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ON SEISMIC WAVES GENERATED BY SMALL EXPLOSIONS [II]

By

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Abstract

Field experiments on seismic wave generation by means of explosions has been carried out by the Exploration Group of Japan and clarified that four different types of wave groups (I, II, III and IV) are generally appeared. Except the wave group II satisfactory conclusions have been reached by many authors. In the previous paper characteristics of the wave group II has been mainly investigated and a proposal in connection with the generation mechanism of this wave group has been done, saying that the waves having the longest wave length in this group must be a kind of surface waves similar to the normal mode waves in the liquid-liquid layers. The present paper is one of the continuations to the subject.

At first computation and comparison of amplitudes, velocities of normal mode waves in the liquid layers to the observation have been performed and ascertained that the characteristics of the main part of the wave group II have many points of similarity to the normal mode waves in the liquid medium.

When the Poisson's ratios of the experimental fields are nearly equal to 0.5 the observed seismic records may seem to be divided into two, that is, *P*- and *S*-zones before and after the head part of the critically refracted *SV* waves.

Secondly through the computations of the amplitudes of the converted waves at the interface it was proved that in the *P*-zone the converted *SV* waves have negligible small amplitudes compared with the *P* waves in the medium of which Poisson's ratio is almost 0.5. Thus in the *P*-zone the circumstances resemble to the liquid conditions. The surface waves under consideration can be looked upon as the normal mode waves mentioned above. While, in the *S*-zone both *P* and *SV* waves are coexisting. The surface waves in this zone (wave groups III and IV) belong to the usual elastic waves in solids.

In connection with the propagation phenomena of the seismic waves the medium, especially in the physical condition that the Poisson's ratio is near to 0.5, can have two different properties such as fluidity and elasticity.

1. Introduction

The seismic waves generated by small charged explosions in the fields covered with alluvial deposits were characterized by four different wave groups,

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namely, of I, II, III and IV respectively (Kubotera [1955, 1957], Tazime [1956, 1957], Sima [1963 a, b], Okada [1963, 1965], Iida, Ohta and Naruse [1966]).

In a previous paper (Kubotera and Ohta [1966]), the problems related to the wave groups of I and II were mainly investigated based upon the experiments carried out by the Seismic Exploration Group of Japan (S.E.G.J.), and it was clarified that the wave group II are composed of a kind of surface waves having a long wave length, a wavelet of direct P waves and refracted SV waves. From these investigations we proposed the possibility that in the wave group II there is a surface wave just equivalent to a normal mode wave in the liquid-liquid layers. The present paper, an attempt is made to describe this possibility.

Now the terms of *signal* and *noise-zone* are usually employed in the field of the seismic prospecting. The noise-zone includes the refracted SV waves (Hatakeyama [1966]) generated at the seismic origin and the dispersive Rayleigh waves which have been called the wave groups of III and IV. The signal-zone, on the contrary, corresponds to the wave groups of I and II except for the refracted SV waves. Hence in the signal-zone no SV waves are to be observed except for the converted SV waves derived from P waves at the boundary surfaces. However, such converted SV waves, as it will be understood in the later discussions, are negligible because of their small amplitudes in our experimental field. Then it may be said that the essential wave groups in the signal-zone are two, that is, the P waves and the surface waves guided by the P waves alone. For this reason signal and noise-zones will be approximated by terms of P-zone and S-zone respectively.

2. Characteristics of the wave group II

It is easy to discriminate between the P-zone and S-zone by using the rectified wave forms (Figs. 1 and 2) drown through some modifications of original seismograms. These two zones are clearely separated at the "refracted S-lines". As had been said in our previous paper it is suggested that preceding the S-lines (P-zone) there is the region concerned essentially with the P waves only, while following the S-lines (S-zone) there is the region which concerns with both P and S waves.

The characteristics of the wave group II, especially the wave having a form of the usual surface wave, have been investigated based upon the experiments of S.E.G.J. carried out at various places every year since 1953.

When the stratified double layer is adopted as a schematic model of the experimental sites the following relations are generally deduced

$$V_p > C_{\mathrm{II}} \geqq V_p' \gg V_s,\ V_s'$$

where C_{II} is the phase velocity of the wave group II, V_p, V_s, V_p' and V_s' are the

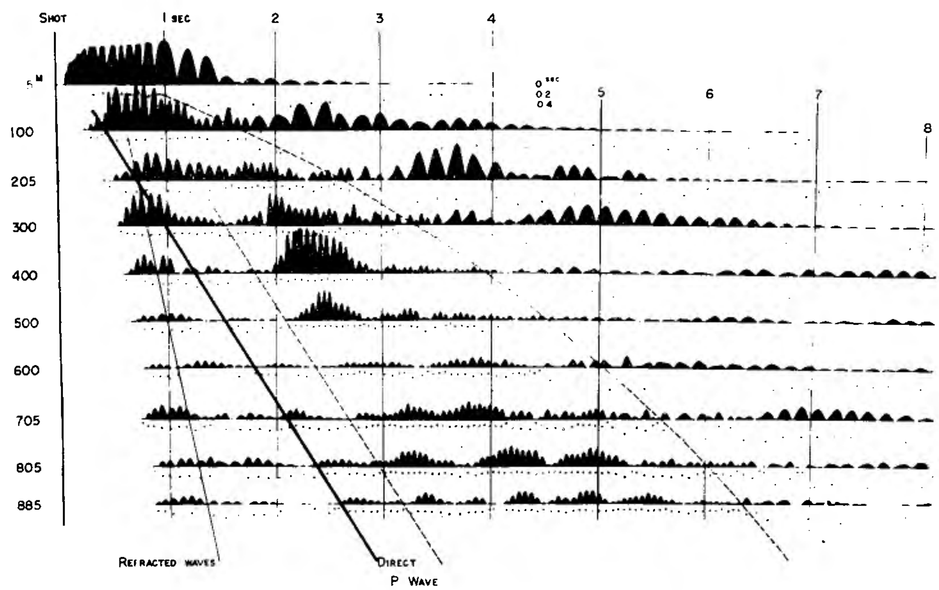


Fig. 1. Rectified wave forms of the vertical component.

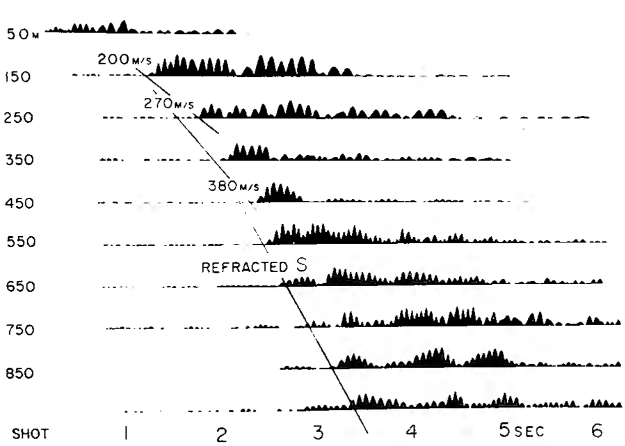


Fig. 2. Rectified wave forms of the horizontal component.

propagation velocities of P and S waves of lower and upper layers respectively.

On the other hand the Poisson's ratios of our experimental field are known to be almost 0.5 from the observations of the P and S waves. Thus the medium under consideration can, as occasion permits, approximated with those in the liquid state. The **wave length** of this wave is the longest among the wave groups and 5~10 times longer than those of the wave groups III and IV. The **amplitude distributions** in depth will be shown using an example of the experiment at Sakata City in 1956. The velocity distribution of that field has been

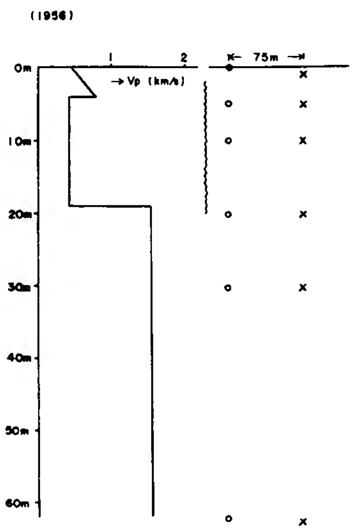


Fig. 3. Seismic profile, spreads of seismometers and shooting points of the experimental field at Sakata City in 1956.

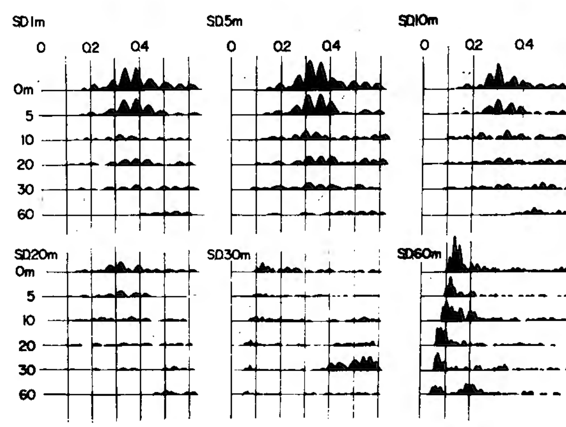


Fig. 4. Records from the various shot-depths.

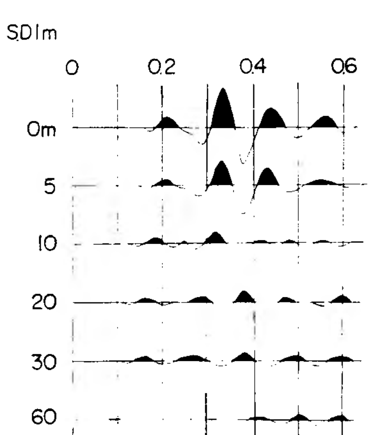


Fig. 5. Closed-up view of the seismograph at the shot-depth of lm.

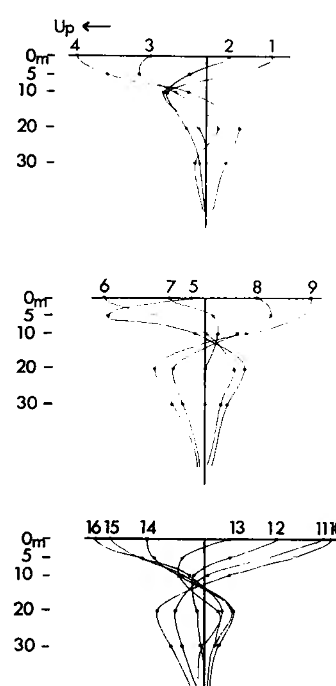


Fig. 6. Amplitude distributions with depth of the wave group II.

determined as shown in Fig. 3. Spreads of the seismometers and shooting points have been also drown in the same figure. The wave forms of the wave group II obtained at that field have been reproduced in Figs. 4 and 5. The records from the various shot-depths (S.D. : 1, 5, 10, 20, 30 and 60 m) have been shown in Fig. 4. The wave group II can be seen in the cases when the shot-depths are shallower than 20 m, but in the cases of the deeper shot points (30 m and 60 m) it can not be found.

According to the seismic profile derived from the P waves there is a distinct discontinuity at the depth of 19 m. This suggests that the wave group II can not be observed as a remarkable phase when the explosives are fired in the lower medium. As shown in Fig. 5, its phases turn over at the depth of about 10 m and its amplitude decreases exponentially with depth. In Fig. 6 the amplitude distributions with depth of this wave have been demostrated in graphs.

3. Comparison between characteristics of the wave group II and the normal mode wave generated in the medium composed of liquid-liquid layers

When our consideration is restricted to the P waves only the characteristics of the main part of the wave group II bear resemblances to the normal mode wave in the liquid-liquid layers. Namely, its phase velocity is lying between the velocities of the P waves in the surface layer and half space, and its amplitude in depth shows the distribution having a loop on the surface, and one node in the layer and decreases exponentially with depth in the half space.

As mentioned beforehand the Poisson's ratios of the experimental fields, as we are concerned, are almost 0.5, thus the media under consideration can be approximated with those in the liquid state.

In order to compare the normal mode waves in the liquid-liquid layers (P-P mode) with the wave group II, phase- and group-velocities and distributions of amplitudes with depth of the P-P mode have been computed theoretically by

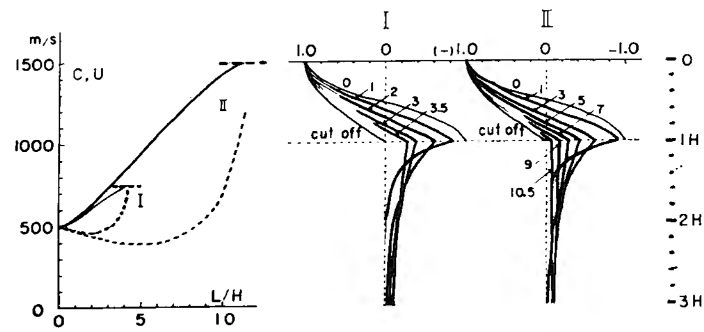


Fig. 7. Dispersion curves and amplitude distributions with depth to the P–P mode in liquid-liquid layers.

using the schematic velocity distributions of the P waves in our experimental fields, and its results have been summed up in Fig. 7. In this computations the following two models have been adopted ;

Case 1. $V_p=750$ m/s, $V_p'=500$ m/s,

Case 2. $V_p=1500$ m/s, $V_p'=500$ m/s,

where V_p and V_p' are the velocities of the P waves in the half space and the surface layer respectively.

The computed results suggest a good agreement with the characteristics of the wave group II and the amplitude distributions with depth.

4. Fluidity and Elasticity of the experimental fields

The discussion in the preceding section insists that the main part of the wave group II is just equivalent to the normal mode wave in the liquid-liquid layers (P-P mode). In the strict sense of the word the P-P mode, however, is the surface wave in the perfect liquid medium. In spite of this, the dispersive Rayleigh waves to be guided in the solid medium, that is, the wave groups of III and IV are also clearly observed. So, to explain the above evidences one might assume that the medium under consideration has two different properties such as fluidity and elasticity. This seems to be incompatible, but it may be possible to disclose this unusuality if the SV waves produced secondarily at the boundaries are, at least in the P-zone, very small in comparison to the P waves, since in this time domain the SV waves generated directly from the origin can not appear because of their slow speeds and thus the medium could be essentially equal to the liquid state.

In order to ascertain this point the amplitudes of the converted waves derived from the incident P and SV waves to the boundary surfaces have been computed in the following cases.

Case A Amplitudes of converted waves at the interface.

Two cases are calculated; one is

(a) Incident P waves from lower medium, and the other is

(b) Incident P waves from upper medium.

Here the velocity ratio of the lower medium (V) to the upper one (V') has been taken as $V/V'=3.0$ (hence $V_p/V_p'=3.0$, and $V_s/V_s'=3.0$). This velocity ratio of $V/V'=3.0$ is a representative to the observation. The velocities of the P and S waves in the lower medium have been taken as;

Case	1	2	3	4	5
V_p	1500	1500	1500	1500	1500 m/s
V_s	900	600	300	150	75 m/s.

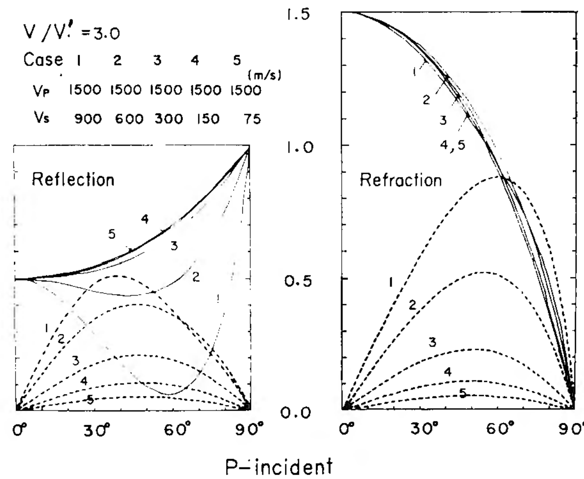


Fig. 8. Amplitudes of converted waves at the interface for incident P waves from lower medium.

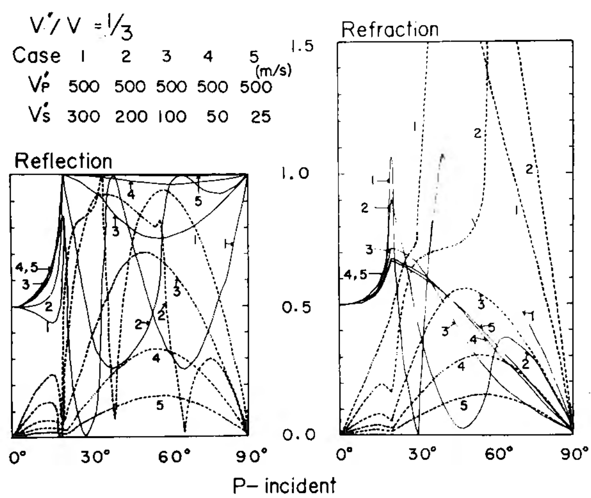


Fig. 9. Amplitudes of converted waves at the interface for incident P waves from upper medium.

where the Poisson's ratios of each case are 0.2188, 0.4048, 0.4792, 0.4949 and 0.4987 respectively.

The velocity of the P waves in the lower medium has been fixed as 1500 m/s, since this has frequently observed in our experimental sites. The computed results of the cases (a) and (b) have been shown in Figs. 8 and 9.

Case B Amplitudes of the converted waves at the free surface in case of incident P waves.

Taking the same velocity ratios between P and S waves in the Case A, computation of the amplitudes of the reflected waves at the free surface has been made and its results have been shown in Fig. 12-(1).

In Figs. 8, 9 and 12-(1) the incident P waves have been taken as unit. Let us make attention to the case 5 in the above figures. In this case the converted S waves (reflected and refracted) have small amplitudes compared with the P waves and thus the effect of conversion is really faint.

As frequently mentioned the Poisson's ratio of our experimental field is almost the value of 0.5. Therefore it is concluded that in the P-zone the amount

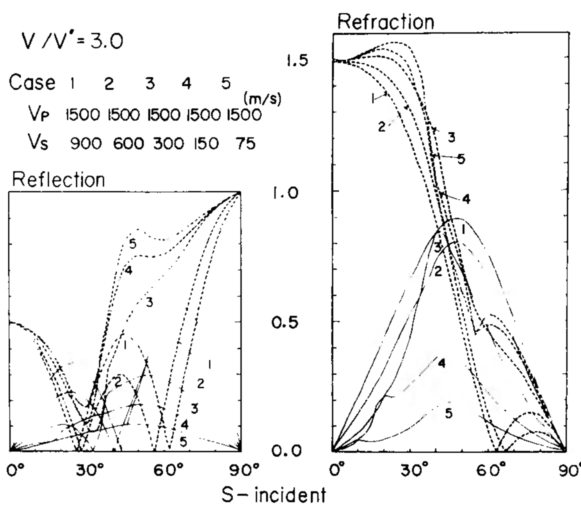


Fig. 10. Amplitudes of converted waves at the interface for incident S waves from upper medium.

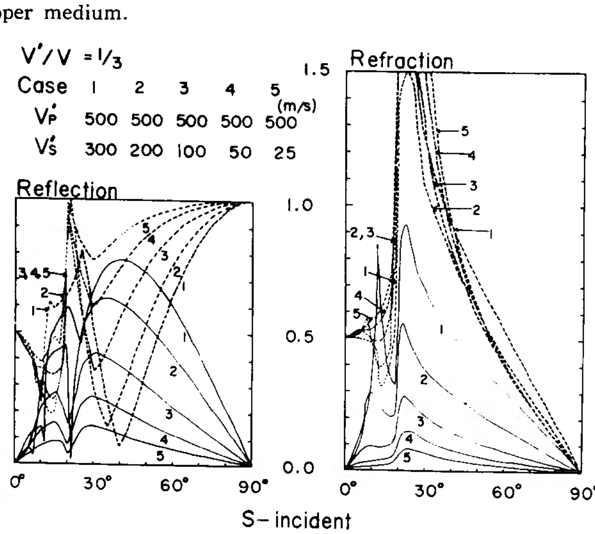
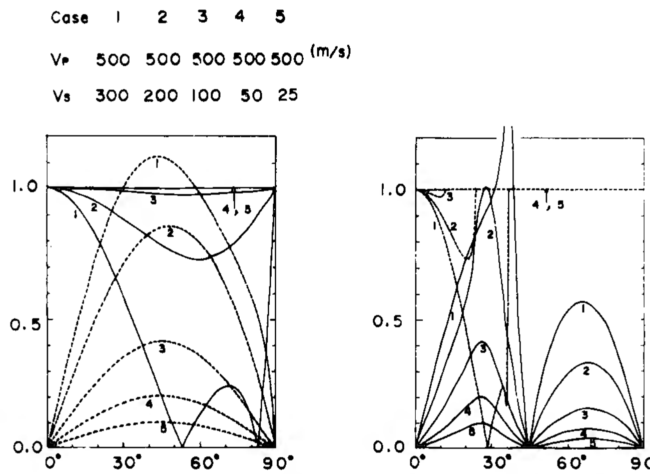


Fig. 11. Amplitudes of converted waves at the interface for incident S waves from lower medium.



(1) (2)

Fig. 12. Amplitudes of converted waves at the free surface.

of energy to S waves is negligibly small in the fields as we are concerned. Then in the P-zone elastic waves recognizable are restricted to the P waves alone and the circumstances resemble closely to the liquid state.

In Figs. 10, 11 and 12-(2) the computed results of the cases where the incident waves are SV type have been shown. From these computations it is said that the refracted and reflected waves are, too, composed mainly of the SV waves in cases when the Poisson's ratios of the medium are almost 0.5. Thus in our field two types of the waves such as refracted (and reflected) S waves and refracted (and reflected) P waves from the incident P waves are coexisting, after the arrival time of the head S waves.

In the elastic medium of which Poisson's ratio is nearly equal to 0.5, in a word, the P and S waves behave independently and therefore there are not much converted waves.

5. Conclusions

From the investigations of the main part of the wave group II generated by the small explosions it is concluded that the characteristics of this type of wave are just equivalent to those of the normal mode waves in liquid-liquid layers. The Poisson's ratios of our experimental field are almost 0.5 and observed seismic records from the explosions can be divided into two, that is, the P- and S-zones before and after the refracted S-lines.

The computations of the amplitudes of the converted SV waves derived from the incident P waves show that in the P-zone the converted SV waves have negligible small amplitudes compared with the P waves when the Poisson's ratio of the medium is almost 0.5. Thus in the P-zone it resembles closely to the liquid state. The surface waves in the P-zone (wave group II) can be conseder-ed as the normal mode waves in the liquid-liquid layers. In the S-zone both P and S waves are coexisting. Then the surface waves in this zone (III and IV) belong to the usual elastic waves in solid. In short, the media similar to our experimental fields as composed of thick alluvial layers behave as liquid in the P-zone and as solid in the S-zone, in connection with the phenomena of the propagation of the seismic waves.

It is wellknown that P, SV and SH waves generated from the dynamite explosions in the ground. The surface waves produced from each wave can be theoretically considered as follows and they have actually been observed;

	Surface wave (wave group)	Derived from
(i)	Normal mode wave in liquid-liquid medium (wave group II),	P
(ii)	Normal mode Rayleigh waves (wave groups III and IV),	SV and P
(iii)	Love waves*,	SH

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* Details of Love waves produced by explosions will be reported in another paper.

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