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44. *Construction of Ocean Bottom Seismograph.*

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1. Introduction

As the last frontier of our planet Earth, the ocean is expecting the human challenge for revealing its unknown territory. Geophysical observations at sea have been rapidly increased in recent years in accordance with other oceanographic observations. Experimental observations of natural earthquakes at ocean bottom have been reported by J. Ewing and M. Ewing,[1] and W. A. Schneider et al.[2-4]

In the Earthquake Research Institute, Professor Kanai[5] constructed, in 1958, a sea bottom seismograph for civil engineering purposes. Moreover, Professor Kishinouye[6] has constructed several models for sea-bottom observation of natural earthquakes thereby solving many basic technical problems of ocean bottom observation. He has also developed a long-life optical recording system with very low power consumption. Continuing his work, our task is to design and construct an ocean bottom seismograph which will serve for practical use. In order to design the instrument, as is always the case of instrument design, we had to decide the exact purpose of the ocean bottom seismic observation.

There may be many purposes for ocean bottom seismic observations. Some of them are for registration of earthquakes with linked land stations, spatial distribution of natural earthquake occurrence in the ocean, observation of distant earthquakes at the oceanic earth's crust, origin of microseisms, and activity of micro-earthquakes, etc. Among these, we have taken up the last one as the purpose of our instrument. We

1) J. EWING and M. EWING, *J. Geophys. Res.*, **66** (1961), 3863.
2) J. T. THOMSON and W. A. SCHNEIDER, *Proc. IRE,* **50** (1962), 2209.
3) W. A. SCHNEIDER and M. M. BACKUS, *J. Geophys. Res.*, **69** (1964), 1135.
4) W. A. SCHNEIDER, P. J. FARRELL, and R. E. BRANNIAN, *Geophysics,* **29** (1964), 745.
5) K. KANAI and T. TANAKA, *Bull. Earthq. Res. Inst.*, **36** (1958), 359.
6) F. KISHINOUYE, Y. YAMAZAKI, H. KOBAYASHI, and S. KORESAWA, *Bull. Earthq. Res. Inst.*, **41** (1963), 819.

have in mind the idea that such observations of micro-earthquakes at the focal region of a great earthquake at sea will reveal the active zone or structure of micro-earthquakes and give us information about what is happening or being prepared in the focal region of any great earthquake.

In addition to the above purpose of the instrument, we have specified that the instrument should be easily handled by an ordinary small oceanographic research vessel whose gross tonnage is about 250 t.

The ocean bottom seismograph will be composed of two main parts, recording instrument and anchoring system. It is necessary that the ocean bottom seismograph be designed with good balance to the winch and other equipment in the research vessel. The instrument and marine system should be assured smooth and safe operation. Thus the maximum depth and maximum life of observation are selected at 2,000 m and one month respectively.

2. Recording Instrument

Composition

The recording instrument is composed of geophones, amplifiers, batteries, chronometer, and controller (Fig. 1). They are contained in a pressure vessel (Fig. 2), within which automatic recording is made. Main specifications of each part are described as follows.

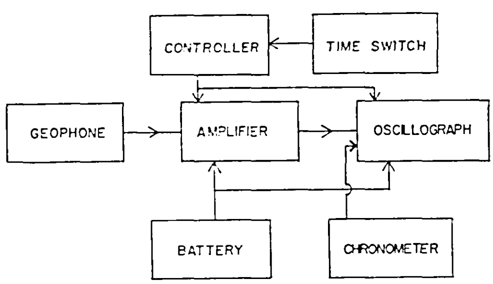

Fig. 1. Block diagram of composition of the ocean bottom seismograph ERIK-IV.

Pressure Vessel

The pressure vessel should be of light weight, small-size, low cost and easy of handling. A commercial steel pipe is used for reducing the expense. Inside diameter of the steel pipe is determined as 24 mm by the dimensions of oscillograph camera. The thickness of the pipe is

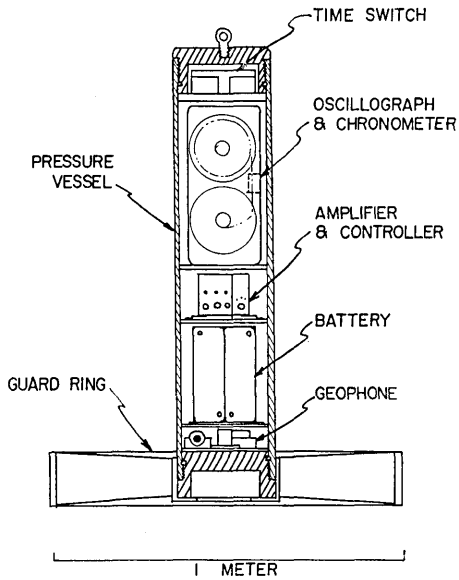

Fig. 2. Outline of the ocean bottom seismograph ERIK-IV.

chosen as 15 mm by taking the safty factor of 1.2 for the limiting pressure of 200 kg/cm^2. The value of the safty factor is selected as small as this so as to reduce the total weight of the instrument.

A guard ring is attached at the base of the pressure vessel so that the instrument stands upright on the sea floor. The water-proofing is achieved by the method of a double O-ring seal as is shown in Fig. 3. This simple and neat mechanism of water-proof proved its effectiveness in field use.

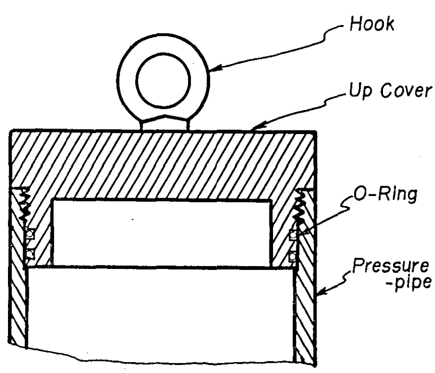

Fig. 3. Sketch of mechanism of water-proofing.

Geophone

In order to save space in the pressure vessel, we had to omit the leveling devices for geophone. We use three HS-1 geophones, one for vertical and two for horizontal components. The natural frequency of these is 4.5 cps. By adding a RC-filter, however, the predominant frequency is shifted to about 2 cps with nearly flat response. The frequency characteristics are shown in Fig. 4. The sensitivity of geophone with filter is about 0.16 volt/kine at 2 cps.

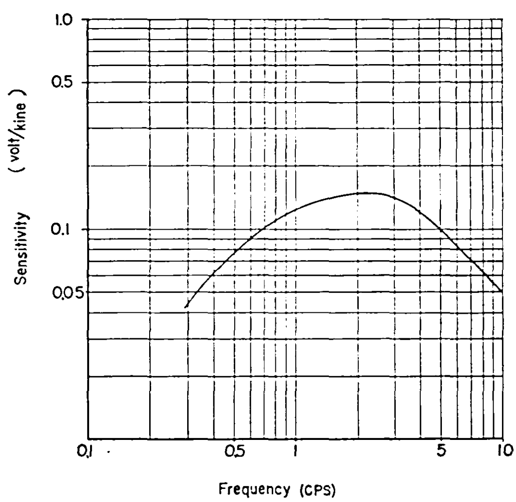

Fig. 4. Geophone response.

Amplifier

The amplifier is composed of compound connection and RC coupling.

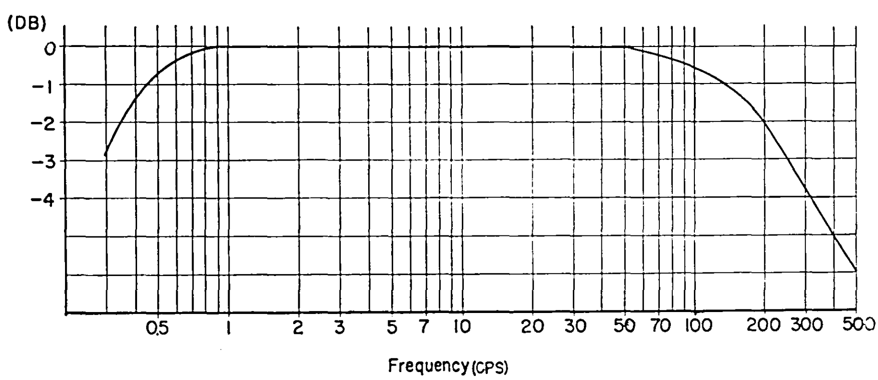

Fig. 5. Amplifier response.

The power voltage is 6 volts. The maximum gain is 80 db. The frequency response is selected as 0.5~150 cps, as is shown in Fig. 5.

Oscillograph camera

The camera is the heart of this kind of recording instrument. The sketch of the camera is presented in Fig. 6. This is of 4 channels with optical 16 mm film recorder, of which techniques have been developed by Professor Kishinouye. The output of the amplifier is led to the galvanometer and is recorded on the 16 mm film. One month recording of seismic signals of three components requires a film 1200 ft long, even though the speed is limited to 7.5 mm/min. In order to put such a long film into the pressure vessel, we divided it into two, namely, we used a double-spool system, each one being 600 ft long. The conventional alignment of galvanometer and film spool is folded back into one to allow it to be put into the cylinder of the pressure vessel. In order to increase the

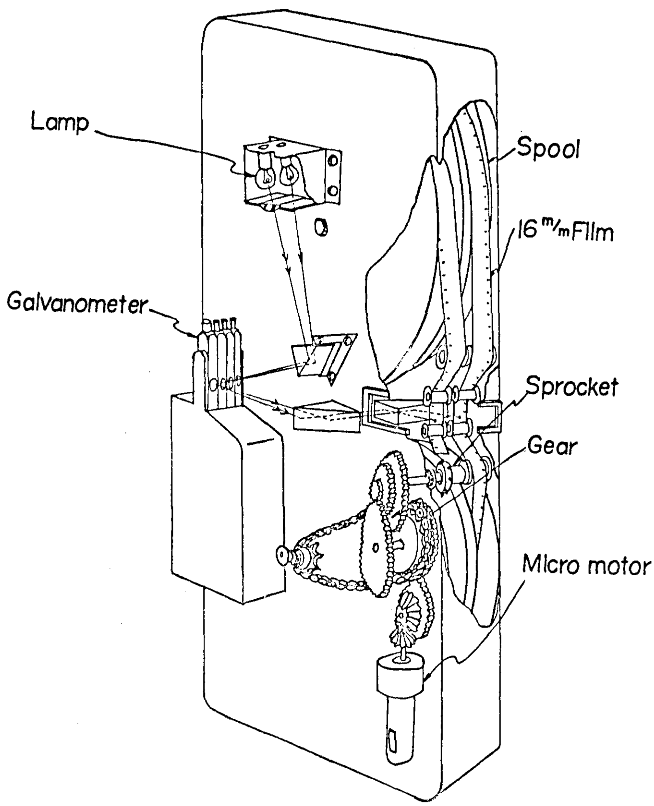

Fig. 6. Simplified sketch of the oscillograph camera.

stability of the galvo image on the 16 mm film, the optical path length is shortened, and low sensitivity of galvanometer is adopted. The lamp of light source is specially made with a very narrow filament and very low power consumption. The width of filament winding is 0.075 mm, and the power required for recording is as low as 6 mA. The two lamps with common mirror system are used instead of a single lamp with double mirror system.

The slow driving of the film is performed by a sprocket which is connected to the governor controlled micromotor through gears. The four speeds are available by changing the connecting gear. The maximum speed is 1 mm/sec and it runs for four days. Then we have speeds of 1/2, 1/4 and 1/8 of the maximum one. The slowest speed gives us one month recording. The four-speed system is favourable for independent use of this camera as a long recorder for other seismic observations.

Battery

As the power source for oscillograph camera and amplifiers, two nickel-cadmium-alkali cells are used. The capacities of these are 23 AH of 6 volts respectively.

Table of main specifications of the ocean bottom seismograph, ERIK-IV

Component	Specifications	Component	Specifications
Pressure vessel	limiting pressure: 200 kg/cm^2 shape: 270ϕ × 1,300 mm guard ring diameter: 1,000 mm total weight: 200 kg	Oscillograph	galvanometer: 4 elements sensitivity of galvo: 20 mm/mA optical length: 20 cm film: 16 mm × 186 M × 2 rolls driving system: micromotor-gear-sprocket driving speed: 4 speeds (gear change device) 60, 30, 15, 7.5 mm/min maximum recording period: one month
Geophone	vertical component: 1 horizontal component: 2 moving coil, velocity type natural frequency: 4.5 c/s sensitivity (with RC filter): 0.16 volt/kine		
Amplifier	channel: 3 max. amplification 80 db frequency response: 0.5～150 c/s	Battery	nickel-cadmium-alkali cells capacity: 6v, 23 AH × 2

3. Rope-buoy system

Among many techniques for setting, anchoring, and recovering the ocean bottom seismograph, we have selected the anchored buoy system. The ocean bottom seismograph is lowered by the rope system to the sea floor, and is held by the anchored-buoy. We leave the ocean bottom

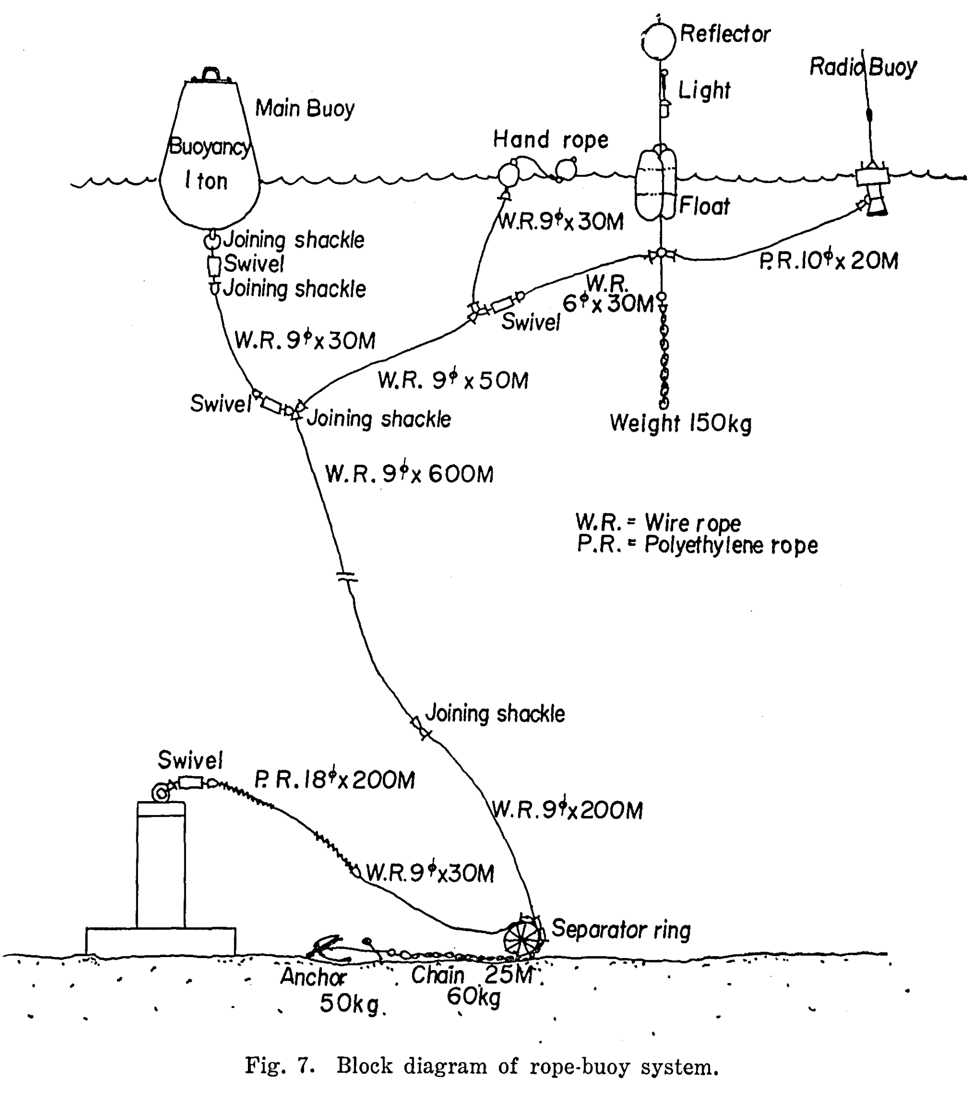

Fig. 7. Block diagram of rope-buoy system.

seismograph in the ocean for a certain period, from several days to one month. The instrument then performs automatic recording of natural earthquakes by itself. This is a kind of so-called robot seismograph. When the time comes, the boat is guided to the buoy station by radio-buoy and corner-reflector. The instrument is then recovered by winding up the rope-system.

The sketch of rope-buoy system is illustrated in Fig. 7. The ocean bottom seismograph is made a soft landing on the sea floor. The rope is once anchored to the bottom a little away from the instrument, then connected to the surface buoy. The rope system is made up of wire rope of 9 mm in diameter, and polyethylene rope of 18 mm in diameter. Wire rope near the surface is used so as to reduce the load due to tidal current. The use of polyethylene rope is to reduce the weight of the rope system in the case of deep sea operation.

We use three buoys, main buoy, light buoy, and radio-buoy. The main buoy maintains the whole load of the system. The light buoy is equipped with intermittent flash-light and corner-reflector for radar. These are to prevent any trouble from other sailing boats. The radio-buoy is for recovery purposes. The construction of such a kind of rope system should be so designed as to conform to the capability of the observation boat and its winch.

4. Field test

The field tests of the recording instrument and rope-buoy system were performed in the summer of 1965 by using the research vessel M/S TANSEI-MARU of the Ocean Research Institute of Tokyo University.

At first, the pressure test of pressure vessel and landing shock test for oscillograph camera were performed at Sagami Bay and Suruga Bay. The pressure tests were done in three steps, the pressure vessel being lowered in the ocean to depths of 500 m, 1,000 m, and 2,000 m, and kept two hours at each depth. The test results were perfect. As for the landing shock test, both galvanometer deflection and driving mechanism proved their stability.

The tests of setting, anchoring, and recovering of the ocean bottom seismograph were performed in the middle part between Manazuru-saki and Hatsu-shima, whose sea depth is about 500 m. The rope-buoy system operated very well, taking about two hours for setting, and for recovering of the whole system.

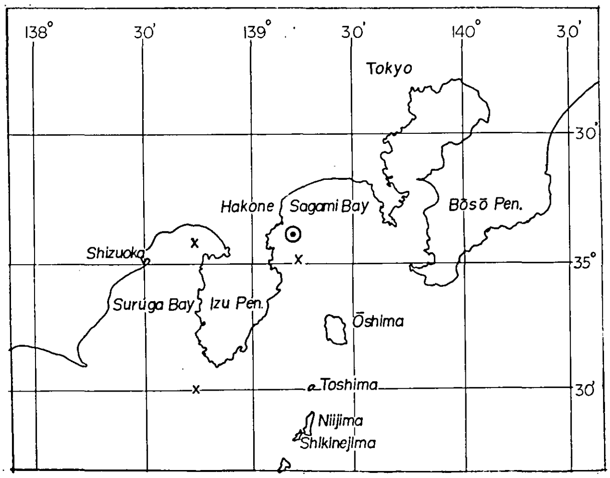

Fig. 8. Locations of field test.
⊙: Observation test. ×: Pressure test.

During these tests, seismic records were obtained for a total of 18 hours. The total number of earthquakes, including very near micro-earthquakes and distant earthquakes, is about 40. Several records of these are presented in Fig. 9.

5. Summary and Conclusions

A practical ocean bottom seismograph is designed, constructed and tested for micro-earthquake observation on the ocean floor.

The system of observation is to settle the ocean bottom seismograph on the ocean floor and to keep it there by anchored-buoy. The recording of natural earthquakes is made automatically and completely within a pressure vessel. After a certain period of observation, for 4 days to one month, the instrument is recovered.

During the field test of the system many micro-earthquakes have been recorded. These records promise that this kind of instrument is adequate for attacking the activities of micro-earthquakes under the ocean bottom.

Acknowledgment

The writers wish to express their hearty thanks to Professor F. Kishinouye for leading them into this work with encouragement and suggestions. They also express thanks to Professors H. Kawasumi and

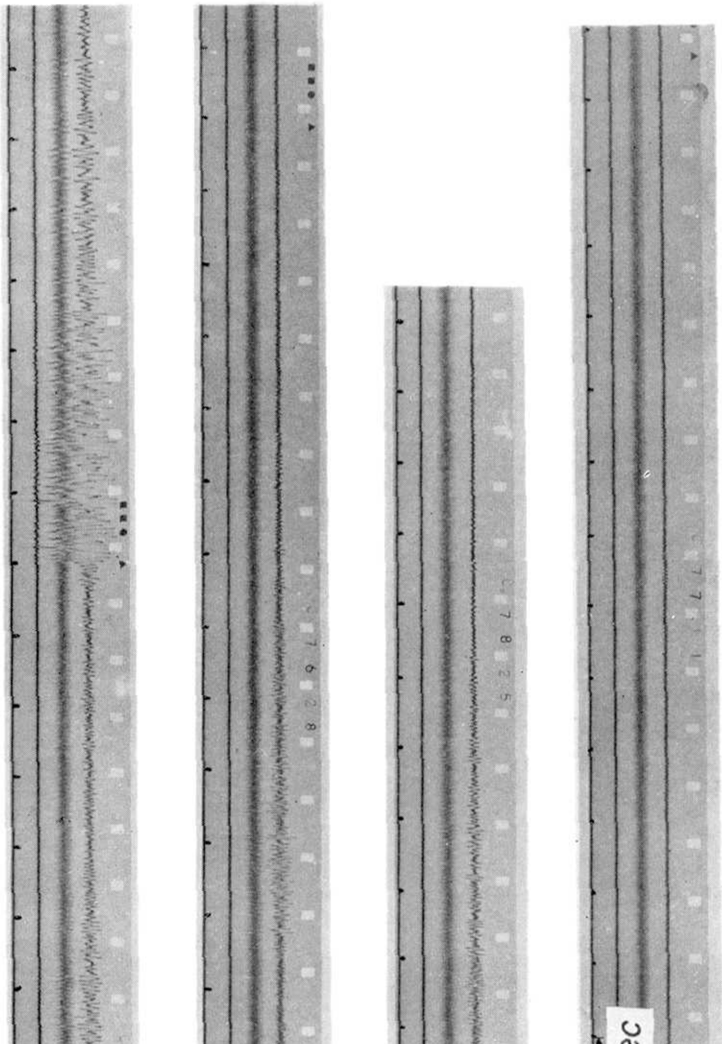

Fig. 9. (a) Examples of ocean bottom earthquake record, obtained at the Sagami Bay. Distant earthquakes and micro-tremor.

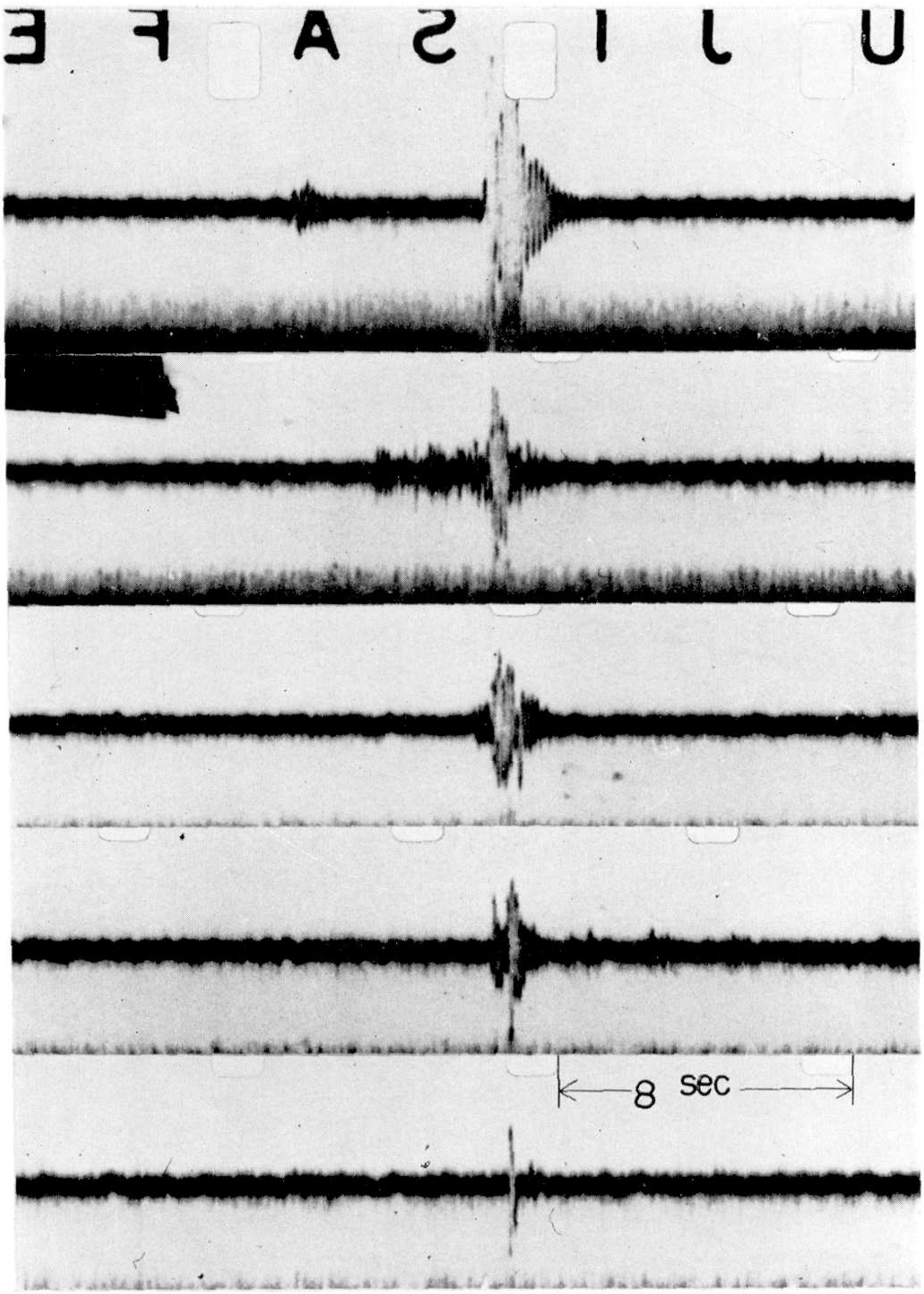

Fig. 9 (b) Examples of ocean bottom earthquake record, obtained at the Sagami Bay. Micro-earthquakes.

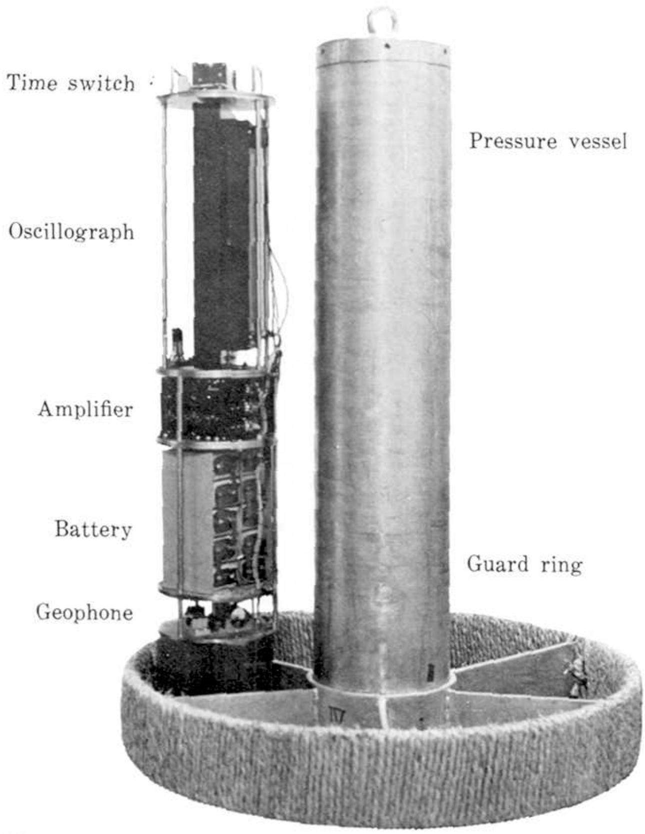

Fig. 10. *Pressure vessel and recording instruments mounted on the platforms.*

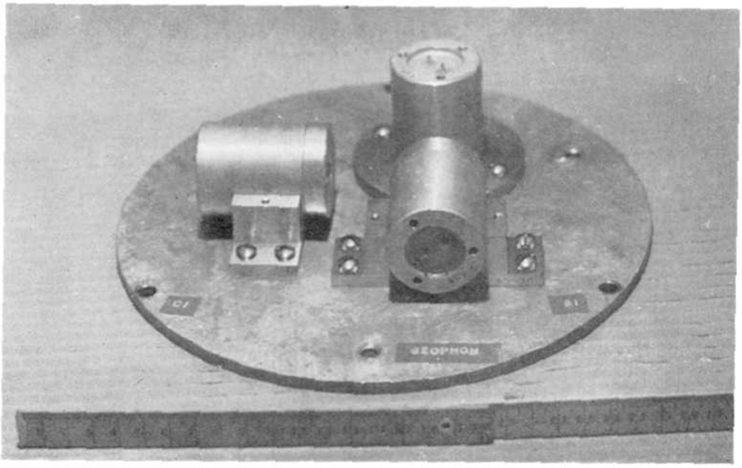

Fig. 11. Three component geophones.

T. Hagiwara for their encouragement throughout this work. Thanks are also extended to Captain M. Sato of M/S MEIYO of Maritime Safety Agency for the design of rope-buoy system, Captain I. Tadama and the crew of M/S TANSEI-MARU of the Ocean Research Institute of Tokyo University for their cooperation in the field test, the third Regional Maritime Safety Headquarters for the use of main buoy, Mr. K. Miyoshi and Mr. K. Kamei for making the oscillograph camera, Mr. T. Takeyama for making pressure vessel, Mr. K. Takei for arranging the necessary materials of marine system, and members of the machine shop of this institute for making materials for urgent use.

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44. 海底地震計の製作

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実用的な海底地震計の設計，試作および海における実地試験を行なつた．

海底用地震計は当地震研究所において，すでに金井教授，岸上教授によつて試作されて来ている．今回試作したものは，岸上教授の開発された方式を根幹として，実用的に取りまとめたものである．計器の使用目的は海底における微小地震観測ということにおいた．また計器の規模としては海洋研究所淡青丸（約250 t）程度の研究船で完全に円滑に取扱えることとした．

観測方式としては海底地震計をワイヤロープ，ポリエチレンロープにて，海底に降下，設置し，それをアンカードブイに繋留し，一定の記録期間の後，揚収する方式を採用した．記録計器は耐圧容器内にすべて収納され，自動記録を行う．機械の主な性能は表に示しておいた．耐圧容器の設計深度は 2,000 m である．記録計は光学方式で全長 1,200 フィートの 16 mm フィルムに 4 成分を記録する．自動記録期間は，フィルムの送り速度 1 mm/sec にて 4 日間，その 1/8 の速度で約 1 カ月である．受振器には物探用の固有周波数 4.5 c/s の速度型上下動，および水平動地震計を使用し，RC フィルターで卓越周波数を 2 c/s にもつてきた．

相模湾における耐水圧試験およびロープブイシステムの敷設揚収試験の結果は良好であり，試験期間中，合計 18 時間にて，遠近大小とりまぜて約 40 コの地震記録が得られた．これらの記録は，この種の海底地震計および観測方式が，大地震発生域における微小地震観測に対して適切であることを意味するものと思われる．
