CHEMICAL ENGINEERING TRANSACTIONS

VOL. 55, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-46-4; **ISSN** 2283-9216

DOI: 10.3303/CET1655072

Influence of Soil Surface Sodium Ion and Soil pH on Dispersion of Cohesive Soil

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The grey relational analysis method based on grey system theory is used, to make theoretical analysis of the chemical factors influencing the cohesive soil dispersion, and the pinhole test and pieces test are adopted to make further experimental analysis of the influence factors of sodium ions, pH and so on. Grey correlation analysis showed that the correlation between pH and sodium ion concentration is relatively high in the chemical properties. At the same time, through the further study on the chemical factors of cohesive soil, we can find that to acquire dispersive soil, it is necessary to have higher pH and higher Sodium ions concentration.

1. Introduction

Dispersed soil is a complicated physical, chemical and mechanical process, in which the soil is dispersed and lost when encountering water. At present, the dispersion mechanism of dispersed soil includes mineral theory, cation theory and pH theory. The mineral theory believed that the dispersion of soil is caused by Montmorillonite; cation theory thought that because the soil contains a large number of Sodium ions, it makes the doubleelectric layer of soil particles become thicker and thus result in soil dispersion (Barbacioru, 2014); pH theory is to describe the dispersion from that pH can influence the charged performance of soil surface. These theories have certain theoretical basis, but each theory has imperfect elements. Practice has proved that these single theories often cannot explain the causes of somesoil dispersion.

The process of formation and the mechanism of the dispersive soil itself are complicated. There are still limitations in the cognition of dispersive soil. Through half a century of research, the depth and understanding of the study are far less than those of other special soils. The study of dispersive soil in China is based on the dispersive soil in the construction project. However, the research focuses on the methods and results of dispersive soil, and the dispersive mechanism of dispersive soil and the dispersive soil in the practical engineering. In the characteristics of basic research is lack of research. It is found that dispersive soils are distributed widely in China. In Xinjiang, Shandong, Shanxi and other provinces. Water conservancy and hydropower and roadbed engineering practice have encountered numerous situations with dispersive soil. Therefore, to study the characteristic of dispersive soil has great significance.

The recent study of dispersive soil has some disadvantages comparing to the expansive soil and other special soil compared. The existing research results have more limitations, lack of practical guidance. There are still some key problems that need to be studied, especially in the decentralized soil dispersion mechanism, determination method, engineering properties, application and engineering survey and so on.In the study of dispersion mechanism of soil dispersion, the study found that a number of cases of dam accidents were related to the dam body material dispersed soil; dispersed soil containing a certain amount of structural instability of the clay minerals, montmorillonite. The dispersive soil is generally in the high pH environment of the alkaline medium environment; engineering water quality is also related to the dispersion soil.

The research, based on the grey correlation analysis, adopts the pinhole test, pieces test and other test methods, through the artificial soil samples preparation, to study the impact of pH, sodium ion and other chemical factors and mineral composition on the dispersion of cohesive soil, to further clarify the dispersion mechanism of clear cohesive soil, providing theoretical basis for the design, construction, and management of dispersed soil engineering.

Please cite this article as: Zhou Q.H., Yu H.L., 2016, Influence of soil surface sodium ion and soil ph on dispersion of cohesive soil, Chemical Engineering Transactions, 55, 427-432 DOI:10.3303/CET1655072

2. Experiment

2.1 Grey relational analysis method

Because of the complexity of dispersedsoil itself and the uncertainty of the relationship between each index and cohesive soil dispersion, the paper selects grey correlation analysis method in the grey system theory as the analysis method forthe association degree between quantitative evaluation chemical properties index and cohesive soil dispersion.

The dispersion degree of the soil samples is selected as the reference sequence for analysis. Set the reference sequence for $X_0 = \{X_0(k) | k = 1,2,\cdots,n\}$, select properties indexes as the comparison sequence and set the comparison sequence as $X_i = \{X_i(k) | k = 1,2,\cdots,n\}, i = 1,2,\cdots,m$ (Chang et al., 2013). In order to eliminate the differences between data, first of all, by dividing the first data of each column, initialize each sequence and obtain the initialized data matrix, then take the difference between the initialize matrix reference sequence and the comparison sequence and get the absolute value, to calculate the proximity between reference sequence and comparison sequence, and thus acquire the data proximitymatrix.Find the minimum $\min_i \min_k \Delta_i(k)$ and the maximum $\max_i \max_k \Delta_i(k)$ values in the proximity matrix, and take the distinguish coefficient $\rho = 0.05$, get the correlation coefficient matrix, and define the correlation coefficient as (Hashemi et al., 2015):

$$\xi_i(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)} \tag{1}$$

In (1), $\Delta_i(k) = |X_0(k) - X_i(k)|, i = 1,2,\cdots,m, \rho \in (0,+\infty)$ is called distinguish coefficient.

Finally, according to the above correlation coefficient matrix, the correlation between soil samples properties and dispersion of cohesive soil is obtained. The calculation relation is shown as follows:

$$\gamma_{i0} = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \tag{2}$$

In the calculation results, the greater a factor correlation value, the higher the association between factors and dispersion degree, and the greater the influence of the factor variation onthe cohesive soil dispersion (Kasman, 2013); on the other hand, it suggests that there is little influence or no effect of the change of factors on the cohesive soil dispersion.

2.2 Sodium ions and pH influence experiment

1) Selection of Experimental Materials

The tested soil is Q3 loess from terrace in the north of Weihe in Yangling, Shaanxi province, and the sodium carbonate reagent selects the anhydrous sodium carbonate reagent produced by Xi'an Reagent Factory (Maharaj et al., 2011).

2) Soil Samples Preparation

In the experiment study of the effect of Sodium ions on dispersion of cohesive soil, the mass fraction of prepared 7 groups of sodium carbonate are respectively 0.04%, 0.08%, 0.12%, 0.16%, 0.20%, 0.40%, and 1% test samples, and a total of 8 soil samples of Yangling soil samples (Mondal et al., 2013). It explores the relationship between Sodium ions and cohesive soil dispersion, respectively using the pinhole test and the piece test to carry out dispersion identification.

In the study of the impact of pH on the dispersion of cohesive soil, the soil preparation and the reagent concentration in soil samples are relatively complex, as shown in Table 1. Respectively measure the pH value of 60 groups of soil samples in Table 1, and use the pinhole test and the piece test to carry out dispersion identification.

3) Experimental Method

The moisture content of the test soil sample is the optimal moisture content, and the compaction degree is 0.95. At present, there is no test procedures for discrimination of dispersed soil. The paper uses the pinhole test and the piece test these two test methods introduced in "Dispersed Soil Research" to make the experiment, and refers to the pinhole test(ASTM D4647-93) made by the American Society for Testing and Materials, and the piece test (ASTM D6572-00) and other two kinds of test rules (Nayak et al., 2014).

3. Results

3.1 Grey relational analysis results

48 groups soil samples are collected from Xinjiang, Xi'an, Gansu, Qinghai, Heilongjiang and other places and what is encountered by some foreign engineering. According to the above method, the correlation between the chemical properties of soil samples and the cohesive soil dispersion index is shown in Table 1.

Table 1: Correlation between chemical index and dispersion of cohesive soil

Chemical factors	Total soluble salt	CO_3^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	Sodium ions	pH
Grey correlation	0.46	0.76	0.89	0.66	0.52	0.74	0.92

The results showed that among the soluble salt content, CO_3^{2-}, HCO_{3-}, Ca^{2+}, Mg^{2+}, Sodium ions, pH and so on several chemical indexes, the correlation between cohesive soil dispersion is generally high. According to the correlation degree, the above chemical properties are sorted (Palanikumar et al., 2012). Then, the order of chemical properties indexes in the influence of cohesive soil dispersion is obtained: pH >HCO_3->CO_3^{2}->Sodium ions>Ca^{2}+>Mg^{2+}> soluble salt content; the correlation between the chemical properties indexes and cohesive soil dispersion, except for soluble salt content, is greater than 0.5, indicating that the chemical index and cohesive soil dispersion are closely related, especially pH, HCO_{3-}, CO_3^{2-} and Sodium ions these 4 indexes have high correlation degree with cohesive soil dispersion (Prasanna et al., 2014).

3.2 Sodium ions and pH impact experiment result analysis

1) Impact of Sodium ionson Dispersion of Cohesive Soil

In order to verify the influence of Sodium ions on the dispersion of soil samples, add different contents of sodium carbonate into non dispersive soil, to study the relationship between Sodium ions and the dispersion of cohesive soil. The test results are shown in Figure 1.

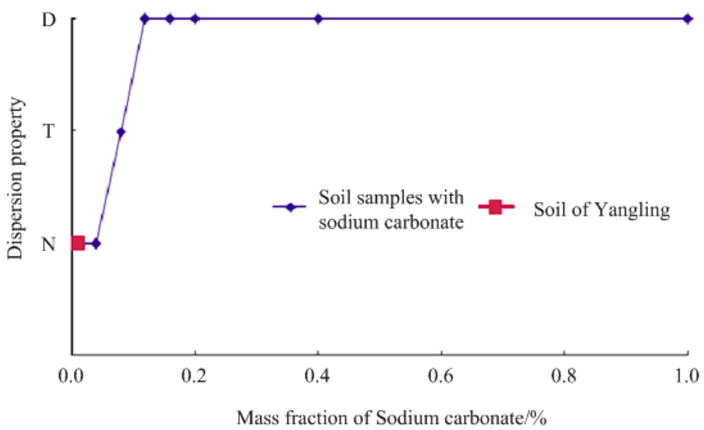

Figure 1: Relation between dispersion of cohesive soil and Sodium ions

Figure 1 shows that the dispersion of soil samples increases with the increase of Sodium ions content after the addition of sodium carbonate into the non-dispersive soil (Raghuraman et al., 2013). The content of sodium carbonate is lower than 0.08%, and the soil sample is non-dispersive soil; it belongs to transitional soil between the range of 0.08% ~ 0.12%, and it exceeds 0.12%, the soil samples belong to dispersed soil. It is worth noting that, since that sodium carbonate isstrong base and weak acid salt, after sodium carbonate being added in the soil, it shows obviously strong alkaline.

2) Effect of pH on Dispersion of Cohesive Soil

Because the pH of soil can change the charge properties of soil particles surface, the influence on physical and chemical properties of cohesive soil is very significant. The pH of soil sample is determined and the dispersion of soil sample is tested, and the results were shown in Figure 2. Figure 2 shows that soil pH and its dispersion are closely linked (Sahoo et al., 2012).If pH is greater than 9.0, soil samples are identified as dispersive soil; if pH is less than 9.0, soil samples are mostly non-dispersive soil. Some soil samples with higher pH are identified as non-dispersive soil. The reason is that the content of Sodium ions is relatively less in the soil sample, which does not reach the degree of decentralization, reflectingthat the dispersive soil is supposed to have high pH and high Sodium ions concentration these two conditions at the same time.

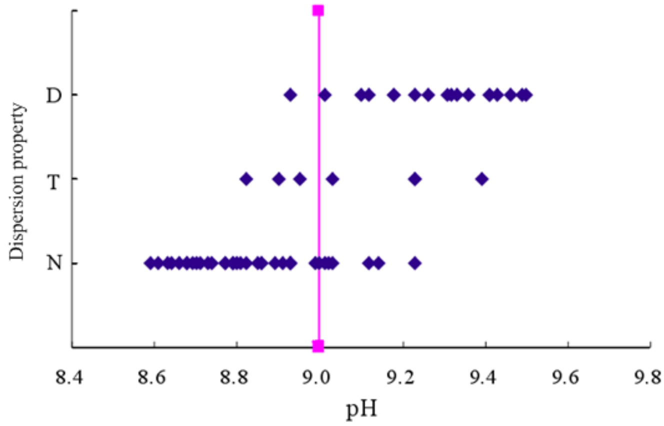

Figure 2: Relation between dispersiion of cohesive soil and pH

3) Dispersion Mechanism Analysis of Sodium ionsand Soil

The common clay minerals are kaolinite, illite and montmorillonite. The different types of minerals inevitably lead to the differences in the spatial structure and properties of minerals. Therefore, the types and contents of minerals are very important for water stability of soils and Mechanical properties have a significant impact. If the montmorillonite adsorption of different cations, and its engineering properties will be different in the water environment, calcium montmorillonite in the presence of calcium ions can be the surface of the soil particles of sodium ions replacement, due to the price difference. A divalent calcium ion displaces two monovalent sodium ions on the surface of the particle, resulting in a significant decrease in the sodium content at the surface of the soil particle, and the calcium-montmorillonite has a lower pH to reduce the dispersibility of the dispersed soil Sodium montmorillonite has a strong dispersibility due to its high pH and high content of sodium ions.

Sodium ions is one of the four most common cations in soil samples. In the evaluation of chemical properties of soil samples.Sodium ions is an important index necessary to be determined. Under normal conditions, liquid substances in the soil is mainly the water. Electrolyte dissolved in water exists in the water in the form of ions or compounds. The electrolyte, water, and cohesive soil particles constitute the soil - water - electrolyte system, to affect the engineering properties of soil (Senthilkumar et al., 2014). It is found that the greater the thickness of double layer of soil particles, the more difficult the flocculation and settlement of suspended soil particles in suspension. When the surface charge of cohesive soil particles is constant, the diffusion layer thickness is negatively related to the ionic valence of ion soluble in aqueous solution, and it is negatively correlated with the square root of ion molar concentration in the solution, while it is positively related to the square root of the dielectric constant and the temperature product. Therefore, the higher the valence state of dissolved ions in water environment, the higher the content, the smaller the diffusion layer thickness, and the smaller the dispersion of soil that the soil reflected (Sherard et al., 2015). In the soil in the nature, cationic ion usually includes Ca^{2+}, Mg^{2+}, Sodium ions and K+, in which what has higher content is Ca^{2+} and Sodium ions, a Sodium ions double electric layer thickness is twice of that of Ca^{2+}. Therefore, if the soil sample contains a large number of Sodium ions, the thickness of the double layer between soil particles increases, the repulsive force is greater than the attraction, and the soil sample is dispersed.

4) Dispersion Mechanism Analysis of pH and Soil

pH is one of the important indexes to measure and evaluate the chemical properties of soil samples in engineering. Soil samples with different pH, the properties will be different. The hydroxyl that the surface and edge of cohesive soilparticles expose to may have a tendency to decompose:

$$SiOH \rightarrow SiO^{-} + H^{+}$$

According to the principle of chemical equilibrium, the reaction is strongly affected by pH.If pH increases, it promotes the chemical reaction equilibrium towards the positive direction, which can produce more H+, and the effective negative charge that the cohesive soil particles show will increase. In addition, the alumina of cohesive soil mineral structure edge has the properties of acid and alkali at the same time, in low pH environment for positive charge, in high pH environment for negative charge (Siddiquee et al., 2010). As a result, the influence of pH of the environment where soil particles stay is very obvious on the properties of the cohesive soil suspension.In low pH environment, the edge of soil particles with a positive charge interact with the surface with negativecharge, making the particle in the suspended liquid flocculating, and tending to be stable; in high pH medium environment, cohesive particles are dispersive (Thanigaivelan and Arunachalam, 2013). Therefore, pH is one of the essential factors for the dispersion of cohesive soil.

If the cohesive minerals in soils samples are dominated by illite, but at high pH conditions, the negative charge on the surface of cohesive soil particles increase, and the number of cationic adsorption also increases, making the double electric layer thickness of particle surface increases, the particles tend to disperse, and the engineering properties as sodium montmorillonite, have strong dispersion (Tang, 2015). This may be the reason why some illite samples are dispersive.

4. Conclusion

We studied the characteristic of the dispersive soil. And the data analysis of the existing research data reveals the factors that affect the dispersion of the clay. The test results also verified the proposed dispersive soil chemical modification principles and effect. The conclusions are as follows:

Firstly, the grey correlation analysis of 48 groups of soil samples from Xinjiang, Xi'an, Gansu, Qinghai, and other parts of foreign engineeringare carried out in this paper. When the content of pH, HCO_{3-}, CO_3^{2-} and Sodium ionsin the soil is relatively high, there will be a higher possibility of soil dispersion, especially alkali soil, when the Sodium ions content is high, the soil is generally dispersive soil; the correlation between Ca^{2+} and Mg^{2+} and the dispersion is relatively high, which indicates that the existence of Ca^{2+} and Mg^{2+}influences the dispersion. The chemical factors that affect the dispensability of cohesive soil should have both high pH and high sodium ion content, but not with the mineral composition. The effect of montmorillonite on the dispensability of cohesive soils was related to the type of montmorillonite. Sodium montmorillonite promoted the dispersion of the soil and the dispersion of montmorillonite was more obvious. Sexual characteristics. The reason sodium montmorillonite accelerates the dispersion of soil is that the soil has both high pH and high sodium ion content.

The results show that Sodium ions and pH have the highest influence on soil dispersion. On this basis, the influence of Sodium ions and pH on the dispersion of cohesive soil is analysed. The results show that the dispersive soil must have two conditions: higher pH and higher Sodium ions concentration.

At present, the researches on dispersive soils are mainly concentrated on the dispersion mechanism and seepage failure. The research on the dispersive soil mechanics is relatively slower than other studies on special soils. It is necessary to study the tensile strength of dispersive soil and its influencing factors, and the factors influencing the characteristic of the dispersive soil.If the cracks occur in the dispersive soil wall, it is very easy to break the dam and lead to the destruction of the water conservancy project. The evolution rule and the influencing factors of the fractured core wall should be analysed carefully in the later research.

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