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13. *Waveform Analysis of S-Pulse from Deep-Focus Earthquakes. Part 1.*

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Summary

An analog computer circuit was constructed for the purpose of deducing the original waveform of S-pulse from seismograms. The present paper deals with the six deep-focus earthquakes in the Japan area by use of the records at Matsushiro with mechanical long-period seismographs. It is ascertained that the original pulse-form thus obtained can be well explained by H. Honda's theory of a spherical seismic origin. Good agreement of the theory with the observations enables us to estimate the apparent radius of the origin.

If we look for an analytically simple function to approximate the reduced pulse-form, the following expression might be used,

$$V(t)=A\cdot\exp(-c^2t^2)\ ,$$

where, A is a function of such factors as earthquake magnitude, hypocentral distance, orientation of nodal planes, and so on.

1. Introduction

The author previously studied the radiation mode of S-waves from a deep-focus earthquake which occurred south of Honshu, Japan.[1] Waveform analysis by an analog computer proved that the original waveform of S-pulse deduced from Matsushiro's record is in good harmony with the theoretical prediction by H. Honda.[2]

This verification was obtained, however, from the study of a single record. It is not necessarily clear whether the theoretical pulse-form fits the other cases equally well. It is also uncertain that seismic disturbances of similar waveform are radiated from a source to all directions.

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[1] K. KASAHARA, "Radiation Mode of S-waves from a Deep-Focus Earthquake as Derived from Observations," *Bull. Seis. Soc. Amer.*, **53** (1963), 643-659.

[2] H. HONDA, "The Generation of Seismic Waves," *Publ. Dominion Obs.*, **24** (1960), 329-334.

It is urgently necessary to work out this kind of test by taking as many examples as possible. The above-stated questions would be answered naturally when this kind of information has been accumulated.

In connection with the second question, A. Ben Menahem has pointed out theoretically the possibility of azimuthal effect in waveform.[3] An observational fact that might substantiate it has also been reported by the present author in the case of the Alaskan earthquake of April 7, 1958.[4] In the present paper, however, the author would like to ignore this possibility and confine his interest to the first type of question.

2. Earthquakes studied

This paper will deal with a group of earthquakes which occurred in the Japan area at a depth of 350 km or more. For the same reason

Table 1. Earthquakes studied.

No.	Time of occurrence (G.M.T.)				Epicenter		Depth	Magnitude	a
		h	m	s			km		km
1	Feb. 18, 1956	07	34	16	30°N,	137.5°E	450	$7\frac{1}{4}\sim7\frac{1}{2}$	36
2	Oct. 8, 1960	05	53	04	40	130	650	$6\frac{1}{4}\sim6\frac{3}{4}$	22
3	Apr. 9, 1957	00	24	44	$30\frac{3}{4}$	$138\frac{3}{4}$	ca. 450	$6\frac{1}{4}\sim6\frac{3}{4}$	13
4	Sept. 1, 1958	15	29	34	37.9	134.8	400~450	—	6.5
5	Sept. 28, 1957	00	27	33	31	138	ca. 450	$6\frac{3}{4}$	5.4
6	July 22, 1957	10	16	37	34.4	136.5	ca. 350	—	2.5

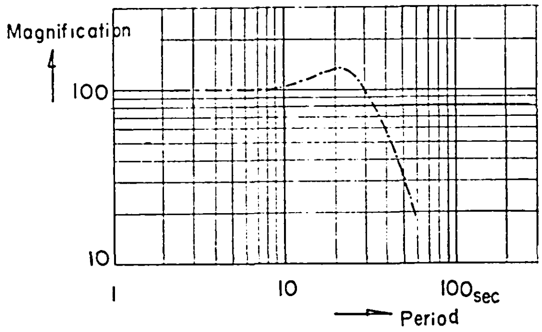

Fig. 1. Frequency response of the seismographs.

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[3] A. BEN MENAHEM, "Radiation of Seismic Body Waves from a Finite Moving Source in the Earth," *J. Geophys. Research*, **67** (1962), 345-350.

[4] K. KASAHARA, "An Attempt to Detect Azimuth Effect on Spectral Structures of Seismic Waves (The Alaskan Earthquake of April 7, 1958)," *Bull. Earthq. Res. Inst.*, **38** (1960), 207-218.

as that given in the previous report, let us use seismograms of Matsushiro recorded with the long-period seismographs of mechanical type. Fig. 1 illustrates their frequency response. Since their magnification is not very high, they only record the signals from large shocks to sufficient amplitude. By courtesy of the Japan Meteorological Agency, seismo-

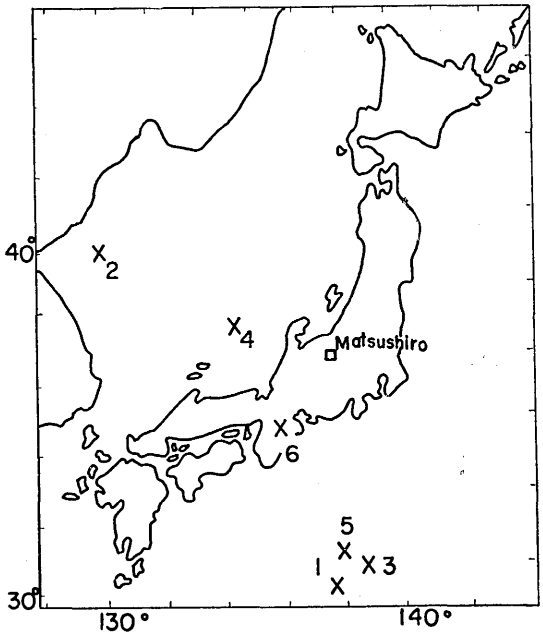

Fig. 2. Location of deep-focus earthquakes (numbers assigned to cross marks refer to the earthquake numbers in Table 1).

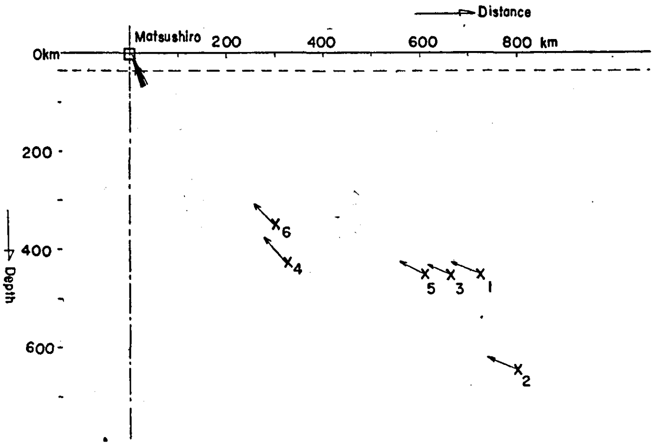

Fig. 3. Epicentral distance of earthquakes plotted against their focal depths.

grams for the six earthquakes are available for the analysis, details of which are given in Table 1. Spatial relation of their foci to the station is illustrated in Fig. 2 as well as in Fig. 3. As can be seen in the latter figure, seismic rays from these foci approach the station with an incident angle of 20–30°, so that we may roughly assume them to be normal incidence. That is to say, all the information about S-phase can be obtained from the records of the two horizontal components.

3. Technique and results of the analysis

An analog computer circuit that is similar to the previous one is constructed for the analysis. Program circuit becomes very simple in this case as we are interested only in the seismographs of mechanical type. It takes the input of recorded trace to compute the corresponding ground motion after necessary reduction for the instrumental influences. Taking the simple conditions of propagation path into consideration, we may consider that the output motion represents the original waveform of the seismic pulse. Reduction which covers the S-phase of each record is repeated by adjusting the level of datum line slightly until we obtain the minimum drift of base line of the output curve.

Fig. 4 illustrates the reduced pulse-forms for the six cases in comparison with the recorded traces, where the ordinate is given in arbitrary scale. It is unfortunate that the records of the NS-component were not available for the analysis since the instrument of this component has been operated with the magnification much lower than another one. Lack of the component has made it difficult to examine the similarity between the waveforms of the two components. This point will be studied, however, in a succeeding paper by using the records for a later period when the discrepancy is reduced.

So far as we are concerned with the basic structures of the reduced pulses, we may apply Honda's pulse-form to all of these cases equally well. This relation can be seen more clearly in Fig. 5, wherein the time scale for each curve is adjusted by the factor σ so that their pulse widths may be equal to each other. The upper curve in the figure represents Honda's theory assuming the step-wise stress change on the origin sphere.[5] If we accept the similarity between the upper and lower curves, we are able to estimate the apparent radius of the origin (a) for each case. In Table 1 are given the results thus

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[5] H. HONDA, *loc. cit.*, 2).

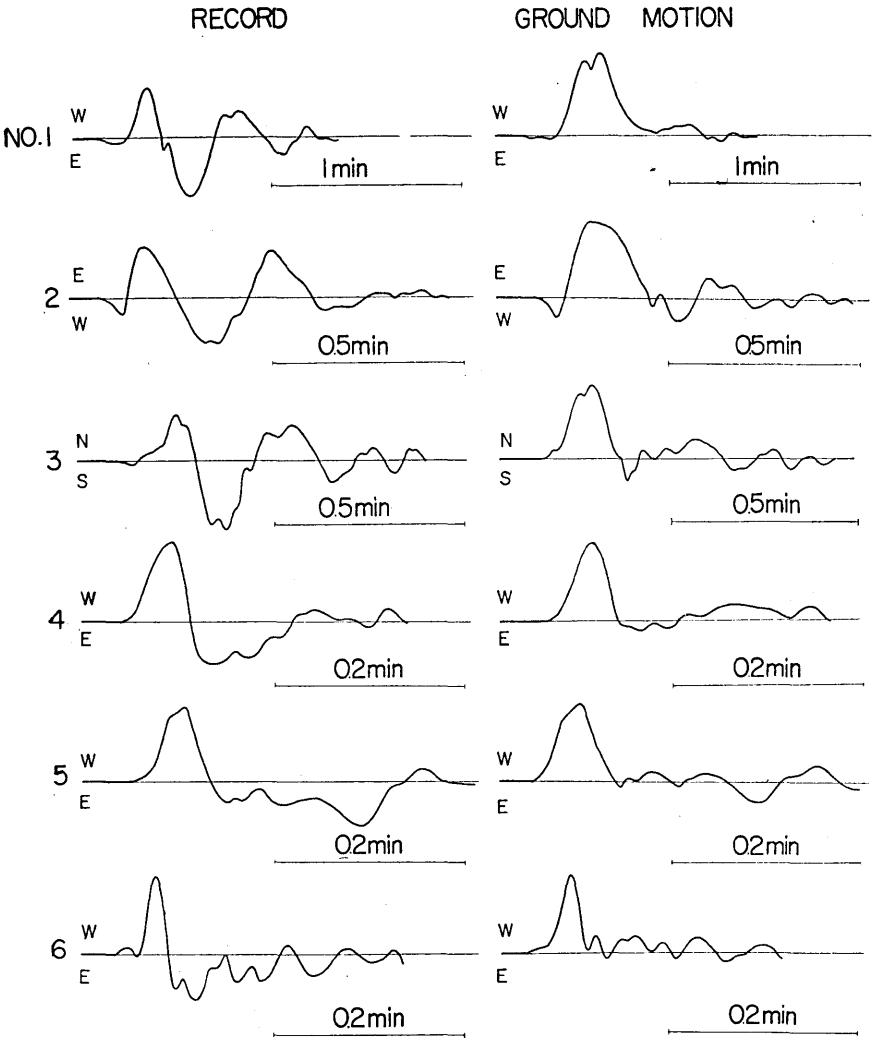

Fig. 4. Reduced forms of S-pulses compared with their waveforms before the reduction (Ordinate is given in arbitrary scale. Earthquake numbers refer to those given in Table 1).

obtained, where the velocity of S-wave in the medium is assumed as 5 km/sec.

The author has formerly studied the P-waves' spectra to learn the relation of the apparent radius of a seismic origin with its earthquake magnitude.[6] Fig. 6 is drawn to compare the present results (black

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[6] K. KASAHARA, "The Nature of Seismic Origins as Inferred from Seismological and Geodetic Observations (1)," *Bull. Earthq. Res. Inst.*, **35** (1957), 474-532.

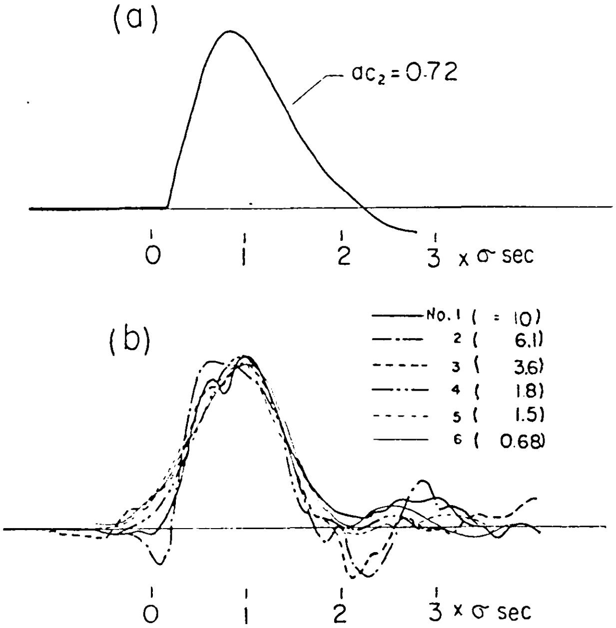

Fig. 5. (a): Pulse-form of S theoretically predicted by H. Honda, where, a and c_2 denote the radius of the spherical origin and the inverse of shear-wave velocity, respectively. (b): Reduced pulse-forms drawn with respect to the modified time scale.

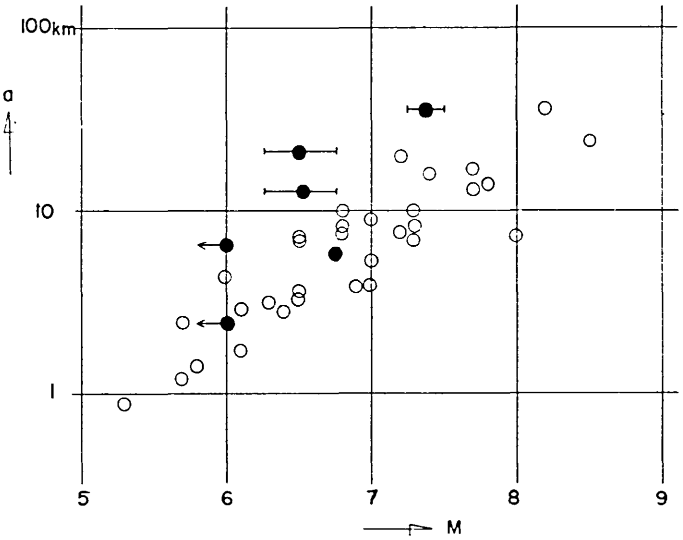

Fig. 6. Apparent radius of earthquakes (a) plotted against their magnitude (M). Black circles represent the results from the present study, whereas the empty ones indicate previous data.

circles) with the former ones (empty circles) which are based on the W. Inouye's theory.[7] The two groups seem to be in good harmony with one another except for a notable tendency that the circles for the former results are located slightly lower than the present ones. The present data is insufficient for drawing any statistical conclusion about this point. The author supposes, however, that the effect might be attributed to the difference of the models used in the respective cases.

It is sometimes necessary in seismology to represent the main part of seismic disturbances by a simple analytical function. One of the examples is a train of sinusoidal motion with duration of several periods, which is often used for estimation of seismic energy. The Ricker pulse used in the field of seismic prospecting is another example.[8] Good similarity between the pulse-forms illustrated in Fig. 5 seems to suggest the possibility of defining a function for this purpose. If we take a position free from any theoretical models and look for a function as simple as possible, the following one might be used:

$$V(t)=A\cdot\exp(-c^2t^2)\ , \qquad (1)$$

where, A is a function of such factors as earthquake magnitude, hypocentral distance, orientation of the nodal planes, and so on, whereas c is a constant depending on the magnitude (M) and can be expressed as,

$$c=10^{2.9-0.51M}\ , \qquad (2)$$

to satisfy the relation of σ to M (Fig. 5).

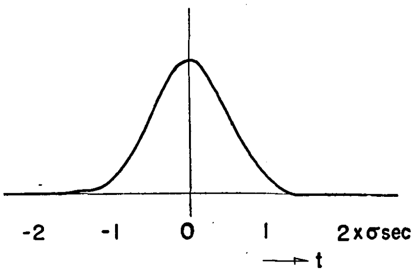

Fig. 7. Waveform based on the propose function.

The above-stated function is introduced tentatively only to show the possibility of defining the standard pulse-form of S from deep-focus earthquakes. Further considerations must be taken from various points of view before the function is generally accepted.

4. Acknowledgments

The author wishes to express his sincere thanks to the Matsushiro Seismological Observatory of the Japan Meteorological Agency, which

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[7] W. Inouye, "Note on the Origin of Earthquakes (Sixth paper)," *Bull. Earthq. Res. Inst.*, **16** (1938), 599.

[8] N. Ricker, "The Form and Laws of Propagation of Seismic Wavelets," *Geophysics*, **18** (1953), 10-40.

kindly provided him with the materials useful for the present study. Construction of the analog computer was participated in by Mr. T. Kobune and the staff members of the Technical Division of this Institute. The author is grateful to them as well as to Miss M. Ishii who assisted him in preparation of the manuscript.

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13. S 波に関する深発地震震源の特性 (第1報)

地震研究所　笠原慶一

地震記録に地震計の特性を補正して「真の地動」を求める操作はアナログ計算機により容易に行うことができる. この方法を用いて, 日本およびその周辺地域の深発地震数例に対しS波部分の波形解析を行つた. 資料は松代の1トン長周期地震計 (主としてEW成分) のものである.

このようにして求めたS波の原波形はいずれも極めて簡単なパルス状をしており, それぞれの時間軸を適当に伸縮すれば, 一つの共通的波形にまとめることができる. これは球状震源の理論(本多)とかなりよく調和しており, 震源における歪力変化が時間に関して階段函数的であるという仮定と矛盾しない. 理論波形との対比から, 球状震源の立場における「見かけの震源」半径を求めることも試みた.

震源模型の立場をはなれて考えれば, 上記の共通的パルス波形は,

$$V(t)=A\cdot\exp(-c^2t^2)$$

の函数でよく近似できそうに見える. 但し A はマグニチュード (M) や震源距離・発震機構等に依存する函数であり, c は今の場合,

$$c=10^{2.9-0.51M}$$

程度と考えられる. 今後の調査によつてこの種の標準波形が更に改善されれば, 地震波動に関する問題を一般的に取り扱う上に有用であろう.