GEOLOGY AND SLOW GROUND MOTION ON FUTURE ACCELERATORS

Shigeru Takeda, Noboru Yamamoto, Hiroshi Matsumoto, KEK, Tsukuba-shi, Japan and
Hirokazu Yosioka, Takafumi Simogouchi, TRL, Takenaka Corp., Inzai-shi, Japan

Abstract

The power spectrum density and coherence function for slow ground motions are studied for the construction of the large future electron-positron linear collider. Dominant part of the ground motion in the low frequency range (f<0.1 Hz) is usually related to the ATL model using the integrated power spectrum density. Recently we have obtained new information on the ground motion. The coherency of the ground motion changes as a function of detailed geological condition even though the value of A is not so different between each other. We will present detailed discussion about this new information.

1 GROUND MOTION AND ATL

Many measurements on the ground motion were made for several accelerator sites and their related sites, since the special interest of accelerator physicists. Any alignment errors cause an orbit distortion and which leads to reduction of the dynamic aperture of the machine. An extreme situation is emittance growth of the accelerating beam. Slow ground motion which frequency components are less than characteristic frequencies of the accelerator has been usually considered as not having serious effect on machine operation, assuming complete space and time coherence of the ground motion. This assumption, however, not exactly works out as a result of ATL model [1]. The ground motion caused by daily or seasonal variation of ground temperature, groundwater level variation, atmospheric pressure variation and earth tides have a large correlation length. The residual part of these variations, however, becomes inelastic component of the ground motion and looses the correlation since the source of the motion is removed. The spectrum of this ground motion, excluding characteristic spectra, is empirically given as,

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

where $P(f)$ is a power spectrum in m^2/Hz, K is constant and f is frequency in Hz. The constant f_0 is depends on geological features and changes from 0.1Hz to 0.01Hz [2]. In our experiments, f_0 is about 0.1Hz for the quiet hard rock region, and about 0.01 Hz for the noisy weak ground region. A typical example of the spectra is shown in Fig. 1. In the $f < f_0$ frequency region, $P(f)$ can be characterized by K/f^2. This slow ground motion occurring like Brownian motion of rocks becomes dominant at this frequency region. The coefficient K strongly depends on the geology of the site and its value is $1 \sim 10^2$ nm^2/Hz. A large spectrum component around f_0 is ocean swell, but which shows good coherence, even if the site were weak ground region [3].

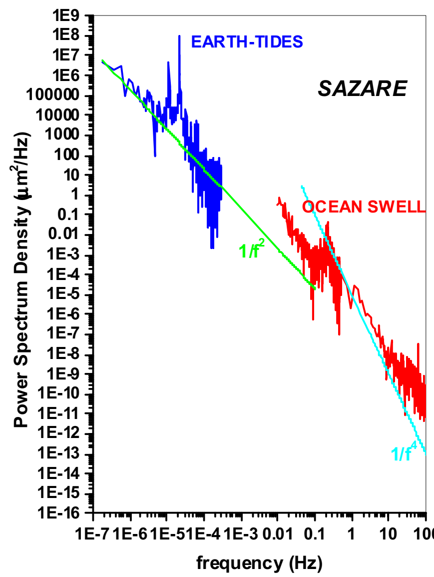

Figure 1: A typical wide band spectra.

The ATL model can be formulated using an auto-correlation function $< y(t+\tau)y(t) >$, as

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

Here, $< X >$ means an ensamble average. Using the definition of a power spectral function,

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

then equation (2) becomes,

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

If we assume that the power spectrum is proportional to the inverse of squared frequency ($f \ll f_0$), we can carry out integration in the right hand side of the equation (4),

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

Putting this result into the equation (1), we find the power spectral function of ATL model as,

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

In the actual experiment, we have to introduce a cutoff frequency $1/\tau_{max}$ in the power spectral function,

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

integration in the equation (5) becomes,

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

In other words, the ATL model will be replaced by,

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

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. The parameters of f_0 and K have strong dependency on the site. Then, if we want a good simulation of the related accelerator, we must formulate an optics including the equation (1) and coherency of the real site. In table 1, we present 10 examples of A-value as a guide of consideration of the ground motion in Japan.

Table 1: ATL COEFFICIENT in JAPAN

No	Site Name	A (nm^2/m/sec)	Geology of the Place
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	SPring8	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

2 INCOHERENT GROUND MOTION

2.1 Effect of the fault

Fig. 2 shows the coherence observed in the granite tunnel. We set one of the two sensors at the fixed point, and the other was set at a distance of 60m spanning over the fault (No. 2) or not spanning over the fault (No. 3). Referred numbers correspond to the numbers of Table 1. No. 2 rapidly decreases its amplitude in the frequency range higher than 0.3Hz, in contrast to the amplitude for No. 3 being almost flat up to 10Hz. The amplitude of No. 2 is about 0.85 in the frequency range lower than 0.3Hz. As a result, we can say that the fault is assignable to the incoherent ground motion in the seismic frequency region (0.1Hz<f<30Hz). The ATL coefficient in the lower frequency range, however, gives only a little difference as shown in Table 1, which may reflect the result of coherency.

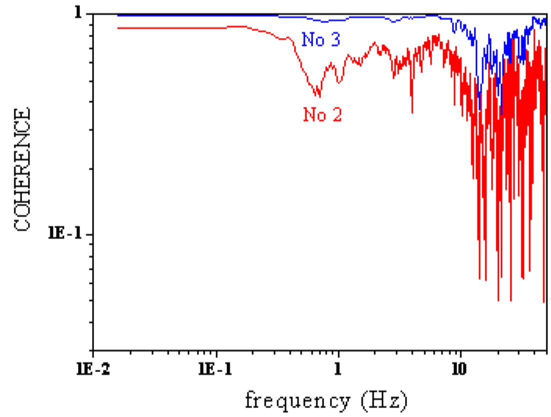

Figure 2: Different coherence in the same tunnel because of including without/with fault in the observed span.

2.2 Effect of Floating Rock

Typical coherency observed in the same granite tunnel, but setting the sensors different spans and positions in the tunnel, is shown in Fig. 3. These data correspond to the No. 9 and No. 10 in Table 1. The red line (No. 9) shows very bad coherence in the frequency range above 0.1mHz. The blue line (No. 10) shows excellent wide band and span coherence in contrast to the red line.

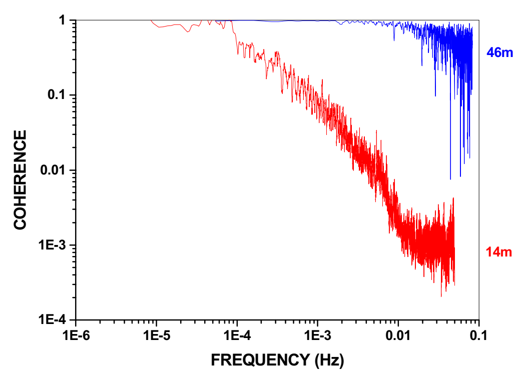

Figure 3: Different coherency in the same tunnel for the non-identical measuring points.

This result points out that the rock of the tunnel was partially broken up into fragments. The difference of frequency characteristics between Fig. 2 and Fig. 3 may be described as a result of degree of fragmentation in the bedrock.

2.3 Effect of Ground Water

Takeda et al gave the difference of coherence between the smooth blasting method (SBM) and TBM using the observed data [4]. An aftereffect of these two excavating methods was shown as distinct difference of the coherence at near the betatron wave-length of LC. SBM induces quite a size of relaxation in the surface layer (about 1m or more). We concluded that excavation using TBM in the hard rock is essential for LC in order to eliminate over-break on the surface of the tunnel [4].

We executed several experiments to get more detailed information about the surface layer of the granite tunnel cut by SBM. The first result was shown at IWAA'99 [5]. We set three sensors at intervals of 17 meters as shown in Fig. 4.

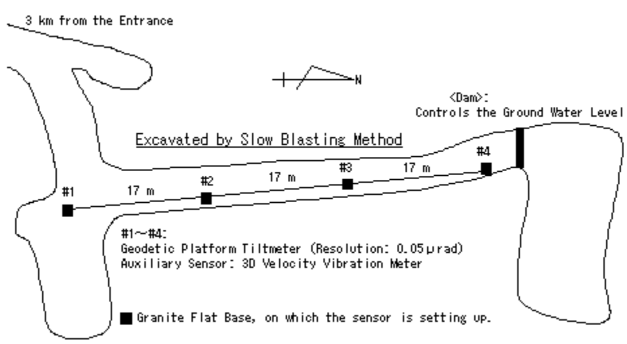

Figure 4: Experimental set-up for a diagonosis of the aftereffects of the smooth blasting method.

No. 6 and No. 7 in Table 1 correspond to the both ends of sensors. The coherence between the middle sensor and the both ends shows very complex daily changes at the frequency range less than 10^{-2} Hz [5]. We speculated that the daily fluctuation is caused by the activity of underground water. In order to check this speculation, we built a dam across the flow to control the water level in the crevices. As a result of this process, Fig. 5 shows flat coherence in the wide frequency range.

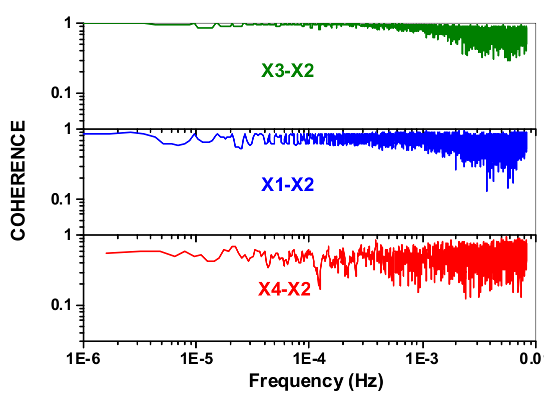

Figure 5: Wide band good coherence obtained by artificial control of the ground water level.

Inferring from the present experimental result, we can say that one of the sources of the incoherency is interaction between grand water with crevices being made by SBM.

3 SEISMIC FREQUENCY REGION

The ground motion in the seismic frequency region usually shows complex spectrum which is composed of smooth spectrum as K/f^4, ocean swell around 0.2Hz, crustal resonance around 3Hz and noises of human activity in the frequency range 1 to 100Hz. Fig. 6 shows several power spectra to understand frequency and site dependence of the ground motion on the seismic frequency region.

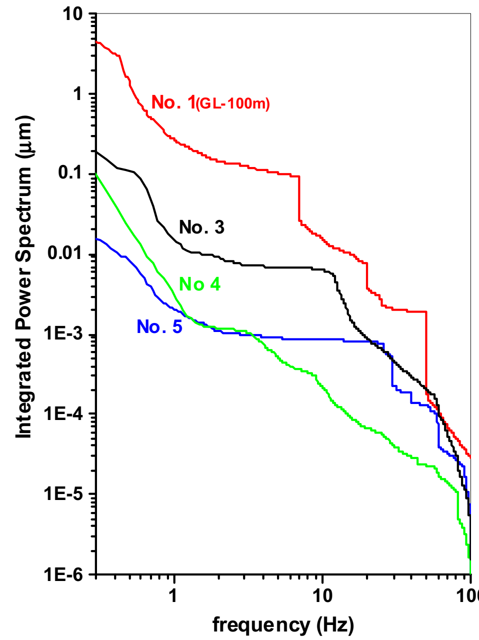

Figure 6: Integrated power spectra for the seismic frequency region of ground motions.

The numbers in Fig. 6 correspond to those of Table 1. We can find easily from Fig. 6 that the amplitudes of the ground motion tightly depend on the site and that the noise levels of human activities strongly depend on the circumstances of the site. On the occasion of accelerator design and of the site selection, we have to take account of these noises being almost incoherent vibration because of their sources being independent of each other [3]. The incoherent vibration levels caused by the accelerator facilities, cooling water system, compressor and air conditioner etc. must be kept in mind.

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