Detection of Soil-Structure-Interaction Effect by System Identification

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Seismic Network for Building and Ground

◆ Seismic Networks for Ground
  ✷ K-NET, KiK-net
    ■ Facilitated by NIED after 1996
    ■ 1000 Site, 20km average distance

◆ Seismic Network for Building
  ✷ Has not facilitated yet, and its construction has been desired.
    ■ Because, there is the mismatch between the observed ground motion and the damage of structure.
  ✷ NILIM* has started to construct the seismic network for building and surrounding ground in 2010

* National Institute of Land and Infrastructure Management
Mismatch between Ground Motion and Damage

- Large ground motion versus smaller structure damage than expected

- **Possible Factors**
  - Designed strength and real strength
  - Evaluation of damage from response
  - Soil Structure Interaction (SSI)

1995 Kobe Earthquake
(Suzuki, Okano et al. 2007)
How to know SSI-effect from Seismograph?

SSI effect is included in the seismograph, and it is difficult to disaggregate SSI effect by simple manipulation of seismograph.

System Identification
System Identification for SSI

Soil Structure Interaction

Inertial Interaction (II)
- \( \theta = \theta_{\text{FIM}} + \theta_{\text{I}} \)
- \( \omega_{\eta} \)

Kinematic Interaction (KI)
- \( |\lambda_{\text{FIM}}| = \frac{Y_{\text{FIM}}}{Y_{\text{FF}}} = \frac{\sin \omega \eta}{\omega \eta} \)

Sway-Rocking Model

Diffraction Function

Foundation Input Motion/Free Field

\( Y_{\text{FIM}} \)
- 6F
- RC-Frame and RC Bearing Wall
- Foundation: RC Pile
- Surface Layer: $V_s \approx 200 \text{m/s}$
- Occupancy: Education
- Location: South Part of Saitama Pref. (near Tokyo)
3/09/2014 Fore-Shock (NIT, Ridge-dir.)

<table>
<thead>
<tr>
<th>Observed</th>
<th>6F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude Ratio</td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td></td>
</tr>
</tbody>
</table>

| Identified                   |          |
| Amplitude Ratio              |          |
| Frequency (Hz)               |          |

<table>
<thead>
<tr>
<th>Observed</th>
<th>1F</th>
</tr>
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<tbody>
<tr>
<td>Amplitude Ratio</td>
<td></td>
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| Identified                   |          |
| Amplitude Ratio              |          |
| Frequency (Hz)               |          |

<table>
<thead>
<tr>
<th>Observed</th>
<th>Ground</th>
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| Identified                   |          |
| Amplitude Ratio              |          |
| Frequency (Hz)               |          |

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<thead>
<tr>
<th>Observed</th>
<th>Foundation Input Motion / Ground</th>
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| Identified                   |                                  |
| Amplitude Ratio              |                                  |
| Frequency (Hz)               |                                  |

<table>
<thead>
<tr>
<th>Observed</th>
<th>Foundation Response / Inertial Response</th>
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<tbody>
<tr>
<td>Amplitude Ratio</td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td></td>
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</table>

| Identified                   |                                        |
| Amplitude Ratio              |                                        |
| Frequency (Hz)               |                                        |

<table>
<thead>
<tr>
<th>k₁ = 3.49e+06 (kN/m)</th>
<th>h₁ = 0.049</th>
</tr>
</thead>
<tbody>
<tr>
<td>k₂ = 7.1e+06 (kN/m)</td>
<td>c₂ = 3.97e+05 (kN*s/m)</td>
</tr>
<tr>
<td>η = 0.071</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YFR-Y₁: bw = 0.20 (Hz)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>df (同定適合値)</td>
<td></td>
</tr>
<tr>
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</tbody>
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<table>
<thead>
<tr>
<th>Inertial Response</th>
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<td>df (同定適合値)</td>
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<th>Diff. Func.</th>
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3/11/2014 Main Shock (NIT, Ridge-dir.)

6F／1F

1F／Ground

Foundation Response

Input Motion

Motion

Foundation

1F／Ground

Observed

Identified

Observed

Identified

Frequency (Hz)

Amplitude Ratio

Frequency (Hz)

Amplitude Ratio

Frequency (Hz)

Amplitude Ratio

Frequency (Hz)

Amplitude Ratio

Observed

Identified

Observed

Identified

Diff. Func.

Diff. Func.

Diff. Func.

YFR-YI: bw=0.20 Hz

dif型(同定適合値)

k_H = 4.63e+06 (kN/m)

c_H = 2.30e+05 (kN*s/m)

 = 0.069

k_1 = 2.49e+06 (kN/m)

h_1 = 0.081

同定対象観測値

同定モデル

同定対象観測値

同定モデル

同定対象観測値

同定モデル

同定対象観測値

同定モデル

同定対象観測値

同定モデル

入力損失 (dif型)

同定対象観測値

同定モデル

入力損失 (dif型)

同定対象観測値

同定モデル

入力損失 (dif型)
4/11/2014 After-Shock (NIT, Ridge-dir.)

\[ k_1 = 2.06 \times 10^6 \text{(kN/m)} \]
\[ h_1 = 0.045 \]

観測: \( \text{bw} = 0.20 \text{Hz} \)
同定対象観測値
同定モデル
入力損失（dif型）

\[ k_H = 6.77 \times 10^6 \text{(kN/m)} \]
\[ c_H = 1.47 \times 10^5 \text{(kN*s/m)} \]
\[ \eta = 0.073 \]

観測: \( \text{bw} = 0.20 \text{Hz} \)
同定対象観測値
同定モデル
入力損失（dif型）

6F／1F

1F／Ground

Foundation
Input
Motion

Foundation Response
Inertial Response

Diff. Func.
Transition of Stiffness and Damping (NIT, Ridge-dir.)

- Stiffness of building: has not recovered in after main-shock
- Stiffness of soil-spring: has recovered in after-shock
- Damping coefficient of soil-spring: has not recovered after main shock
Effect on Maximum Building Response

- Adopt r.m.s. response (standard deviation) as substitute of maximum response

  - Assumptions
    - Response is stationary random
    - Peak factor is constant

  - Benefit
    - Directory calculated by identified transfer functions and parameters
# SSI Effect on R.M.S. Building Response

<table>
<thead>
<tr>
<th>Transfer Function</th>
<th>r.m.s. Building Resp.</th>
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</table>
| **Building vs. Foundation**  
Input Motion (II) | \( |H_{X_1/YFM}(\omega)| = \left| \frac{Z_{1obs} - Z_0 - \Theta_0 H}{\omega^2} \right| |Y_{FIM}| \)  
\( \sigma_{X_1/YFM} = \sqrt{2 \int_0^\infty |H_{X_1/YFM}(\omega)|^2 S_0(\omega) \, d\omega} \) |
| **Building vs. Free Filed**  
ground motion (II+KI) | \( |H_{X_1/FF}(\omega)| = \left| \frac{Z_{1obs} - Z_0 - \Theta_0 H}{\omega^2} \right| |Y_{FF}| \)  
\( \sigma_{X_1/FF} = \sqrt{2 \int_0^\infty |H_{X_1/FF}(\omega)|^2 S_0(\omega) \, d\omega} \) |
| **Building vs. Foundation**  
Response  
(Fixed Base Response) | \( |H_{X_1,fix}(\omega)| = \left| \frac{Z_{1obs} - Z_0 - \Theta_0 H}{\omega^2} \right| |Z_0 + \Theta_0 H_{obs}| \)  
\( \sigma_{X_1,fix} = \sqrt{2 \int_0^\infty |H_{X_1,fix}(\omega)|^2 S_0(\omega) \, d\omega} \) |

- **Input Motion**

\[ p S_f(\omega) = \text{cnst.} \rightarrow S_0(\omega) \propto \omega \] approximately
Transition of SSI Effects (NIT, Ridge-dir.)

- Reduction by KI is almost constant
- Reduction by II decreased after main shock

Eq. Reduction by ...

\[
\frac{\sigma_{X_i/FF}}{\sigma_{X_i/FIM}} \quad \text{Kinematic Interaction (KI)}
\]

\[
\frac{\sigma_{X_i/FIM}}{\sigma_{X_i/FM}} \quad \text{Inertial Interaction (II)}
\]

\[
\frac{\sigma_{X_i/FF}}{\sigma_{X_i/FM}} \quad \text{Kinematic Interaction + Inertial Interaction (KI+II)}
\]
Conclusions

- The stiffness of RC building has not recovered, but the soil spring stiffness has recovered gradually in after-shocks.
- The response reductions by kinematic interaction (KI) have been almost constant in fore/main/after-shocks.
- Contrary the response reductions by inertial interaction (II) have decreased after main shock.