A Study of Data Logging System and the Southern Ocean Buoy's Motion

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***Abstract*—We moored a large buoy system in the Southern Ocean (60°S, 140°W) during 2012/01/16 – 2012/12/19. The safely moored buoy system collected valuable data. This time, a logger was developed for operation and assessed. Event analyses use collected data of the tension gauge of the buoy, acceleration information, and a magnetic direction. Furthermore, FFT analysis from a tension gauge and an accelerometer were conducted. Comparison of these with satellite data showed good agreement.**

Keywords—***Southern Ocean; FFT; Buoy; Logger***

I. Introduction

JAMSTEC developed a long-term moored buoy system (Fig. 1, Fig. 2) for use in the Southern Ocean. The buoys, secured by a 5000 m mooring cable, weigh 800 kg, and are 5.32 m high, with 1.8 m diameter. Sensors (CTD, compass, ADCP) are attached to the buoy (Fig. 2).

The buoy developed for this study was placed at (Fig. 3) of 60°S, 140°W during 2012/01/16–2012/12/19. This point is the southern limit of the installed buoy system. It is meaningful to install a buoy at this point; the installation point is extremely important for Antarctic weather measurements.[1,2,3,4] The constantly obtained data are valuable especially for the Southern Ocean from now on. We collected and analyzed. This data is a cable of tension and a buoy movement and billow. Moreover, a logger was installed so that the influence of a magnet might measure the influence that it has on compass.

However, existing measurement loggers cannot acquire data year-round. Therefore, JAMSTEC developed small, low-power logging equipment.[10] After these buoy systems collected data, their data were examined. Analyzed results of information related to the validity of a logger design and engineering are described here.

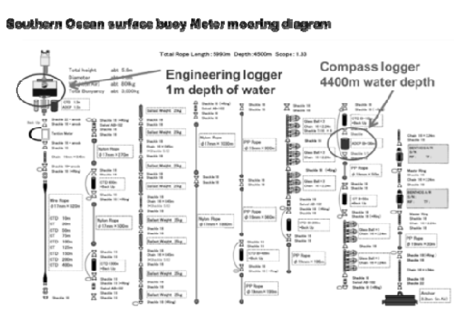

Fig. 1 Southern Ocean buoy diagram.

Fig. 2 Southern Ocean buoy float.

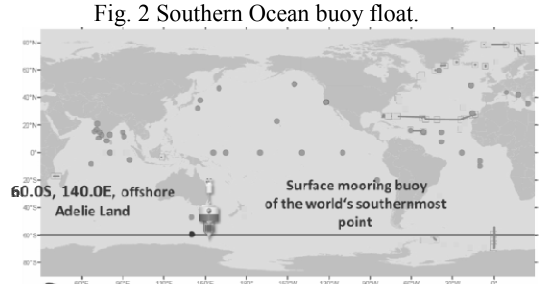

Fig. 3 World's southernmost surfaced moored buoy.

II. Southern Ocean buoy system logger

This logger is a super-low-power-consumption type of buoy. The equipment uses 7.8 V and is 2 mA (14.4 mW) during sleep mode. Moreover, it is 43 mA (309.6 mW) at the time of SD card record. This logger's board size is 60×60×60 mm (Fig. 4). Moreover, a maximum of 32 G bytes of data storage is possible for this equipment. A point with a serial buffer, which is 64 K bytes, is its salient feature. This logger can collect high-speed mass serial data from an accelerometer. It not only miniaturizes the logger. Balance with the battery size is an important element. Details and the measuring results of the logger are described herein. After collecting data from these buoy systems, analyses of the data confirmed that the equipment operated safely and acquired data for one year in an environment of about 0 °C. Moreover, the data were validated using the acquired data.

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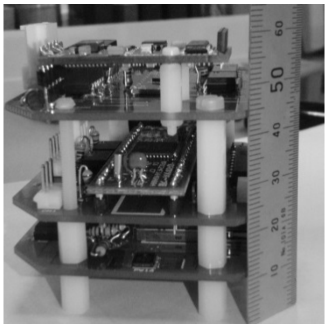

Fig. 4 Logging System.

A. Engineered Logger details

The engineered logger installed in the buoy float measures the mooring cable tension and the float acceleration(AMU-182BR) by sampling of 4-minute 10 Hz for every 3 hr. It had 2 direct 2 parallel composition using three B6200 batteries (3.9 V, 40 Ah, lithium sulfuryl chloride cell). In addition, because used batteries were reused this time, battery capacity of one piece was set as 29 Ah. Therefore, it has a period of 13.5 months with operation at 7.8 V and 58 Ah. Details of the electric power distribution are presented in Table I.

TABLE I. ENGINEERING LOGGER ELECTRIC POWER TABLE

	Consumption current (mA)	**Loop Time (S)**	**Electric capacity (Ah)**
SLEEP	3.6	10230	3.41E-03
Acceleration and tensionMeasurement	43.8	255	1.03E-03
Accelerometer data reading	33	250	7.64E-04
SDHC Write	43	15	5.97E-05
Accelerometer Memory Clear	33	40	1.22E-04
Sensor Wait	24	10	2.22E-05
	Tatal	10800	5.41E-03

B. Compass logger details

With Compass(HMR3400) Logger, magnetic information obtained with a compass was measured in deep of water of 4400 m. 50 samplings (0.27 Hz) were conducted every 20 min for 3 min. Here, B0036 type batteries (3.9 V, 30 Ah, lithium sulfuryl chloride cell) were used by 2 serial 3 parallel. In addition, because the batteries were reused this time, the battery capacity of one piece was set to 22 Ah. Therefore, at 7.8 V and 66 Ah, an operation period of 13.4 months can be attained. Table II presents the power consumption.

TABLE II. COMPASS LOGGER ELECTRIC POWER TABLE

	Consumption current (mA)	**Loop Time (S)**	**Electric capacity (Ah)**
SLEEP	3.6	10230	3.41E-03
Compass Measurement	43.8	255	1.03E-03
SDHC Write	43	15	5.97E-05
	Tatal	1200	5.41E-03

C. Result of logger operations

Results after recovery are shown in Tables III–V.Although a problem exists by which measurement became physically impossible because of a cable break of the tension meter for engineering logger as operating time, the accelerometer operated safely during one year (Table III). The compass logger battery was insufficient after 4/17. It was stopped (Table IV). In addition, the engineering and compass logger were investigated onboard at UTC2013/01/04 10:00:00 on 'R/V MIRAYI'. The engineer logger data are presented in Tables III–V, demonstrating normal performance during the investigation.

As a situation of operation at that time,

1) The track record of operation was about 353 days.
2) About RTCC, a delay of 15 min and 20 s arose.
3) Battery voltage fell rapidly to 7.77 V from the initial value 7.81 V, but the voltage remained sufficient.
4) Data were 5680; the total data volume was about 1.47 G bytes. The data acquisition rate was 97%.

The logger performed well and was fully operational. The delay of RTCC was slight. However, we thought that RTCC was overdue like RTCC (temp: 25 °C, 60 S/month, Non TXCO) for a cars. Therefore, RTCC was assumed to shift from the beginning. The time adjustment with an external measurement apparatus was performed as shown in Eqs. (1)–(4).

Power ON:T_start_utc=2012/01/16 10:00:00
Power OFF:T_end_utc=2013/01/04 10:00:00
Logger time error: T_{error}=920 S

$$T_{error} = T_{end\_rtc} - T_{end\_utc} \qquad \text{Eq. (1)}$$

$$T_{sum} = \sum_{T\_end\_utc}^{T\_start\_utc} T \qquad \text{Eq. (2)}$$

$$\alpha = \frac{T_{error}}{T_{sum}} \qquad \text{Eq. (3)}$$

$$T = \alpha \times \Delta T + T_{\_start\_utc} \qquad \text{Eq. (4)}$$

However, the compass logger stopped measurement by 2012/04/17. Therefore, about one-fourth of the expected data were obtained. Probably, the compass logger started sleep and it became impossible to start the compass because of insufficient battery capacity. Table V shows extracted data. Although the compass logger conducted the stop of operation, it can be said that it had fitted in the data volume which we expected mostly.

TABLE III. LOGGER WORKING TIME

		Stop Day	**Work day**	**Situation**
Engineering logger	Accel.	2013/1/4	353	No problem
	Tension	2012/2/13	28	Cable Break
Compass Logger	Compass	2012/4/17	92	Electrical discharge

TABLE IV. LOGGER RTCC ERROR AND BATT

	RTCC Error	Start BATT (V)	Recovery BATT (V)	Situation
Engineering logger	920 S	7.81	7.77	RTCC Late
Compass Logger	-	7.80	1.25	Work Stop

TABLE V. LOGGER DATA SIZE

	Number	Size	Recovery rate	Error rate
Engineering logger	5,680	1.48 GB	100 %	3.12 %
Compass Logger	6,629	169 MB	25.21 %	0.0 %

D. *Logger's electrical property*

The logger continued operating satisfactorily in terms of electrical consumption, as explained in chapters II.B and II.C. However, the battery for the compass logger was insufficient, thereby interrupting measurements. Some investigation of battery capacity at the time of low temperatures is necessary from now on. Because this used a lithium battery, the error of residual quantity calculation is large. Therefore, electrically, although a battery problem exists, the logger exhibited the expected operation.

III. ANALYSIS OF THE LOGGER RECOVERY DATA

Development of a buoy requires investigation of the tension, the acceleration, and the compass information that is acquired. However, the acquired data are not normal. We cannot the design and dynamic analysis of a buoy. Then, to confirm normally nature about the collected data, time series event analysis using an accelerometer and a tension meter was conducted this time.

To investigate whether the logger collected data normally, we investigated whether a time series event that occurred with the buoy was apparent. The event was regarded as a result. Both data agreed well, as verified by related explanations in chapters III.A–III.C. Moreover, unique movement is apparent for compass data.

A. Consideration from a tension value

Time series data are shown in Fig. 5 for tension gauge data. The tension data are shown for 2012/01/16–02/13. This buoy-related event is shown in Fig. 5. The wind velocity and wave height are meteorological satellite data. Wind speed data [6,7] and the wave height data [8] were used. Satellite data are averages for five days. Therefore, an instantaneous value actually becomes an about 0.5–2 times the size.

1) 2012/01/06 of Fig. 5 is in the situation where the buoy anchor was dropped to 'Umitaka Maru'. The tension change of the wire at the time of an anchor arrival bottom is known well.

2) 2012/02/12 03:00 has 1 ton of tension change. This becomes a cause of a problem occurring in the signal cable between a tension meter and logger.

3) is also the same and is considered that a value is attributable to cable abnormalities.

4) 2012/02/13 The signal wire was disconnected after 18:00. It was impossible to acquire the tension meter signal.

From 2012/02/12, since the temperature and humidity meter and wind direction and anemometer which was being installed in the upper part of a buoy break down and the data acquisition by Iridium satellite communication is impossible, it applies to 02/12–13. It is expected that it was a storm in this ocean space. In addition, the wave height was inferred as 6.135 m from satellite data during that time of strong winds. The wave height becomes less than this, creating intense sea spray (wave splash) that continued striking the buoy.

Therefore, it can be shown that it caused observation equipment failure. It operates normally because the logger data can reflect an event exactly. Its data are also normal as a result. The installation method of the intensity of a signal wire and a sensor must be considered during the buoy design.

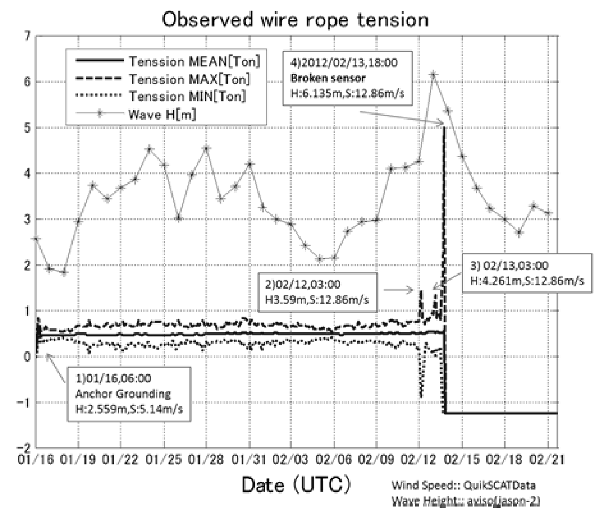

Fig. 5 Event shown by the tension meter.

B. *Consideration from the accelerometer of a buoy*

The event of 2012/02/13, when poor tension gauge measurement occurred, was entered in the data for one year of an accelerometer (Fig. 6). The average value of the acceleration of each measuring point is a strange value in some places. For example, these cases are events 1), 2), 3), and 4). Because of the time when the logger was not able to receive data from the accelerometer and the logger returned the error, this occurred when the inclusion data do not fill 2400 pieces. Errors are 3.12 % grades from Table V. It is satisfactory even if this is removed. The acceleration of Z shaft orientations of an accelerometer shows -1 G according to a stable state. Annual average value is -1.0133 G. The overall measurement itself succeeded.

Event 5) shows that the buoy was pushed on its side by "R/V MIRAI" onboard at the time of recovery (2400 data were acquired).

An error situation is portrayed in Fig. 7.

The errors are concentrated in January–April as the number of errors. This is regarded as a problem of rs232c communication of the logger and an accelerometer. Therefore, it is not an inherent problem in the logger or accelerometer itself.

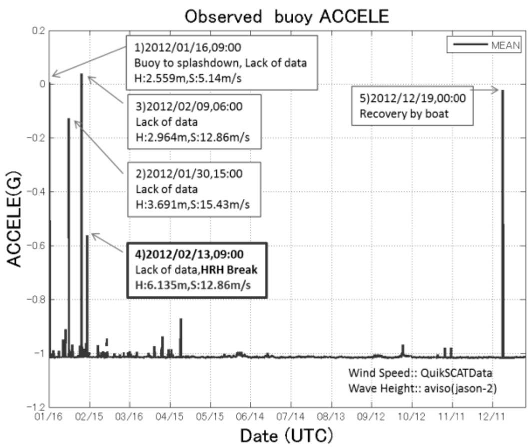

Fig. 6 Event of acceleration meter.

1) There is no relevance with wave data. It is difficult to consider what is dependent on vibration.

2) During winter at the time of low temperatures that a problem tends to generate electrically (June–September), the number of errors are few and stable.

3) If it is a logger's programming miss, although the number of errors comes out on the average, it has not come out.

4) If a reading programming glitch from an SD card occurs, although the number of errors comes out on the average, it has not come out.

The acceleration data have a little error data. The error data are number 2400 count in once samples, which is satisfactory even if this error is removed.

C. Compass logger of data

Data presented in Fig. 8 were collected using a compass logger. They are not subject to the influence of the magnetism of the Antarctic, and can fully take eight directions. The cable can also show rotation in response to the influence of a current from this data. Now, the compass of ADCP and the compass logger data are under careful analysis.

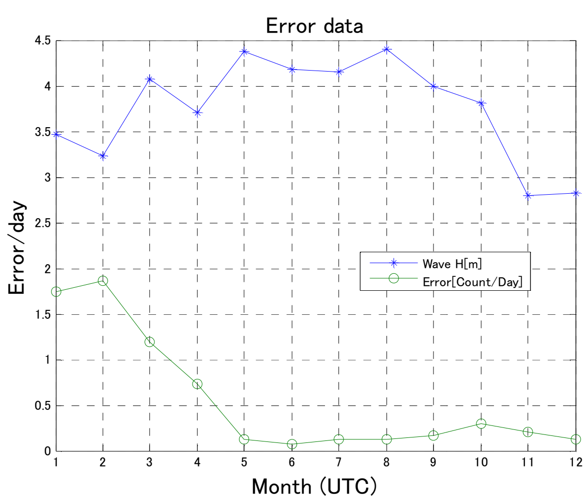

Fig. 7 Accelerometer error.

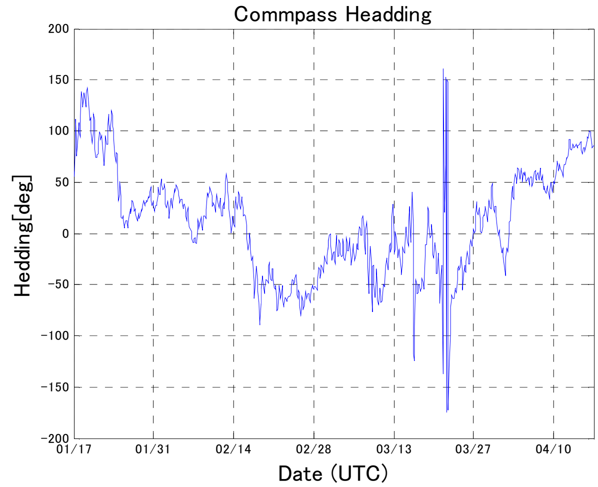

Fig. 8 Compass data.

IV. FREQUENCY ANALYSIS

Frequency analysis was done to compute wave height data, which are important for motional analysis (tension and acceleration) of a buoy from the collected data. The buoy movement can be inferred from the tension meter value. However, tension meter data run short by cable disconnection. The technique of guessing wave height from acceleration data is used. The collected tension and acceleration data are analyzed using FFT. The power which the oceanographic phenomena around ocean space give to a buoy in FFT analysis is analyzed. The wave height is calculated from the frequency. If wave height data are compared with satellite data, then the wave height of this ocean space can be confirmed. The satellite data are a five-day moving average.

Therefore, these data are not data showing the wave height of a momentary ocean space. A logger can show the wave height every 3 hr from logger’s data, which has great value for dynamic analysis.

A. Frequency analysis of a tension data

The tension gauge value is the power received complexly the wave, the wind, wave motion, etc. The buoy safety requires measurement and analysis of these influences. These data are also important for dynamic analysis. Frequency analysis of the tension value was conducted. Figure 9 shows the main frequency of FFT of a tension value (2012/01/16–2/13). In general, the tension value frequency is displayed near 0.1–0.5 Hz. Therefore, ocean space considers this frequency band to be the frequency of a tension meter that occurred under conditions of given the buoy. At this time, the average frequency is 0.2623 Hz and the average cycles is 5.27 S.

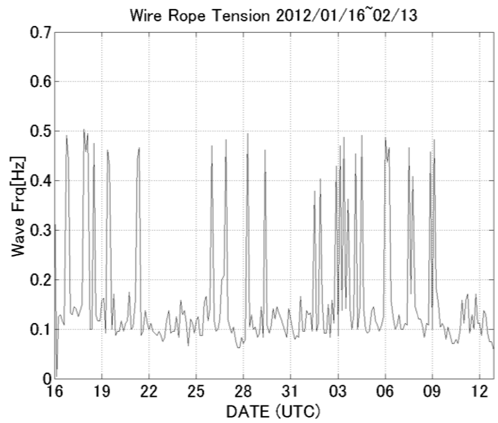

Fig. 9 Frequency change of tension.

The cycle is dependent on the wave shape. The wave height is also calculable if frequency is known (Eq. 5).

This time, there is no shelter in the circumference.

There is sufficient depth, it asks for the wavelength, is designated as a=1/10, and computes. The influences of the style, etc. These were considered and this value of 1/10 was used in many cases. The average wave height is set to 3.07 m from the average frequency. Although the average value of this period of satellite data has a low value computed as 3.40 m, it can be said that the obtained value is mostly in agreement (Table VI).

As a reason to explain the error, it is about 0.5–2-times the average wave height (significant wave height) generally comes. The possibility exists that the logger gathered instant wave height. The satellite data were insufficiently precise. The data are a 5 day moving average.

$$\begin{cases} \lambda = 1.56 \cdot T^2 \\ H = \lambda \cdot a \end{cases} \qquad \text{Eq. 5}$$

Eq. (5) shows a general formula used for wavelength calculation of ocean space. The parameters are wavelength λ : m, periodic T: s, and wave height H: m. Wave heights calculated from the satellite data and frequency of the period to 2012/01/16–02/13 are presented in Fig. 10.

Correlation between satellite and buoy data is high. The tension value of the buoy was subject to the strong influence against wave height in this period from these data.

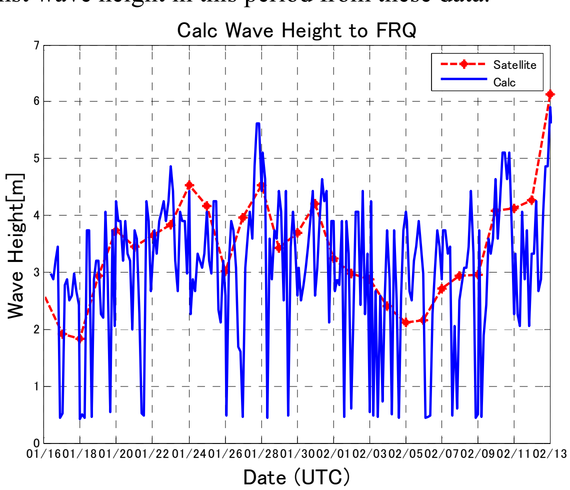

Fig. 10 Wave height calculation result from a tension gauge.

TABLE VI. AVERAGE PEAK VALUE (TENSION METER)

	Frequency (Hz)	**Cycle (S)**	**Wave height (m)**
Satellite wave height	-	-	3.40
FFT analysis wave height	0.2623	25.21	3.07

B. FFT analysis of the acceleration data

The analysis results of FFT in January (summer) and July (winter) are presented as an example in Fig. 11.

In 2012/1/26 00:00:00, the tension meter was normal. Accelerometer and tension meter data are shown in Fig. 12.

The accelerometer is extremely sensitive. A point different from a tension gauge will measure the characteristic vibration of the buoy by a billow.

The compound power of the characteristic vibration of a wave, the flow velocity, a wind, sinuosity, and a buoy is received. Therefore, to ascertain the same value as a tension meter from an accelerometer, one can merely calculate the peak value of FFT of the remaining portion with the frequency of the characteristic vibration of a buoy removed. Past mooring data show numerical values of the characteristic vibration of a buoy as 2.84 S with a 1.97–3.0 S grade (0.33–0.51 Hz) and a mean period.[5] The wave motion (0.1–0.33 Hz :Buoy Motion Zone) is regarded as equivalent to the value of the tension gauge given to the buoy from ocean space. Regarding the accelerometer data, 0.3–0.5 Hz (the cycle 2–3 s grade) is greater than that shown in Fig. 12. This is the characteristic vibration of a buoy system.

When this frequency portion is extracted and considered, in Fig. 12, it is at 0.14 Hz that the peak of Power of an accelerometer and a tension gauge show agreement. It is necessary to calculate the maximum of Power in an about 0.1–0.3Hz frequency range to find 'the main frequency of a tension meter' using this characteristic from an accelerometer.

Results of the FFT analysis of an accelerometer (Fig. 11) to the maximum, January is 0.308 Hz (cycle 3.24 S) and July is 0.446 Hz (2.24 S). The characteristic vibration of the buoy by a billow is apparent here. Near 0.1–0.3 Hz (3.3–10 S) of FFT analysis, a cycle will be set to 7.05 S on 01/26. On 07/26, similarly, the cycle will be set to 5.7 m (0.175Hz).

Therefore, the expected wave situation is that the wave height was 7.7 m on 01/26 and that on 07/26 was 5.0m. Satellite data show values of 3.055 m and 4.471m. Those are not instantaneous values, as explained in Chapter IV.A.

This technique was used for the average by acceleration meter data of a single year. It is thought that it is a wave height 3.83 m. The average of satellite data is also 3.78 m and was mostly in agreement (Table VII). The monthly average value is presented in Fig. 13. Results show that the monthly average error in comparison to satellite data is less than 1.5 m. The data are mostly in agreement.

Therefore, wave height can be inferred from the accelerometer data using this technique. The wave height can be inferred from accelerometer data when tension meter data are missing. It is also possible to ascertain the value of a missing tension meter when investigating the relation between wave height data and a tension meter.

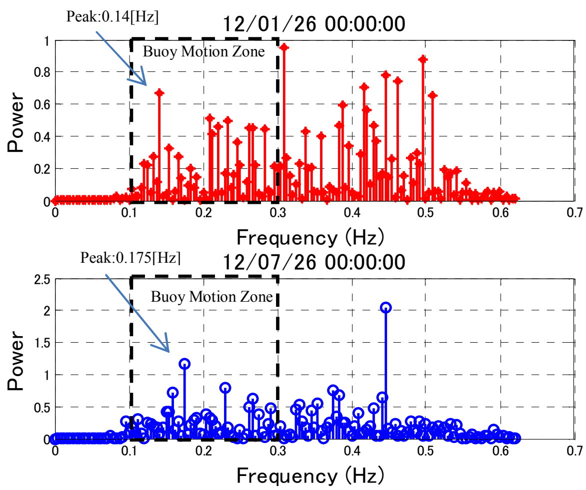

Fig. 11 FFT of Acceleration Data.

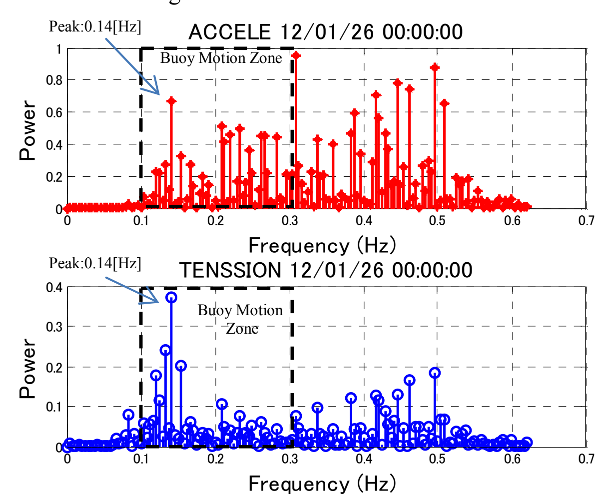

Fig. 12 FFT of Acceleration and Tension Data.

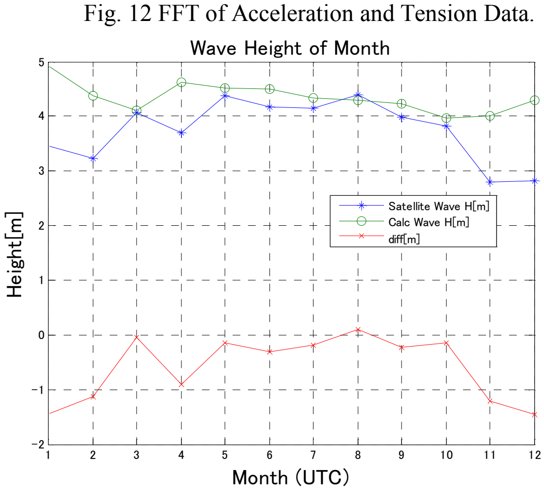

Fig. 13Wave hight calc to Accele.

TABLE VII. WAVE HEIGHT CALCULATION RESULT FROM AN ACCELEROMETER

		Peak Frq. (Hz)	**Cycle (S)**	**Wave H(m)**	**Satellite H (m)**
2012/1/26	tension	0.14	7.14	7.7	3.06
	accel.	0.14	7.14	7.7	
2012/7/26	tension	-	-	-	4.47
	accel.	0.175	5.7	5.0	
1 year mean	tension	-	-	-	3.78
	accel.	0.217	4.61	4.32	

V. ANALYSIS OF THE RECOVERED LOGGER DATA

The logger's validity was verified using the accelerometer and the tension gauge data. Sufficient work, such as recording of measurement and data, must be done for one year. Calculation of the battery capacity at low temperatures is also a subject for future research. The obtained data are also appropriate. A complementary technique using the FFT result of an accelerometer is proposed for instances when tension gauge data are missing. Results show that a comparison with the wave height of satellite data is also good. The Analyses using tension gauge and accelerometer data measured by this logger were conducted as basic data of dynamic tension calculation of a wire cable in the sea, which is our purpose. Those data were feedback to improve the design of a new weather measurement buoy.

A microcomputer has many FFT functions in recent years. The frequency obtained with tension and an accelerometer is transmitted by satellite communication. Those measurement data are useful to calculate the shape of the wave, height, etc.

This logger operated stably for a long period, and its operation was confirmed. It was used also as logging equipment for 'the tsunami buoy system'. This system can operate stably.

Acknowledgments

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