New generation CPTU wireless transmission technology-Great progress in practice

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ABSTRACT: Cone penetration test (CPT) is an important in situ test method, developing towards multifunctional and wide field. However, in actual penetration, the existence of long cable brings many inconveniences and even security risks, which limits its development in the field of ultra-deep CPTU and marine CPTU. The wireless transmission of test data is particularly necessary, but the existing wireless CPT technologies have not been widely recognized and applied due to their limitations. In this paper, to realize wireless transmission of CPT test data, three key technical problems have been solved: power supply of probe, upward transmission of collected information, display and storage of test data. Based on this, a new wireless CPTU system based on rechargeable probe, special probe, ground transmitter, and new-type tester was developed. Field tests show that the system has stable technical performance, reliable test data, fast operation, exhibiting great application potential in situ testing of geotechnical engineering.

Keywords: Wireless transmission; CPT/CPTU; Special probe; Radio wave; Rechargeable probe

1. Introduction

As an important in-situ testing technology, cone penetration test (CPT) has been widely used in geotechnical engineering due to its advantages of simplicity, rapidity and economy [1,2]. With the rapid development of science and technology, CPT testing is developing rapidly in the direction of digitalization, multi-function and high precision [3-5]. At present, piezocone penetration test (CPTU) with pore water pressure sensor has been widely used in the world. In addition to cone tip resistance and lateral friction resistance, pore water pressure of soil layer also can be obtained， exhibiting better ability to evaluate the engineering properties of soil [6,7]. In particular, CPTU technology has gained prominence in environmental geotechnical, energy geotechnical and deep-sea geotechnical fields and relevant series of products have also been developed. More testing functions have also been achieved through CPTU equipped with various kinds of sensors such as electrical resistivity sensor, seismic sensor, heat flow sensor, radioisotope sensor, laster-induced fluorescence sensor and visual sensor [8-11].

The trend of wide field and multi-function of CPTU technology puts forward higher requirements for its penetration depth and information transmission capacity. In the field operation of CPTU, the soil layer information collected by the probe is transmitted to the ground by coaxial through cable in probe rod. However, the existence of long cables limits penetration depth, hindering the development of CPTU technology in Marine geotechnical engineering [12]. Especially, as shown in Figure 1, pass ing cables one by one through

Figure 1. A schematic diagram of a long cable passing through the probe rods

the probe rods greatly increases the waste of manpower, time and cost, causing a lot of inconvenience and even safety risks for piezocone penetration [13]. Therefore, wireless transmission of CPTU test data is particularly necessary.

Some instrument companies and research institutes at home and abroad have developed the wireless cone penetration test system [14-16]. Storage wireless CPT technology based on data acquisition card has been proposed for a long time (Figure 2). It realizes the wireless transmission of test data through the communication between the underground acquisition card and the ground acquisition card after the penetration is completed and the probe rod is pulled out [17]. Although storage wireless CPT system achieves the wireless transmission of test data, it can not display test data in real time. When encountering complex

geology or hard strata, the penetration can not be terminated in time, which can easily lead to the damage of the probe rod. Therefore, the storage wireless CPT system is rarely used in practical engineering. GEOTECH in Sweden has developed NOVA series

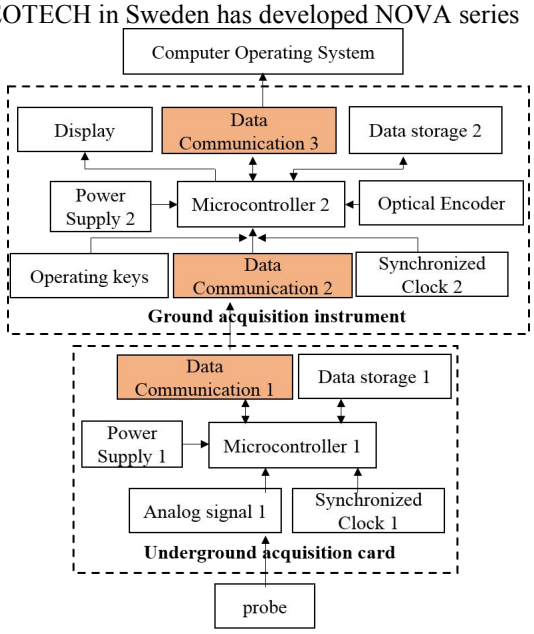

Figure 2. Storage wireless CPT system

products (NOVA ACOUSTIC and NOVA RW) based on acoustic and radio communication technology [18]. It completes the wireless transmission of the collected data through the acoustic/radio transmitter installed on the probe and the acoustic/radio receiver on the ground. Netherlands A.P. van den Berg Company developed a wireless CPTU system (OPTOCONE) based on optical transmission [19]. NOVA ACOUSTIC, NOVA RW, and OPTOCONE system can be used with advanced probes and acquisition instruments abroad, which greatly improves the multi-function and automation of CPTU technology. However, the shortcomings of sound wave, radio wave and light wave transmission such as poor anti-interference ability, attenuation and confidentiality greatly limit the depth and accuracy of wireless CPTU penetration [20-22]. This hinders the further development of cone penetration technology in the direction of wide field, multi-function and automation.

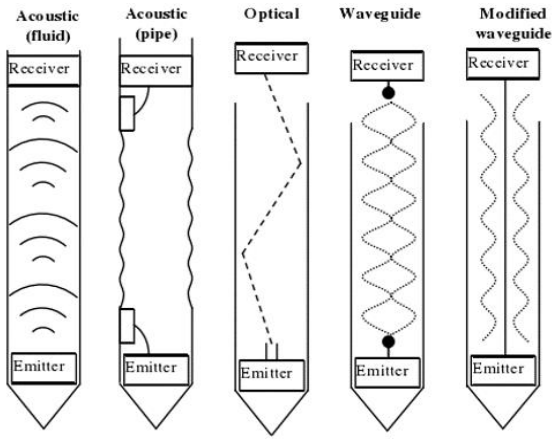

Figure 3. Schematic diagram of wireless CPT transmission of sound wave/radio wave/light wave[15]

The objective of this study is to introduce a new wireless cone penetration test system. Firstly, the key technology of wireless transmission of test data in traditional CPT system are analyzed. Based on this, the corresponding design schemes are put forward in order to achieve wireless transmission of CPT technology. Indoor debugging and field test results confirm that the wireless CPT system has stable data transmission, reliable test data and convenient operation, exhibiting great application potential in in situ testing.

2. Wireless CPTU system design

Traditional CPT/CPTU system is mainly composed of probe, probe rod, long cable, acquisition instrument, depth encoder and upper computer. The soil data collected by the probe will be transmitted upward to the acquisition instrument through a long cable. At the same time, the acquisition instrument provides power to the probe through the cable to ensure its continuous operation. At the same time, the acquisition instrument provides power to the probe through the cable to ensure its continuous operation. Therefore, three key problems need to be solved to realize wireless transmission of CPT/CPTU system: (1) power supply of probe, (2) upward transmission of test data, (3) display and storage of collected data.

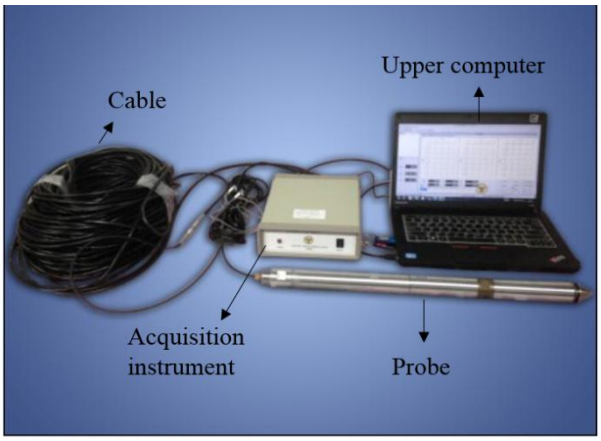

Figure 4. Traditional CPT system with cable

Based on this, rechargeable probe, special probe rod, ground transmitter, and new-type tester have been designed to solve these three key technical problems. After years of research and debugging, a new wireless cone penetration test system which can achieve no-cable transmission of test data has been developed. The details of wireless CPTU system design are as follows.

2.1. Rechargeable probe

In order to realize the self-power supply of the wireless probe, a rechargeable power supply device is installed on the traditional probe [23], as shown in Figure 8. The power supply device is mainly composed of rechargeable lithium battery, charging socket, power switch, indicator lamp and power supply cylinder. The power supply device is equipped with switches to avoid power consumption when not working. The indicator lamp is set to display the power supply of the probe

conveniently. The microUSB can charge the power supply device on the probe at any time. High capacity lithium battery can continuously power the probe. After the high capacity lithium battery are fully charged before penetration, the static penetration operation can work for more than 20 hours, which fully meets the engineering requirements.

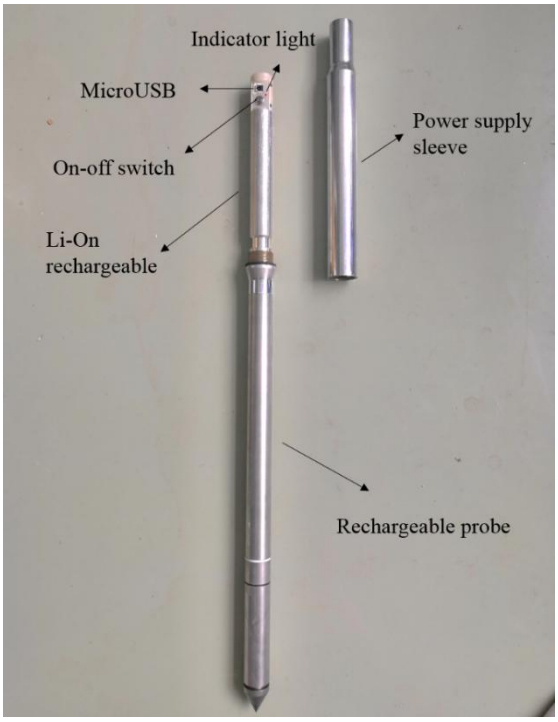

Figure 5. Rechargeable probe for Wireless CPT System

2.2. Special probe rod

The special probe is modified on the basis of the traditional one, as shown in Fig. 6. It mainly includes circular waveguide, male connector, female connector and conductive connector, etc. Different from traditional probe rod, the circular waveguide is a tubular structure that is constructed from enclosed conductor medium and there is a segmented wire inside the hollow rod body [24]. The two ends of the probe rod are the male connector and the female connector respectively in order to connect different probe rods. Sealed conductive parts are respectively arranged in the male connector and the female connector. A compression spring is also provided

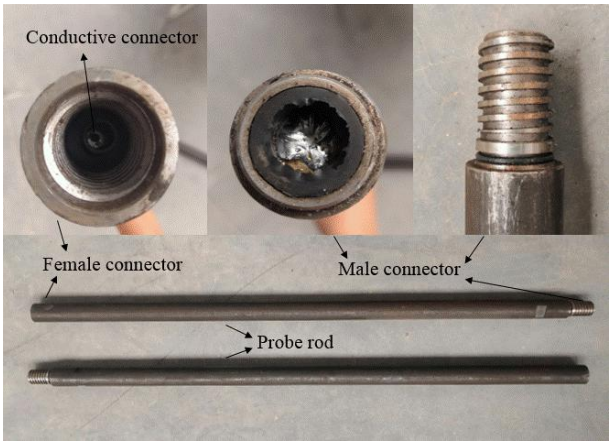

Figure 6. Structural Composition of special probe rod

in the female connector as the conductive connector between the male and female connectors to ensure the transmission of test data. In addition, the molded rubber sealing ring in the connectors and the o-ring on the male connector can ensure the sealing between the probe rods.

The application method of the new special probe rod is basically the same as that of the traditional one. After the male and female joints of the two probes are tightened and butted by the compression spring, the rubber blocks in the joints are extruded and closely connected with each other. It not only guarantees the insulation and waterproof sealing function of the probe under the action of groundwater pressure, but also realizes the wireless transmission of information between the probes. More importantly, the new probe rods are independent and interchangeable and can be inserted to achieve deep penetration.

2.3. Ground transmitter

A ground transmitter can be mounted on top of the probe rod is designed as shown in Figure 7 on the left. The high-speed wireless data transmission module is adopted, and the communication distance can reach 800 meters, indicating the advantages of low delay and high response. The ground transmitter can convert the received digital signal into radio wave signal and transmit it to the air through an external antenna. At the same time, the new tester can receive radio wave signals transmitted by ground transmitter through receiving antenna, and convert them into digital signals for real-time display and storage. This not only realizes the wireless transmission of test data, but also facilitates the installation of probes and saves manpower and time.

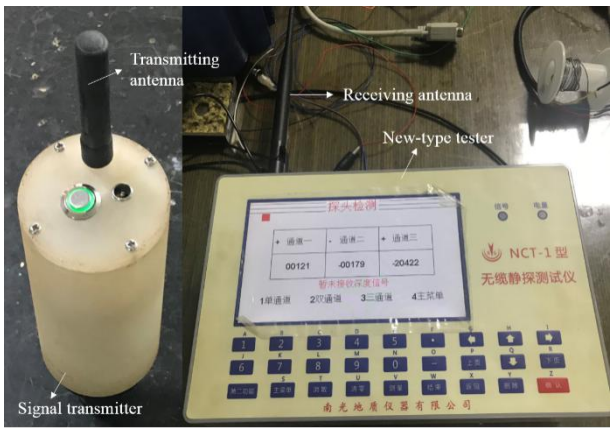

Figure 7. Ground signal transmitter and new-type tester

2.4. New-type tester

A new-type tester instrument for wireless static penetration system has also been developed (Figure 7). The new wireless tester integrates operation, reception, display and storage functions. The schematic diagram of the new tester is shown in Fig. 8. The 16-bit single-chip computer is adopted as the core of the New-type tester main computer, indicating low-power and high-performance. Large capacity Flash storage is adopted, which makes the storage program and data large and reliable. In order to ensure long-term operation in the field, we use large capacity lithium battery as the power supply of new wireless tester. The test data can be received in the form of radio waves by the receiving antenna on the new tester and converted into digital signals. Then the new tester can display and store the collected data in real time. After the penetration operation, data can be obtained through USB interface for post-processing.

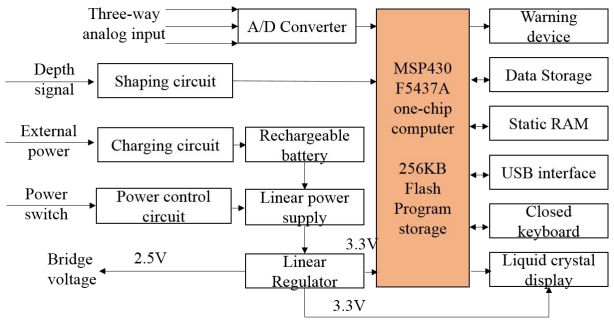

Figure 8. Circuit schematic diagram of the new-type tester

Generally speaking, during the static penetration test, the power supply installed on the probe continuously supplies power to the underground device. A set of special probe rods placed together one by one can provide a path for communication. The data signals collected by the probe are transmitted upward to the ground transmitter along the special probe rods. The ground transmitter converts the received test data into radio waves and sends them into the air. The new tester receives radio waves through an external receiving antenna and restores them to data signals for real-time display of test curves. The whole process is simple, continuous, fast and stable, achieving the wireless transmission of test data in situ testing of geotechnical Engineering.

3. Features of Wireless CPTU system

Wireless CPTU system based on self-powered probe, special probe rod, ground conductor and new-type tester can realize no-cable transmission of test data. Compared with the existing storage wireless CPT technology, it can display the test data collected by the probe in real time, which is more safe and controllable. It also does not have the inherent disadvantages of sound wave, radio wave and light wave wireless transmission technologies, such as signal attenuation, transmission distance and so on. More importantly, the appearance of special probes is similar to that of traditional probes. It only needs to install the probes one by one through the male and female joints, which saves time and manpower costs and eliminates the inconvenience and hidden dangers caused by the long cable in the penetration process. Because of the independence of the probes, it is convenient to install the probes, and the deeper static cone sounding operation can be realized.

The probe is equipped with a large capacity lithium battery, which can work continuously for about 20 hours after being fully charged. It eliminates the need to rely on the long cable to get power from ground meters or dedicated power sources for traditional cable static penetration system.

The operator can set the alarm value according to the actual situation of the static penetration site and the maximum load that the probe can bear. Once the measured value reaches the alarm value, the tester will buzz the alarm to ensure the safety of the static detection operation, so as to avoid the damage of the probe rods caused by unexpected circumstances.

The developed wireless static penetration system can be used in conjunction with various penetration systems such as double cylinder static detectors, wheel and crawler hydraulic static sounding vehicles. At present, the new wireless CPTU system primarily has the following functions. (a) Single bridge, double bridge, pore pressure three bridge and cross plate shear probes can be calibrated to check whether the error range of various probes conforms to the relevant specifications and standards. (b) It can also be used for static penetration test of single bridge probe, double bridge probe, pore pressure three bridge probe. (c) The excess pore water pressure dissipation and cross plate shear probe test of pore pressure three bridge probe can be carried out. More importantly, the developed wireless static penetration system has no limitation of data capacity and transmission distance. Therefore, as long as the probe is further upgraded, it can promote the multifunction and advancement of CPTU technology.

4. Indoor debugging and field testes

In order to verify the stability and reliability of the wireless static penetration system, indoor debugging and field testing were carried out. As shown in Figure 9, the charging process of the chargeable probe is simple

and convenient. After full charge, the battery has strong endurance ability, meetting the needs of wireless CPT field test. Figure 10 shows the field operation of wireless static penetration. It does not require a long cable to pass through the probes in advance. In addition, the ground transmitter can send the test data in the form of radio waves to the new tester for real-time display and storage. Obviously, compared with the traditional penetration process, it is more convenient and faster, saving time and manpower.

Figure 9. Charge test of probe power supply

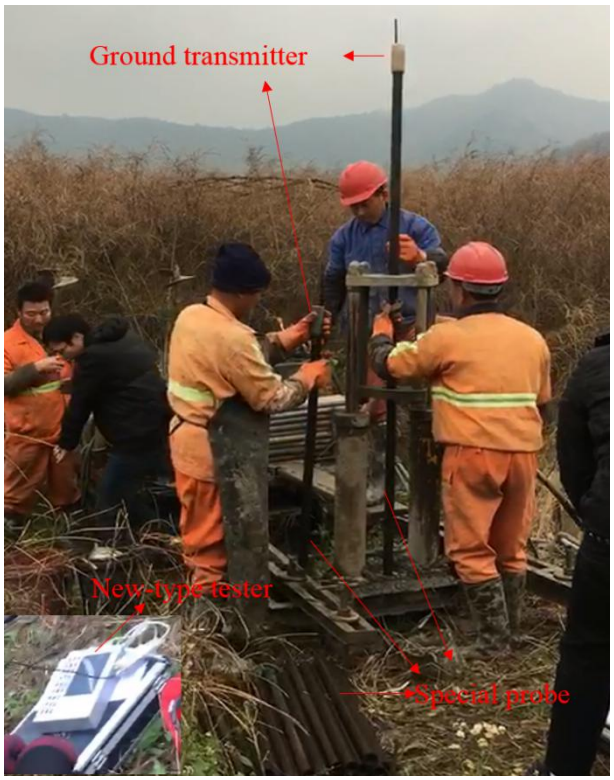

Figure 10. Field Tests of Wireless Static Penetration System

Moreover, the wireless static penetration system is used for field measurement at a construction site in Fuyang, Anhui Province. According to the requirement, the dual bridge probe made in China is used to collect soil data. Fig. 11 shows the variation curves of tip and sleeve stress with penetration depth for different penetration holes. It is evident that the penetration depth of the wireless static penetration system is up to 50m, and the test data collected by the probe can be stably transmitted to the ground of the new tester through a series of special probes.

From the field test process, wireless static penetration system has obvious advantages compared to the traditional static penetration system. (a) It realizes wireless transmission of probe test data, indicating the stability and reliability of the system. (b) It avoids the cumbersome work of a long cable passing through a series of probes one by one, saving manpower and cost with convenient operation process. (c) The special probe rod has the characteristics of simple structure and mutual independence. Deeper penetration can be achieved by adding probes, which is contributed to the development of ultra-deep CPTU and marine CPTU. (d) The special probe rod can be easily used in combination with the mechanical hand for static penetration technology to realize the automation and intelligence of CPTU technology, which is a very advanced direction in the field of in-situ testing. Therefore, the wireless static penetration system has great application prospects in the field of in-situ testing. Next step, we will improve the probe of the system to achieve more functions and collect more soil parameters in combination with advanced sensor technology such as electrical resistivity sensor, seismic sensor, heat flow sensor, radioisotope sensor and so on at home and abroad.

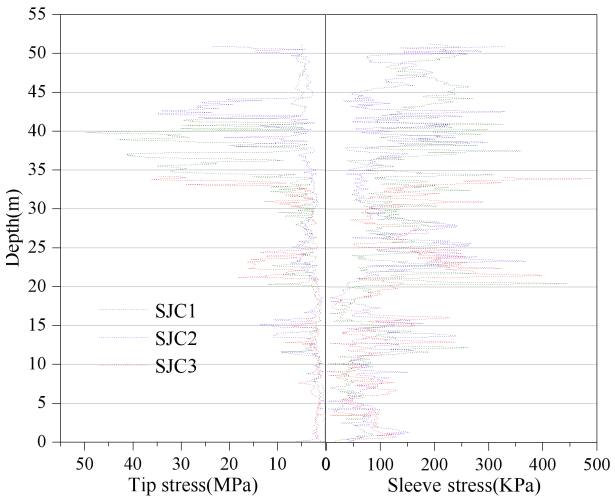

Figure 11. Tip and sleeve stress data from three different penetrations in field.

5. Conclusion

Wireless transmission technology is one of the advanced development directions in the field of static penetration, which can promote the automation and intelligence of in-situ testing. The existing storage and waveguide wireless transmission static penetration detection system has not been widely applied because of limitations, such as real-time display, transmission distance, signal attenuation and so on.

In this paper, a new wireless static penetration system based on rechargeable probe, special probe, ground transmitter, and new-type tester was developed. The new wireless system solves the problem of power supply of probe and upward transmission of test data

without cable for traditional CPT system. In addition, the ground transmitter is used to transmit the collected test data in the form of radio waves to the new tester for real-time display and storage.

The field test data show that the wireless system has stable performance, reliable test data, convenient and fast operation, exhibiting great application prospects especially in the field of ultra-deep and Marine static penetration.

Acknowledgement

Majority of the work presented in this paper was funded by the National Key R&D Program of China (Grant No. 2016YFC0800200), the National Natural Science Foundation of China (Grant No. 41672294 and No. 41877231)

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