

Research on Dispersive Discrimination Test Methods of Illite Clay Soils in Zhejiang

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Abstract-Numerous studies indicate that dispersive clay minerals are mostly composed of montmorillonite, while the major mineral composition of dispersive clay is illite in Zhejiang Province. Based on the particularity of dispersive clay soil in this region, A series of experimental study and comparison and analysis work have been done to make test methods and discrimination results of the crumb test, the pinhole test, the double-hydrometer test and the pore water soluble salt test are more closed with engineering practice. The test methods were improved, and the discrimination standard of the double-hydrometer test was modified. For different test methods have different mechanisms, the dispersion of soil cannot be comprehensively distinguished by single one test, so, the synthetic discrimination method was proposed to judge the dispersion of clay accurately. The experimental results provide a theoretical basis and technical guidance for soil choice in related engineering projects.

Keywords-geotechnical engineering; dispersive clay soil; test research; Zhejiang; illite

I. INTRODUCTION

The dispersive clay is a clay that in low salinity water, the cohesion between the fine particles are most or all disappeared, and along with particles self-disperse into the primary-clay particles [1]. Despite some related studies show that the dispersion of clay almost have no influence on permeability[2], but due to its low anti-erosion ability, the stronger the dispersion, the smaller the permeation damage slope, so, it likely to cause piping leakage of dam, subgrade instability, etc. Therefore, it is very harmful to engineering. In recent years, it is one of the special soil types that attracts much attention in rock engineering field. Dispersive clay has been found in Australia, North America, India, Western Europe, and it also has been found in Heilongjiang, Shandong, Guangxi, Xinjiang and other provinces [3]. Since the dispersive clay has been discovered and recognized in 1950, many experts have done a lot of researches on it and achieved many valuable results. To discrimination method of

dispersive clay, the famous American engineer Charade (J.L.Sherard), etc [4], took ubiquitous phenomenon of the dam dispersive clay erosion and lixiviation destructions in United States into study since 1970. They put forward four test methods to identify dispersive clay, namely: crumb test, pinhole test, double-hydrometer test and pore water soluble salt cation test. Bell [5] researched the dispersive clay tests and believed that these test results were not entirely reliable, they cannot match well with each other. American Society for Testing and Materials (ASTM) has successively made three kinds of testing rules to discriminate clay dispersion, they are double-hydrometer test, pinhole test and crumb test.

Since the research of dispersive clay started late in China, so, there is no relevant code and specification to guide test procedures, mainly use foreign research methods. Nevertheless, some new concepts are proposed by our researchers through studying on dispersive clay. Yuezhong Qin[9] proposed to discriminate the soil dispersion by the mole rate of Na pinhole test. Henghui Fan[10] adopted the double-hydrometer test, pinhole test, crumb test, pore water soluble salt cation test and percentage of exchangeable sodium ion test five kinds of test methods to discriminate soil dispersion, but the results are not exactly consistent, there are some differences between each other; so, he based on his practical experience, according to the characteristics of the various tests, giving various test weighted value, which provided us with a more reasonable and reliable synthetic discrimination method to discriminate soil dispersion[11]. Zhanliang Tian[12] analyzed and summarized the research achievements recent years through the dispersion mechanism of dispersive clay, the discrimination methods of dispersive clay and engineering prevention and control of dispersive clay.

But up to now, many researchers point out that mineral composition of dispersive clay is most montmorillonite, while mineral composition of dispersive clay in Zhejiang area is illite, existing specifications or US ASTM D4221-99 standard is not applicable by considering the particularity of

this region dispersive clay. In this paper, the research aimed at the fill of reservoir dam, a lot of work has been done, and has improved test methods of the crumb test, the pinhole test, the Double-hydrometer test and the pore water soluble salt cation test, adjusted double-hydrometer test discrimination standard. Finally, according to the test results of the above four methods, it provides a synthetic discrimination method to discriminate this kind clay dispersion.

II. THE BASIC PHYSICAL PROPERTIES OF THE SOIL

Test soil samples selected the fill of reservoir dam, the soil physical and mechanical properties are shown in Tab. 1. From Tab. 1, the specific gravity of Group 26 of the soil was 2.68 ~ 2.74. particle composition of clay (<0.005mm) content reached 30.0% ~ 48.6%, the majority of that about 35%. From the water ratio limit, the liquid limit water ratio is 24.5% ~ 37.2% and plastic limit water rate is 12.5% ~ 20.8%, plasticity index is 10.0 ~ 16.7, it discriminated as a sand-contained low liquid limit clay.

III. MINERAL COMPOSITION OF THE SOIL

In order to study the mineral composition of the 26 soil samples. The samples have been taken the X-ray mineral phase quantitative analysis, and the results are shown in Tab. 2. As it can be seen from Tab. 2, the 26 soil samples are all free of montmorillonite, illite content reached 6.5%~27.6%, kaolin content reached 0~9.5%, other minerals content reached 71.2%~93.5%. Therefore, from the analysis of mineral composition, soil dispersion should be caused by illite. Content distributions of illite (see Fig. 1).

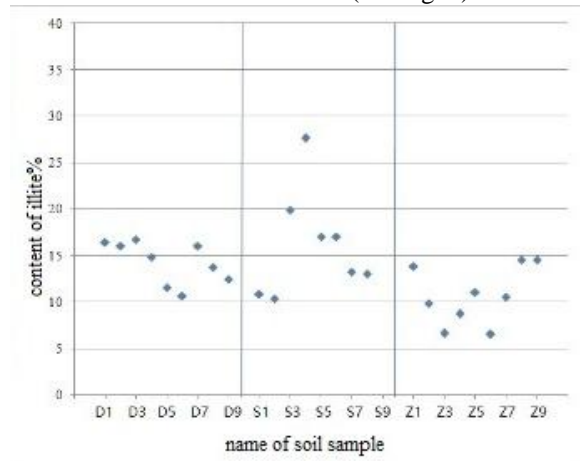


Figure 1. Content distributions of illite

IV. DISPERSION DISCRIMINATION TEST METHOD[6-8,13]

The properties of dispersive clay are related to its physical and chemical state and electrochemical properties of the soil particle surface, while, test methods that commonly used for geotechnical engineering cannot reflect the chemical state of the soil and the soil particle surface electrochemical properties, so, the methods cannot be used to discriminate clay dispersion. At present, there are no relevant test regulations in China, we still use tests that American Society

for Testing Materials are proposed: double-hydrometer test, pinhole test, pore water soluble salt test these four test methods to discriminate soil sample. For the common case illite clay in Zhejiang, in order to make test results of these four methods more close to the reality, and make the results match well, this paper has done some improvements about the four test methods and discrimination standard.

A. Crumb Test

Crumb test base on colloidal chemistry point of view that dispersive soil in water is due to the precipitation of colloidal particles, therefore, it take different degrees of colloidal precipitated as the discrimination standard. The test soil samples are made into a side length about 7mm ~ 15mm square soil clod, then put them into the water, recording time, according to the clods particles dispersed in water properties and water turbidity to divided the dispersion grade of the soil samples into non-dispersion, transitional, dispersion and high dispersion four levels.

B. Double-hydrometer Test

Double-hydrometer test holds that the clay soil often shows granular structure, it is not easily broken down into individual particle in water, but for dispersive clay particles is very easy to disperse and flow away in water. Thus, soil samples need to take twice hydrometer tests to determine the clay (<0.005mm) content, then obtain the ratio --- dispersion. The first time is the conventional method of adding the dispersant, the second time is non-conventional method without dispersant.

Dispersivity calculations in double-hydrometer:

$$\text{Dispersivity} = \frac{\text{clay content}(<0.005\text{mm}) \text{ in conventional test}}{\text{clay content}(<0.005\text{mm}) \text{ in non-conventional test}} \times 100\% \quad (1)$$

Previous studies on dispersivity discrimination standards are as follows: non-dispersion soil, the dispersivity<30%; transitional soil, dispersivity reach30%~50%; dispersive soil, the dispersivity> 50%. This paper based on the particularity of illite clay soil in Zhejiang area proposed the double-hydrometer method discrimination standard: non-dispersion soil, the dispersivity<60%; transitional soil, dispersivity reach60%~ 80%; dispersion soil, dispersivity> 80%.

C. Pinhole Test

Pinhole test simulates that under a certain water head, soil pore walls of the particles have the ability to bear some of the kinetic energy of the water flow and erosion resistance, which represents the force required by separating particles. Pinhole test apparatus adopt equipment in Zhejiang Research Institute of Water Estuary self-made (see Fig. 2), the undisturbed soil sample or compacted to the required density of the dry soil sample was putted through a diameter at its axial center of the pore 1.0mm and then used distilled water (or test required water) to conduct seepage test. Then observed the pinhole situation of fluvial abrasion at all levels of water head, then, determined the dispersivity properties of soil according to the pinhole and changes in water flow and water color. Its discrimination standard: ①dispersive clay:

under 50mm head, 10min end, flow rate up to 0.8 ~ 1.8ml /s, water moderate turbidity ~ turbidity, final pinhole aperture is not less than 1.5mm. ②Transitional clay: under 180mm head, 5min end, flow rate up to 1.2 ~ 2.8ml /s, water become turbid., pinholes final aperture is not less than 1.5mm; or under 380mm head, 5min end, flow rate of 1.8ml /s above, water gradual turbid. ③non-dispersive clay: under 380mm head, 5min end, flow rate does not exceed 1.8ml /s, water is clear, final pinhole aperture is substantially unchanged.

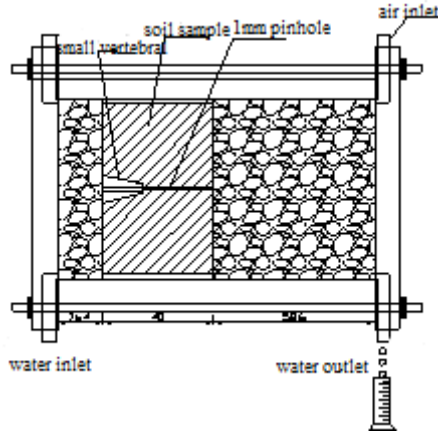


Figure 2. Schematic diagram of pinhole test device(The unit in the figure is mm)

D. Pore Water Soluble Salt Test

Pore water soluble salts test from chemical point of view holds that the relative amount of dissolved sodium ions of pore water in dispersive clay and other alkali cation (calcium and magnesium) is the major factor to determine the clay dispersion. Mixing soil and distilled water closely to the liquid limit of consistency, using a filter with a vacuum suction device or centrifuge to separate the pore water sample, determining the calcium, magnesium, sodium, potassium these four kinds of metal cation in the pore water samples, the total amount called as TDS. PS (Sodium percentage) refers as the sodium cation proportion. Then we can get the relationship between soil dispersion and TDS curve in Fig. 3.

$$TDS = Na^+ + K^+ + Ca^{2+} + Mg^{2+} \quad (2)$$

$$PS = Na^+ / TDS \quad (3)$$

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+}) / 2} \quad (4)$$

Pore water soluble salt test quantitative analysis the soil sample dispersion by the sodium ion and other alkali cation (calcium and magnesium) relative amount dissolved in the pore water; it is also a relatively reliable method. It extracted saturated soil pore water by equipment that developed by Zhejiang Research Institute of Water Estuary (see Figure 4),

when extract the pore water, firstly put into a same-size paper in the funnel, then load the vicinity of the liquid limit soil sample in the funnel, and make sure the soil is closely contact with the funnel around, assemble equipment as Fig.4, soil pore water drop from soil to suction flask graduated cylinder under the external atmospheric pressure then get clear pore water.

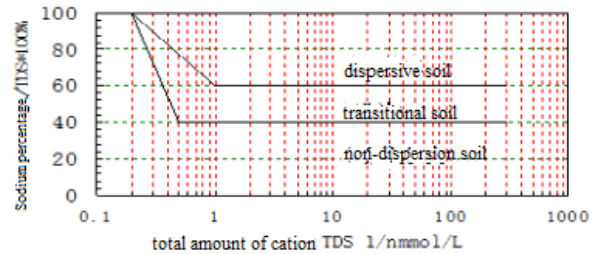


Figure 3. Relationship curve of soil dispersion with TDS



Figure 4. Extraction device of saturated soil pore water

E. Synthetic Discrimination Method and Steps

Due to the different mechanisms of these four test methods for discriminating dispersive clay, single one test method cannot comprehensively determine the dispersion of soil. Therefore, we should adopt a synthetic discrimination method to determine its dispersion. Taking account of the four methods, the crumb test and the pinhole test are closest to actual state of engineering, they can more directly and effectively reflect the dispersion of the soil. They should be considered firstly. In addition, the author has modified double-hydrometer test discrimination standard through a large number of experimental studies and analysis and comparison work. So that the determination result that use the modified double-hydrometer test discrimination standard can be adopted as the primary basis for discrimination. For these reasons, we recommend that this clay dispersion of synthetic discrimination step as follows:

Step one: crumb test, pinhole test and double-hydrometer test, if there are 2 (or 3) of the test results consistent with the discrimination result, the soil sample can be determined its level for the dispersion.

Step two: If the above 3 kinds of results were all inconsistent with each other, Then, when pore water soluble salts the test result is consistent with one outcome above

three tests results, the soil sample can be determined its level for the dispersion.

Synthetic discrimination flowchart see Fig. 5.

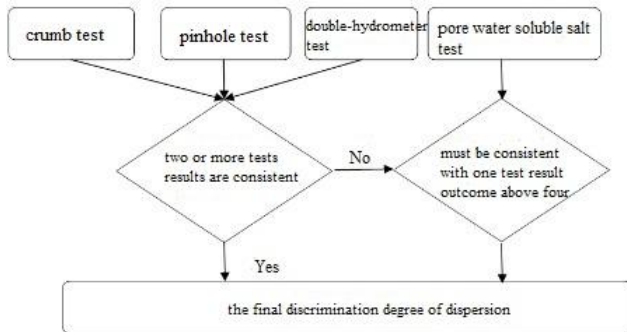


Figure 5. Flowchart of dispersive clay

V. ANALYSIS OF TEST RESULTS

A. Test Results

26 soil samples were separately carried on crumb test, double-hydrometer test, pinhole test and pore water soluble salt test, which four tests different dispersion and synthetic discrimination results in Tab. 3.

B. Analysis of Test Results

Through the results for 26 groups of clay samples from the reservoir dam were tested by methods described above, the discrimination results obtained from above four methods and synthetic discrimination method comparing apparent showed as follow (Tab. 3):

(1) The results of crumb test that is determined as dispersed or transition, which is consistent with the synthetic discrimination results; there are just four groups of soil samples results compared to the synthetic discrimination results showed inconsistent.

(2) Pinhole test results compared with the discrimination results, there are 14 groups of soil samples are the same, and another seven groups of soil sample results are determined as transition but synthetic discrimination determined as dispersion, the remaining soil sample test results showed non-dispersible while synthetic discrimination determined as dispersion or transition.

(3) The modified double-hydrometer test results are most consistent with synthetic discrimination results, only five groups of soil sample results showed inconsistent with the synthetic discrimination results, which indicate that the double-hydrometer test discrimination standard proposed by this paper is right.

(4) Comparing 17 groups soil samples of pore water soluble salts test results with the synthetic discrimination results, there are only 3 groups of soil samples are consistent, and another 6 groups of soil samples test results are determined as transition while synthetic discrimination determined as dispersion, the remaining soil sample test results are determined as non-dispersible while synthetic discrimination determined as dispersion or transition.

From the above tests results, for the crumb test, pinhole test, double-hydrometer test, pore water soluble salt test four kinds of dispersive clay discrimination methods, considering of the particularity of the soil in this region, the first three test methods are more efficient and reliable, they can be the main basis to discriminate the clay dispersion.

From the analysis of mineral composition of soil samples, due to illite is also a relatively unstable weathered intermediate product, in alkaline condition, it will adsorbs a large amount of Na^+ when it take off the potassium, so, it has highly dispersity as montmorillonite. Through testing the 26 groups reservoir dam soil samples, we can get that when the soil is free of montmorillonite, while illite soil content 6.5%-30.0%, the clay also show dispersion.

VI. CONCLUSION

(1) Many practical engineering and survey results have shown that the mineral content of clay is most illite in Zhejiang area, so, the main factor that causes soil dispersion is illite.

(2) By comparison with test results, the crumb test and the pinhole test results are more consistent with the synthetic discrimination results, these two test methods are more directly and effectively reflect the dispersion of soil, so, they can be the main basis to discriminate this clay dispersion.

(3) For the special case of the illite clay, this paper modified the double-hydrometer test discrimination standard and proposed the discrimination standard of double-hydrometer test is non-dispersion soil, dispersity<60%; transition soil, dispersity60%~80%; dispersion soil, dispersity>80%.By analyzing and comparing hundreds of clay groups test results, obtaining that the modified double-hydrometer test discrimination standard can be used as the main basis to discriminate clay dispersion for Zhejiang illite clay.

(4) Due to different test methods have different mechanisms, which cannot be comprehensively discriminated soil dispersion by single one test, so, it is recommended to take the synthetic discrimination method to discriminate the clay dispersion accurately.

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TABLE I. TEST SOIL SAMPLES BASIC PHYSICAL PROPERTY

Numbering of soil sample	specific gravity	particle composition(%)			liquid limit w_L /%	plastic limit w_P /%	plasticity index I_P	Fine Soils According to Plasticity Diagram
		>0.075 /mm	0.075~0.005 /mm	<0.005 /mm				
D1	2.69	28.7	36.3	35.0	24.9	14.9	10.0	CL
D2	2.70	26.5	35.6	37.9	26.3	16.3	10.0	CL
D3	2.70	19.4	41.2	39.4	27.4	17.0	10.4	CL
D4	2.69	23.3	41.5	35.2	26.8	16.7	10.1	CL
D5	2.70	26.8	40.3	32.9	27.0	16.4	10.6	CL
D6	2.69	17.4	47.1	35.5	25.6	15.2	10.4	CL
D7	2.70	25.2	41.4	33.4	27.0	16.7	10.3	CL
D8	2.70	26.7	39.3	34.0	27.1	16.5	10.6	CL
D9	2.69	28.4	37.8	33.8	26.1	15.8	10.3	CL
S1	2.72	22.3	37.8	39.9	29.8	17.8	12.0	CL
S2	2.72	19.9	36.0	44.1	28.5	16.1	12.4	CL
S3	2.71	20.9	38.6	40.5	29.0	17.4	11.6	CL
S4	2.71	27.7	38.7	33.6	28.7	17.0	11.7	CL
S5	2.70	24.0	39.1	36.9	26.3	15.7	10.6	CL
S6	2.69	24.5	38.8	36.7	26.3	16.2	10.1	CL
S7	2.69	26.7	37.3	36.0	26.2	16.1	10.1	CL
S8	2.68	29.3	37.9	32.8	26.2	16.0	10.0	CL
Z1	2.69	39.1	30.9	30.0	24.5	13.6	10.9	CL
Z2	2.69	18.0	52.0	30.0	27.3	16.6	10.7	CL
Z3	2.70	17.9	50.5	31.6	34.5	20.8	13.7	CL
Z4	2.70	16.8	48.1	35.1	22.6	12.5	10.1	CL
Z5	2.69	33.4	36.6	30.0	25.3	13.6	11.7	CL
Z6	2.73	2.5	57.1	40.4	24.9	14.7	10.2	CL
Z7	2.71	4.8	56.5	38.7	30.0	17.9	12.1	CL
Z8	2.70	8.9	56.0	35.1	26.7	16.5	10.2	CL
Z9	2.74	3.0	38.6	58.4	37.2	20.5	16.7	CL

TABLE II. ANALYSIS OF EXPERIMENTAL SOIL CLAY MINERAL COMPOSITION

Numbering of soil sample	illite/%	montmorillonite/%	kaolin/%	Other minerals/%
D1	16.4	0	4.9	78.7
D2	16.0	0	0.0	84.0
D3	16.7	0	0.0	83.3
D4	14.8	0	0.0	85.2
D5	11.5	0	5.9	82.6
D6	10.6	0	3.9	85.5
D7	16.0	0	5.6	78.4
D8	13.7	0	3.4	82.9
D9	12.4	0	1.5	86.1
S1	10.8	0	9.0	80.2
S2	10.3	0	7.5	82.2
S3	19.9	0	6.9	73.2
S4	27.6	0	1.2	71.2
S5	17.0	0	7.4	75.6
S6	17.0	0	7.5	75.5
S7	13.2	0	8.4	78.4
S8	13.0	0	6.6	80.4
Z1	13.8	0	0.0	86.2
Z2	9.8	0	0.0	90.2
Z3	6.6	0	3.2	90.2
Z4	8.7	0	0.0	91.3
Z5	11.0	0	7.5	81.5
Z6	6.5	0	0.0	93.5
Z7	10.5	0	0.6	89.5
Z8	14.5	0	2.6	82.9
Z9	14.5	0	9.5	76.0

TABLE III SOIL DISPERSION DISCRIMINATION RESULTS

Numbering of soil sample	double-hydrometer test	crumb test		pore water soluble salts test				pinhole test						Soil sample dispersion of synthetic discrimination
				Na^+	TDS	PS	Discrimination	dry density	water head	Ended aperture	Ended flow	water color	Discrimination	
	dispersion(%)	level	Discrimination	cation content(1/n) mmol/L	%			g/cm^3	mm	mm	ml/s	-		
D1	79.3	4	highly dispersed	2.20	5.55	40	transition	1.81	180	2.0	1.56	turbid	transition	dispersion
D2	69.2	2	transition	2.30	8.25	28	non-dispersible	1.78	1020	1.0	2.94	slight turbid	non-dispersible	non-dispersible
D3	76.1	2	transition	1.70	5.70	30	non-dispersible	1.76	380	3.0	1.85	turbid	transition	transition
D4	93.5	4	highly dispersed	2.50	8.01	31	non-dispersible	1.74	380	<2.0	1.02	turbid	transition	dispersion
D5	96.3	4	highly dispersed	2.00	6.81	29	non-dispersible	1.72	380	<3.0	1.25	turbid	transition	dispersion
D6	85.1	3~4	disperse	2.00	7.82	26	non-dispersible	1.73	180	/	1.58	slight turbid	transition	dispersion
D7	94.3	4	highly dispersed	2.90	7.50	39	near transition	1.73	50	2.0	1.05	moderate turbid	dispersion	dispersion
D8	98.5	4	highly dispersed	4.40	9.49	46	transition	1.71	180	2.0	1.79	turbid	transition	dispersion
D9	94.1	4	highly dispersed	2.50	5.87	43	transition	1.68	1020	2.5	3.57	slight turbid	non-dispersible	dispersion
S1	78.9	3	dispersion	2.00	4.40	45	transition	1.74	1020	3.0	2.63	slight turbid	non-dispersible	transition
S2	88.1	4	highly dispersed	4.10	9.02	45	transition	1.72	380	>1.5	1.52	moderate turbid	transition	dispersion
S3	85.1	4	highly dispersed	2.48	5.92	42	transition	1.71	1020	1.0	2.27	transparent	non-dispersible	dispersion
S4	98.8	4	highly dispersed	1.90	4.81	40	transition	1.76	50	3.0	0.37	turbid	dispersion	dispersion
S5	95.7	4	highly dispersed	1.90	5.20	37	non-dispersible	1.73	50	4.0	1.67	turbid	dispersion	dispersion
S6	80.9	3~4	dispersion	2.30	7.14	32	non-dispersible	1.74	380	4.0	1.00	turbid	transition	dispersion
S7	88.1	4	highly dispersed	2.10	5.20	40	transition	1.74	1020	3.0	3.11	turbid	non-dispersible	dispersion
S8	90.2	4	highly dispersed	2.60	7.64	34	non-dispersible	1.73	1020	1.0	2.17	slight turbid	non-dispersible	dispersion
Z1	89.0	2	transition	/	/	/	/	1.68	180	1.6	1.56	slight turbid	transition	transition
Z2	58.9	1	non-dispersible	/	/	/	/	1.61	1020	1.0	3.12	clear	non-dispersible	non-dispersible
Z3	68.7	1	non-dispersible	/	/	/	/	1.57	380	2.5	6.90	gradual turbid	transition	transition
Z4	90.6	3	dispersion	/	/	/	/	1.64	50	3.0	1.33	moderate turbid	dispersion	dispersion
Z5	79.8	2	transition	/	/	/	/	1.72	380	2.1	2.04	slight turbid	transition	transition
Z6	96.8	4	highly dispersed	/	/	/	/	1.63	50	2.2	1.15	turbid	dispersion	dispersion
Z7	42.9	1	non-dispersible	/	/	/	/	1.58	1020	1.1	1.56	clear	non-dispersible	non-dispersible
Z8	81.5	1	non-dispersible	/	/	/	/	1.69	380	1.6	1.58	moderate turbid	transition	transition
Z9	69.9	1	non-dispersible	/	/	/	/	1.48	1020	1.8	1.53	clear	non-dispersible	non-dispersible