Brownian Ground Motion And Dynamic Alignment of the Accelerator

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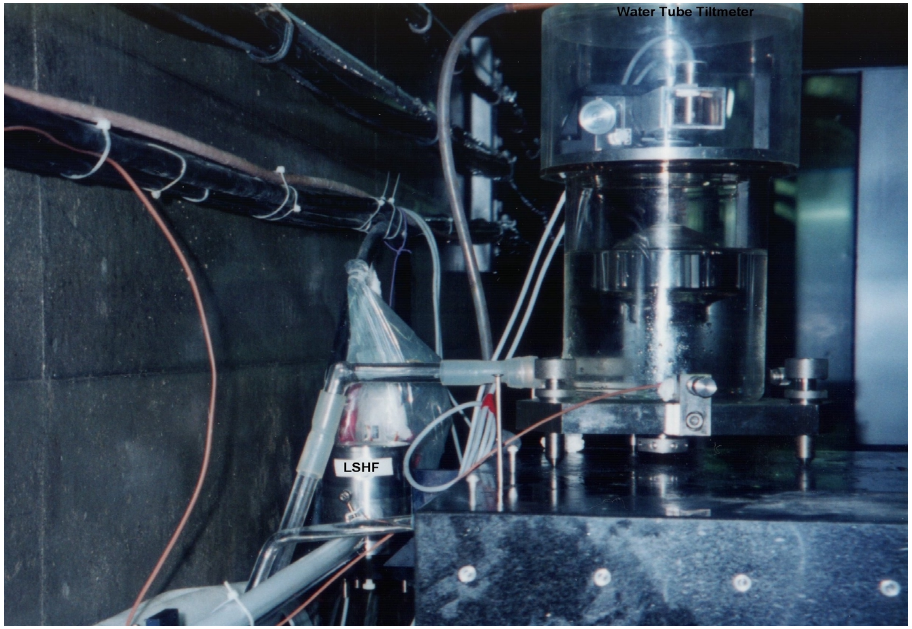
- **Power Spectrum Density and Coherence**
- **Slow Ground Motion and Geology**
- Slow Ground Motion and Excavation Methods

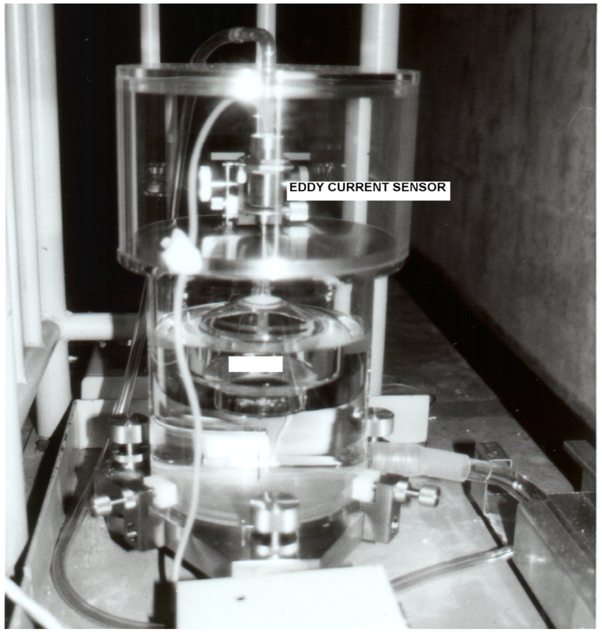
Typical Parameters of Linear Collider

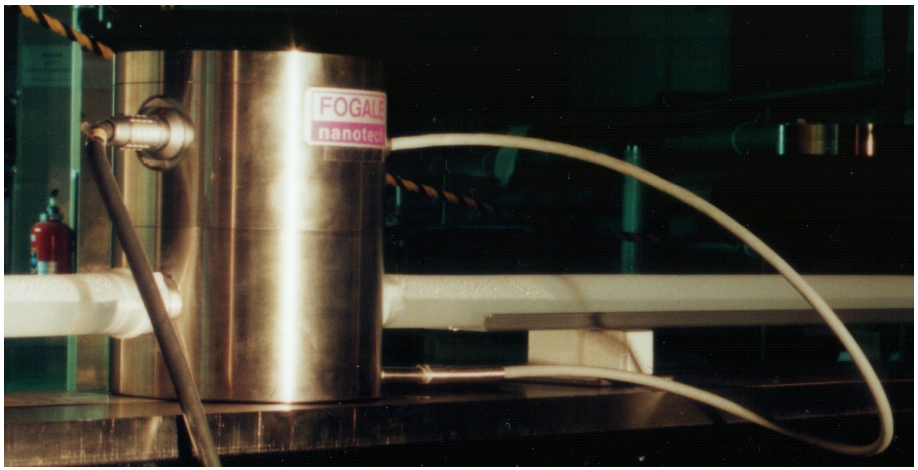
		X-band	C-band	
Beam Energy Entrance/Exit	E0/E1	10/500	10/500	GeV
Particles/bunch	N	0.8	1.0	10^{10}
Invariant Emittance	ε_{N_y}	30	30	nm
Bunch length	σ_z	80	200	μm
β at entrance	β_0	4	4	m
Rf frequency	f	11.4	5.7	GHz
Accel. gradient	*dE/ds*	45	32	MeV/m
Iris radius/wavelength	a / λ	0.16	0.14	
ATL coefficient	A	1	1	nm^2/s/m
Stable time for $\in$ =0.1	t	3	24	hours

Brownian Ground Motion and Dynamic Alignment of the Accelerator

Sensors for Studies







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Empirical Continuous Power Spectrum Density ;

$$P(f) = \frac{K}{4\pi^2 f^2 (f_0^2 + f^2)}, \tag{1}$$

f_0 : 0.1Hz - 0.01Hz

In the hard rock region: $f_0 \approx 0.1$Hz

$f = f_0$ $P(f) = K/f^2$

Brownian motion of rocks becomes dominant

K strongly depends on the site

The ATL model:

Formulation using an auto-correlation function

$$< y(t+\tau) y(t) >$$

$$\Delta y(\tau)^2 = 2 < y(t)^2 > -2 < y(t+\tau) y(t) > = A \cdot L \cdot \tau. \tag{2}$$

$< X >$: an ensamble average

Definition of a Power Spectrum;

$$P(f) = \int_{-\infty}^{\infty} < y(t+\tau) y(t) > e^{-2\pi i f \tau} dt d\tau , \tag{3}$$

$$A \cdot L \cdot \tau = 4 \int_{-\infty}^{\infty} P(f) \sin^2(\pi f \tau) df . \tag{4}$$

[$f = f_0$]

$$4 \int_{-\infty}^{\infty} P(f) \sin^2(\pi f \tau) df = K \cdot \tau \tag{5}$$

Power Spectrum of ATL model as,

$$P(f) = \frac{A \cdot L}{4\pi^2 f^2} . \tag{6}$$

[Actual Experiment]

$$P(f) = \frac{K}{4\pi^2 f^2 + (1/\tau_{max})^2} , \tag{7}$$

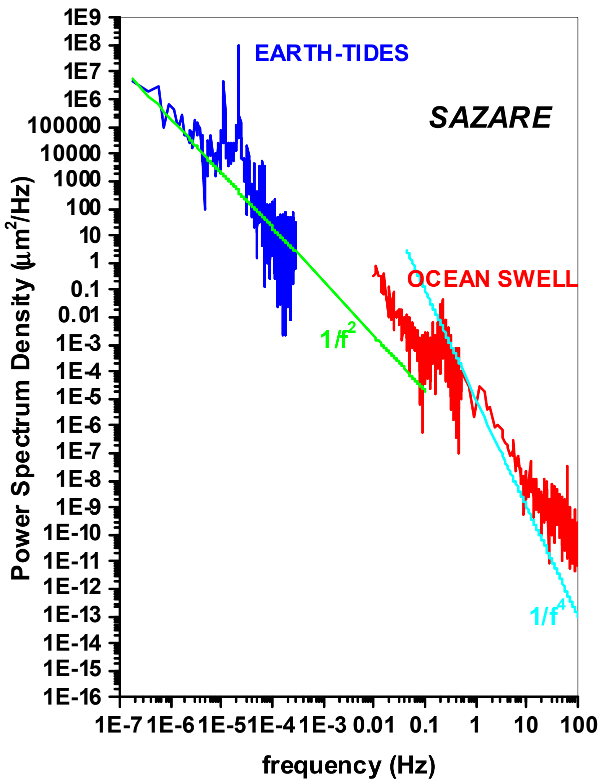
$1/\tau_{max}$: cutoff frequency

The Integration of Equation (5);

$$4 \int_{-\infty}^{\infty} P(f) \sin^2(\pi f \tau) df = K \tau_{max} (1 - e^{-\tau/\tau_{max}}) . \tag{8}$$

[ATL Model]

$$\Delta y(\tau)^2 = A \cdot L \cdot \tau_{max} (1 - e^{-\tau/\tau_{max}}) . \tag{9}$$



Recently, many accelerator physicists use ATL model for their accelerator simulation because of simplification of the calculation. But we have to take account of **applicable limitations in the light of coherency of the ground motion spectrum.**

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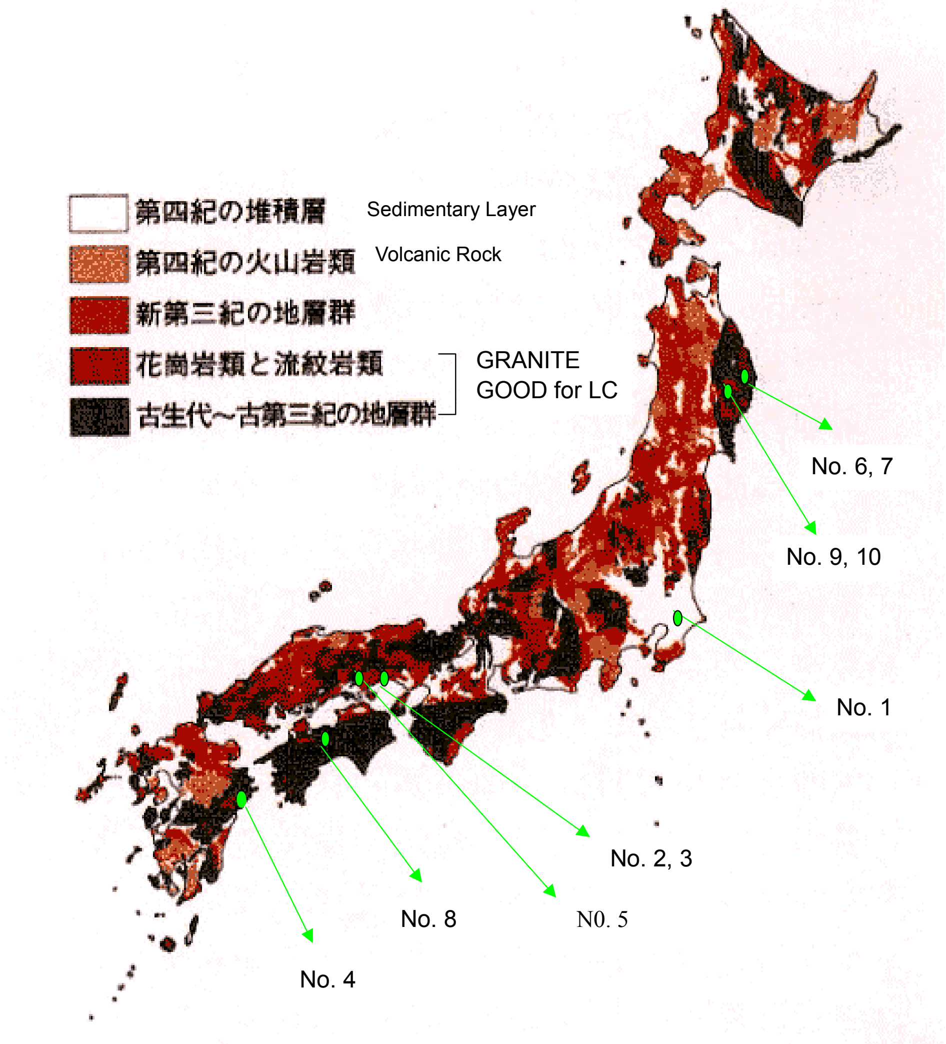
Geological Map and ATL



Geological Map of Japan and the Related Sites for ATL Table.

Described numbers are the same in figures and Table.

ATL COEFFICIENT in JAPAN

No	Site Name	A ($nm^2/m/sec$)	Geology of the Site
1	Tunnel of KEKB	4.0E+01	Clay and Gravel
2	Rokkoh-1	3.6E+01	Granite (near Fault)
3	Rokkoh-2	3.3E+01	Granite
4	Miyazaki	1.5E+01	Diorite
5	Spring-8	8.0E-01	Granite
6	Kamaishi-1	1.4E-01	Granite (Crack and Water)
7	Kamaishi-2	5.7E-02	Granite
8	Sazare	5.0E-02	Green Schist
9	Esashi-1	5.7E-03	Granite (Floating Stone)
10	Esashi-2	2.0E-03	Granite

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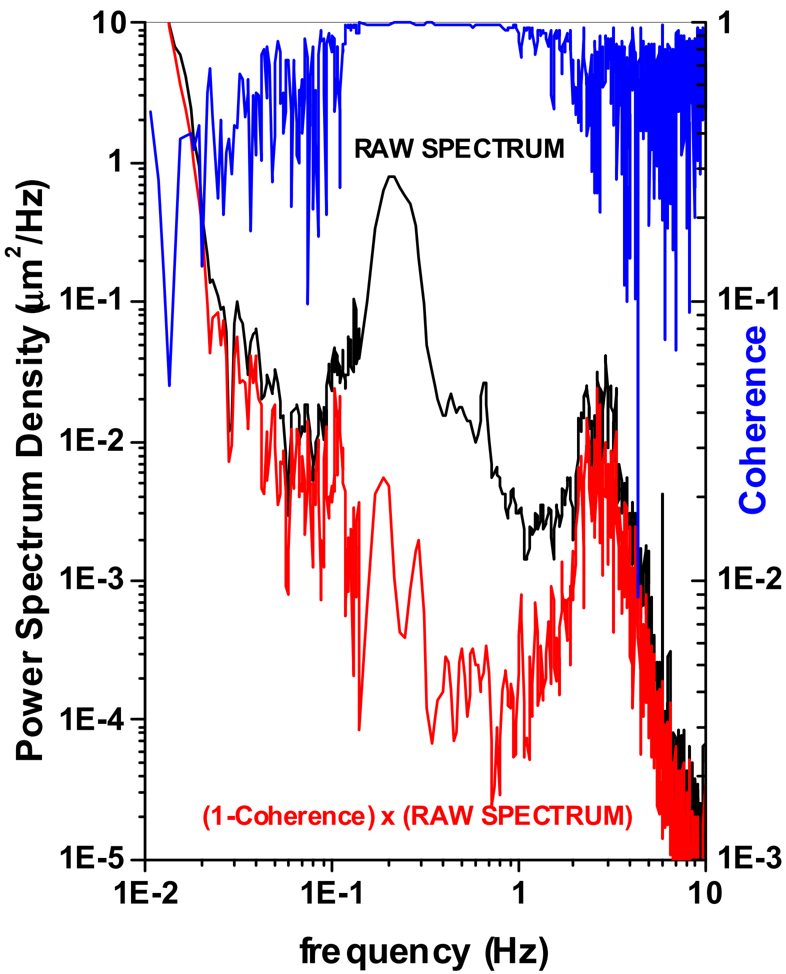
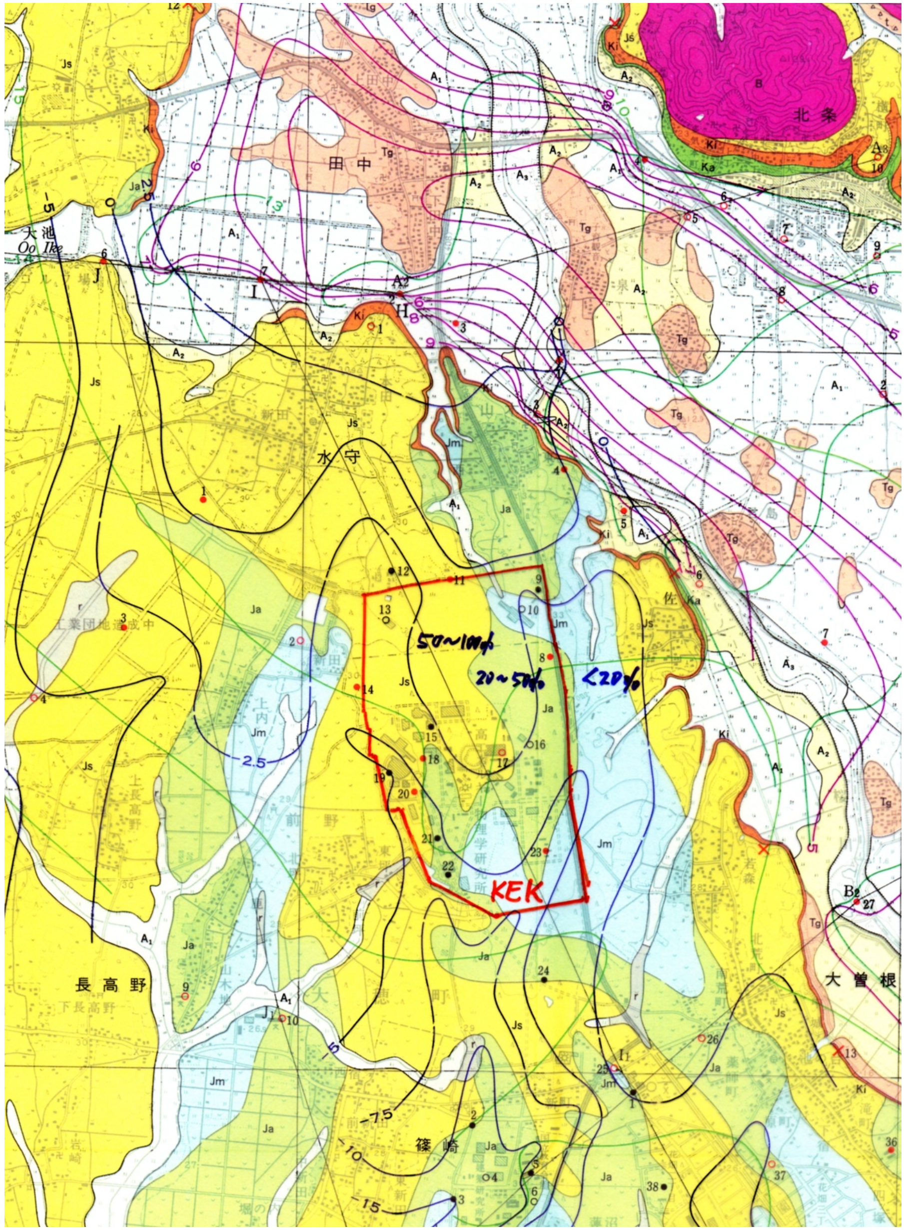
Brownian Ground Motion and Dynamic Alignment of the Accelerator Coherence-1



Ground motion in the noisy site (KEK). Coherence between two points at a distance of 48 m. Power spectra for the two points are the same. Incoherent spectrum is given by the equation shown in the figure. A big bump spectrum, around 0.2 Hz, corresponds to the ocean swell. The incoherent spectrum around 3 Hz comes from traffic noises. This incoherent vibration gives an amplitude of 83 nm. That is, the tunnel in KEK should have a depth of 900 m, providing we want the amplitude of 1 nm.



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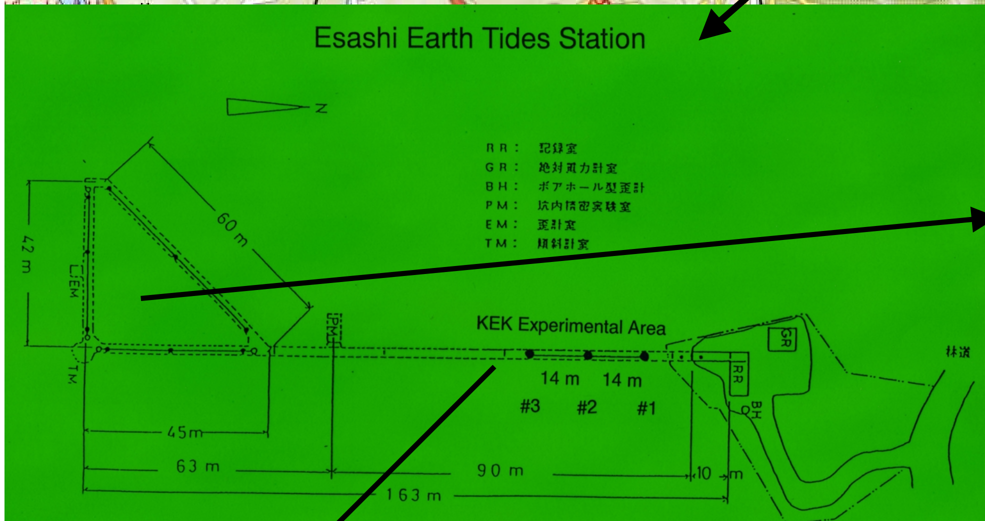
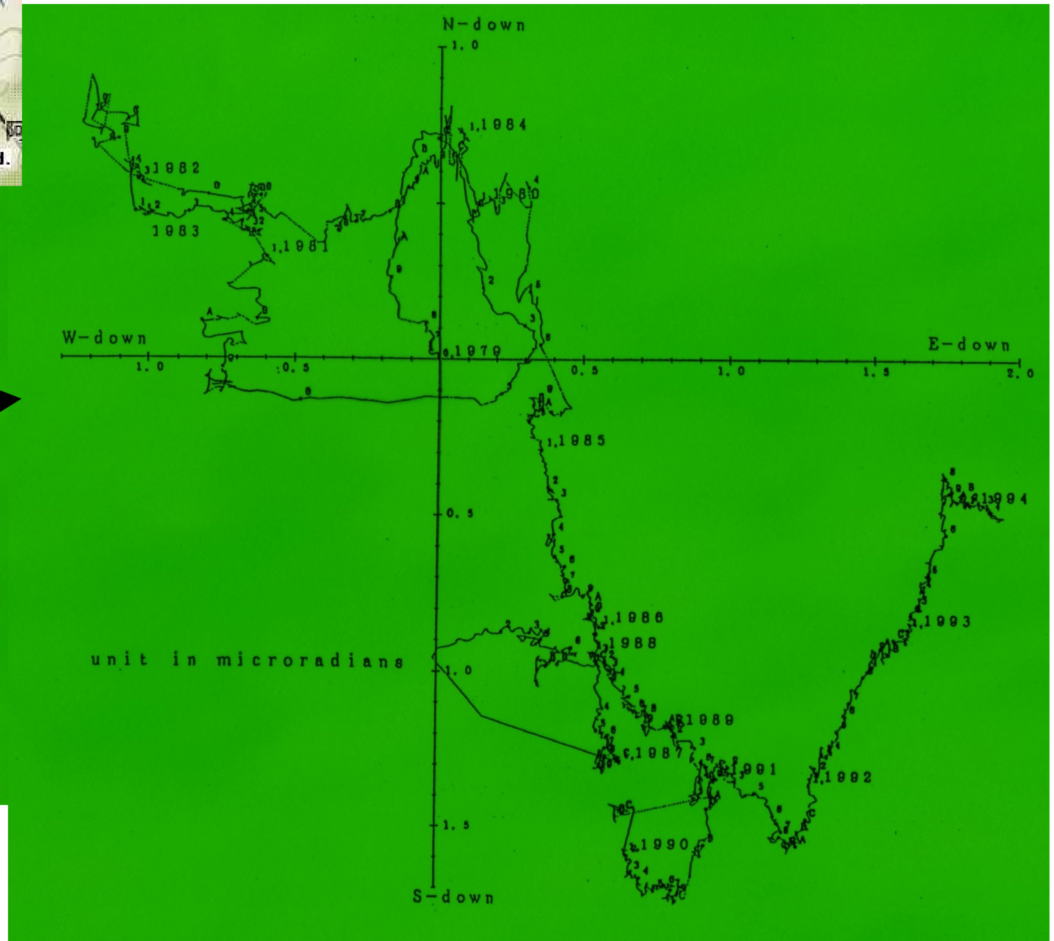
観測地点の詳細と長期間の傾斜変動観測例



第１図　観測点の位置

Fig.1 Locations of observation sites.

KEK観測施設（1994年～現在）



第５図　日平均値で表した1979年６月の施設開設以来の経年傾斜変動ベクトル

Fig.5 Secular tilting motion since the opening of the station in June 1979.

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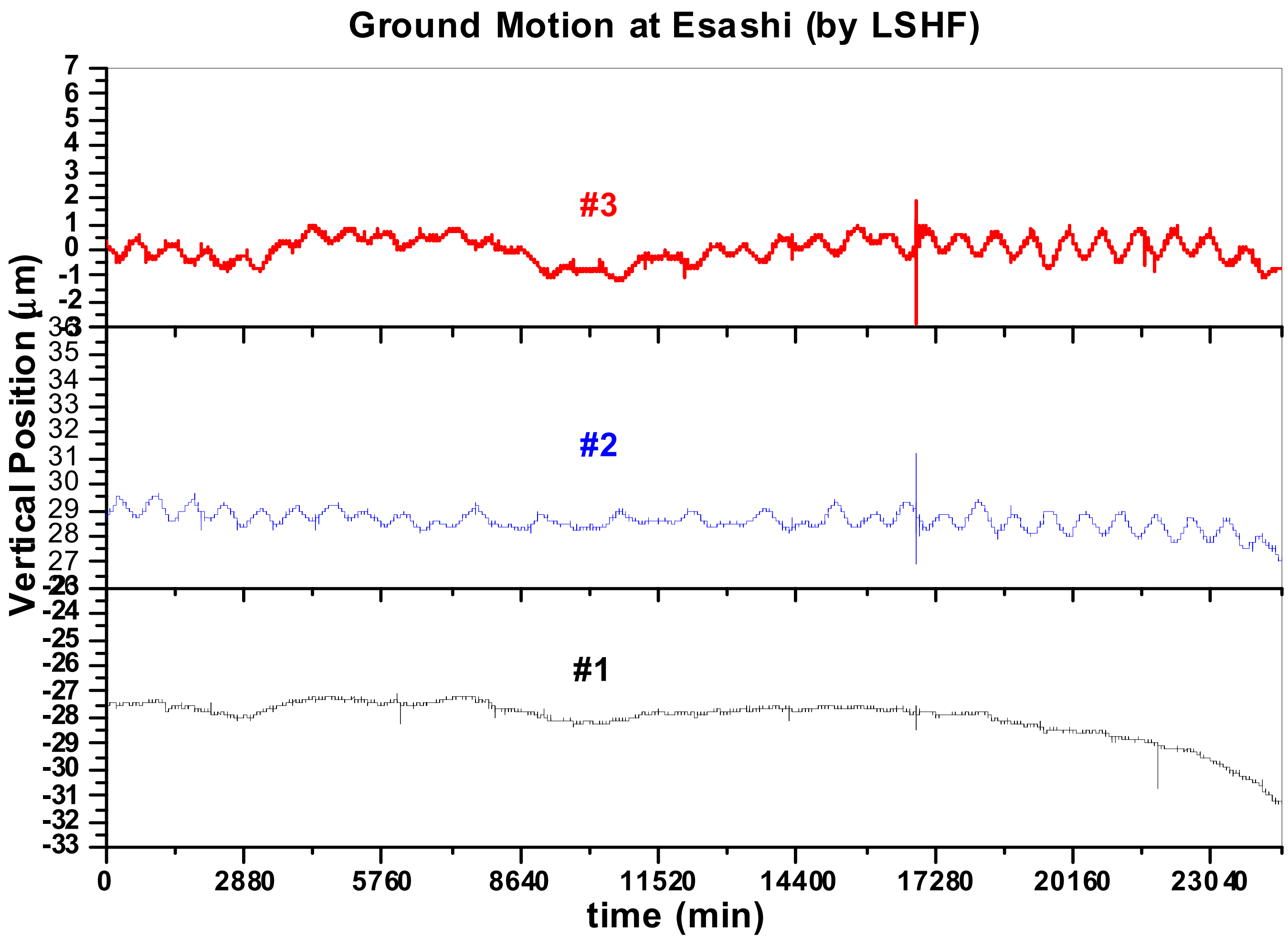

The time series data on the vertical ground motions observed at three points being 14 m apart between one another.

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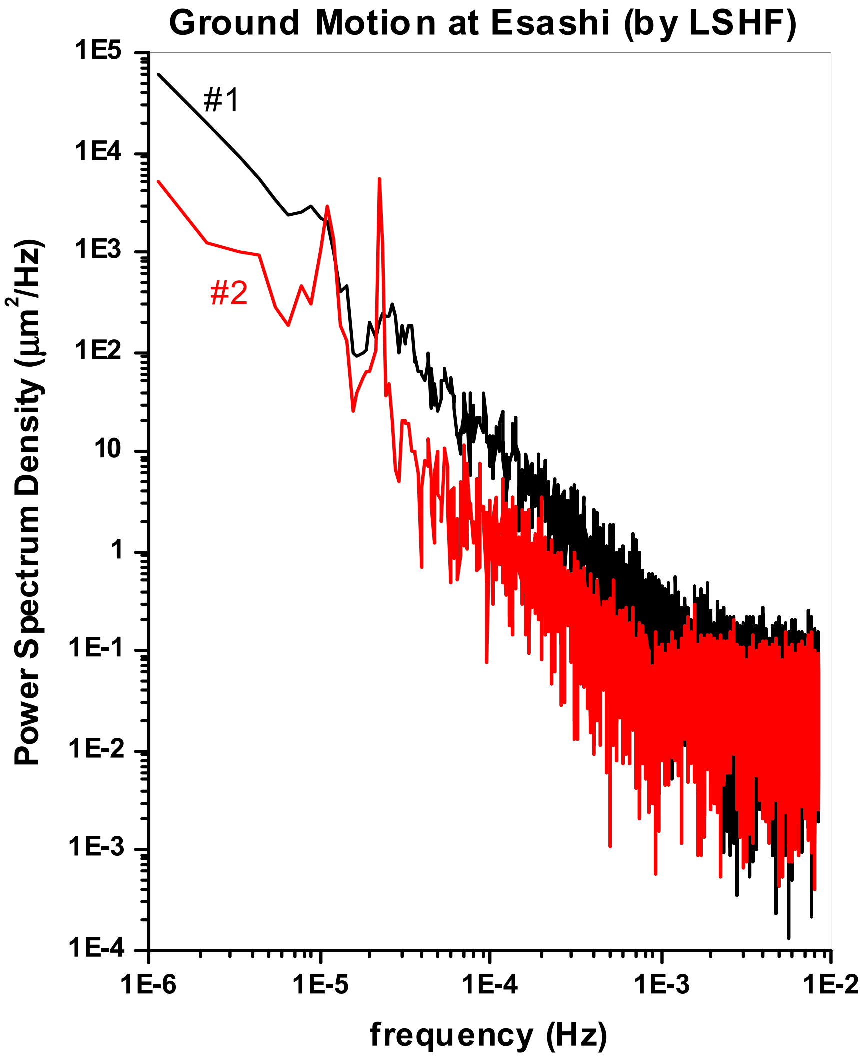
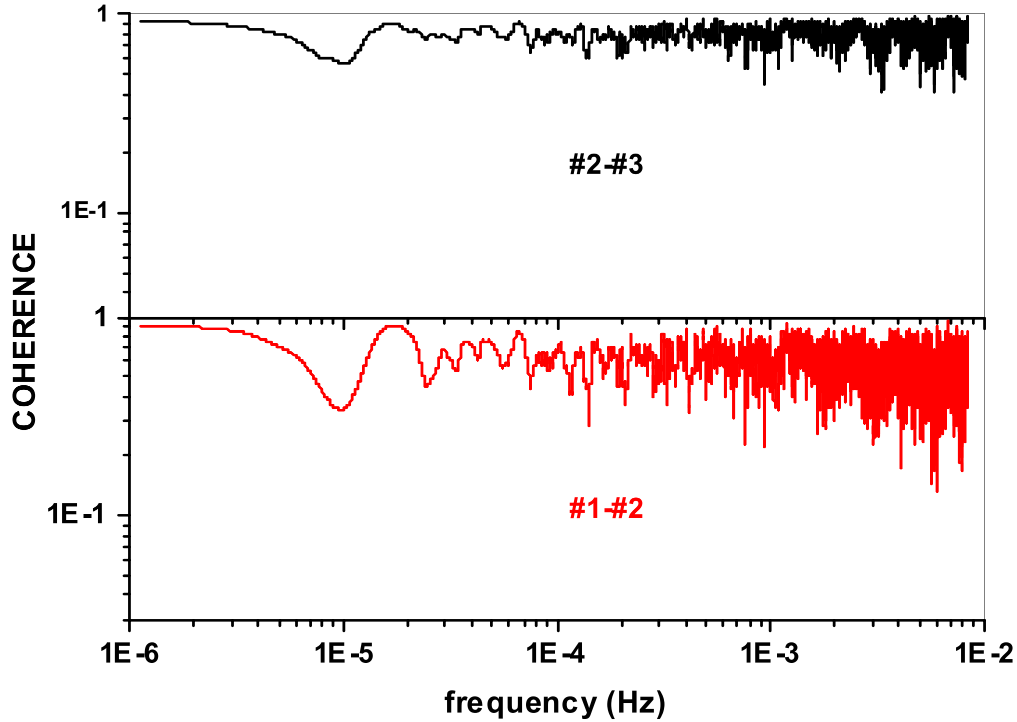
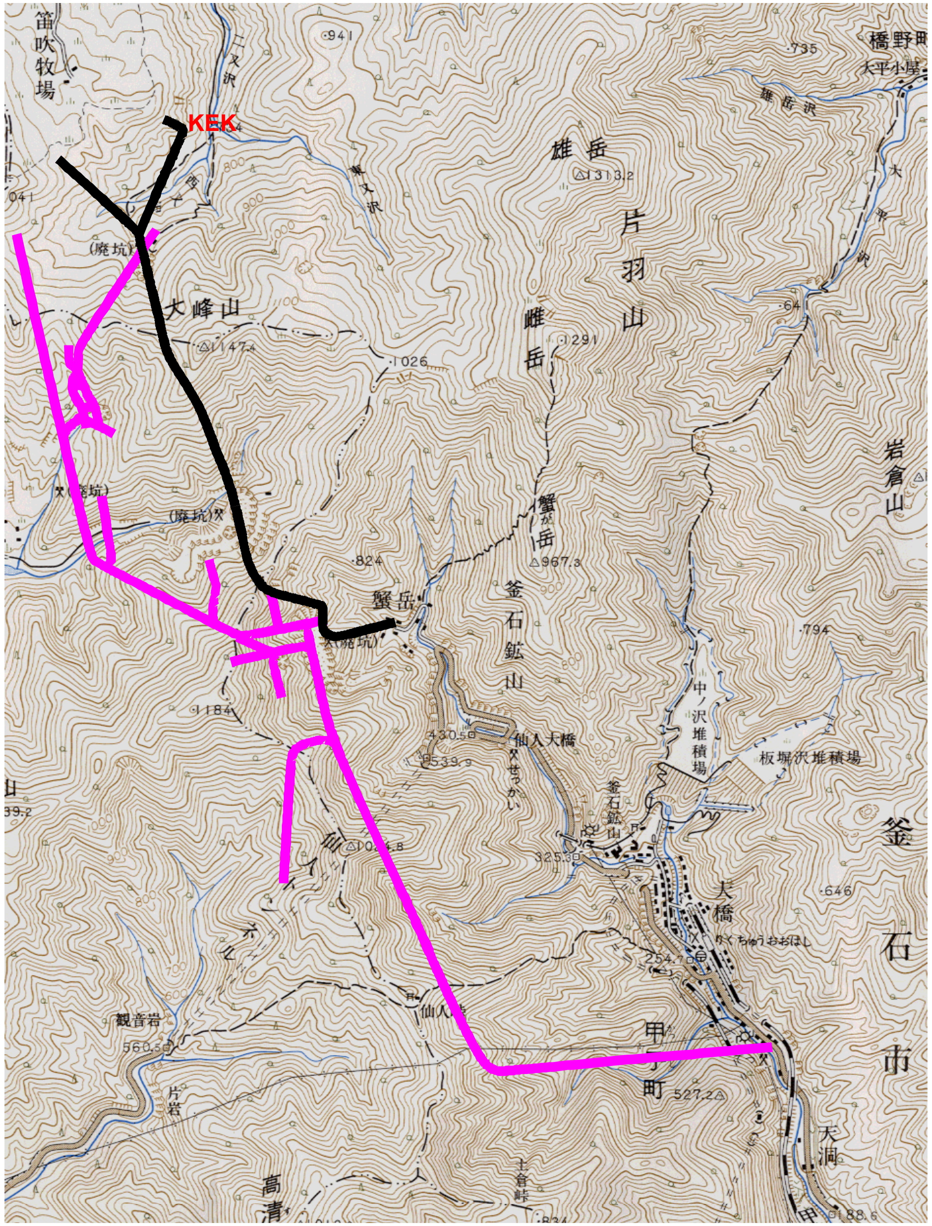


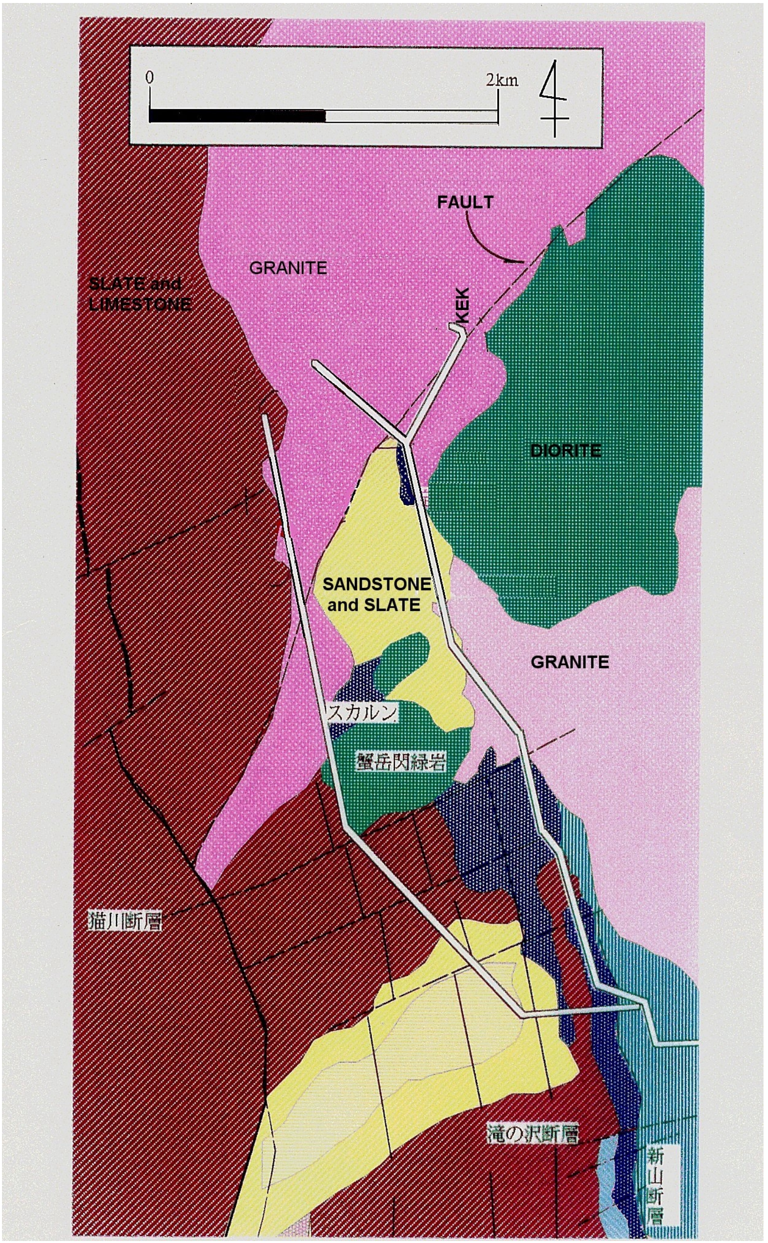


Coherence in the Granite Tunnel Having a Floating Lumped Rock.

Except the #1 lumped rock position, we get good coherence.

#1 shows no earth-tide spectrum. *ATL* coefficient in this point is a little bad as shown in the previous *ATL* Table.





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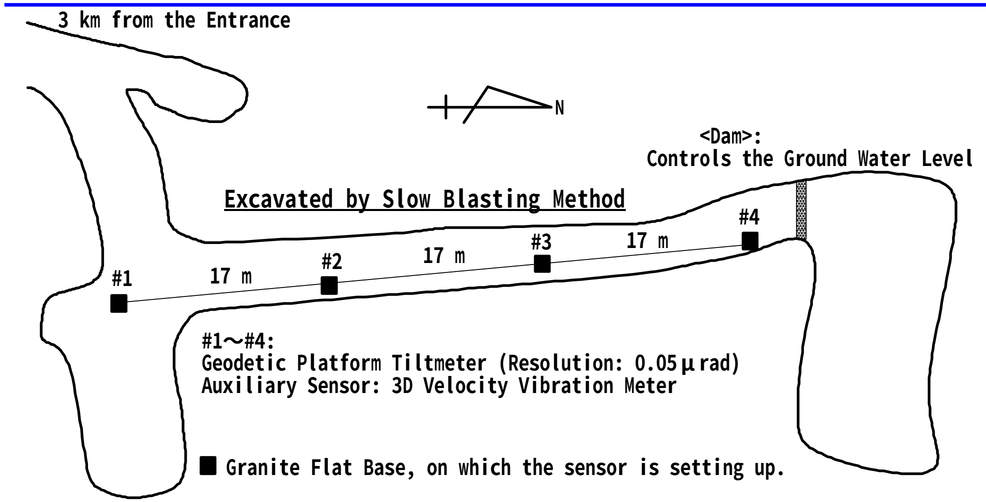
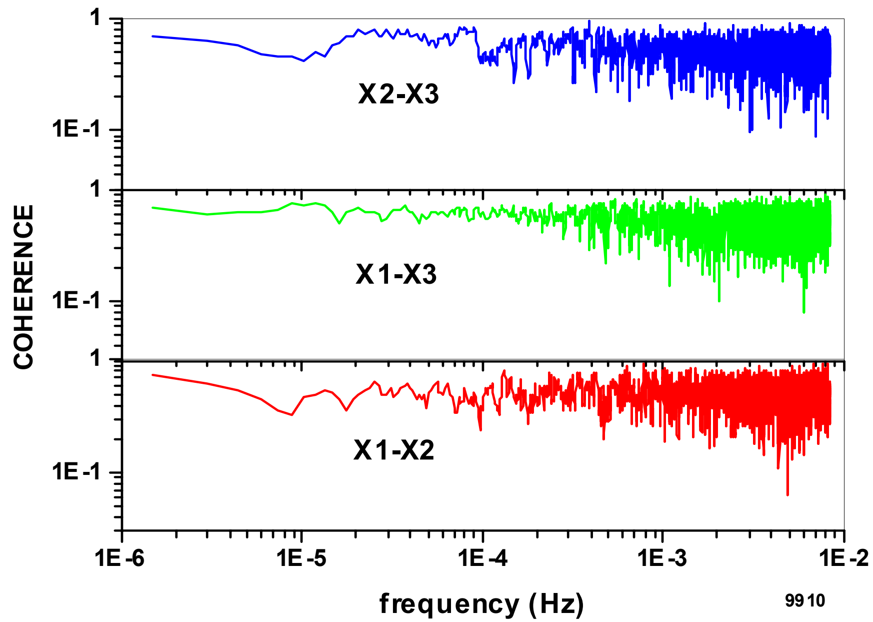
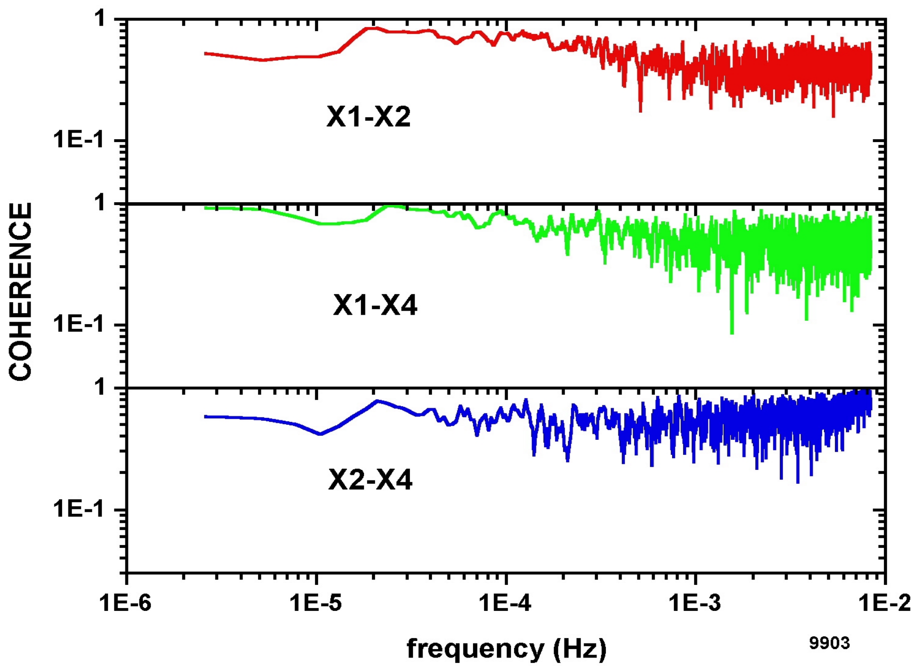
Brownian Ground Motion and Dynamic Alignment of the Accelerator   Coherence-2







EFFECT of BLASTING CREVICE:

We executed several experiments to get detailed information about the surface layer of the granite tunnel cut by SBM.

The coherence shows very complex changes without the dam.

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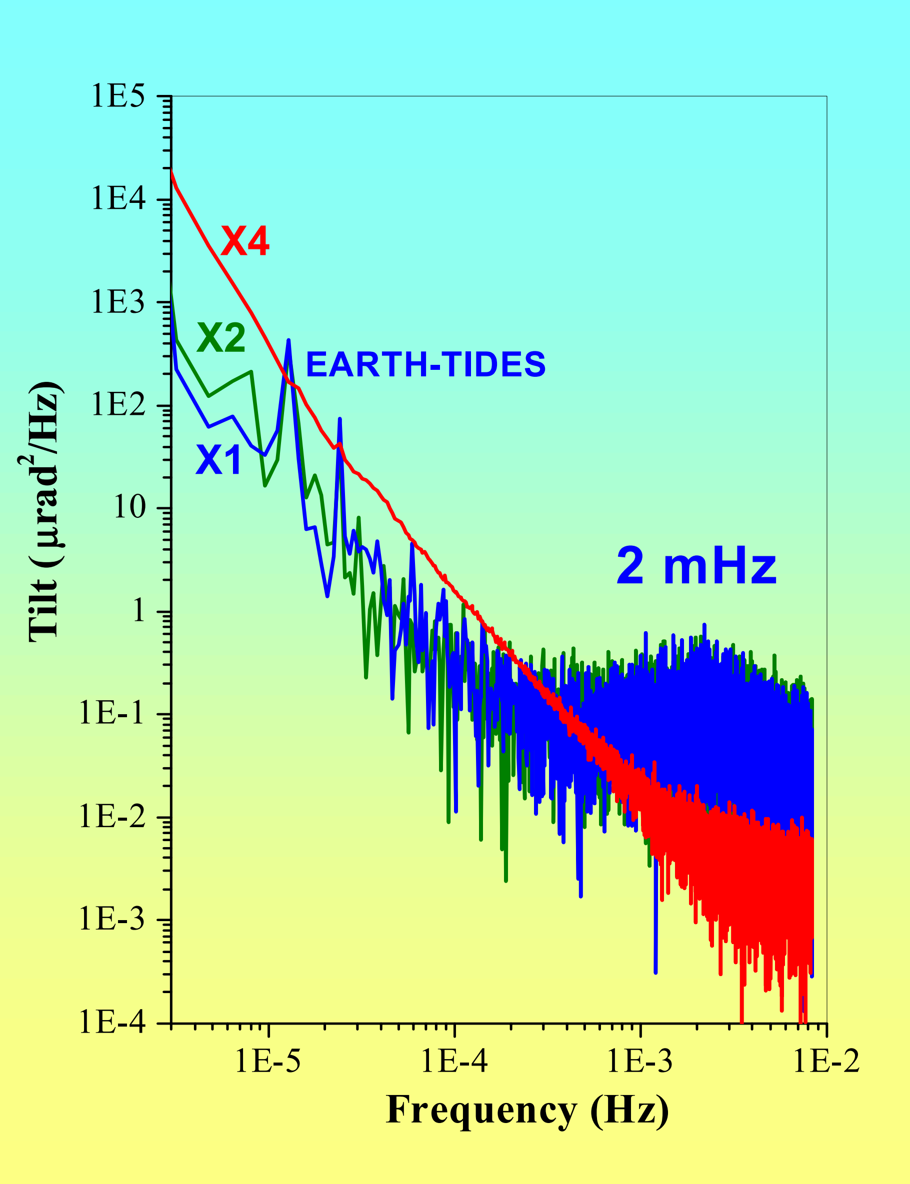

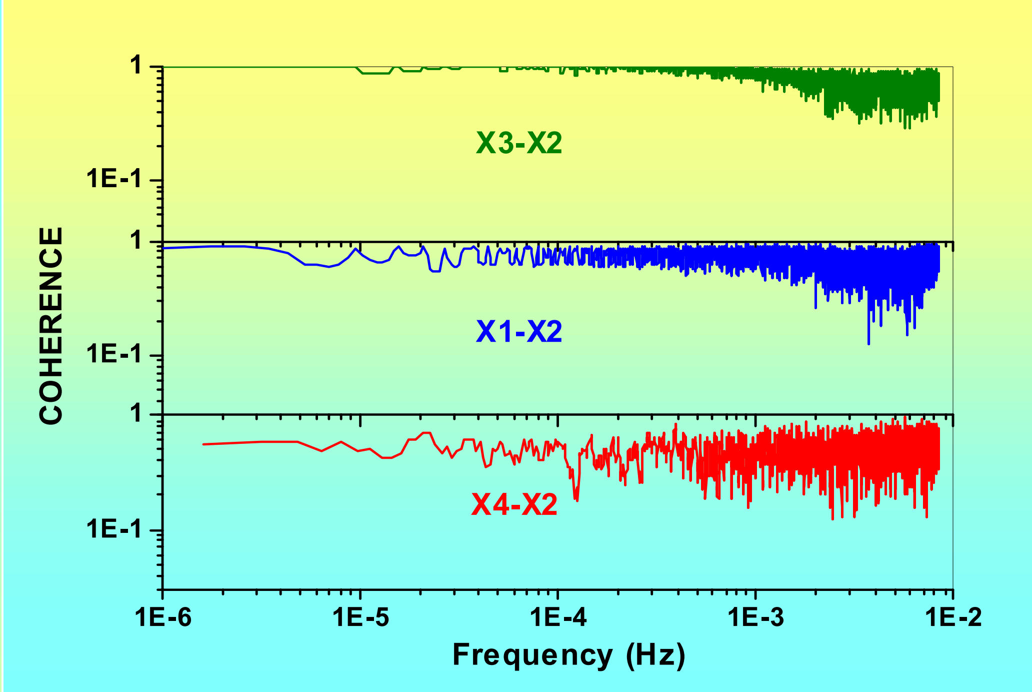

In order to check the activity of underground water, we built a dam across the flow to control the water level in the crevice.

- #2 was mostly suffered by the reaction between the crevice and the water.
- #4 is another effect, such as lumped rock like Esashi.

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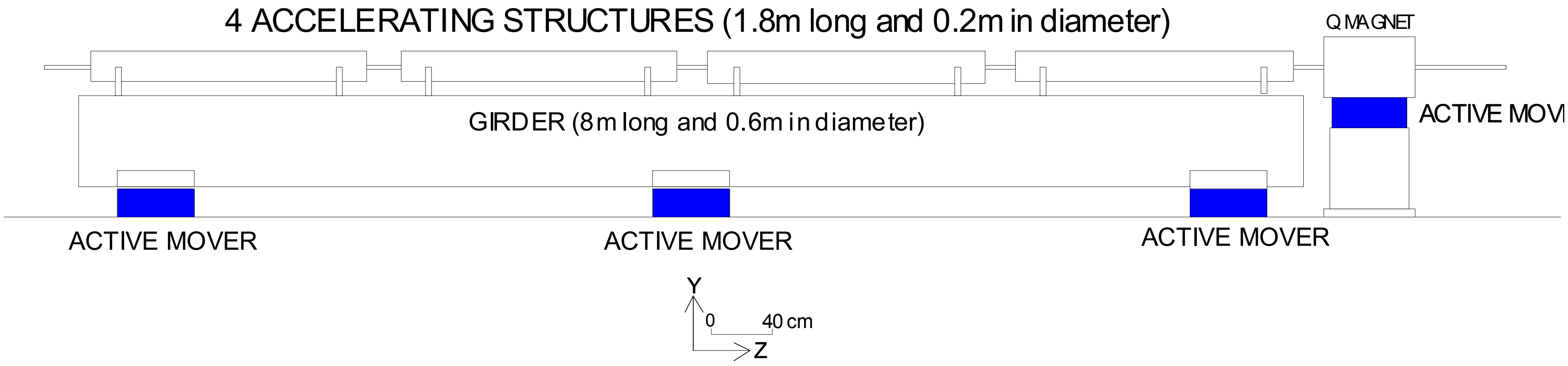
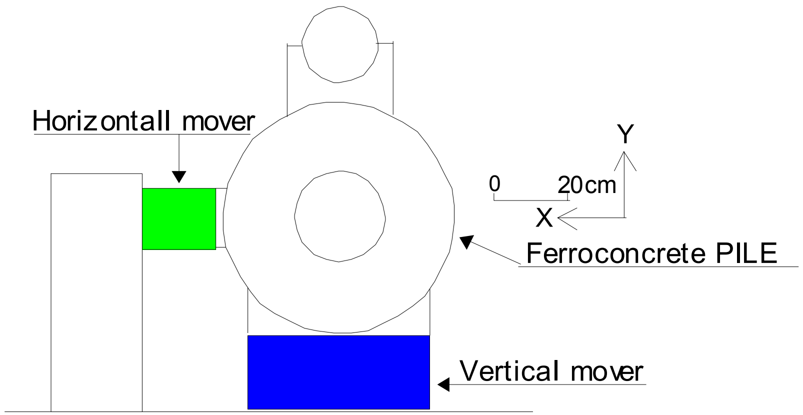
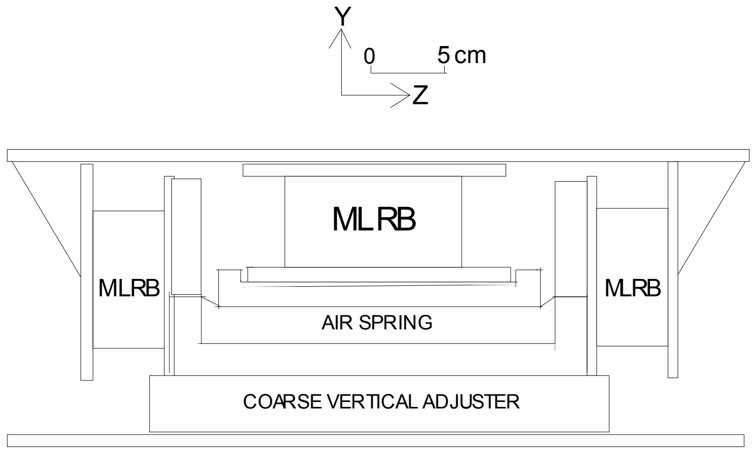




Crossection of the girder and the movers.



Detail drawing of the vertical active mover.

架台の共振点：

X 軸方向： 5.8Hz、12.5Hz、16Hz、29Hz、

Y 軸方向： 12〜16Hz のブロード共振、30Hz、90Hz、

Z 軸方向： 2.3Hz、5.6Hz、8Hz、80Hz、

ガーダーのクリープ特性と高剛性化

加速管： 長さ 1.8m

重量 250kg

使用数 8,000 台

設置精度 30μm

ガーダー及び調整機構は３μm 以下の確度で再現性

コンクリートパイルの鋼板巻きの低価格ガーダーは、そのクリープ特性の評価が製作条件に強く依存して非常に困難であることが判明

強く伸張したピアノ線材（PC 鋼棒）をコンクリートで固めた円柱架台

クリープ歪み進行過程の計算：クリープの進行が４μm 以下になるのが製作後約一年掛かる。

表－１　ガーダー材料の諸元

材料	断面積 (cm^2)	断面２次モーメント (cm^4)	ヤング率 (ton/cm^2)	単位長重量 (kg/m)
PC 杭：600φ，t=90	1,473	493,415	410	375
角形コラム：600□，t=16	363	203,000	2,100	285
RC：600□	3,600	1,080,000	210	864

PC 杭は肉厚 90mm の円筒状とし、９φの PC 鋼棒 12 本を一様に配置した。

表－２　各ガーダー材料諸元に対する固有振動数（Hz）

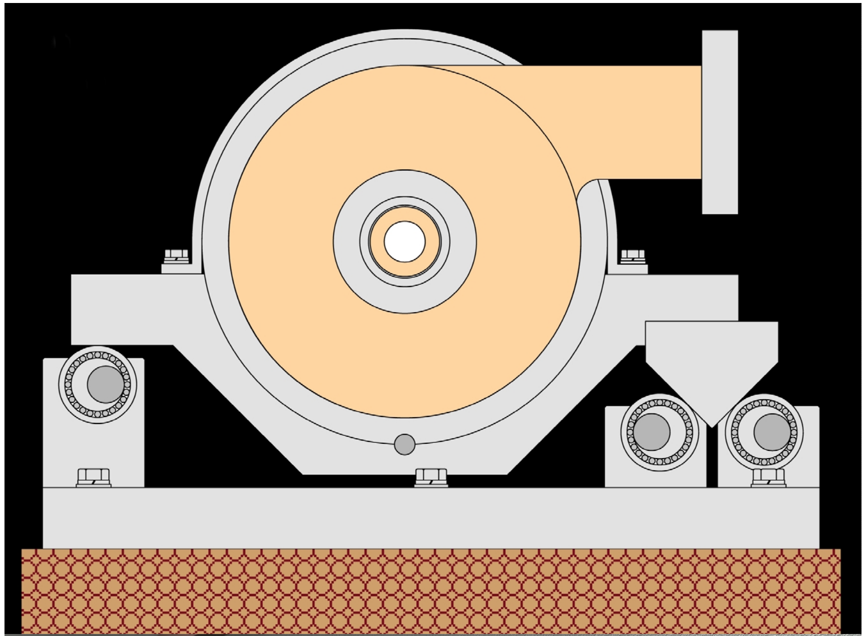
モード次数	１次	２次	３次	４次	５次
モード形状	Y	θ_Z	θ_X	弾性モード	弾性モード
PC 杭	5.0	5.8	7.0	33.8	228.0
角形コラム	5.0	5.8	7.0	51.6	355.9
RC	5.0	5.9	7.1	26.7	175.7

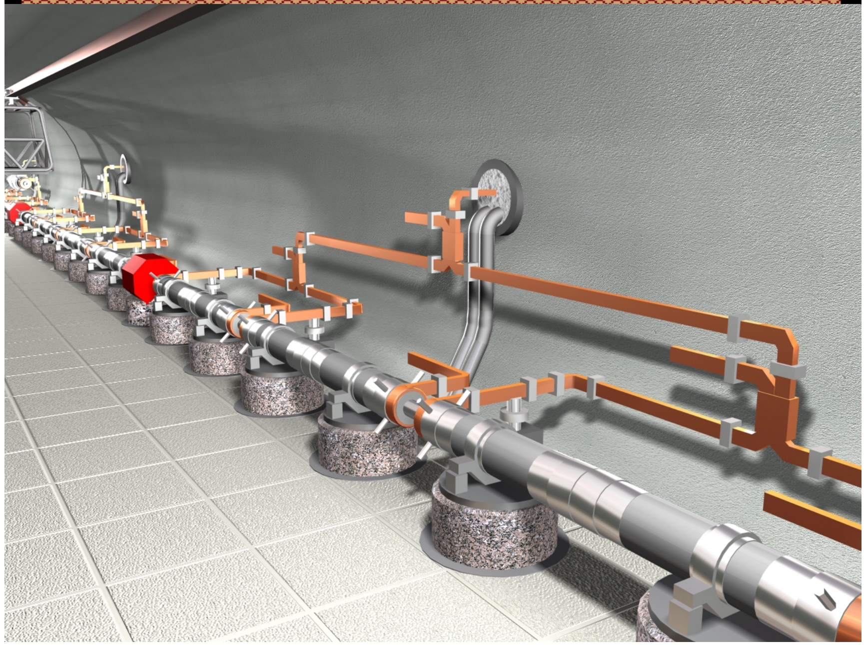
以上から、RC 杭方式の代わりに、PC 杭を使う方が LC のガーダーとして有効であることが分かった。残る問題で解決せねばならないことは、

１）PC 杭方式の方が RC 杭方式に比べて、製作費が３.５倍になること、

２）５Hz の Y 方向振動に対するダンパーが必要なこと、

３）ガーダーの重量が３トンと重くなり、その分能動駆動機構の負荷が大きくなる。





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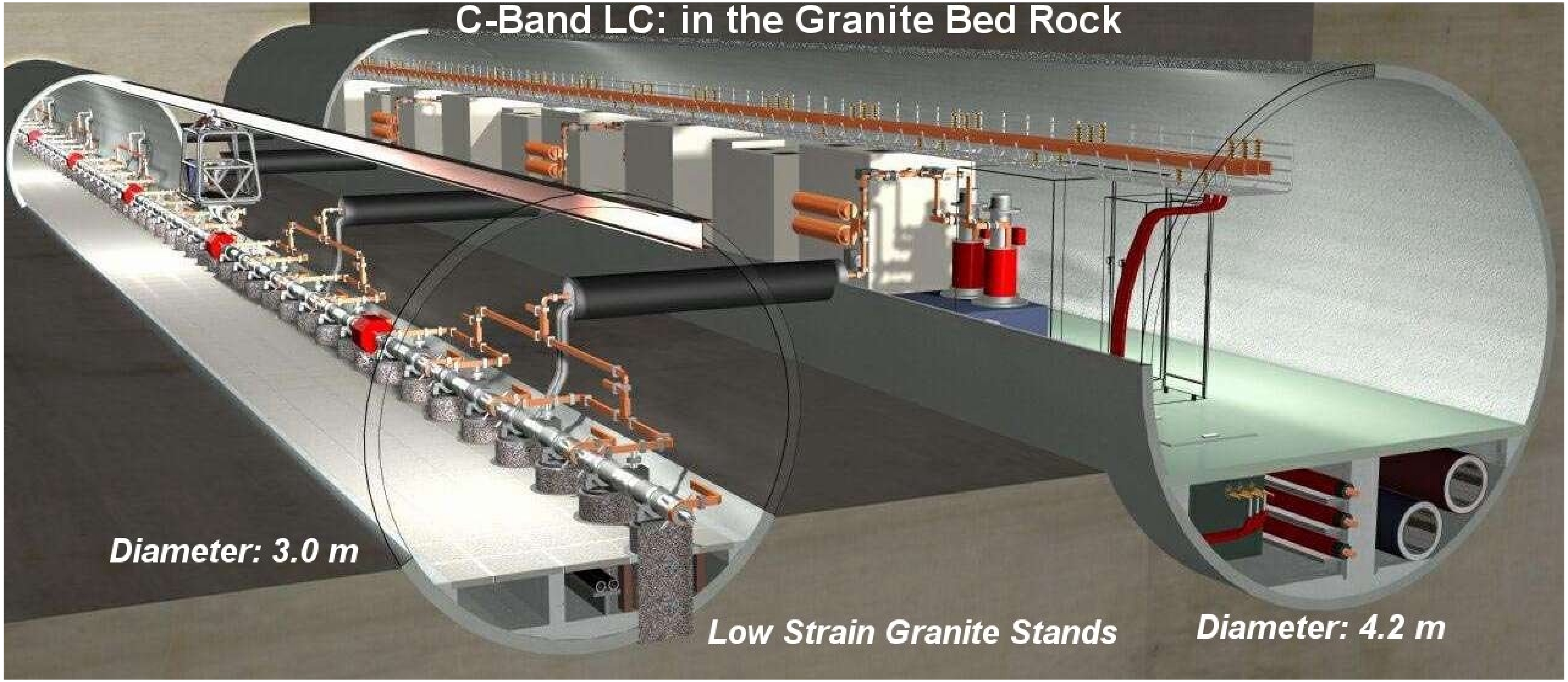

- It is essential to search the site being $A < 1$ nm^2/m/sec for the long term stability of the alignment.
- TBM is the best solution for cutting the tunnel of LC.
- The separated tunnel is preferable to suppress the noises in the accelerator tunnel caused by the accelerator facility.
- We have to pay attention to local fluctuation of the *ATL* coefficient and the coherence around the betatron wave length for the construction of the long scale LC.

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