Detection of Soil-Structure-Interaction Effect by System Identification

○Hajime Okano
Kobori Research Complex Inc. Tokyo, Japan
Tatsuya Azuhata
NILIM, Tsukuba, Ibaraki, Japan

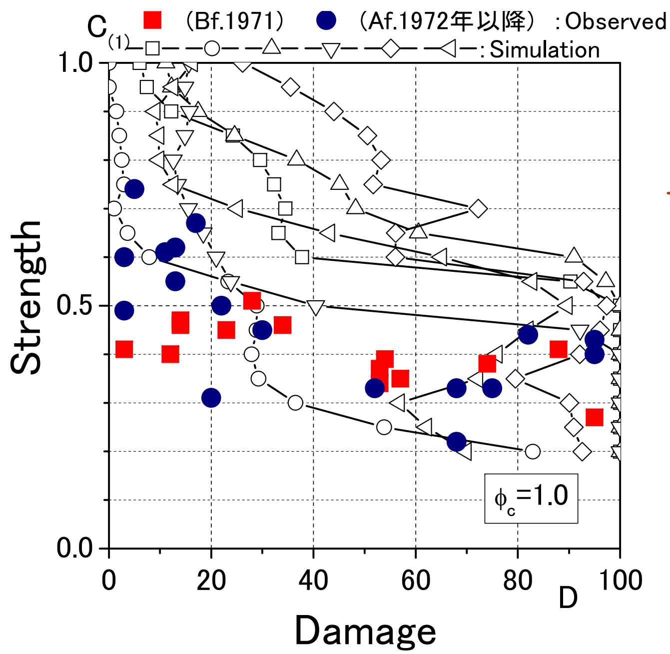
Seismic Network for Building and Ground

- Seismic Networks for Ground
  - K-NET,KiK-net
    - Facilitated by NIED after 1996
    - 1000Site,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 <u>surrounding ground</u> in 2010

* National Institute of Land and Infrastructure Management

Mismatch between Ground Motion and Damage

- Large ground motion versus smaller structure damage than expected



1995 Kobe Earthquake
(Suzuki, Okano et. al 2007)

✧ Possible Factors

- Designed strength and real strength
- Evaluation of damage from response
- <u>Soil Structure Interaction (SSI)</u>

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.

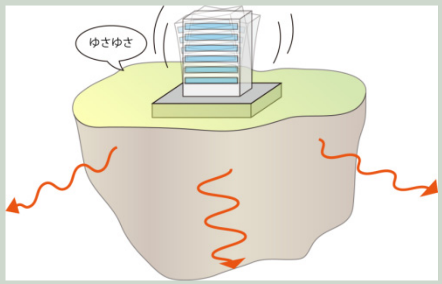
↓

System Identification

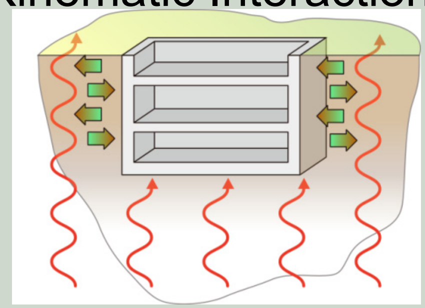
System Identification for SSI

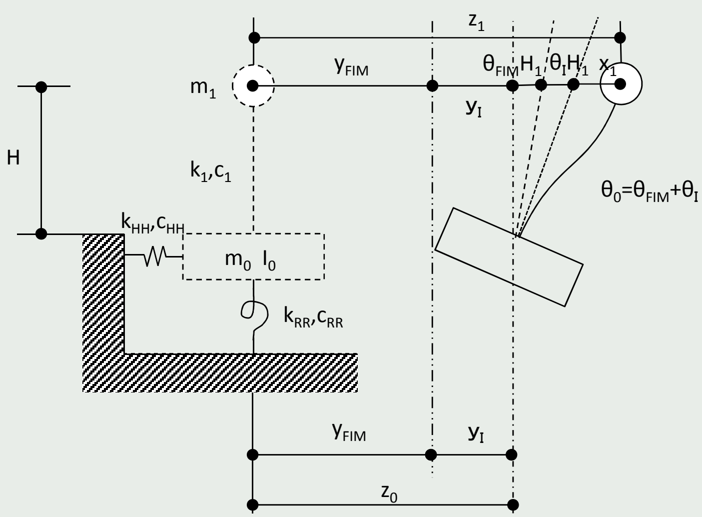
Soil Structure Interaction

Inertial Interaction (II)

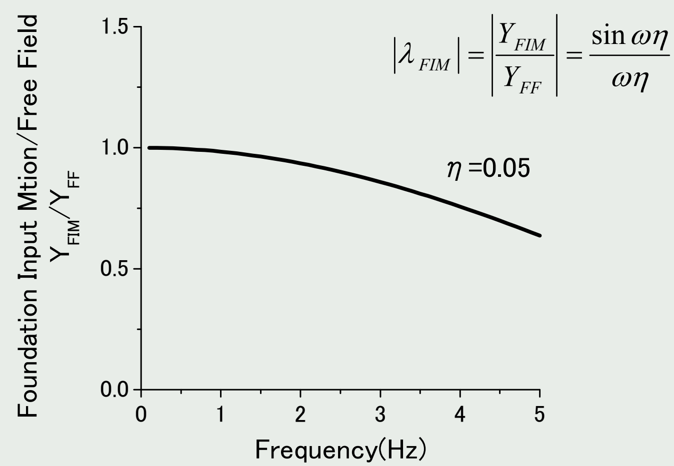


Kinematic Interaction (KI)





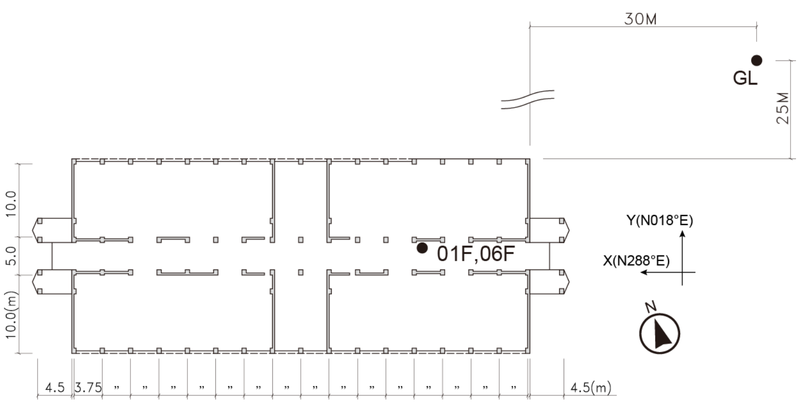
Sway-Rocking Model



Diffraction Function

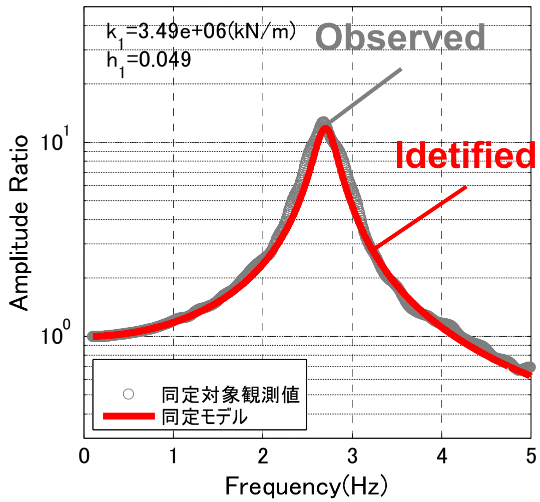
NIT

- 6F
- RC-Frame and RC Bearing Wall
- Foundation: RC Pile
- Surface Layer :Vs ≒ 200m/s
- Occupancy :Education
- Location :South Part of Saitama Pref. (near Tokyo)

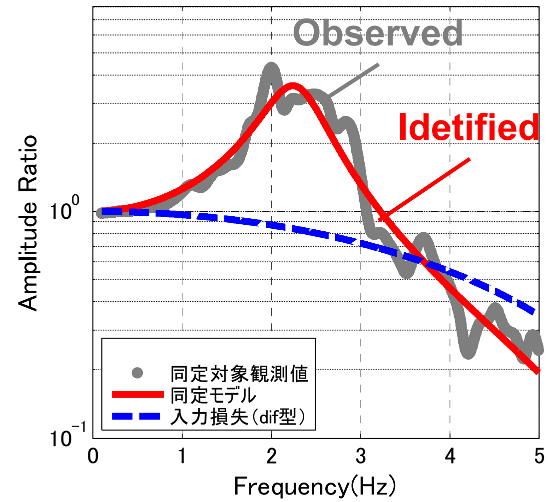


3/09/2014 Fore-Shock (NIT, Ridge-dir.)

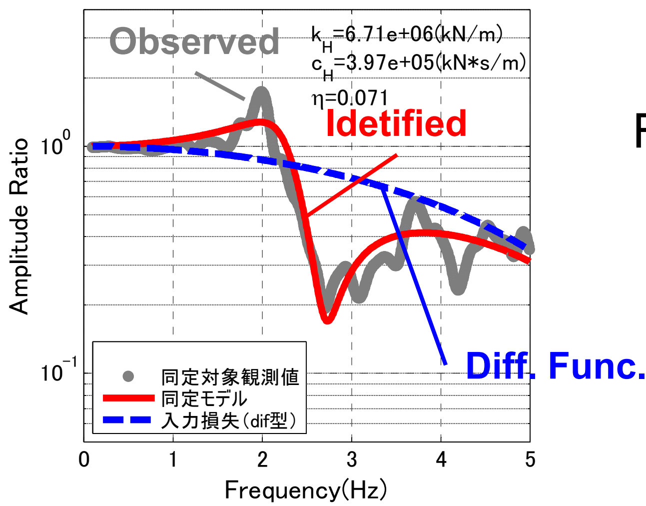
6F
／1F



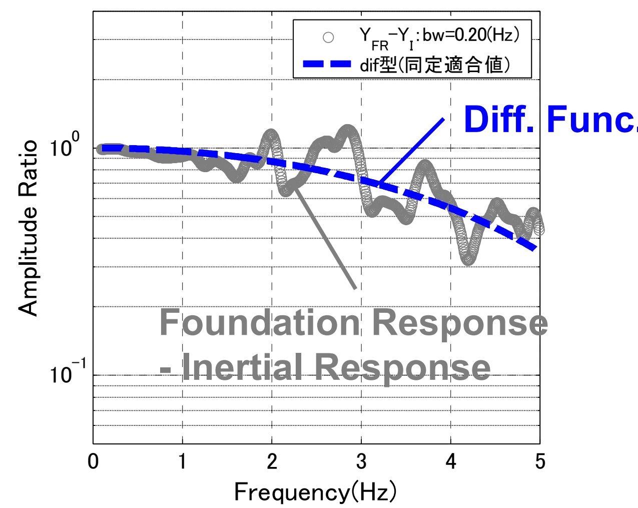
6F
／Ground



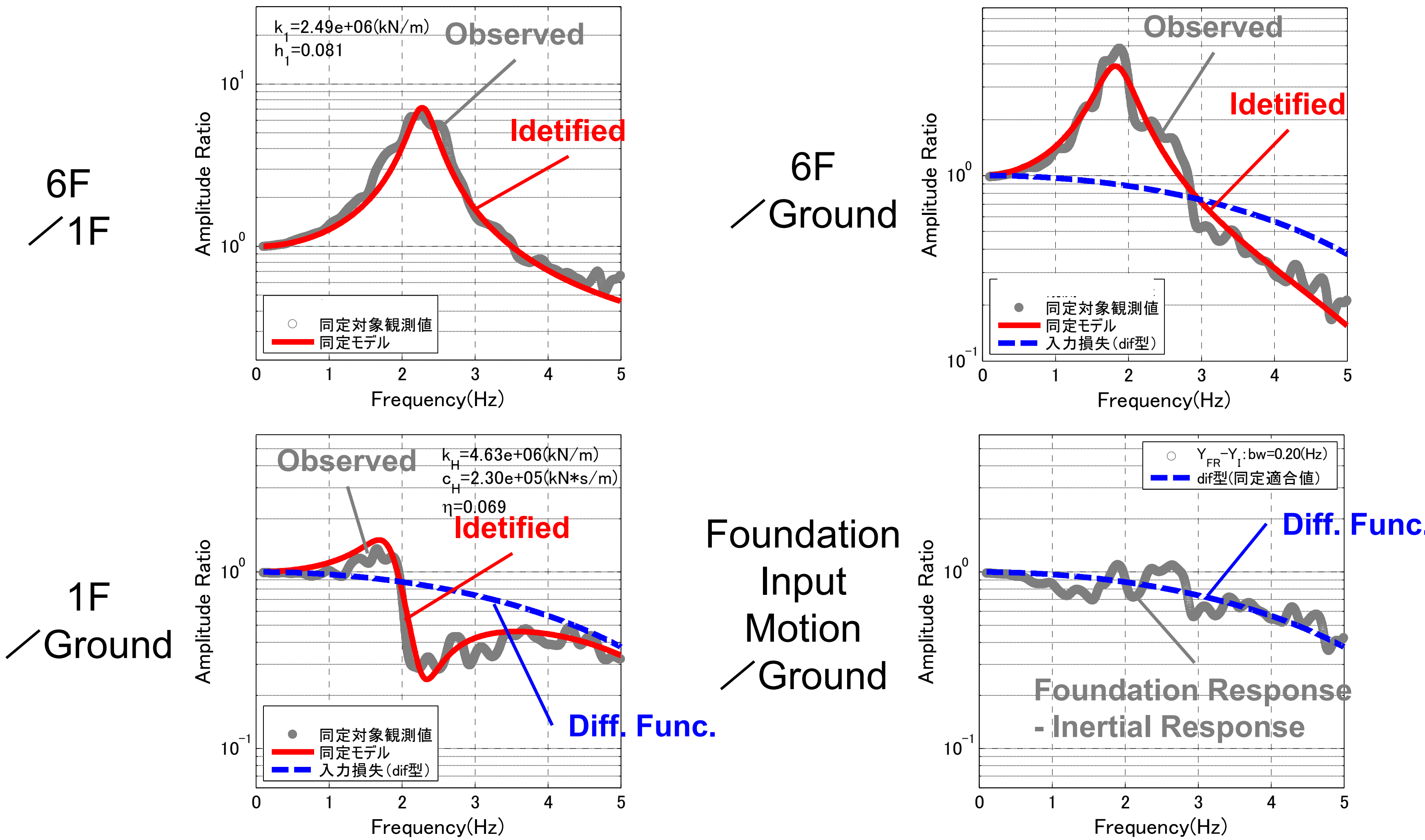
1F
／Ground



Foundation
Input
Motion
／Ground

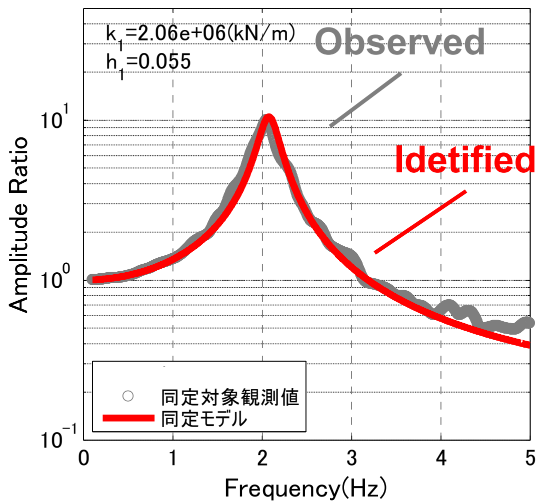


3/11/2014 Main Shock (NIT, Ridge-dir.)

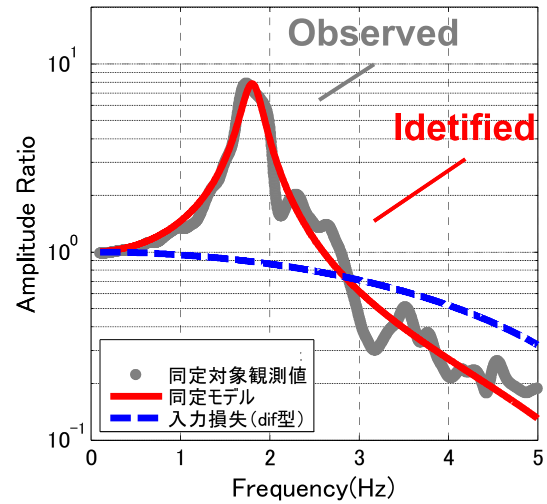


4/11/2014 After-Shock (NIT, Ridge-dir.)

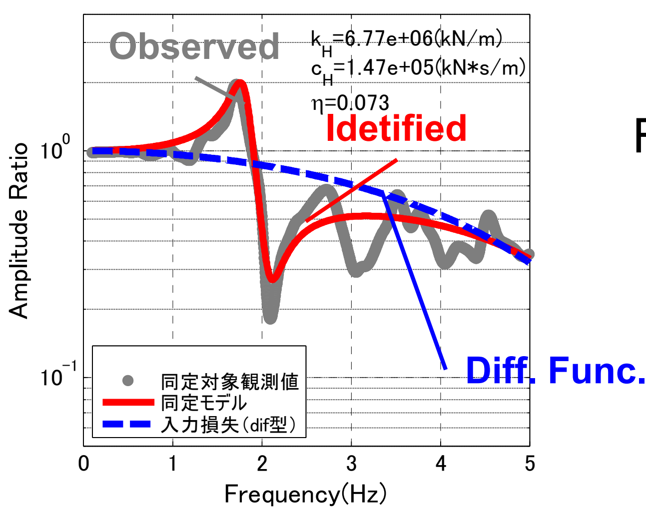
6F
／1F



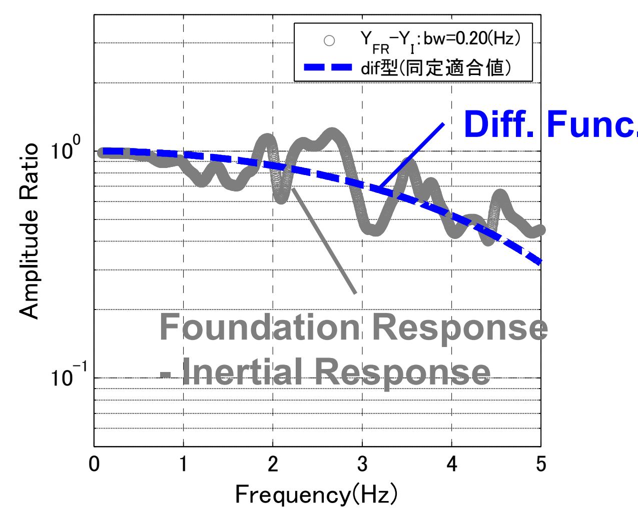
6F
／Ground



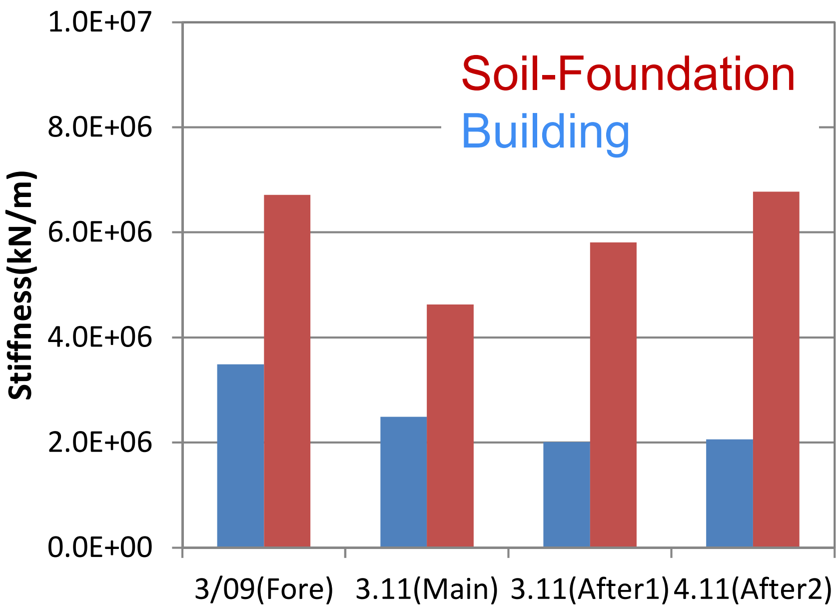
1F
／Ground



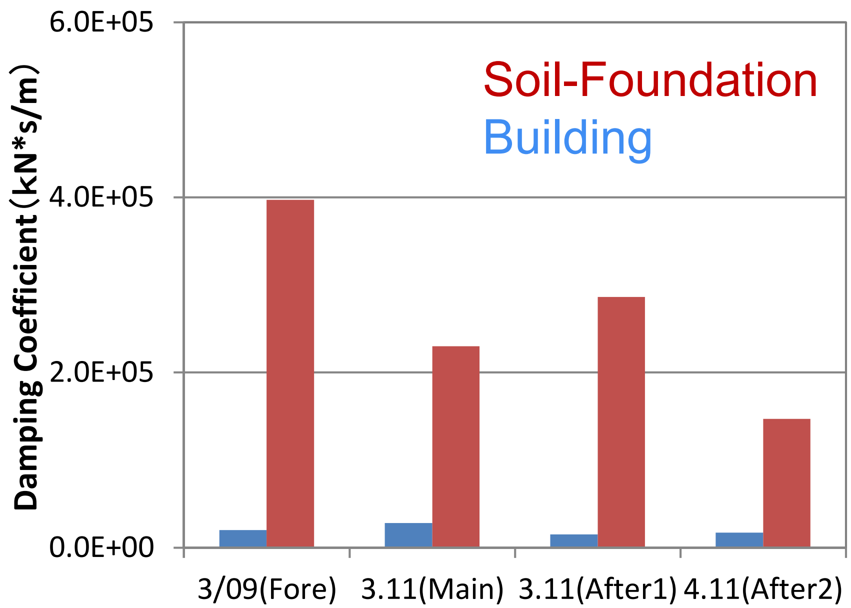
Foundation
Input
Motion
／Ground



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



Stiffness



Damping Coefficients

- 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

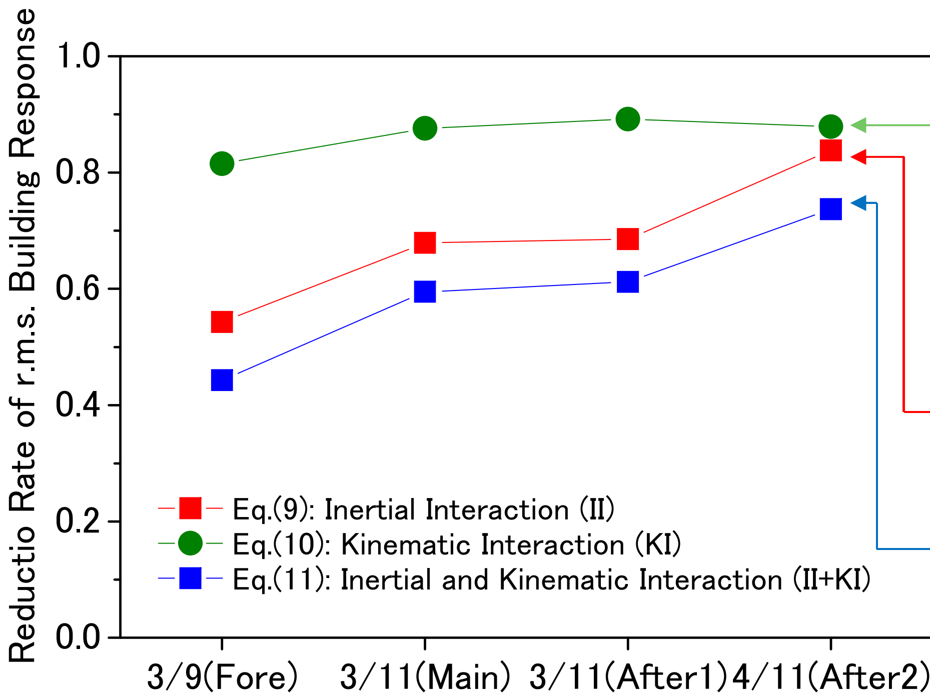
SSI Effect on R.M.S. Building Response

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

- Input Motion

$${}_pS_V(\omega) = \text{cnst.} \quad \xrightarrow{\text{approximately}} \quad S_0(\omega) \propto \omega$$

Transition of SSI Effects (NIT, Ridge-dir.)



Eq.	Reduction by …
$\dfrac{\sigma_{X_1/FF}}{\sigma_{X_1/FIM}}$	Kinematic Interaction (KI)
$\dfrac{\sigma_{X_1/FIM}}{\sigma_{X_{1fix}}}$	Inertial Interaction (II)
$\dfrac{\sigma_{X_1/FF}}{\sigma_{X_{1fix}}}$	Kinematic Interaction + Inertial Interaction (KI+II)

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

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.