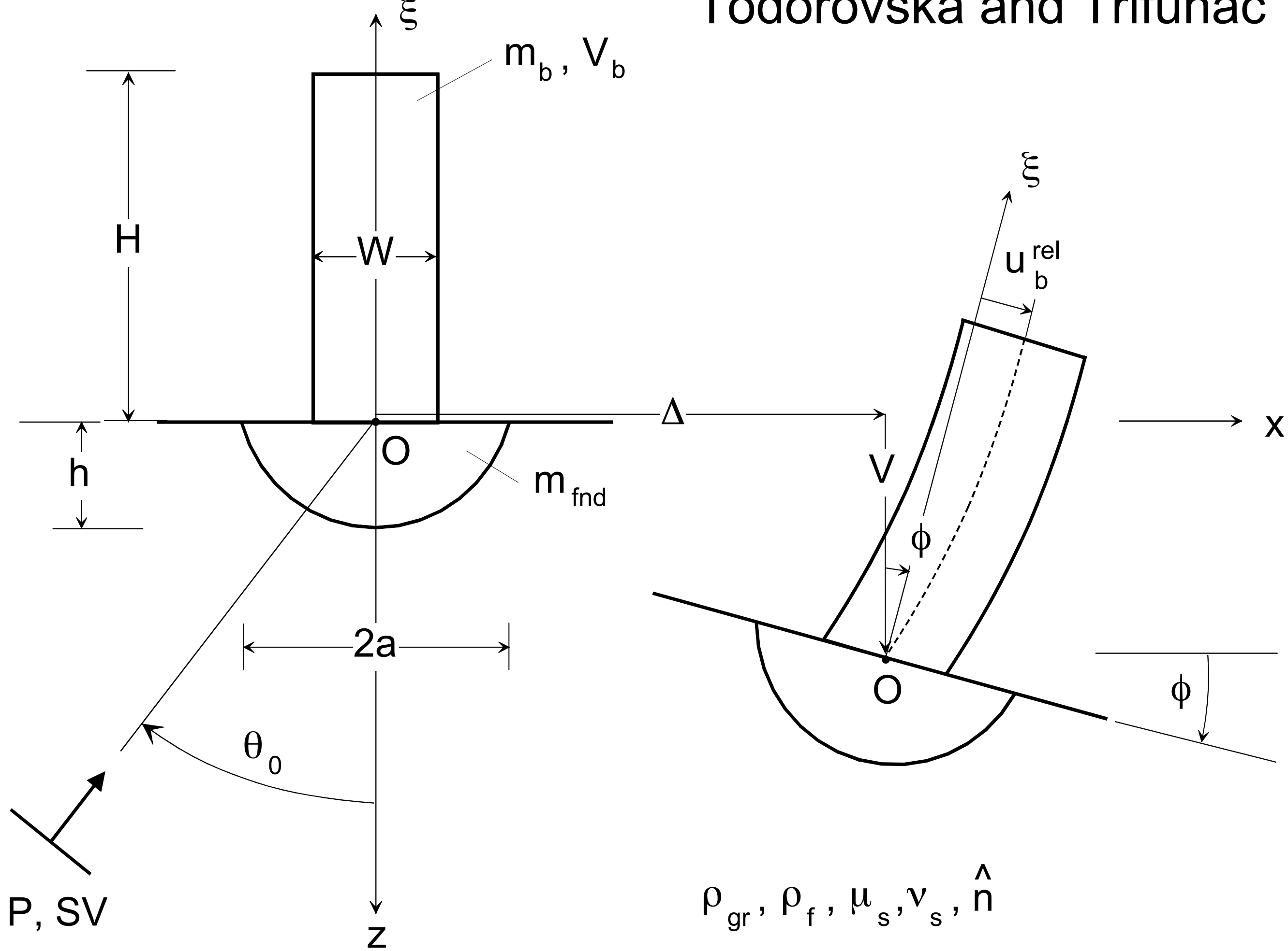
A: Yes. Vibrating structures act as sources of vibrations. The mechanism is **soil-structure interaction.**

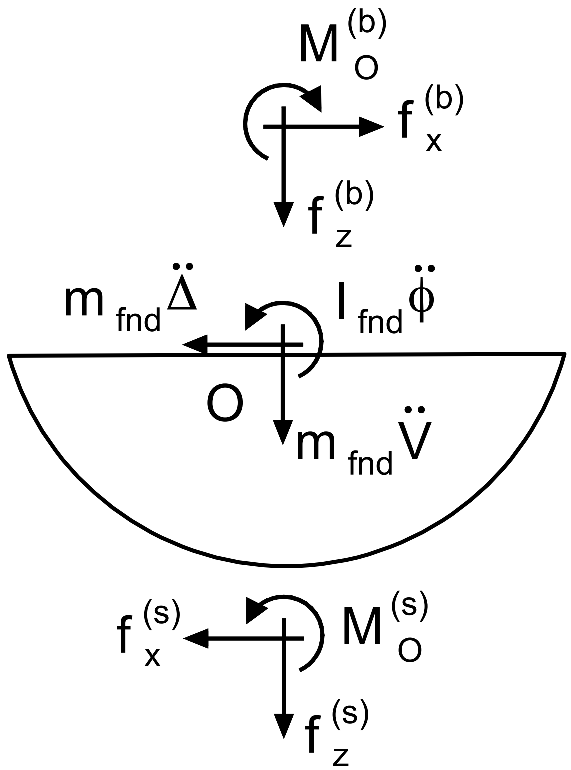
Soil-structure interaction:

- **Dynamic** soil-structure interaction - is a phenomenon that occurs when the soil supporting the structure is flexible and deforms when subjected to **feedback forces** from the vibrating structure.
- **Kinematic** soil-structure interaction refers to modification of the free-field motion due to **scattering** of incident waves from the excavation in the soil where the foundation is embedded.
- Roots: Sezawa and Kanai (1935, 1936); Biot (1940s).

Model

Todorovska and Al Rjoub 2006a,b
Todorovska and Trifunac 1990





Substructure method:

$$\mathbf{F}^{(s)} = \mathbf{F}^{(s)}_{\text{driv}} + 2\mu\left[K^{(s)}\right]\mathbf{\Delta}$$

$$\mathbf{F}^{(b)} = m_b\omega^2\left[M_b\right]\mathbf{\Delta}$$

$$\omega^2 m_{\text{fnd}}\left[M_{\text{fnd}}\right]\mathbf{\Delta} - \mathbf{F}^{(\text{s})}_{\text{driv}} - 2\mu\left[K^{(s)}\right]\mathbf{\Delta} + \omega^2 m_{\text{b}}\left[M_{\text{b}}\right]\mathbf{\Delta} = \mathbf{0}$$

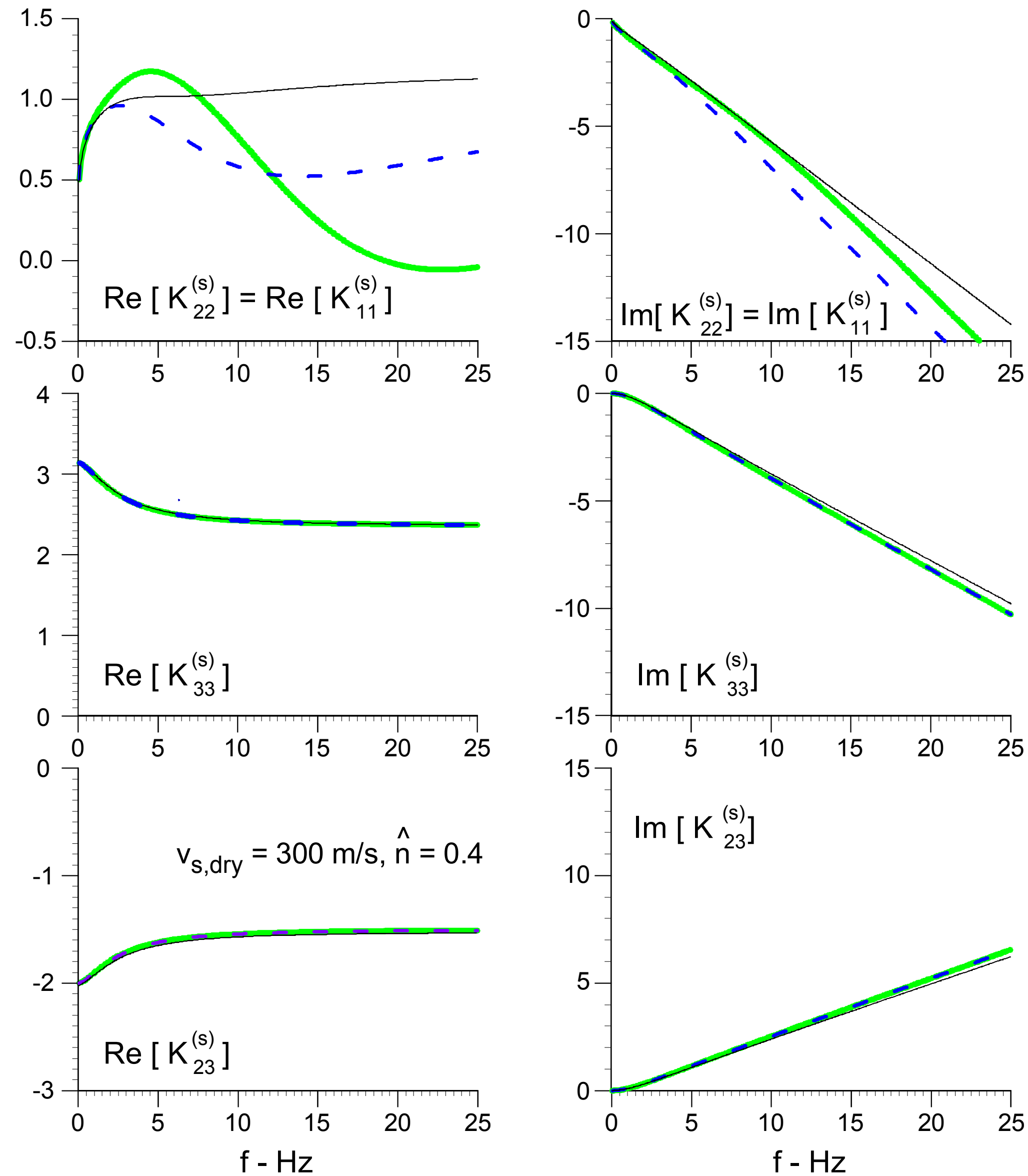
$$\mathbf{\Delta} = \left[\frac{\omega^2 m_{\text{fnd}}}{2\mu}\left[M_{\text{fnd}}\right] + \frac{\omega^2 m_{\text{b}}}{2\mu}\left[M_{\text{b}}\right] - \left[K^{(s)}\right]\right]^{-1} 2\mu\ \mathbf{F}^{(\text{s})}_{\text{driv}}$$

Example:

Real part
(foundation stiffness):

Imaginary part
("radiation" damping):

foundation stiffness matrix



$f_1 = 2.5$ Hz

$v_{s,dry} = 300$ m/s

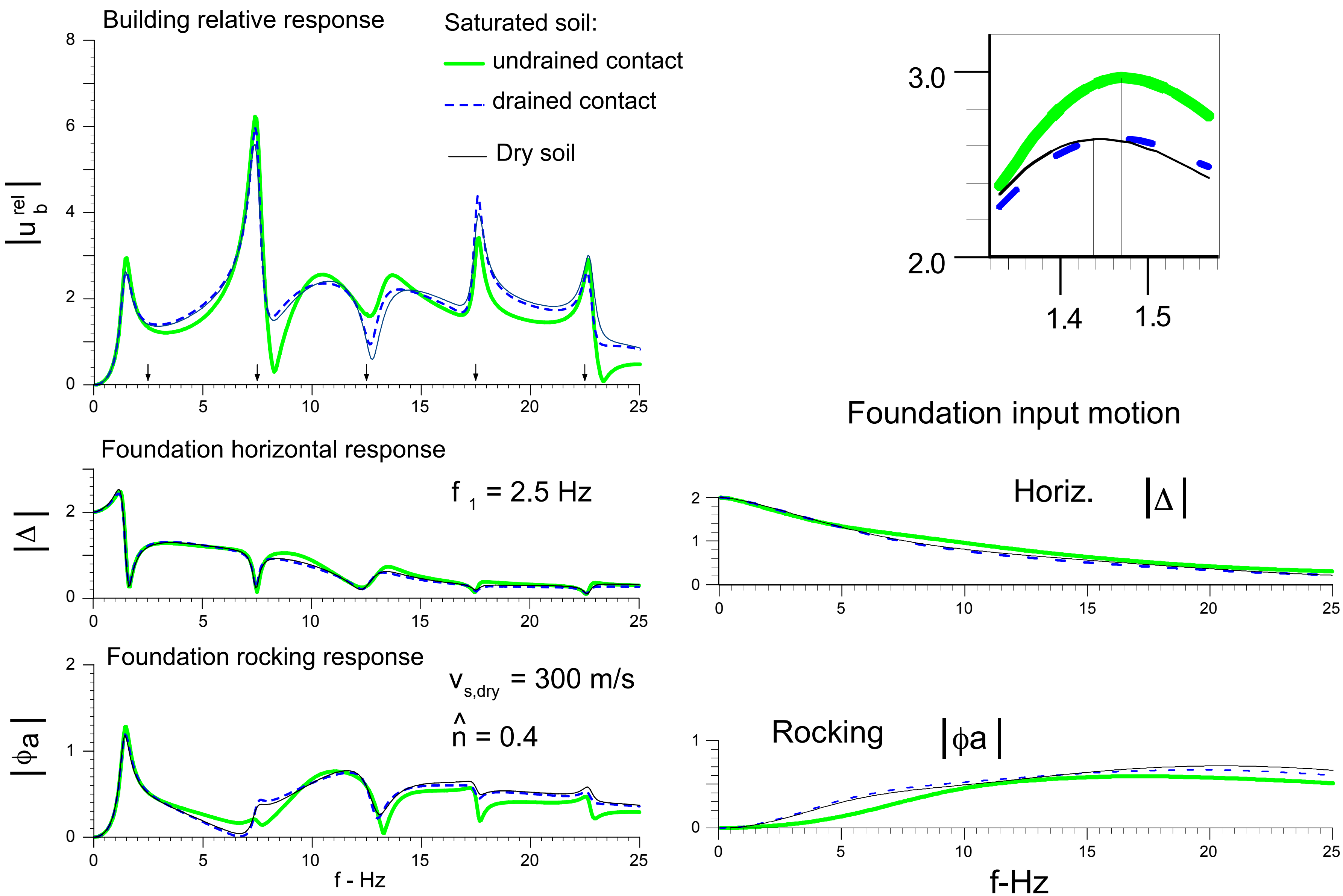
$\hat{n} = 0.4$

Saturated soil:

undrained contact

drained contact

Dry soil


Building relative response
Saturated soil:
undrained contact
drained contact
Dry soil
$|u_b^{rel}|$
Foundation horizontal response
f_1 = 2.5 Hz
$|\Delta|$
Foundation rocking response
$v_{s,dry}$ = 300 m/s
$\hat{n}$ = 0.4
$|\phi a|$
f - Hz
Foundation input motion
Horiz.
Rocking
f-Hz
1.4
1.5
3.0
2.0

Some concepts:

- **Free-field motion**: motion of the soil if the structure is not there.
- **Foundation input motion**: motion of the excavation. Represents the free-field motion modified by the scattering of the incident waves from the foundation. It represents the "true" input motion exciting the structure.
- **Foundation motion**: differs from the input motion because of additional motion due to feedback forces from the building.

Some facts concerning buildings as sources of rotational vibrations:

- Even perfectly symmetric structures (i.e. without eccentricities) are excited by torsion and rocking due to the rotational components of the foundation input motion.
- The foundation input motion can have rotational components even when the free-field motion does not. This is due to the wave passage (the incident motion arrives with different phase at different points along the contact between the soil and the foundation, which creates moments).
- The foundation stiffness matrix is coupled.
- Horizontal force applied on the building will result in foundation rotation.

Implications:

- Buildings, trees, geologic formations etc. excited to vibrate by wind, e.g., or other ambient noise, act as sources of rotational waves in the ground (about 0.1 – 10 Hz for buildings 1-50 stories high).
- A building excited by a shaker can serve as a source of monochromatic rotational waves.
- Experiments: Luco et al. 1975, Foutch eta al. 1975, Favela 2004.

References:

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- Todorovska, M.I. & Y. Al Rjoub (2006). Plain strain soil-structure interaction model for a building supported by a circular foundation embedded in a poroelastic half-space, Soil Dynamics and Earthquake Engrg, 26(6-7), 694-707. (Special issue on Biot Centennial – Earthquake Engineering).
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