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3D Location Estimation of Drill-bit for HDD Method Using Giant-magnetostrictive Vibrator
超磁歪振動子を用いたHDD工法におけるドリルビット三次元位置推定

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1. Introduction

HDD Method is commonly used as a way for laying pipeline of electricity, gas, water supply, etc. with Non-open cut. When the method is used, location of drill-bit in the ground must be determined at any time, and this determination accuracy affects location of buried pipe directly. The conventionally-known method for determining location of the drill-bit is the method using electromagnetic wave. However, it can determine the location only just above drill-bit. Therefore it can't be used in case there are houses and other buildings on the line of construction. In addition, it also can't accurately determine in case electromagnetic wave is affected by any factors, for example electromagnetic wave is affected by moisture content of ground, and there is a steel tower near the construction site.

The purpose of this research is to measure the elastic wave generated by drill-bit from underground with multiple sensors placed on ground, and to establish the method of 3D location estimation of drill-bit from arrival time difference of elastic wave to each sensor, and then finally to operate this system in full-scale. As one of the research to do that, in this experiment we examined the availability of characteristic elastic wave generated by giant-magnetostrictive vibrator.

2. Measuring principle

If possible, location estimation shall be conducted by measuring the time lag between generation of the elastic wave and arrival of this wave to each sensor. However, it is actually difficult to start measuring as soon as the elastic wave is generated because there isn't sufficient electricity near the drill-bit. Therefore, the location estimation like usual triangulation cannot be applied. Thus, the measuring is started as soon as the elastic wave reach one of the sensors placed on ground, and 3D Location Estimation is conducted from the arrival time difference of elastic wave to each sensor. At first, we think about the case using two sensors. Henceforth, in this research a direction of drill-bit on the surface of the ground is x-axis, a direction perpendicular to x-axis on the surface is y-axis, and an upper direction perpendicular to the surface is z-axis. **Fig. 1** is the model of the case that two sensors and drill-bit are on a surface perpendicular to the surface of the ground and parallel to the x-axis. In this model, we suppose that the layer model around the construction site is uniform and the elastic wave transmits to sensor taking the shortest path without inflection. The location of drill-bit cannot be determined completely with two sensors, but from the model of Fig. 1 it is found that the drill-bit exist on the locus indicated by **eq. (1)**.

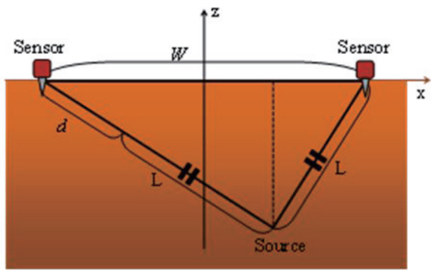

Fig. 1 Model of Location Estimation

$$z = -\sqrt{(W^2 - d^2)(\frac{x^2}{d^2} - 0.25)} \quad \cdot\cdot\cdot (1)$$

W: Distance between both sensors
D: Distance difference from each sensor to Source

Where, d is described by arrival time difference of elastic wave to two each sensor and transmission velocity of elastic wave v. Considering changes of transmission velocity by soil property, it would appear that eq. (1) has three unknown letters z, x, v.

Secondly, we think about the case that there isn't drill-bit on the plane surface of Fig. 1. From eq. (1), locus of 3-dimension is indicated by **eq. (2)** using y.

$$z = -\sqrt{(W^2 - d^2)(\frac{x^2}{d^2} - 0.25) - y^2} \quad \cdot\cdot\cdot (2)$$

For these reasons, locus that has four unknown letters x, y, z, v is obtained by measuring elastic wave from drill-bit with two sensors. Thus, if we can obtain four loci, it would appear that it is possible to determine location of drill-bit by solving their solution. Also, when we actually apply them to location estimation, it is necessary to consider location relation of sensors and drill-bit.

3. Experimental method

Fig. 2 shows a schematic of the experimental setup. The soil of experimental site is about clay layer but it of surface of the site is gravel layer. This experiment was conducted by measuring elastic wave generated by giant-magnetostrictive Vibrator. It was used with it thrust into a pile made of steel hammered in the ground during this experiment. As input waveform, an up-chirp waveform whose frequency is 50-200Hz was used. Its input times was 2s. To measure this wave, multiple geophones were used as receivers. Setup of these geophones is shown in **Fig. 3**.

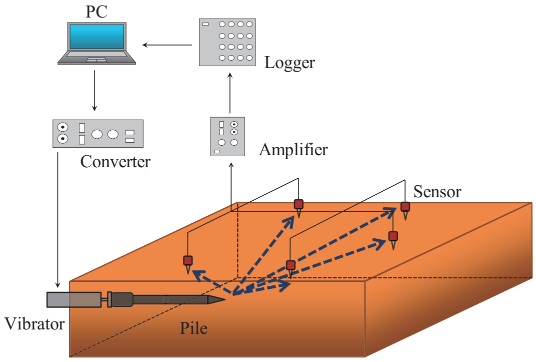

Fig. 2 Schematic of experimental setup

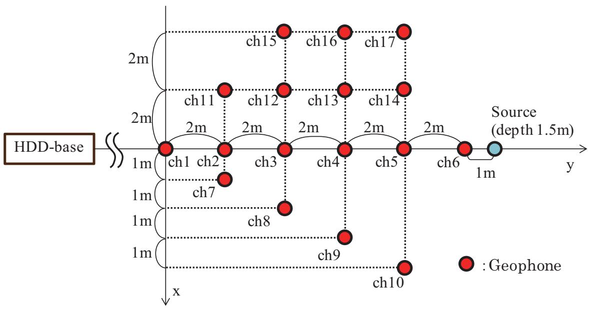

Fig. 3 Setup of geophones

4. Result of experiment

Fig. 4 (a) and (c) show waveforms measured at Ch6 and Ch4. Fig. 4 (b) and (d) show waveforms filtered by band pass filter whose range of frequency is 80-180Hz. **Fig. 5** shows the time-frequency maps obtained by applying wavelet transform to the waveforms of Fig. 4 (a) and (c). Sensor at Ch6 is the nearest sensor to the source. Its waveform indicates that the elastic wave generated by giant-magnetostrictive vibrator reaches sensor at Ch6 with keeping characteristics of input waveform. But compared to Ch6, the waveform of Ch4 is so noisy. Therefore it is difficult to extract characteristics of input waveform. However, by using band pass filter, it gets easier to do that. Fig. 5 indicates that the frequency of the waveform of Ch6 and Ch4 increases with time. From this, S/N ratio decreases with increasing distance from the source especially at the higher frequencies but these waveforms keep characteristics of input waveform even at Ch1.

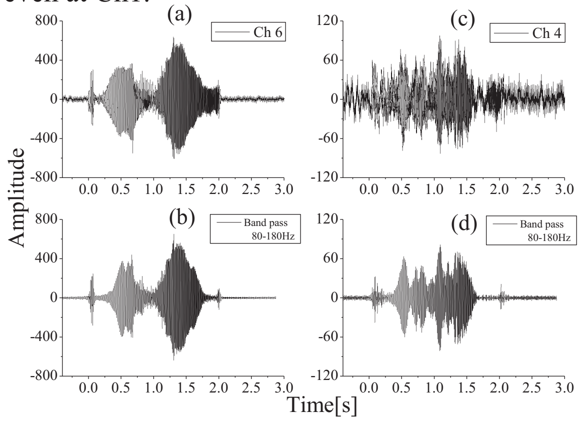

Fig. 4 Measured and filtered waveform of Ch6 and 4

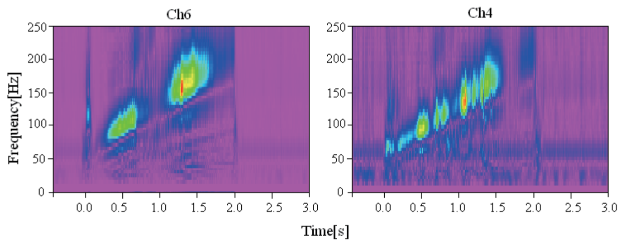

Fig. 5 Time-Frequency map of Ch6 and 4

5. Conclusions

The purpose of this research is to measure the elastic wave generated by drill-bit from underground with multiple sensors placed on ground and to establish the method of 3D location estimation of drill-bit from arrival time difference of elastic wave to each sensor. In this experiment, the availability of elastic wave generated by giant-magnetostrictive vibrator is examined. S/N ratio decreases especially at the higher frequencies with increasing distance from the source. But, It was confirmed that elastic wave generated by giant-magnetstrictive vibrator reach to Ch1 with keeping characteristics of input waveform. For these reasons, we think that there is a possibility of the method of location estimation using this elastic wave.

Acknowledgment

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