
G. Gazetas, A. Ziotopoulou
National Technical University, Athens
The First Question:

Is SSI properly assessed with the conventional SHAPE and AMPLITUDE of the normalised CODE Spectra? (especially for soft soils)
The Second Question:

How critical are the Response Spectra for Highly Inelastic Geotechnical Systems? (e.g., sliding systems)
Performance–Based Geotechnical Earthquake Engineering

Slowly but steadily

Progress is finally being made

Already accepted:
for Retaining Systems, Slopes, ...

In the early stages of development:
for Shallow and Deep Foundations
Current Seismic Codes

- (Gravity) Retaining walls
- Embankments / Natural Slopes

Designed (indirectly) for inelastic deformation $\Delta \sim 10\text{–}30\text{ cm}$:

$$A_{DESIGN} = \frac{1}{2} A$$
Conventional Solution: "Capacity" Design

New Concept: Beyond "Capacity" Design

Plastic "hinging"
The First Question:

Is SSI properly assessed with the conventional SHAPE and AMPLITUDE of the normalised CODE Spectra? (especially for soft soils)
The Recognised Effects of SSI

Structure on RIGID Base

Structure on COMPLIANT Ground

$m \quad K, \beta$

$H$

$K_x \quad K_R$

$\tilde{T} > T$

$\tilde{\beta} > \beta$
SEISMIC CODES:
Smooth "Average" Response Spectrum

Invariably Decreasing Base Shear
These SHAPES imply that (even on very soft soils) SSI is always beneficial.

Yet several documented cases (Mexico, Loma Prieta, Kobe, Kocaeli, ...) where SSI was detrimental.
These SHAPES do not resemble ACTUAL spectra.

Especially those:

1. Recorded on soft soil sites ($T_s > 0.8 \text{ s}$)

2. Affected by rupture directivity

($M > 6.5$, $D < 5 \text{ km}$)

\[ S_a \text{ increases with } T, \text{ beyond } T \approx 0.6 \text{ sec} \]
The concept of AVERAGE spectrum for each one soil category:

Individual Spectra of Soil Category D
Processing 24 Records
(Mexico, Loma Prieta, Kobe)

- Normalised using $T/T_a$
- Normalised using $T/T_v$
- Averaged without normalisation over $T$

Period: $T$ ; $T/T_a$ ; $T/T_v$
To further explore the shape of response spectrum, after a suitable normalisation of the Period axis.

To develop a new Design Spectrum, which avoids the conceptual pitfalls of current code Spectra.
Parameter Study

- **Soil Thickness**: $H = 30 \text{ m}$, $H = 60 \text{ m}$

- **Shear Wave Velocity**:
  $$V_{S,30} = 100 \text{ m/s}, 180 \text{ m/s}, 260 \text{ m/s}, 360 \text{ m/s}$$

- **Distribution $V_S(z)$**:
  - homogeneous, linear, top crust

- **Soil–Rock Velocity Ratio**:
  $$I = \frac{V_{s,\text{rock}}}{V_{s,\text{soil}}} = 1.5 - 5$$
Type of Soil Profiles

$V_R = 1.5 \, V_S(z = H)$ to $V_R = 5 \, V_S(z = H)$
Selection of Excitations

- 7 Earthquakes of $M \approx 6 - 8$
- “Usual” Records on Rock / Hard Soil
- Scaling (up or down) of records:
  \[
  \text{PGA} \equiv A = 0.2\,\text{g}, \, 0.4\,\text{g}, \, 0.6\,\text{g}
  \]
“Rock” Motions Selected as Base Excitation

Aegion

Dayhook

Sakarya

Superstition Mtn.

Gilroy

Stone Canyon

Lucerne

(g)
Statistics:

2116 Analyses

Soil Class C/D
Processing of Spectra

\[ \frac{S_\alpha}{A} \]

\[ \frac{S_\alpha}{A} \]

\[ \frac{T}{T_p} \]
Bi–Normalised (BN) Spectrum

Soil Class C/D
Surprisingly, the BN Spectrum is nearly “Unique”
Against:
• Soil Stiffness
• Inelastic Behaviour
Effect of Soil Stiffness

$S_\alpha / A$

$T / T_p$

- 180 m/s
- 260 m/s
- 360 m/s
Chi-Chi: Normalized and “Bi-Normalized” spectra for soil types B, C, D, E

Xu + Xie (2004)
Inelastic versus Equivalent Linear

$S_a / A$

$T / T_p$

3.75

NL-DYAS

SHAKE
$S_\alpha / A$

$T / T_p$

mean ± one standard deviation
Principal Consequences of BN Spectrum

⇒ 3.75 instead of 2.5

⇒ sharp PEAK instead of PLATEAU

SSI can be DETRIMENTAL
main Limitation in Using BN Spectrum:

- How to estimate $T_p$ ...

Dominant Period Controlled:
Sometimes by $T_S$, sometimes by $T_E$
The Second Question:

How critical are the Response Spectra for Highly Inelastic Geotechnical Systems? (e.g., sliding systems)
Symmetric sliding

Asymmetric sliding

\[ A_C = \mu g \]

\[ A_C = \mu g \cos \beta - g \sin \beta \]
The importance of changing polarity

\[ A(t) \]
\( A_H(t) \)

- **A**: \( m/s^2 \)
- **V**: \( m/s \)
- **D**: \( m \)

- 0.5 sec
- 2 sec
- 1.6 m
- 0.5 m
Your Comments are most Welcome