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2. *Determination of Earthquake Magnitude from Total Duration of Oscillation.*

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1. Introduction

A method for the simple estimation of the magnitude M of local and near earthquakes from the total duration of oscillation $F—P$ has been investigated for the observation network of the Wakayama Micro-earthquake Observatory.

The final formula is applicable to the earthquakes of which epicentral distances are smaller than 1000 km and focal depths not deeper than 60 km with some merits compared with the ordinary method using the maximum amplitudes.

2. Data

The data used in this paper are:

i) The observational result of the Wakayama Micro-earthquake Observatory, Earthquake Research Institute, for 1965[1], and

ii) The determinations of earthquake origin by the Japan Meteorological Agency (J. M. A.) for the major earthquakes in 1965[2], in which the magnitudes were determined by using Tsuboi's formula[3],

$$M=\log (A_N^2+A_E^2)^{1/2}+1.73 \log \Delta-0.83, \tag{1}$$

where A_N, A_E are maximum ground amplitudes of N- and E-components (μ), Δ is epicentral distance (km).

The observation network of the Wakayama Micro-earthquake Observatory consists of twelve substations distributed in Kii Peninsula, southwestern Honshu as shown in Fig. 1 and all the stations except Kinomoto (a radio telemetering station) are equipped with the short period vertical seismographs of the same characteristics, i.e.

$$T_1=1.0 \text{ sec}, \qquad T_2=0.025 \text{ sec},$$

velocity sensibility=40∼120 μ kine/mm at 1 to 10 c/s, ink writing on a drum recorder with paper speed of 4 mm/sec with second, minute and hour marks from the crystal clock as well as hour marks from NHK radio broadcasting.

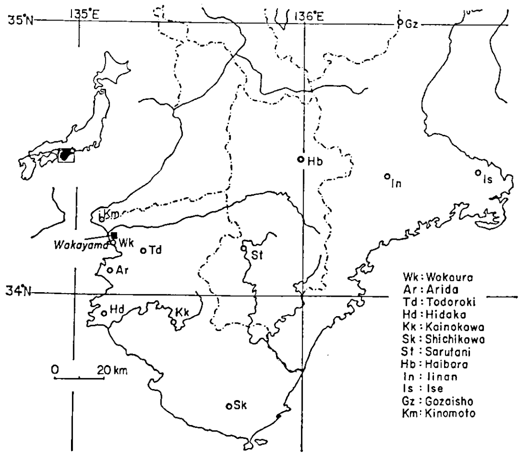

Fig. 1. Location map of the seismograph stations of the Wakayama Micro-earthquake Observatory.

3. Personal errors in reading F—P

Fig. 2 shows examples of the independent readings of F—P for ten local earthquakes by various interpreters engaged in the routine work in the Observatory. The magnitude scale given in the figure is the equivalent one to F—P assuming Eq. (3) which will be stated later.

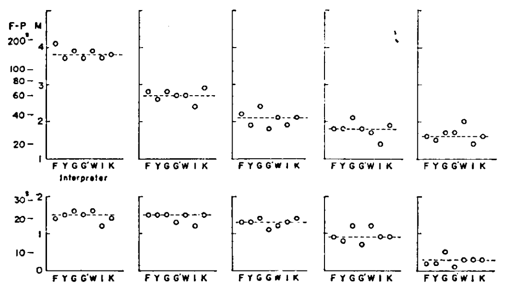

Fig. 2. F—P's independently read by various interpreters ($M=M'_{F-P}$ by Eq. (4), F, Y, $\cdots$: initial of interpreter).

The discrepancies due to personal errors are usually smaller than ± 0.3 in the equivalent magnitude, therefore its influence on the determination of magnitude appears to be comparatively smaller than that preestimated from the difficulty in fixing the end of oscillation F.

4. Constancy of $F—P$ recorded at short epicentral distances

In Fig. 3, the $F—P$'s recorded by the Wakayama network are plotted against the $S—P$'s for the major felt earthquakes which occurred in Kinki District in June 1965.

Although there exists a scattering of $\pm 0.3 \sim 0.4$ in the equivalent magnitude around the mean value, a constancy of $F—P$ in each earthquake event with respect to the hypocentral distance may be granted in a first approximation for short hypocentral distances, say less than 200 km or so, signifying at the same time, the independency of $F—P$ on the recorded maximum amplitudes.

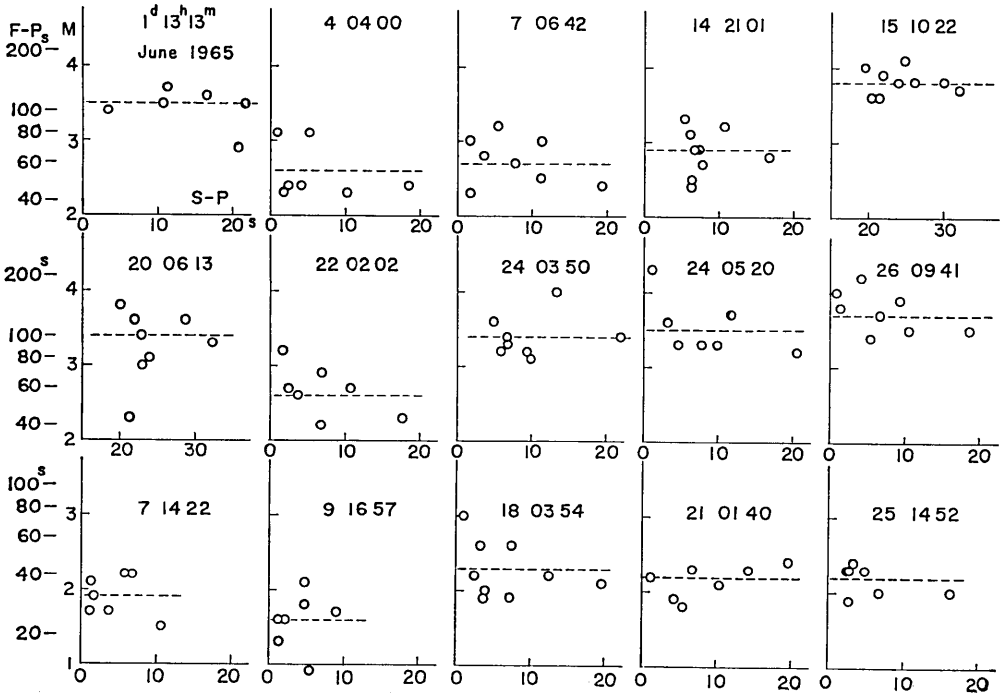

Fig. 3. Relation between $F—P$ and $S—P$, showing the independency of $F—P$ on the hypocentral distance at short hypocentral distances ($M = M'_{F-P}$ by Eq. (4)).

5. Formulas determining magnitude from $F—P$

By analogy with the amplitude-magnitude relation, the following expression was expected in the relation between the $F—P$ and the magnitude:

$$M = \alpha + \beta \log (F—P) + \gamma(\Delta), \tag{2}$$

where α, β: constants and $\gamma(\Delta)$: a function of epicentral distance Δ (or hypocentral distance r more strictly speaking).

Since the third term can be neglected at short epicentral distances as already mentioned in the previous section, we get a simpler formula in such case:

$$M = \alpha + \beta \log (F—P), \tag{3}$$

In order to obtain the constants in Eq. (3) suited to the data of the Wakayama network, the $F—P$'s recorded at the substations of the Observatory were plotted against the magnitudes determined by J.M.A. (M_{JMA}) for 33 earthquakes which occurred in and near Kii Peninsula, as shown in Fig. 4, and it yielded the following equation:

$$M = -2.36 + 2.85 \log (F-P). \tag{4}$$

The magnitude obtained by Eq. (4) is designated as M'_{F-P}. This formula nearly coincides with that given by Bisztricsany[4)] (1958), which was applied to the Sakhalin stations by Solov'ev[5)] (1965), i.e.

$$M = \alpha + 2.25 \log (F—P), \tag{5}$$

where α is a constant depending on the instrument.

In order to examine the applicability of Eq. (4) to the earthquakes at larger epicentral distances, the differences $M'_{F-P} - M_{JMA}$ were plotted against the epicentral distance Δ(km) as shown in Fig. 5, where M'_{F-P} is the mean value for all the recorded stations and Δ is represented by that of Sarutani station. There exists a proportional relation expressed by

$$M'_{F-P} - M_{JMA} = 0.17 - 0.0014\Delta. \tag{6}$$

Inserting Eq. (6) in (4), we get the final formula:

$$M = -2.53 + 2.85 \log (F-P) + 0.0014\Delta. \tag{7}$$

The magnitude calculated by Eq. (7) is designated as M_{F-P}.

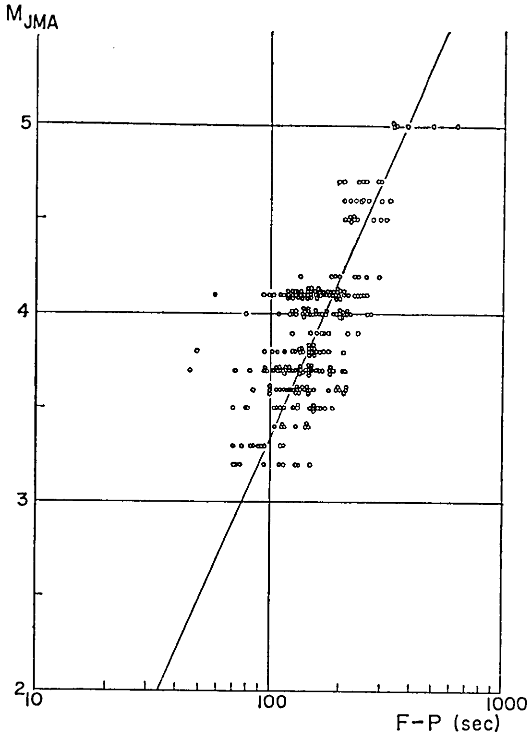

Fig. 4. Relation between the magnitude determined by the Japan Meteorological Agency (M_{JMA}) and the F—P's recorded at the substations of the Wakayama Micro-earthquake Observatory.

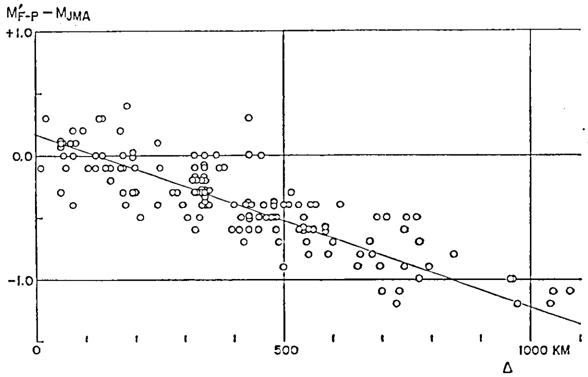

Fig. 5. Relation between the deviation $M'_{F-P}-M_{JMA}$ and the epicentral distance Δ.

The results of comparison of M'_{F-P} with M_{JMA} for the major earthquakes in various parts of Japan are shown in Fig. 6, and are superposed in Fig. 7. The numerical results are given in Table 1. From these figures and table, it is concluded that the final formula (7) is applicable to the earthquakes of which epicentral distances are smaller than 1000 km with sufficient accuracy of $\pm 0.2 \sim 0.3$ (standard error). The applicability of the formula to the earthquakes deeper than 60 km has not yet been ascertained since the magnitude is not given by J.M.A. when the focal depth is deeper than 60 km.

Because the coefficient of the third term is very small, it might be rather appropriate to use Eq. (4) instead of (7) for the earthquakes of short epicentral distances say less than 200 km or so, sacrificing a slight degree of accuracy (almost insignificant compared with the observational errors) to save trouble to calculate the epicentral distance.

Fig. 8 shows the degree of scatterness of M'_{F-P} calculated from the data at individual station compared with the mean for the network.

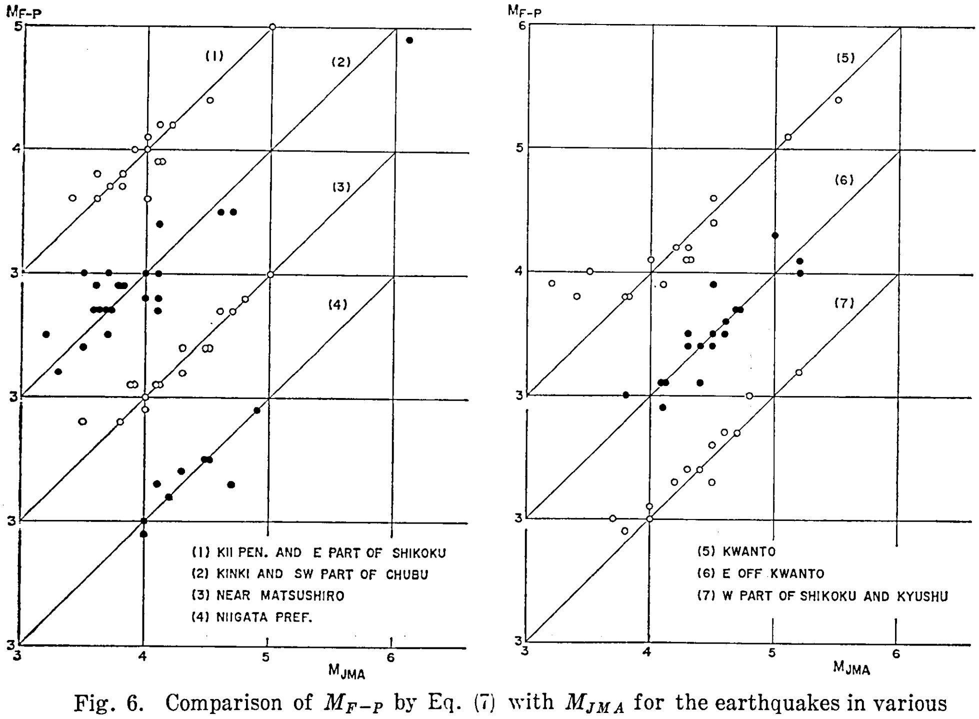

Fig. 6. Comparison of M_{F-P} by Eq. (7) with M_{JMA} for the earthquakes in various parts of Japan.

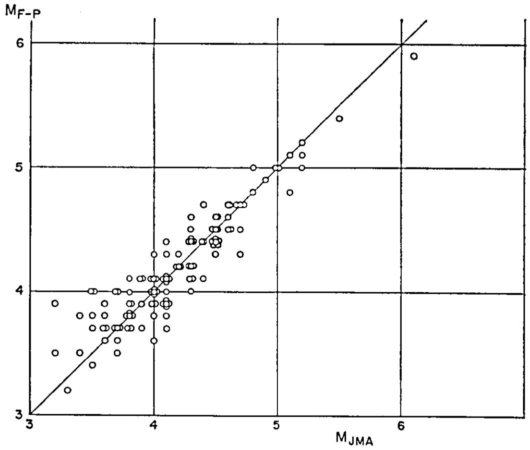

Fig. 7. Comparison of M_{F-P} with M_{JMA} for the earthquakes in Japan excluding Tohoku and Hokkaido.

Table 1. Numerical result of the comparison M_{F-P} with M_{JMA}.

REGION	Δ (KM)	$\overline{\Delta M}$	S.D.	N
(1) KII PEN. AND E PART OF SHIKOKU	<130	-0.02	±0.16	16
(2) KINKI AND SW PART OF CHUBU	100~250	0.00	±0.22	21
(3) NEAR MATSUSHIRO	340±	+0.03	±0.12	16
(4) NIIGATA PREF	400~650	-0.02	±0.18	9
(5) KWANTO	300~500	+0.06	±0.29	15
(6) E OFF KWANTO	500~750	0.00	±0.18	18
(7) W PART OF SHIKOKU AND KYUSHU	300~550	+0.07	±0.13	13
WHOLE JAPAN EXCEPT TOHOKU AND HOKKAIDO	<600	+0.01	±0.16	118

$\overline{\Delta M} = \Sigma(M_{F\text{-}P} - M_{JMA})/N$

$\text{S.D.} = \sqrt{\Sigma \Delta M^2/(N-1)}$

Since the scatterness may depend not only upon the background noises at the stations, but also to some extent upon the skill of the interpreter who reads the records, it is desirable to adopt the mean of at least three stations to secure accuracy of determination.

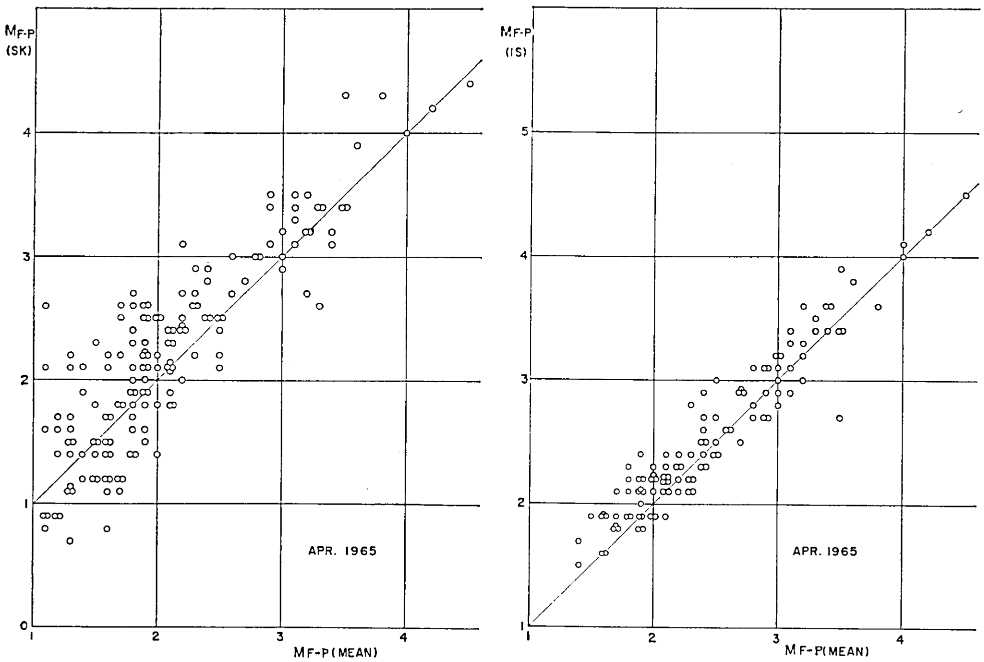

Fig. 8. Comparison of M_{F-P} calculated from the $F—P$ at individual station (SK: Shichikawa, IS: Ise) and the mean for all the stations.

6. Magnitude determined from $F—P$ and the maximum amplitudes

In Fig. 9, the maximum amplitudes (on a logarithmic scale) recorded at Shichikawa and Ise are plotted against the magnitude determined from $F—P$ (M_{F-P}), by the network for the local earthquakes near Wakayama city. Since these earthquakes occurred in a concentrated domain of about 15 km in diameter, they are considered to have been recorded at nearly a constant epicentral distance at each station ($\Delta \fallingdotseq 80$ km at Shichikawa and 150 km at Ise respectively). The proportional relationship between log Am and M_{F-P} shown in Fig. 9 implicitly confirms the applicability of Eqs. (4) and (7) to the smaller magnitude of 1 to 4.

7. Estimation of the b in magnitude frequency relation from frequency distribution of $F—P$

Assuming Eq. (4), we can estimate the coefficient b in the magnitude frequency relation

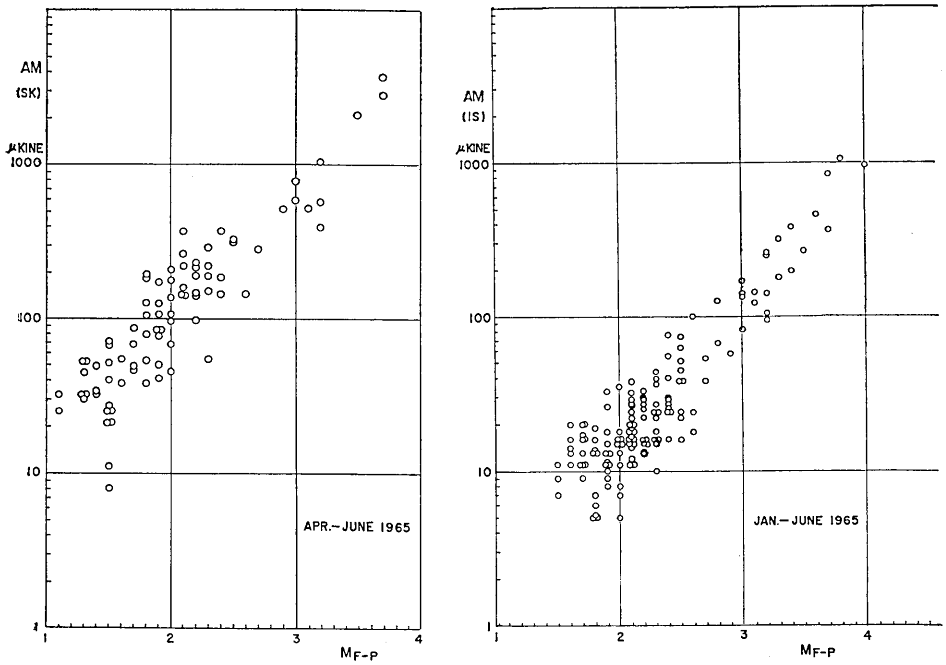

Fig. 9. Relation of the maximum velocity amplitudes (vertical component) recorded at Shichikawa (SK, $\Delta \doteqdot 80$ km) and Ise (IS, $\Delta \doteqdot 150$ km) to M_{F-P} for the earthquake swarm near Wakayama city.

$$\log N(M) = \text{const} - \text{b}M$$

from the data of $F—P$ obtained at a given station through the following procedure.

If we count the frequency of earthquakes in the intervals of $F—P$ corresponding to the magnitude intervals given by Eq. (4) for the earthquakes with $S—P$ smaller than a given value $(S—P)_0$, it gives the frequency distribution of magnitude for the earthquakes in a hemispheric domain with a radius of $k \times (S—P)_0$ km from the station, where k is the Omori's constant or V_{S-P} and then the coefficient b is estimated by the ordinary method.

Two examples are shown in Fig. 10. The b's for the earthquakes with $S—P$ less than 3 sec at Arida and Hidaka are estimated in the figure to be 0.75 and 0.91 respectively. The fact that both values fall within the range of normal ones obtained by the ordinary method using the maximum amplitudes implicitly confirms again the approximate

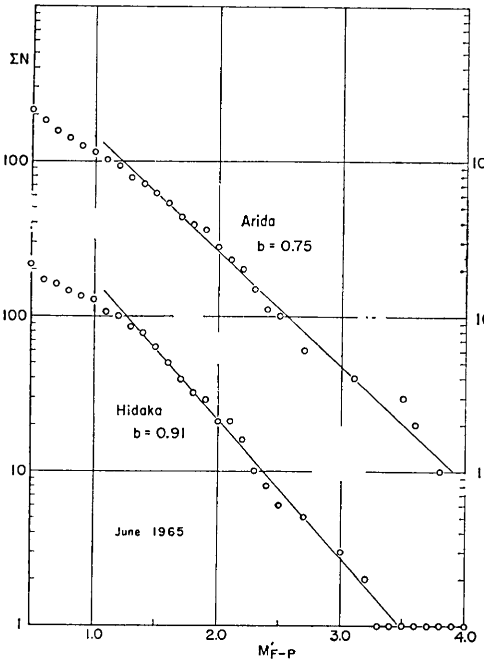

Fig. 10. Cumulative frequencies of M'_{F-P} calculated from the $F-P$'s at Arida and Hidaka for the earthquakes with $S-P \leq 3$ sec.

correctness of the present formulas within the magnitude range of 1 to 3, in which it has not yet been directly ascertained by the comparison of M_{F-P} with M_{JMA}.

8. Summary and Conclusion

An empirical formula

$$M = -2.53 + 2.85 \log (F-P) + 0.0014\Delta$$

was given for the determination of magnitude from the $F-P$'s observed by the observation network of the Wakayama Micro-earthquake Observatory.

For the earthquakes of short epicentral distances, a simpler formula neglecting the correction term of Δ,

$$M = -2.37 + 2.85 \log (F-P)$$

is more conveniently applied.

The largest merits of the present method are:

1) Coverage of the wide range of magnitude with a single seismograph, without such troubles as 'saturation' or 'under exposure' in the case of the maximum amplitudes, and,

2) The simplicity of the treatment, especially for the earthquakes of short epicentral distances.

With these merits, the formulas can be appropriately utilized for the simple estimation of the magnitudes of local earthquakes, and for the selection of earthquakes from the observational data to list up in catalogue of major earthquakes or to write into the seismicity map.

The studies concerning such problems as the comparison of the magnitude determined by the present method with that calculated by the Muramatsu's formula[6], which is applicable to the wide range of magnitude and currently used by Japanese investigators, the applicability of the present formulas to the deeper earthquakes, the relations between $F—P$ and M in the records obtained with the seismographs of different characteristics, and so on, are postponed to the future.

9. Acknowledgments

The writer wishes to express his sincere thanks to Professor S. Miyamura for his kind advice and encouragement throughout this study.

References

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2. 総振動時間による地震の規模の決定

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和歌山微小地震観測所の高感度地震観測網で記録された局地〜近地地震の総振動時間 $F-P$ と気象庁決定のマグニチュード M との関係を調べた結果，同所の $F-P$ データを用いて，震央距離 1000 km 以下の浅い地震の M を決める式が得られた．この式で決めた M は，3〜6 の範囲で気象庁決定の M とよく一致し，1〜3 の範囲で，最大振幅の対数と比例関係があり，またこの式を仮定して $F-P$ の頻度分布から求めた M 別頻度分布の係数 b は一般に得られるような値になった．

$F-P$ による M の決定は，

i) 大きすぎて振幅が測れない地震の場合でも $F-P$ は測れるので，一台の地震計で M の広い範囲 (1〜6 位) をカバーできる，

ii) 震央距離に対する補正項の係数が小さいので，局地地震 ($\Delta<200$ km) の場合には，$F-P$ は震央距離に関係なく一定値をとるとみなすことができ，一々震源距離を求めないでも M を決めることができる，などの利点があるので，験震表から主な地震を選び出したり，記録をみて簡単に概略の M の値を推定したりする目的には有効に利用できるものと考えられる．