



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 32: Effects of Soil-Structure Interaction

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ERD of Foundations - Modules

1. Introduction
2. Shallow Foundations
3. Pile Foundations
4. Well Foundations
5. SSI for Deep Foundations
6. Miscellaneous

Module - 5

SSI for Deep Foundations



Module - 5: Chapters

1. Introduction to Soil-Structure Interaction
2. Effects of Soil-Structure Interaction
3. SGM and Wave Propagation
4. Ground Response Analysis
5. Soil-Pile Interaction

Chapter -1: Major Effects of SSI

- 1. Major Effects of Dynamic SSI**
- 2. SSI Systems: Direct and Substructure Methods**
- 3. Beneficial Effects of SSI**
- 4. Impedance Functions**

Schematic Effects of Presence of Soft Soil

Control Motion + Effect of Soil



Modified Free-Field Motion
+ Effect of Base (e.g. Foundation)

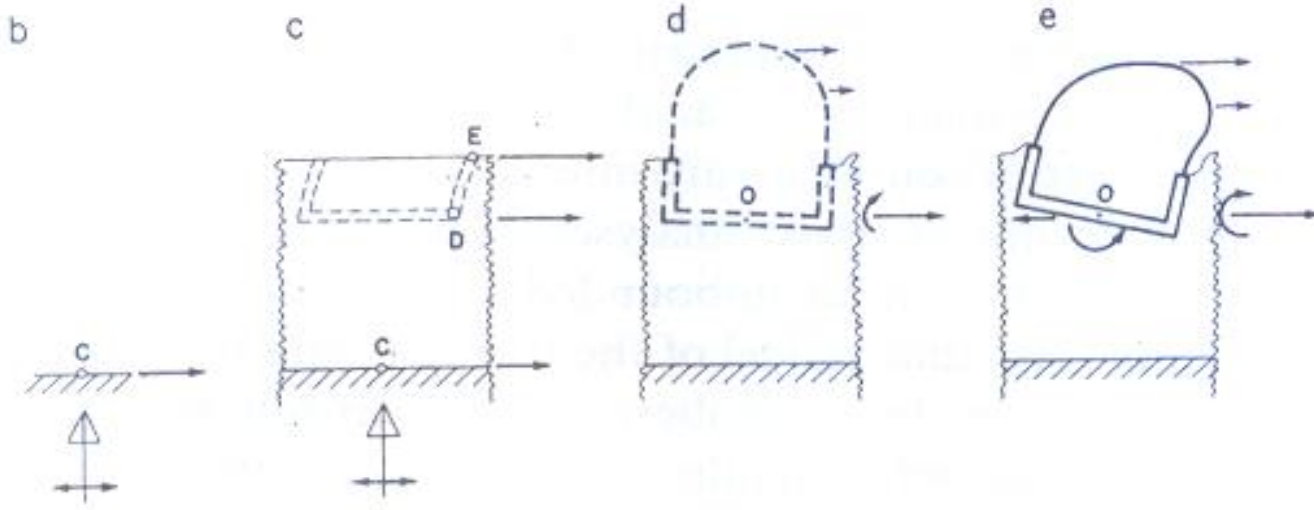


Kinematic Interaction (K.I.)
+ Effect of Structure (e.g. Structure)



Inertial Interaction (I.I.)

Effects of SSI - Structures on Soft Soil



Seismic response of structure founded on soft soil
(b) Outcropping rock; (c) Free field response;
(d) Kinematic interaction; (e) Inertial interaction

Major Effects of Dynamic SSI

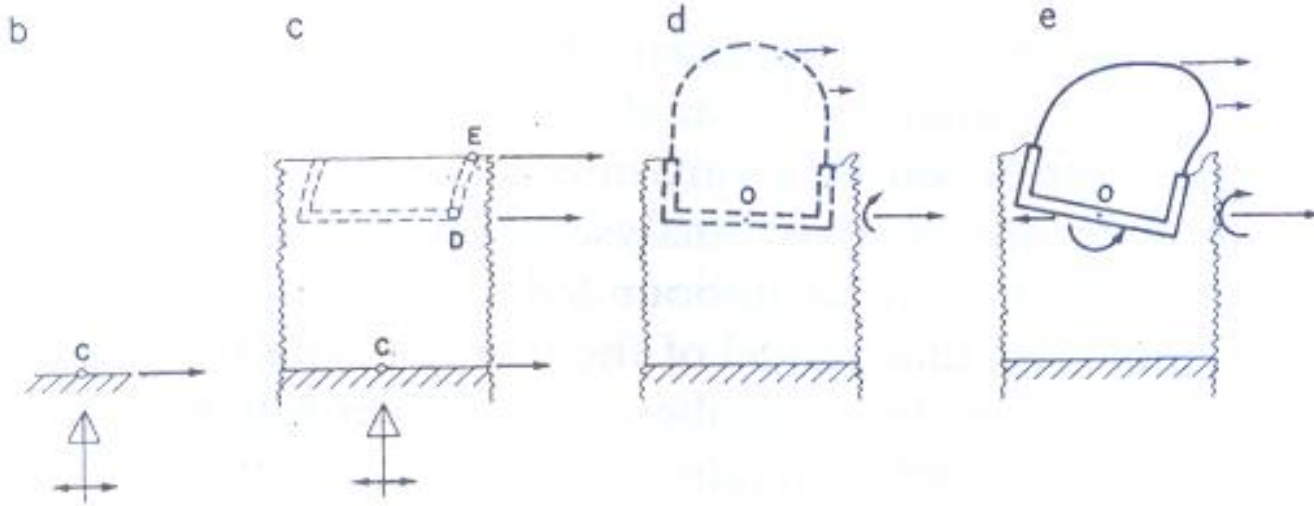
First, the seismic-input motion acting on the structure-soil system will change (Fig. 2d). Because of the amplification of the site (free-field response), the translational component will in many cases be larger than the control motion and, in addition, a significant rocking component will arise for an embedded structure. Each frequency component of the motion is affected differently, resulting in, for example, an acceleration time history, which is quite different from the control motion. This amplification of the seismic motion is held responsible for the fact that structures founded on a deep soft-soil site have been damaged more severely in actual earthquakes than have neighboring structures founded on rock.

Second, the presence of the soil in the final dynamic model (Fig. 2e) will make the system more flexible, decreasing the fundamental frequency to a value which will, in general, be significantly below that applicable for the fixed-base structure. The implication of this reduction will depend on the frequency content of the seismic-input motion. In certain cases, the fundamental frequency will be moved below the range of high seismic excitation, resulting in a significantly smaller seismic input "felt" by the structure.

Major Effects of Dynamic SSI

Third, the radiation of energy of the propagating waves away from the structure will result in an increase of the damping of the final dynamic system (Fig. 2e). For a soil site approaching an elastic half-space, this increase will be significant, leading to a strongly reduced response. For a soil site consisting of a shallow layer, it is possible that no waves propagate away from the structure. In this case, only the material damping of the soil will act, and no beneficial effect on the seismic response is to be expected. In any soil-structure analysis, it is very important to determine for a specific site whether the loss of energy by radiation of waves can actually take place. It is reasonable to assume that the soil-structure interaction increases the more flexible the soil is and the stiffer the structure is. On the other hand, it will be negligible for a flexible structure founded on firm soil.

Effects of SSI - Structures on Soft Soil



Seismic response of structure founded on soft soil
(b) Outcropping rock; (c) Free field response;
(d) Kinematic interaction; (e) Inertial interaction

Overall Effects of Dynamic SSI

- It is obvious from the many opposing effects that it is, in general, impossible to determine a priori whether the interaction effects will increase the seismic response. However, if the first effect discussed above (the change of the seismic-input motion, Fig. 2d) is neglected when the interaction analysis is performed, the response will in many circumstances be smaller than the fixed-base response obtained from an analysis that neglects all interaction effects.
- For this approximate interaction analysis, the control motion is directly used as input motion in the final dynamic system (Fig. 2e).
- The fixed-base analysis leads to larger values of the global response, as, for example, the total overturning moment and the total transverse shear, and thus to a conservative design.

Overall Effects of Dynamic SSI

- Economic considerations normally dictate that, when designing structures, that reduction in seismic forces which results from considering the approximate soil-structure interaction analysis be used. There are also some exceptional cases where the simplified interaction effects will govern the design.
- It is important to stress that this approximate method of calculating the interaction, a method that neglects the free-field site analysis (Fig. 2c) and the geometric averaging due to the embedment effect is inconsistent.
- For special structures (e.g. nuclear power plants), SSI is always analyzed considering all effects. It is true that taking the flexibility of the underlying soil into account when calculating the seismic response of a structure does complicate the analysis considerably.

Assumed Linearity

SSI: Soil is mostly assumed as a linear. Though Nonlinear Analysis is also possible.

Total Solutions: Sum of the responses of the free field and the interaction part. Therefore, nonlinearity cannot be considered until Direct methods are used.

Interaction: $KI + II$

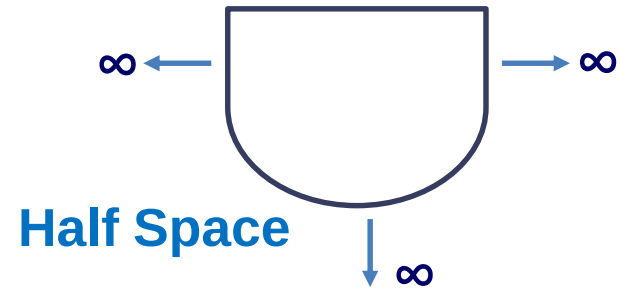
Free Field Motion = Ground Response Analysis (GRA)

SSI Systems

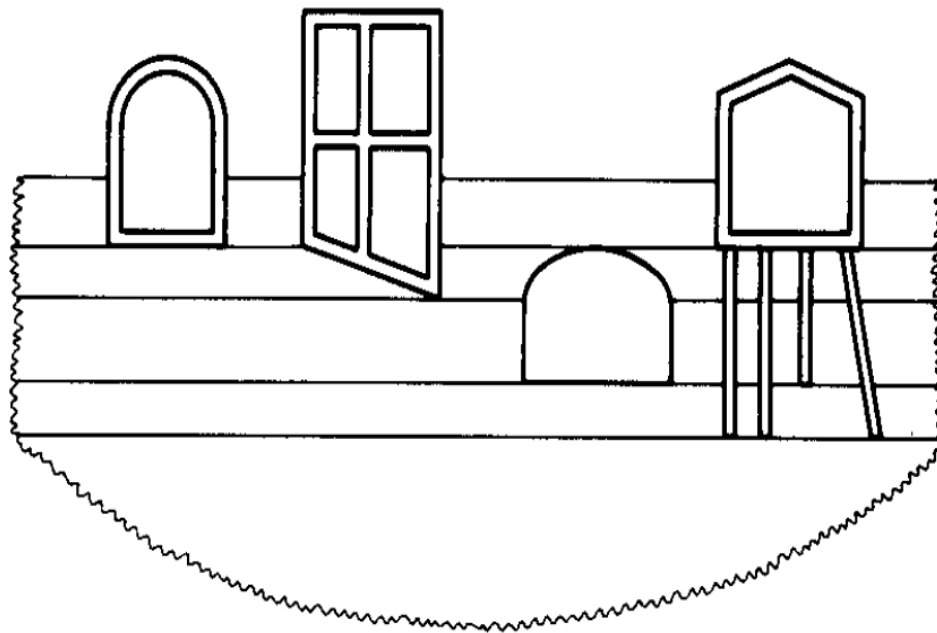
SSI System: The soil consists of horizontal layers resting on a half space.

Both consisting of isotropic viso-elastic material with hysteretic damping.

The properties may vary with the depth but remain constant within the individual layers. The structure can be embedded inside the soil.



SSI Systems



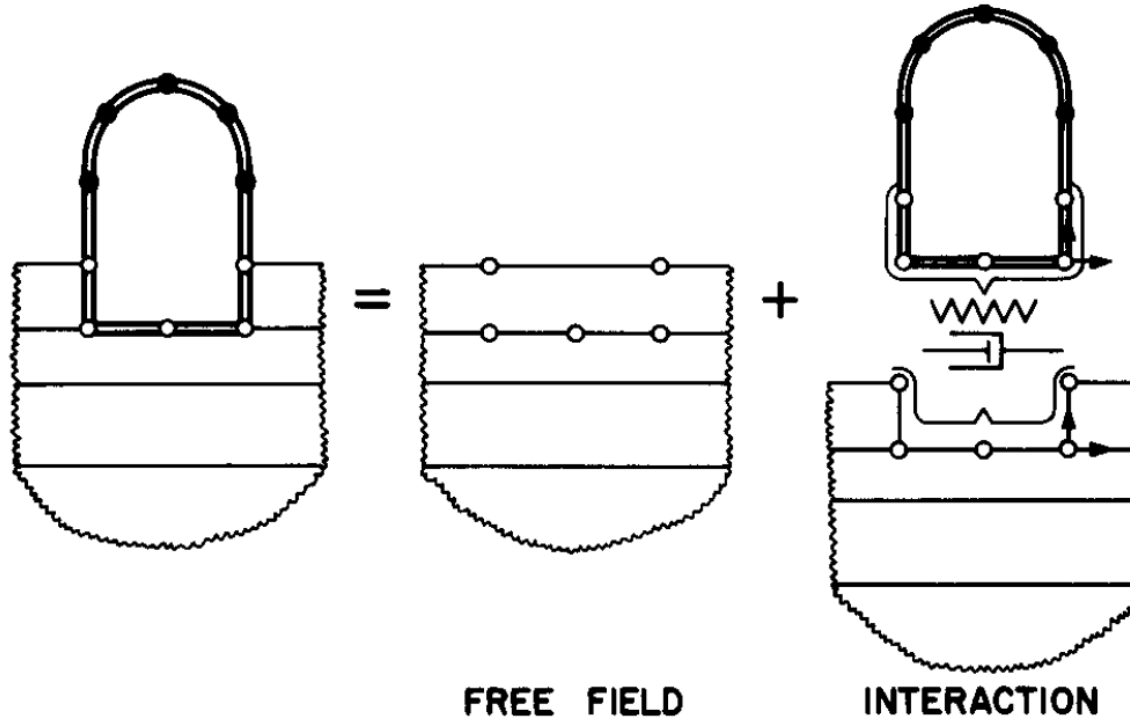
Direct & Substructure Methods

Direct Method: The FFM is applied at the fictitious boundary at some distance from structure. Both soil and structure are considered together. Advantage: Nonlinearity of the soil can be considered.

Substructure Method: Two systems

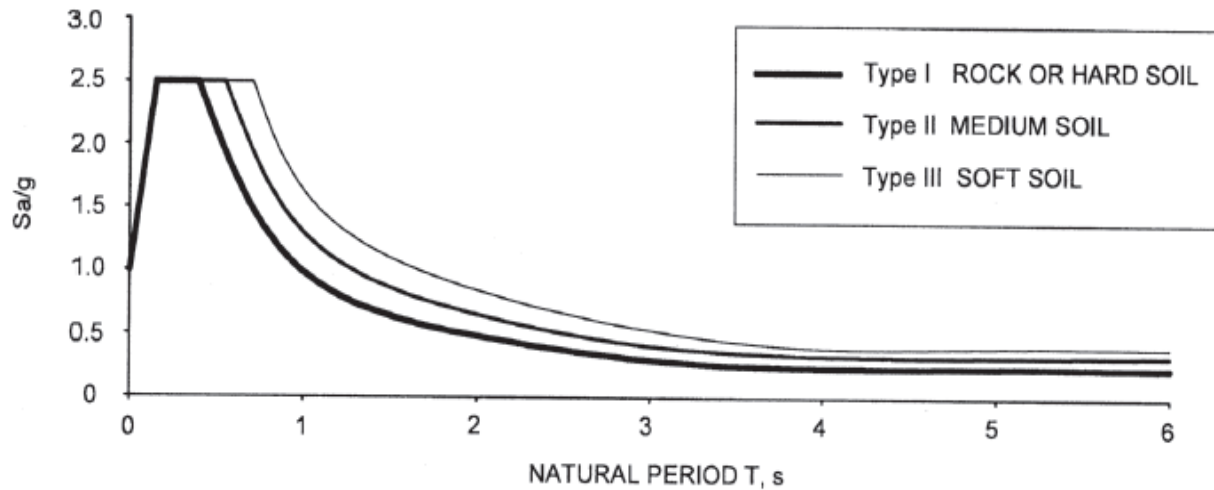
1. Foundation Subsystem: including soil
2. Structure Subsystem

Direct and Substructure Methods



Beneficial Effects of SSI

- The presence of soil makes the system flexible and thus decreasing natural frequency or increasing natural period.
- Normally acceleration for the structures founded on soft soil is smaller than that for the structures founded on rock.



2B SPECTRA FOR RESPONSE SPECTRUM METHOD

Beneficial Effects of SSI?

- In general, SSI leads to smaller accelerations and stresses and thereby smaller forces in the structure.
- However, there are numerous documented case histories where the perceived beneficial effects of SSI have led to oversimplification in the design leading to unsafe design in foundations and superstructure (Mylonakis and Gazetas, 2000).

Impedance Functions

The equation of motion for harmonic excitation is

$$M\ddot{u} + C\dot{u} + K_{st}u = P(t)$$

$$u = U_0 e^{i\omega t} \quad \text{and} \quad P(t) = P_0 e^{i\omega t}$$

The dynamic impedances (K^*) at a particular frequency ω

(a) For Viscous Damping:
$$K^* = K_{st} - M\omega^2 + i\omega C$$

(b) For Hysteretic Damping:
$$K^* = K_{st}(1 + 2i\zeta) - M\omega^2$$

A Comparison Gives
$$iK_{st}2\zeta = iC\omega \quad \text{means} \quad C = \frac{2\zeta}{\omega} K_{st}$$

Where K_{st} is static stiffness matrix, M mass matrix and C is damping coefficient matrix. In general, dynamic impedances (K^*) may be represented in a general form

$$K^* = K_{st}(k_1 + ik_2)$$

References:

**Wolf J.P. (1985), “Dynamic Soil-Structure Interaction”,
Prentice-Hall, Inc., Englewood Cliffs, N.J., USA**

Thank You

