EARTHQUAKE MOTION CHARACTERISTICS OF OSAKA PLAIN

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SUMMARY

Earthquake motion on the ground surface of the Osaka plain is of much longer duration than that on the surrounding mountainous regions. A secondary wave arrives about 20 seconds after the main wave. This wave, identified as a surface wave propagated on the sedimentary layer of the Osaka plain (bedrock depth: 700~1,400m), we named ATOYURÉ. The ATOYURÉ is not observed in long-distance earthquakes or local earthquakes in the Osaka plain, but is clearly notable in middle-distance earthquakes.

1 OUTLINE OF SEISMIC OBSERVATION

As shown in Fig.1, the Osaka plain is part of a submerged basin of oval shape with a 40km minor axis and 80km major axis and a relatively distinct bordering of mountainous regions—the Ikoma range, Izumi range, Awaji Island and the Rokko range. Roughly two-thirds of this basin being occupied by Osaka Bay, with an average depth of 20m, the Osaka plain is on the northeast of the bay. Most of our observation stations (S, A, Y, C, M and R) are on the x-x line (Fig.4), which crosses the plain obliquely. Station S is located in the Ikoma range, R in the Rokko range and A on Uemachi plateau. Y is to the north of A. The bedrock depth is about 700m slightly to the east of Y and 1,400m around C. This indicates that an undersurface mountain range runs roughly from north of south, passing right under A, as shown in section x-x of Fig.4. Fig.2 shows soil profiles, seismograph depths and earthquake motion observation directions at observation stations. This report is based on records of 27 earthquakes, as shown in Fig.1, which occurred from 1970 to 1982. Their magnitudes range from 4.0 to 6.1, J.M.A. seismic intensity scale at Osaka being 0 to III. Numbers in the figure are our registration numbers.

2 SIMULTANEOUS OBSERVATION RECORDS

Fig.3 shows example seismograms recorded simultaneously at observation stations. This earthquake, whose hypocenter was in the southern part of Nara Prefecture (No.112, Fig.1), arrived at S first and R last. The hypocentral depth being known, the straight-line distance from the hypocenter to each station can be determined. On the assumption that earthquake waves travel a straight course at a constant velocity, the velocity of the main wave propagated through the bedrock under the Osaka plain is calculated at 3.2km/sec. This value is constant as regards a number of earthquakes. Unlike S or R,

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which are on bedrock, A is on the plain. Assuming that the earthquake reaches the bedrock 700m beneath A in accordance with the same geometric rule, the seismogram indicates that arrival time at A is about 0.95 seconds after the time calculated for the arrival at the bedrock beneath A. This time lag represents the time required for propagation through the sedimentary layer upward to A. On the basis of this, average propagation velocity Vs through the sedimentary layer beneath A can be determined, from 700/0.95, as being 740m/sec.

After the main wave (Fig.3, ①), gradually attenuation, continues for about 20 seconds, another wave (Fig.3, ②), arrives band-passed in appearance. This is the ATOYURÉ, which lasts about 20 seconds, and is followed by a similar wave of lesser amplitude.

Regarding the propagation of this series of waves, we hypothesize as follows:

1) First, body waves travelling from the hypocenter along straight courses reach the bedrock under the plain. Next, surface waves arrive, travelling on the bedrock surface.

2) Since the wave is propagated thence upward through the thick sedimentary layer in S-wave form, it arrives at the ground surface with some time lag, and forms the main wave on the plain surface, involving S-wave multi-reflections. (Fig.4, course ①)

3) The surface wave arriving at the nearer mountainous region (for example, the Ikoma range), and forming a new surface wave which is propagated through the plain sedimentary layer at lower velocity. (Fig.5)

4) This new surface wave is propagated from the Ikoma range to the plain like a sea wave, part of it reaching A about 20 seconds after the main wave's arrival. This surface wave is the ATOYURÉ, which lasts for roughly the same duration as the main wave on the bedrock. (Fig.4, course ②)

5) From any one point in the mountainous regions, the wave enters the plain travelling linearly, as a surface wave. Viewed from one point on the plain, a wave which will pass through that point enters roughly on a perpendicular from the mountainous region boundary. (Fig.6)

6) Somewhat later, the surface wave is transmitted from the opposite Rokko range to the plain by the same mechanism and propagated in the reverse direction. (Fig.4, course ③)

3 SURFACE WAVES PROPAGATED ON THE PLAIN SEDIMENTARY LAYER

3.1 Time-distance Diagrams

For each earthquake, the time required for the bedrock surface wave to travel from the hypocenter to the surrounding mountainous regions or the bedrock under the plain can be determined from seismograms. Correction with respect to hypocentral location and depth, yields the time difference between commencement of the main motion and arrival of the ATOYURÉ.

The location of the foot of a perpendicular drawn from one observation station to the mountainous region can be roughly inferred from the topography of the Osaka plain. The length of the perpendicular can then be determined. Fig.5 summarizes the relation between the time and distance thus obtained.

The graph at left represents surface waves from the Rokko range, that at right showing those from the Ikoma range. The relative position of each station in the diagram at left differs from that in the diagram at right because of the topography of the surrounding mountainous regions. Since there are so many lines between A and C in the diagram at right, that portion is enlarged at left in the diagram. The numbers in the graphs are earthquake

numbers shown in Fig.1.

Although there are some exceptions, a propagation velocity of 600m/sec can be obtained constantly from the records on the Rokko and Ikoma ranges. This is the velocity at which a wave entering from the surrounding mountainous region is propagated on the plain sedimentary layer as a surface wave.

The time-distance relationship can be shown more clearly by band-passing the entire original wave and isolating it at around 1Hz, as shown in Fig.7.

3.2 Boundary Line between Plain and Surrounding Mountainous Regions

At the Ikoma range north of Mt. Iimori, terrace gravel is developed, making the mountain range boundary slightly indistinct. This area, however, has no great effect on observations at our stations. In contrast, the Ikoma range south of Mt. Iimori to the Yamato river has little terrace gravel and in addition, has a rather straight boundary line from north to south; this makes for easy analysis; perpendiculars can be drawn fairly accurately from each station to the Ikoma range. The boundary of the Rokko range, however, is not so simple. Fig.6 shows perpendiculars from each station on the plain to the Ikoma and Rokko ranges.

3.3 Verification of Surface Wave

Based on the analysis above, a wave arriving 20 seconds after the commencement of the main motion is inferred to be a surface wave entering from the surrounding mountainous region and being propagated on the plain sedimentary layer at 600m/sec. We confirmed of dispersion by band-passing, using 12 bands. Fig.7 gives an example band pass. As shown in the figure, the plain surface wave (ATOYURÉ) is distinct at B.P. ⑤ through ⑨, maximum at B.P. ⑦ (1Hz) and ⑧. In these band-passed seismograms, ATOYURÉ amplitude is greater than that of the main wave, which is roughly the same as the amplitude of the second ATOYURÉ. This has already been established on the bases of velocity response spectra (References 1 and 2). The large main wave at B.P. ⑩ to ⑫ (2 to 3Hz) may be attributable to S-wave multi-reflection in the sedimentary layers. The predominant wave-length of the surface wave propagated on the plain (600m/sec/1Hz) is 600m. Therefore, the surface wave cannot appear clearly at B.P. ⑩ to ⑫. It should be noted that surface wave dispersion is demonstrated by the difference in maximum peak (acceleration amplitude) time position per frequency band, as shown by a dotted line in Fig.7; the maximum peak time position at 1Hz (B.P. ⑦) is later than those at other frequency bands around 1Hz.

4 DIFFERENCE BETWEEN EARTHQUAKE MOTION CHARACTERISTICS IN SURROUNDING MOUNTAINOUS REGIONS AND PLAIN

4.1 Periodic Characteristics

We obtained response spectra at each station and divided the period into 50, calculating average ($\bar{x}$), standard deviation (σ_{n-1}) and values with a confidence coefficient of 80% (1.28 σ_{n-1}) at each period. Fig.8 plots the average ($\bar{x}$) and these values (1.28 σ_{n-1}). Fig.8 indicates that the predominant period at S on the bedrock is around 0.3 to 0.6 seconds, that at R, also on the bedrock, being around 0.5 to 0.8 seconds. This difference of about 0.2 seconds is attributable to differences in geographical features and ground conditions. Predominant periods at A and Y on the diluvium and at C and M on the alluvium, unlike those on the bedrock, have peaks at around 0.15 to 0.5 seconds and 0.8 to 1.5 seconds. Checking against the seismograms discloses that the peak at

0.15 to 0.5 seconds represents the main wave periodic component, that at 0.8 to 1.5 seconds constituting the ATOYURÉ periodic component. Moreover, it is notable that, whereas spectra on the bedrock exhibit relatively simple period characteristics, those on the plain have a number of predominant periods over a wide range, indicating a complex response. This suggests that periodic characteristics on the diluvium or alluvium are related to the complex sedimentary layer structure as well as to the plain location at the station.

4.2 Maximum Acceleration

Maximum acceleration (A) and hypocentral distance (X) are plotted on the logarithmic graph in Fig.9. Figures in the graph indicate magnitude. Dots based on simultaneous observations at S and R are linked with a dotted line. The regression formula expressing the relation between maximum acceleration (A) hypocentral distance (X) and magnitude (M) is also shown in Fig.9.

Fig.10 shows the amplitude ratio of maximum acceleration at each of the stations, A, Y, C, M and R, to the maximum acceleration at station S. Values are corrected with respect to hypocentral distance using Fig.9. Fig.10 reveals that the acceleration amplitude ratios at each of the stations on the plain surface are, in most cases, about twice, sometimes five times, the ratio at the station on the surrounding bedrock. Fig.11 shows the amplitude characteristics of the surface layer by plotting the amplitude ratios of maximum accelerations at different depths to the accelerations at a depth of 60m (30m for station A). According to this figure, amplitude ratios at the surface layer are, in general, two to six times, which is equivalent to or greater than amplitude ratios at stations on the plain relative to those on the bedrock. This analysis discloses that acceleration amplitude is heavily affected by the ground structure of the surface layer.

4.3 Earthquake Duration

Earthquake duration, defined as the period during which vibration continues at an amplitude one-fifth or greater that of the amximum acceleration, was determined for each station. Based on the seismograms obtained, the ratios of duration were calculated for A, Y, C, M and R relative to duration on the bedrock at S and are shown in Fig.12. This figure indicates that durations at A, Y, C and M, all on the plain, exceed those at S and R, on the bedrock, some by five times. Such long durations on the diluvium or alluvium of the plain are primarily the result of the ATOYURÉ, which occurs after the main motion.

REFERENCES

1 TORIUMI, I. "Study on Earthquake Motion Characteristics in Osaka Plain," Summaries of Technical Papers of Annual Meeting of A.I.J., Oct., 1974,

2 TORIUMI, I. "Earthquake Characteristics in Plain," Proc. of 4th Japan Earthquake Engineering Symposium, Nov. 1975

3 TORIUMI, I. OHBA, S. MURAI, N. "Propagation of Earthquake Wave in Osaka Plain," Proc. of 6th Japan Earthquake Engineering Symposium, Dec. 1982

4 MURAI, N. OHBA, S. TORIUMI, I. "Comparison of Earthquake Motion Characteristics of Osaka Plain and the Surrounding Mountainous Regions," Proc. of 6th Japan Earthquake Engineering Symposium, Dec. 1982

5 OHBA, S. MURAI, N. "Amplification Characteristics of Earthquake Motion in Osaka Plain," The 18th Japan National Conference on Soil Mechanics and Foundation Engineering, June 1983

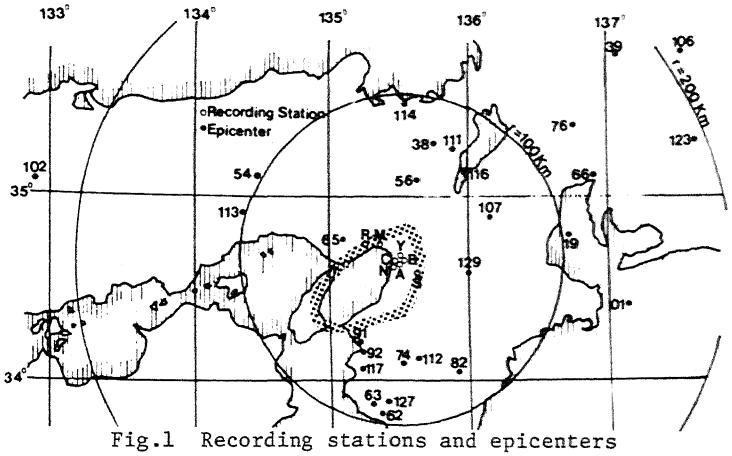


Fig.1 Recording stations and epicenters

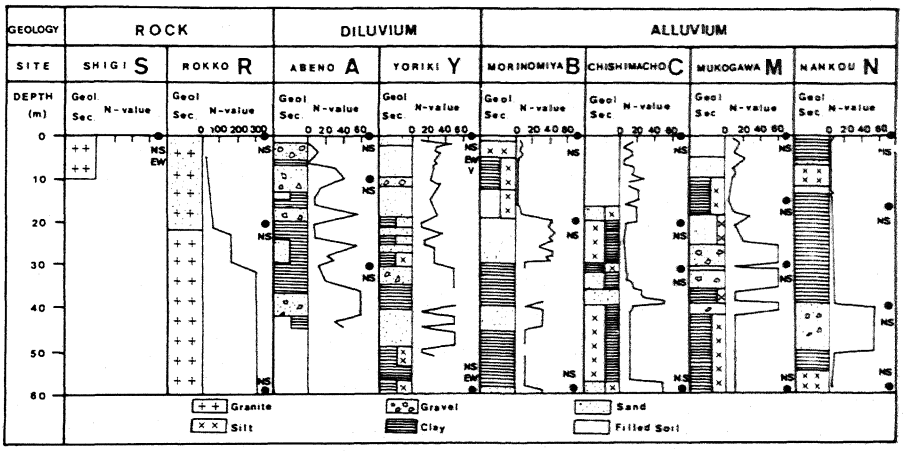


Fig.2 Soil profiels at observation stations and the locations of seismograph

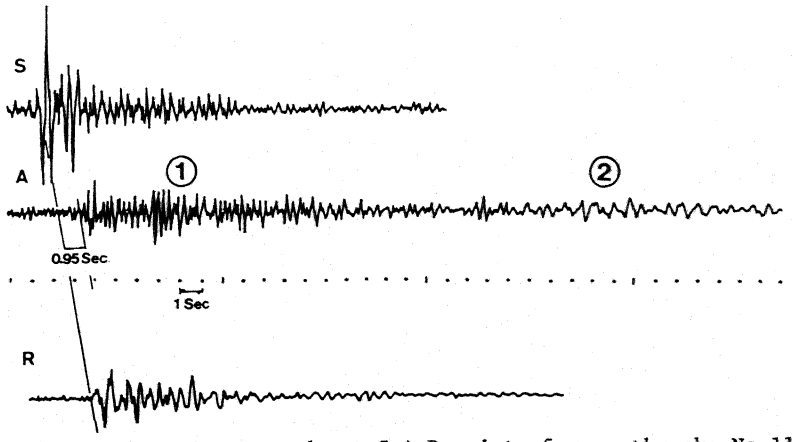


Fig.3 Acceleration records at S•A•R points for earthquake No.112

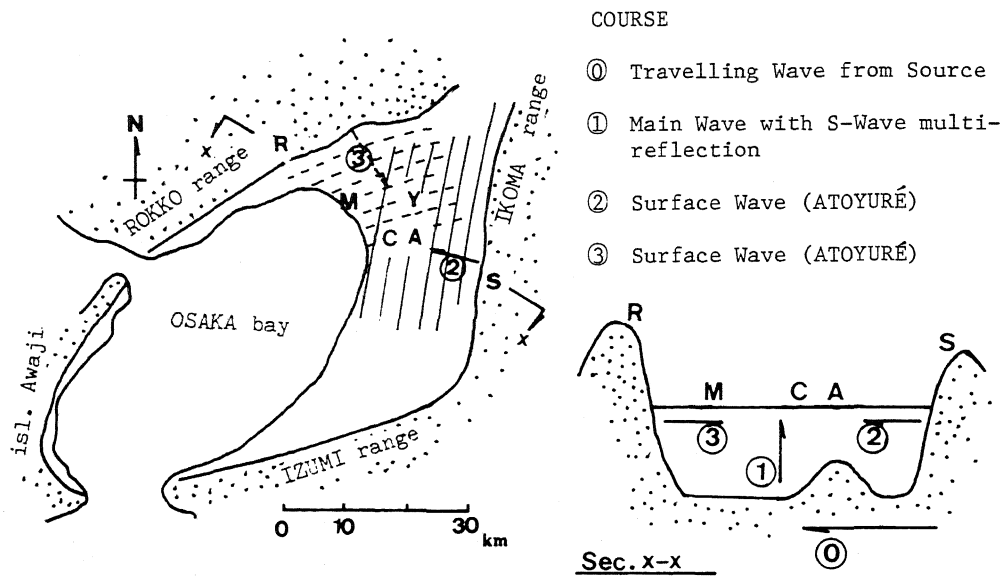


Fig.4 Travelling course of earthquake wave to plain

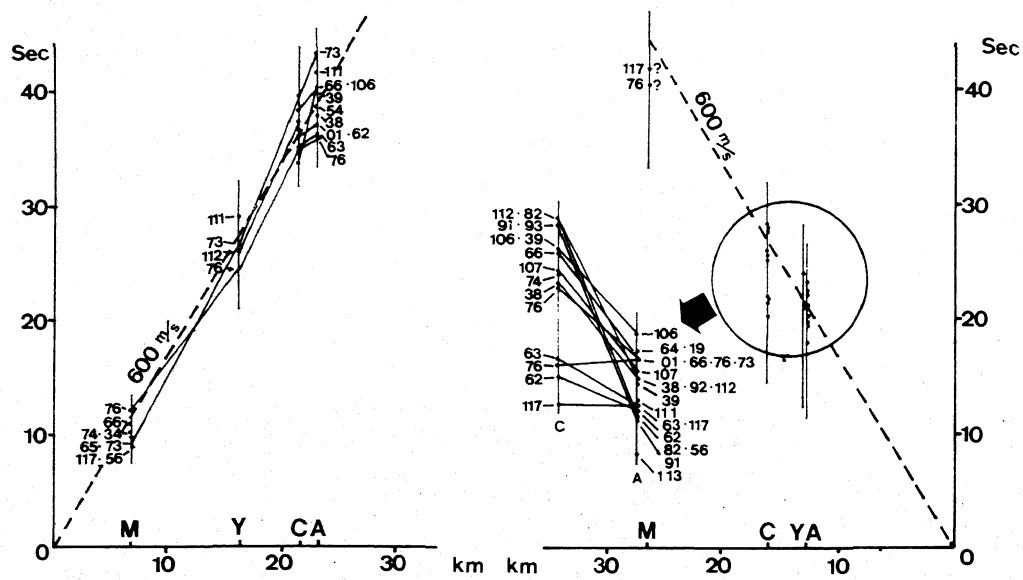


Fig.5 Time-distance diagrams for surface wave "ATOYURÉ"
left:from Rokko range right:from Ikoma range

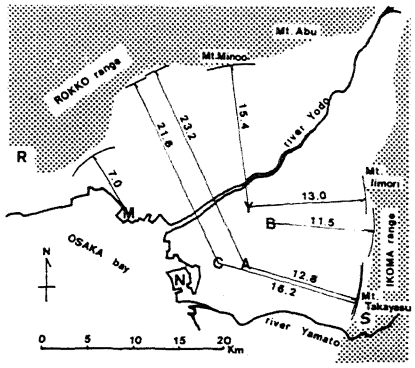


Fig.6 Input line from range to each observation point

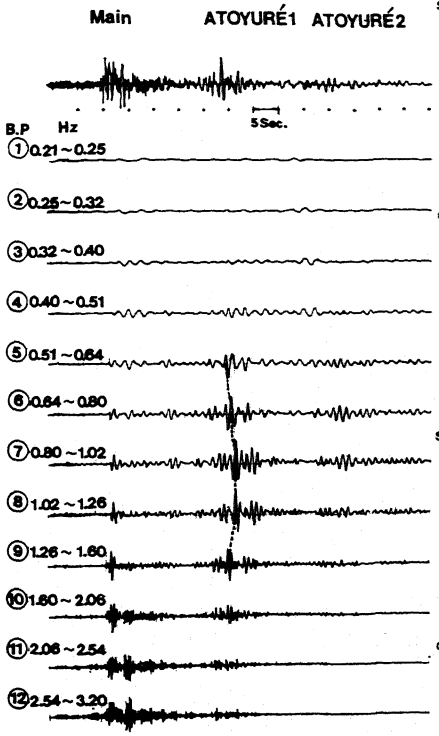


Fig.7 Band passed wave of "ATOYURÉ" (No.62A)

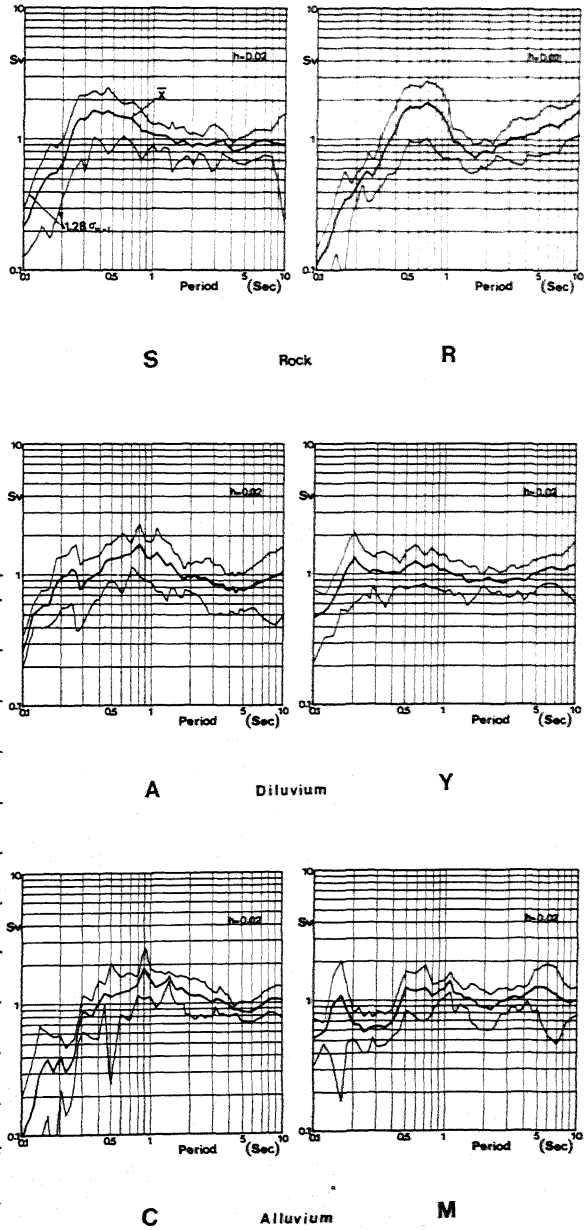
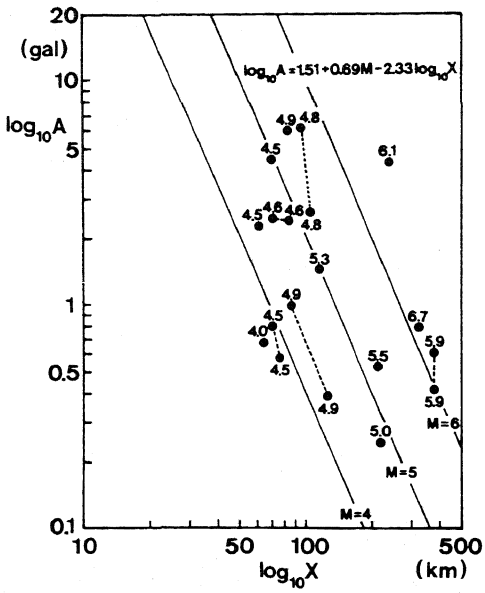


Fig.8 Velocity response spectra (Short-distance earthquakes of within 100km epicentral distance.)



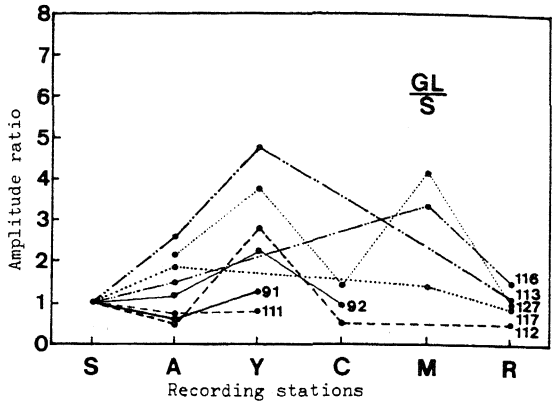


Fig.10 Amplitude ratio of maximum acceleration

Fig.9 Relation between maximum acceleration and hypocentral distance for magnitude

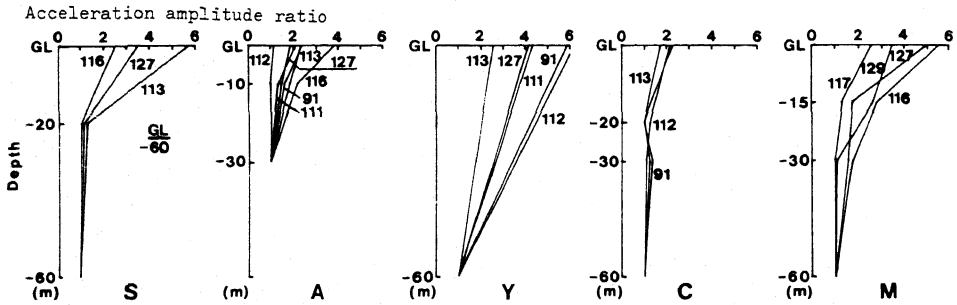


Fig.11 Relation between acceleration ratio and depth

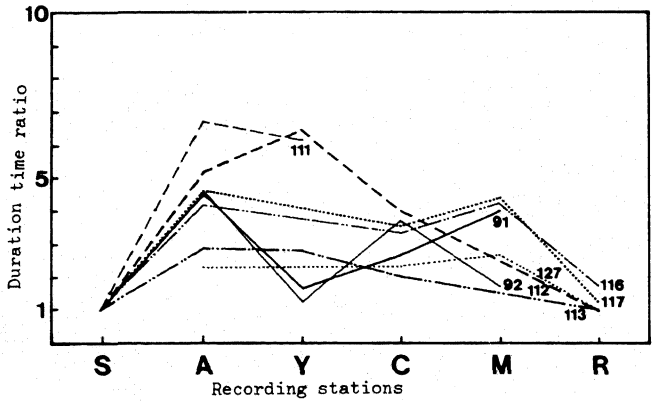


Fig.12 Duration time ratio