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# Experimental Study on Physical and Mechanical Properties of Expansive Soil Polluted by Heavy Metals

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**Abstract.** With the rapid development of economy, heavy metal pollution has brought serious harm to the engineering construction in expansive soil area. The Experimental study are to further reveal its physical and mechanical properties, and better guide the engineering practice. The effects of heavy metal ion concentration on compaction, permeability and unconfined compressive strength of expansive soils were studied by preparing 3 different concentrations of  $Pb^{2+}$  and  $Zn^{2+}$  polluted expansive soils in Nanyang city of Henan Province. The results show that with the increase of heavy metal ion concentration, the maximum dry density and permeability coefficient of contaminated soil increase, and the optimum water content and unconfined compressive strength decrease. At the same heavy metal ion concentration, lead-contaminated soil has a higher permeability coefficient and less unconfined compressive strength than zinc-contaminated soil. Compared with the lead contaminated soil, the maximum dry density of the dyed soil is larger and the optimal water content is smaller. The change of the dry density has a significant effect on the permeability coefficient, and the larger the dry density, the smaller the permeability coefficient. It can be seen that heavy metal pollution can change the physical and mechanical properties of expansive soil.

## 1. Introduction

Expansive soils are widely distributed in China, such as Guangxi, Henan, Hubei, Anhui and other areas to varying degrees. Due to the acceleration of industrialization and the impact of human activities, expansive soils suffer from serious heavy metal pollution, resulting in increased expansibility, structural cracking, destroying the stability of the soil structure. Therefore, it is of practical significance to study the changes of physical and mechanical properties of heavy metal contaminated expansive soil for engineering construction[1-2].

In view of the nature of contaminated soil, a great deal of research has been done by scholars at home and abroad[3-6]. Ratnaweera et al[7] found that the shear strength of contaminated soil decreases with the increase of the concentration of heavy metals. Turer et al[8] found that the swelling of kaolin increases through the test of lead, zinc and alkali pollution. Li Yi et al[9] through the shear strength test of zinc contaminated soil, found that the shear strength of contaminated soil is not obvious in the shear process. Du Panxiao et al[10] studied the strength and environmental characteristics of cement-solidified heavy metal contaminated soil. Wubin et al[11] studied the



influence of cement content and zinc ion concentration on mechanical properties of cement-solidified zinc contaminated soil. Chu Chengfu et al[12] studied the engineering properties of zinc-contaminated clay. It was found that with the increase of zinc ion concentration, the relative density of soil particles increased, the liquid and plastic limits decreased, the compressibility of soil increased, the compression coefficient increased, and the compression modulus decreased. Cha Fusheng et al[13] studied the engineering properties of heavy metal-contaminated clay. Heavy metal ions can lead to the decrease of clay content, soluble salt content, cation exchange capacity and unconfined compressive strength of soils. Li Jiangshan et al[14] studied the leaching characteristics and mechanism of solidified heavy metal contaminated soil by leaching with acid solution, and obtained the effects of different  $\text{KH}_2\text{PO}_4$  content, leaching time and PH on leaching behavior of lead.

The research status at home and abroad is based on the properties of heavy metal contaminated soil and solidified contaminated soil. There are few experimental studies on the physical and mechanical properties of expansive soils polluted by heavy metals, and the study has certain practical and theoretical significance.

## 2. Test materials and methods

### 2.1 Test material

The test soil was taken from Shigang Town, Neixiang County, Nanyang City, Henan Province. The soil depth was 2m, showing brown-red. The basic physical properties of the soil were measured. As shown in Table 1, the analysis belonged to weak expansive soil. Lead nitrate ( $\text{Pb}(\text{NO}_3)_2$ ) and zinc nitrate hexahydrate ( $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ ) were selected as pollutants in expansive soils.

Table 1. Basic physical properties of soil indicators

Moisture content (%)	Dry density ( $\text{g}/\text{cm}^3$ )	Liquid limit (%)	Plastic limit (%)	Optimum moisture content (%)	Maximum dry density ( $\text{g}/\text{cm}^3$ )	Free expansion rate (%)	
25.31	1.38	2.68	48.8	28.33	23.1	1.54	58

### 2.2 Test methods

The concentration of lead and zinc ions (the ratio of ion mass to dry soil mass) were 1 000 mg/kg, 5 000 mg/kg and 10 000 mg/kg respectively. The soil sample is dried, ground with wood on a rubber board, and sifted 2 mm according to the requirements. The soil sample under the sieve is taken. According to the requirements, a certain amount of heavy metal ions compounds are dissolved in the distilled water and stirred to make a solution. The solution is evenly mixed with dry soil, and the test is carried out according to the regulations.

## 3. Test results and analysis

### 3.1 Compaction test

Compaction test is a method to understand the compaction characteristics of soil, obtain the maximum dry density and the best moisture content of soil, and provide a basis for engineering design and construction.

According to "Geotechnical Test Rules" (GB/T50123-1999), compaction tests were carried out on unpolluted soils and expansive soils contaminated by different concentrations of heavy metal ions. The test results are shown in Figure 1-3.

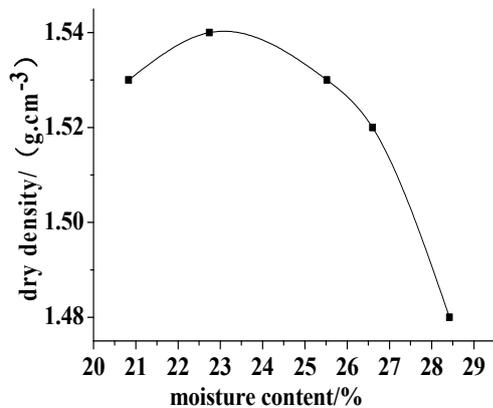


Figure 1. The relationship between dry density and moisture content

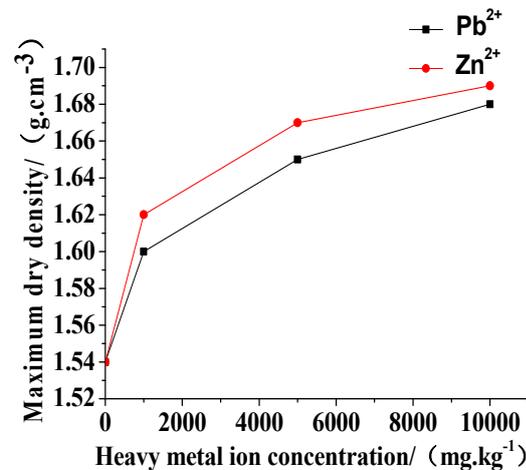


Figure 2. The relationship between the maximum dry density and the concentration of heavy metal ions

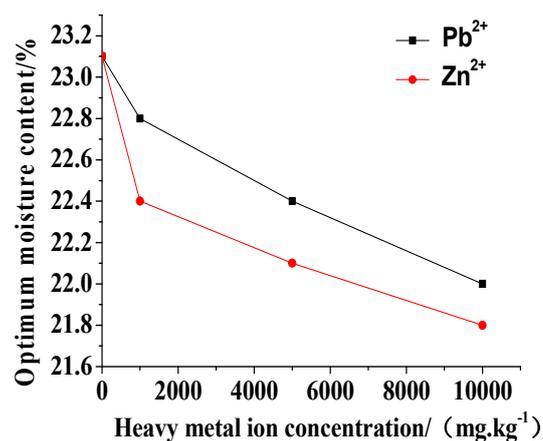


Figure 3. The relationship between the optimal water content and the concentration of heavy metal ions

Figure 1 shows the relation curve of dry density of unpolluted expansive soil with moisture content. As can be seen from the curve in the analysis diagram, with the increase of moisture content, the dry density first increases and then decreases, and the optimal water content and the maximum dry density exist. Therefore, the compaction effect is not good if the water content is too high or too low.

Figure 2 and Figure 3 show the relationship between the maximum dry density of the expansive soil and the optimum water content as a function of heavy metal ion concentration. According to the research and analysis, with the increase of heavy metal ion concentration, the maximum dry density of lead and zinc contaminated soil increases, and the optimum water content decreases. At the same heavy metal ion concentration, the zinc-contaminated soil has a larger maximum dry density and a smaller optimum moisture content than the lead-contaminated soil. When the concentration of heavy metal ions exceeds a certain limit, the difference between the maximum dry density of zinc contaminated soil and lead contaminated soil and the difference between the optimum moisture content gradually decrease. This is mainly due to the heavy metal ions entering the soil, forming a velvety structure[15], and the soil particles are rearranged, so that the expansive soil changes the compaction effect.

### 3.2 Penetration test

Permeability refers to the performance of water permeating and flowing in soil pores. The permeability coefficient is usually expressed by the permeability coefficient, and is affected by the particle size, gradation, density and temperature of the soil.

Because the measured permeability coefficient of the contaminated soil is small, the variable head penetration test is adopted. According to the Geotechnical Test Procedure (GB/T50123-1999), different concentrations of heavy metal ions are mixed into the remolded soil. The inner diameter of the ring cutter is 61.8mm, height 40mm, after press forming, vacuuming is saturated, and the test is carried out according to the regulations. The test results are shown in Figures 4-5.

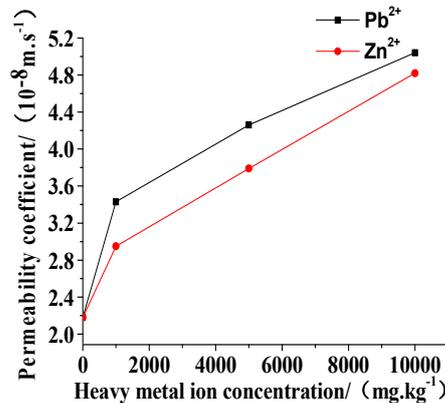


Figure 4. The relationship between the permeability coefficient and the concentration of heavy metal ions

Figure 4 shows the relationship between the permeability coefficient of contaminated expansive soil and the concentration of heavy metal ions (the controlled dry density is 1.48g/cm<sup>3</sup>). It is found that the permeability coefficient increases with the increase of heavy metal ion concentration, and the increasing rate decreases gradually. The permeability coefficient of lead-contaminated soil is larger than that of zinc-contaminated soil at the same heavy metal ion concentration. When the concentration of heavy metal ions exceeds a certain limit, the difference between the permeability coefficient of lead-contaminated soil and zinc-contaminated soil is larger. The value gradually decreases. This is due to the heavy metal ions into the expansive soil, will control the thickness of the electric double layer thinning, expansive soil particles between a larger permeability channel[16], resulting in the sample permeability coefficient increases with the concentration of heavy metal ions.

Figure 5 shows the relationship between permeability coefficient and dry density of unpolluted expansive soil. The curve shows that the change of dry density has a significant effect on the permeability coefficient, and the permeability coefficient decreases with the increase of dry density. At the same time, a linear fitting line can be used to express the relationship between the permeability coefficient and dry density, and the linear fitting line is  $y = -14.09x + 23.064$ , and the fitting degree reaches 99%. Due to the increase of dry density, the pore size that controls the permeability coefficient decreases, leading to a decrease in permeability coefficient.

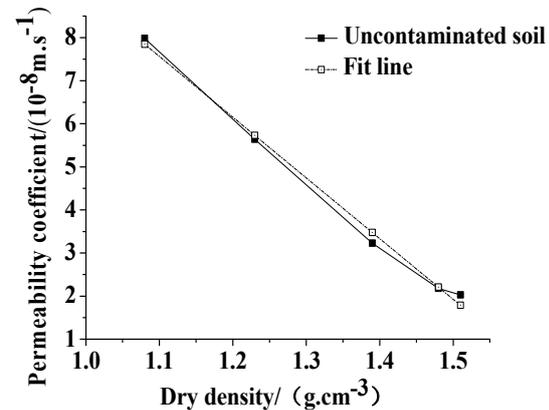


Figure 5. The relationship between permeability coefficient and dry density

### 3.3 Unconfined compressive strength test

In order to understand whether the concentration of heavy metal ions has a certain influence on the unconfined compressive strength of the contaminated expansive soil, an unconfined compressive strength test is carried out.

The test method is to mix the polluted expansive soils with different concentrations of heavy metal ions evenly and put them into cylindrical moulds with a diameter of 39.1 mm and a height of 80 mm in five layers. After reaching a certain degree of compactness, the samples are sealed and placed in a standard curing room (the curing temperature is 20 °C, the humidity is 100%, and the time is 24 hours). An electro-hydraulic servo soil dynamic triaxial apparatus controlled by a microcomputer is used to carry out the test. The axial strain rate is controlled to be 0.8mm/min. The test results are shown in Figure 6.

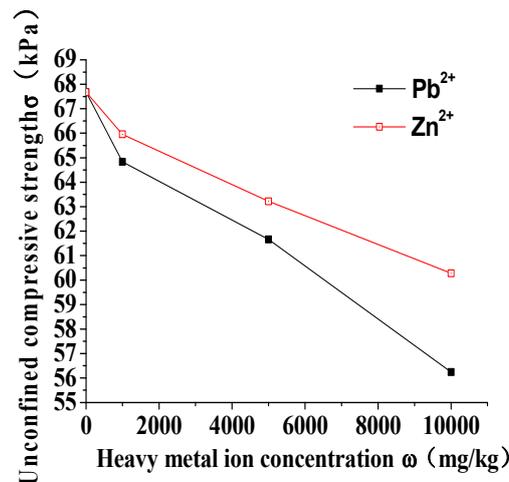


Figure 6. The Relationship between unconfined compressive strength and heavy metal ion concentration

Figure 6 is a graph showing the relationship between the unconfined compressive strength of contaminated expansive soils as a function of heavy metal ion concentration. The curve in the figure shows that as the concentration of heavy metal ions increases, the unconfined compressive strength decreases continuously. Under the same heavy metal ion concentration, the lead-contaminated soil and the zinc-contaminated soil have less unconfined compressive strength. When the concentration of heavy metal ions exceeds a certain limit, the difference between the unconfined compressive strength of lead contaminated soil and zinc contaminated soil gradually increases. This is because heavy metal ions enter the expansive soil, resulting in a decrease in the cohesive force between the soil particles, and an effective contact area is reduced, thereby reducing the unconfined compressive strength.

It can be seen that the heavy metal ions contaminated expansive soil breaks the internal balance between the soil particles, changes the electric field and interconnection of the particles, weakens the cementation surface[17-18], thus changing the physical and mechanical properties of expansive soil.

#### 4. Conclusion

By adding 3 different concentrations of heavy metal contaminated expansive soil and non-polluted expansive soil for comparison, the maximum dry density, optimal water content, permeability coefficient and unconfined compressive strength are discussed, and the following main conclusions are obtained.

(1) As the water content increases, the dry density increases first and then decreases, and the optimal moisture content and maximum dry density exist. With the increase of heavy metal ion concentration, the maximum dry density of lead and zinc contaminated soil increases, and the optimal water content decreases. Under the same heavy metal ion concentration, the zinc-contaminated soil has a larger maximum dry density and a smaller optimal moisture content than the lead-contaminated soil.

(2) With the increase of heavy metal ion concentration, the permeability coefficient increases, and the increasing rate decreases gradually. Under the same heavy metal ion concentration, the lead-contaminated soil has a larger permeability coefficient than the zinc-contaminated soil, the change of dry density has a significant effect on the permeability coefficient. As the dry density increases, the permeability coefficient decreases.

(3) As the concentration of heavy metal ions increases, the unconfined compressive strength decreases continuously. Under the same heavy metal ion concentration, the lead-contaminated soil has less confined compressive strength than the zinc-contaminated soil.

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