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MEASUREMENT OF GROUND MOTION IN VARIOUS SITES

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Abstract

This paper is an overview of a study program, initiated at DESY, to measure ground vibration of various sites which can be used not only for site characterization for the International Linear Collider (ILC) design, but also for future generation synchrotron radiation facilities. Examples of site characterization, using DESY's ground motion data, have been provided.

1 Motivation

It is envisaged that the ILC will collide nanometer-size e^-e^+ beams (σ_x~500 nm, σ_y~5 nm) at a center-of-mass energy of 500 GeV, and possibly, up to 1 TeV, at a high luminosity of $2 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ [1]. Maintaining a vertical beamsize in the order of 5 nm in collision, is a challenge since ground motion may cause the beams to simply miss each other at the IP (Interaction Point) and emittance growth, induced by betatron oscillations due to magnet movements. For the case of synchrotron radiation facilities, ground motion can cause point instability of a sample against the incoming beam and emittance growth.

For performance optimization of an accelerator, it is imperative to study ground motion, resultant from geology and human activity, commonly referred to as 'cultural noise', as specific to each site.

The site characterization program of DESY consists of a comprehensive database of measured ground motion spectra for 20 sites, comprising high energy laboratories, synchrotron light sources and reference sites, around the world, and is available to the scientific community [2, 3].

2 Methodology & Equipment

The methodology employed for this study was to use the same equipment and data analysis techniques for all the measured sites in order to characterize each site without a bias. Reference sites chosen for this program are situated in geologically stable and remote locations with low cultural noise content.

Moreover, each site was measured in various locations in the vicinity, such as deep/shallow tunnel vs. surface, experimental halls vs. general buildings, in order to evaluate cultural noise situation particular to each site. In majority of the cases, the measurement period was one week or longer, so that variation with respect to day and night, weekday and weekend was apparent.

Ground motion measurements were performed using state-of-the-art Güralp triaxial feedback seismic sensors [4]. Three CMG-3TDs (frequency range: 360(120) s-80 Hz) and two CMG-6TDs (frequency range: 60 s-80 Hz) were utilised for this purpose. Seismometers measure absolute motion, since measurements are relative to an inertial frame. The resolution of the instruments is better than 0.02 nm, integrated, at 1 Hz, in all three axes, which is sufficient to measure ground motion even at quiet sites.

$$rms(f_1, f_2)^2 = \frac{1}{T}\sum_{f=f_1}^{f_2} PSD(f) \qquad (1)$$

Power Spectral Density (PSD) of a discrete signal, measured for a measurement period T, in this case 60 s, was calculated, using Fast Fourier Transform (FFT) and the result was summed to obtain root mean square (rms) displacement (see Eq. 1 for the definition of rms), in a particular frequency band (f_1-f_2). For these measurements, a cut frequency of $f > 1$ Hz was used for integration. Average spectra were calculated, for every 15 minutes or longer, in order to smooth out single event noise. Data analysis techniques are described in [2, 5] in detail.

3 Cultural Noise

Fig.1 shows average PSDs of some of the sites measured and compared to a reference site, Moxa seismic station, near Jena, Germany. The general shape of the PSDs follows $1/f^4$ behavior which is a random walk noise trend.

Ground motion spectra can be divided into two regions: slow (or correlated) motion, at f < 1 Hz, is referred to as 'slow ground motion' [6]. This region contains the microseismic peak at 1/7Hz (frequency range of 0.1 to 0.25 Hz), which is caused by the coastal waves and can even be seen in the center of the continents. It is clearly visible in all the PSD spectra shown in Fig.1.

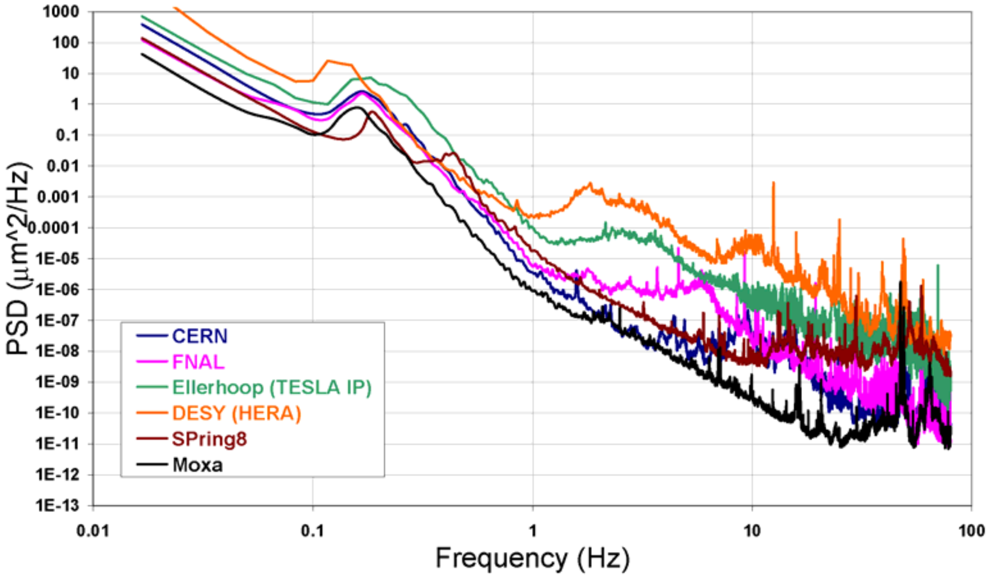

Figure 1: Average PSDs, in the vertical direction, of several sites, including a reference site, Moxa

On the other hand, the region at f > 1 Hz, where cultural noise dominates, is referred to as 'fast ground motion' [6]. In addition, this part of the spectrum depends on the geology, the facility, and whether a measurement is performed in a tunnel or on the surface. The corresponding rms spectra are shown in Fig.2. For example, HERA (DESY) is situated in a shallow tunnel configuration, few tens of meters deep, and DESY is in close proximity to the city of Hamburg. The corresponding PSD, contains high cultural noise content, 3 orders of magnitude higher than Moxa at 1 Hz. In addition, geology of northern Germany consists mainly of quaternary sand and marl (in small part) [1] which means that the site is more susceptible to environmental noise. The effect of cultural noise on another site, with a similar geology, is seen when HERA (DESY) is compared with Ellerhoop, a sparsely populated village, 17 km northwest of Hamburg. Ellerhoop was the proposed site for the IP region of TESLA. The average rms vertical motion for surface measurement is 17 nm for Ellerhoop and 52 nm for HERA at a cut frequency of f > 1 Hz.

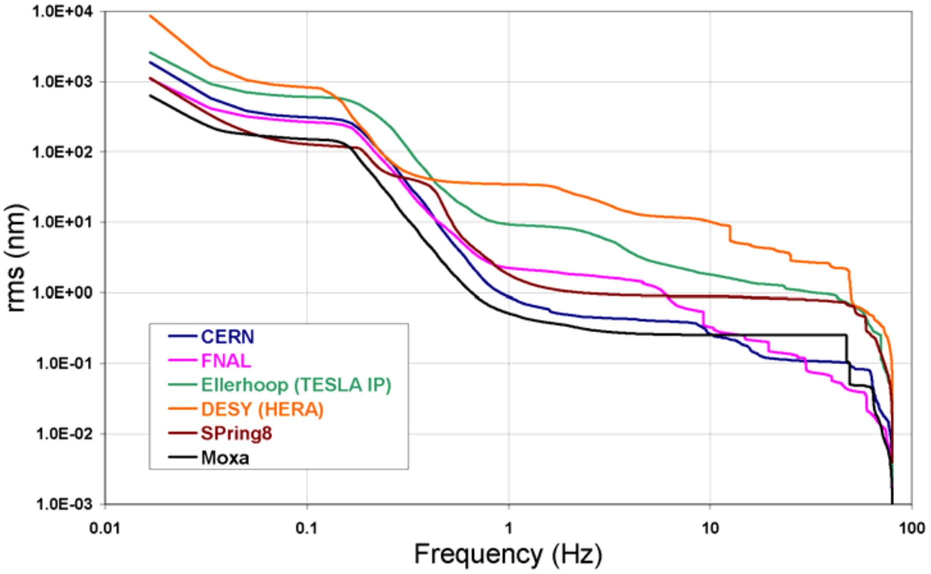

Figure 2: Integrated PSDs of the sites in Fig. 1, at f > 1 Hz cut value, in vertical direction

The rms vertical motion of CERN LHC tunnel is 2 nm, compared to the reference site Moxa (rms ~ 1 nm), Fig 2. LHC tunnel is situated in a deep tunnel configuration, around 100 meters, in mainly stable and watertight bedrock [1], especially, the section which is situated near Jura Mountains. This kind of tunnel configuration counteracts the effect of cultural noise due to road traffic on the Franco-Swiss border.

The integrated PSD of Spring8 (a third generation synchrotron radiation facility) in Harima, Japan, at 1 Hz is 2 nm. This is a quiet site situated in a low population density area with hard rock geology, again pointing to a low human and environmental noise plus, existence of a suitable geology. Table 1 is a compilation of average rms (f > 1 Hz, vertical) of all the sites measured including the spread or standard deviation σ in nm [2, 3].

4 Site Characterization

4.1 Variation with Respect to Time

Most sites, especially those with high cultural noise content exhibit large variation with time, during day, between day and night and weekend versus weekday. In Fig. 3, this variation is illustrated in the HERA tunnel for the duration of one week spanning 6-12 June, 2005. The data is displayed in three frequency bands, f < 1 Hz, f > 1 Hz and f > 3 Hz. Average rms amplitude between day and night, during weekday, varies by a factor of 5, and between weekday and weekend, by a factor of 2. In the low frequency band (f < 1 Hz), where cultural noise has little or no impact, there's very little fluctuation with respect to time.

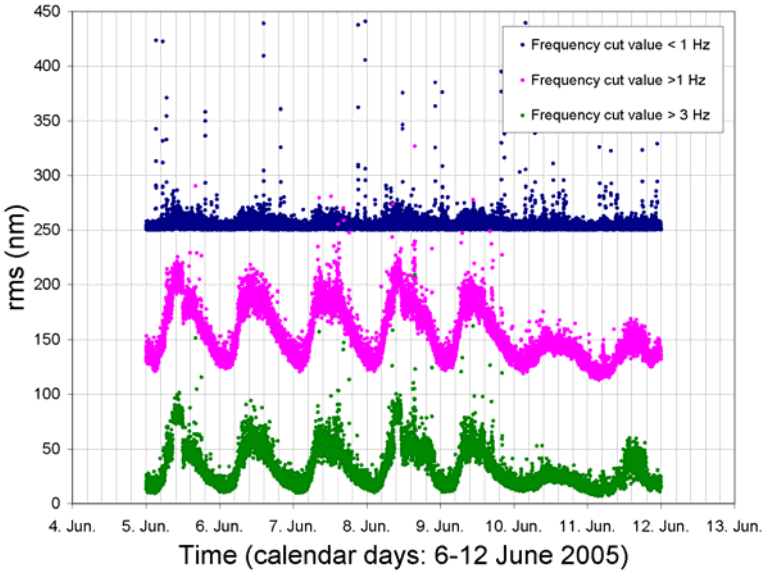

Figure 3: rms amplitude, in the vertical direction, of three frequency bands versus time in the HERA tunnel. Weekend peaks, with reduced amplitude are seen on the right. Each plot is shifted up in the y axis for clarity.

4.2 Variation with Respect to Tunnel Depth

Variation of ground motion spectra in a deep tunnel (100 m), in this case, the LHC tunnel, compared with simultaneous measurements taken on the ground surface shows the advantage of choosing a deep tunnel, with a geological composition of hard rock, mostly, for a linear collider, if possible. In Figure 4, the PSD spectra of the LHC tunnel are lower by three orders of magnitude compared to the surface (average rms: 2 vs. 22 nm respectively). Measurements in Numi tunnel in Fermilab, with an approximate depth of 40 m, are compared with the surface measurement, a site 60 km west of Fermilab. The average rms, at f > 1 Hz cut value, is ~ 3 nm for Numi tunnel and ~ 30 nm for the surface measurement.

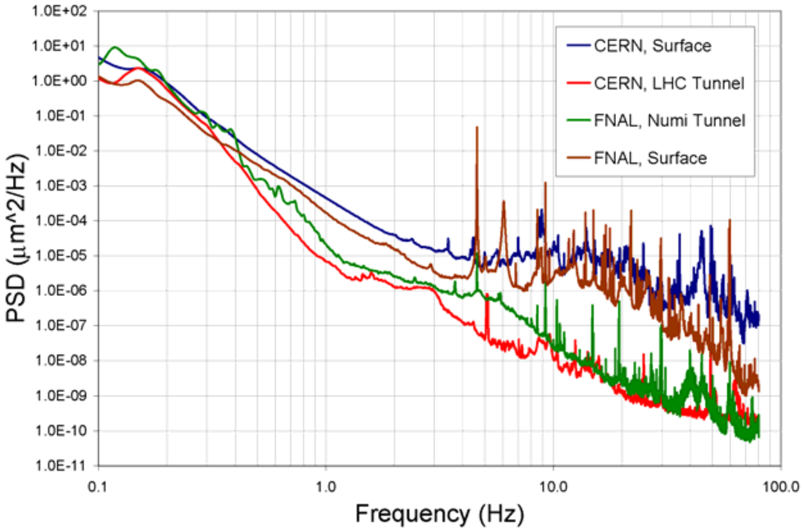

Figure 4: PSD Measurement in the LHC tunnel vs. surface and Numi tunnel in Fermilab vs. surface.

In Fig. 5, rms distribution (normalized to the selected bin width) for various sites is displayed. The reference site, Asse rock salt mine in Germany (measurements performed at a depth of 900 m), sits in the most left corner of the plot with a narrow width (see Table 1). In addition, the shape of each distribution differs, markedly, from another. In both CERN and Fermilab data, one can notice that there are two peaks in their distribution signifying variation between 'quiet' and 'noisy' periods within a day.

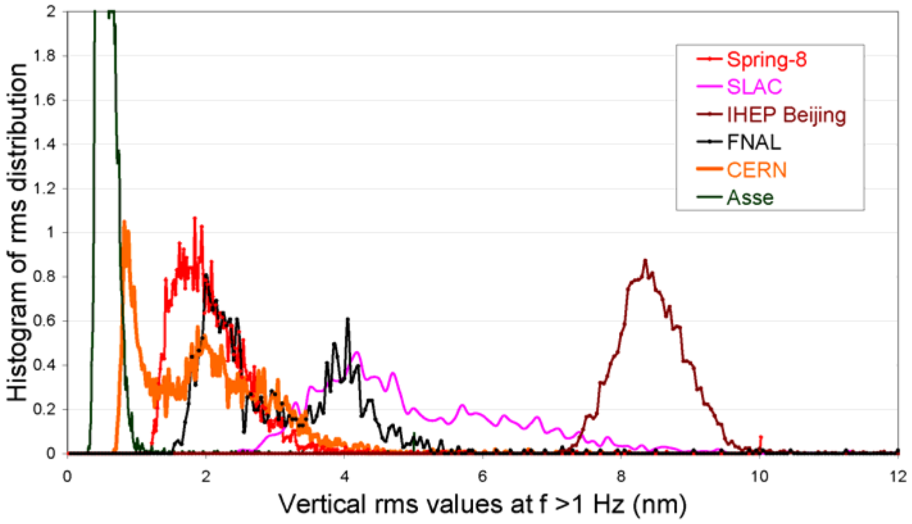

Figure 5: Histogram of the rms distributions (at f > 1 Hz, in vertical direction) for 6 'quiet' sites.

4.3 rms vs. Frequency Bands

One method to characterize a site is to investigate average rms values in different frequency bandwidths across the PSD spectra.

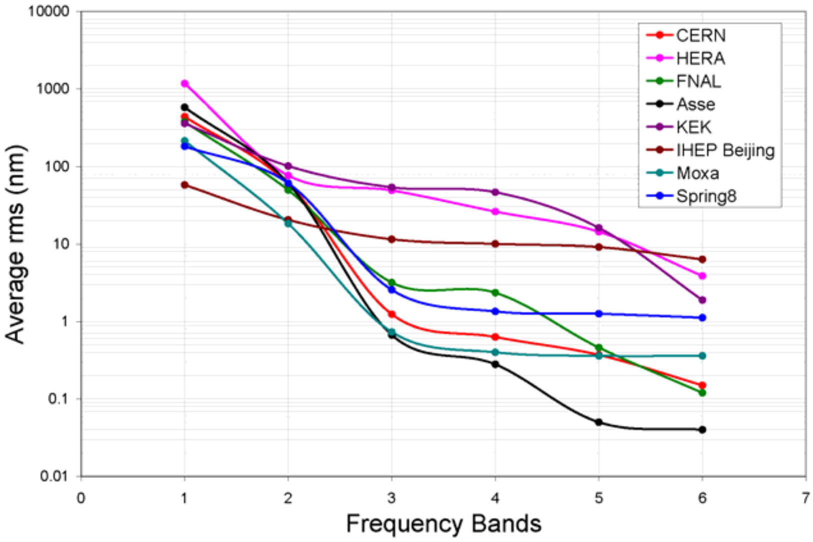

Figure 6: Average rms in several frequency bands, as described in the text, for 8 measured sites.

In Fig. 6, frequency bands labeled from 1-6, refer to f > 0.1, f > 0.3, f > 1.0, f > 3.0, f > 10.0 and f > 30.0 Hz. The lines through the data points are for guiding the eye only. This way, rms spectra are 'simplified' into several data points, and hence, one can visualize the difference between the sites easily. It can be noticed that there are mainly two kinds of sites: 'quiet' such as CERN and Spring8 and 'noisy' such as HERA and KEK. The two reference sites, Moxa and Asse, are the lowest lines in the plot, as expected.

However, occasionally, there are sites which can be classified as ‘medium’, such as IHEP Beijing, which belongs neither to ‘quiet’ nor to ‘noisy’ category. In addition, its average rms varies little across the frequency bands plotted, indicating relative weakness of cultural noise sources and their variation. This is also seen in Fig. 5, where the rms distribution of IHEP Beijing, has almost a Gaussian shape, although its rms value is higher than ‘quiet’ sites (average rms: 8 nm, see Table 1).

Table 1: Average rms (at f > 1 Hz) of Measured Sites

	Site Location	**rms (nm)**	**σ(nm)**
1	ALBA Cerdanyola	18.3	9.5
2	APS Argonne	10.5	1.0
3	BESSY Berlin	72.8	28.1
4	BNL	87.8	30.2
5	CERN, LHC Tunnel	1.8	0.8
6	Ellerhoop (TESLA IP)	17.4	8.4
7	DESY HERA	51.8	18.9
8	DESY XFEL, Schenefeld	38.7	16.6
9	DESY XFEL, Osdorf	28.9	11.9
10	DESY Zeuthen	64.0	40.4
11	ESRF Grenoble	71.6	34.9
12	FNAL Batavia	2.9	0.9
13	IHEP Beijing	8.4	0.5
14	KEK Tsukuba	78.0	36.0
15	LAPP Annecy	3.3	1.6
16	Salt Mine Asse	0.5	0.1
17	Seismic Station Moxa	0.6	0.1
18	SLAC Menlo Park	4.8	1.2
19	Spring-8 Harima	2.0	0.4
20	SSRF Shanghai	292.0	164.0

5 Summary

DESY’s ground motion measurement database [2, 3] has the advantage in that, same equipment and analysis techniques were utilized for all the measurements. It is available to the scientific community and can be used to characterize sites for future accelerators.

Acknowledgements

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