Using of Piezoelectric Ceramic Sensor to Measure the Shear Wave Velocity of Bangkok Clay

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Abstract

This paper presents the measurement of the shear wave velocity at the Soil Mechanics Laboratory of the Department of Civil and Environmental Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok. The research proposes a new technique to measure the shear wave velocity by using piezoelectric ceramic sensors. The details of this new technique and its interpretations on Bangkok clay material are clearly explained. The research found that this new technique is a reasonable technique, giving the shear wave velocity result in good agreement with the shear wave velocity data of the field test.

Keywords: piezoelectric ceramic materials, shear wave velocity, Bangkok clay

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1. Introduction

Currently, the Laboratory of Soil Mechanics, Department of Civil and Environmental Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok develops the new test set-up for measurement of the shear wave velocity, V_s, by means of elastic shear wave propagation. This new test uses the principle of wave propagation through soils as described in [1]. [2] used similar piezoelectric ceramic sensors to examine the anisotropy of clay and [3] used piezoelectric ceramic sensors to assess the disturbance of soil samples.

This shear wave velocity is an important parameter in earthquake engineering and the prediction of soil structure interaction. The shear wave is generated and received by piezoelectric ceramic sensors placed at opposite ends of the soil sample. The shear wave velocity is calculated from the tip to tip distance between the two sensors and the time required by the shear wave to cover this distance as shown in Eq. (1).

$$V_s = L/t \quad (1)$$

where V_s is the shear wave velocity, L is the tip to tip distance between two sensors and t is the required time to cover this distance. The required time can be calculated by using Equation 2.

$$t = t_t - t_c \quad (2)$$

where t_t is the total travel time and t_c is the offset time.

2. Operation of Piezoelectric Ceramic Materials

The working principle of piezoelectric ceramic sensors is based on the properties of piezoelectric ceramic materials as described by [4]. A voltage applied to faces of a combination of two piezoelectric ceramic materials causes one to expand while the other contracts, causing the entire element to bend as shown in Fig.1. Similarly, a lateral disturbance of the piezoelectric ceramic sensors will produce a voltage so the piezoelectric ceramic sensors can be used as both shear wave sending and receiving sensors. Measurement of time delay of the shear wave between sending and receiving sensors will provide the shear wave velocity as described in [5] and [6].

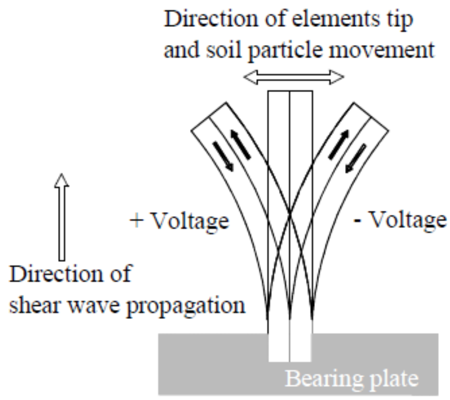

Fig. 1 Operation of piezoelectric ceramic sensor (after [4])

There are two types of piezoelectric ceramic sensors as described by [1]. One is a series connected element and the other is a parallel connected element. The series connected element is shown in Fig. 2a. Note that the polarization is oriented in opposite directions for each plate. An electrical wire lead is attached to each of the outer electrode surfaces. The parallel connected element is shown in Figure 2b. In this second type of elements, the polarization has the same direction for both plates. The electrical connections are attached such that the two outer electrode surfaces are the same pole and the center electrode is the other pole. To attach an electrical wire lead to the center electrode, a portion of the element must be ground away. The series connected element is better used as receiver. On the other hand, the parallel connected element is better used as transmitter. However, this research uses only the parallel connected type for both transmitter and receiver transducers due to the advantage in measurement of sending signal.

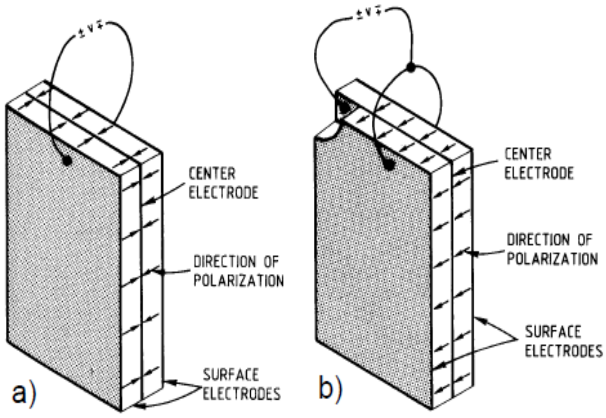

Fig. 2 Types of piegoeloctrict ceramic sensors : a) Series and b) Parallel connected elements (after [1])

Figure 3 shows the schematic detail of the sending sensor. Figure 4 shows the sending sensor using in this research. This sensor is a non-magnetic piezoceramic with non-magnetic electrodes and non-magnetic reinforcing materials. This sending sensor (T220-A4NM-303Y) is manufactured from the Piezo System, Inc. The size of the sending sensor is 12.7 mm in width, 15.9 mm in length and 0.51 mm in thickness. The research uses this sensor to send the shear wave because of the strong sending signal.

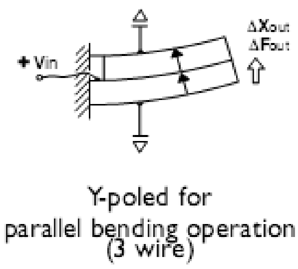

Fig. 3 Schematic of the piezoelectric ceramic sensor

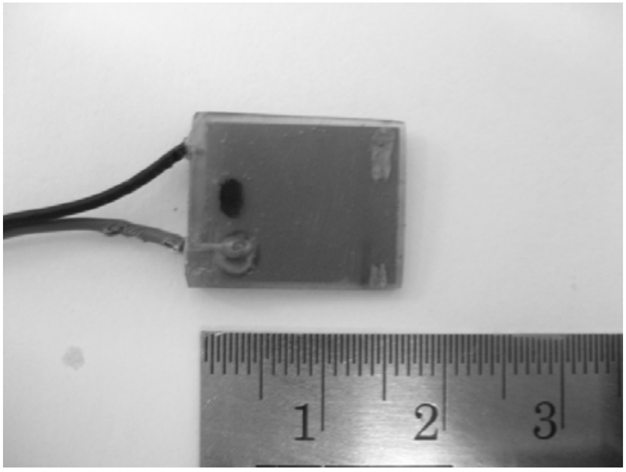

Fig. 4 The piezoelectric ceramic sensor

Fig. 5 shows the schematic test set-up. A personal computer generates a signal through a sound card with 5V peak to peak as suggested by [7]. This signal is amplified to 40V peak to peak. An oscilloscope is used to measure the arrival time between a sending signal and a receiving signal. A voltage pulse is applied to the sending sensor, this causes it to produce a shear wave. When the shear wave reaches the other end of the soil sample, distortion of the receiving sensor produces another voltage pulse. The receiving sensor is directly connected to the oscilloscope to compare the difference in time between the sending and the receiving signals. The shear wave velocity measurements are usually performed with frequencies ranging between 2 to 12 kHz, at strains estimated to be less than 0.0001 %. At low frequencies, signals can be influenced by a near-field effect. At high frequencies, the receiving signal is very weak and difficult to interpret. In most cases, signals are averaged 32 times in order to get a clear signal.

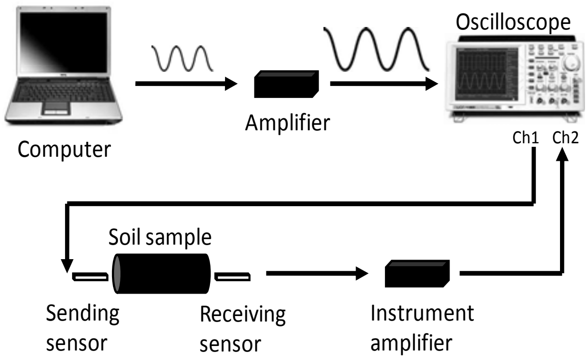

Fig. 5 Schematic of shear wave measurement and associated electronics

3. Quality Assurance of Piezoelectric Sensors

Before performing tests, it is essential to calibrate the complete system. To ensure that there is no delay time in the measurement due to the electronics, ceramics and coating material. Fig. 6 shows that the sending and receiving sensors are connected and performed the test to measure the offset time. The test result is depicted in Fig. 7 showing the offset time of 4 μs. The measurement of shear wave velocity in soil sample by means of piezoelectric ceramic sensors is clearly described by [5] and [6]. Then, the sending and receiving sensors are placed away from each others at the suitable height and distance by clamping. No shear wave arrival should be recorded when perform the test in the air or in the water. Fig. 8 shows the mounting of the piezoelectric ceramics sending and receiving sensors on the Bangkok clay sample.

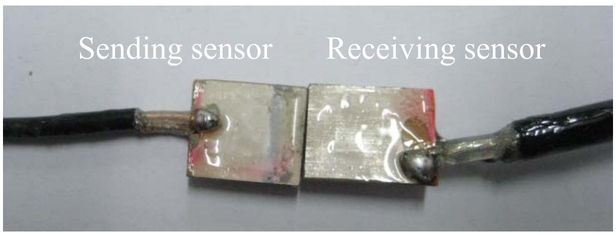

Fig. 6 Quality assurance of piezoelectric ceramic sensor

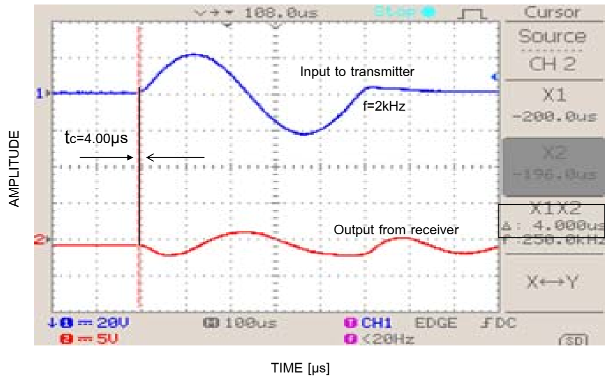

Fig.7 Calibration of piezoelectric ceramic sensor

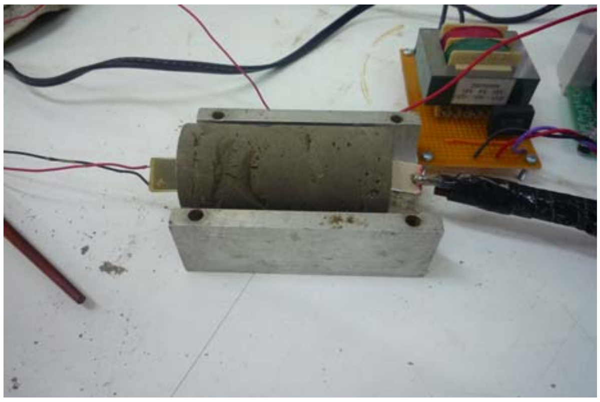

Fig. 8 Mounting of piezoelectric ceramic sensor on the Bangkok clay sample

4. Bangkok Clay Materials

The geological condition of Bangkok is reported by [8] that Bangkok is situated on a large plain underlain by alluvial and deltaic sediments of the Chaophraya basin. This plain is about 13,800 km^2 in area and is generally known as "the lower central plain". The plain was under a shallow sea 3,000 to 5,000 years ago and the regression of the sea took place around 2,700 years ago, leaving the soft deposits, which form the lower central plain. This plain consists of thick clay known as Bangkok clay on its top layer, and its thickness is about 15 to 20 m in the Bangkok city area. The soft clay has very low shear strength, and is highly compressible, as it has never been subjected to mechanical consolidation.

The undisturbed Bangkok clay is sampled at the King Mongkut's University of Technology North Bangkok in Bangkok campus as seen in Fig. 9. Borehole 1 (BH 1) is located in front of the Department of Civil and Environmental Engineering Technology as shown in Figure 10. Bangkok clay samples are collected from depth of 4.0, 5.0 and 13.0 m. These undisturbed Bangkok clay samples are kept in the glass container with high humidity as seen in Figure 11. The engineering properties of Bangkok clay are shown in Table 1. From a comprehensive investigation of soil characteristics at 9 different sites around Bangkok, The generalised Bangkok soil and shear wave velocity profiles are reported by [9] as shown in Fig. 12. They first estimated shear wave velocity from specific field and laboratory soil data of the 9 sites using several published empirical correlations and then confirmed such estimates with actual insitu shear wave measurements at another 4 sites around Bangkok using a downhole method.

Fig. 9 Sampling of Bangkok clay

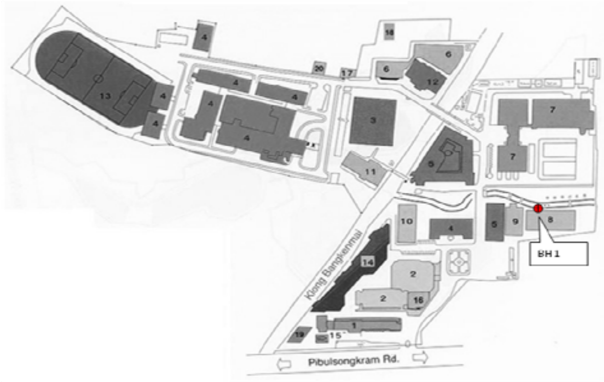

Fig. 10 The location of borehole 1 (BH 1) at the King Mongkut's University of Technology North Bangkok, Bangkok campus

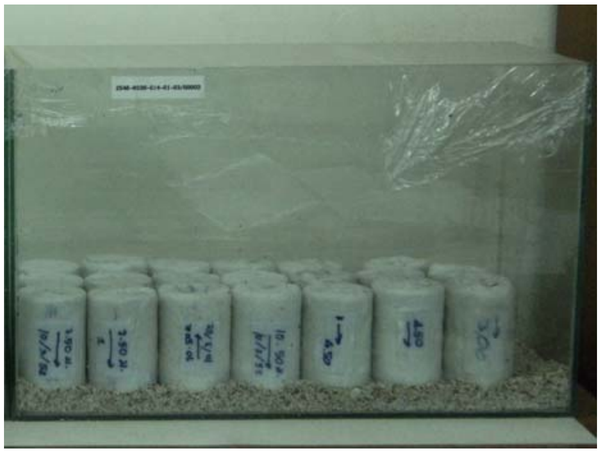

Fig. 11 Undisturbed Bangkok clay sample storage

Table 1 Engineering properties of Bangkok clay

Depth (m)	Mass density, ρ (kg/m^3)	Specific gravity, G_s	Water content, w (%)
4.0	1600	2.71	49.6
5.0	1470	2.72	90.1
13.0	2030	2.68	53.1

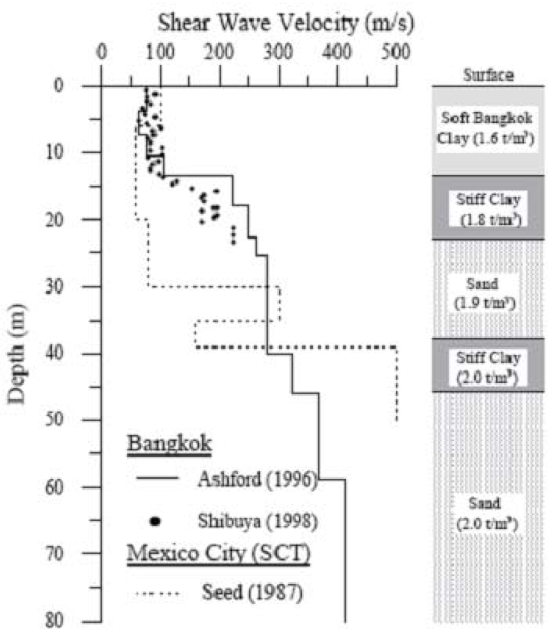

Fig. 12 Generalised Bangkok soil and shear wave velocity profiles (after [9])

5. Experimental Results

Fig. 13 showed the shear wave velocity of Bangkok clay sample from 4.0 m depth. There was a cross-talk at the beginning of the receiving signal. The total travel time, t_t, was 830 μs and the offset time was 4 μs. So, the required time, t, was 826 μs according to Eq.(2). The tip to tip distance between the transducers was 63 mm. Therefore, the shear wave velocity, V_s, of 76.3 m/s was obtained by using the Eq. (1). Fig. 12 showed the shear wave velocity profile of Bangkok formation. At the 4.0 m depth, the Bangkok soil was considered as the soft Bangkok clay with the shear wave velocity of about 70 m/s as reported by [9].

In similar way, the shear wave velocity of Bangkok clay sample at 5.0 m was measured. As seen in Fig. 14, the total travel time, t_t, of 610 μs and the required time, t, was 606 μs. The tip to tip distance was 32 mm and the shear wave velocity, V_s, was 52.8 m/s, corresponding to the shear wave velocity from the field test of about 60 m/s as seen in Fig. 12. For Bangkok clay sample at 13.0 m depth, the total travel time, t_t, of 456 μs as shown in Figure 15 and the required time, t, was 452 μs. The tip to tip distance was 60 mm and the shear wave velocity, V_s, was 132.7 m/s. At the 13.0 m depth, Fig. 12 .showed the shear wave velocity of about 100 m/s. Shear wave velocity results of Bangkok clay were shown in Table 2. Therefore, the shear wave velocity results measured from the piezoelectric ceramic sensor were in good agreement with the shear wave velocity data from the field test as seen in Fig. 16.

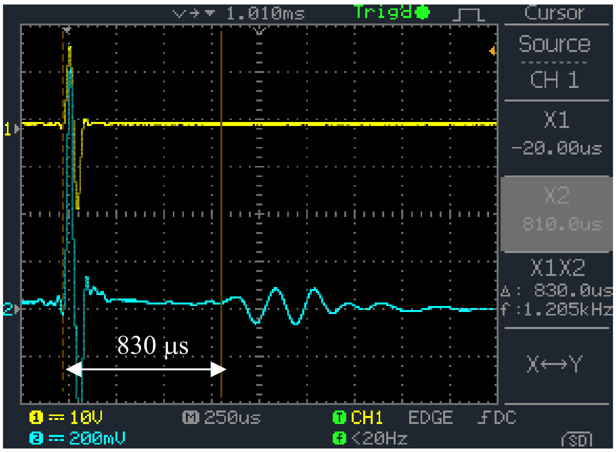

Fig. 13 Shear wave result of Bangkok clay at 4.0 m depth

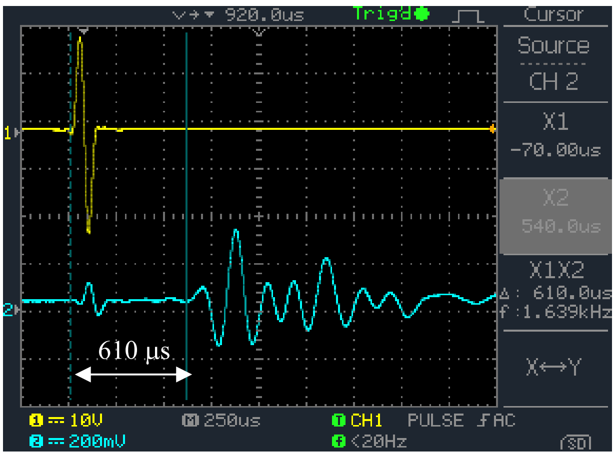

Fig. 14 Shear wave result of Bangkok clay at 5.0 m depth

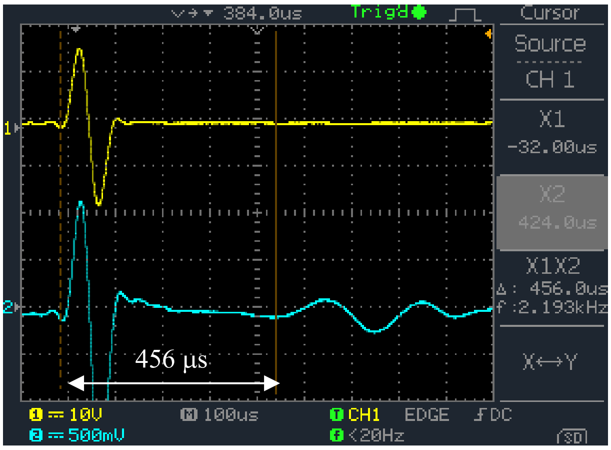

Fig. 15 Shear wave result of Bangkok clay at 13.0 m depth

Table 2 Shear wave velocity with depth of Bangkok clay

Depth (m)	V_s (m/s)
4.0	76.3
5.0	52.8
13.0	132.7

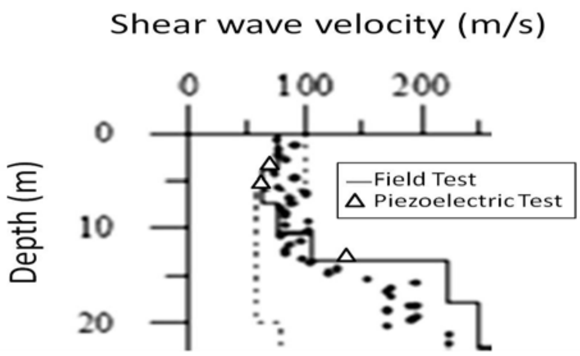

Fig. 16 Shear wave velocity results both the piezoelectric and the field tests with depth of Bangkok clay formation

6. Conclusions

The Soil Mechanic Laboratory of the Department of Civil and Environmental Engineering Technology, College of Industrial Technology was able to measure the shear wave velocities with depth of Bangkok clay by means of the piezoelectric ceramic sensors. These shear velocities were reasonable and in good agreement with the shear wave velocity data from the field test.

7. Acknowledgement

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8. References

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