PERFORMANCE TEST OF STS-2 SEISMOMETERS WITH VARIOUS DATA LOGGERS

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1. INTRODUCTION

For the future linear collider project, stable area, having less vibrational noise, is preferable. We have been measuring ground motion in various areas in Japan in order to know characteristics of ground motion. During measurement, we sometimes experienced bad coherence in huddling test even on a granite table.

To understand this phenomenon, we made a performance test of STS-2 with various data loggers to check electric noises from data loggers as well as performance of STS-2. Test results are reported in this paper.

2. SPECIFICATION OF STS-2 AND DATA LOGGERS

2.1. STS-2

We used two STS-2 seismometers of Streckeisen. The specification of STS-2 is listed in Table 1. The level of STS-2 noise is listed in Table 2 and shown in Fig.1 [3].

Table 1: Specification of STS-2

Specification	Description	Specification	Description
Company	Streckeisen, Switzerland	Clip Level	1.3 (cm/sec)
Response	0.00833-50Hz	Generator Const	2*7.5 (V/(cm/sec))
Component	2 horizontal and vertical	Damping	h=100%

Table 2: STS-2 noise level

Frequency (Hz)	Acceleration 0-P (m/sec^2)	Velocity 0-P (m/sec)	Displacement 0-P (m)	$PSD_{STS\text{-}2\_noise}$ 0-P ($\mu m^2/Hz$)
0.001708	7.660E-11	7.138E-09	6.651E-07	4.424E-01
0.01	5.445E-11	8.666E-10	1.379E-08	1.902E-04
0.1	5.000E-11	7.958E-11	1.267E-10	1.604E-08
1	1.490E-10	2.371E-11	3.773E-12	1.424E-11
4.985	3.555E-09	1.135E-10	3.624E-12	1.313E-11
11.174	1.957E-08	2.787E-10	3.970E-12	1.576E-11

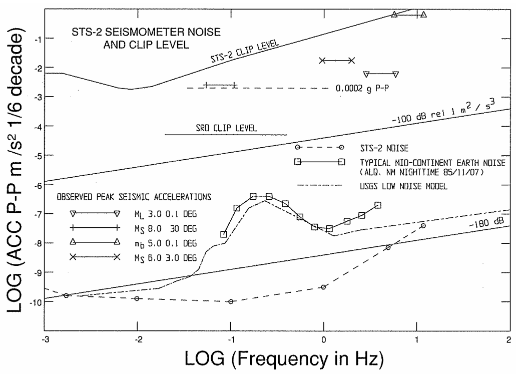

Fig. 1: STS-2 noise level

2.2. DATA LOGGERS

We used three types of data loggers, Q330 of Quanterra Inc., Graduo (DS2000 series) of Onosokki Co. Ltd. and LS 7000XT of Hakusann Corp. The specification of them is listed in Table 3.

Table 3: Specification for three types of data loggers

Specification	Description
Type	Q330
Company	Quanterra Inc., USA
Input Channel	6
Input Range	±10V, ±1V
Resolution	24bit ⊿Σ type
Dynamic Range	135dB typ @100Hz
Power	DC12V

Specification	Description
Type	Graduo (DS2000 series)
Company	Onosokki Co.,Ltd., Japan
Input Channel	8
Input Range	< ±10V
Resolution	24bit ⊿Σ type
Dynamic Range	100dB<
Power	DC12V

Specification	Description
Type	LS7000XT
Company	Hakusan Corp., Japan
Input Channel	6
Input Range	±20V
Resolution	24bit
Dynamic Range	135dB typcally better <5Hz
Power	DC12V

3. EXAMPLE OF BAD COHERENCE

Some examples of coherence in huddling test with two STS-2 seismometers are shown in Fig.2 and Fig.3. Fig.2 shows the coherence between two STS-2 observed on a granite table in the SPring-8, and Fig.3 shows that obtained on a concrete floor in the Chigasaki Research Institute of J-Power (C.R.I.). Both figures are for vertical ground motion. The ground motion in the SPring-8 is less than that in the C.R.I.. From these spectra, it is conceivable that there might be some relation between the amplitude of ground motion and the coherence among sensors. Some number of items can be listed as a source of this bad coherence, such as (1) measurement limitation of seismometers, (2) electric noises from data loggers, (3) natural frequency of seismometers. We made a performance test in order to understand this phenomenon.

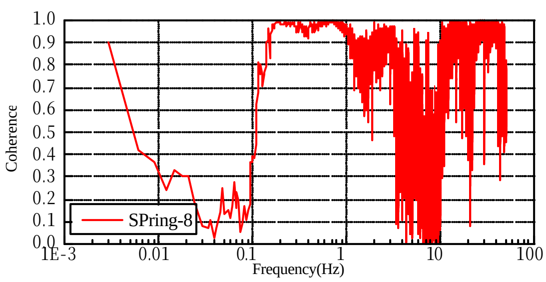

Fig.2: Example of bad coherence

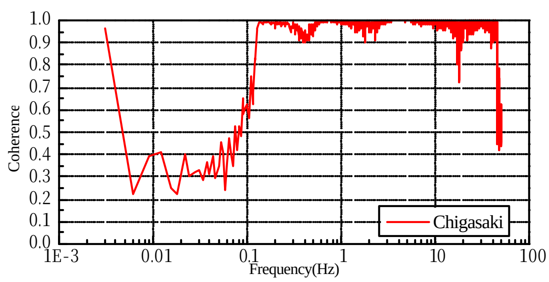

Fig.3: Example of good coherence

4. ELECTRIC NOISES FROM DATA LOGGERS

Bad coherence is not only caused by seismometer noises but also caused by electric noises from data loggers. Here, the electric noise from a data logger, LS-7000XT, was examined because it was used as a reference. In this test, input connectors were terminated with locked STS-2, amplifier and UPS, and data was recorded for 30 minutes. The system of this test is shown in Fig.4, and the power spectrum density (PSD) is shown in Fig.5.

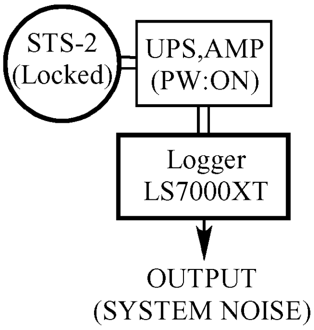

Fig.4: System of logger noise test

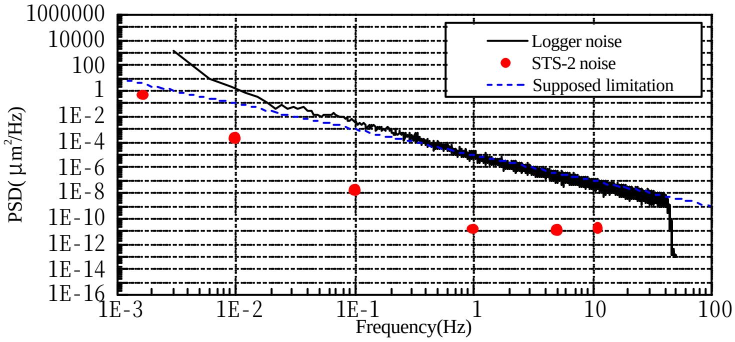

Fig.5: Electric noise from LS-7000XT

From this spectrum, it can be seen that the electric noise from LS-7000XT is much higher than STS-2 noise. The measurement limitation looks coming from only data logger, LS-7000XT, with measurement system, STS-2, UPS and amlifier.

This measurement limitation can be expressed as the following formula.

$$PSD_{\mathrm{limit}}\left(mm^2 / Hz\right) = 1.0 \times 10^{-5} \times Frequency^{-2} \qquad (1)$$

5. SET UP OF PERFORMANCE TEST

We found that the electric noise from the data logger with measurement system, which we had used, was bigger than the STS-2 noise level. It is necessary for us to obtain data loggers having less electric noises to measure the ground motion with STS-2. Then, we made a performance test to examine various data loggers. In this test, we used two STS-2 and three data loggers, Q330 of Quanterra Inc., Graduo of Onosokki Co. Ltd. and LS-7000XT of Hakusan Corp. This test was carried out in a working room in the SPring-8. Two seismometers were set on a granite table, and signals from both seismometers were measured and recorded with two data loggers at one time. The signal flow is shown in Fig 6. The test was made for three cases as listed in Table 4.

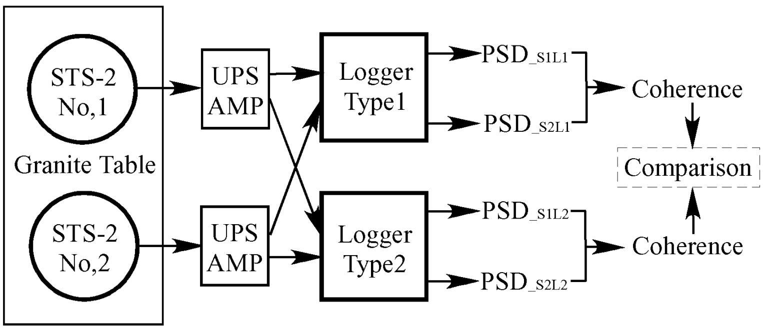

Fig.6: Signal flow in the performance test

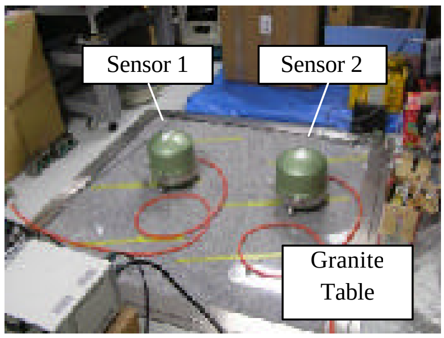

Photo.1: Setup of the test

Table 4: Cases of performance test

	Sensor	Data Logger *1)	Start Time *2)
CASE-1	STS-2 No.1 and STS-2 No.2	**Type 1**: Q330 (Gain:20V) **Type 2**: Graduo (Gain:1V)	27-May 2004, at 14:50
CASE-2		**Type 1**: Q330 (Gain:20V) **Type 2**: Graduo (Gain:0.01V)	27-May 2004, at 15:30
CASE-3		**Type 1**: Q330 (Gain:20V) **Type 2**: LS7000XT (Gain:1V)	27-May 2004, at 16:10

*1) The sampling frequency was set to be 100Hz for Q330 and LS7000XT
The sampling frequency was set to be 102.4Hz for Graduo
*2) 30 minutes consecutive duration

6. RESULTS OF THE PERFORMANCE TEST

The data recorded are time series in velocity. From these data, Power Spectrum Density (PSD) and coherence between two sensors were analysed. The results of the CASE-1 are shown in Fig 7, those of the CASE-2 in Fig 8, and those of the CASE-3 in Fig 9, respectively.

The coherence plots show some slight difference between the CASE-1 and CASE2, although PSDs are almost the same. This slight difference might be caused by the difference in sampling frequency between Q330 and Graduo. In the CASE-3, PSDs and coherences are almost the same to those in the CASE-2. In all cases, we cannot find noticeable difference among these three data loggers.

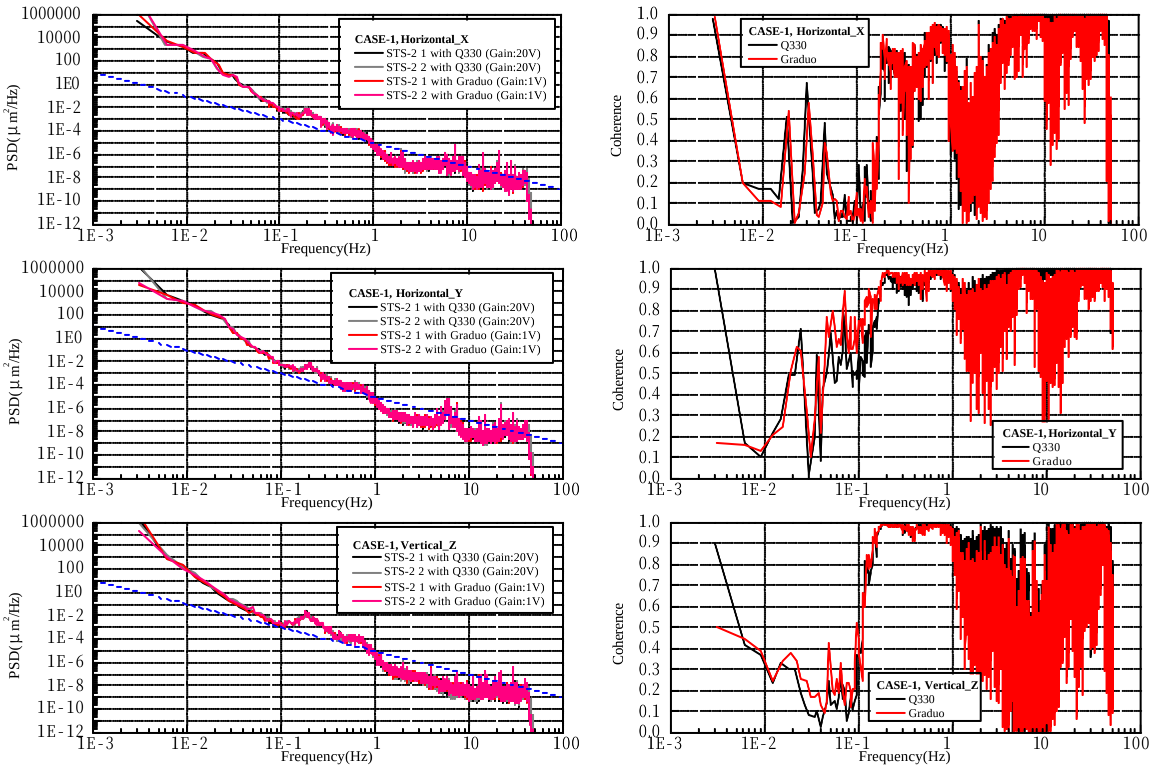

Fig 7: PSDs and Coherences in the CASE-1

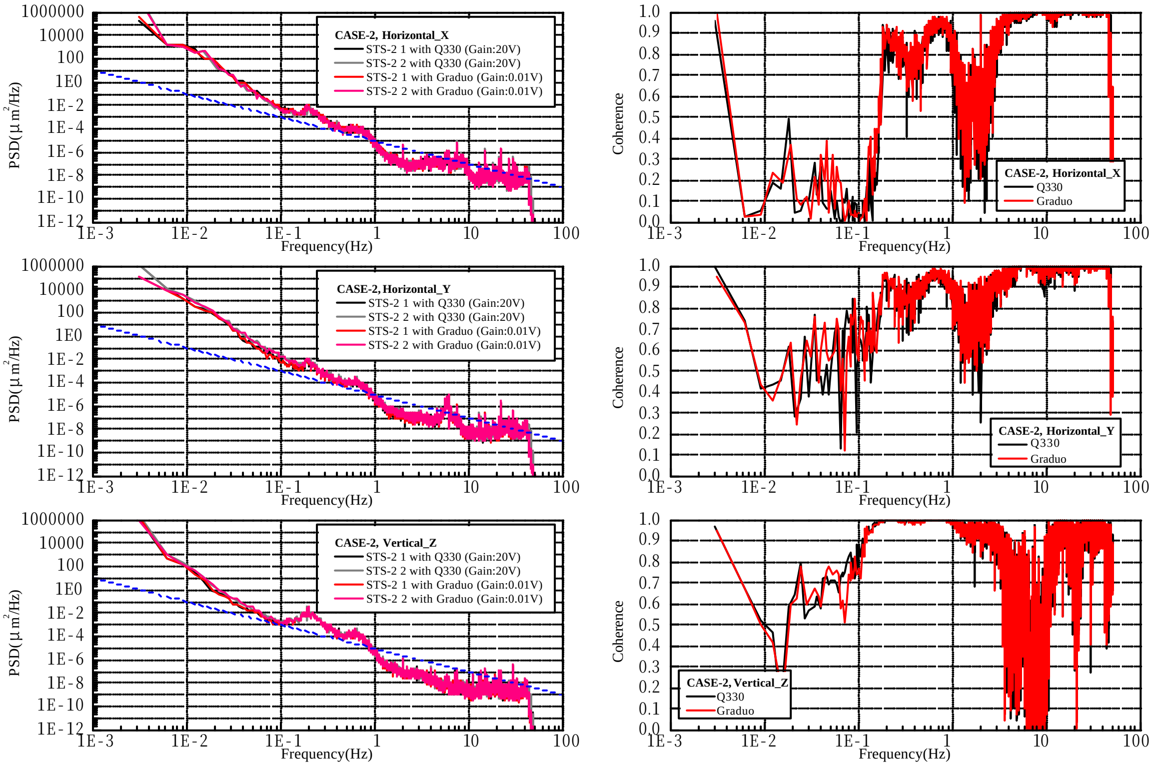

Fig 8: PSDs and Coherences in the CASE-2

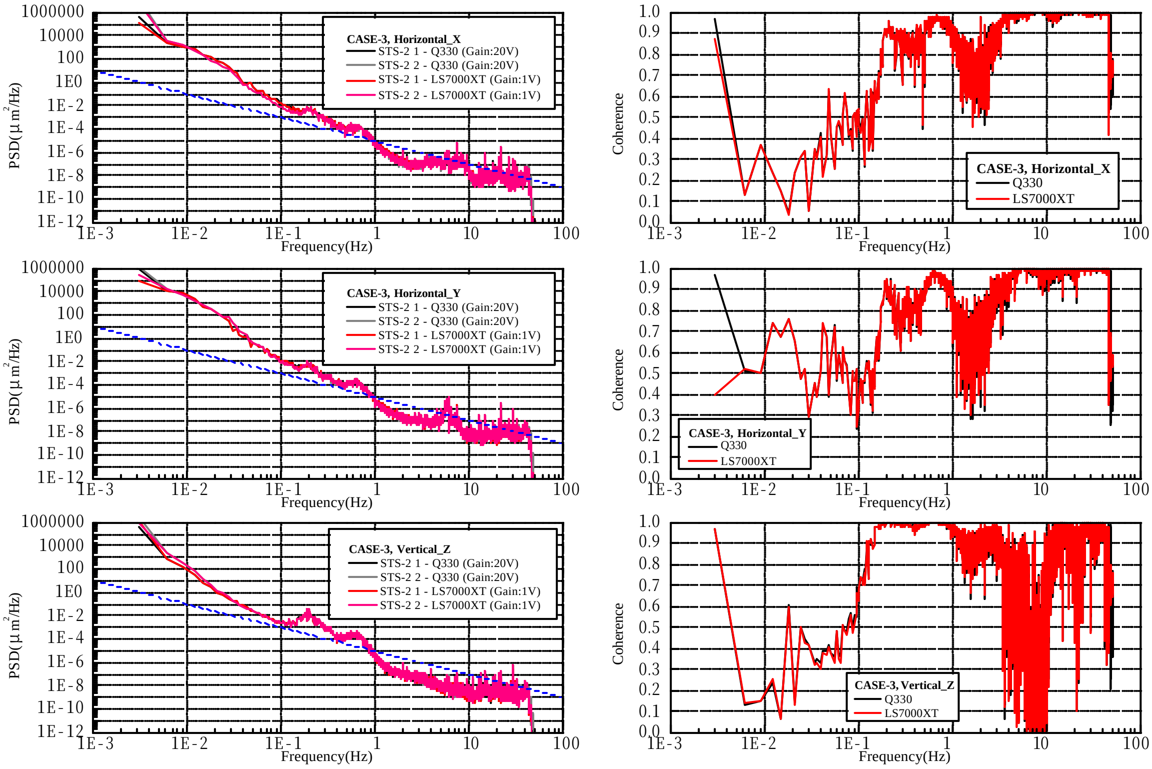

Fig 9: PSDs and Coherences in the CASE-3

From these plots, coherence degrades in the frequency region lower than 0.2Hz and in the frequency region higher than 1Hz as well. However, noticeable difference is not observed among data recorded with these three different data loggers. In the frequency region higher than 1Hz, coherence degrades when the PSD close to the measurement limit shown by dotted lines in the spectrum. Coherence shows degradation in the frequency region lower than 0.2Hz in spite of that the PSD higher than the measurement limit.

7. STUDY FOR COHERENCE DEGRADATION IN LOW FREQUENCY REGION

Bad coherence in the frequency region lower than 0.2Hz was pointed out in Chap.6. When we tried to know this phenomenon, we considered that the source of this phenomenon is caused by wind, temperature and cable vibration. Then, we made some tests at C.R.I. of J-Power. The test was made for four patterns as listed in Table 5. As the data was not measured at one time, amplitudes of each PSDs are different. PSDs and coherences obtained in this test are shown in Fig.10.

Table 5: Patterns of test

Pattern	Sensor	Data Logger *1)	Sensor Cable	Wind Shelter
1	STS-2 No.1 and STS-2 No.2	LS-7000XT (Gain:1V)	**Fixed**	**Setup**
2			**Fixed**	Not - Setup
3			Not - Fixed	**Setup**
4			Not - Fixed	Not - Setup

*1) The sampling frequency was set to be 100Hz.
*2) 30 minutes consecutive duration

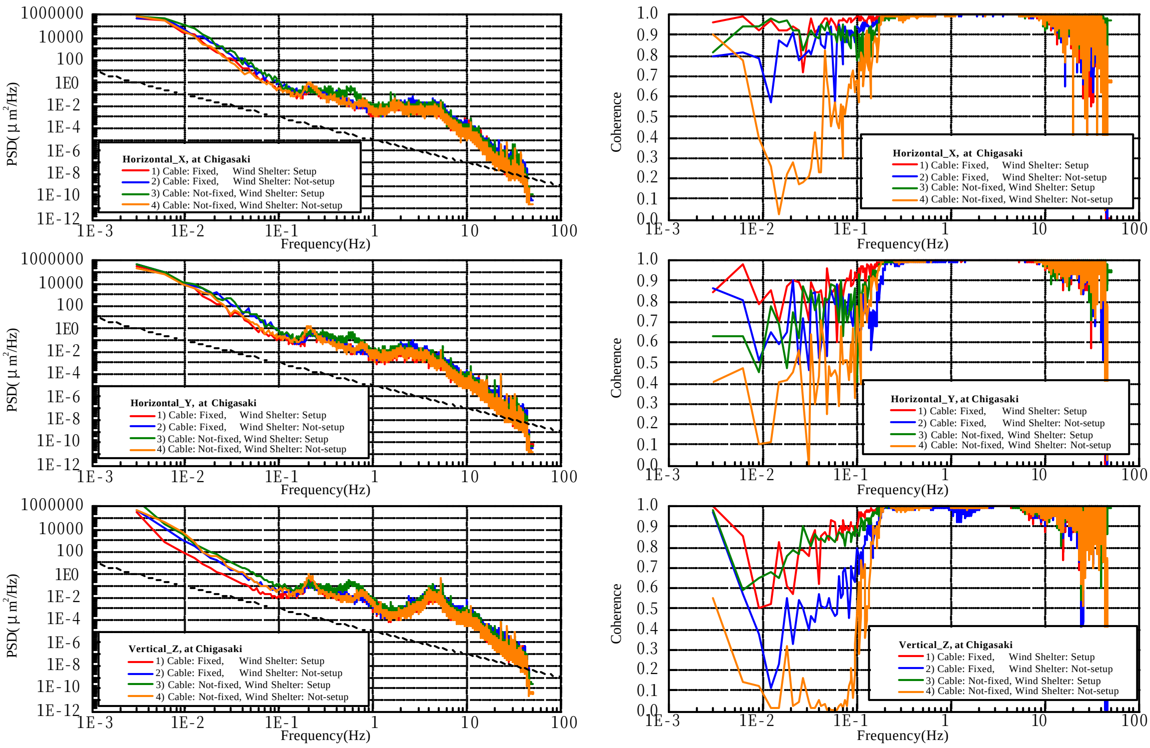

Fig.10: Effects by improvement of sensor set up

From these plots, the coherence in pattern 1 is best for all components, in spite of that the amplitude of PSD is lowest in the frequency region lower than 0.2Hz. The effects of wind shelter and fixation of cables are admitted. We can find that there are some possibilities to prevent degradation of coherence by how to set up seismometers. However, we have just started this type of tests, and it is necessary for us to examine this phenomenon further.

8. EXAMPLES OF THE PAST GROUND MOTION MEASUREMENT

We have been measuring ground motion in various areas in Japan. Some results of these measurements are shown. The measured areas are shown in Fig. 11, and the conditions of measurements are listed in Table 6. PSDs obtained in these measurements are shown in Fig.12.

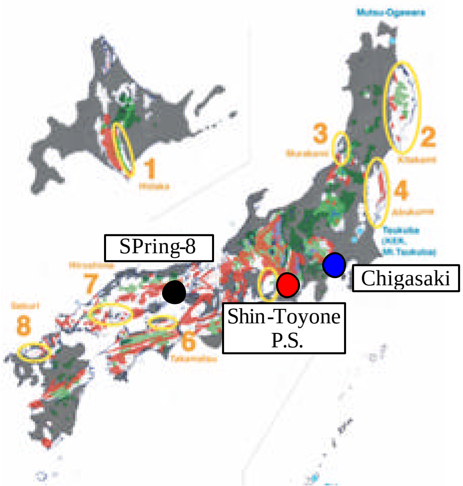

Fig.11: Measured areas

Table 6: Condition of past measurements

	Sensor	Data Logger *4)	Start Time *5)
SPring-8 *1) **(Ground)**			27-May 2004, at 16:10
Shin-Toyone P.S *2)	STS-2	LS-7000XT	13-Mar 2004, at 15:30
Chigasaki *3) **(Ground)**			9-Sep 2004, at 15:30

*1) On the granite table located in the south of the SPring-8 ring.

*2) Hidroelectric P.S. located in the east of Aichi along the Tenryu River

*3) Research Institute of J-Power located in the middle of Kanagawa

*4) The sampling frequency was set to be 100Hz.

*5) 30 minutes consecutive duration

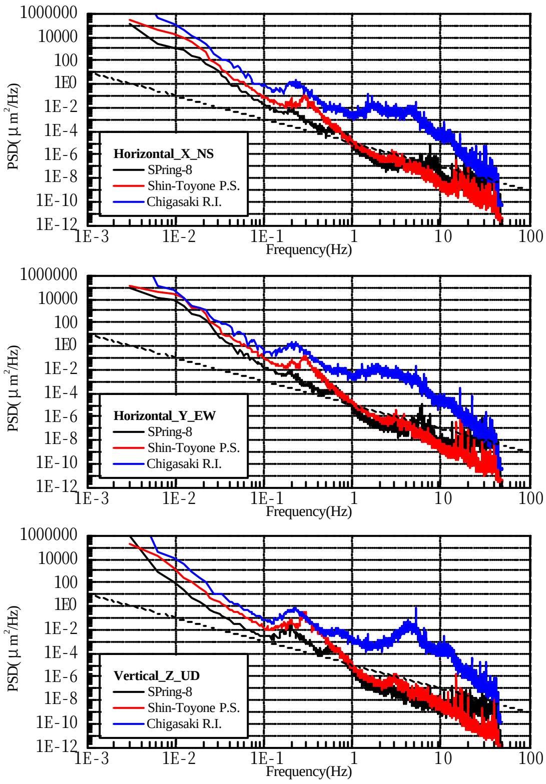

Fig.12: Results of PSDs in three areas

SPring-8 and Shin-Toyone power station are located on the hard rock areas. On the other hand, the Chigasaki Research Institute of J-Power are located in Chigasaki town, whose area is reclaimed ground. It can be seen that the hard rock area has less magnitude in the ground motion from Fig.12. In the frequency region higher than 1Hz, the amplitudes of PSDs for the hard rock area are sometimes close to or lower than the measurement limit derived in Sect.4. So, these PSDs for the hard rock area show just the measurement limit in some part of the frequency region higher than 1Hz.

9. SUMMARY

The performance test of STS-2 with various data loggers was made in the SPring-8, and some speculation for the measurement limitation is presented. The results of this test are summarized as follows.

- The measurement limitation of STS-2 and a data logger is derived from the specification of STS-2 and electric noise test of the data logger.
- We made a performance test of STS-2 with three data loggers, each of which are products of different companies. But we cannot observe any noticeable difference among these data loggers.
- The source of the measurement limitation is found to be electric noises from data loggers with STS-2 seismometer and its measurement system.
- In the huddling test, the degradation in the coherence between two STS-2 seismometers is caused because the PSDs are less than the measurement limit in the frequency region higher than 1Hz. However, the source of the degradation in the coherence in the frequency region lower than 1Hz is not found yet.
- The examples of measurement data for ground motion in hard rock areas are shown. It can be seen that the PSDs are just showing the measurement limit in some part of the frequency region higher than 1Hz. We should be careful about the measurement limitation when we measure the ground motion in quite area.

REFERENCES

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[2] Y. Nakayama, et al., “Characteristics of ground motion at KEK and SPring-8”, Proceedings of the Epac04, July. 2004.
[3] Manual of STS-2, Streckeisen.