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Bridge Behaviour Monitoring System on the Honshu-Shikoku Bridge

Système pour l'observation du comportement des ponts reliant Honshu et Shikoku

Das Brückenverhalten-Überwachungssytem der Honshu-Shikoku-Verbundbrücke

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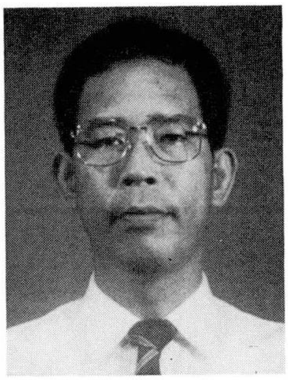

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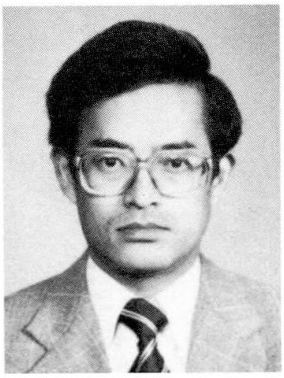

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SUMMARY
In this paper, the monitoring of bridge behaviour of the Honshu-Shikoku Bridges is explained with regard to the purposes, items and configuration of the monitoring system, as well as examples of collected data. To this end, the Ohnaruto Bridge, which is subject to the most severe natural conditions, is used as an example.

RESUME
L'objet de cette monographie est de décrire les objectifs et les éléments de l'observation, la structure du système et quelques exemples de données de l'observation du pont d'Oonaruto, soumis aux conditions naturelles les plus sévères, à titre d'exemple de l'observation du comportement des ponts reliant les îles de Honshu et de Shikoku.

ZUSAMMENFASSUNG
Diese Abhandlung beschreibt die Honshu-Shikoku-Verbundbrücke (Brücke zwischen der japanischen Hauptinsel und der Insel Shikoku), eine Brücke, die den strengsten Naturbedingungen ausgesetzt ist. Sie ist ein Musterbeispiel für die Überwachung des Brückenverhaltens. Es werden Zweck, einzelne Gegebenheiten und die Struktur des Überwachungssystems sowie typische Messdaten dieser Brücke besprochen.

1. OUTLINE OF THE HONSHU-SHIKOKU BRIDGE PROJECT

The aim of the Honshu-Shikoku Bridge Project is to link Honshu with Shikoku via three highway and railroad routes by building long bridges over the Inland Sea, which has always been a major factor in the economy, industry, traffic, and culture of Japan from ancient times.

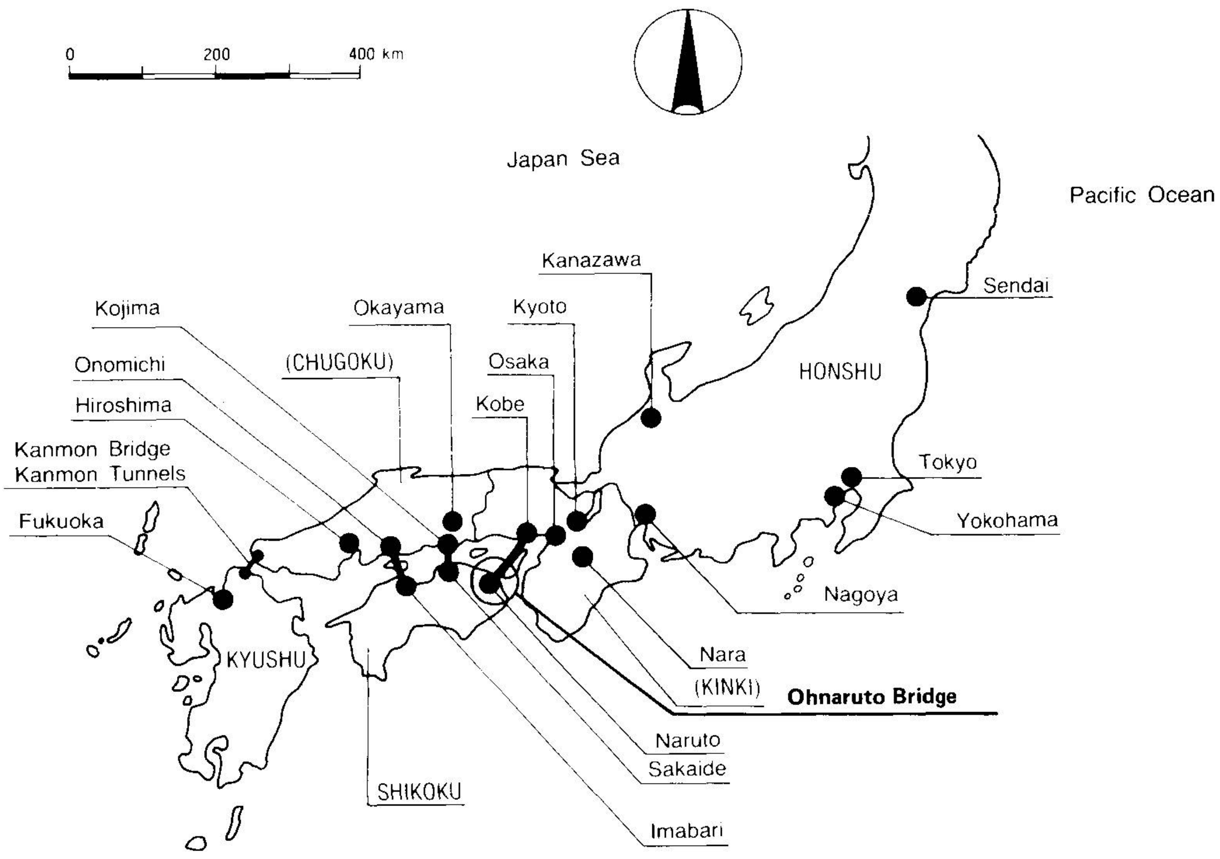


Fig. 1 Three Routes and the Location of the Ohnaruto Bridge

In general, the bridges are being built where the water is deep, currents are strong and natural disasters such as typhoons and earthquakes frequently take place. Also the straits over which the bridges will span are major sea routes which are congested with a great number of ships. Moreover, the construction sites are located in areas designated as national parks and where fishery is thriving. Accordingly, various mitigating measures have been taken for this project.

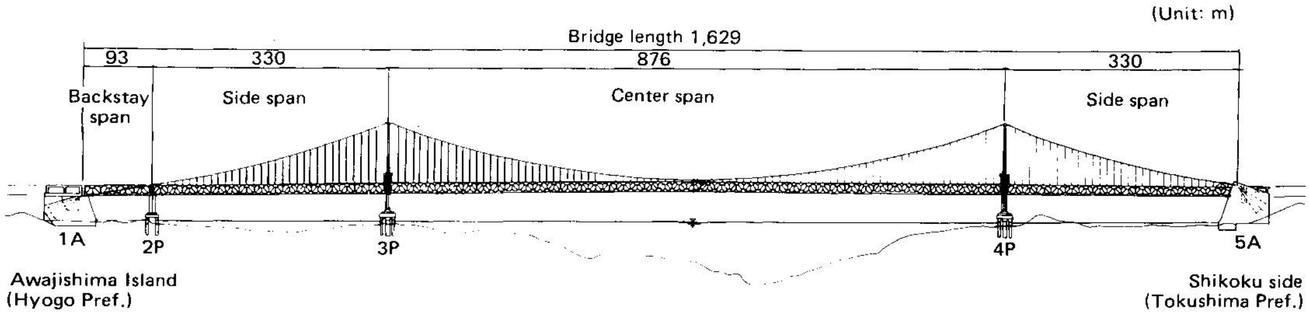


Fig. 2 General View of the Ohnaruto Bridge (Side View)

The Ohnaruto Bridge, a highway-railroad, dual-purpose suspension bridge, has been constructed initially. Only this bridge faces the open sea, and is subject to very severe wind conditions (basic wind velocity: 50 m/s). Further, this bridge is situated closest to the Tosa Sea and the sea area around the Kii Peninsula, both of which are expected to be the seismic origins of large-scale earthquakes, and thus will be built according to earthquake-resistant design standards of Honshu-Shikoku bridges.

Under these circumstances, the monitoring of bridge behavior (described below) has been conducted to verify the technical standards concerning resistance against wind and earthquake, including the measurement of response characteristics of the bridge under natural wind and earthquake.

2. PURPOSES AND ITEMS OF THE MONITORING OF BRIDGE BEHAVIOR

The purposes for monitoring the bridge behavior are shown in Table 1. As can be seen from this Table, methods and locations for recording data depend on purposes.

Table 1 Purposes of Monitoring of Bridge Behavior

Purpose		Immediacy of Data	Location of Recording	Method of Data Recording (See Table 2)
Traffic control		Required	Administrative office	Graphic display
Bridge structure control	Daily control			Operation monitoring table
	Check of the soundness of bridge structure	Not required	1A	Magnetic tape
Collection of data for future wind- and earthquake-resistant designs				

- Traffic control:

  Data collected by anemometers and seismometers are transmitted regularly to the administrative office and monitored on a graphic display for restriction of traffic when necessary.

- Bridge structure monitoring:

  This comes under two categories: daily control use requiring real time data and checking of the soundness of bridge structure requiring accurate detailed long-term data.

  Maximum values of data detected at regular intervals by certain measurement instruments for wind, earthquake and vibration are transmitted to the operation monitoring table in the administrative office for daily check. To check the soundness of the bridge structure, for long-term maintenance purposes, the latest data is not required. Accordingly, raw data are recorded on magnetic tapes for later analysis via housed measurement instruments located at point 1A (see Fig. 2).

- Data collected for future wind- and earthquake-resistant designs are also analyzed later.

3. SYSTEM FOR MONITORING THE BRIDGE BEHAVIOR

The configuration of the monitoring system is diagrammed in Fig. 3. Measurement instruments are listed in Table 2. The spatial arrangement of the instruments is shown in Fig. 4.

A propeller anemometer, used mainly for traffic control provides data which are later analyzed for average wind speed, wind speed distribution for heights, maximum instantaneous wind speed, direction of wind, gust, intensity of turbulence and power spectrum of wind.

An ultrasonic anemometer yields data for analysis of factors such as power and cross spectra and spatial correlation of wind, as well as wind speed and direction (including angle of inclination).

The accelerometer was installed to measure responses of the bridge structure to external forces caused by wind, earthquake etc.

The system consists of sensors installed on the bridge structure and other elements, the measurement board and the monitoring instruments installed at 1A, the operation monitoring table installed in the administrative office, and a transmitter for the transmission and reception of data between devices.

Data are sent to the measurement board in the form of current or voltage through the transducer. The measurement instruments process data at all times, receiving, evaluating and storing all values.

Data necessary for monitoring are transmitted from 1A to the administrative office, a distance of approximately four kilometers, via optical fiber for supervision by ASTEC, the Automatic Supervisory Telemeter and Telecontrol System.

The operation, control and supervision of various processing devices can be executed not only via peripheral devices at 1A, but also by transmitting remote operation signals via the optical fiber line from the operation monitoring table in the administrative office.

In the case of earthquakes, the recording and storage of data on magnetic tapes are executed automatically when the scales of earthquakes exceed a certain Richter level, to ensure complete recording of sudden outbreaks. For winds, these operations are executed both automatically and manually. When earthquakes and winds occur simultaneously, the recording of earthquakes is executed preferentially.

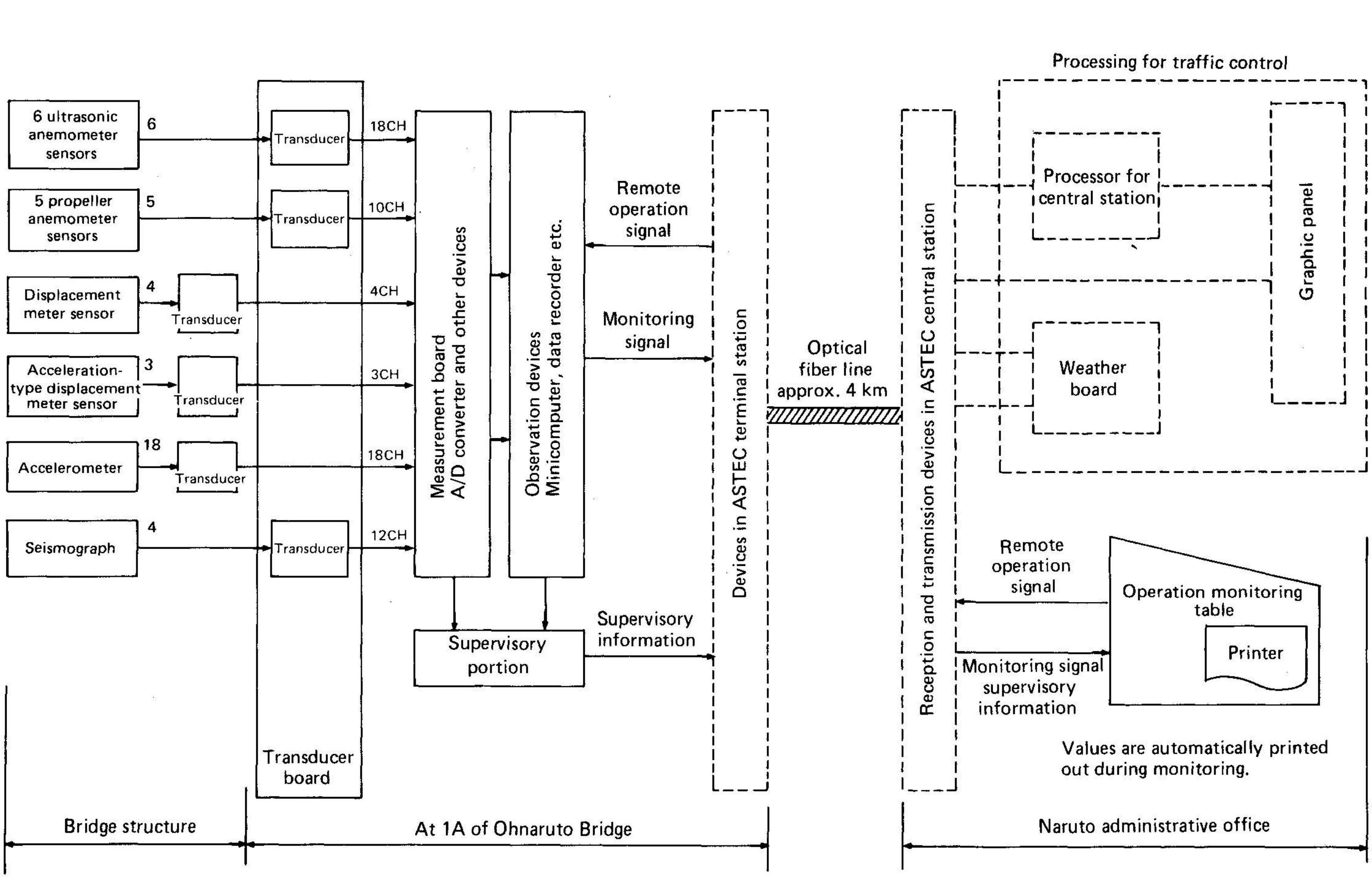


Fig. 3 System Configuration

Table 2 Measuring Instruments

Measuring Instrument					Data Recording	
Instrument	Quantity	Component	Number of Channels	Installation Location (See Fig. 2)	Monitor (Administrative Office)	Magnetic Tape Recording (1A)
Propeller anemometer	6**	Wind speed (horizontal), wind direction	12^{CH}	P_1 P_2 P_3, P_4, P_5, P_6	Graphic display → FDD; Operation monitoring table	—— ; MT (10^{CH})
Ultrasonic anemometer	6	X, Y, Z (→ Main stream direction, angle of inclination)	18^{CH}	S_1, S_2, S_3, S_4, S_5, S_6	——	MT (18^{CH})
Seismograph	4	X, Y, Z	12^{CH}	G_1 G_2 G_3, G_4	Graphic display; Operation monitoring table → P	MT (12^{CH})
Accelerometer	18	T (Transverse to bridge axis)	4^{CH}	3T 6T 4T, 10T	Operation monitoring table → P	For winds MT (2^{CH}); For earthquakes MT (4^{CH})
		L (longitudinal)	7^{CH}	2L, 5L, 6L 8L, 10L, 11L, 12L	Operation monitoring table → P	For winds MT (3^{CH}); For earthquakes MT (7^{CH})
		V (Vertical)	7^{CH}	3V, 4V 8V, 9V, 12V 1V 7V	Operation monitoring table → P; Operation monitoring table → P	For winds MT (7^{CH}); For earthquakes MT (5^{CH})
Acceleration-type displacement meter	3	V (Vertical)	3^{CH}	1V, 3V, 4V	Operation monitoring table → P	——
Displacement meter	4	L (longitudinal)	4^{CH}	SSL, CSL, SNL, CNL	Operation monitoring table → P	——

* FDD: Floppy disc, P: Printer, MT: Magnetic tape
** One of the six units belongs to another system.

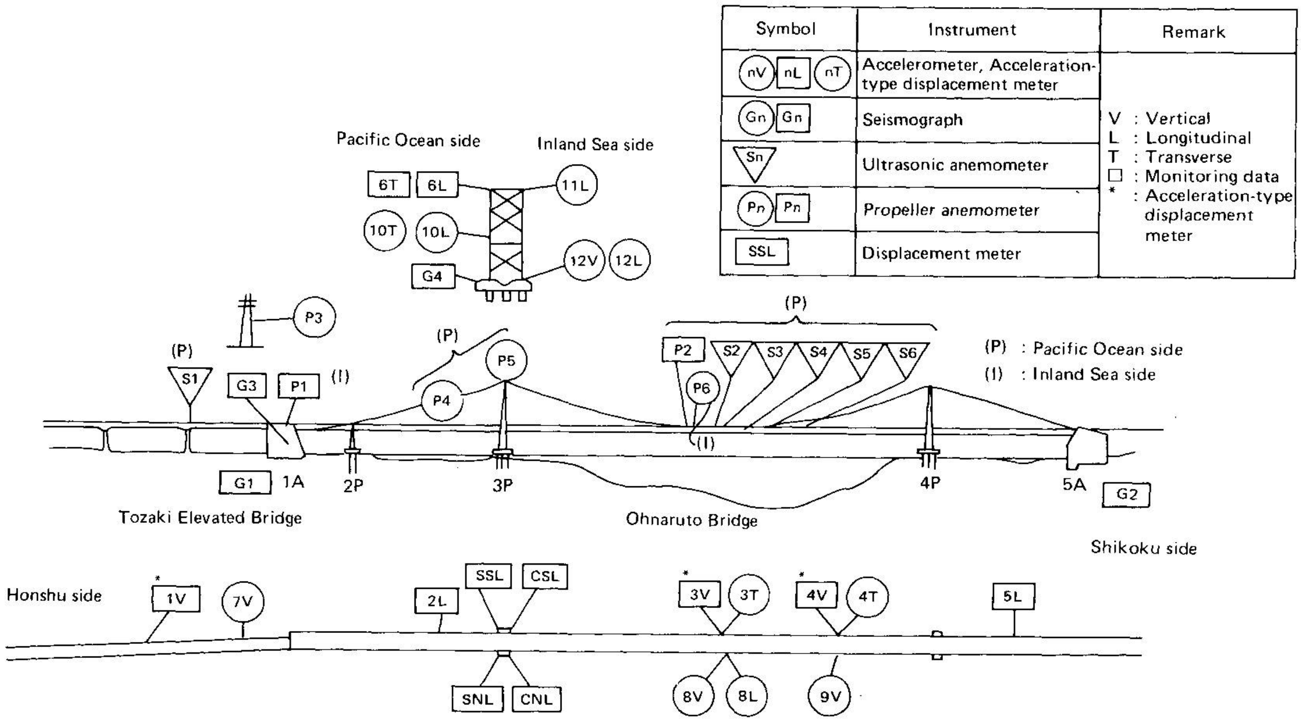


Fig. 4 Arrangement of Measuring Instruments

4. DATA ANALYSIS

Fig. 5 shows raw data collected by the propeller anemometer in the middle of the central span, and Fig. 6 shows an example of the analysis of the data. In Fig. 6, the solid line shows values calculated according to the Hino's Expression below, and the dotted line shows the result of the spectrum analysis. Fig. 7 shows accelerations measured in the direction transverse to the bridge axis, and Fig. 8 shows vibration displacements in the direction transverse to the bridge axis obtained by integrating data in Fig. 7 via FFT (Fast Fourier Transformation) using the band pass filter 0.04 to 2.5 Hz. These data, collected over two years since the opening of the bridge, are insufficient as the measurement period is short and neither strong winds nor large-scale earthquakes have occurred during this period. Accordingly, we will continue to collect data for verification regarding design.

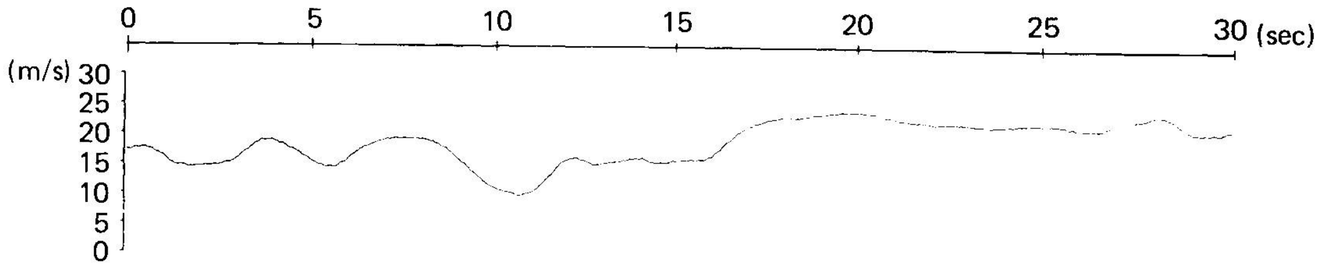
Power spectrum of wind speed (Hino's Expression)

$$Su(f) = 0.476 \times \frac{\overline{u}^2}{\beta} \times \{1 + (\frac{f}{\beta})^2\}^{-5/6}$$

$$\overline{u}^2 = 6.0 \times Kr \times (U_{10})^2$$

$$\beta = 1.169 \times 10^{-3} \times \frac{\alpha U_{10}}{\sqrt{Kr}} \times (\frac{Z}{10})^{2m\alpha - 1}$$

α : Wind speed exponent
Kr: Surface friction coefficient
f : Frequency
Z : Vertical altitude (meters)
m : Correction coefficient at the time of strong wind



Propeller 31 CH (In the middle of the central span, U component, Pacific Ocean side)

Fig. 5 Wind Velocity

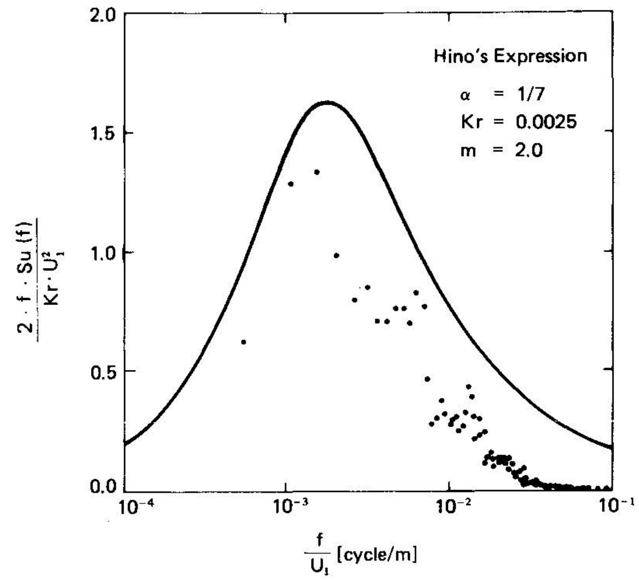


Fig. 6 Power Spectrum of Wind

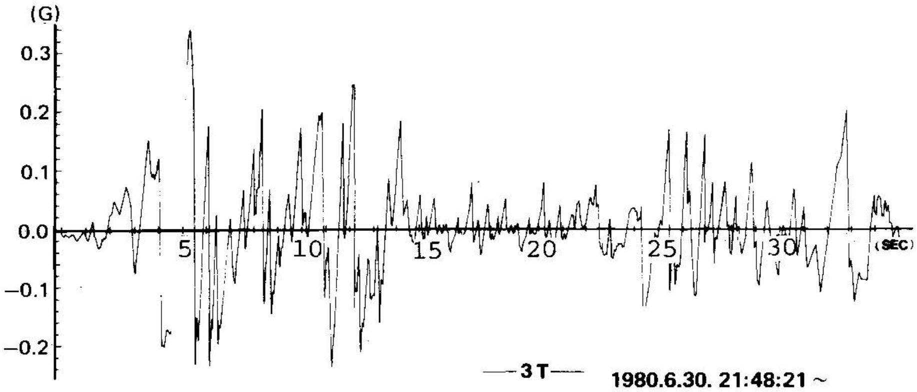
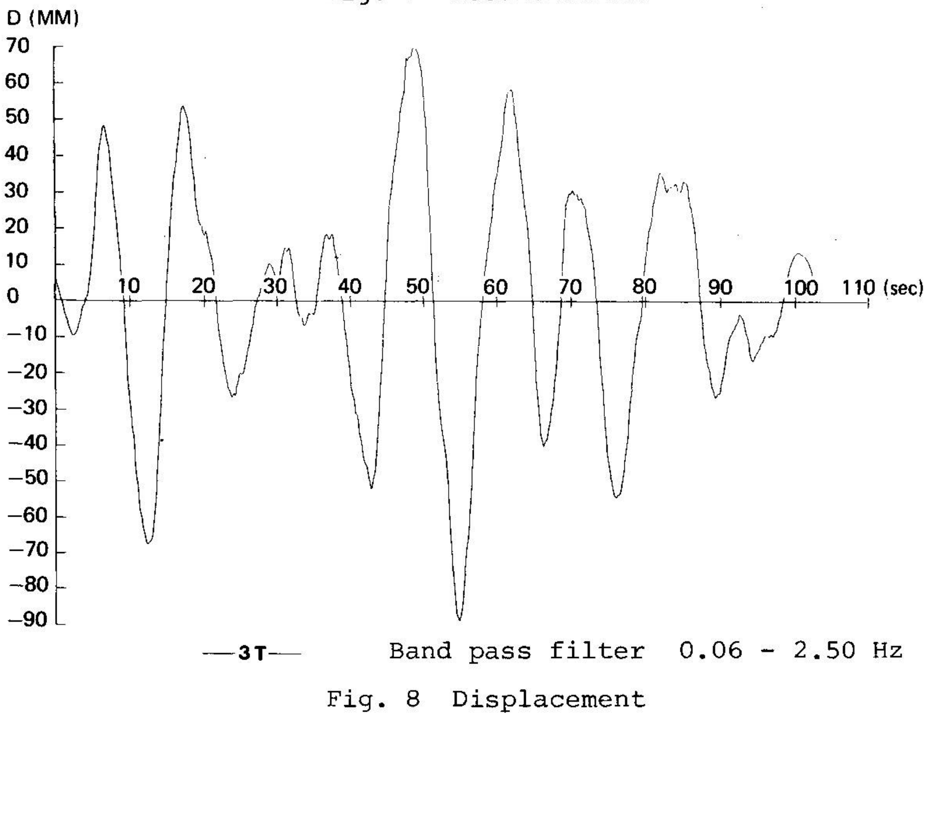


Fig. 7 Acceleration



—3T— Band pass filter 0.06 - 2.50 Hz

Fig. 8 Displacement