Bulletin of the Earthquake
Research Institute
Vol. 45 (1967), pp. 739-748

39. *An Automatic On-line Data Processor for Micro-earthquake Field Observations.*

By Hideteru Matumoto,

Earthquake Research Institute.

(Read September 27, 1966.—Received June 30, 1967.)

Abstract

Automatic data processing in seismology has been developed using both digital[1),2),3)] and analogue techniques,[4),5)] in order to standardize seismic identification as well as to decrease the burden of station seismologists in the interpretation work against the increasing amount of earthquakes recorded at sensitive modern stations. Both analogue and digital methods have their own merits in theory and practice. For the real time processing of abundant flow-in of continuous multichannel data, analogue techniques seem to be more handy and economical than the digital ones.

In this paper, the author describes one of the most useful logical circuits to process and print out seismic information automatically by making use of the semi-analogue technique and shows details of the instrument constructed, together with results of its actual operation in field observation.

1. Introduction

The interpretation of the arrival of earthquake waves and artificial vibrations has been carried out by experienced seismogram interpreters who use characteristic features in amplitude and period existing in natural and artificial seismic waves. However, in direct electronical processing,

1) K. Aki, "An Automatic Interpretation of the Initial *P*-Wave by Making Use of the Digital Computer." Read at the 443rd Monthly Meeting of the ERI, June 28, 1966.

2) P. L. Fleck, "FASTABUL (A Fast Automatic Station Bulletin Program)." *Technical Note*, 1967-3 Lincoln Laboratory.

3) H. W. Brisco and P. L. Fleck, "A Real Time Computing System for LASA." Read at Spring Joint Computer Confabulation, Boston, April 1966.

4) M. Tsujiura, "Frequency Analysis of Seismic Waves (1)," *Bull. Earthq. Res. Inst.*, **40** (1966), 873-891.

5) C. A. Wagner, "Automatic Event Detector and Location." *Semiannual Technical Summary Seismic Discrimination*, Lincoln Laboratory, 30 June, 1965.

it is difficult to discriminate earthquakes with certainty from all kinds of ground noises by only the variation in the amplitude and period of the vibrations obtained by a single seismometer, and it becomes necessary to add more relevant seismic information for automatic interpretation.

For this purpose, the present author adopted the tripartite seismometer array, and employed the time difference and amplitude similarity of each seismometer out-put, in order to select the wave which propagates across the array. The accuracy and capability of the seismometer array method have been discussed and verified,[6),7),8),9),10),11),12)] all the logical switching circuits being constructed to cope with the time accuracy required to determine the azimuth and the velocity of propagating wave by making use of the array method with the greatest degree of accuracy. Accordingly, in this construction all logical judgment is done with a switching speed of less than one milisecond, but the printing is executed only once a second with an accuracy of the nearest second owing to the limitation of the printer used. This printer is manufactured by OKI Electric Industry Co., Ltd. as a monitor time recorder of accidents in the routine electric plant operation.

On-off contacts are required for the operation of the printer, mechanical relays being employed in the processor out-puts to meet the requirements.

The seismic data which are required to be processed and printed-out by the newly constructed instrument are as follows:

1. The latest arrival time of *P* wave of all three arrival times at the tripartite stations.

2. Approximate azimuth to the seismic source from the station in six directions determined by the order of arrival times at the tripartite

---

6) S. MIYAMURA and M. TSUJIURA, "Direction of Approach and Apparent Velocity of Near Earthquake Initial Motion," *Bull. Earthq. Res. Inst.*, **37** (1959), 359-374.

7) K. AKI, "Study of Earthquake Waves by a Seismometer Array," *Bull. Earthq. Res. Inst.*, **40** (1962), 371-389.

8) K. AKI and H. MATUMOTO, "Study of Earthquake Waves by Means of a Seismometer Array," *Bull. Earthq. Res. Inst.*, **41** (1963), 279-292.

9) M. OHTAKE, "A Distorted Distribution of Apparent Velocities Observed With Ultra-Sensitive Tripartite Network," *Zisin* (II). **18** (1965), 15-24.

10) T. MIKUMO. "Determination of *P* Wave Velocity and Direction of Wave Approach from Station Arrays," *Bulletin of the Disaster Prevention Research Institute*, [1], **15** (1965)

11) M. HASHIZUME. "On the Accuracy of Tripartite Method." *Bulletin of the Disaster Prevention Research Institute*, [1] **15** (1965), 7-29.

12) M. HORI and H. MATUMOTO. "Observation of Ultra-Microearthquakes by Means of Multiple Seismometer Array Method in the Vicinity of Wakayama. Central Japan." *Zisin* [II]. **20** (1967), 41-49.

stations.

3. Arrival time of S wave determined as the arrival of the wave with an amplitude of vibration two or three times larger than the average amplitude of the waves following the P phase.

4. Arrival time of the wave which reaches initially the five preset amplitude grades after the interpretation of P wave as an indication of maximum amplitude.

5. The time of completion of the seismic signal as an identification of signal duration.

After all the above data have been printed out, one blank line of recording paper is fed into the record to separate this data from those of the next earthquake.

2. Logical Construction

The present seismological conditions introduced for the identification of seismic information in the electronic semi-analogue technique are:

1. P wave arrives at all three seismometers with similar amplitudes within a certain time interval which is given by the wave velocity and the distances between the seismometer sites.

2. The amplitudes of S wave are certainly greater than the mean amplitude of wave train which follows after the initial P wave group.

3. After the S wave the vibration of ground either decreases gradually or first increases and then decreases, finally disappearing below a certain level.

In order to express the seismological conditions described above, the author constructed the instrument as shown in Figs. 1 and 2.

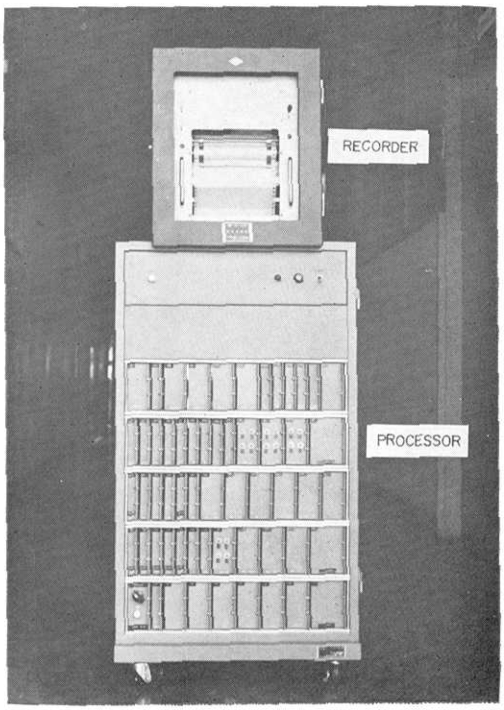

Fig. 1. Appearance of the instrument and the recorder. The height of the processor is 90 cm.

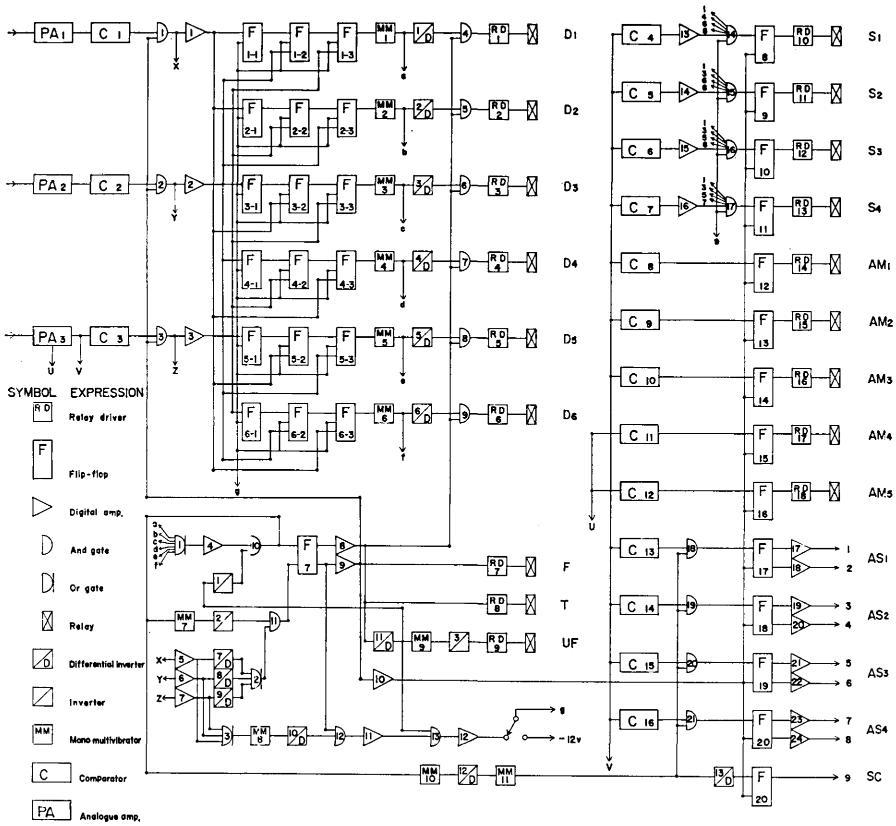

Fig. 2. Circuit diagram of the instrument.

This instrument executes the processing work according to the following electronic logics.

1. Determination of arrival time and azimuth of P wave.

Three amplitude comparator circuits C_1, C_2, C_3 in Fig. 2 are prepared and they are set so as to detect the arrival of wave with amplitude two or three times larger than the preset mean level of ground noise at the sismometer sites, and six flip-flop circuit trains $F_{1\text{-}1}$-$F_{1\text{-}2}$-$F_{1\text{-}3}$~$F_{6\text{-}1}$-$F_{6\text{-}2}$-$F_{6\text{-}3}$ as shown in Fig. 2 (D circuitry), verify the propagation velocity of the wave and make azimuth signals for the recorder utilizing the arrival order and time differences of the signals when the signals from the amplitude comparator circuits C_1~C_3 are offered. Moreover, when all three circuits C_1, C_2 and C_3 fail to offer the signal to the flip-flop trains within a preset time, all flip-flop circuits are cleared with registrations of signal arrival and put back to the initial waiting condition of the trains soon after the preset time is over, in order to reject the processing of low velocity waves or the registration of artificial ground noise causing the mis-operation of azimuthal determination.

2. Determination of arrival time of S wave

In the interval from one second to one and half second after azimuth determination of P, the wave amplitude is sampled and classified by the amplitude comparators $C_{13}\sim C_{16}$ and four flip-flop circuits $F_{17}\sim F_{20}$ in Fig. 2 (AS circuitry) registered the information of the amplitude in 4 grades. On the other hand, four amplitude comparators $C_4\sim C_7$ in Fig. 2 (S circuitry) make signals indicating absolute amplitude grade for the waves following after the sampled waves, the signal being compared with the registered information in $F_{17}\sim F_{20}$ for the detection of the arrival of S wave.

3. Classification of wave amplitude.

Five amplitude comparator circuits $C_8\sim C_{12}$ shown in Fig. 2 (AM circuitry) are prepared for the determination of the absolute wave amplitude, the processing being executed after the azimuth of the P wave has been determined. Accordingly, the stamps of the amplitude grade are printed for all seismic waves except the initial motion which was used to determine the azimuth of the earthquake, even when the wave amplitude reaches initially to a certain amplitude grade.

4. Time of completion of seismic waves

The author adopts the circuit construction of amplitude comparators $C_1\sim C_3$ so as to detect the wave with amplitude of three times larger than the mean level of the ground noise in order to detect the P wave arrival with the set-up characteristic of the circuit, and also to detect the wave amplitude smaller than the level of two times greater than the ground noise for the interpretation of the termination of seismic signals by the set-off characteristic of the circuit. Accordingly, when vibration of ground decreases below the level of two times greater than the ground noise level at any seismometer site, one of the amplitude comparators $C_1\sim C_3$ makes a completion out-put of seismic wave for the F circuitry in Fig. 2.

5. Separation of earthquakes.

The completion signal also excites the circuitry UF as shown in Fig. 2, and two seconds after all seismological processing and printing have been carried out one blank line of the recording paper is fed in order to separate the stamps of each earthquakes.

6. Detail of the recorder.

a) Number of print types for the indication of in-put signals are sixteen or twenty-four in the standard construction. (We use the recorder with sixteen events printer.)

b) The time marking print-type is driven by a synchronous motor, the fundamental accuracy of the time being affected by the frequency stability of the oscillator which supplies the power to the motor.

c) The phenomena are represented by one of sixteen (or twenty-four) stamps or print-types of the alphabetic or numeric characters which are printed at the exact second after the phenomena, simultaneously with the time marking stamp indicating the corresponding date and time.

Result and Discussion

The instrument was operated in parallel with the conventional analogue recorders[13] from 1st July 1966 to 30th July 1966, at Nakano near Matsushiro[14], in order to verify the capability and reliability of the instrument. The instrument worked only temporarily during the observation period, owing to mechanical troubles of the recorder, e.g. breakdown of the relay caused by too frequent earthquake occurrence.

Nevertheless, we could examine the logical construction of the instrument by more than ten thousand earthquakes, and verified the capability of it. Samples of the practical operation records are shown in Fig. 3.

The first block of stamp lines inscribed with No. 1 in the printed-out record in Fig. 3 are stamps of recorder, in which all sixteen types for the phenomena are printed. Blocks of Nos. 2, 3, 4, 5, 9 and 11 are samples of correctly processed data, and No. 6 shows the sample of determination of false P wave. No. 7 is the mis-determination of azimuth, Nos. 8 and 10 show the samples of determination of false S wave, all numbers of the record corresponding to the numbers inscribed in the graphic record.

Fig. 4 shows the detailed comparison of the record of this processor with the corresponding graphic record. Time correspondence of the phenomena between the processed stamps and the visible trace has been

13) H. MATUMOTO, "A Mobile Ultra-Sensitive Seismograph Array System by Means of Magnetic Tape Recorder," *Bull. Earthq. Res. Inst.*, **43** (1965), 441-449.

14) M. HORI, "Matsushiro Earthquake Swarm and Its Peripheral Seismicity," *Bull. Earthq. Res. Inst.*, **45** (1967), 489-503.

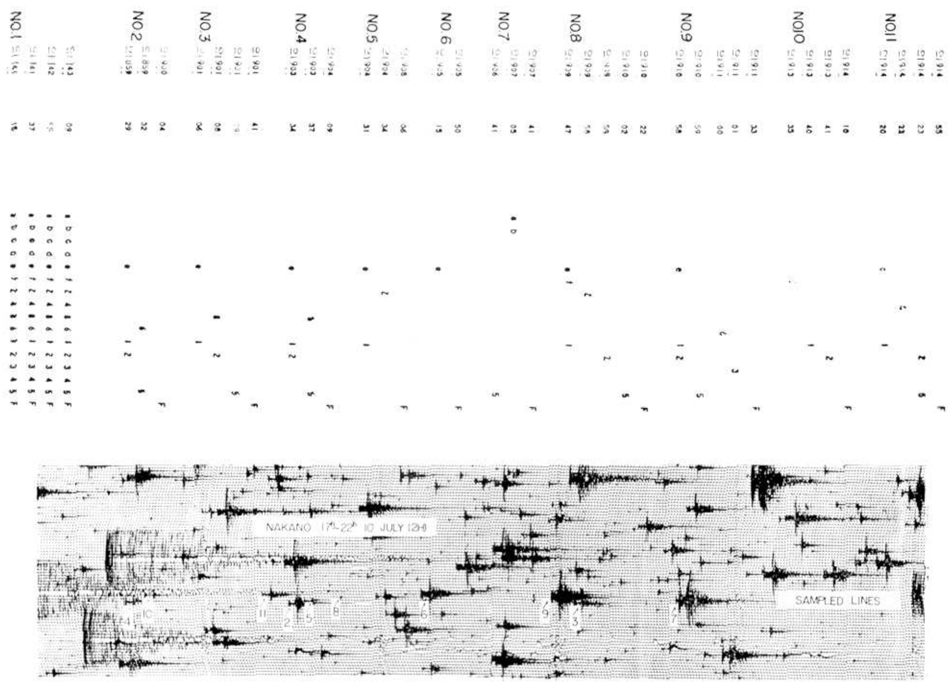

Fig. 3. A sample of the record compared outwardly with the analogue record. No. 1~11 are manually inscribed to show the point-out for each event.

verified by the comparison. One of the daily results of the comparison is shown in Fig. 5. The mis-operations which are verified by the comparison of two kinds of records seem to be induced by either a trivial logical deficiency of the instrument or special conditions in the Nakano station.

The most numerous mis-operation, shown in Fig. 5, are concerned in identification of false *P* waves. Such will be removed by the addition of certain logical circuits which monitor the ground vibration state before the arrival of the *P* wave and make certain the identification of *P* wave by the discrimination of either initial wave or the later phase of the seismic wave trains.

The second mis-operation is the determination of false *S* wave. This will also be removed by the above logical addition which corrects the identification of *P* wave.

The third mis-operation is the omission of *S* phase. Such are induced by crude fault in the design of the logical construction which will be easily remedied by the addition of one more amplitude comparator of 6 and-gate which works parallel with and-gate 14~17 in Fig. 2 (*S* circuitry)

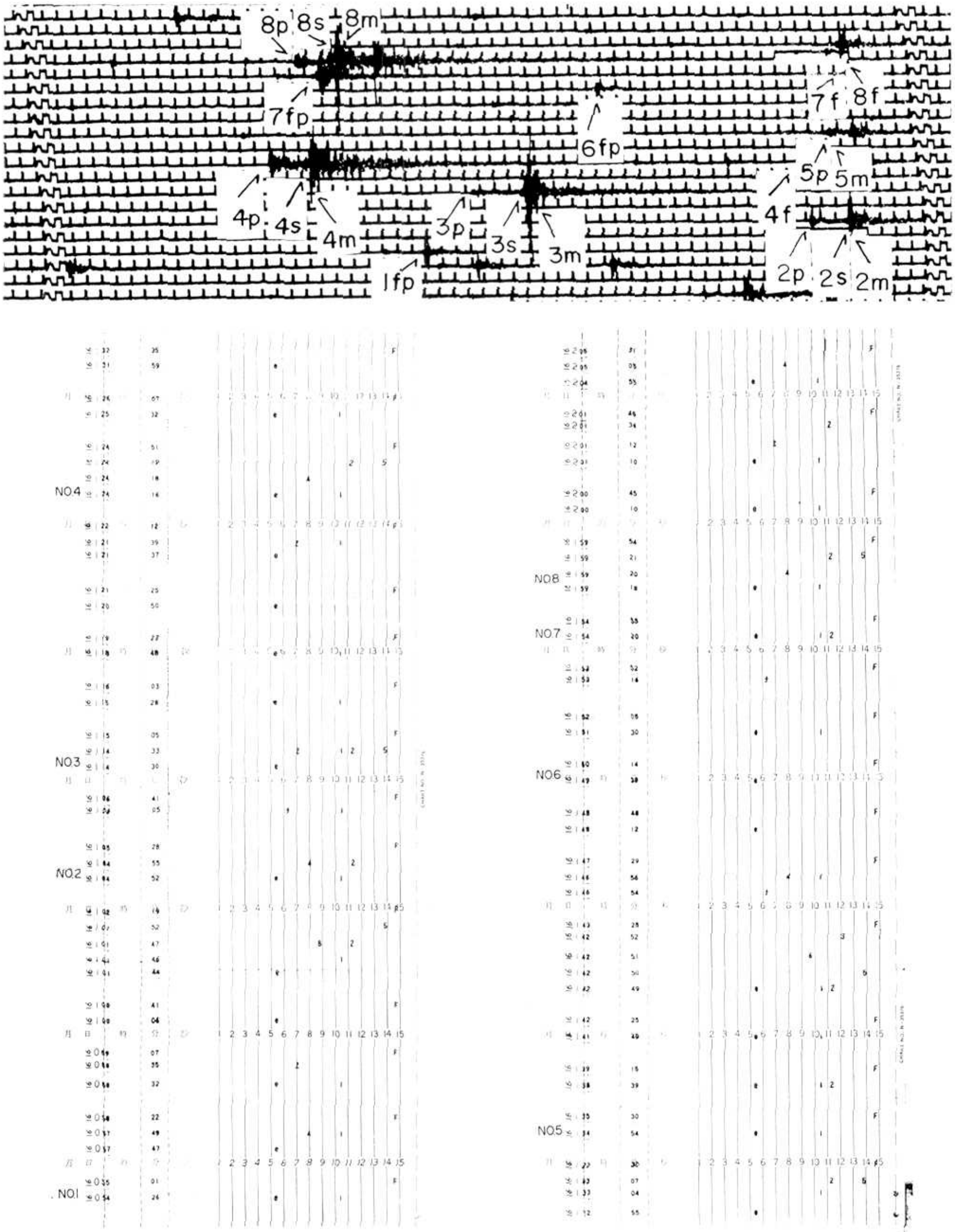

Fig. 4. A sample of the record compared minutely with the analogue record. The numeric characters (1~8) in the analogue record show the earthquake numbers that correspond to the numbers in the process record (No. 1~8). *p*, *s*, *m* and f_p in the analogue record show the seismic interpretation point of the processor for *P* wave, *S* wave, maximum amplitude wave and the false *P* wave.

and the printer channel.

The last of the mis-operations is mis-determination of the azimuth. This is induced by the disturbance by artificial ground vibrations or the remaining vibration of the previous earthquake existing before the arrival of the processed earthquake at one or two seismometer sites. Such cannot be removed by the logical construction without decreasing the accuracy of completion time, but can be decreased without sacrificing the capability of the method by the selection of the seismometer site or the increasing of the number of array seismometers.

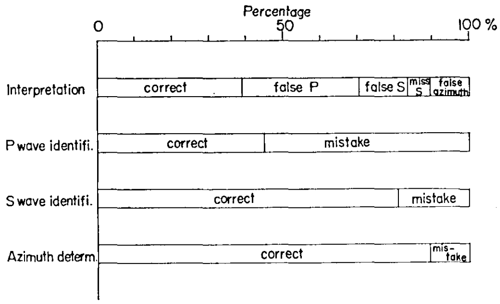

Fig. 5. One of the classification results of the daily process record compared with the corresponding analogue record.

3. Conclusion

The automatic analysis and precessing of the seismic data must be developed step by step in parallel, in both the analogue and digital computing system utilizing their own combined merits.

Actually the operational result of the present instrument was not very satisfactory, but the fundamental procedure of the semi-analogue data processing has been discovered by this experience. A more certain logical construction should be incorporated in future which will increase the reliability and capability of the processor.

Acknowledgment

The development of the present instrument was planned and promoted by Prof. S. Miyamura, to whom the author wishes to express his hearty thanks. The author also thanks Mr. N. Onuma of OKI Electric Indusrty Co., Ltd. the manufacturer of the instrument. The contribution of Mr. M. Hori and Mr. K. Kanjo in the field operation at Nakano station is also greatly appreciated.

39. 微小地震野外常時観測のための直接情報処理装置

地震研究所　松　本　英　照

地震予知計画の一環として微小地震の常時観測がとりあげられ，微小地震の観測態勢は全国的に整備されてきたが，各観測所では多量に蓄積される記録の処理におおくの人力と費用を消費され観測所の運営に問題が生じつつあるようである．また1965年来の松代地震の観測においては，確認しうるすべての地震に対して，人力による情報解析処理をおこなうことは不可能にちかく，早急な地震情報自動処理装置の開発がのぞまれた．

筆者はこの早急な要求に対応すべく装置を構成し，1966年7月長野県中野市における松代周辺の松代地震に関連した地震活動調査に際し，従来のアナログ観測装置と併用して観測をおこない地震情報解析を人力，自動の二方法によつておこなつてみた．

自動処理装置の記録器に使用してあるリレーが1日1000をこえる地震とその何倍かの印刷情報数のために再三故障をおこし，長期連続観測にたいする処理の信頼度をたしかめることはできなかつたがこの観測結果により，この装置が微小地震常時観測にたいし即時の情報自動処理を有効におこないうることをたしかめえた．

この装置は地震の人工的土地雑音にたいする判別と到来方位決定のために地震計配列法による地震計出力を使用し，種々の判別はアナログ量を直接電気論理回路で処理する方式を採用した．

この装置が処理する地震情報は次の5点である．

1. 初動到達時刻．
2. 初動到達方位．
3. S波到達時刻．
4. 最大振幅．
5. 地震動終止時刻．

これらの情報は現象表示の活字により現象判別直後の正秒に秒単位の刻時と並列に印刷される．

初動到来方位は配列された点の地震計への地震波到来順位から判別しうる6分方位 (a～f) が装置により判別され最終到着点の初動到達時刻とともに印刷される．S波到来時刻は，初動到達後1秒より1.5秒までの0.5秒間の平均振幅を4段階 (2, 4, 8, 16) にわけて記憶し，その記憶振幅の3倍の波が到達した時刻とし，比較基準となつた平均振幅の段階をあらわす数字 (2, 4, 8, 6) を印刷する．最大動振幅については土地雑音を基準としてその40倍から10000倍までを5段階に区別して判別し1～5の印刷をおこなう．終止時刻にはFを印刷する．

上記の印刷情報を併用したアナログ記録の人力処理情報と比較し処理装置の信頼性をしらべた結果は第5図のようで十分満足のできるものではなかつたが，装置規模を拡大することにより誤処理をとりのぞく方法，およびこの装置では処理をおこなわなかつた振動の周期や初動のおしひき等の必要な処理事項までをふくめた微小地震観測所における直接処理の可能性がこの装置の実験的使用により確認された．よつてここに構成した装置とその論理組立の方法について報告した．