Mechanical behavior of storage ring girder in Korea-4GSR under gravity and vibration loads

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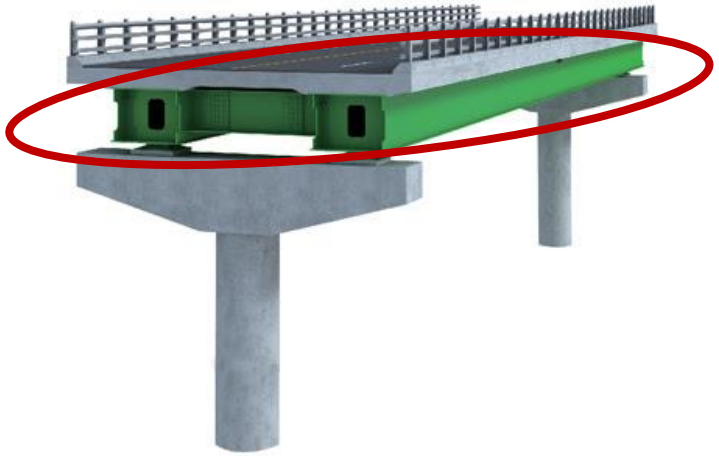
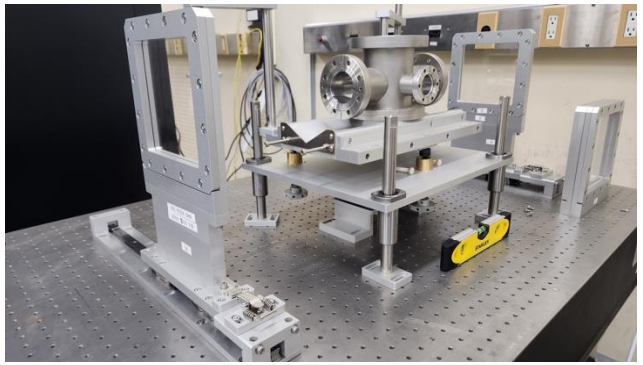
Brief introduction of a girder

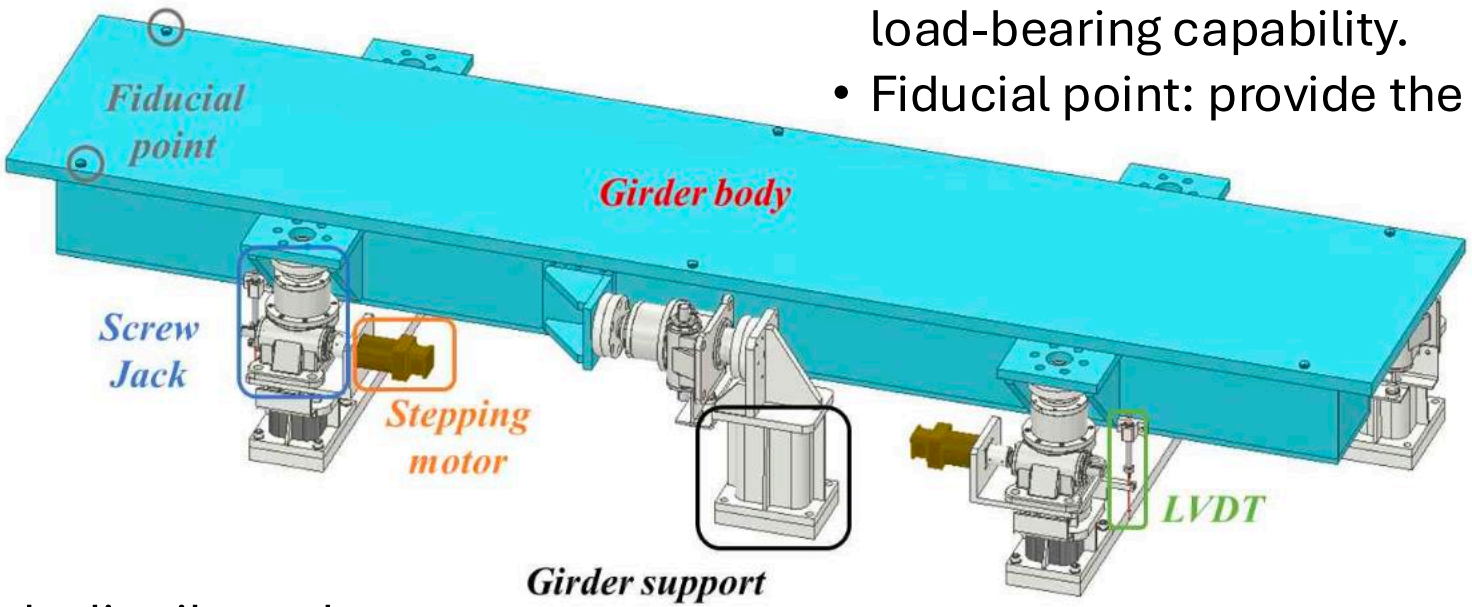




Supporting body system for the massive object

Configuration of a 4GSR Magnet girder

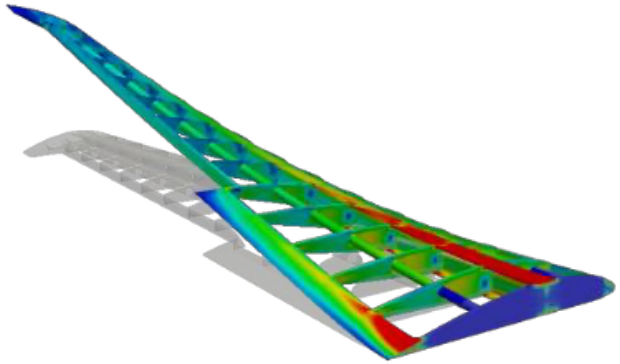
Body
- Internal ribs: to achieve the required stiffness and load-bearing capability.
- Fiducial point: provide the alignment network.

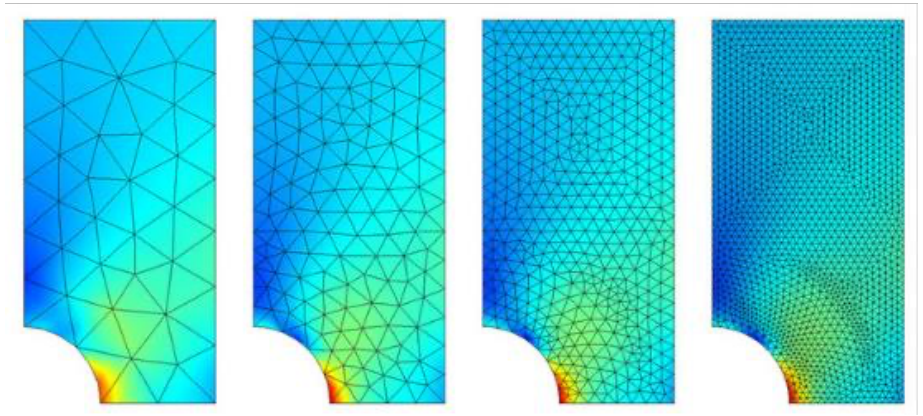


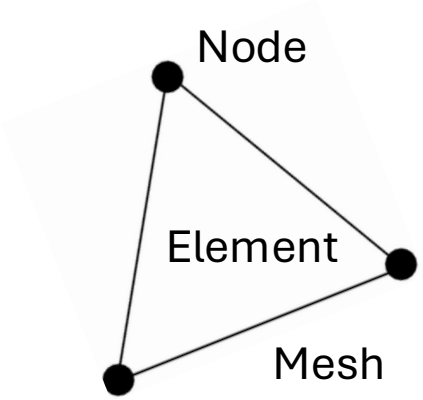
Support
- Four points: evenly distribute the mass.
- Ball screw jack: minimize the friction to allow precise alignment.
- High ratio gear: ultrafine control (3.9 um/rev).

Linear variable displacement transducer (LVDT)
- Magnet sensor: detect the high-precision displacement.
- Feedback: monitor and adjust the position.

Finite Element Method (FEM)





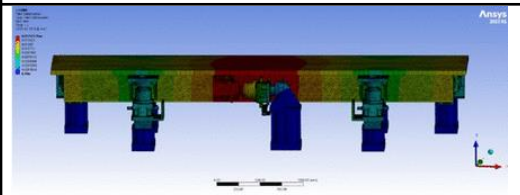
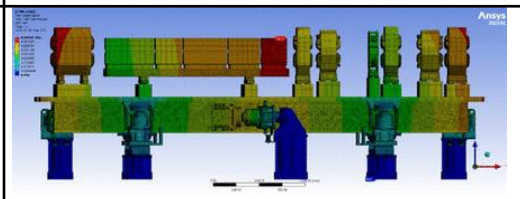
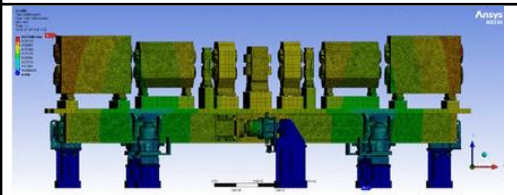
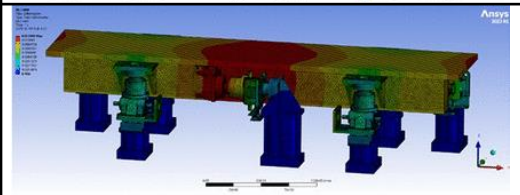
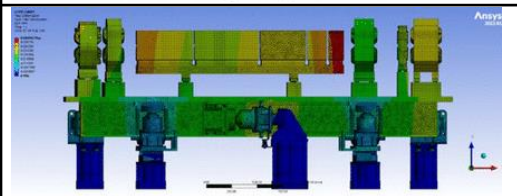


$$[\boldsymbol{K}]\{\Delta\} = \{\boldsymbol{f}\}$$

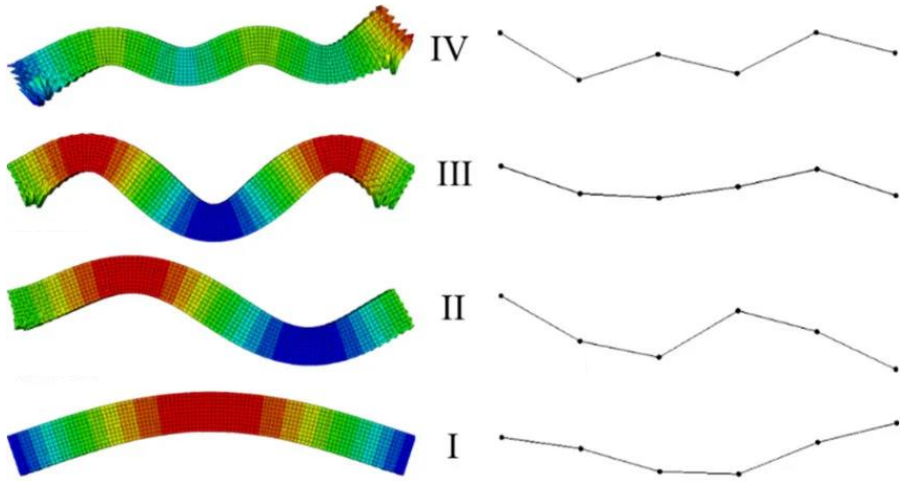
$[\boldsymbol{K}]$: Stiffness
$\{\Delta\}$: Displacement
$\{\boldsymbol{f}\}$: Loads

- To calculate the mechanical variables by splitting into small pieces.
- Node: the point degree of freedom (Δ, displacement) is computed.
- Element: the discrete unit that have its mechanical properties (e.g. elasticity, area, length).
- Mesh: usually automatically determined how small each unit is.

Static structural analysis

Type	Displacement [um]	Shape of result	Note
Type_1	17.4		Own weight (4.5 ton)
	49.1		Type_1_U (9.6 ton)
	75.6		Type_1_C (13.5 ton)
Type_2	12		Own weight (3.9 ton)
	44		Type_2_U (7.8 ton)

Modal analysis



- To calculate the natural oscillation of an object and its pattern.
- Without external force, vibrates by intrinsic properties like inertia and restoration.
- Assume the simple harmonic motion for all modes.
- When stiffness and inertia are balanced.

$$[M]\{\ddot{x}\} + [K]\{x\} = 0$$

$[M]$: Mass
$[K]$: Stiffness
$\{x\}$: Displacement
$\{\Phi\}$: Modal shape

$$\{x\} = \{\Phi\}\sin(\omega t) = \{\Phi\}e^{i\omega t}$$

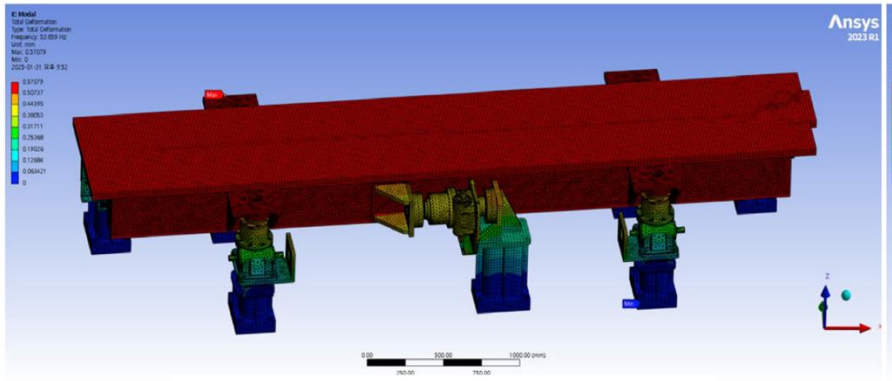
$$\{\ddot{x}\} = -\omega^2\{\Phi\}e^{i\omega t}$$

$$-\omega^2[M]\{\Phi\}e^{i\omega t} + [K]\{\Phi\}e^{i\omega t} = 0$$

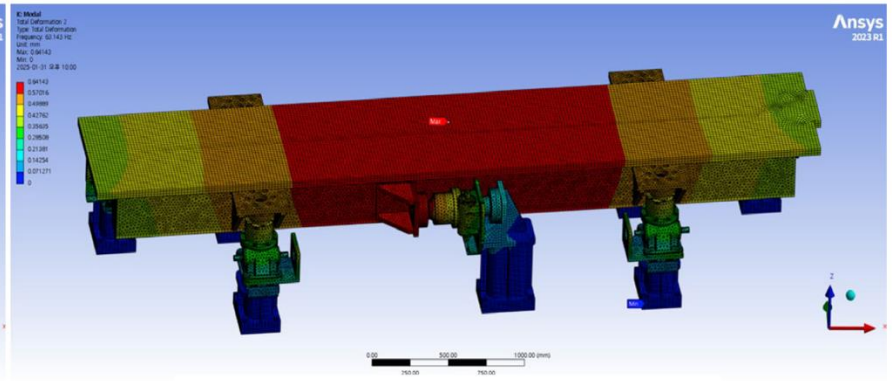
$$([K] - \omega^2[M])\{\Phi\} = 0 \quad (\{\Phi\} \neq 0)$$

$$\det([K] - \omega^2[M]) = 0$$

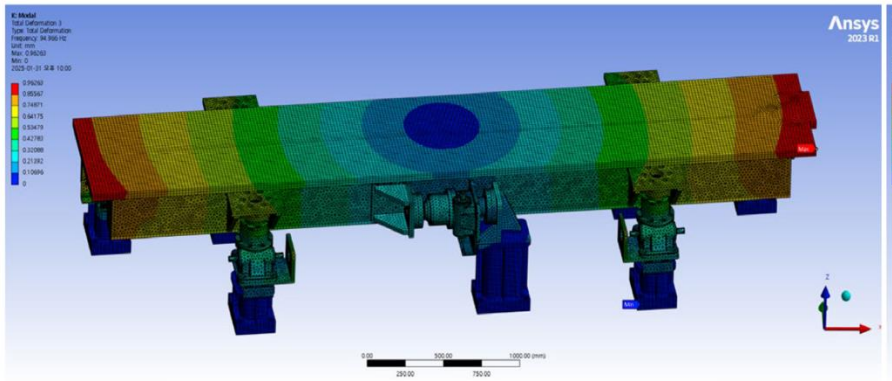
Natural frequency of the girder



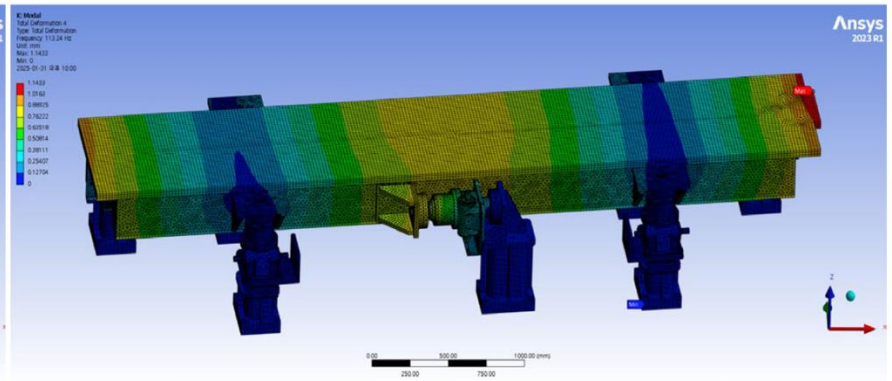
1st Mode: higher than 50 Hz (a) 1st mode



(b) 2nd mode +Roll

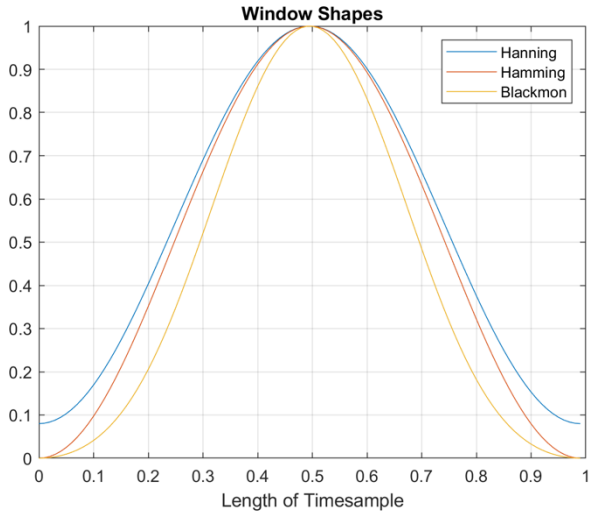


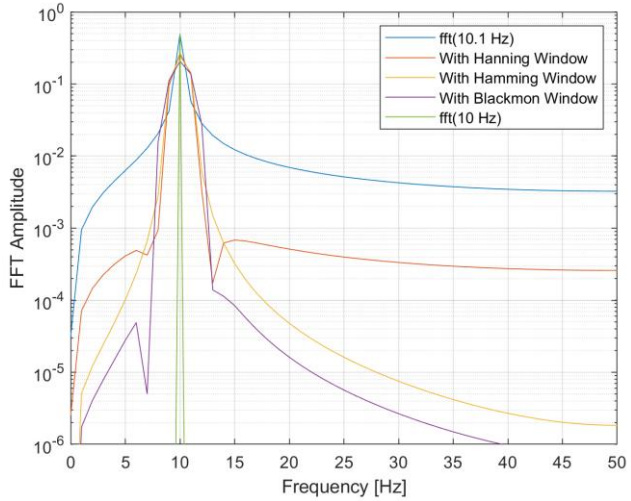
(c) 3rd mode +Torsion



(d) 4th mode +Vertical

Power spectral density (PSD)





- To evaluate the impact of the specific frequency among random vibrations.
- Focusing on the frequency rather than time.
- Density means output is more independent of the methods used to capture the data, making more data directly comparable.
- Note: Power does not mean, say, Watts, but signal squared is generally referred to ‘power’, literally showing the magnitude of the vibrational intensity.

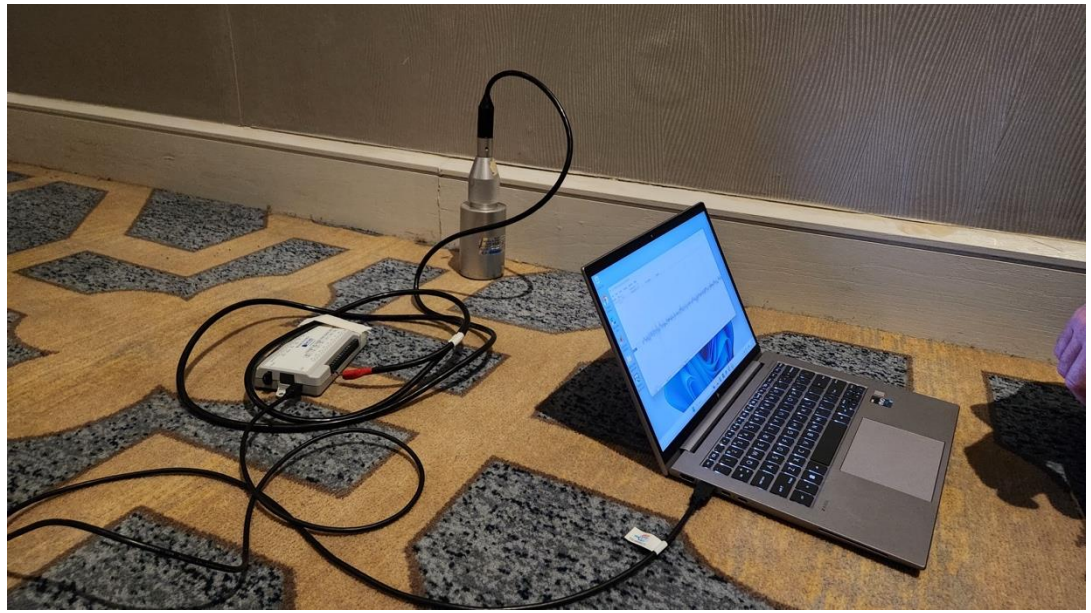
Random vibration measurement

Purpose

- Mitigate external vibration to maintain the stability.
- Quantify the effect of the ground motion.
- Check whether the stability is tolerable within the beam size (x: 4.5 um, y: 2.9 um).

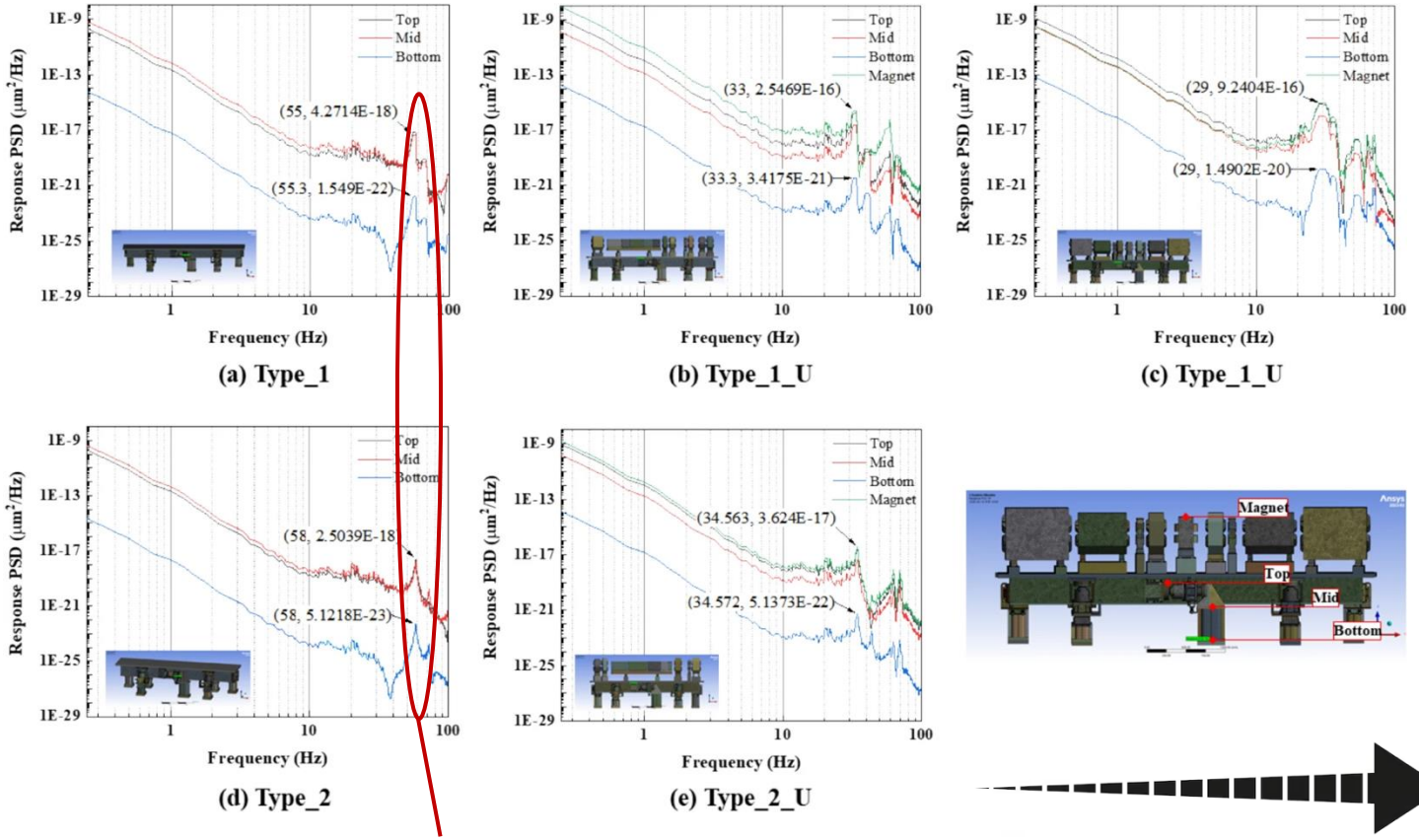
Measurement

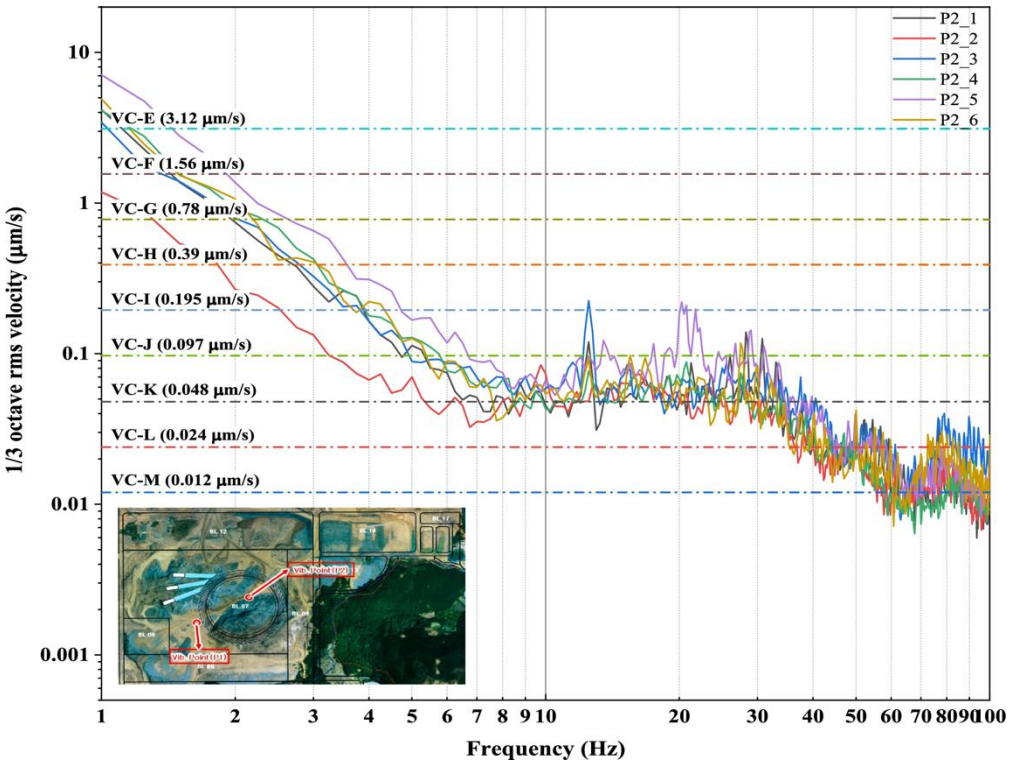
- Several points on the construction area.
- Used high-sensitive accelerometer (10 V/g).
- $Total\ variance\ [\mu m^2] = \int_{f_1}^{f_2} PSD(f)df$



Example of the ground motion surveying

Random vibration analysis





Vibration amplification
frequencies slightly offset from natural frequencies identified in modal analysis

Vibration transmission
From bottom to magnet, amplitude is magnified

Ground motion
The lower the frequency, the higher PSD respond gets

Technical significance

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Structural stability

- Deformed in nanometer scale, tolerable compared to the beam size.
- Have stiff skeleton and is feasible to install and operate.

Ground motion

- Achieved higher natural frequency than the external noise.
- Displacement of the electromagnet due to ground vibrations was at the level of 39.7 pm.

Future research

- It is inherently challenging to isolate and evaluate the impact of girder errors exclusively from the cumulative effects of all errors.
- Fabrication of a prototype and on-site experiments to validate and improve the findings of this study.

THANK YOU