Establishment of New Low-Cost and High-Resolution Real-Time Continuous Strong Motion Observation Network by CEORKA

T. Akazawa
Geo-Research Institute, Japan

M. Araki
aLab Inc., Japan

S. Sawada & Y. Hayashi
Kyoto University, Japan

M. Horike
Osaka Institute of Technology, Japan

SUMMARY:
We develop a new low-cost data logger (KS-002D) for the CEORKA strong-motion network. The data logger can send the observed continuous data in real-time through Internet connection and back-up the same data in large-capacity memory card inserted into the data logger. These features solve the significant problems of the previous CEORKA's system and ensure reliable storage of valuable data. The observed data show that the new data logger can obtain broadband and high-resolution data ranging from strong motions to microtremors. The data logger also gets the high accuracy clock signals from GPS. The developed data loggers are installed to CEORKA's stations, in addition to old data loggers which are working as back-up system.

Keywords: Strong Motion Observation, Continuous Observation, Real-Time, Data Logger

1. INTRODUCTION

The Committee of Earthquake Observation and Research in the Kansai Area (CEORKA), which is located in the Kansai district in Japan, was set up in December 1991 as a collaborative strong motion observation project by several general construction companies, consulting companies and individual researchers in universities (Toki et al., 1995). CEORKA developed quasi-real-time automatic observation system consisting of 11 strong motion observation stations, deployed in the Osaka and Kobe area and started formal operation in April 1994. The system adopted broadband servo-velocity type sensor (VSE-11 for horizontal and VSE-12 for vertical component) and data logger (CV-901NVR) with a 16bit A/D converter. During the 1995 Kobe Earthquake (Mw6.9) and its aftershocks, CEORKA network obtained high accuracy near field records and made a significant contribution on later progress of strong motion research. After the earthquake, CEORKA deployed additional observation stations and established observation information delivery system using e-mail and home page (Kagawa et al., 2004). Fig. 1 shows location of the CEORKA observation stations as on April 2012. The total number of observation stations is 20 stations that CEORKA established plus 5 more stations that belong to CEORKA member.

CEORKA network has obtained many high accuracy velocity records, not only during major earthquakes (e.g. 1995 Kobe Earthquake described above and 2011 Tohoku Earthquake) but also during moderate earthquakes (M>2) occurred in and near the Kansai district. On the other hand, the previous CEORKA's system has a few significant problems. The first is the data transfer method. It takes a few minutes for small event and tens of minutes or one hour for long time shaking, in order to collect the time history records, because dial-up telecommunication lines are used. The second is the data collection method. The data logger starts saving the observed data when the ground shaking exceeds a preset trigger level. This "trigger" method often cannot store the valuable data properly. The final is the data storage method. Due to limit capacity of used SRAM memory card, inserted into the

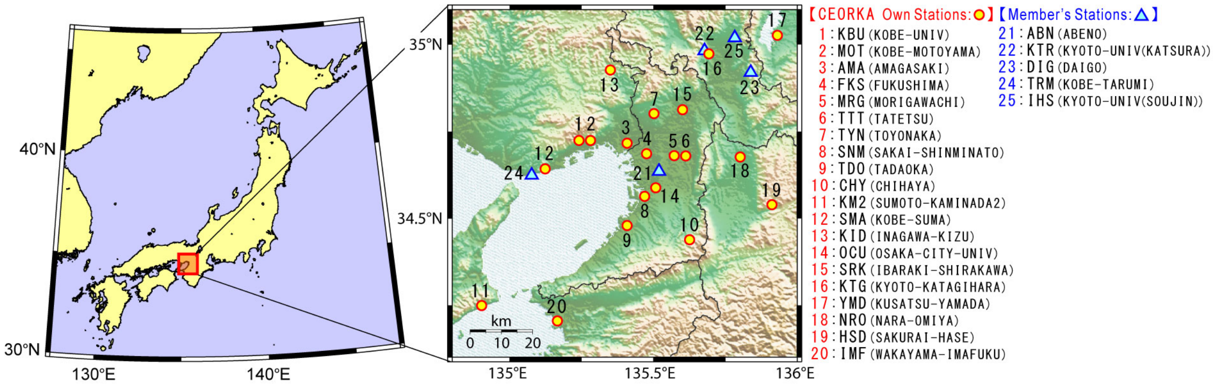

Figure 1. Location of observation stations.

data logger and used for data storage, the recordable time is limited to one hour. These problems are caused by technical limitations in the time of installation of old data loggers, in 1994 to 1997 year.

In order to solve the problems, we developed a new low-cost data logger KS-002D for the CEORKA network. Additionally, we developed high-resolution real-time continuous strong motion observation network in the Kansai district using the CEORKA network. Here, we explain the specification of the new data logger, the basic configuration of the new strong motion observation system and the background of development of the new network. Additionally, we analyze accuracy of the records observed by the new data logger.

2. SPECIFICATION OF NEW DATA LOGGER

The new data logger KS-002D employs technology of a low cost IT strong motion seismometer (e.g., Takano and Ikeda, 2008; Toriumi and Takano, 2008). The cost of data logger is lowered by removing sensor from the IT seismometer and accommodating it to an external sensor. Table 1 shows the specifications of the new data logger as compared with the old data logger CV-901NVR. The new data logger has two 24bit A/D converter. This converts the inputted analog signals to digital ones with 100Hz sampling in real-time. The new data logger also can correct internal clock by GPS or Internet.

Table 1. Comparison of specifications of the old and new data logger.

	Old Data Logger (CV-901NVR)	New Data Logger (KS-002D)
Number of Channels	6	8
A/D Converter	16bit	24bit
Sampling Frequency	50 / 100 / 200Hz	100Hz
Clock Correction	GPS / Radio Time Signal	GPS / Internet
Connection Method	Dial-up	Always-on
Data Transfer	Serial	Ethernet
Bit Rate	9600 / 19200 / 38400bps	100 / 10Mbps
Record Method	Trigger	Continuous
Storage Medium	SRAM Card	SD (SDHC) Card
Storage Capacity	Max. 8MB	Max. 16GB
Max. Storage Time	About 2 hours (When stored by 100Hz sampling on 8MB of SRAM card.)	About 3 month (When used 16GB of SDHC card.)
Waterproof Performance	Non-waterproofed	Waterproofed / Non-waterproofed

The use of Internet is effective when GPS antenna has difficulty for installing. Additionally, the data logger has Ethernet connecter and SD card slot. The former transmits the digitized signals of 10 samples per 0.1sec to the data collection server, and the latter stores the same signals into SD (or SDHC) card. By using SDHC card which has capacity of 16GB, the 100Hz sampled continuous observation data can be stored in about three month.

3. BASIC CONFIGURATION OF NEW STRONG MOTION OBSERVATION SYSTEM

Fig. 2 shows the basic configuration of the new strong motion observation system developed for the CEORKA network. Seismometer (VSE-11&12) output consists of low gain signals (full scale of 200kine) and high gain signals (full scale of 5kine), 3 channels per each type of signal and 6 channels in total. The previous CEORKA's system has inputted all of these signals to the old data logger (CV-901NVR) with six input channels. The new system input the signals to the new data logger (KS-002D) with eight input channels. To get high accuracy clock signals from GPS system, the new data logger has a GPS module. The background of development of the new data logger is explained in Chapter 4. In a view of future improvements of the observation, the previous system was equipped with "branching box" to branch ground motion velocity signals from seismometer to additional data loggers. The old data logger is connected to one of the connection terminals of the box. In the new system, the new data logger is connected to another one. By this method real-time observation is realized, while maintaining the previous observation system in the same time. The new data logger is connected to the always-on connection line and the digitized signals are transmitted in real-time to data collection server installed in CEORKA secretariat through the Internet. If the system are failed to transmit data to the server due to trouble of network, the data can be retrieved from the card by sending proper command of the new data logger. This ensure storage of data of weak ground motions, such as small and teleseismic events, which the trigger method used by the old data logger couldn't obtain.

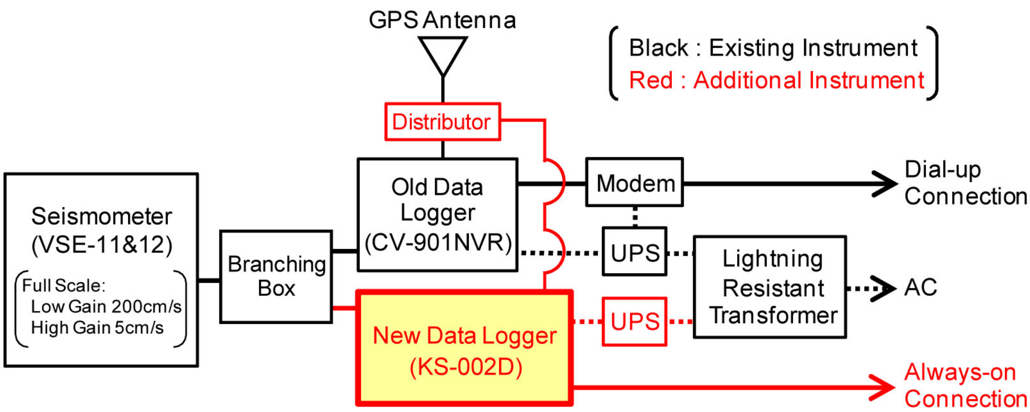

Figure 2. Basic configuration of new strong motion observation system.

4. DEVELOPMENT OF NEW STRONG MOTION OBSERVATION NETWORK

The new data loggers were installed progressively in CEORKA's stations from March 2009 and the full-scale operation of the new observation system started in August 2011. As described previously, the seismometer has two type output signals: low gain and high gain signals. At the beginning of this project, we planned to use only low gain ones using one 24bit A/D converter and developed data logger KS-001 with four input channels. This data logger was installed at 3 stations as the 1st stage in March 2009. However, the analyzed results of obtained records revealed that the resolution of records was lower than resolution of high gain records obtained by old data logger. On the other hand, when the data logger was inputted with high gain signals, the result became opposite. In order to solve above problem, we developed the new data logger KS-002D with eight input channels to obtain both high and low gain signals. Then, at the 2nd stage in February 2010, the new data logger was installed at 7 stations. At the stations in which KS-001 was already installed, a lower cost data logger AK-002 with four input channels was added. This addition made possible observation equivalent to the new data logger. Additionally, at the 3rd stage in February 2011, the new data logger was installed at 9 stations. Then, the 2011 Tohoku Earthquake was occurred and new observation system obtained high accuracy records at many stations. The records are shown in Fig. 3. At the 4th stage in August 2011, the new data logger was installed at 5 stations. At this moment, the installation of the new data logger and the development of new strong motion observation network by this project were completed. During developing of the new network, an always-on connection lines and LAN are newly prepared. Additionally, at the stations that had difficulties in installing GPS antenna, Internet was used to correct internal clock. Table 2 shows equipping for CEORKA's stations: type of new data logger, always-on connection line, LAN connection and clock correction.

Table 2. Equipping of the new data logger of CEORKA's stations.

		Station Name	New Data Logger	Always-on Connection Line	LAN Connection	Clock Correction
CEORKA Own Stations	1	KBU	KS-002D	Existing Line	Wired	GPS
	2	MOT	KS-002D	ADSL	Wired	GPS
	3	AMA	KS-002D	ADSL	Wired	GPS
	4	FKS	KS-002D	ADSL	Wired	GPS
	5	MRG	KS-002D	ADSL	Wired	GPS
	6	TTT	KS-002D	WiMAX	Wired	GPS
	7	TYN	KS-002D	ADSL	Wired	GPS
	8	SNM	KS-002D	ADSL	Wired	GPS
	9	TDO	KS-001 & AK-002	Existing Line	Wireless	GPS
	10	CHY	KS-002D	ADSL	Wired	GPS
	11	KM2	KS-002D	-	-	GPS
	12	SMA	KS-002D	ADSL	Wired	GPS
	13	KID	KS-002D	ADSL	Wired	GPS
	14	OCU	KS-001 & AK-002	Existing Line	Wireless	GPS
	15	SRK	KS-002D	Existing Line	Wireless	GPS
	16	KTG	KS-002D	ADSL	Wired	GPS
	17	YMD	KS-002D	ADSL	Wired	GPS
	18	NRO	KS-001 & AK-002	ADSL	Wired	GPS
	19	HSD	KS-002D	ADSL	Wireless	GPS
	20	IMF	KS-002D	ADSL	Wired	GPS
Member's Stations	21	ABN	-	-	-	-
	22	KTR	KS-002D	Existing Line	Wired	Internet
	23	DIG	KS-002D	Optical Line	Wired	Internet
	24	TRM	KS-002D	-	-	GPS
	25	IHS	KS-002D	Existing Line	Wired	Internet

5. OBSERVATION RECORD EXAMPLES AND ANALYSIS

Here we extract records of the 2011 Tohoku Earthquake, of several another events and microtremor from observed continuous record of the new data logger and analyze accuracy of the records by comparison with the records obtained by the old data logger and microtremor-meter. In the figures of this chapter, the maximum values of waveforms are the new data logger's one and the spectra are calculated for the main amplitude segment of record, indicated by the double arrow. Other than the 2011 Tohoku Earthquake, the figures show records of the high gain channel.

5.1. 2011 Tohoku Earthquake (Mw9.0)

Fig. 3 shows observed velocity waveforms of EW component obtained at all CEORKA's stations during the 2011 Tohoku Earthquake. In this figure, the underlined stations show records of the low gain channel. The reason is that maximum amplitudes exceed scale limit of the high gain channel. Additionally, the stations marked by circle on the left side, show records obtained by the new data logger. The other stations show records obtained by the old data logger, mostly due to the reason that the new data logger had not been installed yet. Arrows indicate onset of P-wave. Most of the waveforms obtained by the old data logger, started later and lost information about P-wave, because initial segment of records stored in the memory card were overwritten by later surface waves. Here, we compare MRG and SRK stations. For the former we use the low gain records, and for the latter the

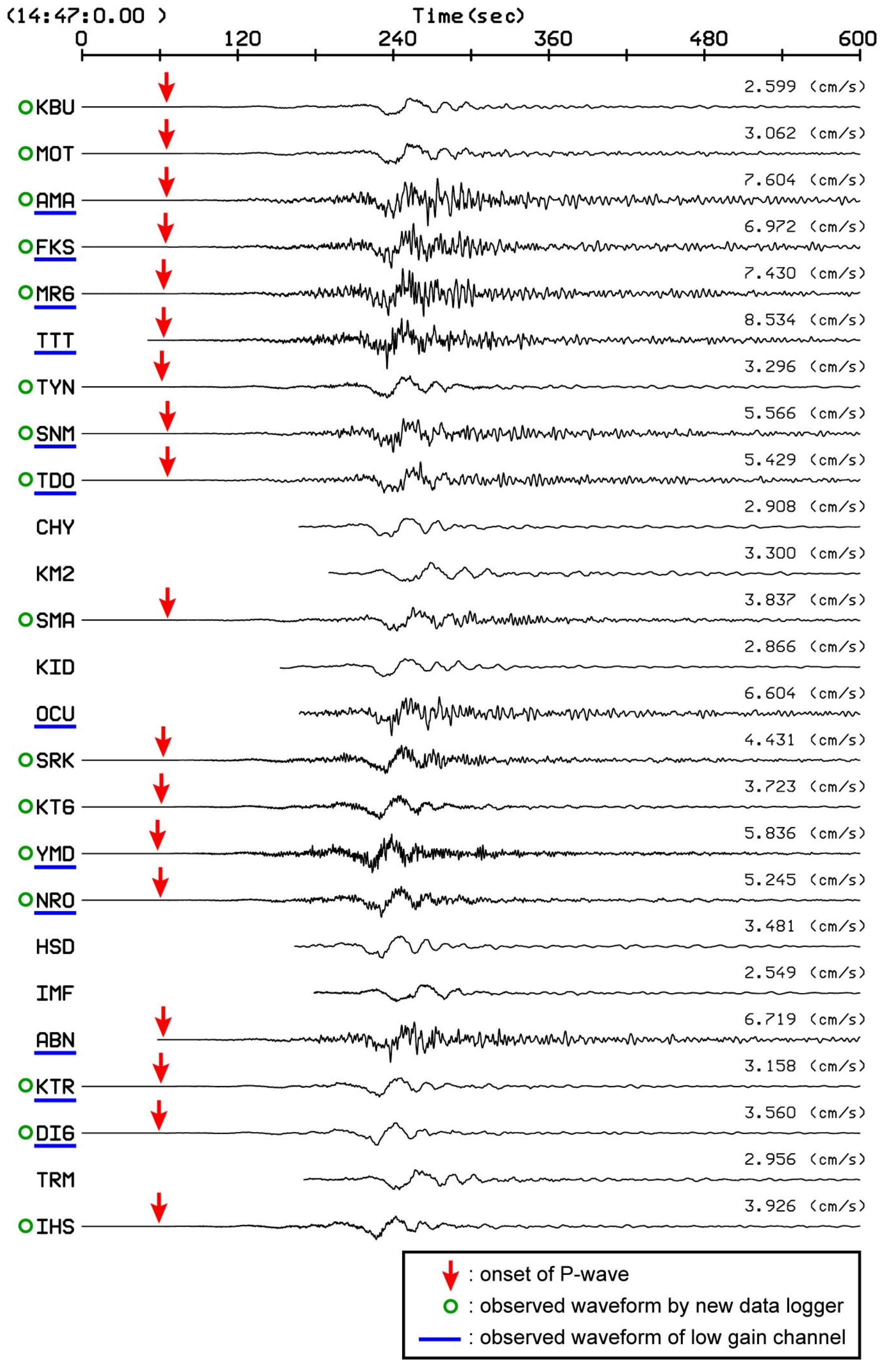

Figure 3. Observed velocity waveforms of EW component obtained at all CEORKA's stations during the 2011 Tohoku Earthquake (Mw9.0).

high gain records. Fig. 4 and 5 show the velocity waveforms and velocity Fourier spectra obtained at each station, respectively. The results for the MRG station show that the waveforms and the spectra in low frequency range of the new data logger approximately correspond to those of the old data logger. On the other hand, the spectra in high frequency range show that records of the new data logger have higher accuracy than records of the old data logger. At the SRK station, both the waveforms and the spectra of the new data logger approximately correspond with ones of the old data logger.

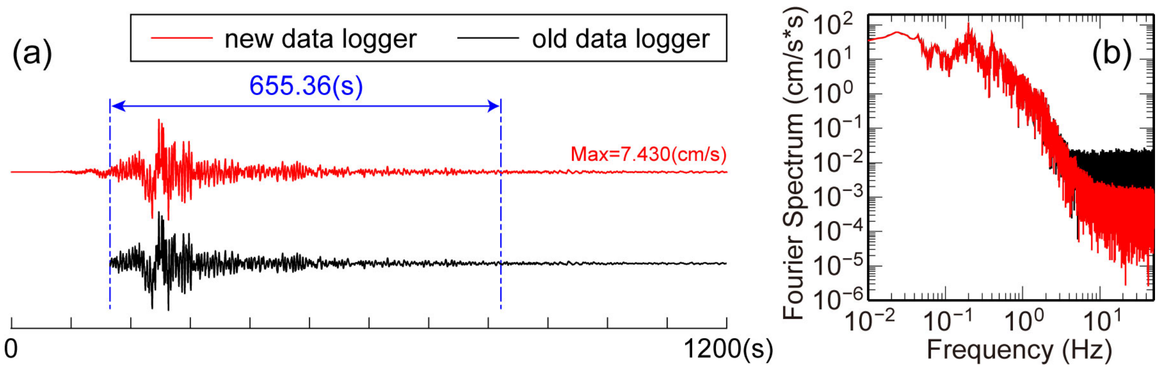

Figure 4. Observed records of EW component for low gain channel obtained at the MRG station during the 2011 Tohoku earthquake (Mw9.0). (a) Velocity waveform. (b) Velocity Fourier spectra.

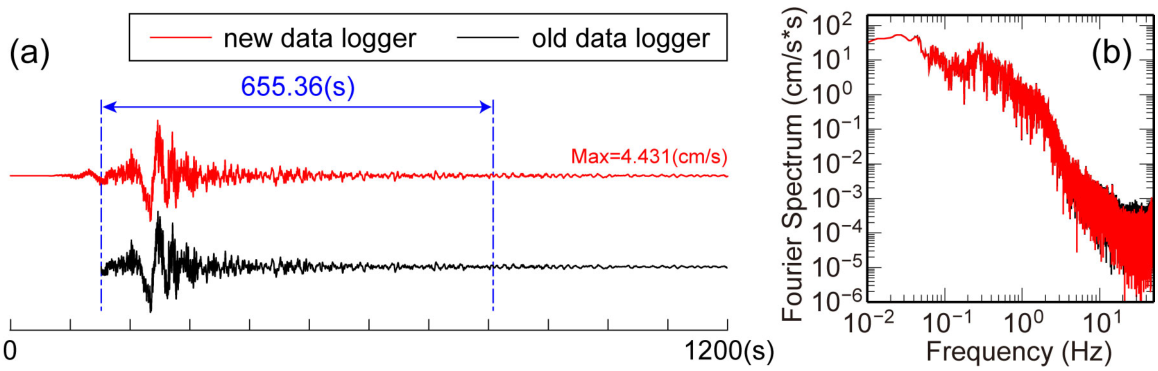

Figure 5. Observed records of EW component for high gain channel obtained at the SRK station during 2011 Tohoku earthquake (Mw9.0). (a) Velocity waveform. (b) Velocity Fourier spectra.

5.2. Event occurred at Kyoto Osaka Border Region in February 15, 2010 (M_{JMA}3.6)

This event is example of the near-field seismic records during a moderate earthquake. Fig. 6 shows the observed velocity waveforms and velocity Fourier spectra of NS component obtained at the FKS station during this event. Similar to the result of the MRG station in Section 5.1, the waveforms and spectra in low frequency range of the new data logger approximately correspond with ones of the old data logger, and the spectra in high frequency range of the new data logger have higher accuracy than ones of the old data logger.

5.3. Event occurred at Ryukyu Islands in February 26, 2010 (M_{JMA}7.4)

This event is example of the intermediate-teleseismic records during a large earthquake. Fig. 7 shows the observed velocity waveforms and velocity Fourier spectra of NS component obtained at the FKS station during this event. In the waveform of the old data logger some part of P-wave and surface waves is lost. The cause is that these parts were not stored to the memory card, because amplitudes of ground motions didn't exceed the preset trigger level. Therefore, this cause is different from the cause of lost data of the 2011 Tohoku Earthquake above. On the other hand, the waveform of the new data logger is completely recorded, from the onset of P-wave to the surface waves. Velocity spectra show the same tendency as in the previous examples.

5.4. 2010 Chile Earthquake (Mw8.8)

This event is example of the teleseismic records during a great earthquake. During this event, the tsunami was also observed in Japan. Fig. 8 shows the observed velocity waveforms and velocity Fourier spectra of EW component obtained at the KBU station during this event. In the waveform of the old data logger some parts are lost. The cause is same as in Section 5.3. The spectra also show the same tendency as in the Sections 5.2 and 5.3.

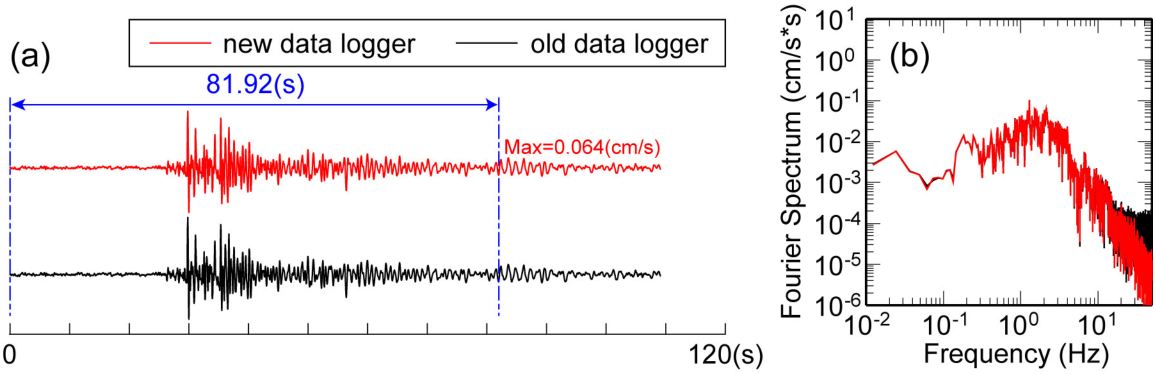

Figure 6. Example of the near-field seismic records of NS component observed at the FKS station during a moderate earthquake (M_{JMA}3.6; Kyoto Osaka Border Region, Japan; February 15, 2010). (a) Velocity waveform. (b) Velocity Fourier spectra.

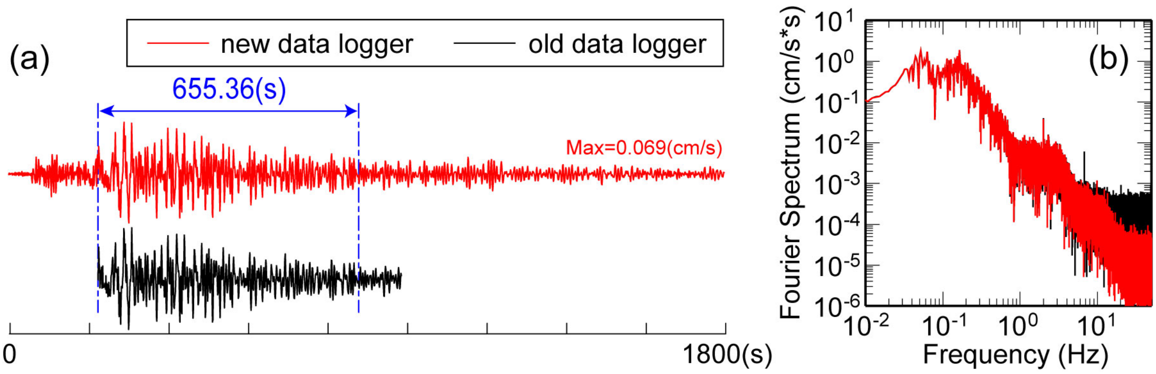

Figure 7. Example of the intermediate-teleseismic records of NS component observed at the FKS station during a large earthquake (M_{JMA}7.4; Ryukyu Islands, Japan; February 26, 2010). (a) Velocity waveform. (b) Velocity Fourier spectra.

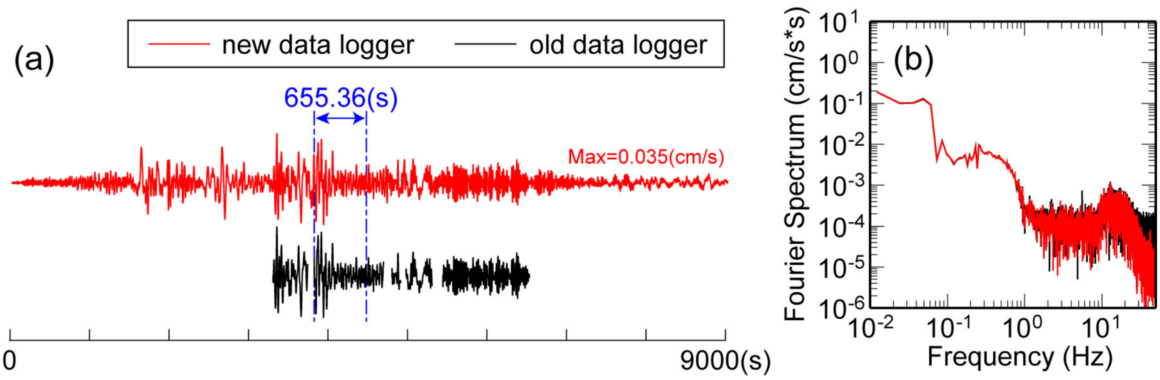

Figure 8. Example of the teleseismic records of EW component observed at the KBU station during the 2010 Chile Earthquake (Mw8.8). (a) Velocity waveform. (b) Velocity Fourier spectra.

5.5. Microtremor

Here, we analyze microtremor records obtained at the FKS and HSD stations. The former is located on the sedimentary basin, and the latter is located on a hard bedrock. For comparison, the record obtained by microtremor-meter SMAR-6A3P is also used. Fig. 9 and 10 show observed velocity waveforms and velocity Fourier spectra of UD component obtained at stations FKS and HSD, respectively.

First, the records at the FKS station are analysed. Two waveforms are shown: for 81.92 sec and 2 sec. Waveform of the microtremor-meter is the integrated acceleration record. All waveforms are passed them through the high-pass filter over 0.1Hz. Although all waveforms show similar trend, waveform of the old data logger includes high frequency waves with small amplitude. Spectrum of the old data logger over 10Hz has a lower accuracy than another records. This result indicates that high frequency waves in the waveform of the old data logger are noise. On the other hand, spectrum of the new data logger approximately correspond to one of the microtremor-meter.

Next, the records at the HSD station are analysed. Waveform examples are shown for 81.92 sec and 5 sec length. Waveform preprocessing is similar to the previous example. Waveform of the old data

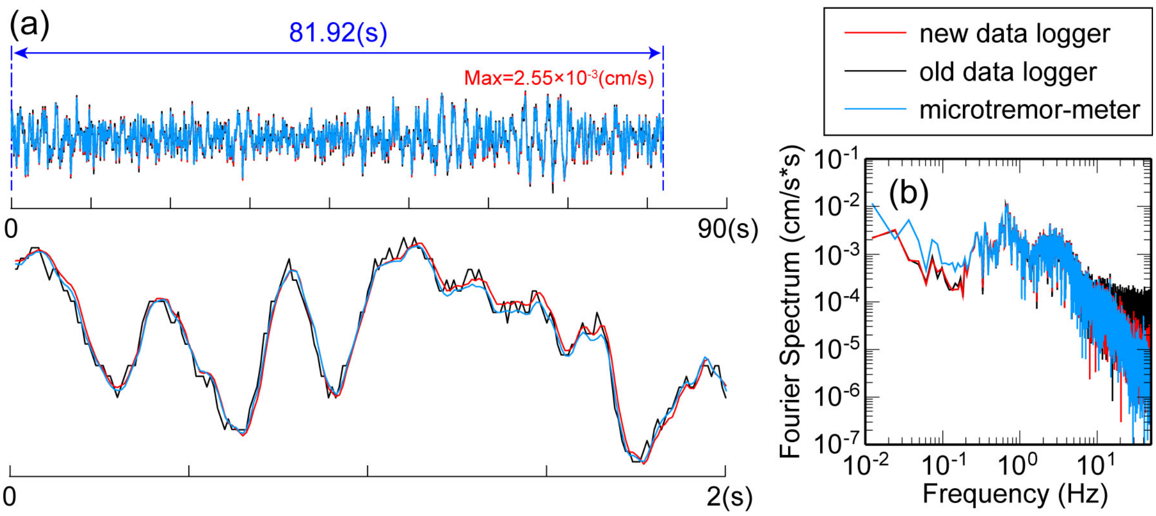

Figure 9. Microtremor records of UD component observed at the FKS station. (a) Velocity waveform. (b) Velocity Fourier spectra.

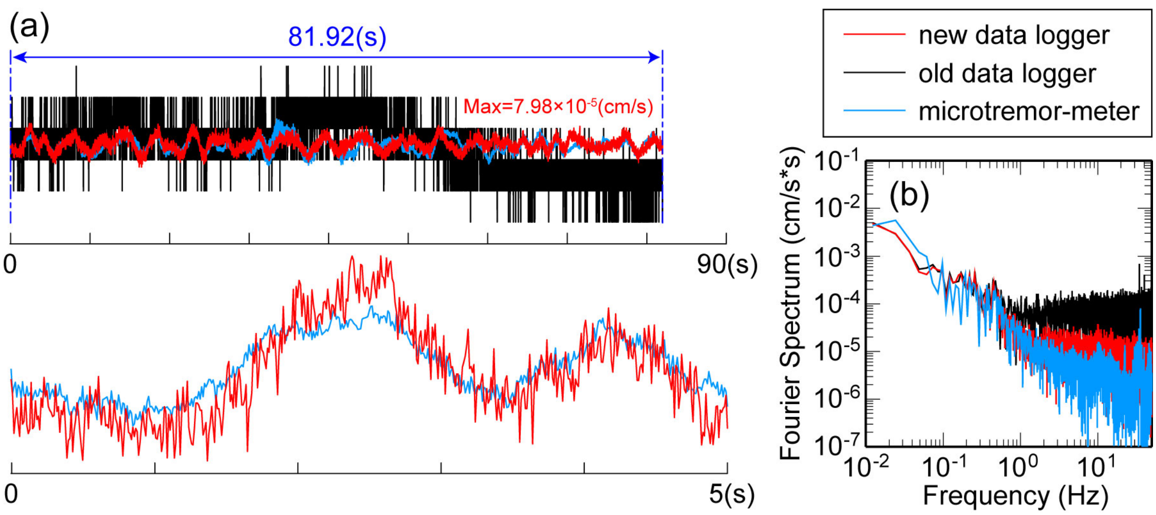

Figure 10. Microtremor records of UD component observed at the HSD station. (a) Velocity waveform. (b) Velocity Fourier spectra.

logger is mostly noise. On the other hand, waveforms of the new data logger and the microtremor-meter show similar trend. However, waveform of the new data logger includes high frequency waves with relatively-large amplitude. Spectrum analysis shows that these waves is the noise component over 20Hz. In the frequency range less than 20Hz, the record of the new data logger approximately correspond to the microtremor-meter.

6. CONCLUSIONS

We developed a new low-cost data logger KS-002D to support real-time connection, continuous observation and high-capacity storage. This data logger solves significant problems of the previous CEORKA's system and ensures reliable storage of valuable data. Moreover, the data logger has eight input channels to obtain both high and low gain signals from the existing strong motion seismograph, already used by the CEORKA network. The data logger also receives high accuracy clock signals from GPS. Then, we installed new data logger in CEORKA's stations and developed high-resolution real-time continuous strong motion observation network in the Kansai district using the CEORKA network. The new CEORKA's system supports parallel observation by the new and old networks. Example of observed data show that with the new data logger we can obtain broadband and high-resolution data ranging from strong motions to microtremors.

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