# Effects of Ground Motion Input on Responses of Structure and Equipment

**Kwangsub Jung*, Tae-Hyun Kwon, In-Kil Choi**

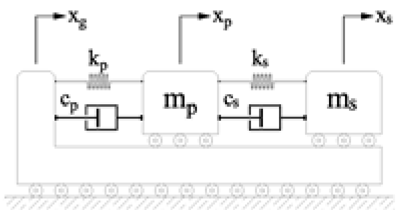
*Korea Atomic Energy Research Institute*

Korean Nuclear Society Spring Meeting

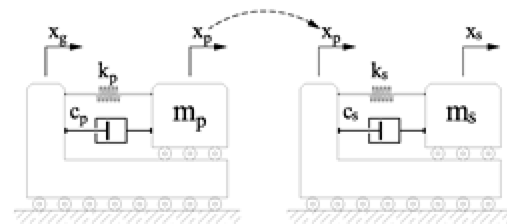
May 12-14, 2021

# Introduction

- Coupled model & uncoupled model

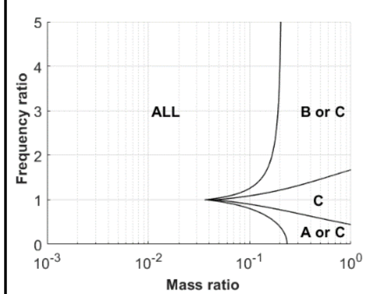
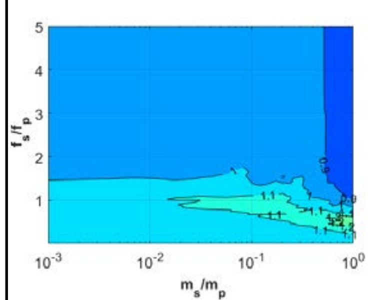
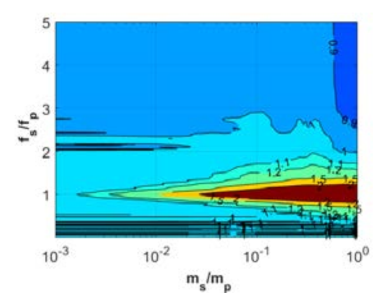



*Coupled model*




*Uncoupled model*

- Decoupling error in ASCE-4 criteria

| | Natural Frequency | Response (to earthquake RG 1.60) | |
|---|---|---|---|
| | Structure | Structure | Equipment |
| Max. Decoupling Error | 10 % | 26 % | 141 % |
| Graph |  |  |  |

# Harmonic Excitation (1)

- Ground motion input is considered as simple harmonic motion.

$$\ddot{x}_g(t) = e^{i\omega t}$$

- Relative displacements and accelerations of the structure and equipment

$$y_p(t) = H_{y_p}(\omega)e^{i\omega t}, \;\; \ddot{x}_p(t) = H_{\ddot{x}_p}(\omega)e^{i\omega t}$$

$$y_s(t) = H_{y_s}(\omega)e^{i\omega t}, \;\; \ddot{x}_s(t) = H_{\ddot{x}_s}(\omega)e^{i\omega t}$$

- Transfer functions for the uncoupled model

$$H_{y_p}(\omega) = \frac{-1}{-\omega^2 + 2i\zeta_p\omega_p\omega + \omega_p^2}$$

$$H_{\ddot{x}_p}(\omega) = -\left(2i\zeta_p\omega_p\omega + \omega_p^2\right)H_{y_p}(\omega)$$

$$H_{y_s}(\omega) = \frac{-H_{\ddot{x}_p}(\omega)}{-\omega^2 + 2i\zeta_s\omega_s\omega + \omega_s^2}$$

$$H_{\ddot{x}_s}(\omega) = -\left(2i\zeta_s\omega_s\omega + \omega_s^2\right)H_{y_s}(\omega)$$

# Harmonic Excitation (2)

- Transfer functions for the coupled model

$$H_{y_p}(\omega) = \frac{\omega^2 - i\omega(1+\mu)2\zeta_s\omega_s - (1+\mu)\omega_s^2}{\Delta}$$

$$H_{y_s}(\omega) = \frac{-i\omega 2\zeta_p\omega_p - \omega_p^2}{\Delta}$$

$$H_{\ddot{x}_p}(\omega) = \frac{-i\omega^3 2\zeta_p\omega_p - \omega^2\left(\omega_p^2 + 4\zeta_p\zeta_s\omega_p\omega_s\right) + i\omega\left(2\zeta_p\omega_p\omega_s^2 + 2\zeta_s\omega_s\omega_p^2\right) + \omega_p^2\omega_s^2}{\Delta}$$

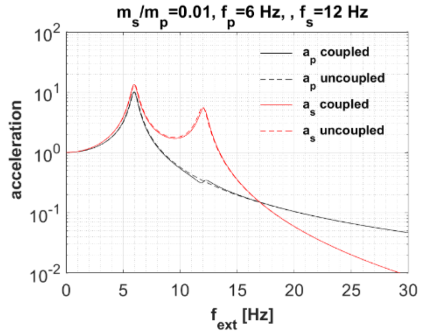
$$H_{\ddot{x}_s}(\omega) = \frac{-\omega^2 4\zeta_p\zeta_s\omega_p\omega_s + i\omega(2\zeta_p\omega_p\omega_s^2 + 2\zeta_s\omega_s\omega_p^2) + \omega_p^2\omega_s^2}{\Delta}$$

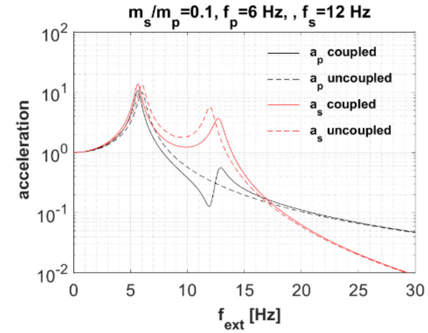
$$\Delta = \omega^4 - i\omega^3\left[2\zeta_p\omega_p + 2(1+\mu)\zeta_s\omega_s\right] - \omega^2\left[\omega_p^2 + (1+\mu)\omega_s^2 + 4\zeta_p\zeta_s\omega_p\omega_s\right] + i\omega\left[2\zeta_p\omega_p\omega_s^2 + 2\zeta_s\omega_s\omega_p^2\right] + \omega_p^2\omega_s^2$$

# Response to Harmonic Excitation

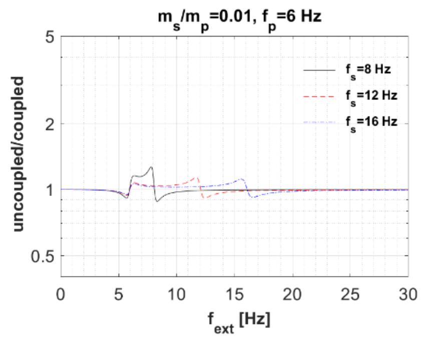
- Response and decoupling error depends on excitation frequency, mass ratio, and frequency ratio.

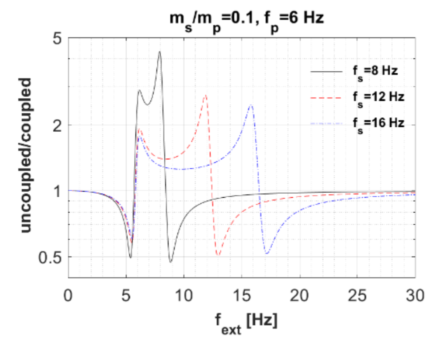
- Response acceleration has peaks due to resonance.




- Decoupling error due to resonance.




| | $m_s/m_p$= 0.01 | | |
|---|---|---|---|
| | $f_s/f_p$= 1.33 | $f_s/f_p$= 2.0 | $f_s/f_p$= 2.67 |
| Peak Error | 27% | 14% | 12% |

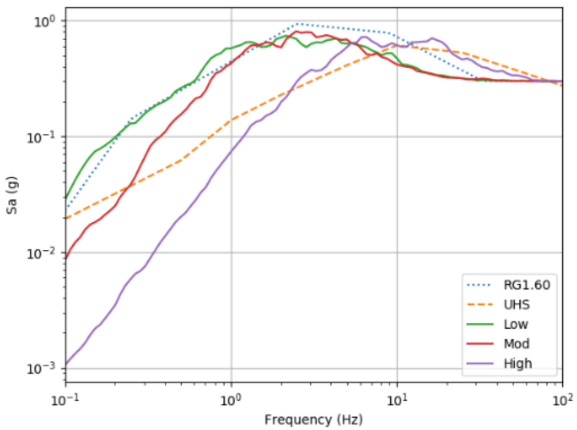
| | $m_s/m_p$= 0.1 | | |
|---|---|---|---|
| | $f_s/f_p$= 1.33 | $f_s/f_p$= 2.0 | $f_s/f_p$= 2.67 |
| Peak Error | 331% | 173% | 146% |

# Seismic Input with Different A/V Ratios

- Peak ground acceleration to velocity (A/V) ratios

- High A/V group has more 5~40 Hz components than other group.

| Group | A/V (g/m/s) |
|---|---|
| Low | < 0.8 |
| Moderate | 0.8 ~ 1.2 |
| High | > 1.2 |




*Acceleration spectrum with different A/V ratio*

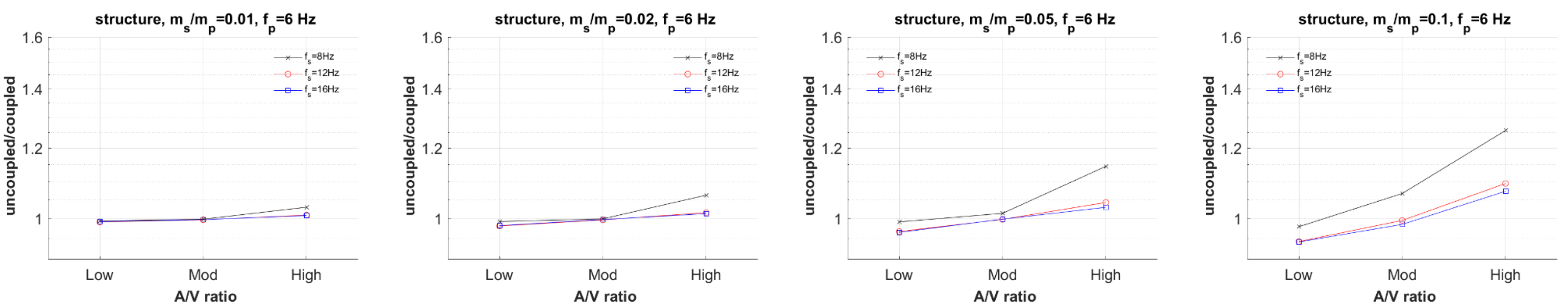
- Method

| A/V ratio | Low, Moderate, High |
|---|---|
| Model | Coupled, Uncoupled |
| Damping ratio | 5% for structure<br>3% for equipment |
| Mass ratio | 0.01, 0.02, 0.05, 0.1 |
| Frequency ratio | 1.33, 2.0, 2.67 |

# Response to Input with Different A/V Ratios (1)

- Decoupling error - structure

- The response error increases as the A/V ratio changes from “Low” to “High”.
- The A/V ratio is dominant in the response error when the mass ratio increases.
- Max. decoupling error is 26% due to resonance. ($f_p$=6 Hz, $f_s$=8 Hz, High A/V input=5~40 Hz)
- The high-frequency earthquakes increase the response error of the uncoupled model.

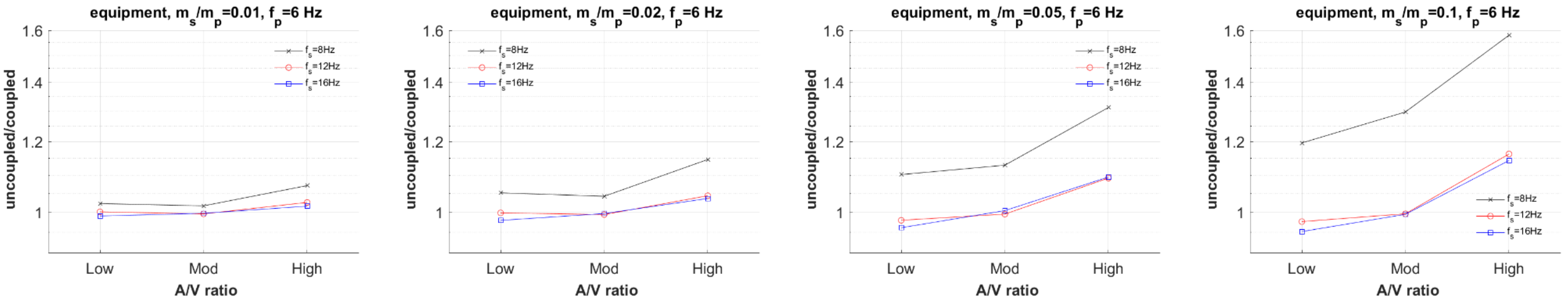



*Response error of the uncoupled model structure*

# Response to Input with Different A/V Ratios (2)

- Decoupling error - equipment

- Decoupling error of equipment is larger than that of structure.
- Max. decoupling error is 58% due to resonance. ($f_p$=6 Hz, $f_s$=8 Hz, High A/V input=5~40 Hz)




*Response error of the uncoupled model equipment*