

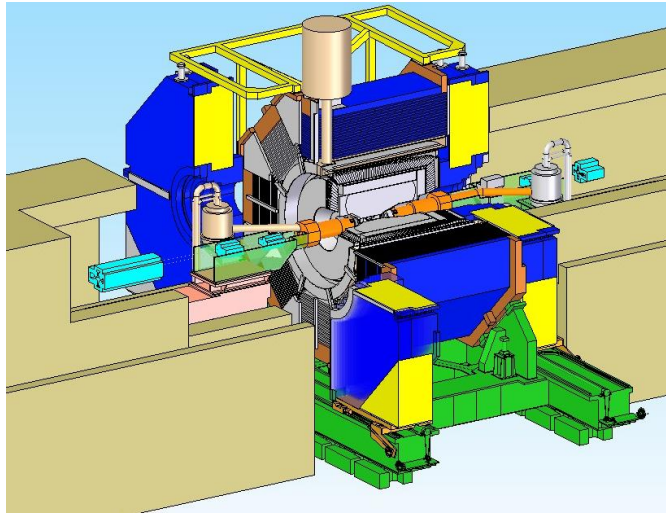
Vibrations studies at KEKB/Belle

KEK

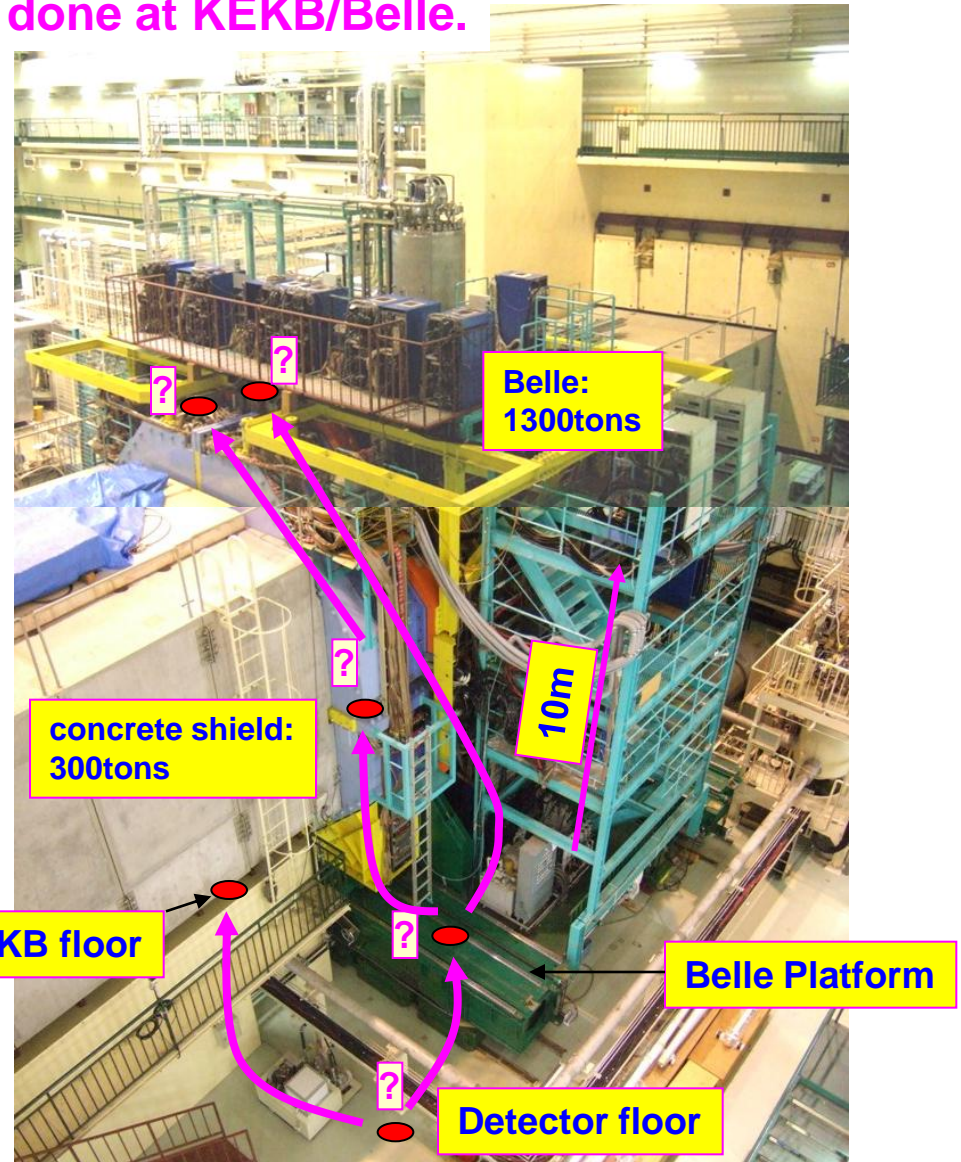
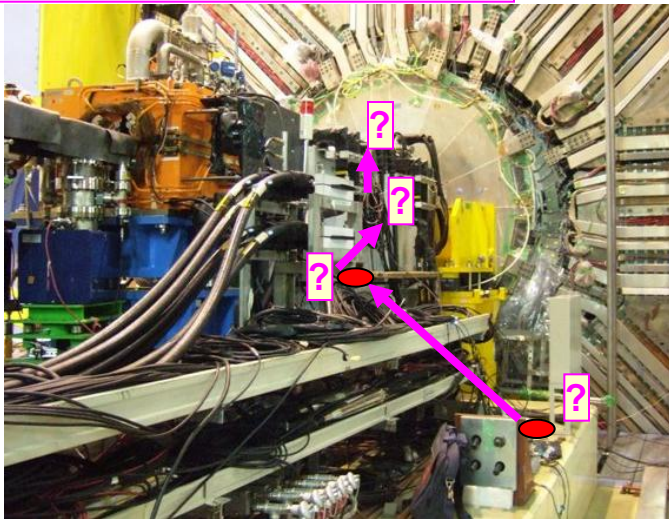
Hiroshi Yamaoka

Introduction

Vibration measurements have been done at KEKB/Belle.



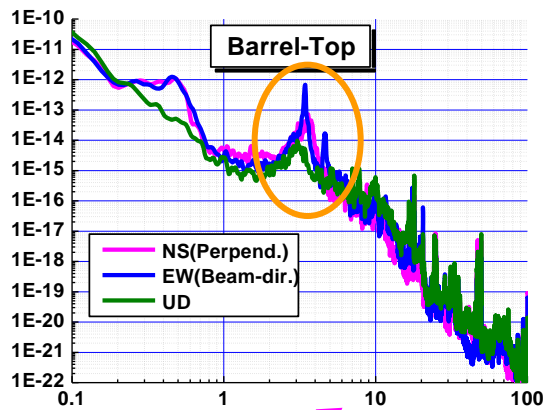
Measure vibrations at KEKB



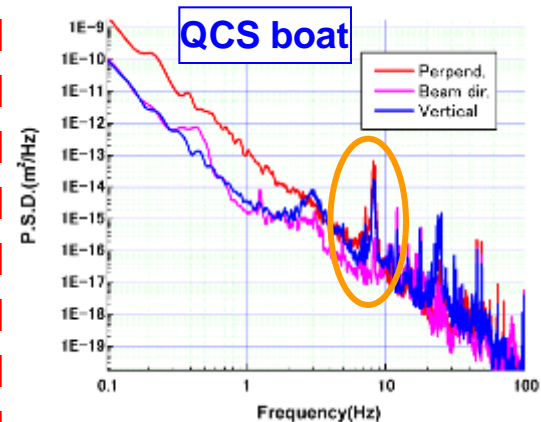
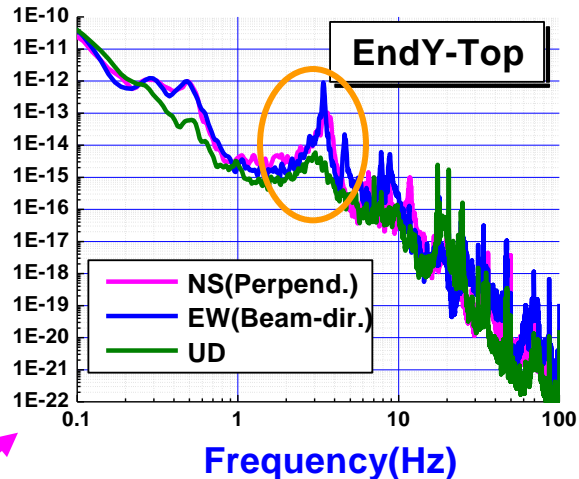
- Is it possible to evaluate these vibrations by FEM?
- Are those calculations consistent with measurements?

Vibration data

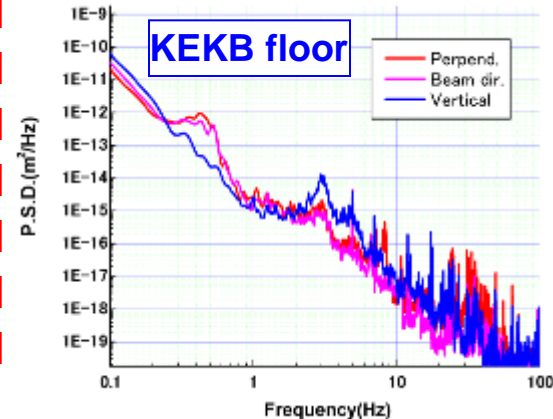
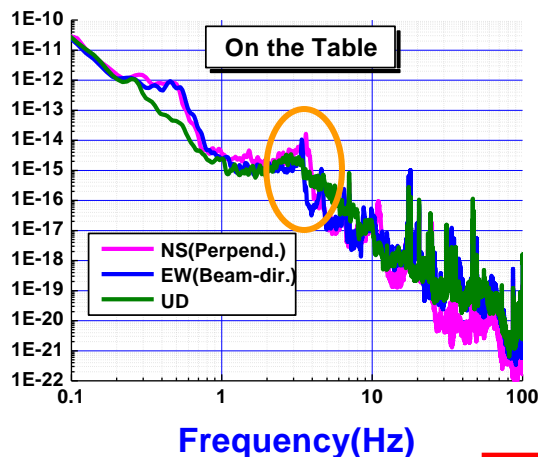
P.S.D.(m²/Hz)



P.S.D.(m²/Hz)

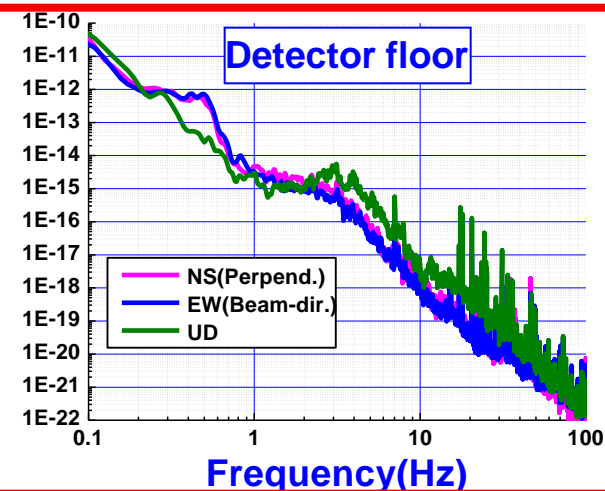


P.S.D.(m²/Hz)



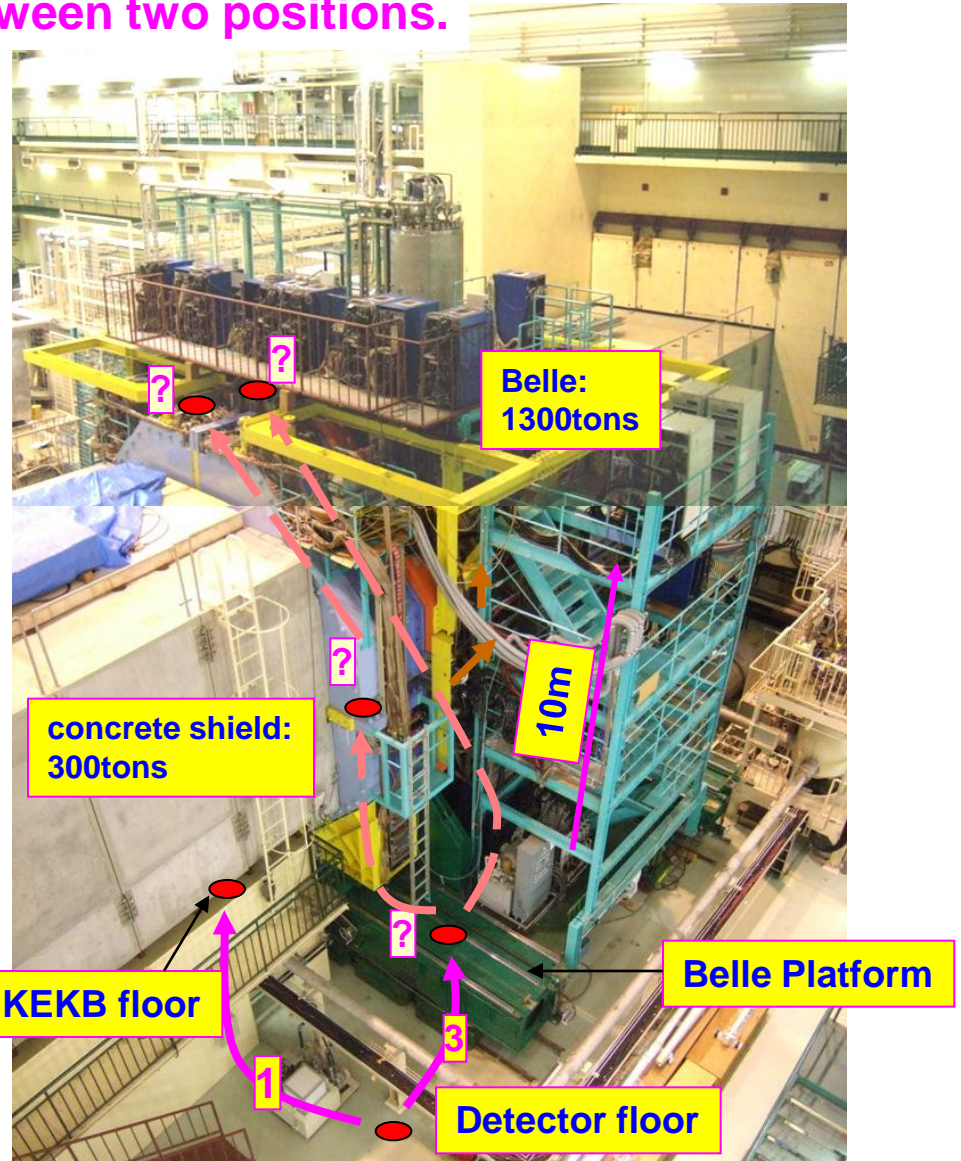
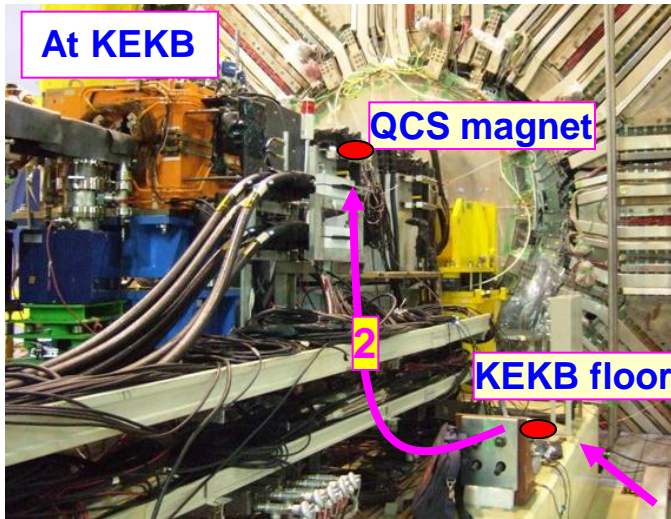
	Integrated amplitude(nm)					
	>1Hz			>10Hz		
	Perpend	Beam	Vertical	Perpend	Beam	Vertical
Barrel-Top	196	301	93	18	12	9
EY-Top	248	354	80	25	17	20
EY-Mid.	204	254	121	14	27	19
Belle platform	105	69	71	13	11	13
Detector floor	50	46	67	4	3	9
KEKB floor	55	45	68	10	5	9
Mag.-table	90	50	76	12	16	19
QCS-boat	250	60	118	15	21	30
QC1RE	241	77	112	52	50	46

P.S.D.(m²/Hz)



Calculations

Respond vibration is calculated between two positions.

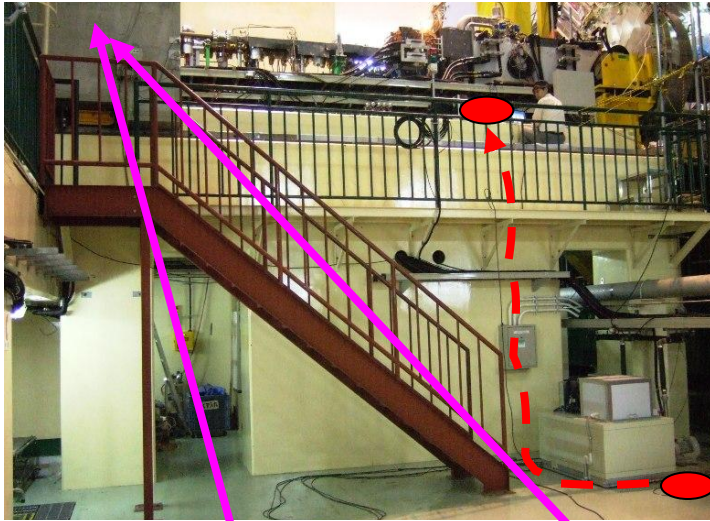


INPUT OUTPUT

1. Detector floor → KEKB floor
2. KEKB floor → QCS magnet
3. Detector floor → Belle platform
4. Belle platform → End cap/ Barrel yoke
(Not yet: Sorry)
→ Needs special technique due to large model.

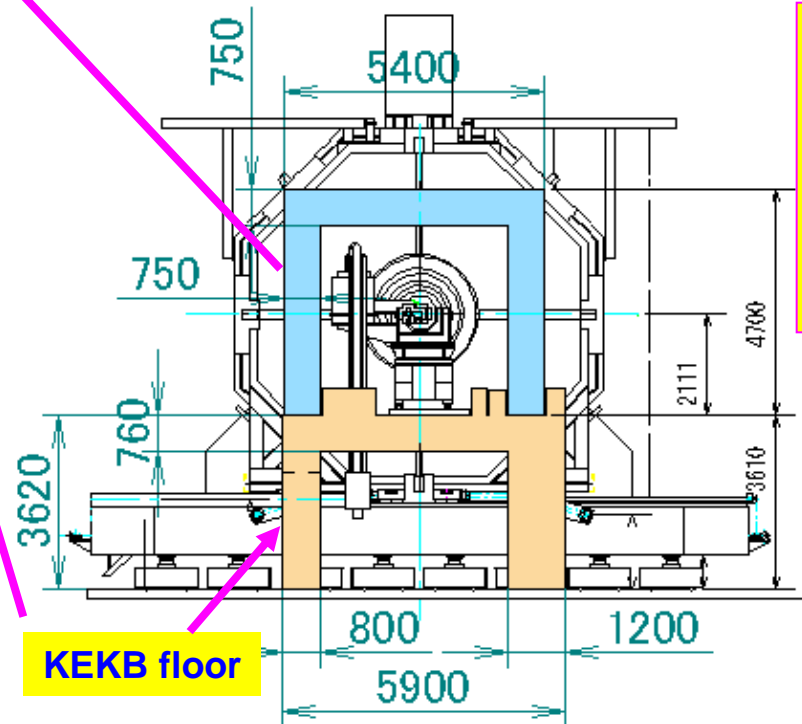
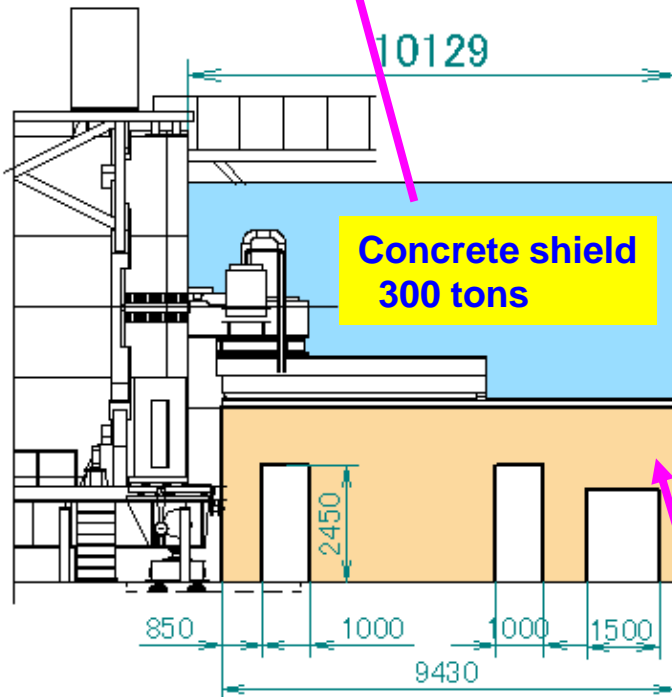
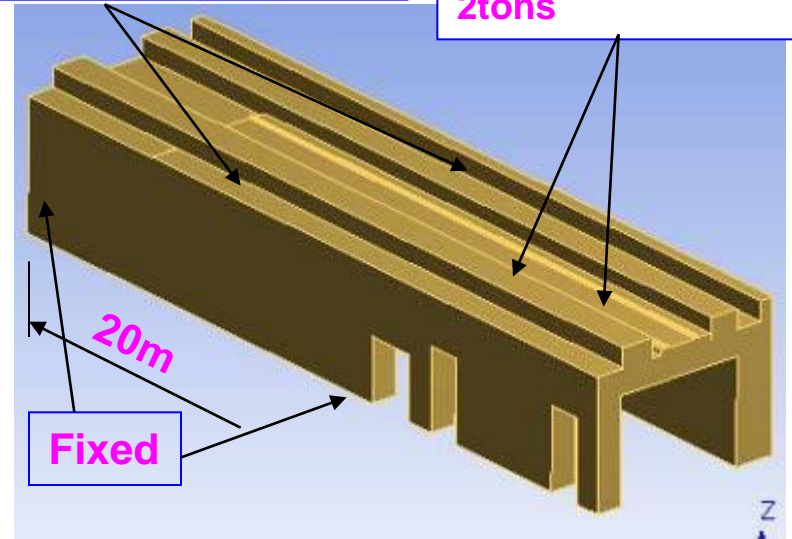
Calculation

1. Detector floor → KEKB floor



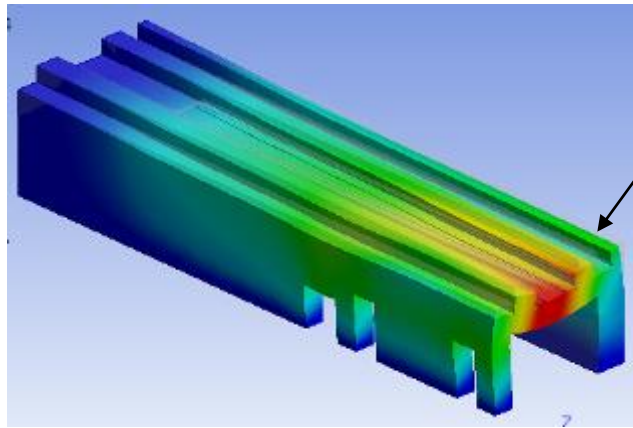
Weight of Concrete shield
300tons

Weight of magnets
2tons



Material
Concrete
E=30GPa
Density=2.3
Damping= 2%

Deformation



Deformation: 0.01mm

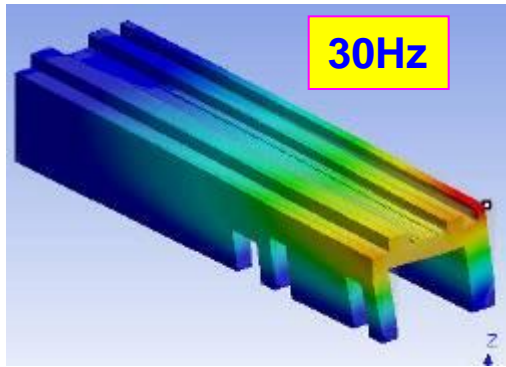
Concrete

E=30GPa

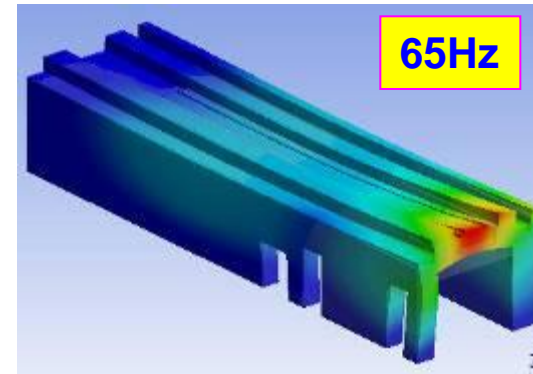
Density=2.3

Damping= 2%

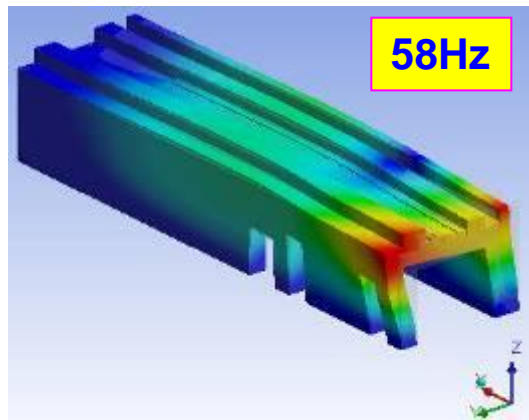
Natural frequencies



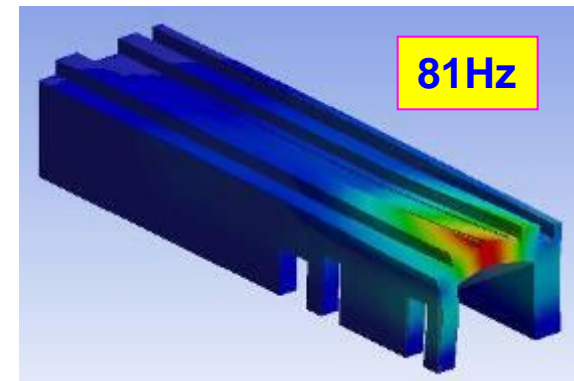
30Hz



65Hz

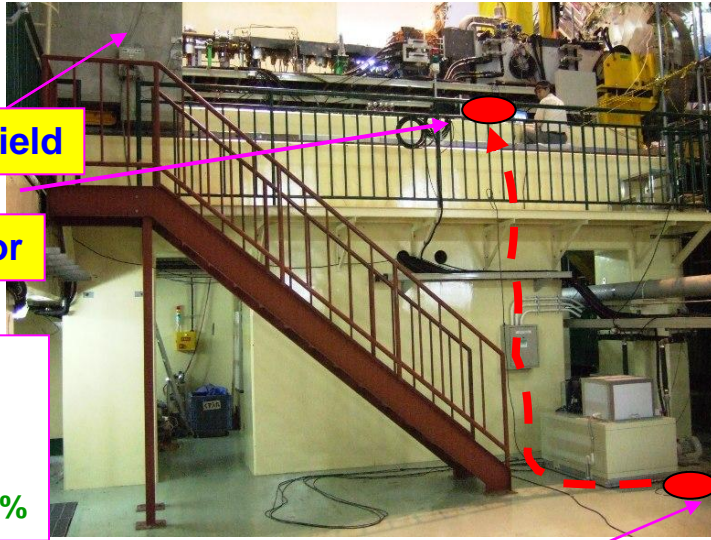


58Hz



81Hz

Respond P.S.D. at KEKB-concrete floor

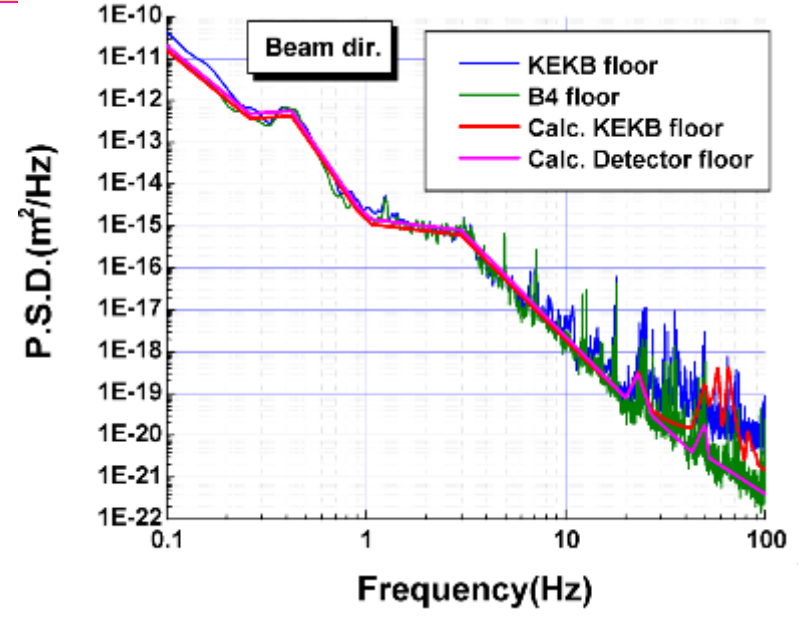
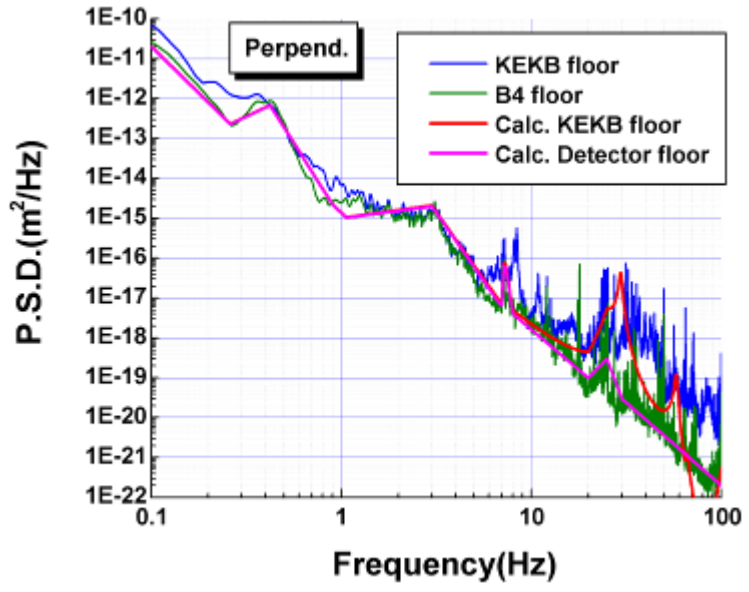
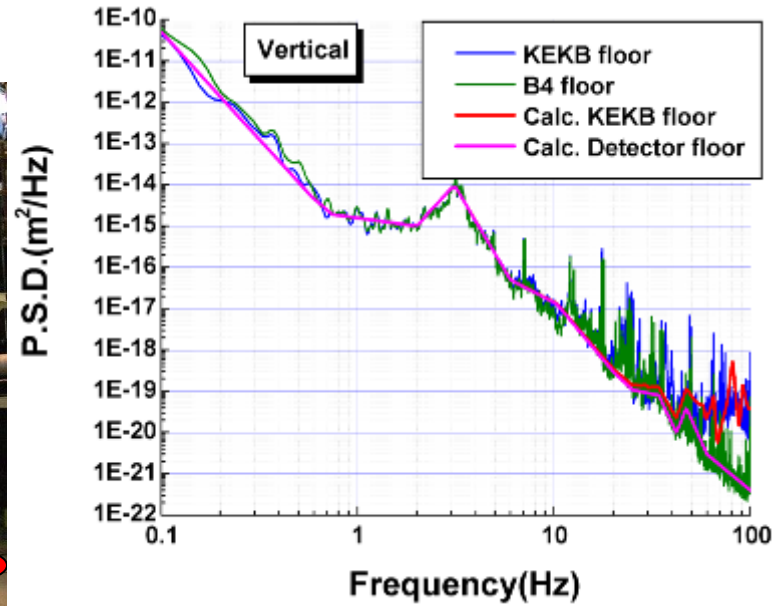


Concrete shield

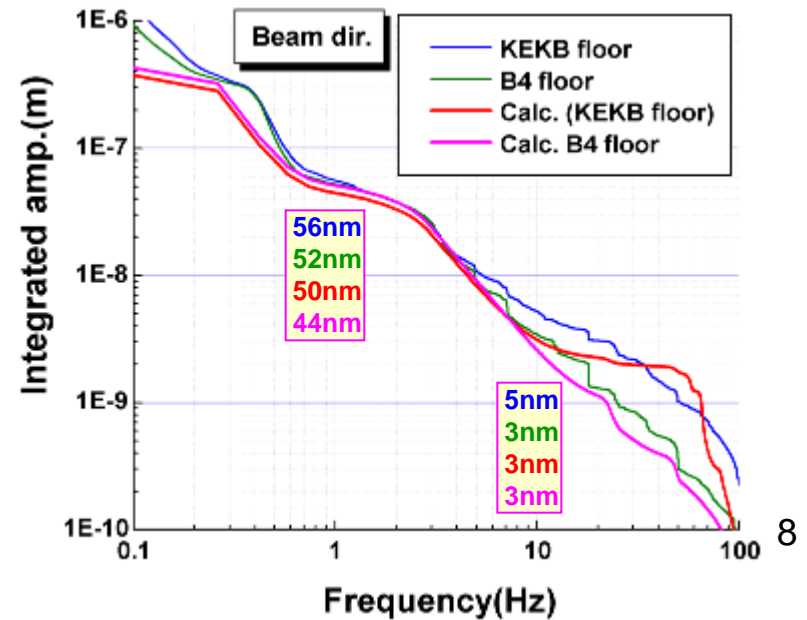
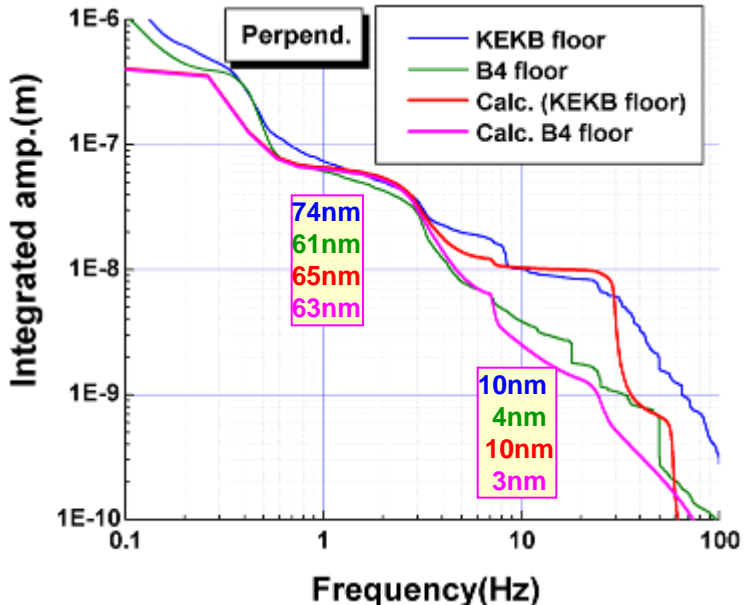
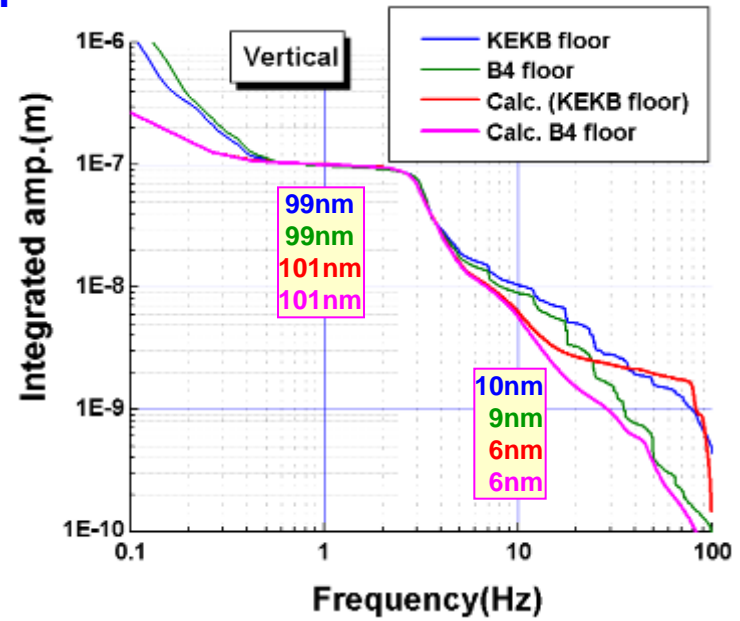
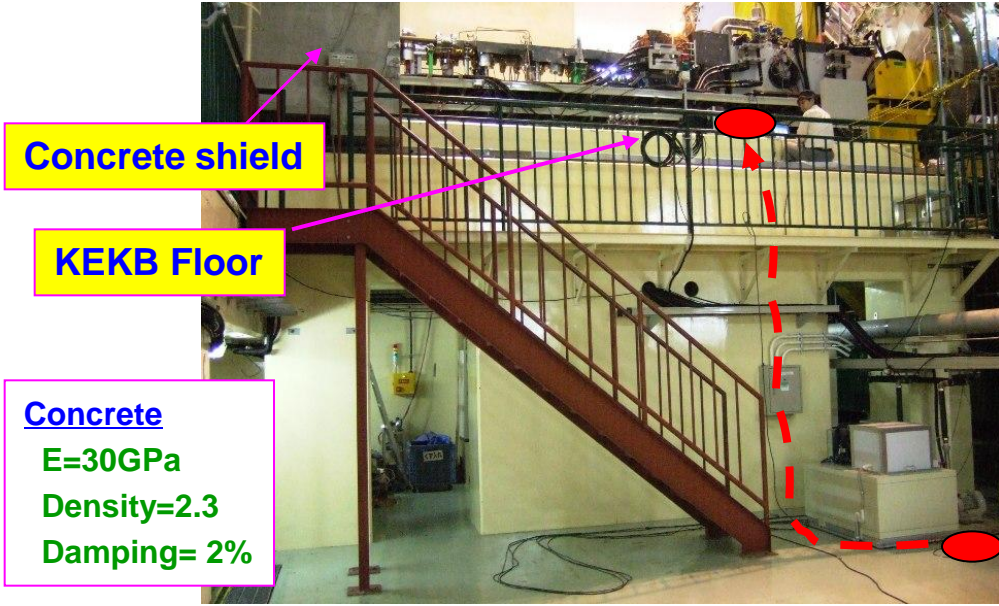
KEKB Floor

Concrete
 $E=30\text{GPa}$
 Density=2.3
 Damping= 2%

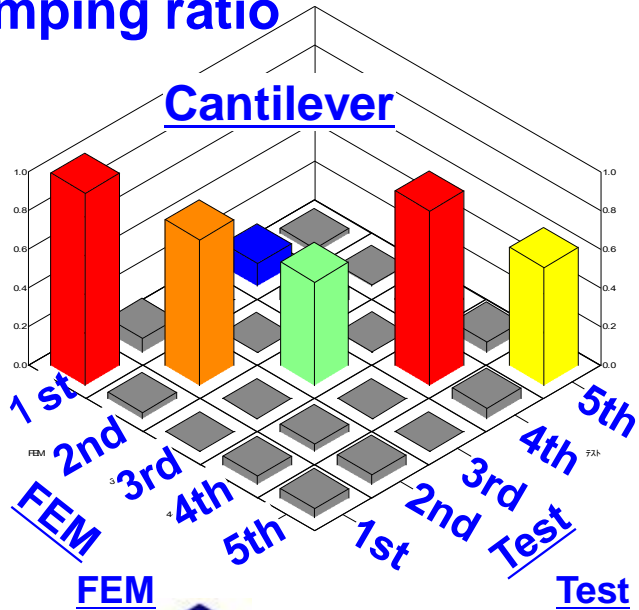
Detector floor(B4 Floor)



Integrated amplitudes of KEKB-concrete floor



Damping ratio



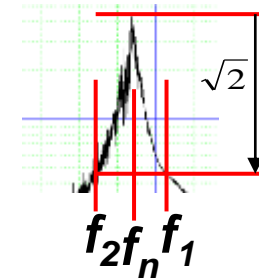
MAC(Modal Assurance Criteria)

$$MAC_{rr'} = \frac{|\langle \phi_r^{test} | \phi_{r'}^{FE} \rangle|^2}{\langle \phi_r^{test} | \phi_r^{test} \rangle \langle \phi_{r'}^{FE} | \phi_{r'}^{FE} \rangle}$$

Modal assurance criteria quantitatively compare all the possible combinations of test and analysis mode shape pairs.

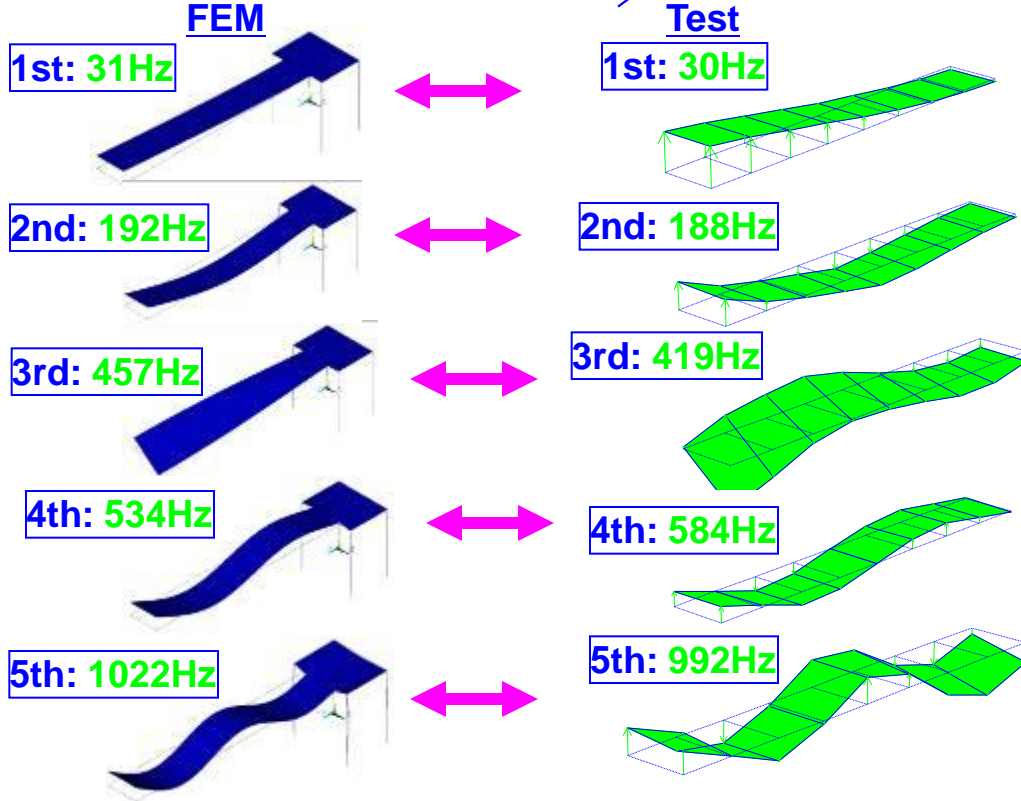
- MAC=1: Mode shape pairs is exactly match
- MAC=0: pairs that are completely independent

Damping ratio measurement

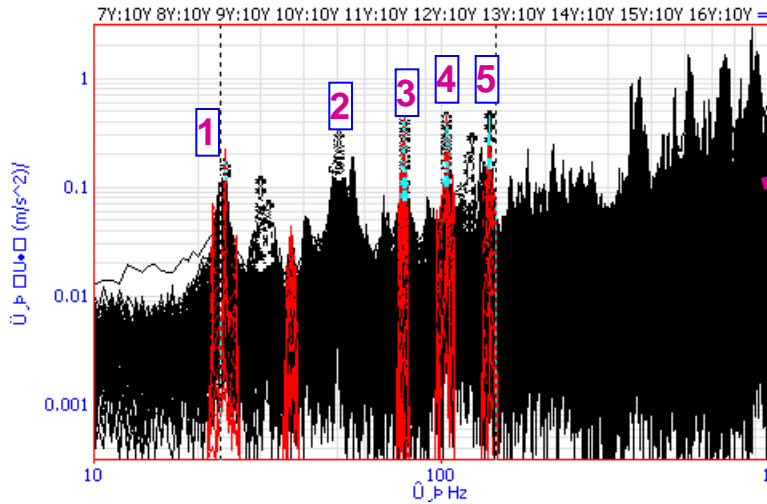


$$\zeta = \frac{f_1 - f_2}{2 \times f_n}$$

Mode	Freq.	Damping(%)
1	30.4Hz	1.68
2	188Hz	0.422
3	419Hz	0.303
4	584Hz	0.113
5	992Hz	8.02E-2

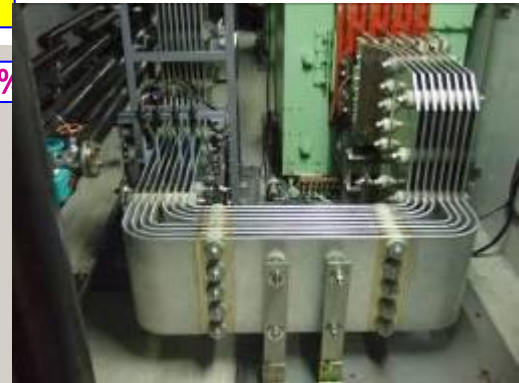


Bus bar line for horn magnet



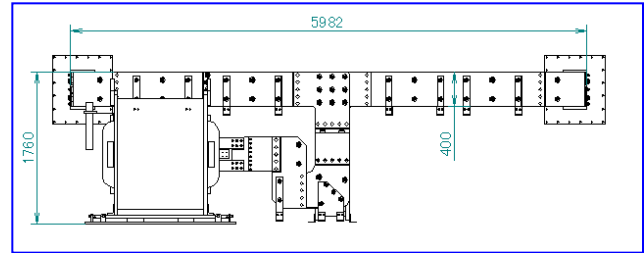
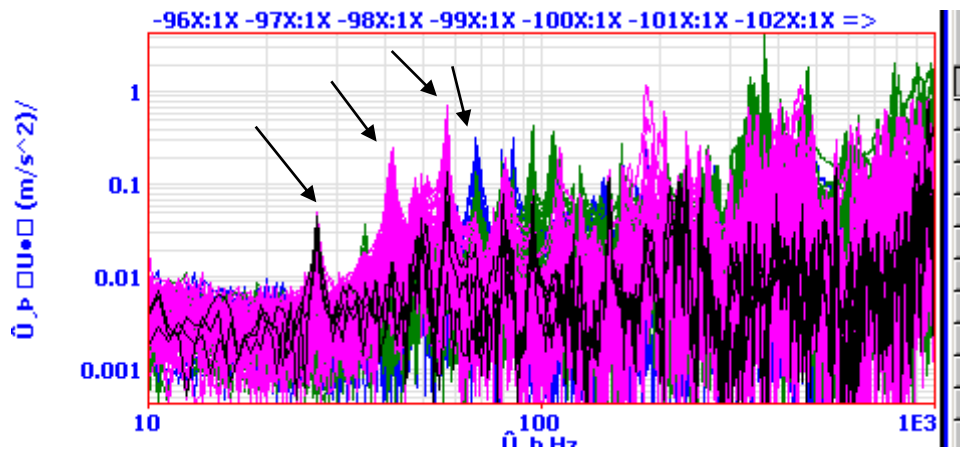
Measurement result-A

No.	Freq.(Hz)	damping (%)
1	23.7	0.196
2	50.9	0.678
3	77.8	0.276
4	103	0.842
5	137	0.474



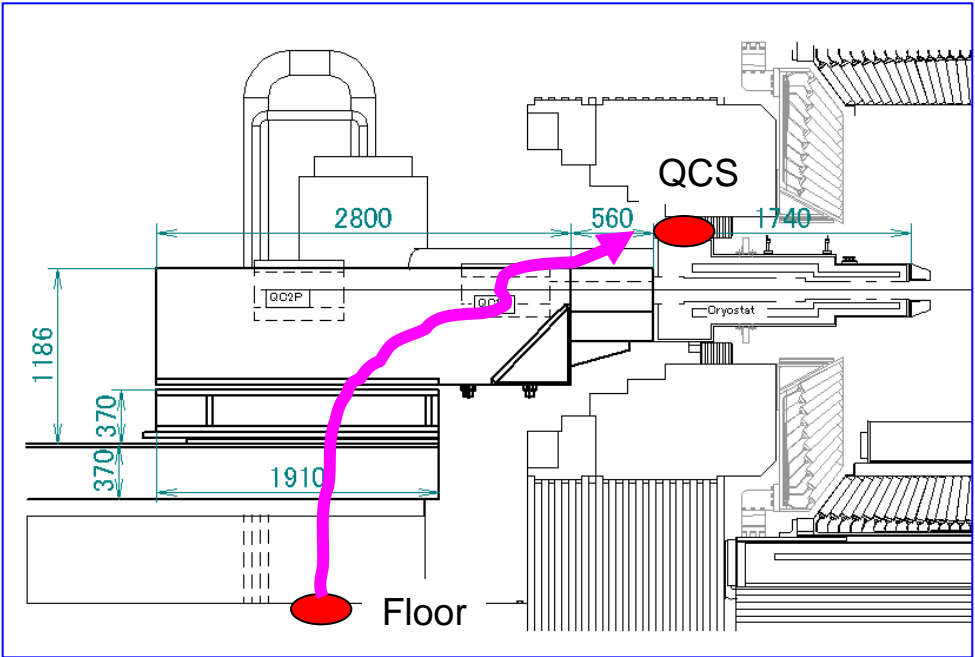
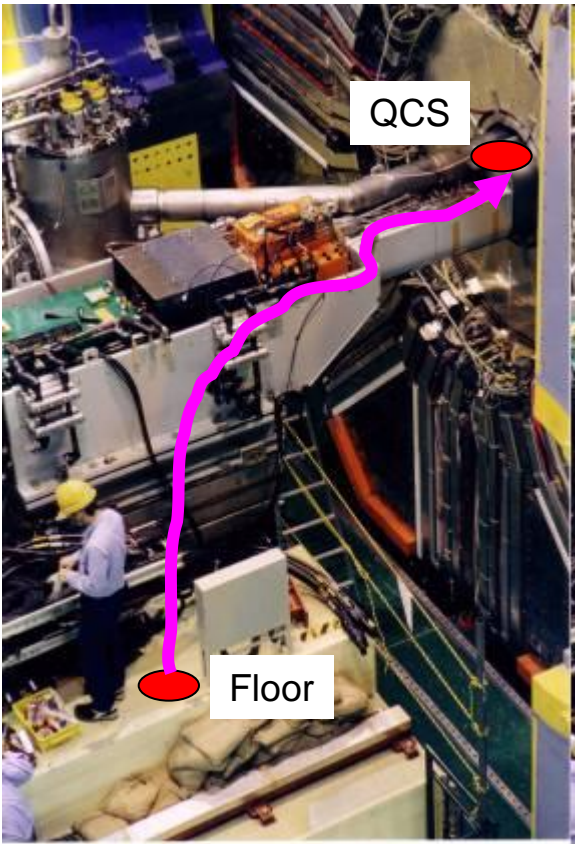
Measurement result-B

No.	Freq.(Hz)	damping (%)
1	26.861	0.66134
2	41.639	0.70658
3	57.435	0.38899
4	68.201	0.72795



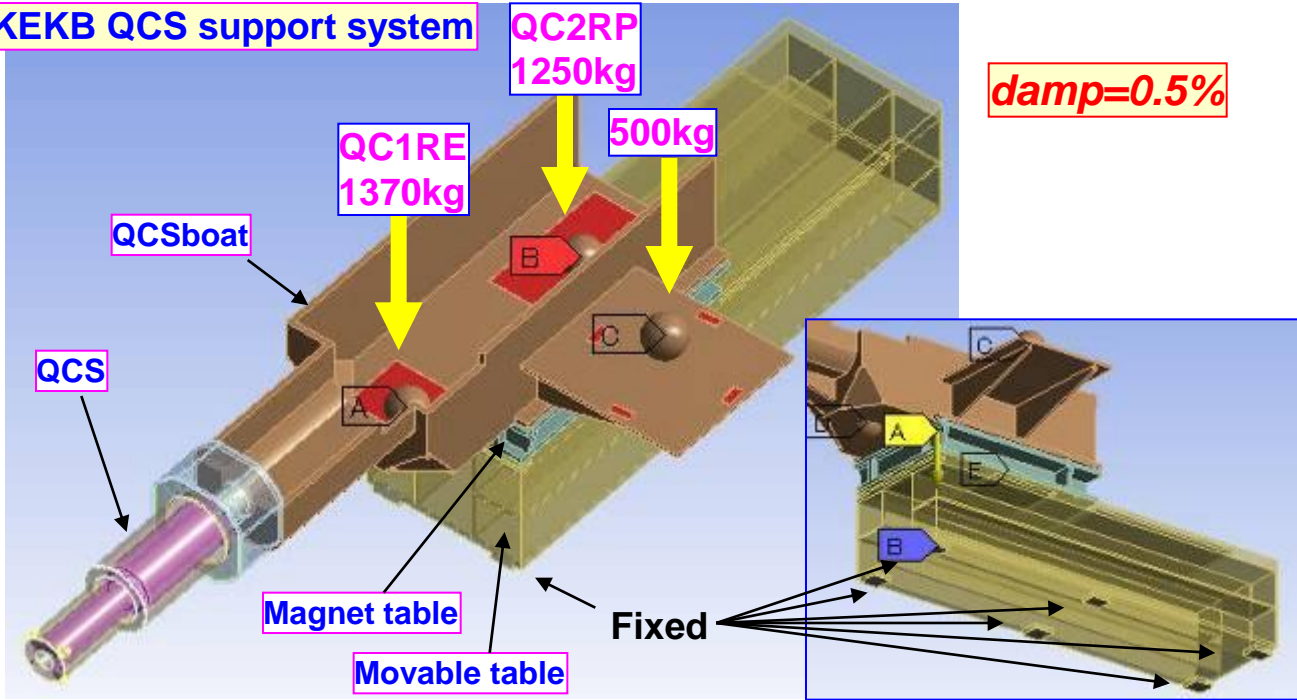
→ Damping ratio should be assumed to 0.5% in FEM. 2% damping seems too high.

2. Vibrations of KEKB-floor and QCS



→ Respond amplitude was calculated and check consistency btwn calc. and meas.

KEKB QCS support system



1. Loads

- Self-weight
- QC1RE: 1370kg
- QC2RP: 1250kg
- Box: 500kg

2. Materials

- Cryostat: SUS
- Coil: Cu
- Supp.-rod: Ti-alloy
- QCS table: SS400

3. Thread bolts

- 10-M30
- 6-M24

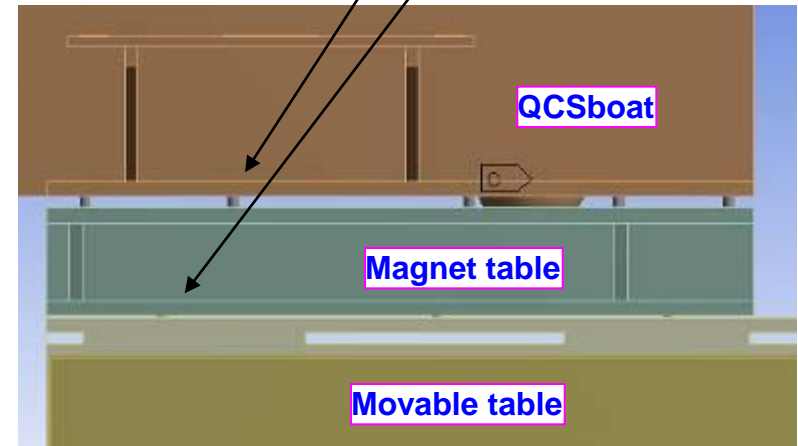
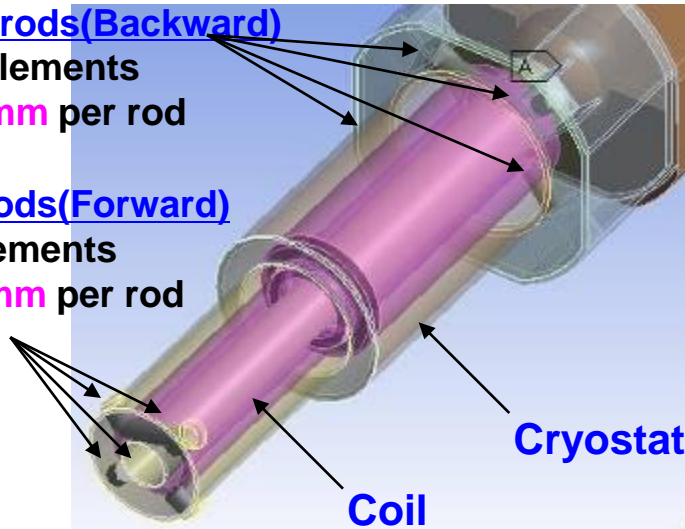
Pre-tension: Not defined

4. Support-rods(Backward)

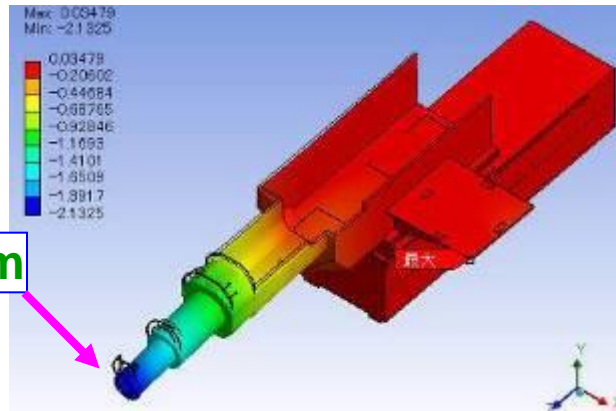
→ Spring elements
 $k=6171\text{kg/mm}$ per rod

5. Support-rods(Forward)

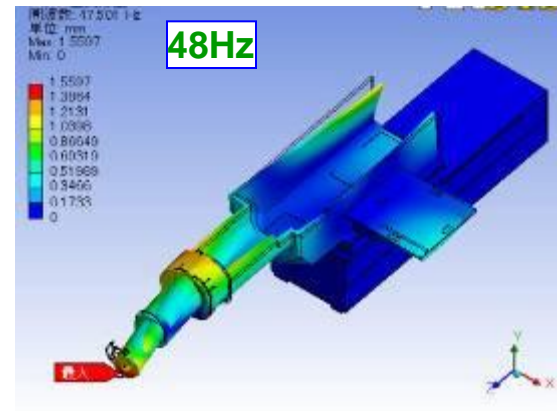
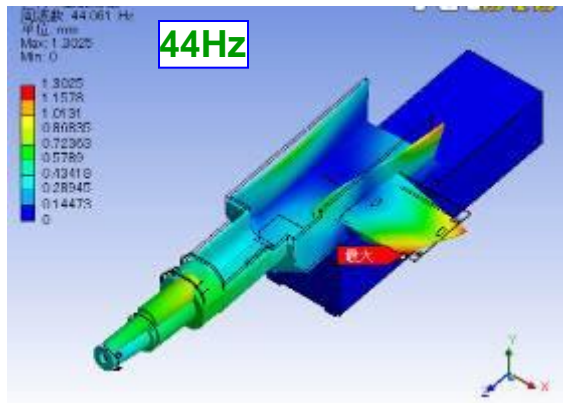
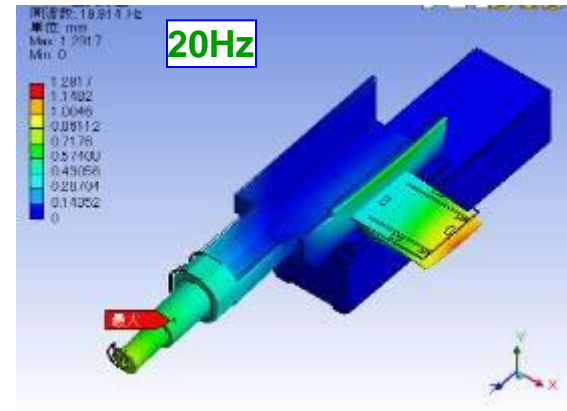
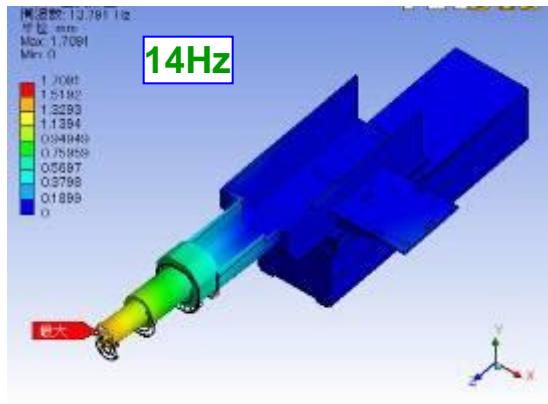
→ Spring elements
 $k=12521\text{kg/mm}$ per rod



Deformation

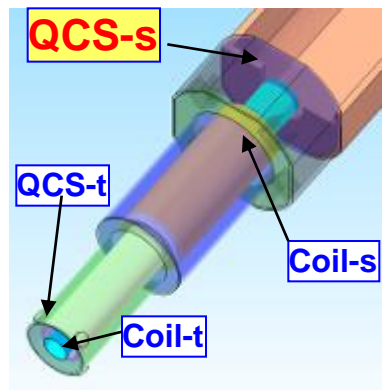
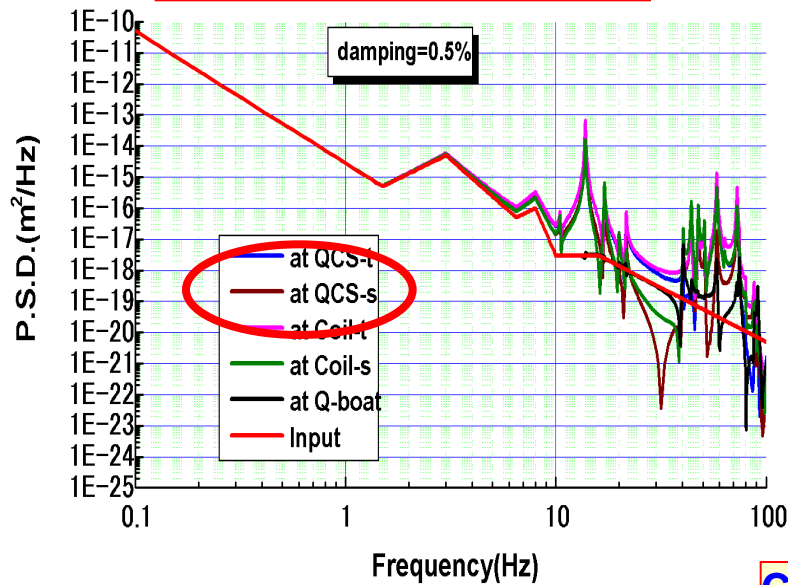


Modal calculation

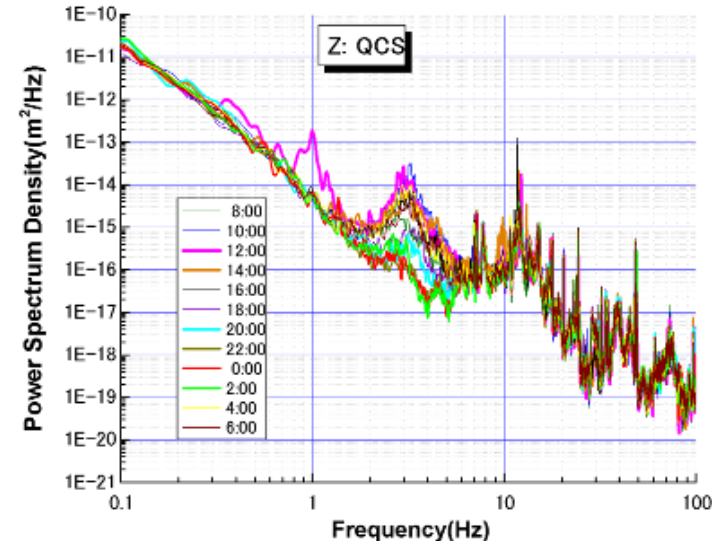


Response amplitude (Vertical direction)

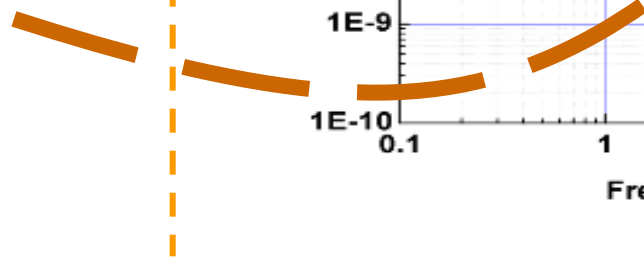
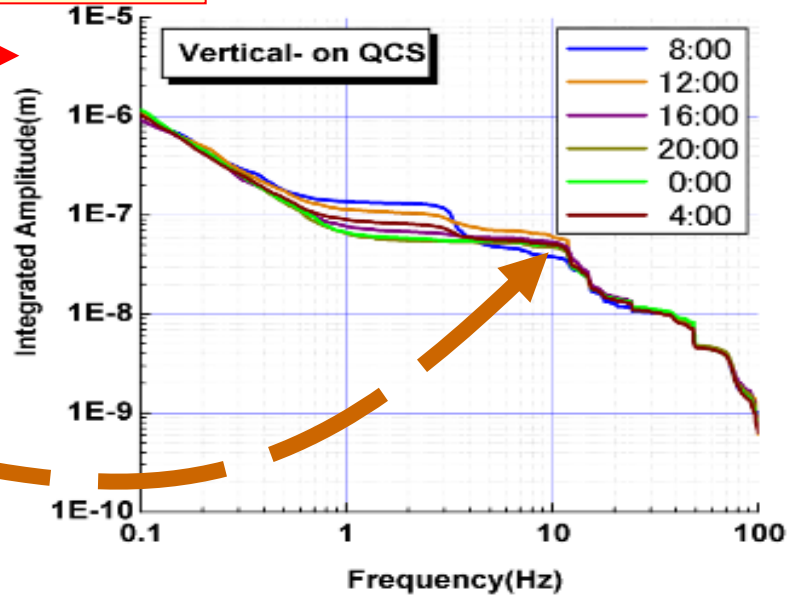
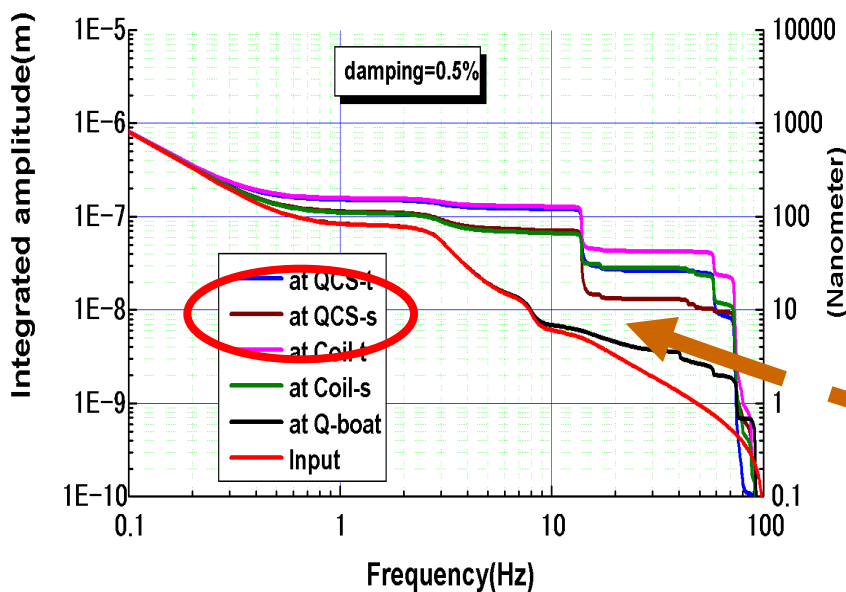
Calculation: *damp=0.5%*



Measurements @QCS-s



Calculation: Measurement



The belle platform

FEM model

Weight of End cap
= 300 tons(Total)

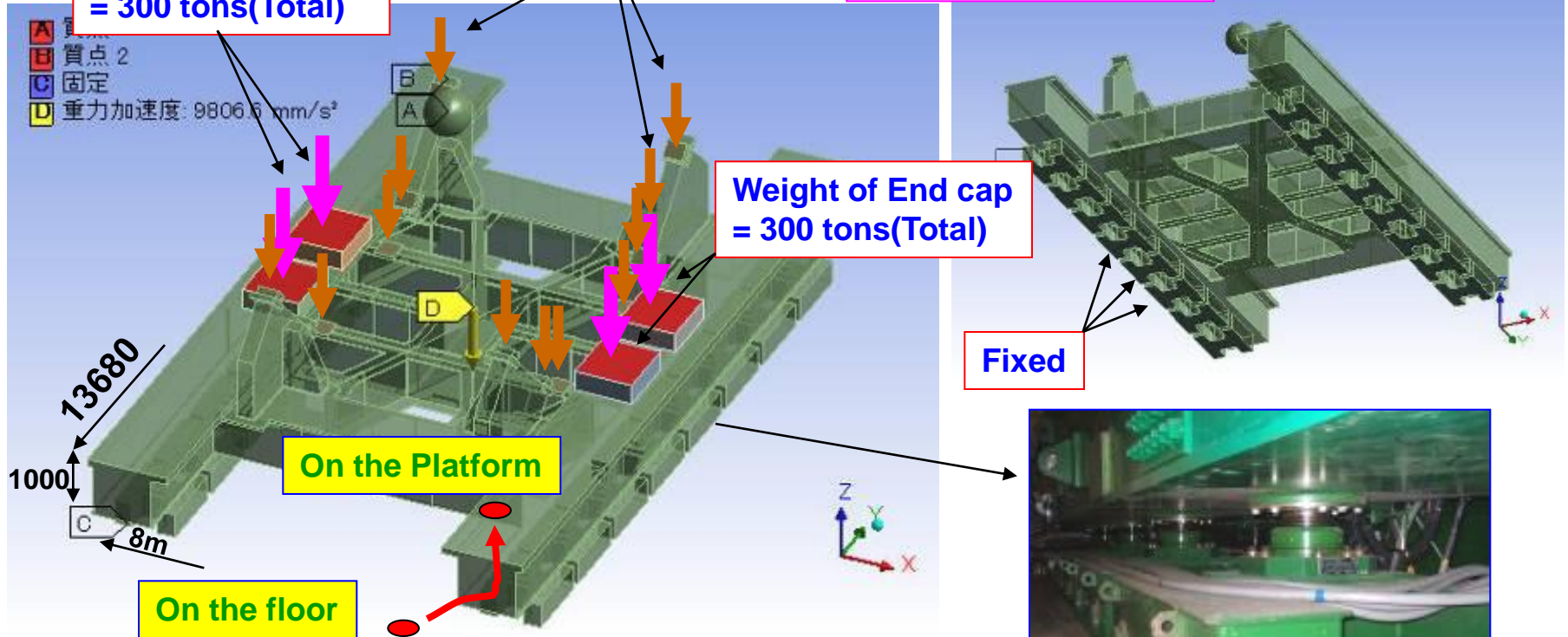
Weight of Barrel yoke
= 650 tons(Total)

Steel

$E=211\text{GPa}$

Density= 7.85

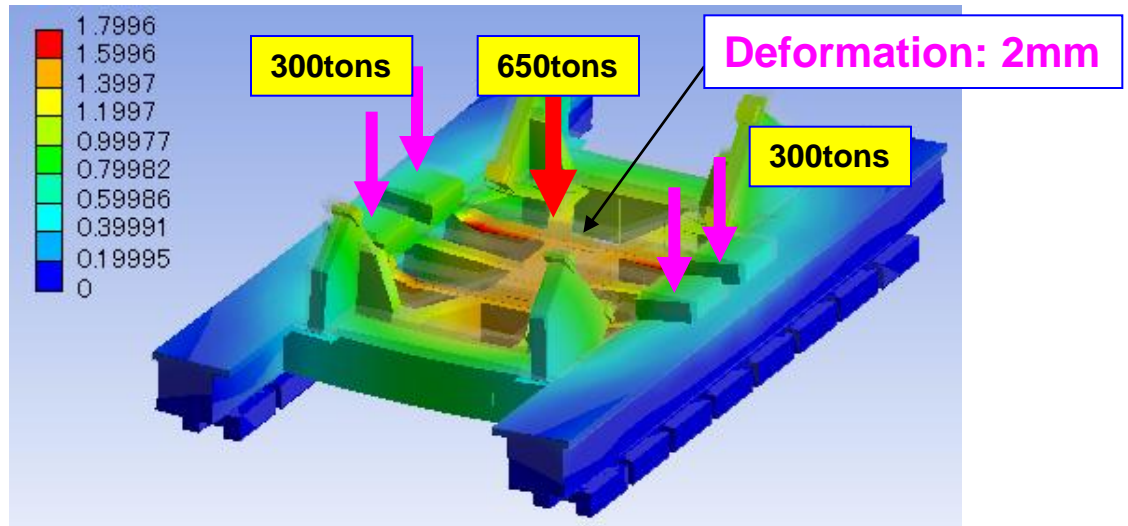
Damping= 0.5%



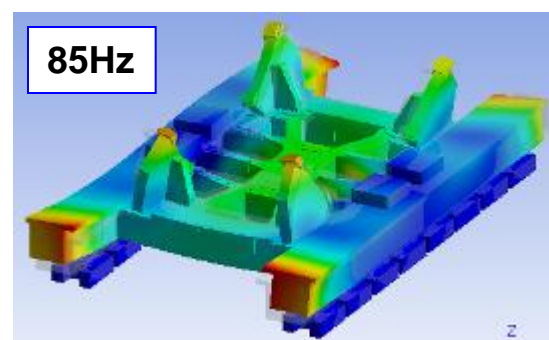
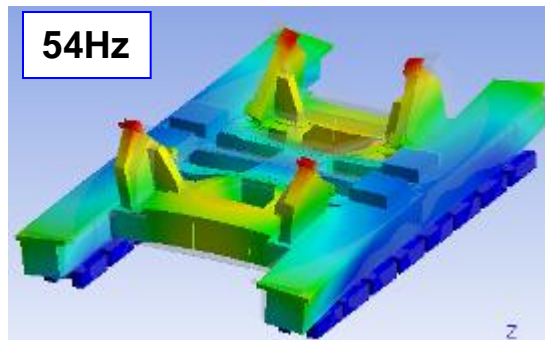
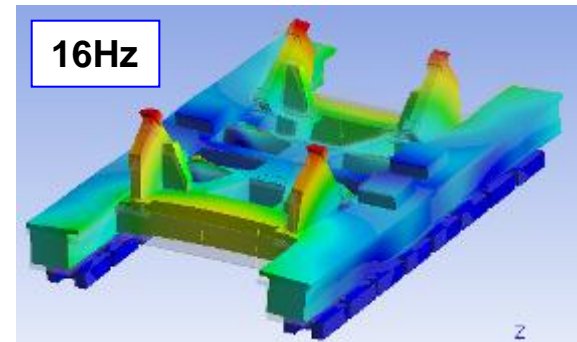
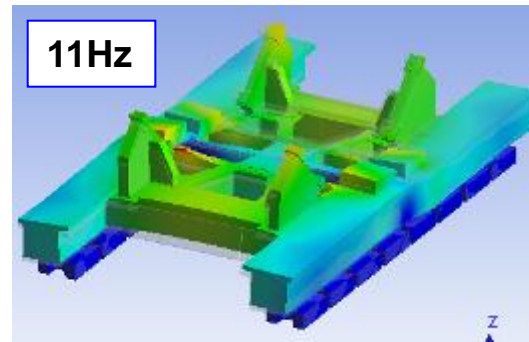
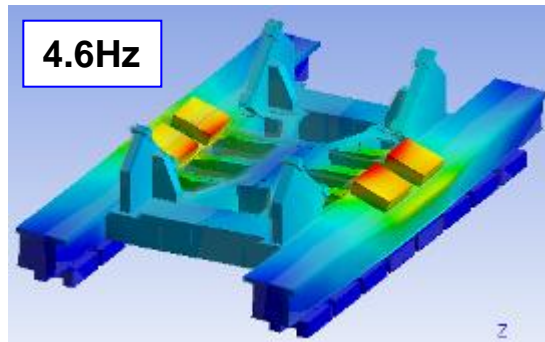
*The weight of end-caps and barrel yoke are taken into account.

The platform is assembled with square pipes reinforced by ribs.

Deformation

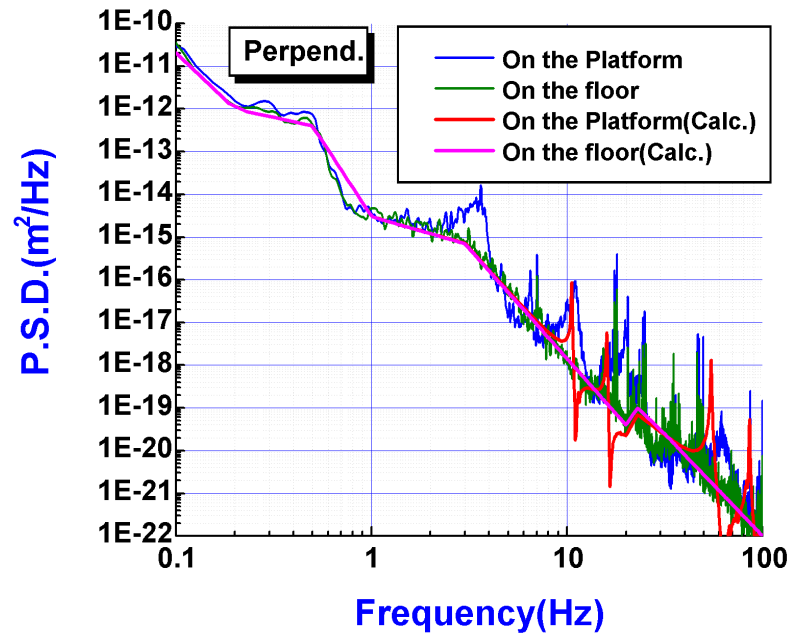
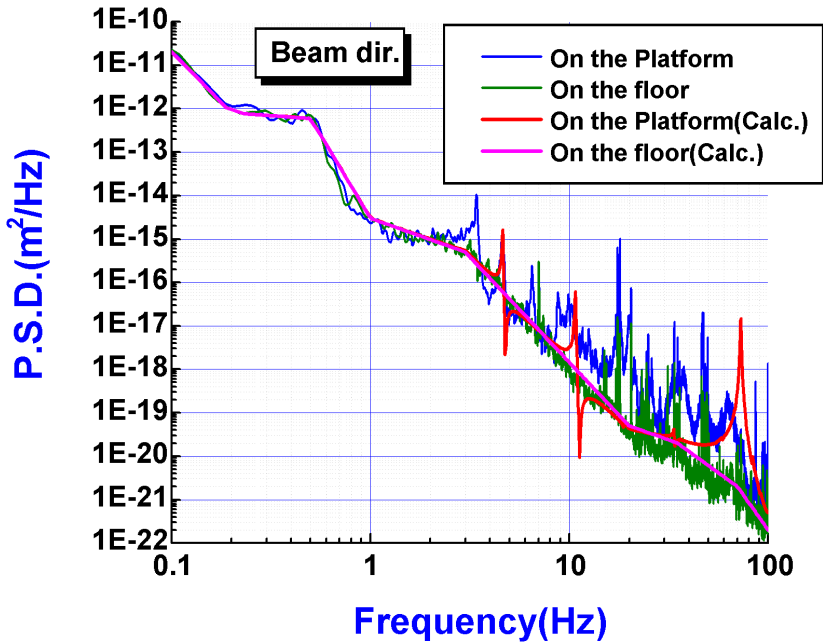
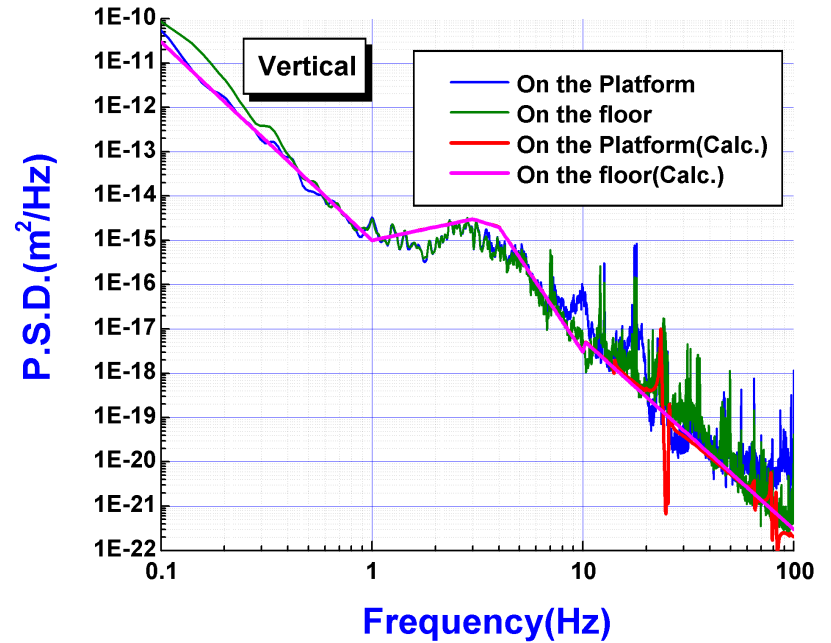
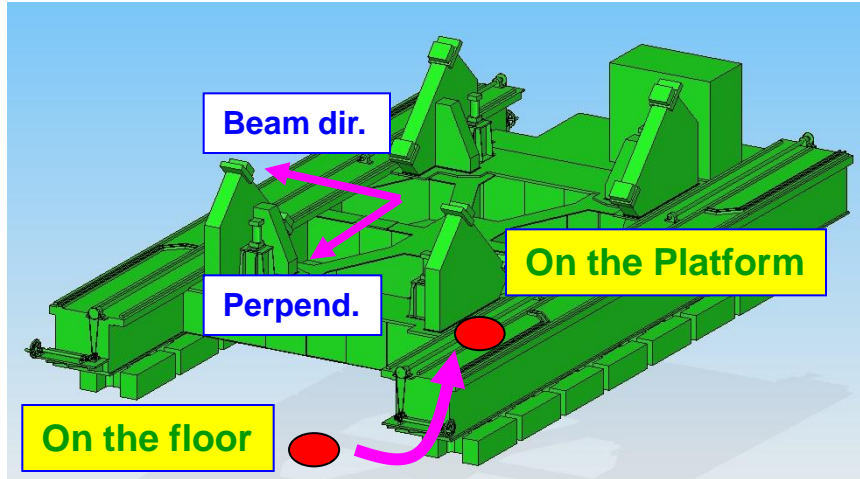


Natural frequencies

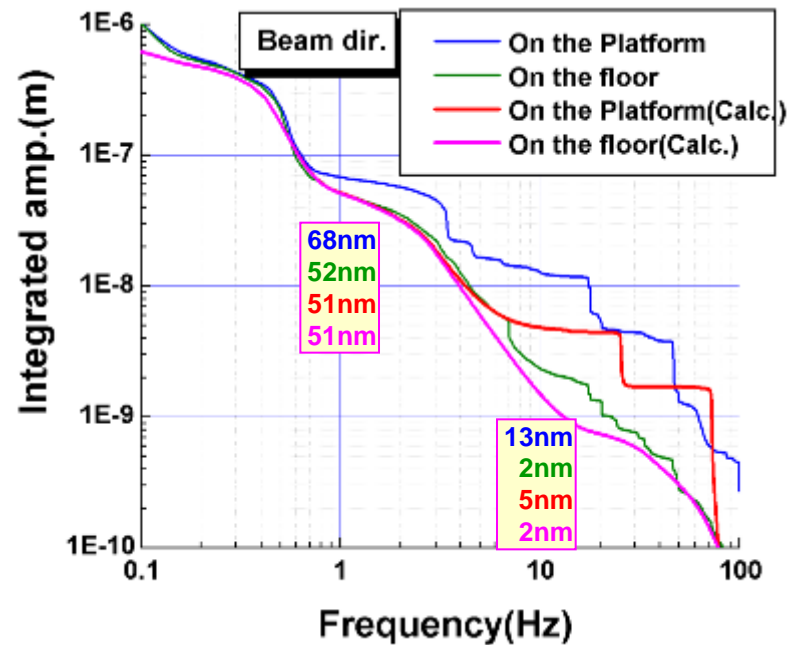
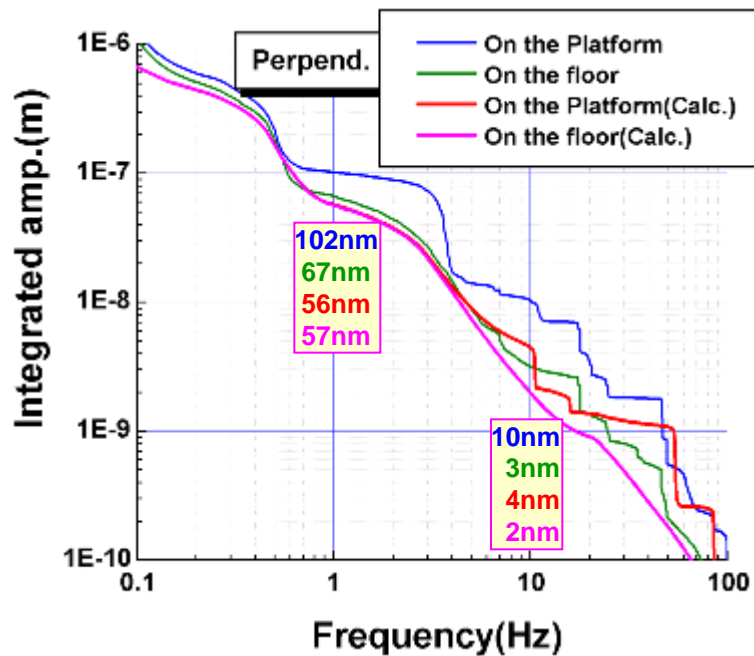
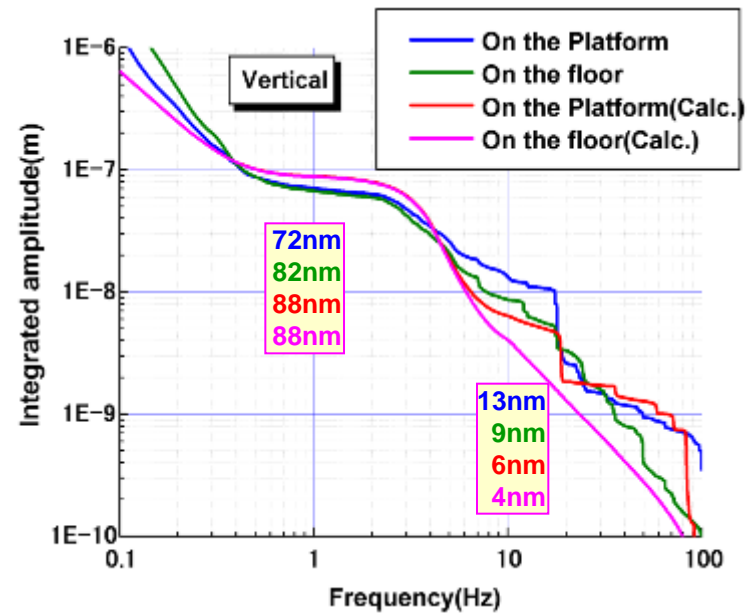
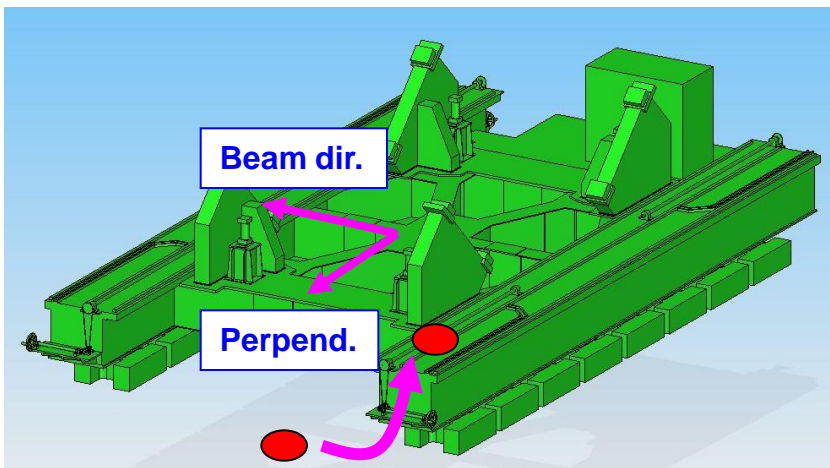


*The weight of end-caps and barrel yoke are taken into account.

Vibrations(P.S.D.)



Vibrations(Amplitude)

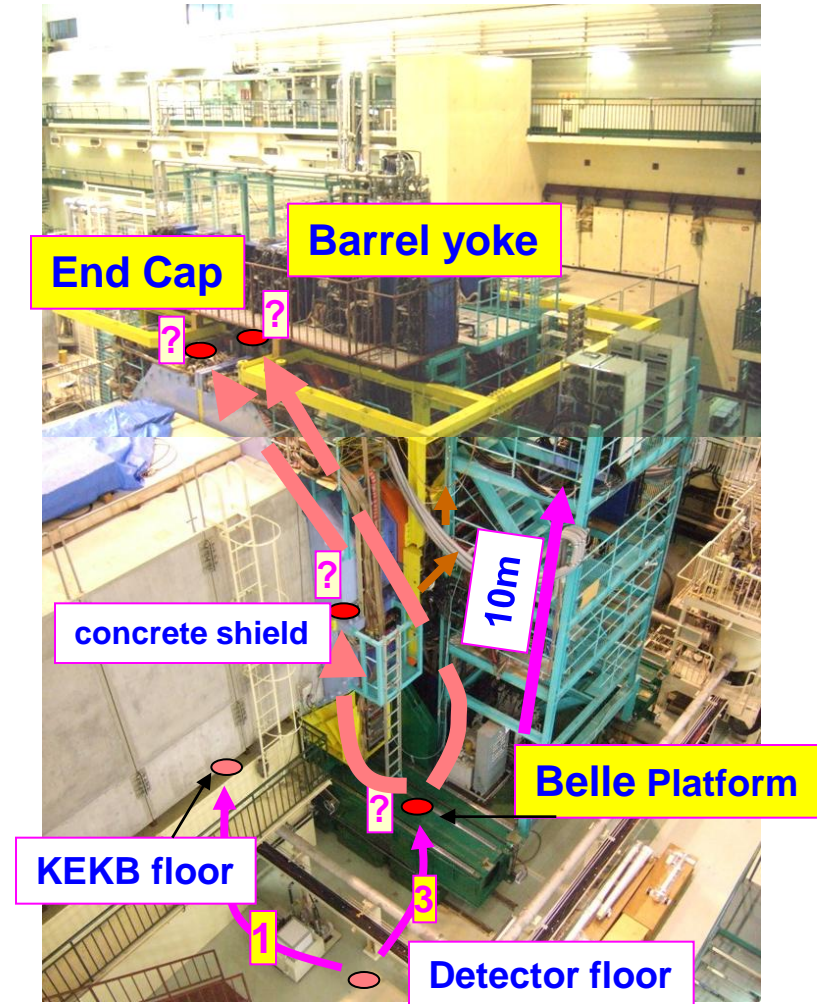
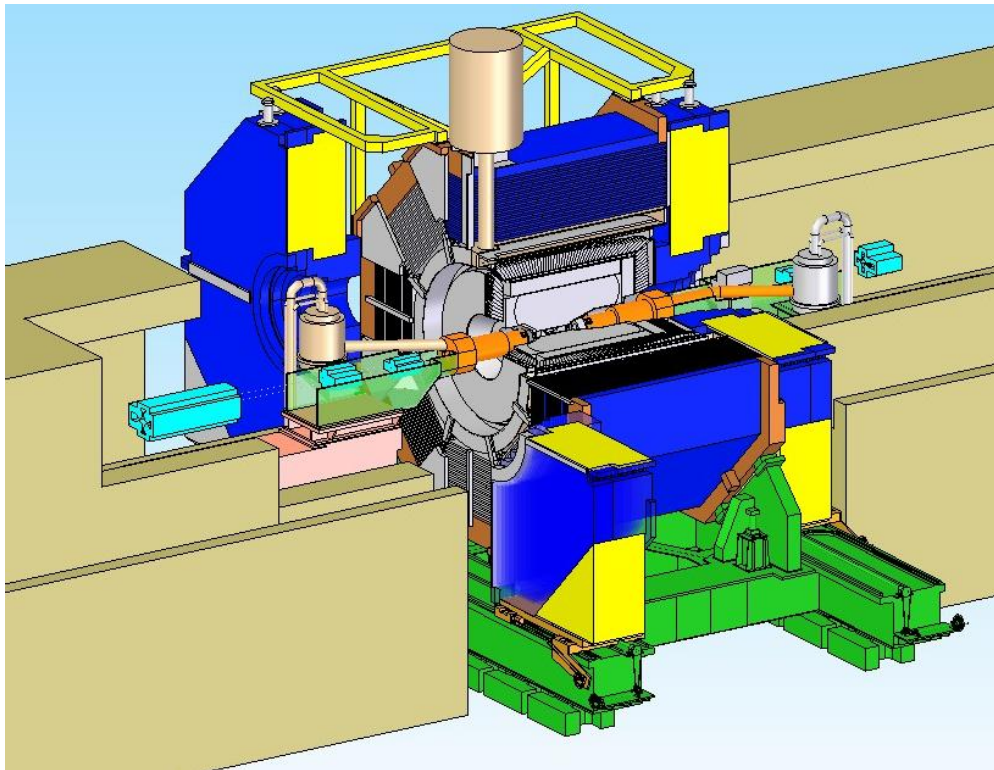


4. Belle platform → End cap/ Barrel yoke

Sorry, this issue hasn't finished yet.

Because,

- The size of FEM model is very big.
- Needs special techniques to reduce the size.



5. Vibration measurement at KEK

Vibration measurement *during the magnet excitation*

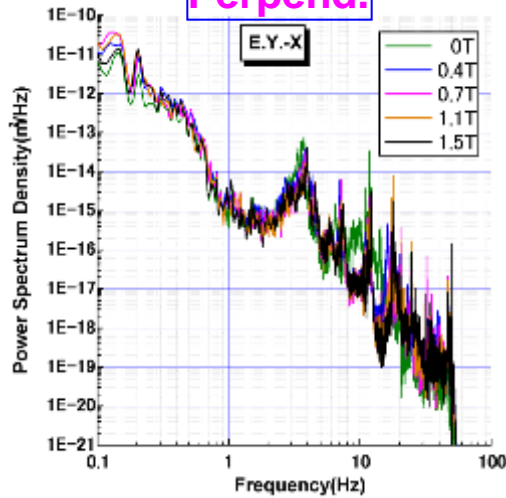
Operating principle:	Electrochemical motion transducer with high damping coefficient
Output signals	Velocity-flat response
Output signal swing	+/-20V (40 V p-p differential)
Dynamic Range	120 dB @ 1Hz
Bandwidth	1 – 75 Hz; <i>Optional: 100Hz</i>
Sensitivity	1 nm @ 10 Hz
Generator constant	<i>Standard: 2000 V/m/s; Opt.: 350 – 20,000 V/m/s</i>
Mass Lock	NONE REQUIRED
Mass Centering	NONE REQUIRED
Maximum installation tilt	Std +/-10 deg (<i>Optional: fully operational at any random orientation</i>)
Mechanical resonances	>200 Hz
Temperature range	Standard: -12 to + 55 °C
Dimensions	75 x 110 x 150 mm
Weight (Al housing)	Appx 0.75 kg
Power – Standard	10 – 15 Vdc; 12 Vdc nominal
Supply current	30 mA



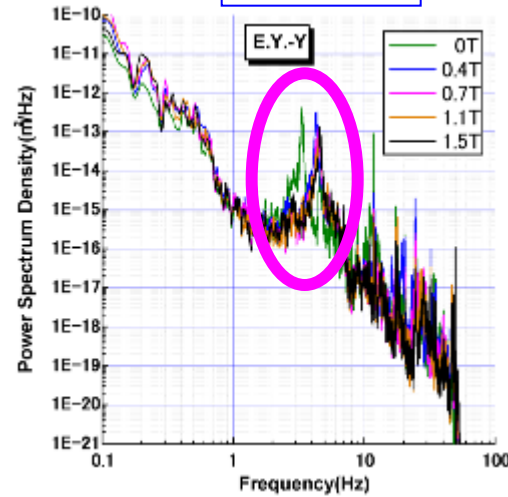
Vibration Measurement *during the magnet excitation*

End-yoke

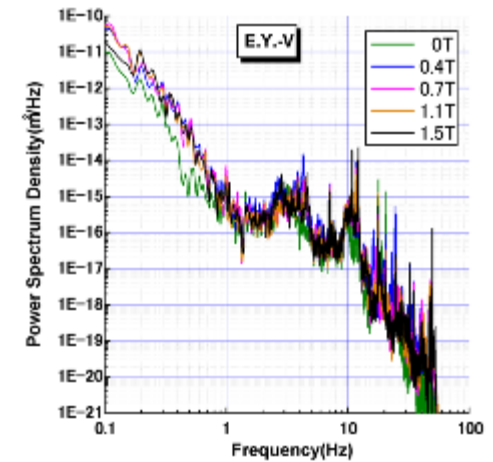
Perpend.



Beam-dir.

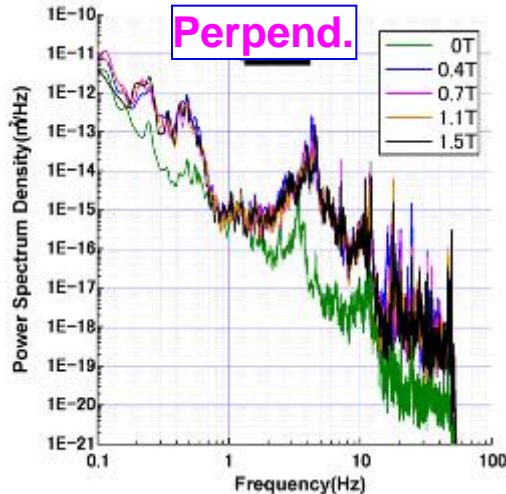


Vertical

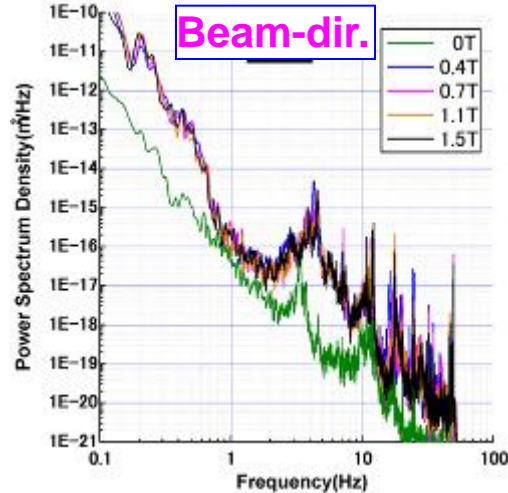


Barrel-yoke

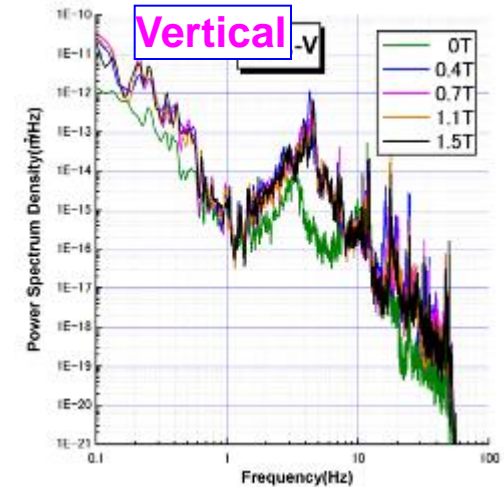
Perpend.



Beam-dir.

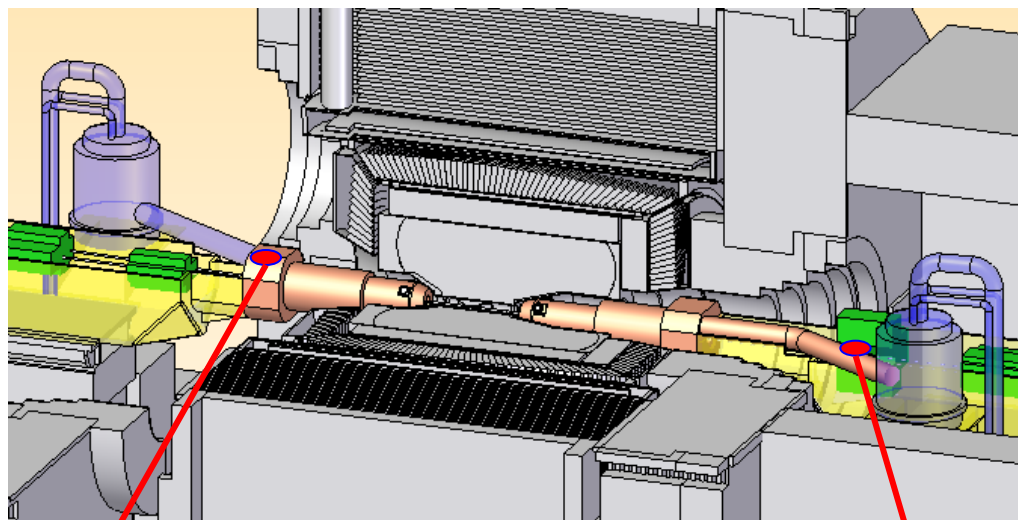


Vertical

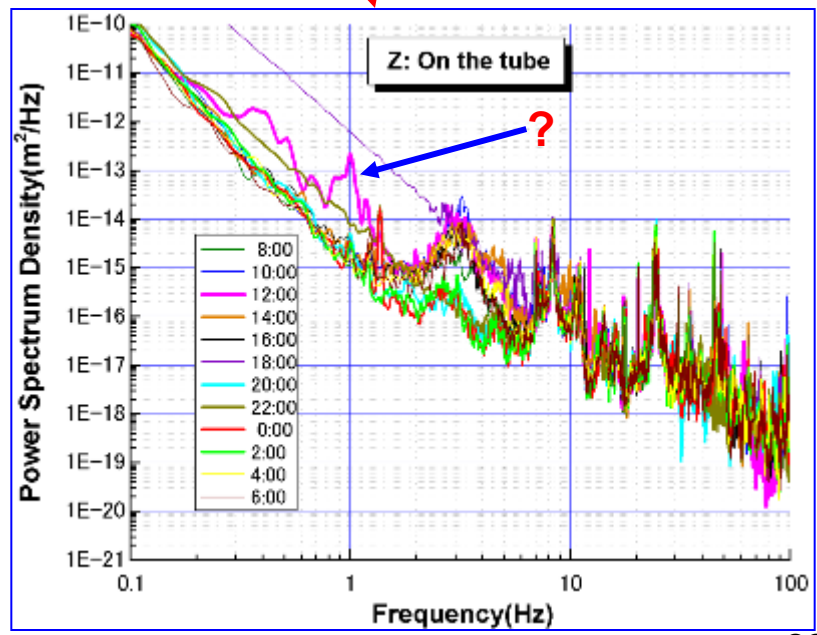
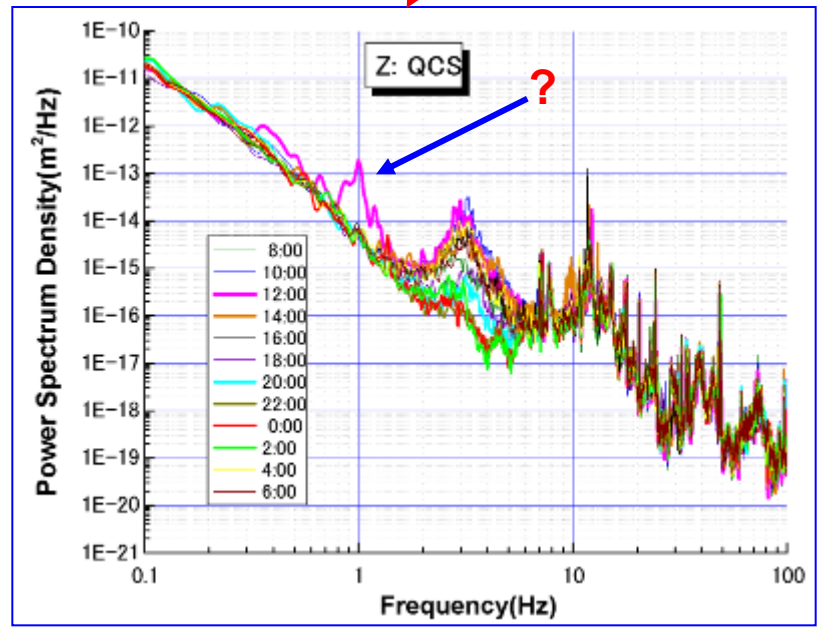


→ Vibrations when the magnet excitation shows different behavior,
Effect of magnetic force should be taken into account in the calculation.

Other measurement: Effect of the QCS magnet cooling-down



P.S.D. in the vertical direction



- What happened at 12:00?? → **Cooling just had been begun.**

Conclusions

Vibration analysis has been performed and compared to measurement data.

1. Detector floor → KEKB floor

Good consistency, FEM model is simple.

Vibration effect is small above 1Hz/10Hz because of high natural frequencies.

2. KEKB floor → QCS magnet

Good consistency.

3. Detector floor → Belle platform

Relatively good.

If the FEM model makes more precisely, it will become better consistency.

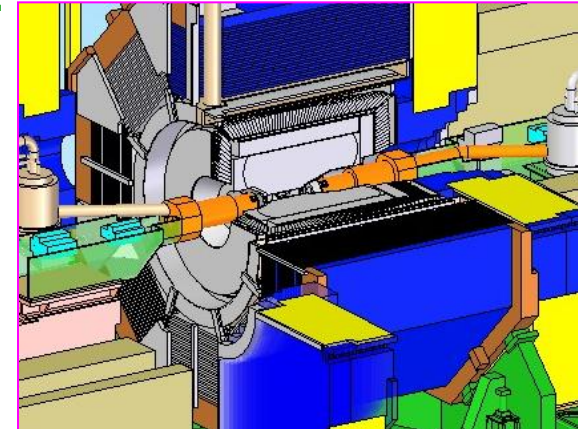
4. Detector floor → End caps/Barrel yoke: Not yet.

Some special techniques for FEM needed due to very large model.

Effect of the magnetic force should be taken into account.

Vibration measurements at KEK

- Belle roll-out will be done in early/middle of Dec.
→ Vibration during roll-out will be measured.
- Vertex detector will be removed from the Belle in mid. Nov.
→ Vibration at central region will be measured.



Detector level was adjusted to the beam level 12 years ago.

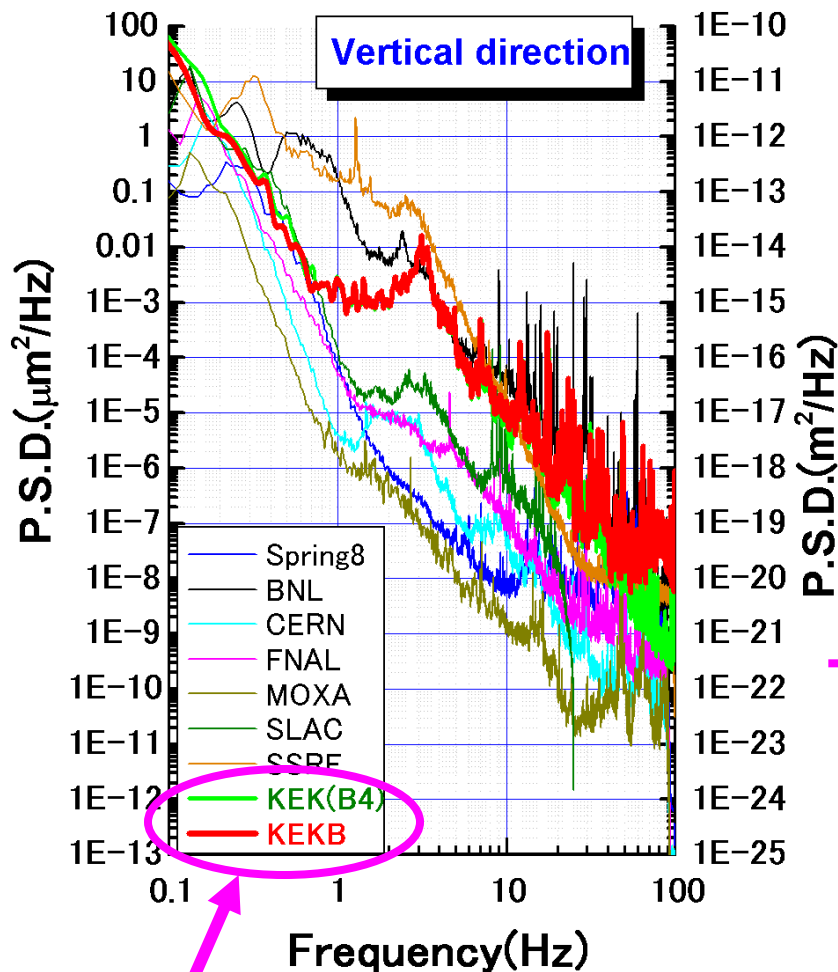
Re-adjustment to the beam level hasn't been done so far.

Detector level also hasn't measured.

→ Detector level will be measured before roll-out.

Comparison of ground motion with various sites

Reference: <http://vibration.desy.de/overview/>

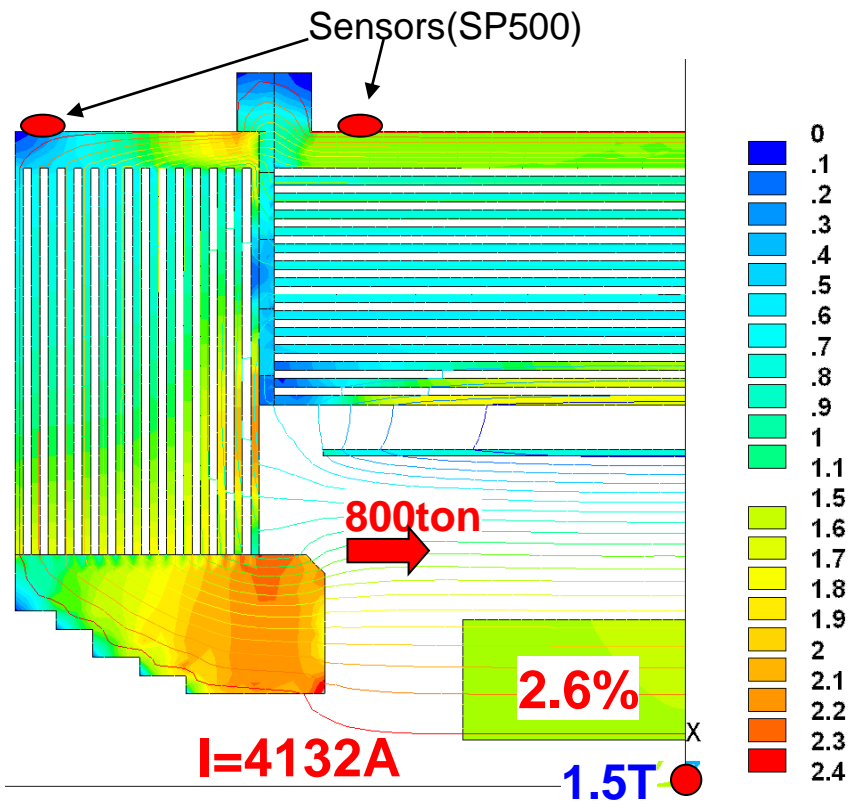
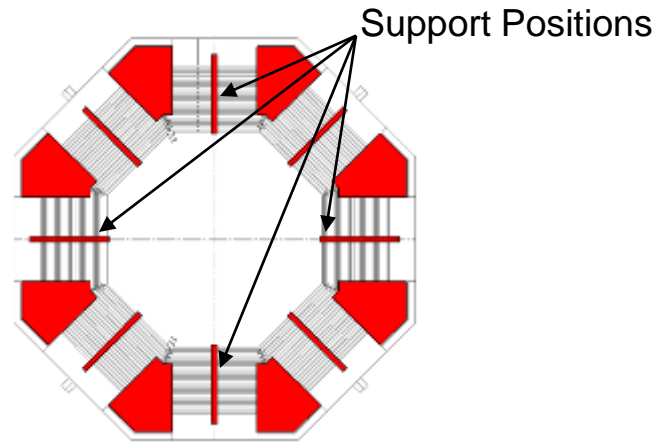


Overview of Measured Sites (Vertical Direction, >1Hz)			
Site location	Average rms (nm)	Day rms (nm)	Night rms (nm)
ALBA, Barcelona, Spain	18.8	42	9.1
APS, Argonne, U.S.A.	10.7	11	9.8
Asse, Germany (salt mine)	0.6	0.7	0.5
BESSY, Berlin, Germany	75	140.7	53.1
BNL, Upton, U.S.A.	89.6	135.3	29.1
CERN LHC, Geneva, Switzerland	1.9	2.8	0.9
DESY HERA, Hamburg, Germany	53.3	77	34.8
DESY XFEL, Osdorf, Germany	29.1	48.4	19.5
DESY XFEL, Schenefeld, Germany	41.1	70	35.1
DESY, Zeuthen, Germany	64.4	75.6	88.5
Ellerhoop, Germany (TESLA IP)	18.2	35.9	9.3
ESRF, Grenoble, France	74	137.2	40.2
FNAL, Batavia, U.S.A.	3	4	2.2
IHEP, Beijing, China	8.5	9	8.1
KEK, Tsukuba, Japan	80.5	125.1	38
LAPP, Annecy, France	3.6	7	1.9
Moxa, Germany (seismic station)	0.6	0.9	0.5
SLAC, Menlo Park, U.S.A.	4.9	7.4	4.1
Spring-8, Harima, Japan	2	2.5	1.8
SSRF, Shanghai, China *	292	444	102

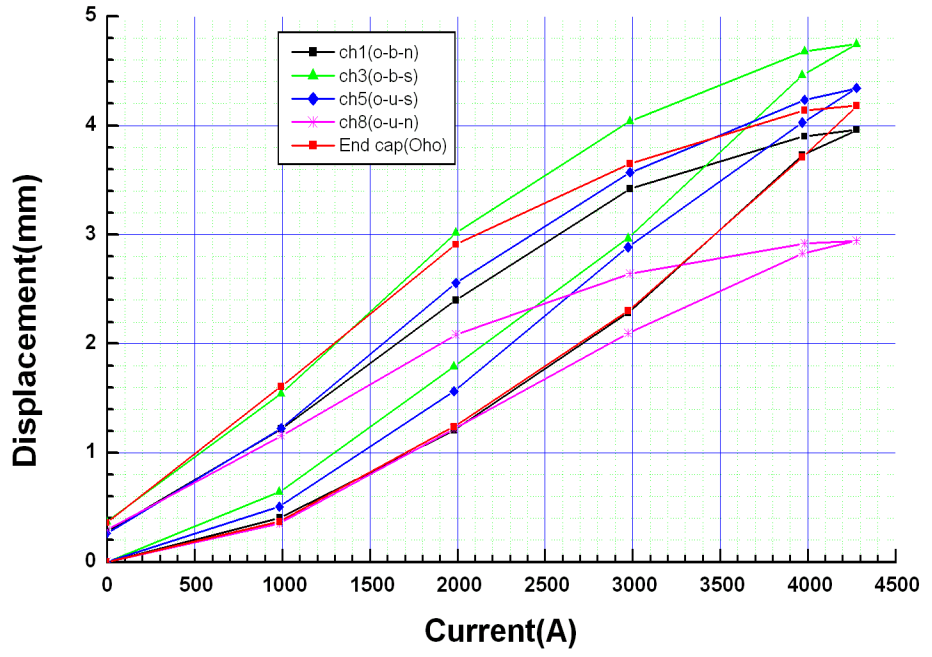
Reference: <http://vibration.desy.de/overview/>

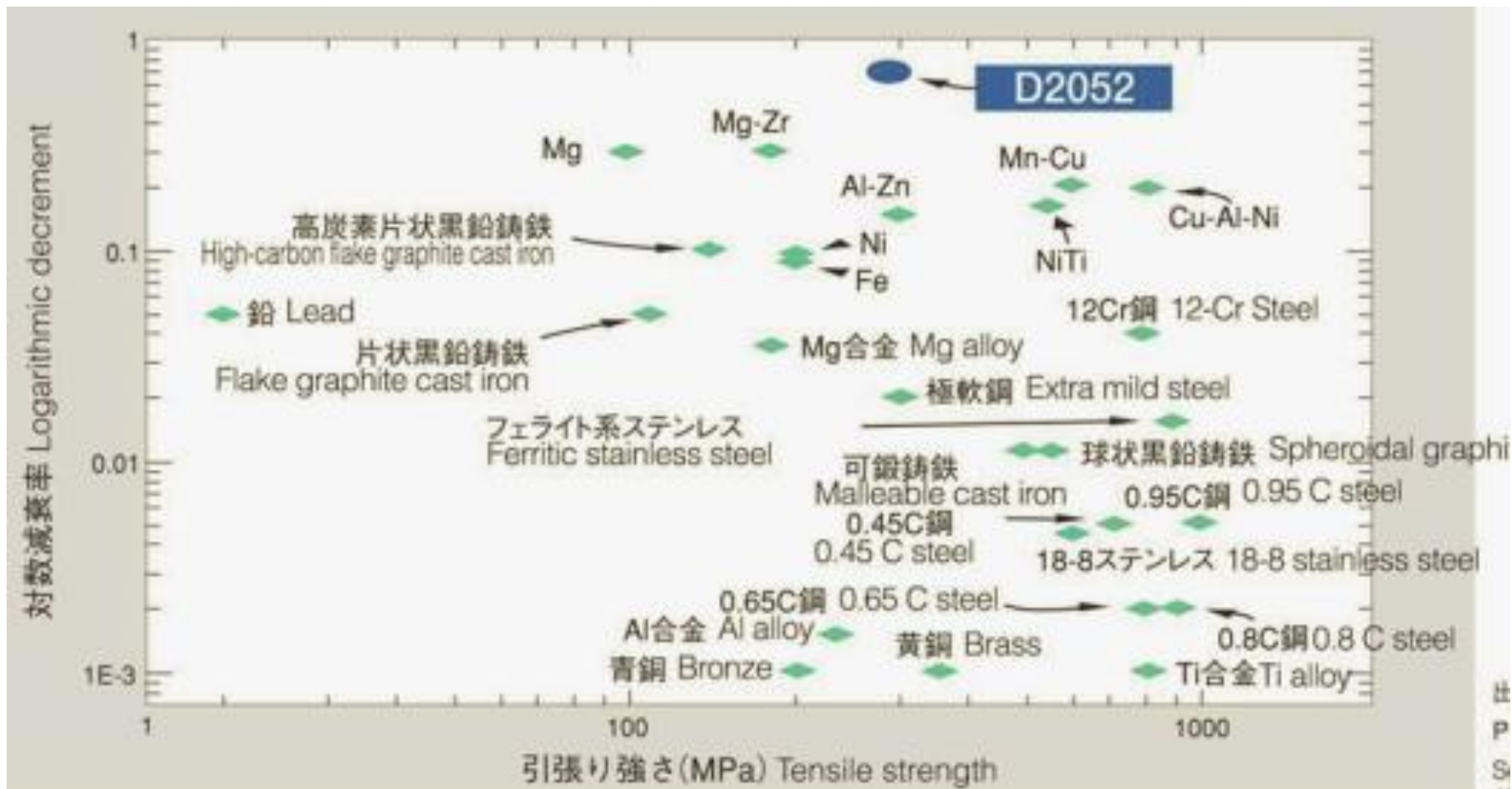
Ground motion at KEK is relatively high.

The Belle solenoid magnet/Yoke

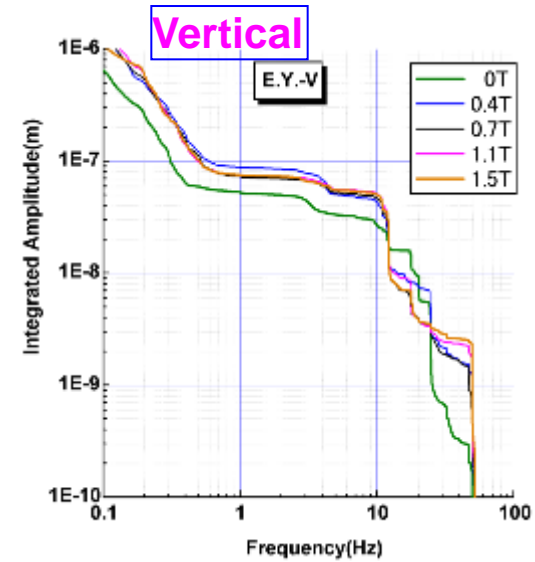
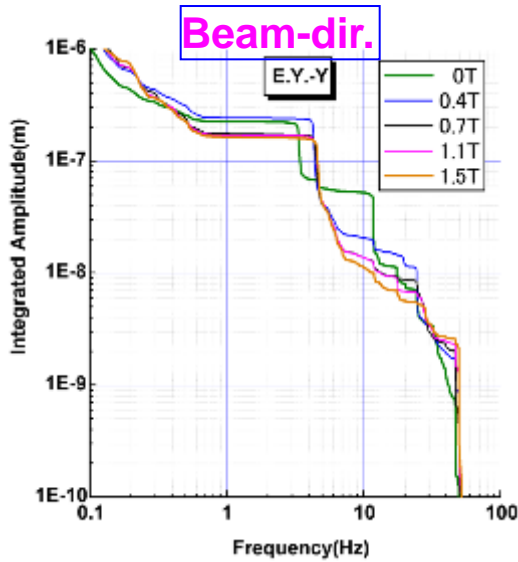
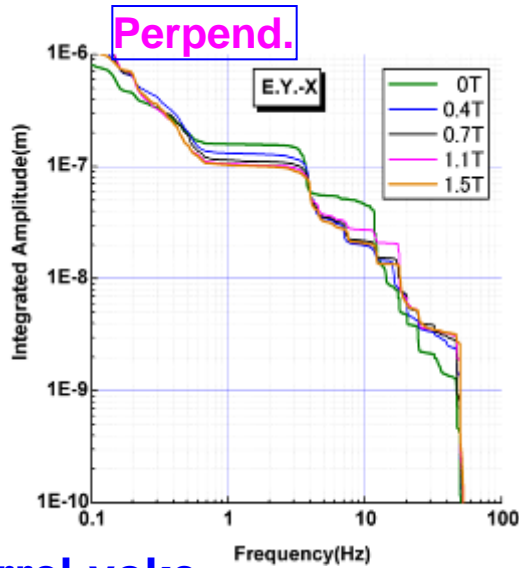


Measured E.Y. static deformations

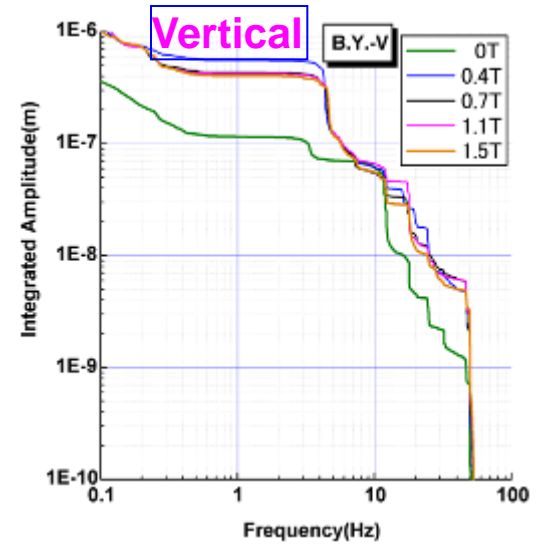
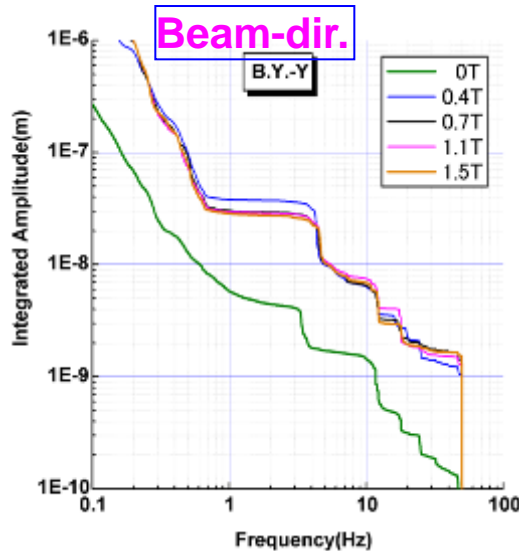
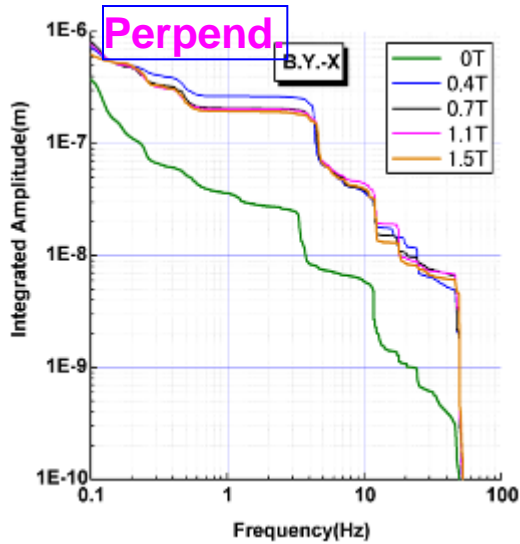




End-yoke

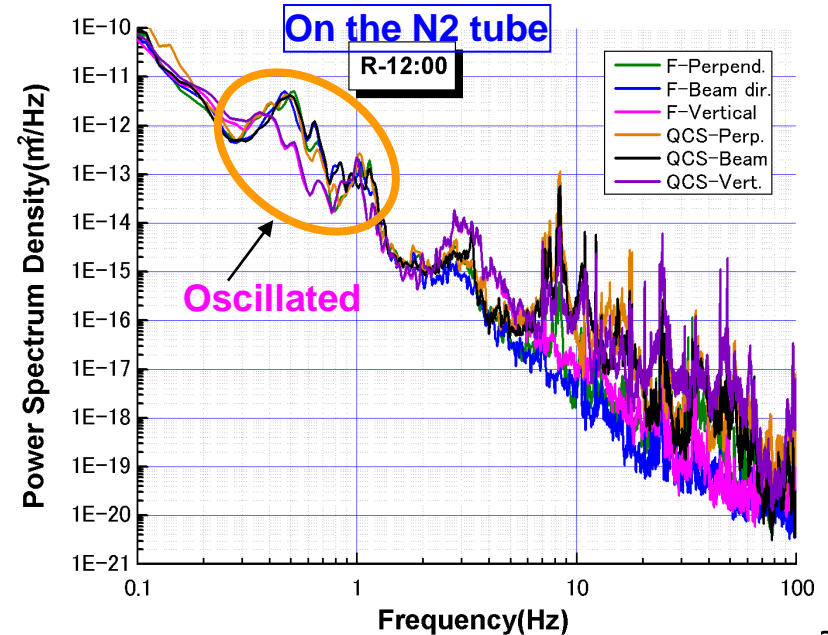
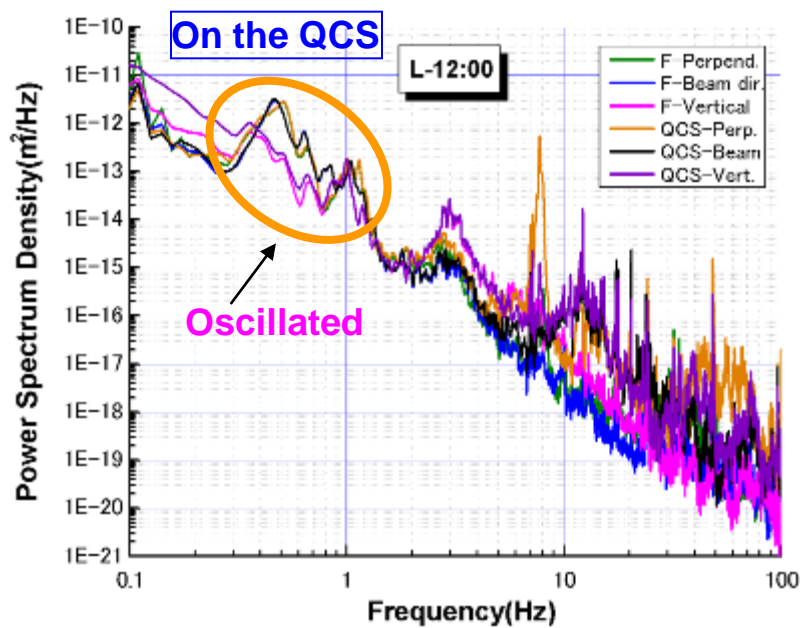
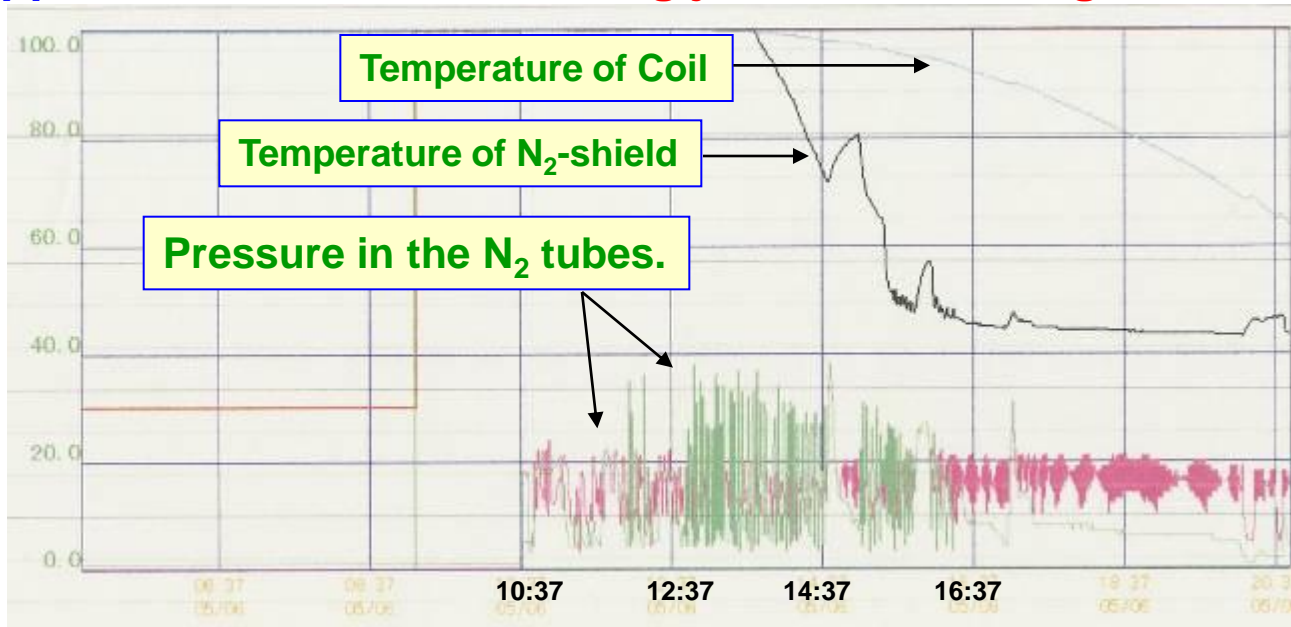


Barrel-yoke



→ Vibrations when the magnet excitation shows different behavior, Effect of magnetic force should be taken into account in the calculation.

- What happened at 12:00?? → **Cooling just had been begun.**



→ Oscillations around 1Hz at 12:00 were observed in all directions.

Concrete	Strength(N/mm ²): F _c	Density(kN/m ³): γ
General	F _c ≤ 36	24
	36 < F _c ≤ 48	24.5
	48 < F _c ≤ 60	25

Young's modulus: E_c

$$E_c = 3.35 \times 10^4 \times (\gamma/24)^2 \times (F_c/60)^{1/3}$$

Ex.) F_c = 21 N/mm²

$$E_{c21} = 3.35 \times 10^4 \times \{(24-1)/24\}^2 \times (21/60)^{1/3} = 21862 \text{ (N/mm}^2\text{)}$$

$$f_n = \frac{1}{2\pi} \cdot \sqrt{\frac{k}{m}}$$

$$k = \frac{EI}{L^3}$$