Research on Soil Shear Strength Device Based on Shear Wave Velocity

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Abstract. The shear strength of soil refers to the ultimate resistance of the shear stress generated by the external load of the soil. The strength problem is one of the most important basic contents of soil mechanics, and shear failure is an important feature of strength damage. At present, the monitoring methods of the soil shear strength device, such as indoor direct shear test, triaxle compression test, large-scale direct shear test on site, and on-site cross shear test, cannot realize real-time measurement in situ in the long-term field. In this paper, a device for measuring the shear strength of soil based on shear wave velocity is proposed, and the shear strength of the soil in situ can be obtained in real time.

1. Introduction
The strength of the soil refers to the stress that causes the soil to break. Therefore, the strength of the soil must first be understood. Since the strength of the soil particles is much larger than the joint strength between the particles, the shear failure of the soil under external force is an important form of soil strength failure. When the shear stress along a certain plane in the soil reaches the shear strength of the surface, the shear deformation will continue to increase, causing the local shear in the soil to be continuously sheared to form a sliding surface. This can cause damage such as slope slippage or foundation instability. Therefore, the so-called soil strength refers to the maximum stress of the soil with shear damage, which can also be called the shear strength of the soil. This is an important mechanical property of soil. It is an important indicator when estimating foundation bearing capacity, evaluating soil stability, and earth pressure of retaining structures. At present, the monitoring methods of soil shear strength cannot be monitored in real time for a long time. This paper proposes a device for measuring the shear strength of soil by shear wave velocity, and monitors the soil in real time through piezoelectric ceramics, integrated circuits and single-chip microcomputer. Shear strength.

2. Principle of measurement
As early as 1963, foreign scholars Hardin and Richart discovered through research that the velocity of the transverse wave in the soil is closely related to the characteristics of the soil. Professor Xia Tangdai of Zhejiang University in the paper published in 2004 deduced the relationship between the shear strength of soft clay and the shear wave velocity.
\[
\tau_f = Ac' + B\rho V_s^2
\]

\[
A = 1 - \tan(45° - \Phi') \tan \varphi' (1 + \sin \varphi')
\]

\[
B = 2(1 + \mu)\varepsilon' (1 - \sin \varphi') \tan \varphi'
\]  

\(\tau_f\) is the shear strength of soft soil, \(c'\) is the effective cohesion of soil, \(\rho\) is the density of soil, \(\varphi'\) is the effective internal friction angle, \(V_s\) is the shear wave velocity, \(\varepsilon'\) is the axial strain of soil, \(\mu\) is the Poisson's ratio of soil, A, B can be obtained by a small number of field experiments or city experiments, so that the shear strength can be estimated. At present, the method of shear wave velocity measurement is observed by an oscilloscope, which is mostly used indoors and cannot be used in actual engineering. This paper aims to achieve long-term real-time measurement in the field through piezoelectric bending elements and integrated circuits to meet the needs of practical engineering.

3. Design of the experimental device

The schematic diagram of the overall experimental device is shown in Figure 1: It is mainly composed of a test tube, a piezoelectric bending element, and a hardware circuit clamping device.

![Figure 1. Schematic diagram of shear wave velocity test device](image1)

Piezoelectric ceramics are functional ceramic materials that convert mechanical energy and electrical energy. The piezoelectric bending piece is divided into a square and a ring-shaped piezoelectric bending piece. Here we choose a square piezoelectric bending piece because it has a better vibration effect. Fix one end of the square bending piece and drive it through the piezoelectric ceramic controller. The other end of the piezoelectric bending piece will swing up and down or swing in one direction. The working mode of the piezoelectric piece is shown in Figure 2.

![Figure 2. The working mode of the piezoelectric piece](image2)
The piezoelectric sheets currently used for geotechnical testing are relatively fragile and are easily damaged in the field. Previously, the Jacquard comb-pie bimorph was used as the experimental material in the laboratory, but the problem of packaging and waterproofing of the piezoelectric sheet has not been solved satisfactorily. At present, the laminated piezoelectric bending piece imported from Denmark is used, and its process structure is shown in Figure 3:

![Figure 3. Piezoelectric sheet process structure diagram](image)

The piezoelectric bending piece utilizes the transverse piezoelectric effect, that is, the piezoelectric coefficient $d_{31}$, and exhibits significant creep characteristics when used statically, so the piezoelectric bending piece is mainly used for dynamic applications. The laminated piezoelectric bending piece is formed by co-firing a multilayer piezoelectric ceramic curved substrate stack. The output of this piezoelectric bending piece is much larger than that of a conventional double wafer. And the electrode of the piezoelectric bending piece is directly led out through three wires, and is not directly exposed to the air. Here we can perform waterproof treatment on the three lead wires through 704 silica gel.

4. Hardware circuit part
The hardware circuit part of the shear wave speed measuring device is mainly composed of a signal generating circuit, a signal receiving circuit, a signal conditioning circuit and a phase detecting circuit. When the system works, the sinusoidal signal generated by the oscillating circuit drives the transmitting bending element to emit the shear wave. After receiving the shearing wave signal, the receiving bending element passes through the amplifying circuit and enters the phase-detecting circuit together with the transmitting signal, and finally collects the high-voltage through the single-chip microcomputer. The usual length is the length of time that the shear wave propagates between the two piezoelectric sheets. The working block diagrams of the specific system is shown in Figure 4:
4.1. Signal Generational Circuit

The signal generation circuit is an RC bridge sine wave oscillating circuit. The frequency of the signal is designed according to the resonant frequency of the purchased piezoelectric piece. Since the frequency is not much higher than several hundred Hz, the OP07 chip is selected as the generating circuit. To generate a fixed frequency sine wave signal. The signal generation circuit is shown in Figure 5:
4.2. Charge Amplifier Circuit

The piezoelectric sensor itself has a high internal resistance and the output signal is very weak. Therefore, the two main purposes of the charge amplifier are: one is to convert the high output impedance of the piezoelectric sensor into a low impedance output; the other is to amplify the weak signal output from the piezoelectric sensor. The OPA129 is an ultra-low bias current monolithic operational amplifier offered in an 8-pin PDIP and SO-8 package. Using advanced geometry dielectrically-isolated FET (Difet) inputs, this monolithic amplifier achieves a high performance level. Difet fabrication eliminates isolation-junction leakage current—the main contributor to input bias current with conventional monolithic FETs. This reduces input bias current by a factor of 10 to 100. Very low input bias current can be achieved without resorting to small-geometry FETs or CMOS designs which can suffer from much larger offset voltage, voltage noise, drift, and poor power-supply rejection. The charge amplification circuit is shown in Figure 6:

![Figure 6. Charge amplifier circuit](image)

4.3. Phase Detector Circuit

After the above processing, two signals can be obtained, one is the signal generated by the signal generating circuit; one is the signal obtained by receiving the shearing wave after receiving the shearing wave, and sending the two signals simultaneously into the phase detecting circuit. The time difference is the time when the shear wave propagates between the two piezoelectric sheets, and finally is displayed by the single chip microcomputer.

5. Experimental Results

Firstly, the shear strength of the soil was measured by the TKA-2U automatic unsaturated soil straight shear instrument. According to the Coulomb formula: 

$$\tau_f = C + \sigma \tan \phi$$

The selected soft clay with a water content of 10% can obtain the internal cohesion and internal friction angle of the soil according to the experimental results.

$$\mu = 0.35, \rho = 1.734 \text{g/cm}^3, \sigma = 7.8 \text{kPa}, \phi = 10.1^\circ$$

Through the indoor test, A and B can be obtained, so that the shear strength of the soil can be estimated, and then the shear strength error obtained by the two methods is compared. The pressure plate area of the laboratory is 3 square meters. We put 5kg, 8kg, 10kg, 15kg, 20kg, 25kg, 30kg, 35kg, 40kg,
and 50kg weight on it, and the normal stress is about according to the conversion. 16.33 kPa, 26.13 kPa, 32.67 kPa, 49.00 kPa, 65.33 kPa, 81.67 kPa, and 98.00 kPa, 114.33 kPa, and 130.67 kPa, 163.33 kPa.

The experimental results are shown in Table 1: where $c_u$ is the shear strength calculated by the Coulomb formula.

| $\sigma$ / kPa | $v_s$ / m·s$^{-1}$ | $\tau_f$ / kPa | $c_u$ / kPa | experiment error / % |
|----------------|-------------------|----------------|-------------|----------------------|
| 16.33          | 74.41             | 11.41          | 10.71       | 6.54                 |
| 26.13          | 92.38             | 13.39          | 12.45       | 7.56                 |
| 32.67          | 98.46             | 14.34          | 13.62       | 5.27                 |
| 49.00          | 121.29            | 17.87          | 16.53       | 8.10                 |
| 65.33          | 134.98            | 20.34          | 19.44       | 4.63                 |
| 81.67          | 150.32            | 23.42          | 22.35       | 4.79                 |
| 98.00          | 170.91            | 28.08          | 25.26       | 11.15                |
| 114.33         | 175.64            | 29.23          | 28.17       | 3.77                 |
| 130.67         | 189.11            | 32.69          | 31.08       | 5.18                 |
| 163.33         | 211.38            | 38.97          | 36.89       | 5.64                 |

6. Conclusion

This paper starts from the actual engineering needs and aims to obtain the real-time shear strength of the in-situ soil. The shear wave velocity is measured by piezoelectric ceramics to estimate the shear strength of the soil. Finally, it is collected by the single-chip microcomputer system. The obtained method has accurate results and can measure the shear strength of the soil in real time. It is expected to be used in actual engineering.

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