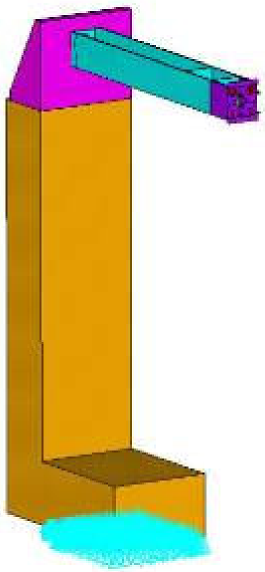
# Vibration Studies at KEK

KEK H. Yamaoka

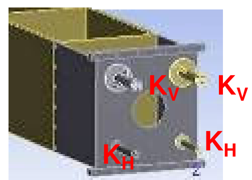
- Calculation results
- Vibration measurements

# Introduction

@LCWS09



Titanium



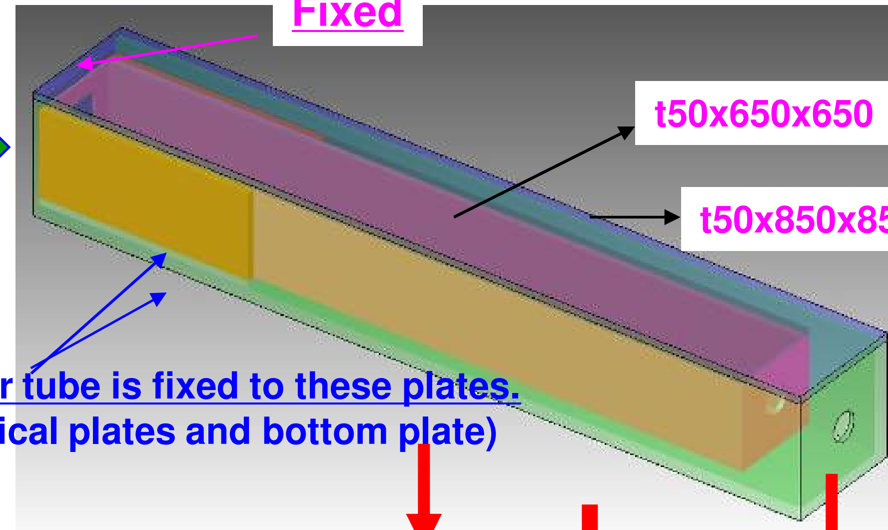

1000kg

4000kg

- Spring constant
- Static loads

are defined.

## New proposal: Double tube




1000kg

Self-weight

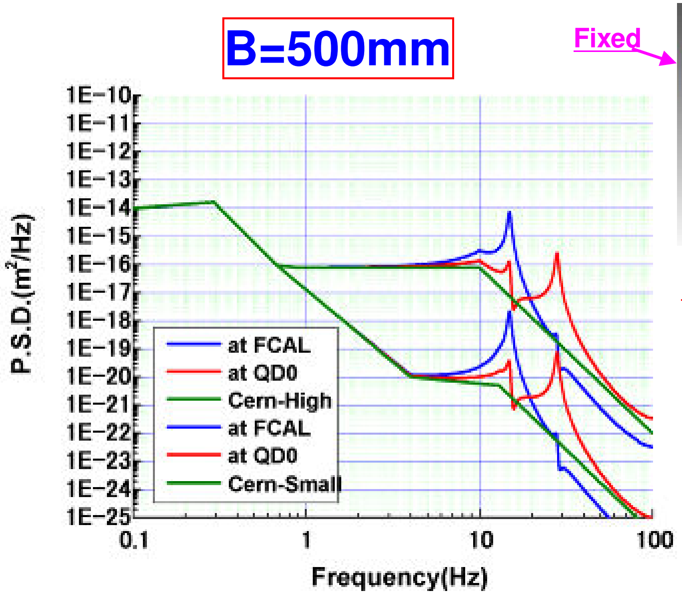
$4000 \times (w/650)^2$ kg

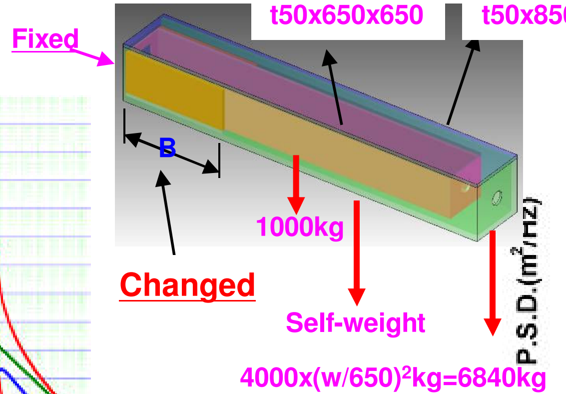
Allowable Amplitude: < 50nm(V)
(Above 5Hz) < 300nm(H)

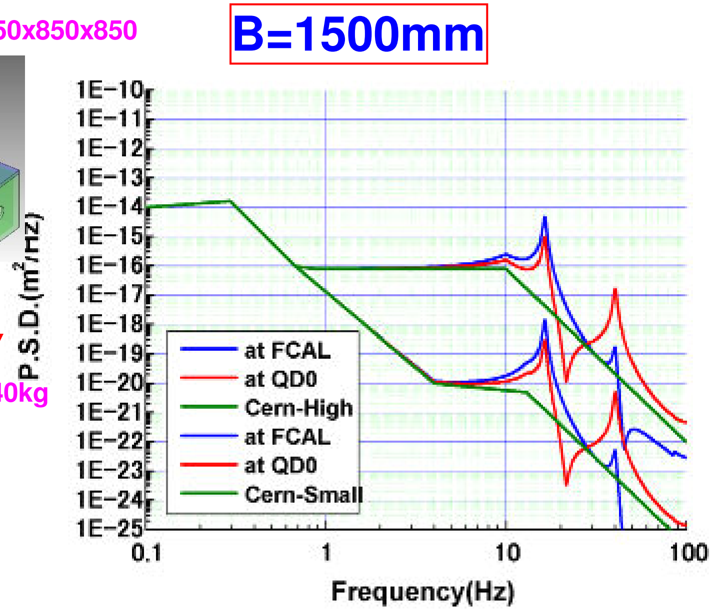
If the FCAL weight is supported at close to the constraint position of the tube, the deformation of the QD0 position must be small even though deformation of FACL support position is big.

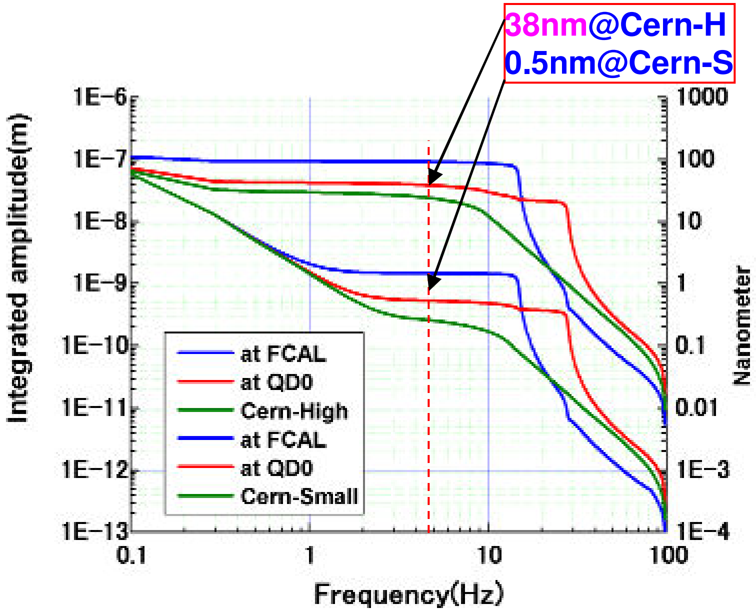
- Support tube consists of double square tube.
- Outer tube supports FCAL.
- Inner tube supports QD0.

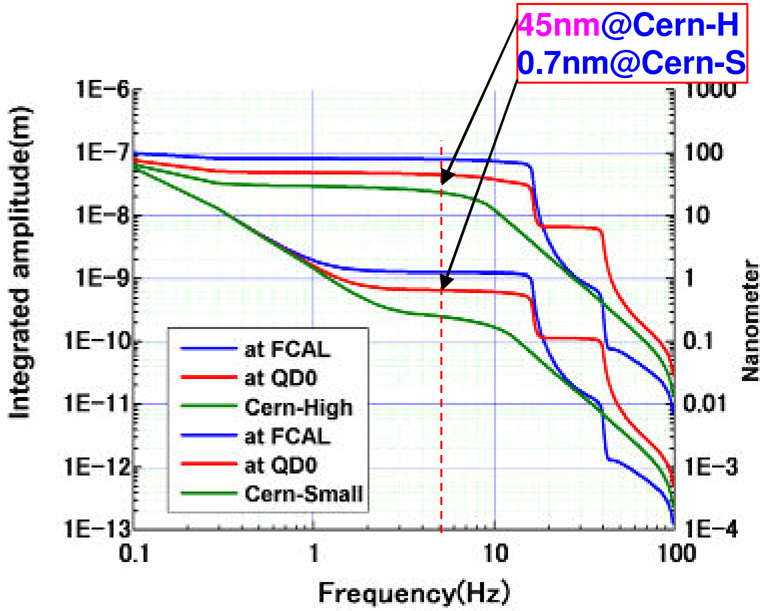
# Integrated amplitudes in case of double tube



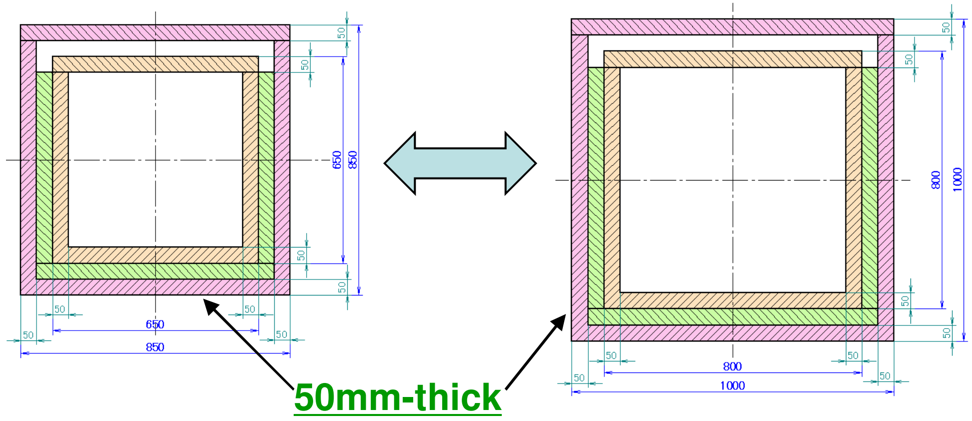



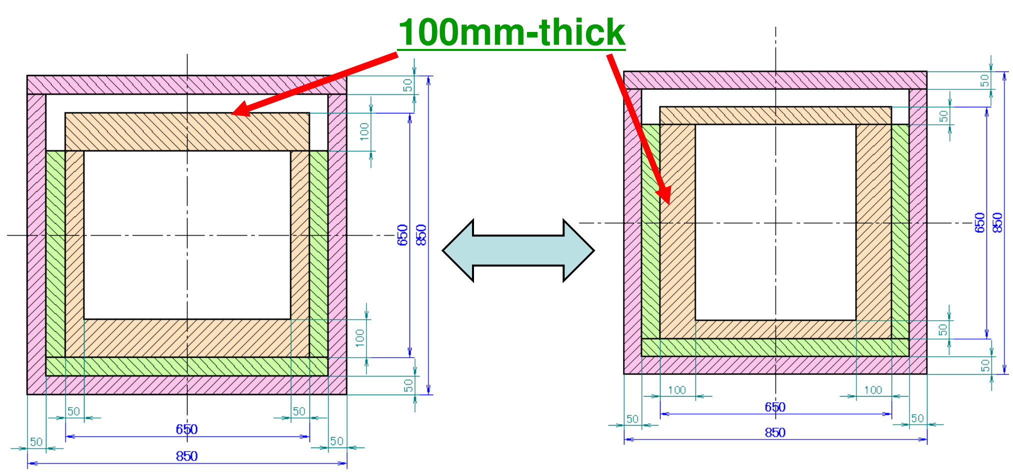
# Other results

## (A) Change tube size(B=500mm, 50mm-thick)

Outer tube: 850x850 | Outer tube: 1000x1000




## (B) Thickness is changed




**Deformation**

850x850

1.2mm@Outer tube

0.6mm@Inner tube

1000x1000

1.1mm@Outer tube

0.4mm@Inner tube

**Resonant freq.**

850x850

15Hz@Outer tube

28Hz@Inner tube

1000x1000

16Hz@Outer tube

30Hz@Inner tube

**Integrated amp.**

850x850(Cern-H)

92nm@Outer tube

38nm@Inner tube

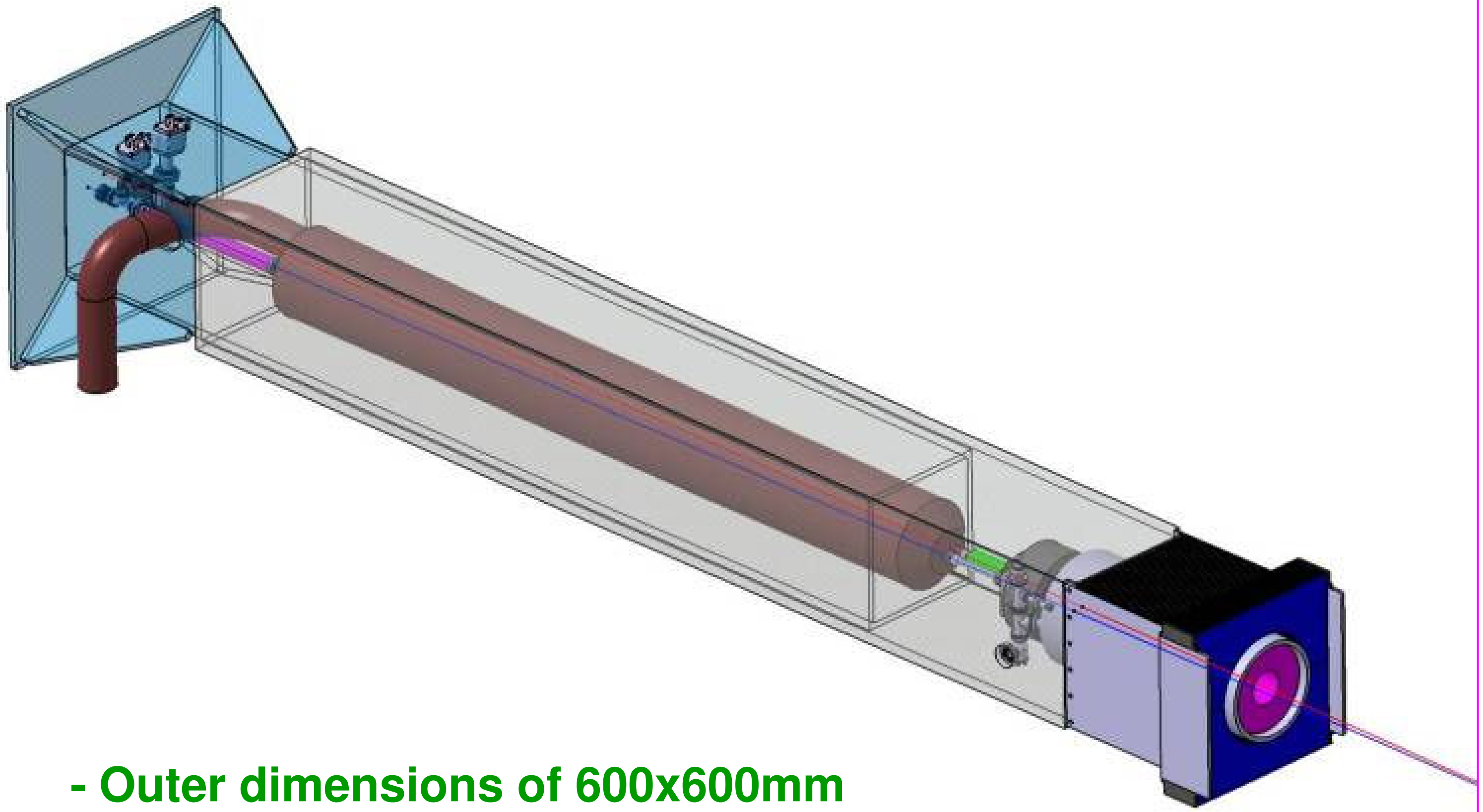
1000x1000

73nm@Outer tube

32nm@Inner tube

**There is no big difference.**

# Realistic configuration by Matthieu san.



- Outer dimensions of 600x600mm
- 25mm thick

# Investigation of consistency between the calculations and measurements

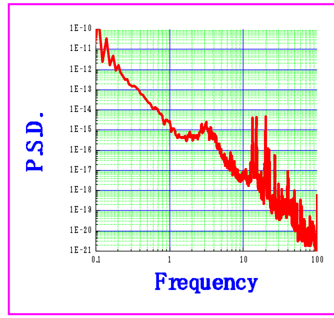
**LION LS10C**

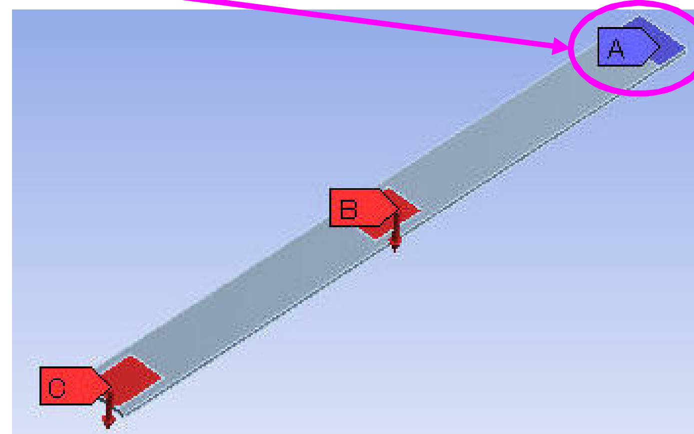
Servo accelerometer

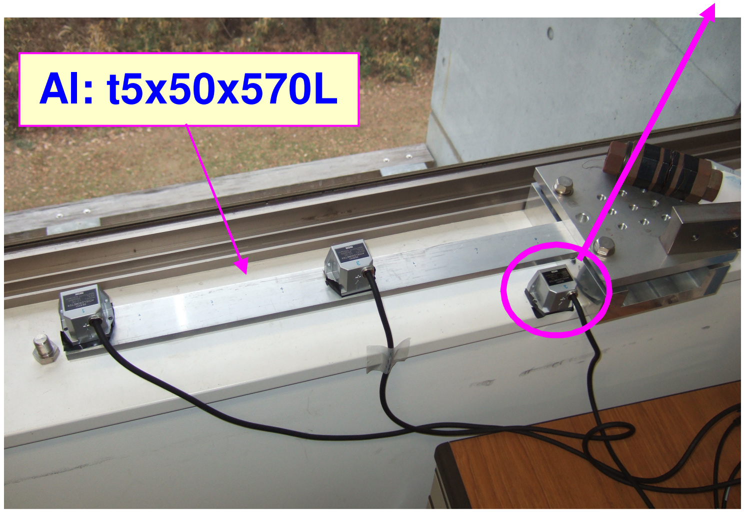
0.3V=1m/s$^2$

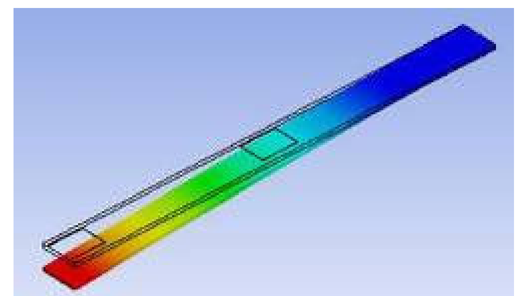
DC~40Hz

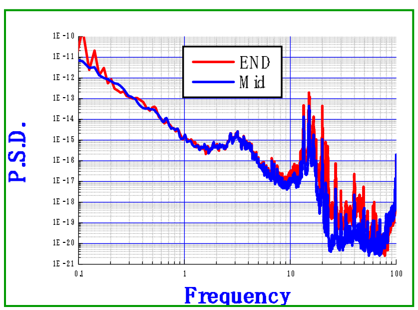
<10$^{-5}$m/s$^2$

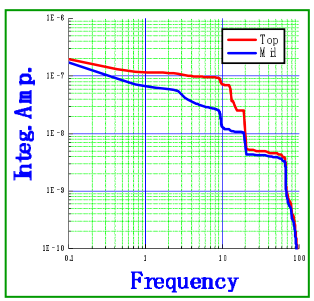


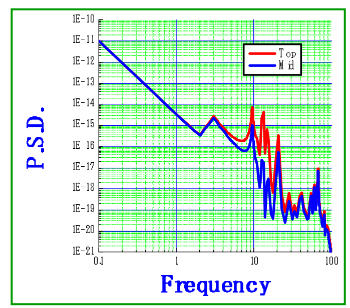



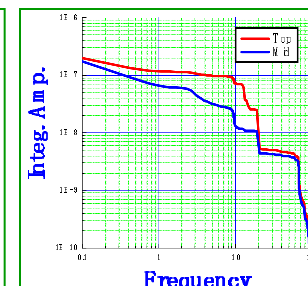





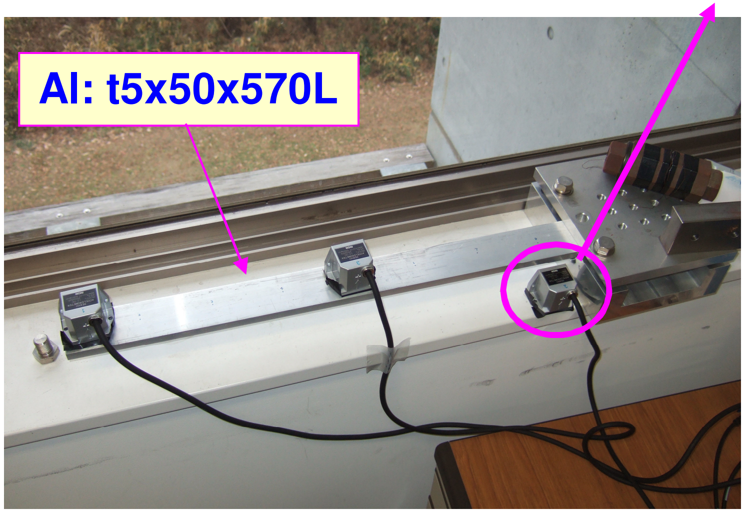



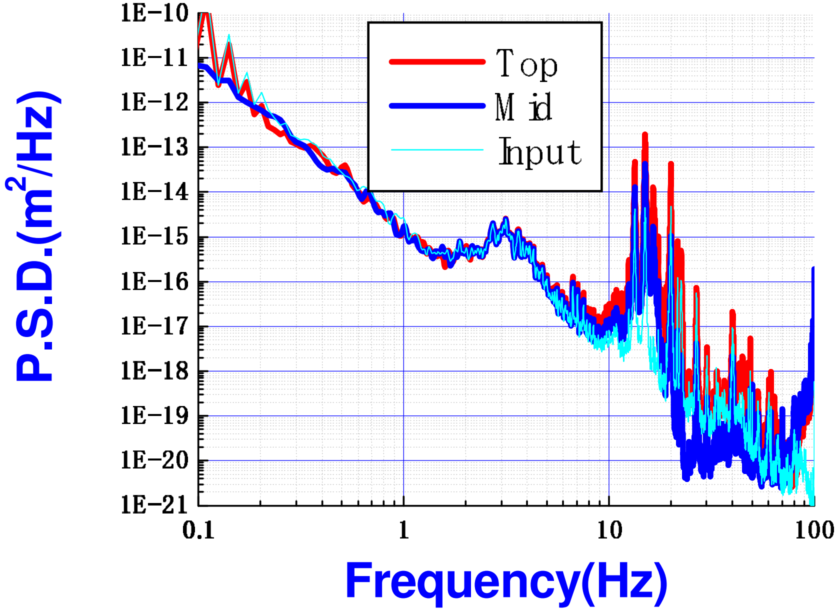



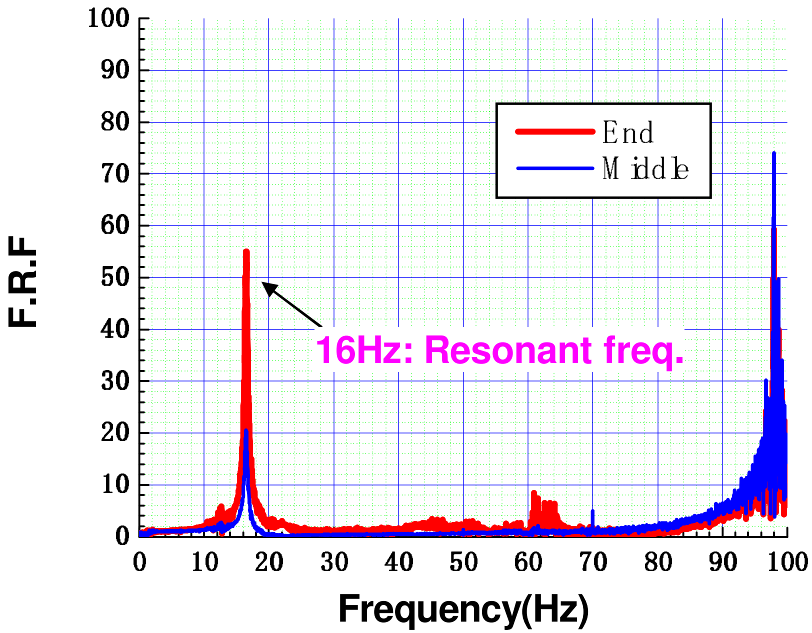



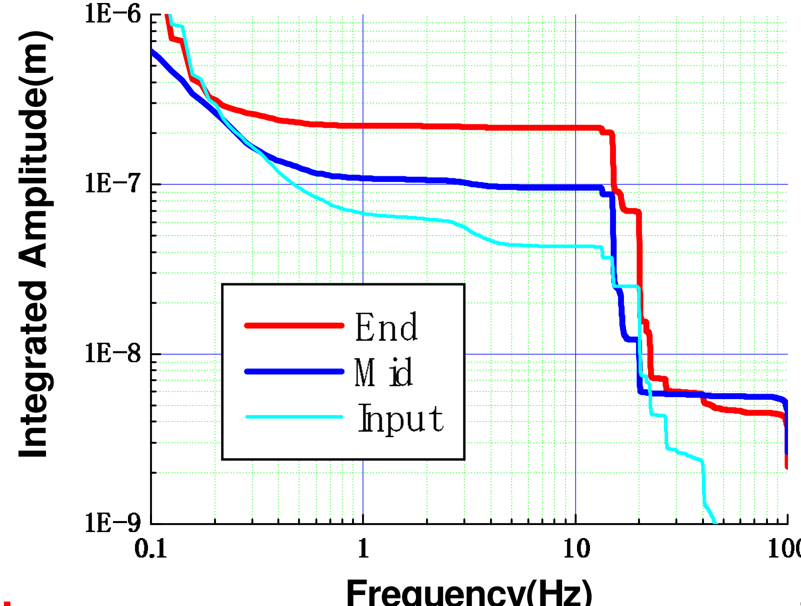

Are those values same?

# Measurement results



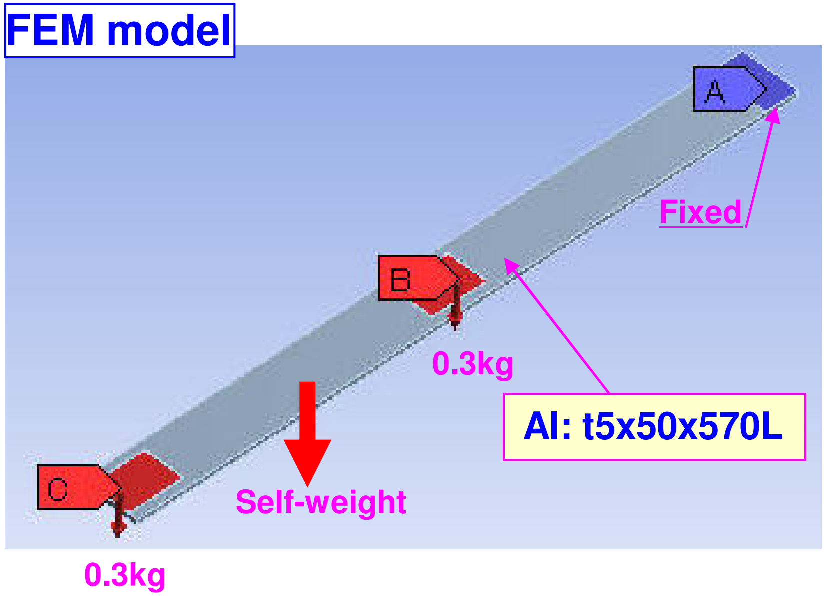



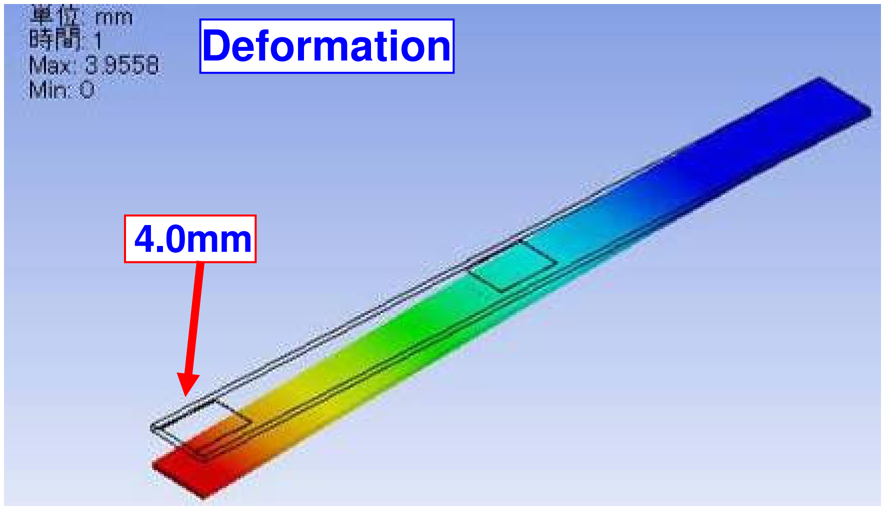



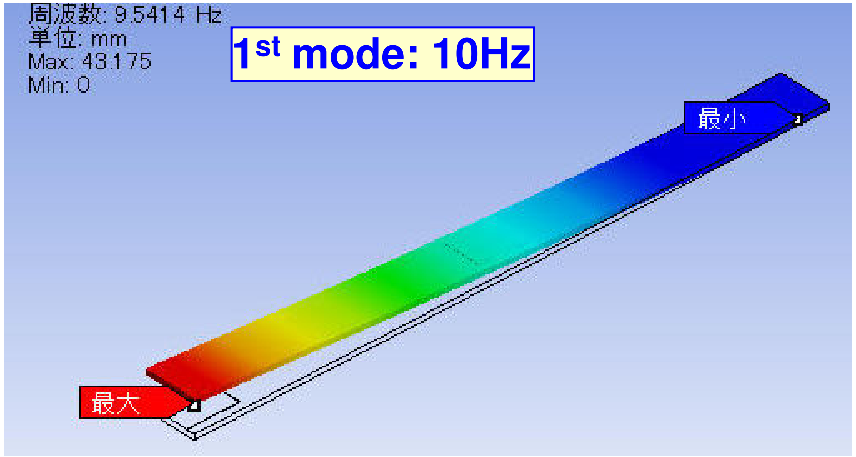



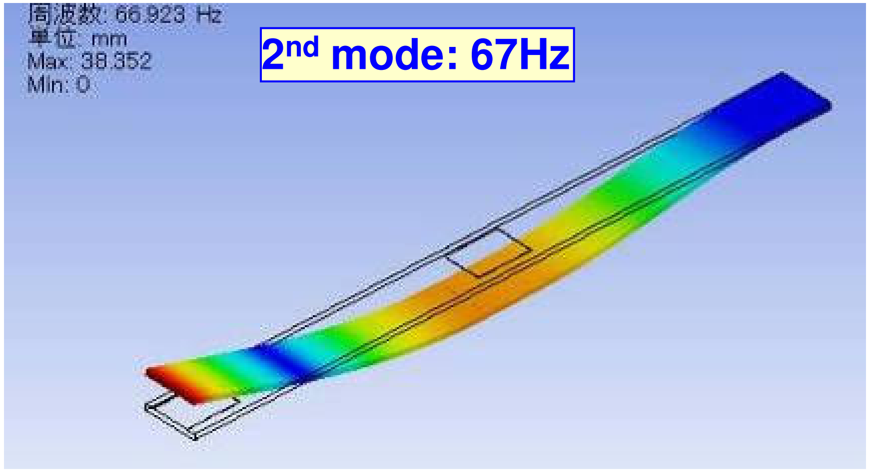

➔ - 1st mode of resonant frequency is ~16Hz.
- Amplitude at top position is ~200nm.

# Calculation results



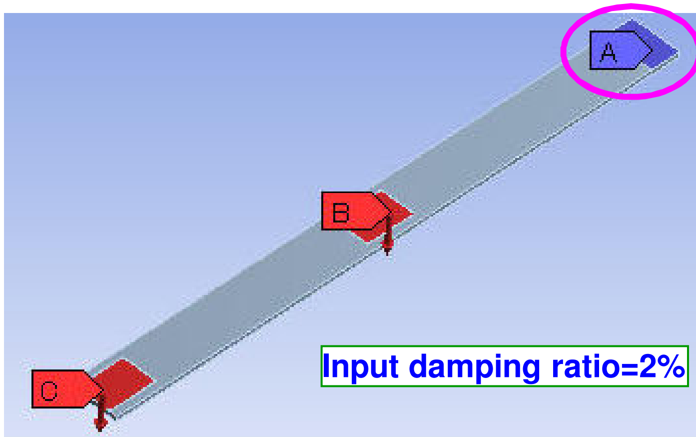



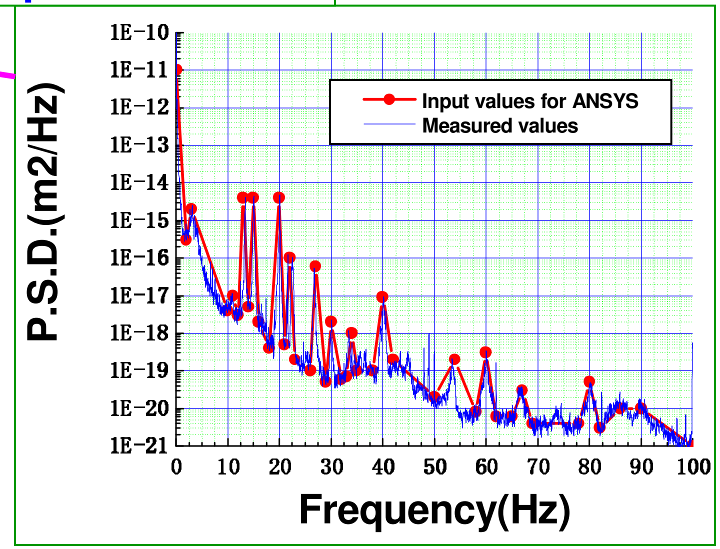



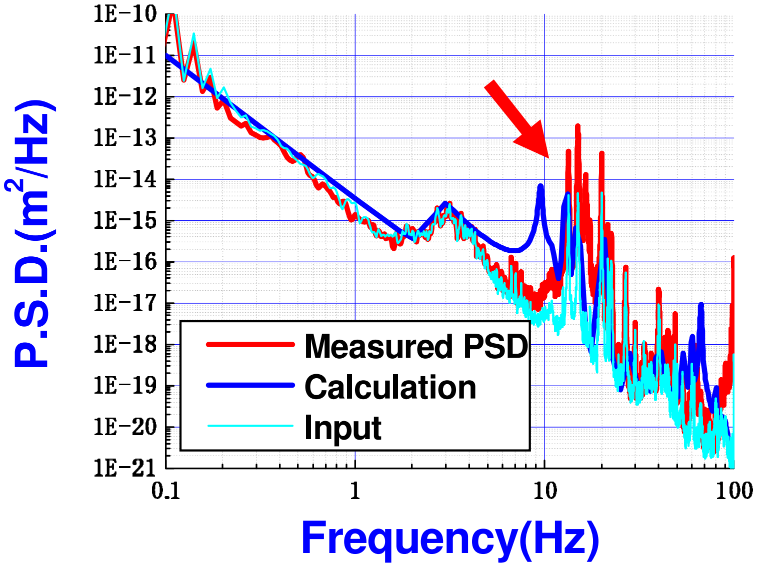

➔ - 1st mode of resonant frequency is ~6Hz lower than the measurement.

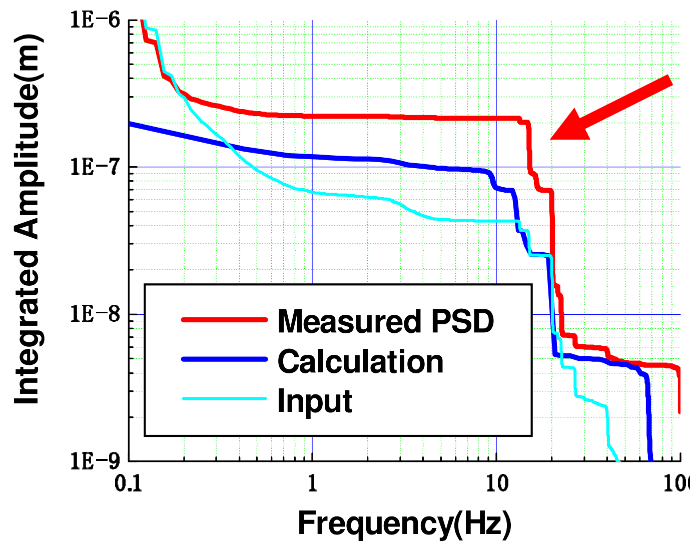
# Comparison PSD/Amplitude between the Calculation and Measurement




Input PSD values



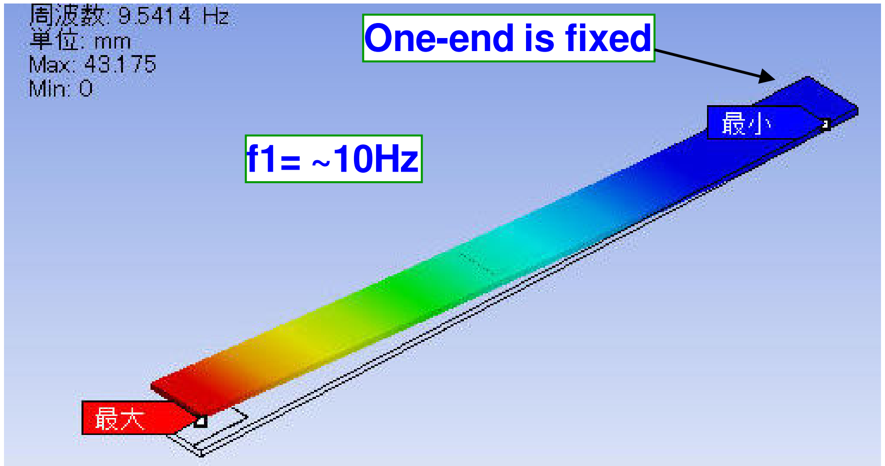



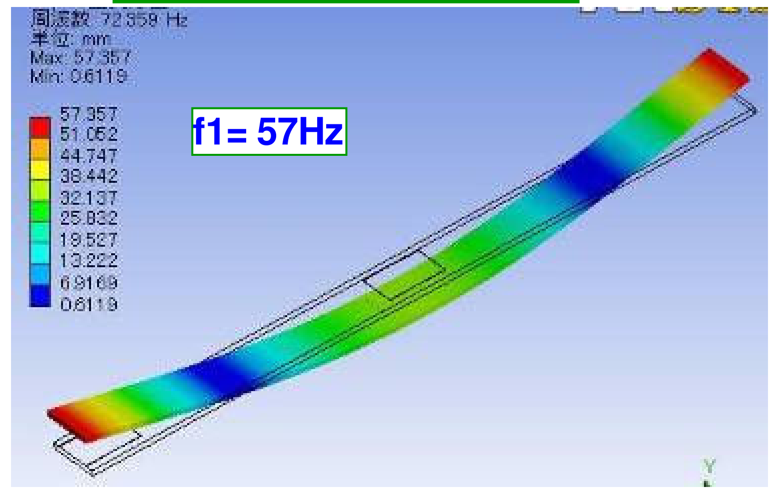



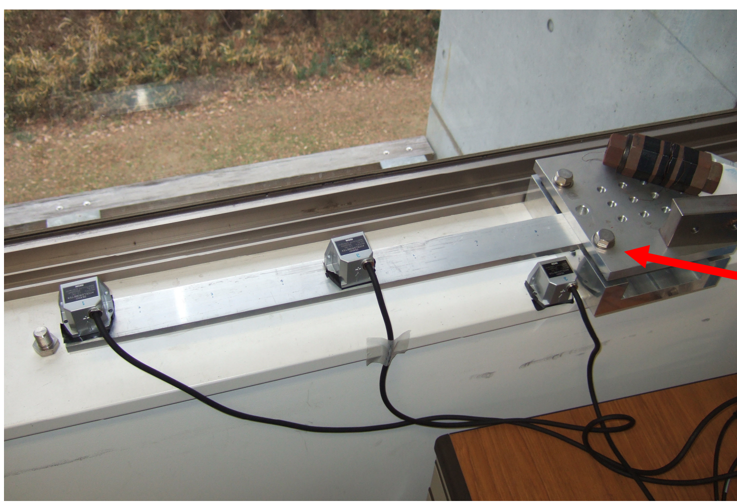

➔ - 1st mode of resonant frequency is ~6Hz different.
- Amplitude is ~100nm different.

# Considerations

**Why is the 1st mode of resonant frequency ~6Hz different?**

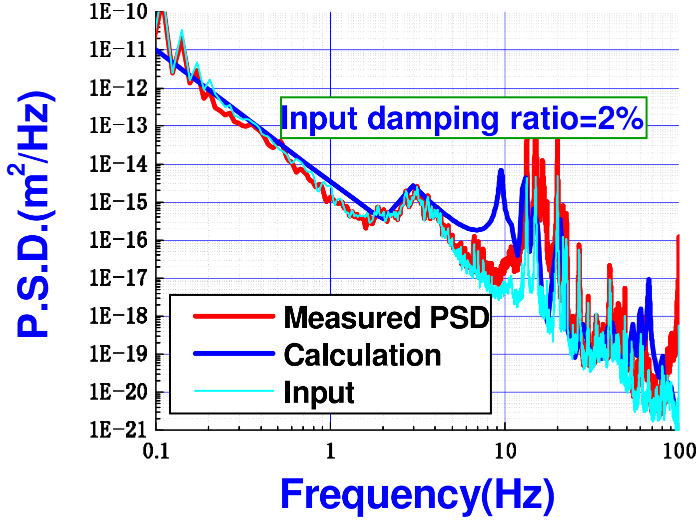


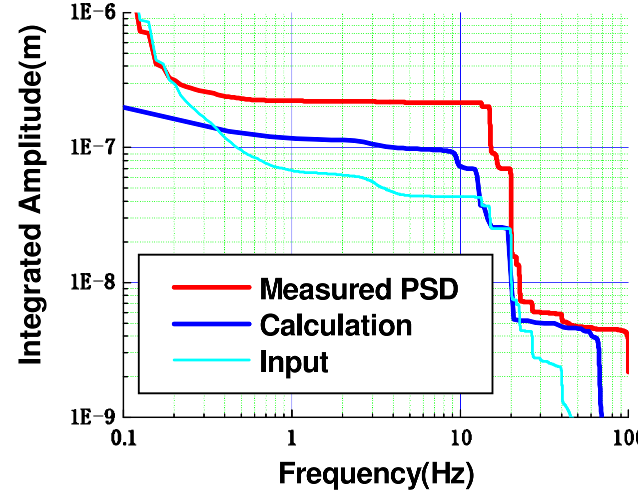



**Because:**
**Constraint position is not perfectly rigid.**
**Therefore, resonant frequency is moved to frequency of *free mode* condition.**

# Why is the amplitude ~100nm different?




➔ It is supposed that ***actual damping ratio is smaller than the assumption.***

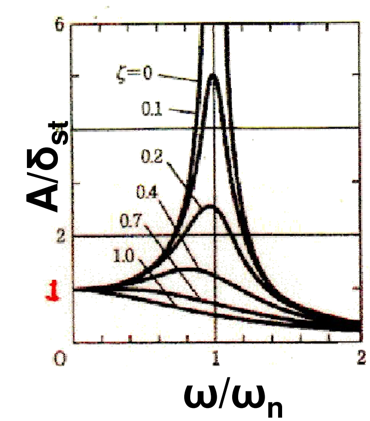
→ **In ANSYS: damping ratio= 2%**

| **Damping ratio(%)** | |
|---|---|
| Ferroconcreate structure | : 5.0 |
| Steel frame structure | : 2.0 |
| Welding structure | : 1.0 |
| *Bolt/Rivet structure* | *: 2.0* |
| Laying pipes | : 0.5 ~ 2.5 |
| Duct for the air conditioner | : 2.5 |
| Cable tray | : 5.0 |
| Liquid in a tank | : 0.5 |

Reference: JEAG 4601-1987

$$m\ddot{x} + c\dot{x} + kx = F\cos\omega t$$

$$X = \frac{\delta_{st}}{\sqrt{\left\{1-\left(\frac{\omega}{\omega_n}\right)^2\right\}^2 + \left(2\varsigma\frac{\omega}{\omega_n}\right)^2}}$$



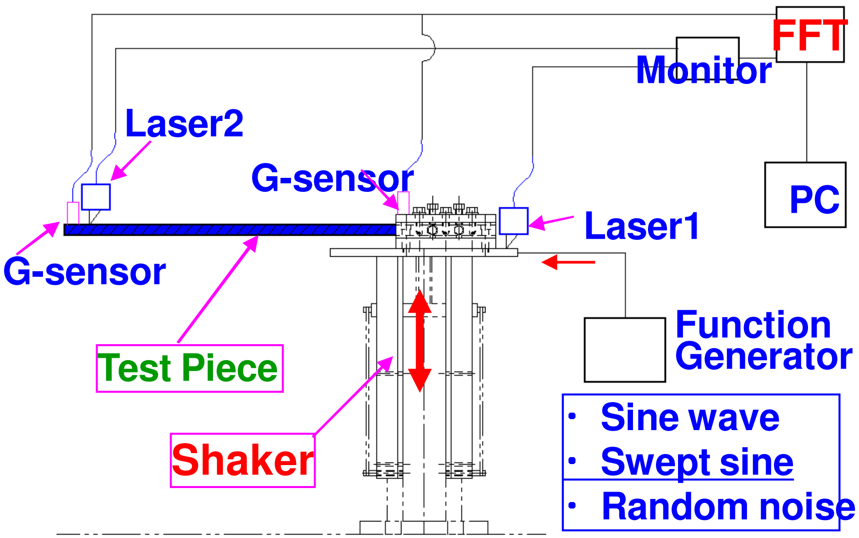

If $\omega/\omega_n = 1$ , $\zeta=0.02$

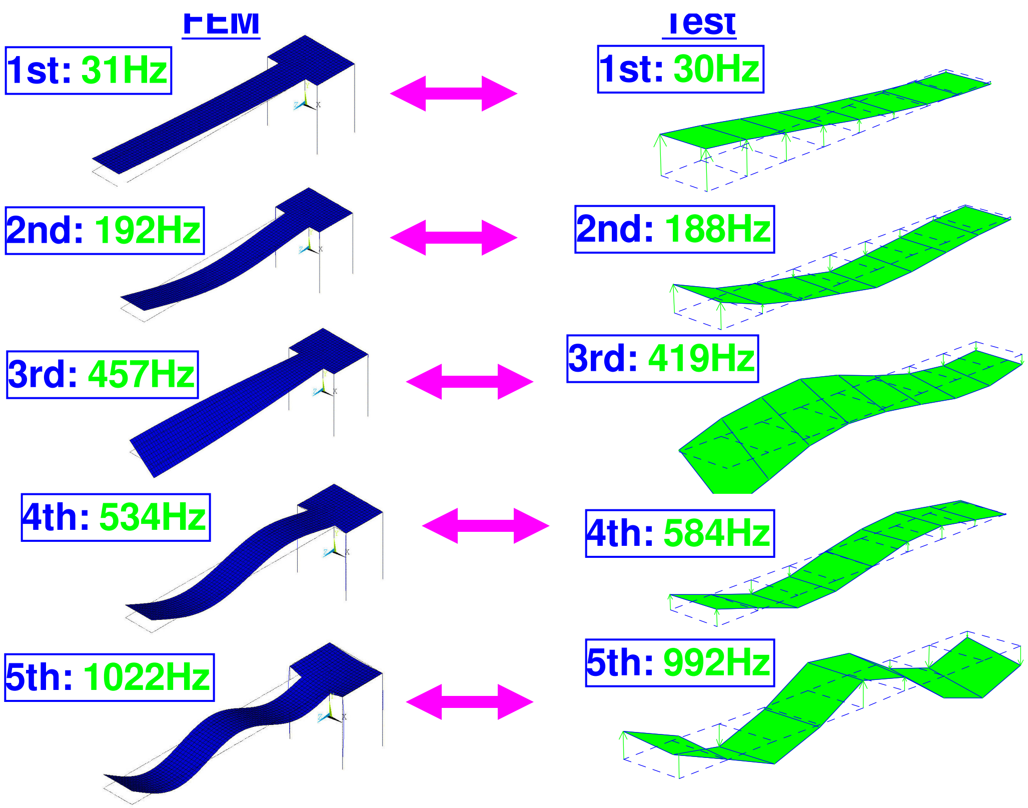
$X/\delta_{st}=25$

If $\omega/\omega n = 1$ , $\zeta=0.01$

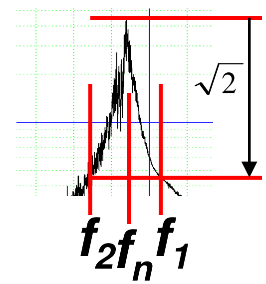
$X/\delta_{st}=50$

# Vibration test




## Damping ratio measurement




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

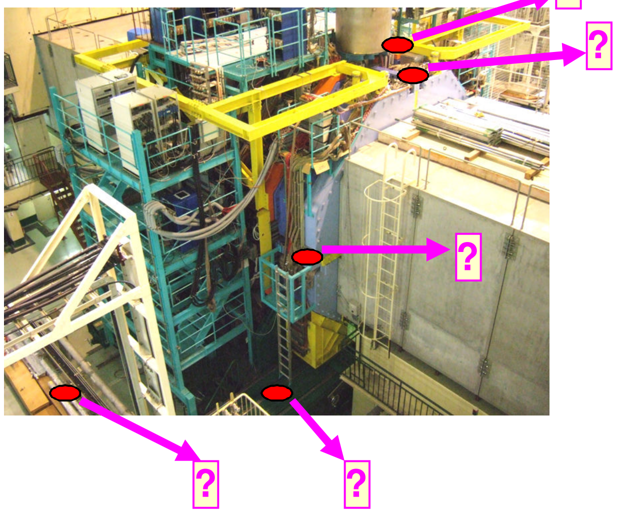
| Mode | Freq. | Damping(%) |
|---|---|---|
| 1 | 30.4Hz | 1.68 |
| 2 | 188Hz | 0.422 |
| 3 | 419Hz | 0.303 |
| 4 | 584Hz | 0.113 |
| 5 | 992Hz | 8.02E-2 |

# Vibration measurements at the Belle/KEKB

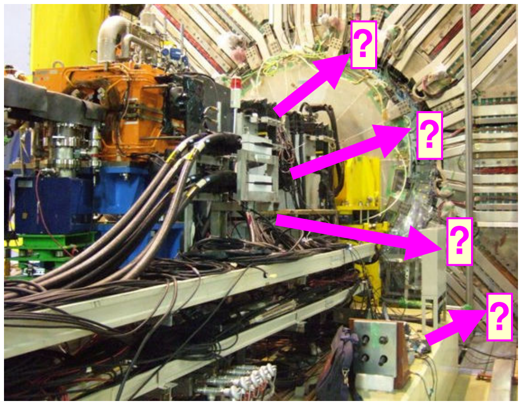
## Study items

- Vibrations on each place
- Influence of air conditioner
- Coherency between both sides

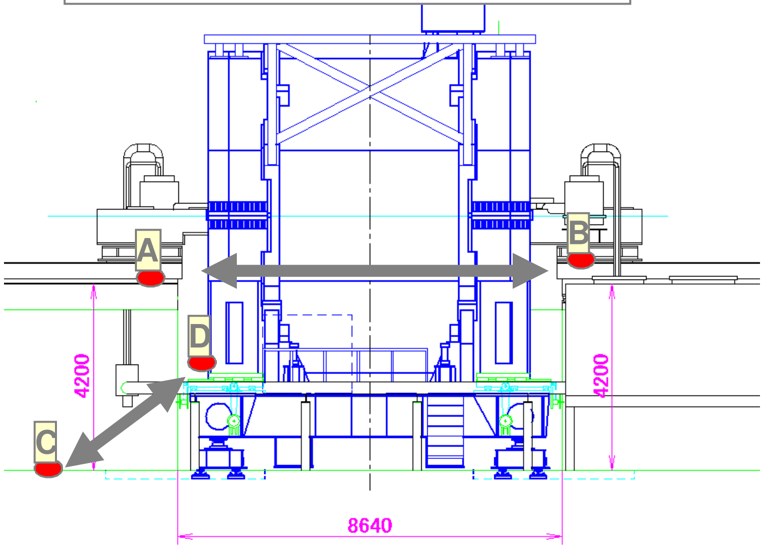
**Measure vibrations on the Belle**



**Measure vibrations on KEKB**

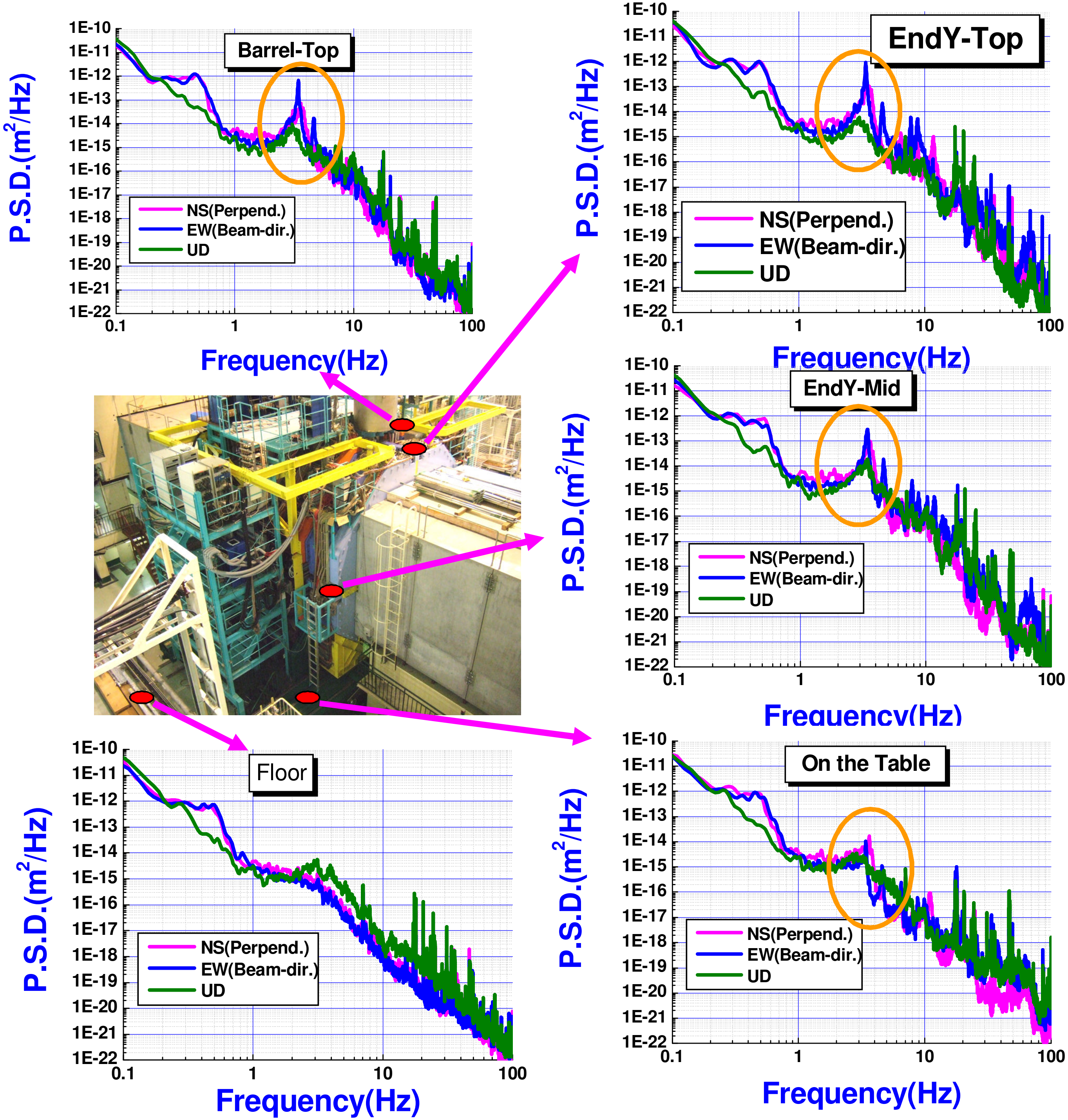


**Coherency between A-B, C-D.**



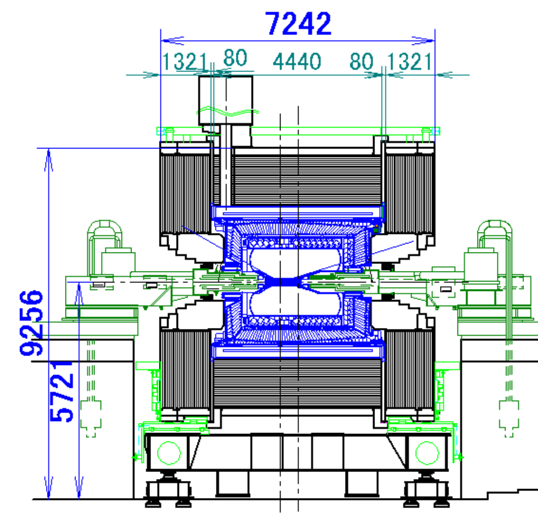

**Influence of air conditions**

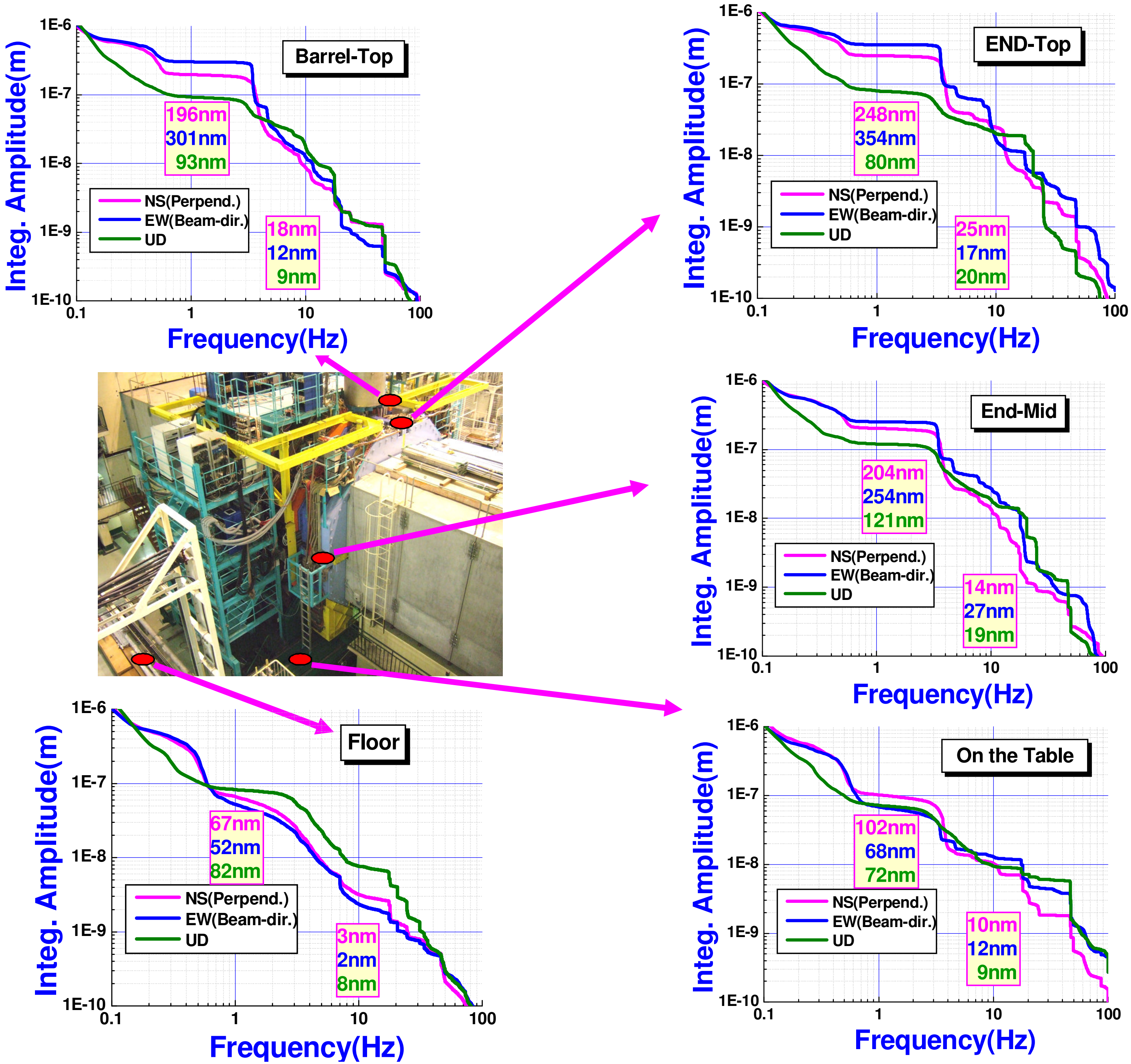
Air conditioner




## Servo Accelerometer MG - 1 0 2

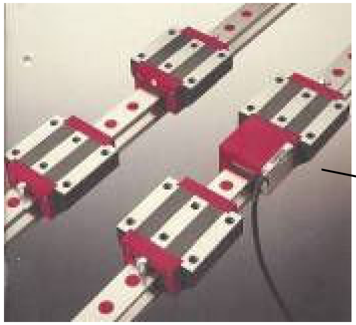
Acc. 0.1 ~ 400Hz Acc.
60dB = 1gal/V

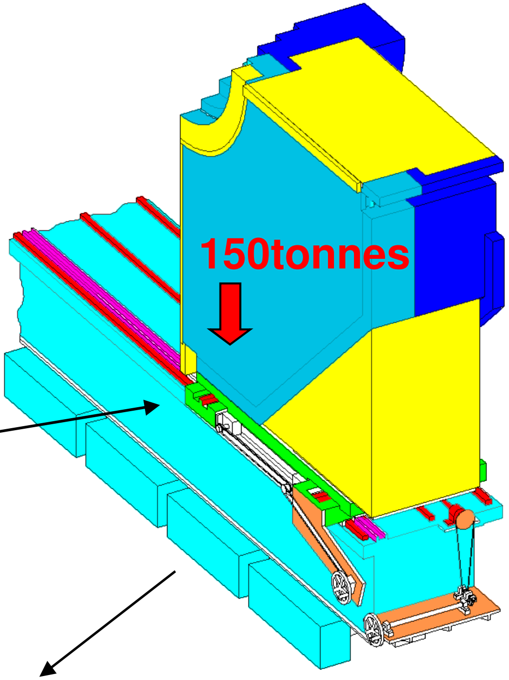


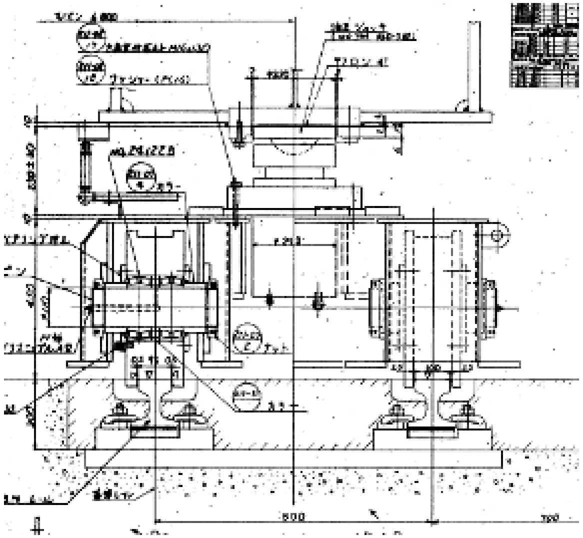

Barrel-Top
196nm
301nm
93nm
18nm
12nm
9nm
NS(Perpend.)
EW(Beam-dir.)
UD
Integ. Amplitude(m)
Frequency(Hz)
END-Top
248nm
354nm
80nm
25nm
17nm
20nm
NS(Perpend.)
EW(Beam-dir.)
UD
Integ. Amplitude(m)
Frequency(Hz)
End-Mid
204nm
254nm
121nm
14nm
27nm
19nm
NS(Perpend.)
EW(Beam-dir.)
UD
Integ. Amplitude(m)
Frequency(Hz)
Floor
67nm
52nm
82nm
3nm
2nm
8nm
NS(Perpend.)
EW(Beam-dir.)
UD
Integ. Amplitude(m)
Frequency(Hz)
On the Table
102nm
68nm
72nm
10nm
12nm
9nm
NS(Perpend.)
EW(Beam-dir.)
UD
Integ. Amplitude(m)
Frequency(Hz)

# Considerations on the measurement result

- First resonance is around ~3-4Hz.
- Amplitude on the barrel is bigger than the table.
- Amplitudes on the End-Y is getting bigger as the position of EY rises

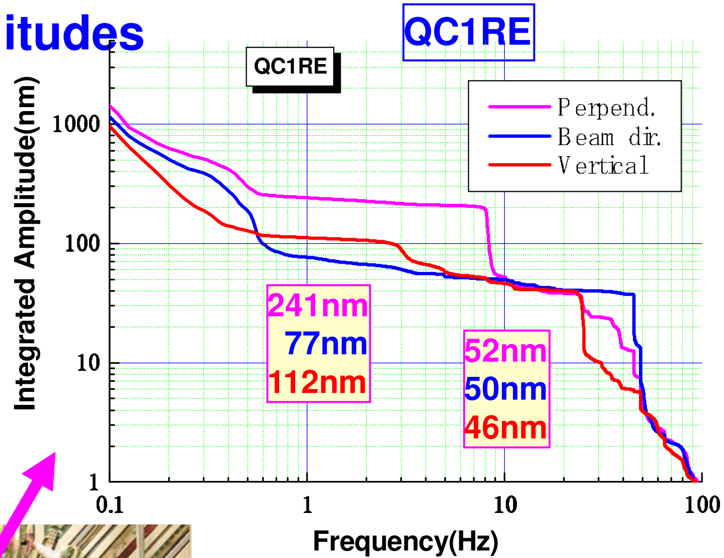


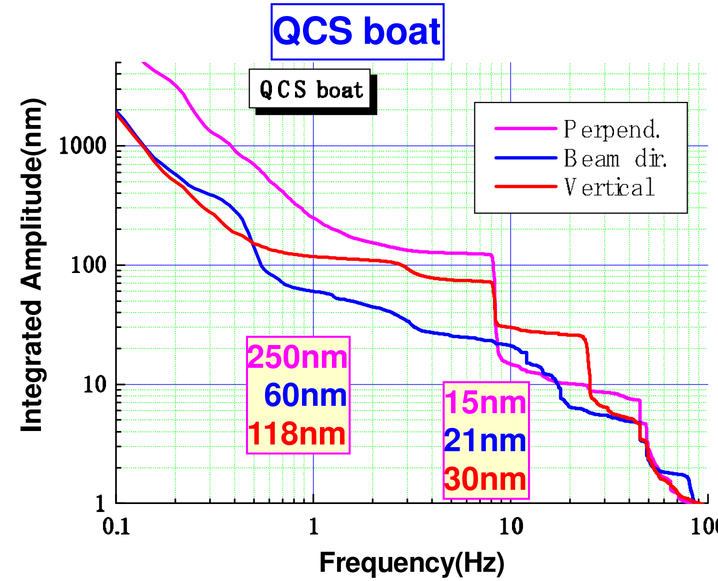


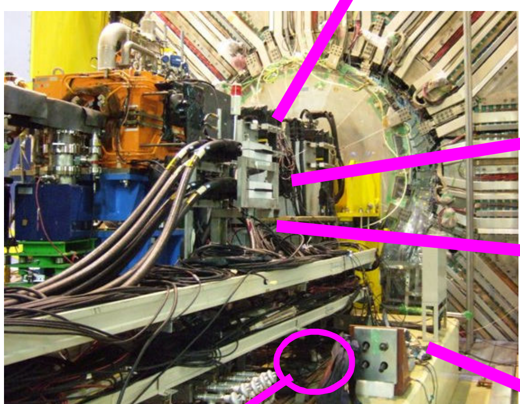



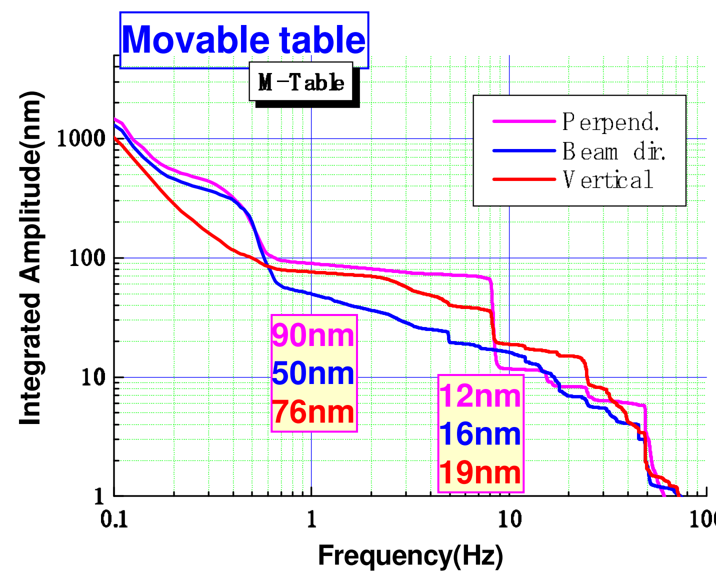
Large amplitudes on the Belle;
- The belle detector is not fixed on the floor.
- The barrel yoke is not fixed on the table rigidly.
- Top of the end-yoke is not fixed.

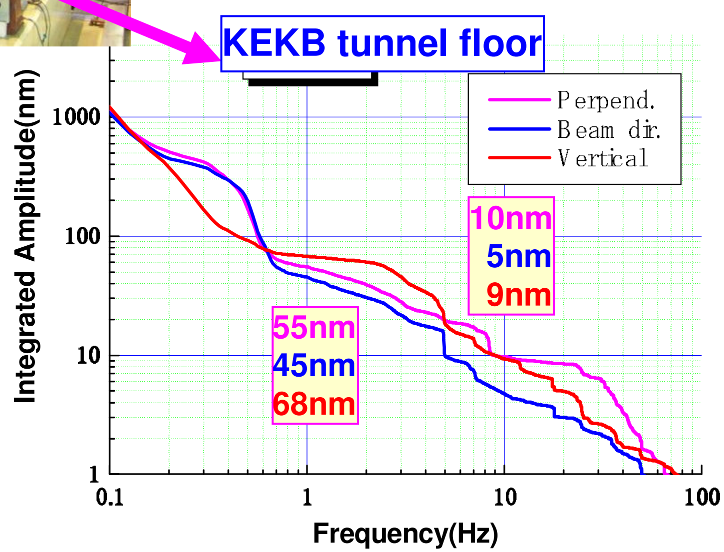
# Integrated amplitudes





# Summary

## 1. Calculations

- Optimization of the double shaped tube has been carried out.
- Matthieu san has proposed a realistic support tube.
- Simple vibration tests have been done.
  → Resonant frequency was measured lower than calculation.
  Measured amplitude is larger than calculation.
  → Investigation of damping ratio is necessary.

## 2. Vibration measurements

(Belle detector)

- First resonance is measured around ~3-4Hz.
- Amplitude on the barrel is bigger than the table.
- The integrated amplitude becomes larger when going from the bottom of the end yoke toward the top.

(KEKB)

Tunnel: H-dir.→ ~0.3Hz ( Micro-seismic ) , V-dir.→ ~3Hz(Resonancy of soil)

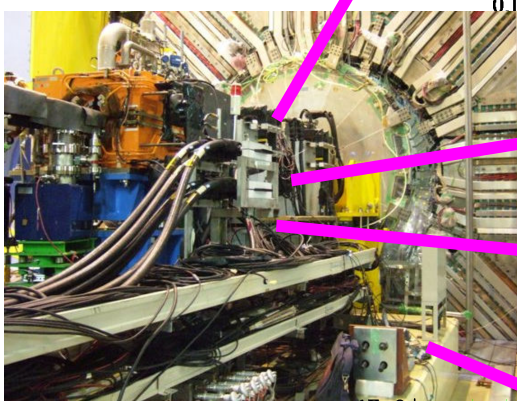
- The integrated amplitude becomes larger when going from the bottom of the component toward the top.
  Q-table, magnet→ Peak around 8Hz was measured additionally.

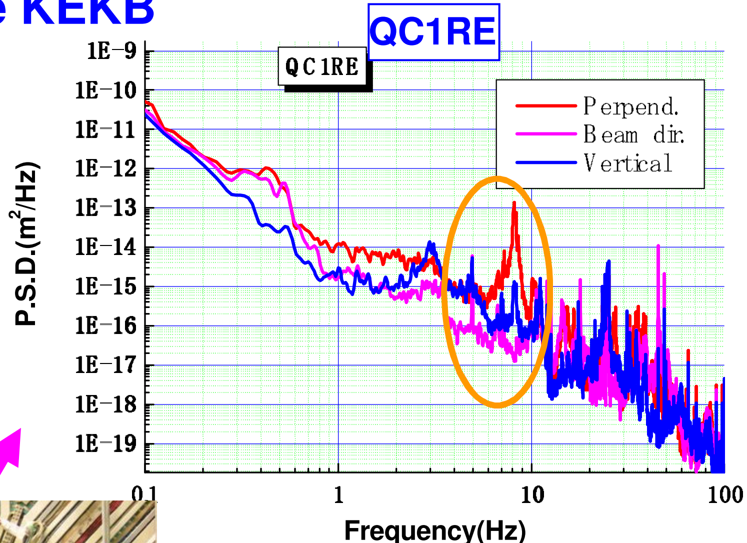
Summary of vibration measurements

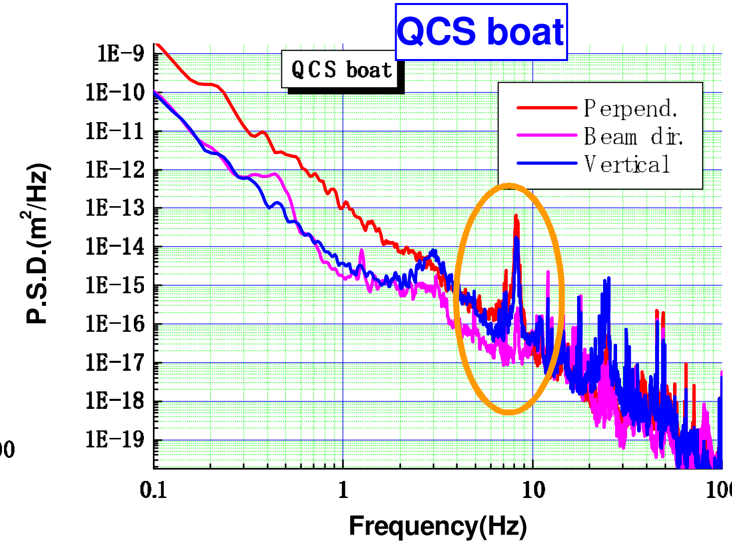
| | Integrated amplitude(nm) | | | | | |
|---|---|---|---|---|---|---|
| | >1Hz | | | >10Hz | | |
| | Perpend | Beam | Vertical | Perpend | Beam | Vertical |
| Barrel-Top | 196 | 301 | 93 | 18 | 12 | 9 |
| EY-Top | 248 | 354 | 80 | 25 | 17 | 20 |
| EY-Mid. | 204 | 254 | 121 | 14 | 27 | 19 |
| Belle stand | 105 | 69 | 71 | 13 | 11 | 13 |
| B4 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 |

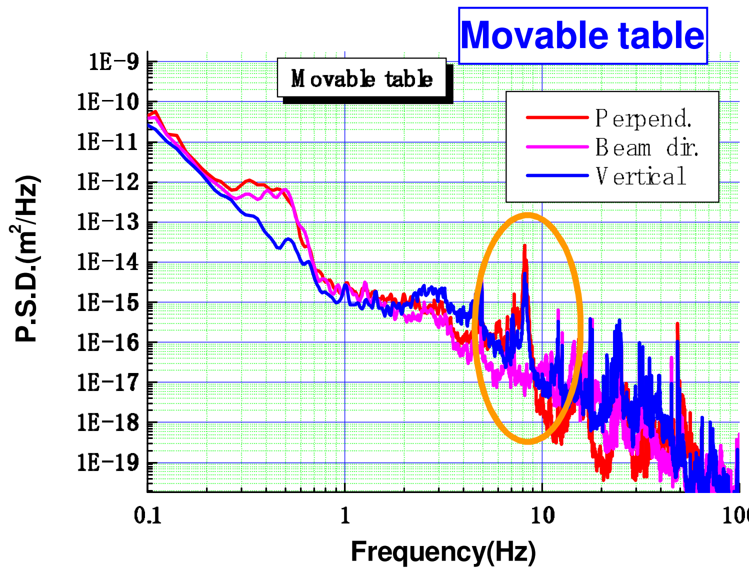
# Vibrations on the KEKB

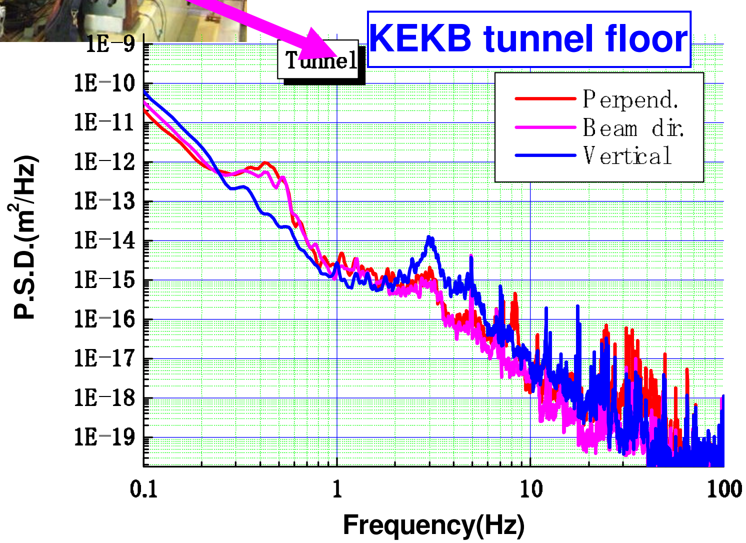
## P.S.D.





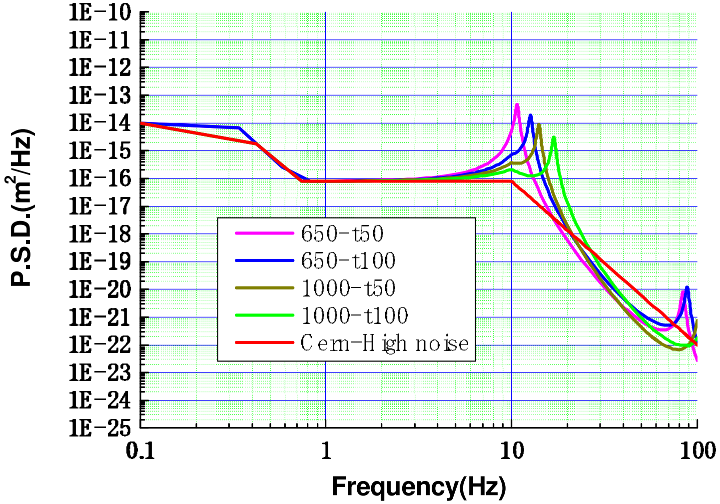




| 地盤状況 | 区分 | 固有周波数（Hz） |
|---|---|---|
| 岩盤・硬質礫層 | 第I種 | 10 Bedrock |
| 砂礫層・ローム層 | 第II種 | 3 Gravel |
| I、II種以外 | 第III種 | 1.3 |
| 沖積層、埋立地 | 第IV種 | 1 Alluvium |

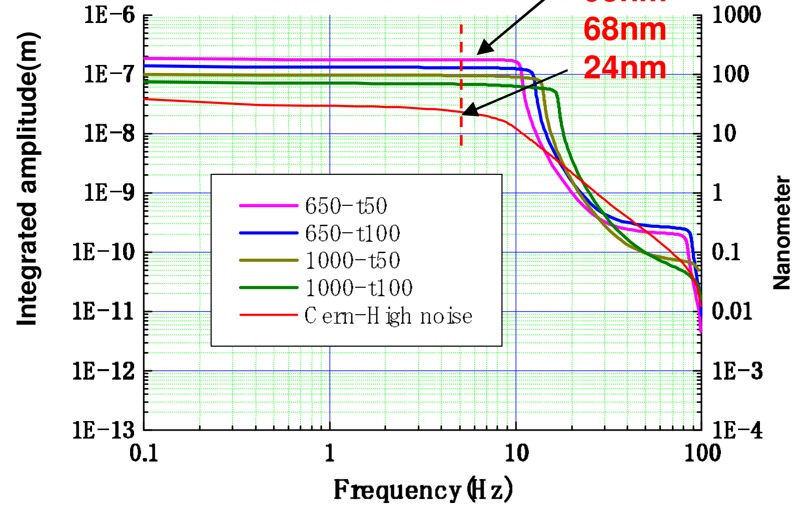
（出典：環境振動工学入門）

# *(Cern-High noise)* P.S.D. values and Integrated amplitudes

## Loads: Self-weight + QD0 + Cal

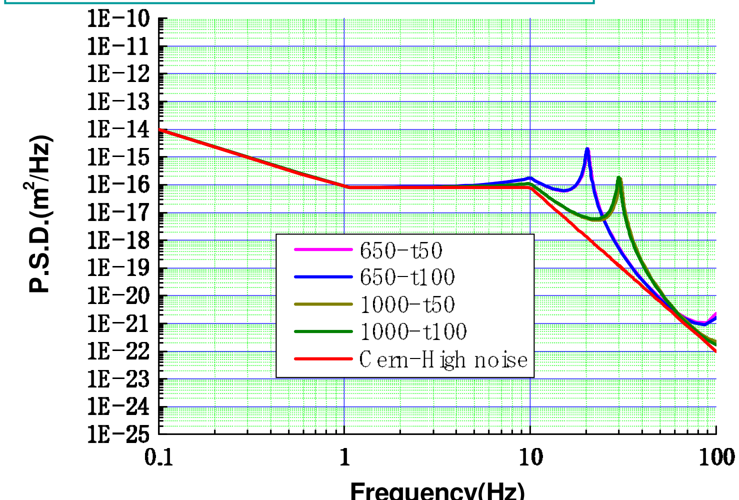



Amp. >5Hz
177nm
130nm
95nm
68nm
24nm

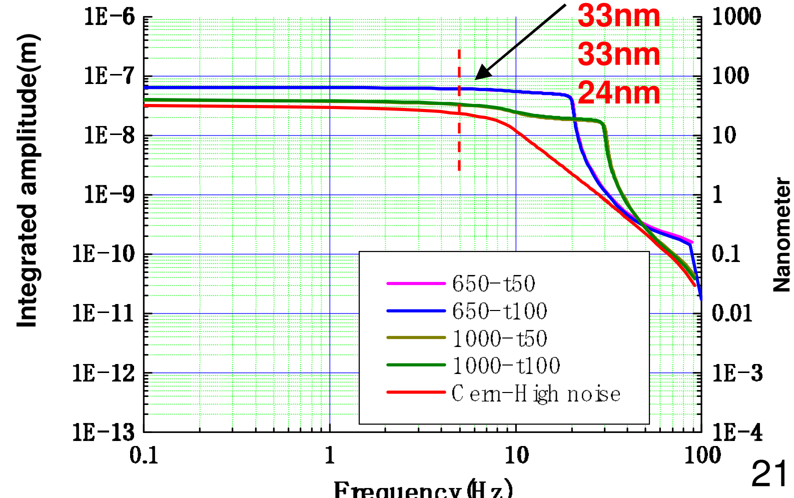



→ Amplitude can not be improved because resonant frequency is not increased.

## Loads: Self-weight + QD0

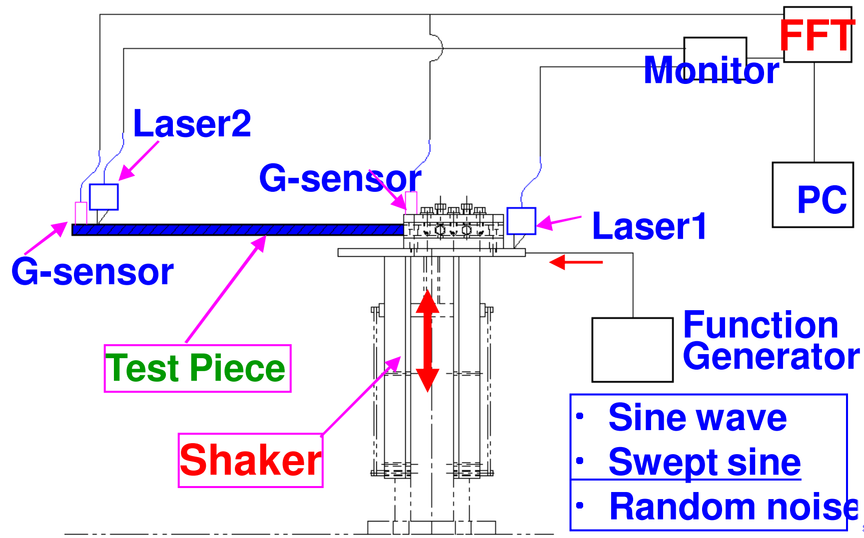


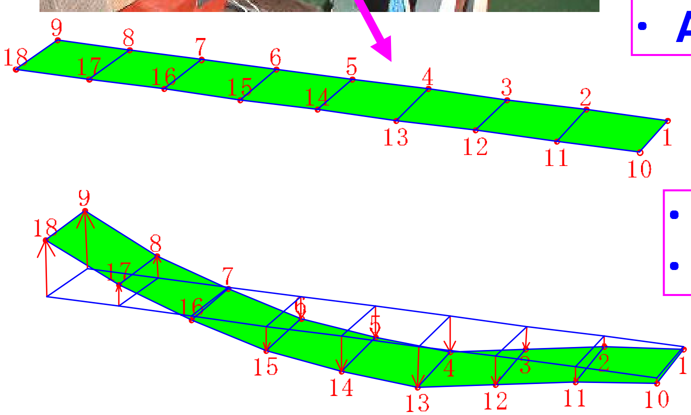

Amp. >5Hz
61nm
61nm
33nm
33nm
24nm



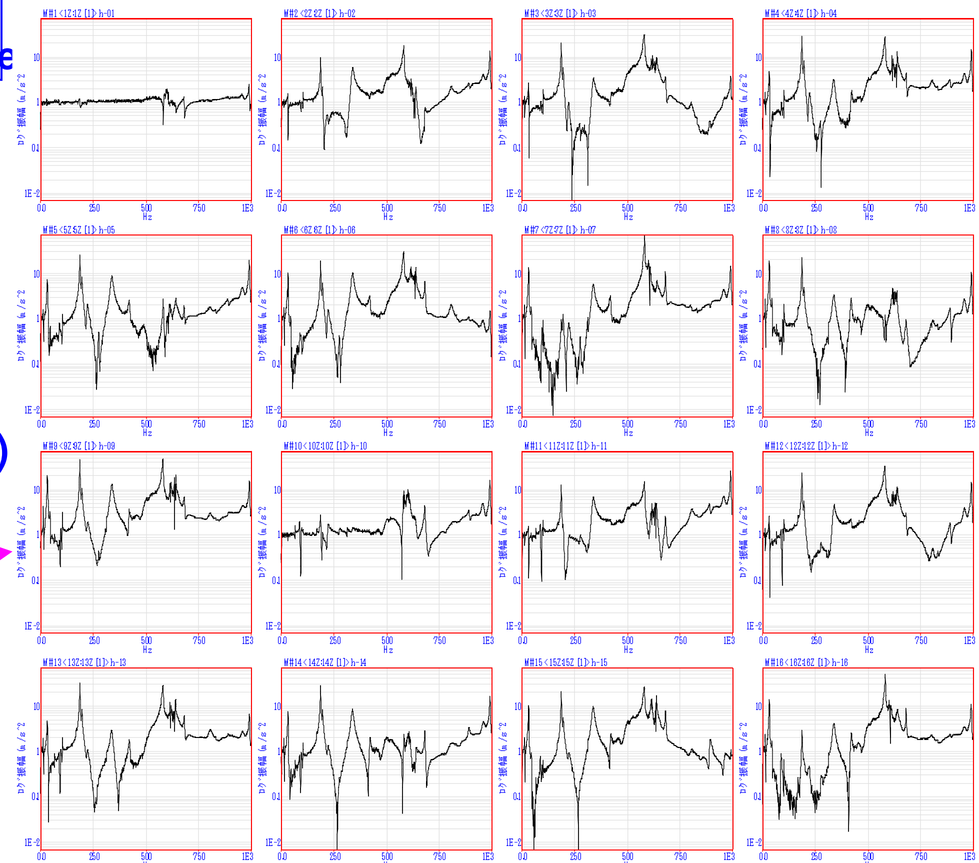

→ Amplitude can be improved because resonant frequency is increased.

# Vibration test



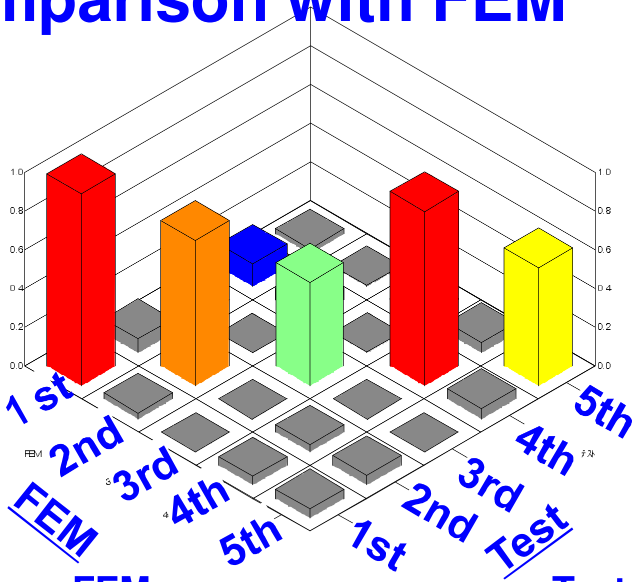



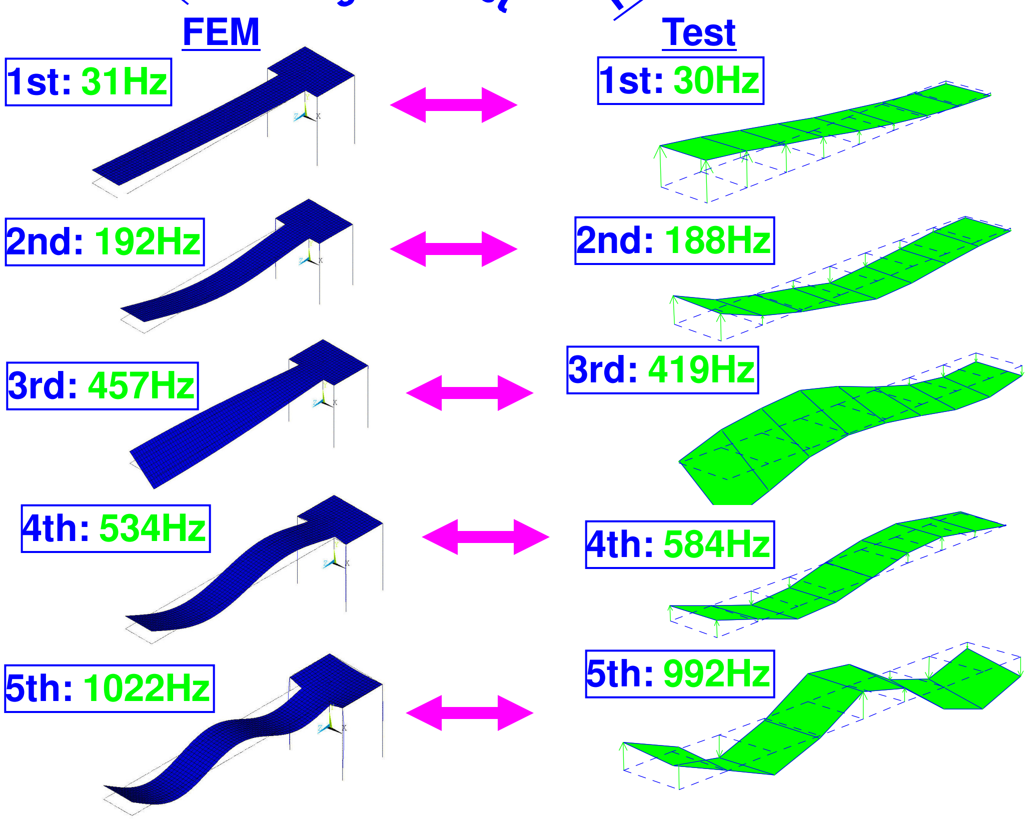
- Acc.(Output)
- Acc.(Input)



- Amplitude
- Phase

# Comparison with FEM



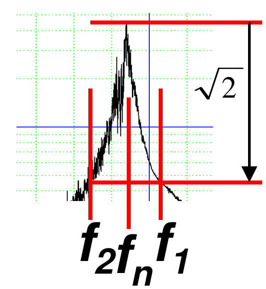

## MAC(Modal Assurance Criteria)

$$MAC_{rr'} = \frac{\left|\{\psi_r^{test}\}\{\psi_{r'}^{FE}\}^*\right|^2}{\left(\{\psi_r^{test}\}\{\psi_r^{test}\}^*\right)\left(\{\psi_{r'}^{FE}\}\{\psi_{r'}^{FE}\}^*\right)}$$

**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

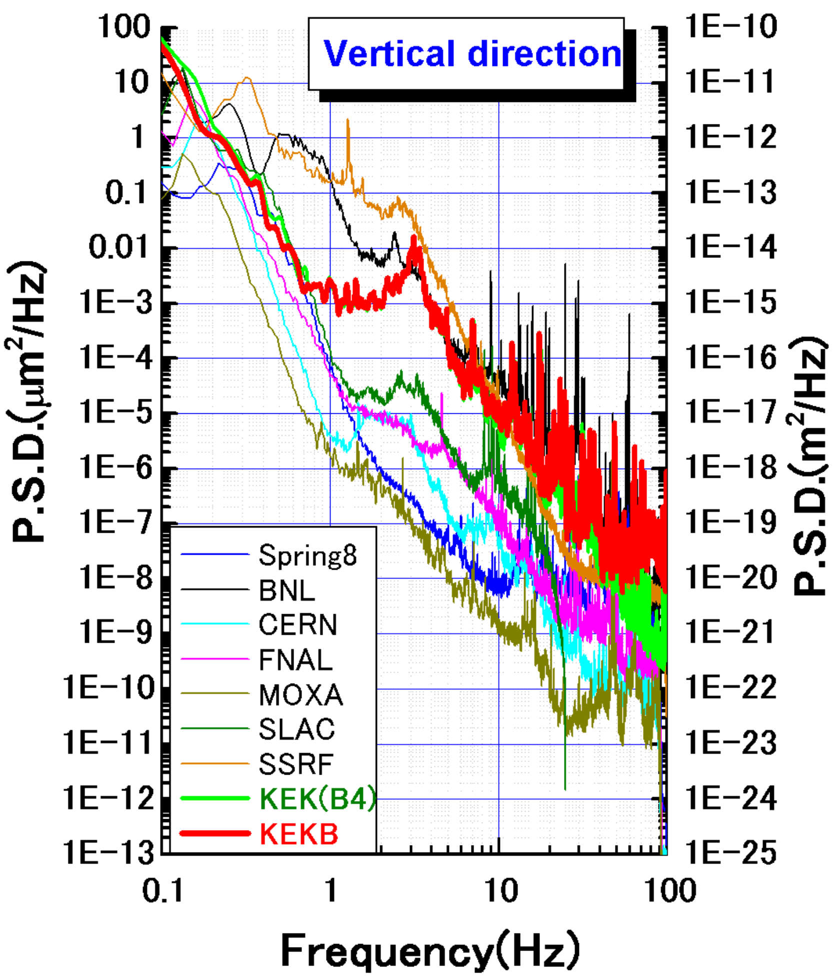



$$\zeta = \frac{f_1 - f_2}{2 \times f_n}$$

| 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 |

# 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/

ference: http://vibration.desy.de/overvie