Study on the application of laser particle analysis in the test of geotechnical particle analysis

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Abstract: In recent years, laser particle analysis method is a new method in geotechnical particle analysis. In this paper, through the particle analysis test of typical soft soil, the differences and control parameters between it and densimeter method are compared. The main conclusions are as follows: (1) the light shading percentage should be controlled between 5% and 20%; the concentration of dispersant (sodium hexametaphosphate) should be 0.04%; the circulating speed of centrifugal pump should be controlled between 1200-2000 RPM. (2) Compared with densitometer, the content of colloidal particles (< 0.002mm) and sand particles (> 0.075mm) measured by analysis method is different, and the content of clay particles (< 0.005mm), silt particles (0.005-0.075mm) and D50 is basically the same.

1. Introduction

Particle composition analysis is one of the basic tests in geotechnical engineering. It has a great significance to determine the type of soil, analyze its physical and mechanical properties and dynamic properties[1]. At present, there are three traditional particle analysis methods: sieving method, densitometer method and pipette method[2]. Among them, the sieving method is suitable for the soil with particle size greater than 0.075mm, and the densitometer method and pipette method are suitable for the soil with particle size less than 0.075mm. For soil with particle size less than 0.075mm, densimeter method has been widely used in particle analysis test of fine-grained soil samples due to relatively simple operation of the instrument. However, this method also has disadvantages such as large workload, poor repeatability, difficulty in dispersing particles and serious underestimate of particle size[3-7]. With the rapid development of modern testing technology, laser particle analysis is emerging. Because of its advantages such as fast testing speed, convenient operation, good repeatability and wide testing range, it gradually has the potential to replace the traditional analysis methods. Due to the limitation of the basic principle and the instrument itself, the test results of different test methods must be different, which will lead to the difficulty of data comparison and selection. Therefore, it is of great theoretical and practical significance to quantitatively analyze the relationship between densitometer and laser particle size analyzer, and to clarify their differences and correlations.

In this paper, firstly, by selecting the same clay for the comparative test under different control parameters, the appropriate range of the control parameters (shading rate, dispersant, centrifugal pump circulation speed, etc.) of the laser particle analysis is determined. Then, the typical clay, silt clay and silt in Tianjin port and Lianyungang area of China are selected, and the particle analysis test is carried out by using the laser particle analysis method. This paper promotes the application and
standardization of laser particle analysis in the field of geotechnical particle analysis.

2. Principle of laser particle analysis
The laser particle analysis method is based on the principle of Mie scattering to measure the particle size distribution. When a beam of parallel monochromatic light hits the particles, the scattering spectrum of the particles will be formed on the focal plane of the Fourier lens. The larger the particle size is, the smaller the scattering angle is, which is the inverse relation-ship between the particle diameter and the scattering angle \((8,9)\). Laser particle sizer calculates particle diameter according to Equation (1) by measuring the energy and spatial distribution of scattered light.

\[
I(\theta) = \frac{1}{\theta} \int_0^\infty R^2 n(R) J_1^2(\theta RK) dR
\]

Where \(I(\theta)\) is the light intensity with angle scattering \(\theta\); \(\theta\) is the scattering angle; \(R\) is the particle radius; \(n(R)\) is the particle size distribution function; \(J_1\) is the Bayes function of the first type; \(K = 2\pi/\lambda\), \(\lambda\) is the laser wavelength.

3. Control parameters of laser particle analysis
In this paper, the Bettersize 3000 plus laser particle analysis manufactured by a domestic company is used for the test. Its test range is 0.01 ~ 3000\(\mu\)m, and its control parameters are mainly light shading percentage, concentration of dispersant and circulating speed of centrifugal pump. In order to select appropriate control parameters, the same clay is selected for the following tests.

3.1. light shading percentage
The light shading percentage is an important parameter used to indicate the attenuation degree of the sample to the laser, and it also directly reflects the concentration of the sample during the test process. The higher the sample concentration is, the greater the light shading percentage is. On the contrary, the less the sample is, the smaller the light shading percentage is. Appropriate shading rate is conducive to ensure the reliability of the test results. Too small light shading percentage may lead to insufficient representativeness of the sample, and too large light shading percentage may cause repeated scattering.

During the test, without adding any dispersant, first add about 600ml pure water into the mixing circulating system, set the circulating speed of centrifugal pump to 1600 rpm, and start the circulating system. Add the prepared sample to the circulating mixing tank one by one, and then measure the median particle size at different concentrations. The experiments were carried out at different concentrations of 0.02g/L, 0.04g/L, 0.08g/L, 0.10g/L, 0.12g/L, 0.14 g/L, 0.18g/L, 0.20 g/L, 0.24 g/L, 0.28 g/L, 0.30 g/L. The test results are shown in Figure. 1 and Figure. 2.

![Figure.1 Relationship between concentration and light shading percentage](image.png)
Figure 2 Relationship between concentration and D50 (clay)

It can be seen from Figure 1 that with the increase of the concentration of soil particles, the light shading percentage of the sample measured by the laser particle analysis increases correspondingly, showing a good linear relationship, and indicating that the suspension prepared by the test is relatively uniform, and the dispersion degree of soil particles in the medium is relatively high. As shown in Figure 2, when the concentration is lower than 0.08g/L, the D50 of the sample decreases with the increase of the concentration. When the concentration is between 0.08g/L and 0.3g/L, the D50 measured has good repeatability, and the corresponding light shading percentage is between 5% and 20%.

3.2. Dispersant concentration

The results show that sodium pyrophosphate or sodium hexametaphosphate is the most effective dispersant in the experiment of clay content\(^{[10-11]}\). In the current standard specifications, sodium hexametaphosphate is generally used as the dispersant. In this study, sodium hexametaphosphate is still used as the dispersant, and the median particle size of the same test sample under different concentrations of dispersant is determined respectively.

In the test, pure water is used as the medium, and the circulating speed of centrifugal pump is set at 1600 rpm, and the light shading percentage is controlled at about 15%. After adding dispersant of different quality and dispersing by ultrasonic for 3 min, the results when the concentration of dispersant is 0.00%, 0.01%, 0.02%, 0.04%, 0.08%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5% are tested respectively, as shown in Figure 3.

Figure 3 Relationship between dispersant and D50 (clay)

According to figure 3, with the increase of concentration of sodium hexametaphosphate, the medium particle size D50 increases gradually, and the effect of dispersant is significant. When the
concentration of dispersant reaches 0.04%, D50 tends to be relatively stable. According to the above test results, it is suggested that 0.04% sodium hexametaphosphate can still be used as the dispersant in the particle analysis of soil samples.

3.3. Circulating speed of centrifugal pump

The laser particle analysis uses a mixing rod and a circulating pump to deliver the substance to be measured in the sample tank to the sample tank inside the instrument. The pump speed directly affects the physical dispersion of the sample.

In order to determine the proper circulation speed of centrifugal pump, 600ml pure water was used as the dispersion medium. The light shading percentage of soil samples was controlled between 10% and 20%. After ultrasonic dispersion for 3 min, the distribution of soil particles was measured at 500 rpm, 600 rpm, 800 rpm, 1200 rpm, 1600 rpm, 2000 rpm and 2500 rpm.

Figure 4 Relationship between centrifugal pump speed and D50

As shown in Figure 4, with the increase of cyclic speed, the median particle size of clay rises first and then tends to be stable. The test results are stable at 1200 ~ 2000rpm. Based on the above results, when the rotating speed of the centrifugal pump is set in 1200-2000 rpm, the repeatability of the measured results is good.

4. Material and Methods

4.1. Test material

The test soil samples are representative soft clay in Tianjin port and Lianyungang port. According to the soil properties, they can be roughly divided into clay, silty clay and silt. The typical physical property indexes are shown in Table 1. A total of 50 groups of comparative tests are carried out. All samples are dried and crushed first; and then divided into two: one is tested by traditional densitometer method, and the other is tested by laser particle analysis method.

| soil samples     | water content | wet density | liquid limit | plasti limit | plasticity index |
|------------------|---------------|-------------|--------------|--------------|-------------------|
| Tianjin port     |               |             |              |              |                   |
| clay             | 43.1          | 1.77        | 46.7         | 22.1         | 24.6              |
| silty clay       | 34.9          | 1.84        | 35.1         | 18.8         | 16.3              |
| silt             | 25.0          | 1.95        | 20.2         | 14.5         | 5.7               |
| Lianyungang port |               |             |              |              |                   |
| clay             | 50.6          | 1.71        | 51.3         | 22.7         | 28.6              |
| silty clay       | 34.2          | 1.86        | 40.3         | 24.8         | 15.5              |
| silt             | 19.8          | 1.98        | 13.1         | 3.3          | 9.8               |
4.2. Test methods
The test process is as follows: with pure water as the medium, set the circulating speed of centrifugal pump to 1600 rpm, and add 4% concentration of sodium hexametaphosphate as the dispersant in the circulating liquid. Then turn on the ultrasonic dispersion device, and slowly add the representative dry soil sample into the sample pool until the light shading percentage of the instrument is between 10% and 20%, and then start the test program, which automatically calculates the particle size and forms particle size distribution curve.

5. Results
In order to facilitate the analysis and comparison of the results of the two test methods, according to the usual soil particle classification habits, the test results are statistically analyzed according to the particle size group, which is, the colloidal particles (< 0.002mm), clay particles (< 0.005mm), silt particles (0.005-0.075mm) and sand particles (>0.075mm) are compared respectively, and the median particle size of the sample D50 (reflecting the concentration trend of particle size distribution) is used to facilitate the study of the overall differences between the two methods.

5.1. Contrast of colloidal particles
In order to facilitate the quantitative analysis of the differences between the test results of the two methods, the following two indicators are defined: absolute error (laser test results - densitometer test results), relative error (absolute error / densitometer test results).

Table 2 Comparison of results of two test methods

| soil samples   | average content of colloidal particles/% | average absolute error/% | average relative error/% |
|----------------|------------------------------------------|--------------------------|-------------------------|
| Tianjin port   |                                          |                          |                         |
| clay           | 18.7                                     | 27.8                     | -9.1                    | -29.5                   |
| silty clay     | 8.8                                      | 13.4                     | -4.6                    | -33.8                   |
| silt           | 2.5                                      | 4.1                      | -1.6                    | -38.1                   |
| Lianyang port  |                                          |                          |                         |
| clay           | 26.0                                     | 35.1                     | -9.1                    | -25.7                   |
| silty clay     | 11.9                                     | 15.0                     | -3.1                    | -20.7                   |
| silt           | 6.3                                      | 13.1                     | -6.8                    | -51.7                   |

Figure 5 shows the comparison of the content of colloidal particles measured by laser method and densitometer method. Among them, soil samples 1 to 16 are silt, soil samples 17 to 34 are silty clay, and soil samples 35 to 50 are clay. It can be seen from the figure that the test results of the two methods are different. Except for some silt samples, the content of colloidal particles measured by laser method is obviously smaller than that measured by densitometer method, and the larger the content of colloidal particles in the samples is, the difference is more obvious. Table 2 further gives the comparison of the
results of the two test methods. It can be seen that the more cohesive soil samples are, the greater the deviation of the content of colloidal particles measured by the two methods is. Lianyungang silt contains more fine particles, and the deviation is significantly greater than that of Tianjin silt. From the statistical analysis of the whole experiment, the absolute error of laser method and densitimeter method is -5.6% and the relative error is -36.9%. That is to say, the average measurement value of laser method is 36.9% lower than that of densitimeter method.

5.2. Contrast of clay and silt particles

Figure 6 and Figure 7 show the comparison of the clay content and the silt content measured by the laser method and the densitometer method respectively. It can be seen from the figure that the difference between the test results of the two methods is relatively small. The clay content and the silt content measured by the laser method are slightly lower than those measured by the densitometer method, and the overall absolute error is 0.1%, -3.5%, and the relative error is -3.7%, -5.2%, which is, the measurement value of the laser method is flat. All of them are 3.7% and 5.2% lower than the densitometer method.

5.3. Contrast of sand particles

Figure 8 shows the comparison of the sand content measured by the laser method and the densitometer method. It can be seen from the figure that the sand content measured by the laser method and the densitometer method has some differences, among which the clay sample has a small difference, the silt and the silty clay have a large difference. The larger the sand content, the more obvious the difference, the overall absolute error is 3.7%. And the relative error is 33.6%, which is, the laser method The average value of the measurement is 33.6% higher than that of the densitometer method.
5.4. Contrast of $D_{50}$

Figure 9 shows the comparison of $D_{50}$ measured by laser method and densitometer method. It can be seen from the figure that the $D_{50}$ measured by the two methods is basically the same. The $D_{50}$ measured by laser method is slightly larger than that by densitometer method, with an overall absolute error of 0.001mm and a relative error of 4.8%. That is to say, the average value measured by laser method is 4.8% larger than that by densitometer method, which is mainly due to the high content of coarse particles and fine particles measured by laser method. The overall $D_{50}$ is larger than that of densitometer.

6. Conclusions

(1) The light shading percentage of laser particle analysis should be controlled between 5% and 20%; when sodium hexametaphosphate is used as dispersant, its concentration should be 0.04%; the circulating speed of centrifugal pump can be controlled between 1200-2000 rpm.

(2) According to the test principle of densimeter and laser method, the equivalent diameter measured by densimeter method reflects the settlement rate of particles, and the laser method reflects the cross-sectional characteristics of particles. Due to the large number of irregular sheet structure and the influence of test operation in clay particles, the content of fine particles measured by densitometer method is higher than that of coarse particles.

(3) Compared with densitometer, the content of colloidal particles ($< 0.002\text{mm}$) measured by particle size analyzer is 36.9% lower, and the content of sand particles ($> 0.075\text{mm}$) is 33.6% higher, and the content of clay particles ($< 0.005\text{mm}$), silt particles (0.005-0.075mm) and $D_{50}$ are basically the same.
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