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การตรวจสอบค่าโมดูลัสเฉือนของดินเหนียวกรุงเทพมหานคร โดยใช้เทคนิคของอุปกรณ์ตรวจวัดแบบเปียโซอิเล็กตริก

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บทคัดย่อ

บทความนี้นำเสนอการประยุกต์ใช้การทดสอบแบบไม่ทำลาย ซึ่งเรียกว่า “การทดสอบเบ็นเดอร์อีลีเมนต์” เพื่อวัดความเร็วคลื่นเฉือนและหาค่าโมดูลัสเฉือนของตัวอย่างดินเหนียวกรุงเทพมหานคร โดยใช้เทคนิคของอุปกรณ์ตรวจวัดแบบเปียโซอิเล็กตริก ข้อมูลจากการทดสอบเบ็นเดอร์อีลีเมนต์ในห้องปฏิบัติการได้ถูกนำไปเปรียบเทียบกับผลการทดสอบในสนามและพบว่ามีความแตกต่างกันจาก 5.3 ถึง 62.3 เปอร์เซ็นต์ เนื่องจากในสนามคลื่นเฉือนเดินทางผ่านชั้นดินที่แข็งกว่า ขณะที่ในห้องปฏิบัติการทำการทดสอบกับตัวอย่างดินที่มีขนาดเล็กและเป็นไปได้ว่ามีความแข็งแรงน้อยกว่า การคำนวณความเร็วคลื่นเฉือนในสนามอยู่บนพื้นฐานของสมมติฐานไอโซโทรปิกอีลาสติกแบบเส้นตรง ซึ่งอาจจะใช้ไม่ได้กับชั้นดินเหนียวกรุงเทพมหานคร ซึ่งอาจจะเป็นอีกสาเหตุที่ทำให้เกิดความแตกต่างของความเร็วคลื่นเฉือน

คำสำคัญ: ดินเหนียวกรุงเทพมหานคร ความเร็วคลื่นเฉือน โมดูลัสเฉือน

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Shear Modulus Investigation of Bangkok Clay Using Piezoelectric Transducer Technique

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Abstract

This article presents the application of the non-destructive testing method so called “Bender element test” to measure the shear wave velocity and determine the initial shear modulus of Bangkok clay samples by means of piezoelectric transducer technique. The laboratory bender element test data of the shear wave velocity were compared with the field test results and were shown to be different from 5.3 to 62.3% due to the field propagating waves passing along layers of higher stiffness while the laboratory test data were performed on small, possibly less stiffer material. The inversion calculation of the shear wave velocity in the field test is based on a linear elastic isotropic assumption which is not valid for the Bangkok subsoil and might be a second reason for the noticed differences in shear wave velocity.

Keywords: Bangkok Clay, Shear Wave Velocity, Shear Modulus

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1. Introduction

The initial shear modulus, G_0, is widely considered to be a fundamental soil stiffness property. It is a parameter for practical geotechnical problems both in earthquake engineering and in the prediction of soil structure interaction. The reliable determination of G_0 and inferring complete stress-strain curves especially in the small and intermediate strains, offers the possibility of deducing the functional relationship between shear modulus and strain as shown in Figure 1. At the very small strain domain (the shear strain values below the linear elastic threshold strain of about 0.001%), the G_0 does not change in the low strain range. This measurement uses the principles of wave propagation showing a direct correlation between the shear wave velocity and G_0 as described in Brignoli et al. [1]. Piriyakul [2] used similar piezoelectric ceramic sensors to assess the disturbance of soil samples and Piriyakul [3] used piezoelectric ceramic sensors to examine the anisotropy of clay soil. Piriyakul [4] applied piezoelectric ceramic sensors to measure the shear wave velocity of Bangkok clay. Piriyakul [5] used the measurement of shear wave velocity to determine the strength development of treated sand by biocementation through microbial carbonate precipitation. Chan [6] studied the effect of bender element installation on the measurement of shear wave velocity and found that the installation of bender element inside the clay samples did not cause disturbance to the sample. The objective of this study is to investigate the initial shear modulus of Bangkok clay by means of piezoelectric transducer technique. The shear wave is generated and received by piezoelectric transducers placed at opposite ends of the soil specimen. The shear wave velocity is calculated from the tip to tip distance between the two transducers and the time required by the shear wave to cover this distance as shown in Equation 1.

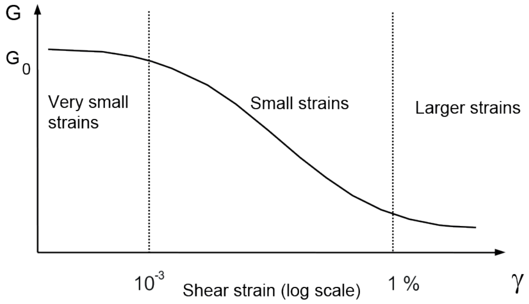

Figure 1 Typical variation of shear modulus with shear strain for soils [1].

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

where V_s is the shear wave velocity in m/s, L is the tip to tip distance between two transducers in mm, and t is the required time to cover this distance in µs as shown in Equation 2.

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

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

After obtaining the shear wave velocity, the initial shear modulus, G_0, in MPa is calculated using the relationship of elastic continuum mechanics as shown in Equation 3.

$$G_0 = \rho . V_s^2 \qquad (3)$$

2. Operation of Piezoelectric Transducer

The principle of piezoelectric transducer is based on the properties of piezoelectric ceramic materials. A voltage applied to faces of a combination of two

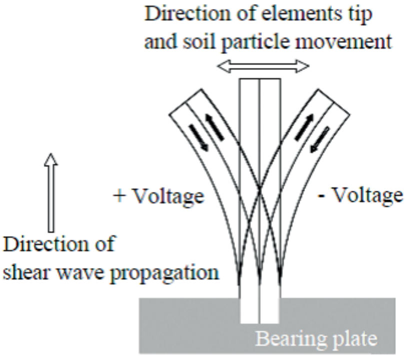

Figure 2 Operation of piezoelectric transducer [8].

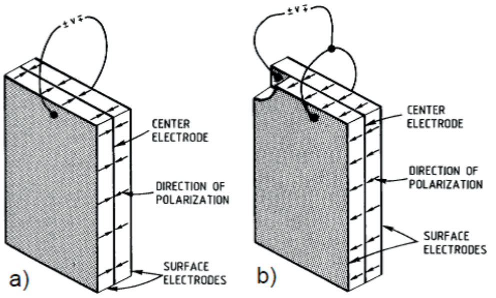

Figure 3 a) Series and b) Parallel connected piezo electric transducers [7].

piezoelectric ceramic materials causes one to expand while the other contracts, causing the entire element to bend as described by Dyvik and Madshus [7] and shown in Figure 2. Similarly, a lateral disturbance of the piezoelectric transducer will produce a voltage so the piezoelectric transducer can be used as both shear wave transmitter and receiver. Measurement of time delay between sending and receiving of the shear wave will provide the shear wave velocity.

There are two types of piezoelectric transducers. One is a series connected piezoelectric transducer and the other is a parallel connected piezoelectric transducer. The series connected piezoelectric transducer is shown in Figure 3a. Noting that the polarization is oriented in opposite directions for each plate. An electrical wire lead is attached to each of the outer electrode surfaces.

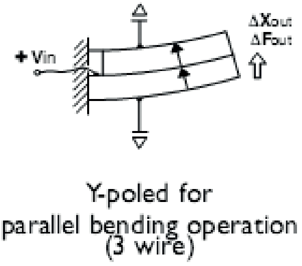

Figure 4 Schematic of the piezoelectric ceramic transducer.

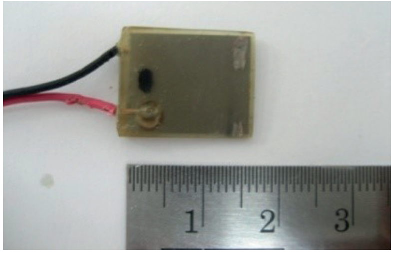

Figure 5 Piezoelectric ceramic transducer.

The parallel connected piezoelectric transducer is shown in Figure 3b. In this second type of piezoelectric transducer, 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 piezoelectric transducer is better to use as receiver. On the other hand, the parallel connected piezoelectric transducer is better to use as transmitter. However, this research uses only the parallel type for both transmitter and receiver transducers due to the advantage in measurement of sending signal.

Figure 4 shows the schematic detail of the piezoelectric transducer and Figure 5 shows the piezoelectric transducer 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)

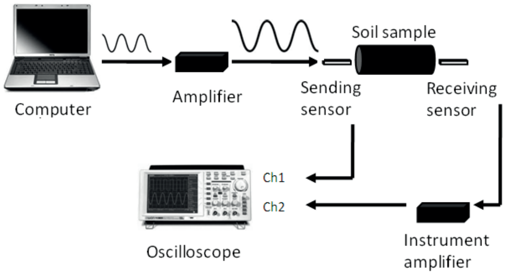

Figure 6 Schematic of shear wave measurement and associated electronics.

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.

Figure 6 shows the schematic test set-up. A personal computer generates a signal through a sound card with 5V peak to peak as suggested by Mohsin and Airey [9]. 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 transducer, this causes it to produce a shear wave. When the shear wave reaches the other end of the soil sample, distortion of the receiving transducer produces another voltage pulse. The receiving transducer 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.

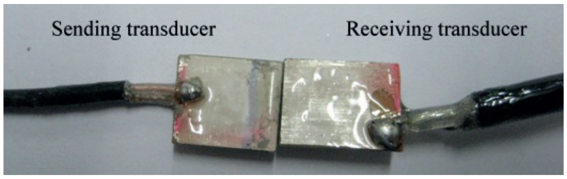

Figure 7 Quality assurance of piezoelectric ceramic transducers.

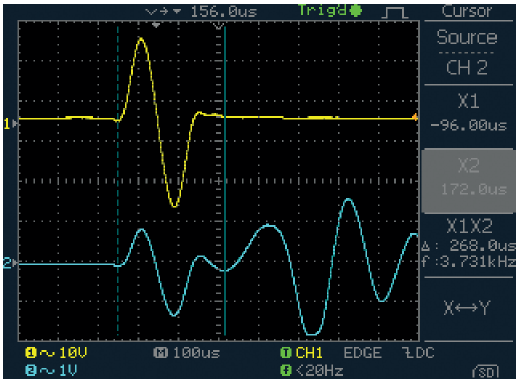

Figure 8 Calibration of piezoelectric transducers.

3. Calibration of Piezoelectric Transducer

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. Figure 7 shows that the sending and receiving transducers are connected and performed the test to measure the offset time. The calibration test result is depicted in Figure 8 showing the sending signal in the sinusoidal waveform with frequency of 2 kHz was sent and the offset time of 4 µs was measured by the receiving transducer. The measurement of shear wave velocity in soil sample by means of piezoelectric ceramic transducers is clearly described by Brignoli et al. [1] and Piriyakul [10]. Then, the sending and receiving transducers 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.

4. Bangkok Clay Material

Bangkok is situated on a large plain underlain by alluvial and deltaic sediments of the Chaophraya basin as reported by Tuladhar et al. [11]. 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. These Bangkok clay samples are collected from ground surface to about 25 m in depth. These undisturbed Bangkok clay samples are kept in the glass container with high humidity. 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 Warnitchai et al. [12] as shown in Figure 9. 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. These data were reanalysed to explore the shear wave velocity profiles of Bangkok subsoil by Teachavorasinskun and Lukkunaprasit [13] and found that the shear wave velocity of the top 30 m could be linearly correlated to the depth from the ground surface in m, z, as shown in Equation 4.

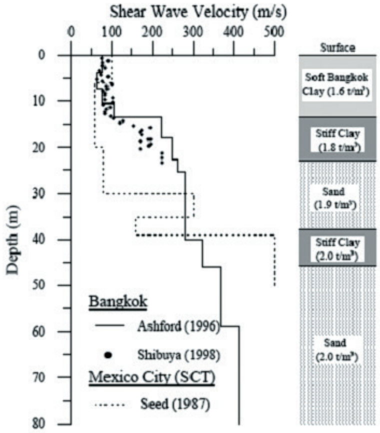

Figure 9 Generalized Bangkok soil and shear wave velocity profiles [12].

$$V_s = 45.4 + 8.8z \tag{4}$$

Table 1 Engineering properties of Bangkok clay

Depth (m)	ρ (kg/m^3)	G_s	LL (%)	PL (%)	w (%)	S_u (ksc)
4.0	1600	2.71	56.2	27.2	49.6	0.32
5.0	1470	2.72	74.8	32.1	90.1	0.21
13.0	2030	2.68	44.5	21.8	53.1	0.46
15.0	1992	2.54	41.4	12.0	26.1	1.22
18.0	2063	2.51	29.5	12.3	22.1	4.00
21.0	2105	2.56	32.8	12.1	25.0	2.75
22.5	2278	2.52	40.4	14.4	22.3	4.00
24.0	2123	2.50	26.4	11.1	17.2	3.74

where ρ is the density in kg/m^3, G_s is the specific gravity, LL is the liquid limit in %, PL is the plastic limit in %, w is the water content in % and S_u is the undrained shear strength in ksc.

5. Experimental Results

The shear wave velocity of Bangkok clay sample at 5.0 m is measured at the atmospheric pressure. The sinusoidal waveform with the frequency of 2 kHz was sent through the Bangkok clay sample and measured 32 times in order to get an averaged value. As seen in Figure 10, the total travel time, t_t, of 610 μs and the required time,

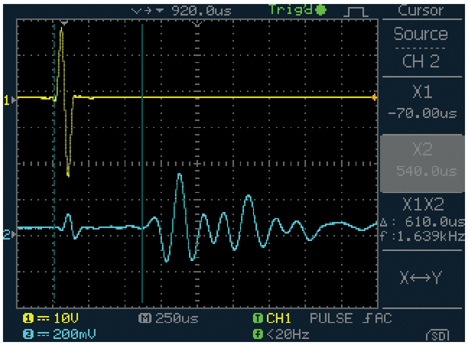

Figure 10 Shear wave result of Bangkok clay at 5.0 m depth.

t, is 606 µs. The tip to tip distance is 32 mm and the shear wave velocity, V_s, is 52.8 m/s, corresponding to the shear wave velocity from the field test of about 60 m/s as seen in Figure 9. In the similar ways, Table 2 shows the shear wave velocity data of the bender element test and the shear modulus with depth. Figure 11 presents the laboratory bender element test data compared with field test results and there were different from 5.3 to 62.3% as shown in Table 3. The bender element test data are lower than the field results. Possible reasons are the propagating waves in the field passing along layers of high stiffness while the laboratory test data is performed on smaller, possible less stiff material. Also the inversion calculation of the shear wave velocity out of the field test is based on a linear elastic isotropic assumption which might not be a suitable method for the Bangkok subsoil.

Table 2 Shear wave velocity and shear modulus results of Bangkok clay with depth

Depth (m)	V_s (m/s)	G_0 (MPa)
4.0	76.3	9.3
5.0	52.8	4.1
13.0	132.7	35.7
15.0	139.1	35.2
18.0	112.7	26.2
21.0	86.8	15.8
22.5	94.3	20.3
24.0	152.5	49.4

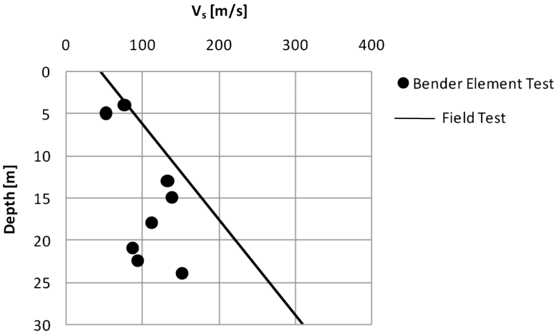

Figure 11 Shear wave velocity results both the piezo electric and the field tests with depth of Bangkok clay formation.

Table 3 Percent error of shear wave velocity

Depth (m)	V_s (m/s) Lab. Test	Vs (m/s) Field Test	% Error
4.0	76.3	80.6	5.3
5.0	52.8	89.4	40.9
13.0	132.7	159.8	17.0
15.0	139.1	177.4	21.6
18.0	112.7	203.8	44.7
21.0	86.8	230.2	62.3
22.5	94.3	243.4	61.3
24.0	152.5	256.6	40.6

6. Conclusions

The application of the non-destructive testing method to measure the shear wave velocity and the shear modulus with depth of Bangkok clay formation is an advantage technique. The Bangkok clay samples were able to be used to perform some other tests such as the unconfined compression test. The laboratory bender element test data of the shear wave velocity were compared with the field test results and found that there were different from 5.3 to 62.3% due to the field propagating waves pass along layers of higher stiffness while the laboratory test data were performed on small, possible less stiff material. The inversion calculation of the shear wave velocity in the field test is based on a linear elastic isotropic assumption which is not valid for the Bangkok subsoil and might be a second reason for the noticed differences in shear wave velocity.

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