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Generation and Propagation of Lateral Wave by Sound Source in Underground Duct
地中ダクト内の音源によるラテラル波の発生と伝搬

Toshiaki Kikuchi[1†], Koichi Mizutani[2] ([1]NDA; [2]Uiniv. of Tsukuba)
菊池年晃 [1†]，水谷孝一 [2]，([1] 防衛大, [2] 筑波大)

1. Introduction

The occurrence of an earthquake and the radiation of seismic waves are highly dependent on the structure of an active fault, and the propagation of waves inside it. Based on observation data, we investigated the relationship between the vibration structure of a hypocenter and the radiation waves. The results indicated that the mechanism by which shock waves propagate along the active faults greatly contributes to the radiation characteristics of seismic waves[1,2)]. In addition, it showed that the lateral wave, which is a boundary wave, contributes to the propagation mechanism in the active fault. However, the active fault is formed a duct structure with two boundaries, and the frequency of propagating seismic waves is the low frequency of several hertz. Also, the propagation from the sound source placed inside the duct is not well known. In this paper, when the width of a duct is smaller than a wavelength, how the lateral wave propagates at the boundary of the duct is verified. From the result, we show that the lateral waves propagate on two adjacent boundaries.

2. Propagation in duct
2.1 Lateral wave

As shown in **Fig.1**, it is known that a part of sound waves incident on a boundary where two mediums are in contact at a critical angle propagates as a lateral wave. The lateral wave at far distance from a sound source is given by [3)],

$$p_1 = 2\mathrm{i}n\exp\left[\mathrm{i}k\left(L_1+L_2+nL\right)\right]\left[km\left(1-n^2\right)r^{1/2}L^{3/2}\right]^{-1} \qquad (1)$$

where $|SC| = L_1$, $|DP| = L_2$, $|CD| = L$,
$R_1 \equiv \left[(z+z_0)^2 + r^2\right]^{1/2}$, $n = \rho_1/\rho_2$, $m = c_1/c_2$

On the other hand, the width of the active fault is not larger than the wavelength of propagating waves, and the adaptation condition is $|kR_1| \approx 1$.

That is, Application of Eq.(1) to the vibration analysis of the active fault is difficult.

2.2 Lateral waves in a duct

In the case of an active faults, it is necessary to consider the lateral waves on two approaching boundaries. Therefore, we examine how the generation and propagation of the lateral waves are performed in a so-called duct structure where the two boundaries are adjacent. As shown in **Fig.2**, a sound source is disposed near the lower boundary, and the upper boundary is located at a position sufficiently far from the lower boundary. Then, the depth of the lower boundary and the sound source are fixed to 21 km and 20 km, respectively, and the depth of the upper boundary is changed. The wave radiated from the sound source is a single pulse of 6 Hz and 1 Cycle.

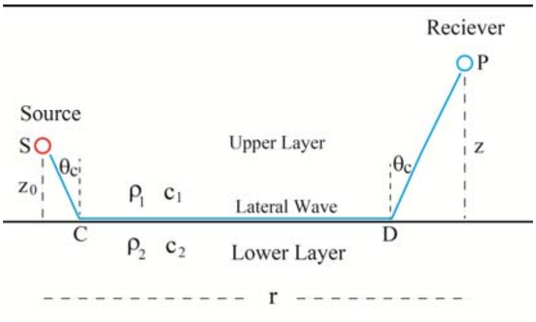

Fig.1 Schematic diagram of lateral wave

We fix the depth of the observation point to 20 km which is the same as the depth of the sound source and observe the received waveform with respect to the horizontal distance from the sound source. When the depth of the upper boundary is 9 km, the received waveform at the horizontal distance of 50 km is shown in **Fig.3**. The horizontal axis is the propagation time from the sound source, and the vertical axis is the normalized amplitude. The marks A, B, C and D are the lower boundary lateral wave, the upper boundary lateral wave, the surface reflected wave and the bottom

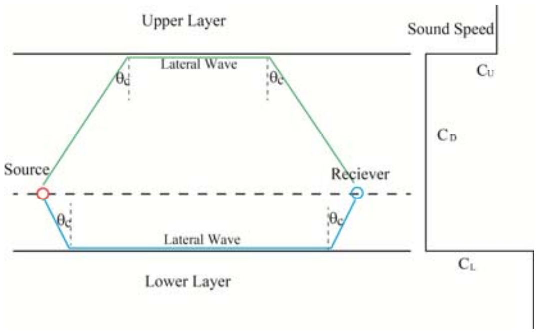

Fig.2 Conceptual diagram of duct model

[†]ads01881@nifty.com

boundary reflected wave, respectively. From this figure it is clear that both the lower boundary lateral wave and upper boundary lateral wave are present. As the horizontal distance of the observation point decreases in this propagation environment, mark B gradually lags with respect to mark A and the amplitude decreases and mark B does not appear below 20 km.

Next, we examine the effect of the depth of the upper boundary. The depth of the lower boundary and sound source are fixed to 21 and 20 km, respectively. Furthermore, the receiving distance is fixed at 50 km. And in this environment, the depth of the upper boundary is increased. Changes of marks A and B are examined while increasing the depth of the upper boundary from 9 km to 19 km. In this case, the depth of the lower boundary (21 km) and the sound source (20 km) are kept constant. The mark A and B approach as the depth of the upper boundary increases, and overlap when the depth of the upper boundary is 14 km. Afterwards they are gradually leave. In this process, the propagation time of the mark A is changed by about 0.5 seconds. From the above results, it is clear that the lateral waves propagated on the upper boundary and lower boundary, even if the two boundary intervals changed from 2 km to 12 km. However, in this process an interference between marks A and B appears.

Next, the effect of the interference between the marks A and B is investigated. When the two boundaries are close to each other, the marks A and B do not separate but be interfere with each other.
Therefore, in order to investigate the interference of the two waves, the sound speed of the lower half space medium is changed. In this case, the depth of the upper boundary is kept constant at 19 km and the source depth is kept constant at 20 km. Then, the distance at which the amplitude of the pulse in which the mark A and mark B interfere is the minimum is obtained. When the velocity of the lower half space medium is increased from 6000 m/s to 9000 m/s, the distance at which the amplitude became the minimum changed from 30 km to 27 km. The results are shown in **Fig.4**. The above figure shows the minimum amplitude interference pulse in the case of C_L: 6000 m/s, the distance: 30 km. The figure below shows the minimum amplitude interference pulse for C_L: 9000 m/s and the distance: 27 km.
When C_L increased from 6000 m/s to 9000 m/s, the interference pulses moved from 30 km to 27 km.

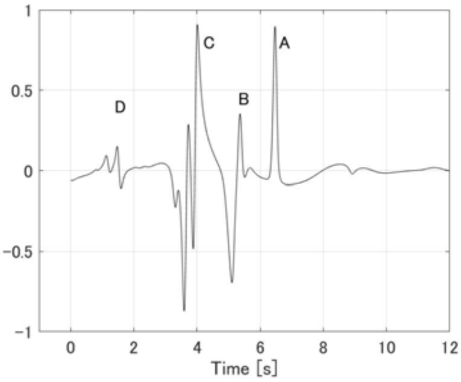

Fig.3 Received wave at 50 km. A: lateral wave on lower boundary, B: lateral wave on upper boundary, C: surface reflected wave and D: bottom reflected wave.

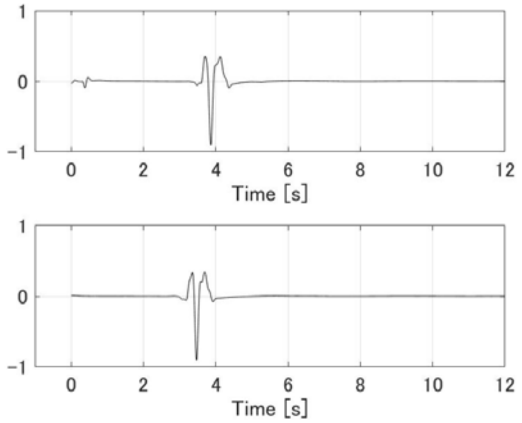

Fig.4 Interference minimum pulse between mark A and B, for C_L:6000 m/s(upper), and C_L:9000 m/s(lower).

Since the velocity of the upper layer medium does not change in this process, it can be seen that the change of the interference pulse becomes faster as the velocity C_L increases.

3. Summary

We simulated the occurrence and propagation of the lateral waves in the duct structure modeling active faults. Then, the relationship between the width of the duct, and the generation and propagation of the pulse was investigated. As a result, even if the duct width is smaller than the wavelength, the lateral waves are generated at the two boundaries, and it is clarified that they propagate together while interfering. These are important results for propagation of shock waves in the active faults.

References

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3. L.M.Brekhovskikh, *Acoustics of Layered Media II*、(Springer 1999), Chapter 3