Characteristics of Unloading Deep Soil Deformation in North China Plain

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Abstract

A compression test was applied to deep sand soil, silt and clay samples in the depth of 199m~479m in North China Plain, to understand their deformation characteristics of unloading after sampling. The result shows that under the loading conditions of 1200 kPa and 3200 kPa, the deformations of soil samples taking from 199～439m depth were 0.43～1.386mm and 0.725～1.896mm, respectively. The deformations of soils with different lithology are also different, i.e. sand soil > clay > silt, in which clay is the most resilient. The analysis of deformation process reveals that the deformation of sand soil in the initial stage is mainly pore compression, and grain abrasion in the subsequent stages; the deformation of clay is the interactive result of grain slippage and breakage; the deformation of silt is pore compression.

Key words：Compression Test, Soil Deformation, Load, Pore space ratio, Unloading

1. Introduction

The groundwater has been seriously over-extracted in China. The deep groundwater extraction in the North China Plain has reached the degree of 177.2%. Considering that the regional subsidence caused by deep groundwater over-extraction may evolve into large scale environmental geological disaster, the lowering bearing capacity of the over-extracted layers attracts more attention. However, due to climate, extraction, leakage supplied deep aquifer, etc., there is serious dewatering of the upper aquifer, which cause loading decrease and then lead to soil mass deformation. If the deformation is underestimated during the prediction of land subsidence, the prediction result may be overrated. Geotechnical test is an important task for acquisition of various soil mass indices and effectively instructing groundwater extraction object, and soil compression test is a basic method for obtaining compression property, estimating regional subsidence. This work takes the typical soil mass of the North China Plain as research object, select deep soil samples of clay, silt and sand soil for two sets, respectively, to discuss the transformation characteristics of the different soil masses of the different depth, in order to provide instruction to reasonably control the deep and shallow groundwater exploitation in the North China Plain.

2. Material and method

2.1 Soil samples collection and physical testing

The samples are collected from ‘Groundwater science and project of Ministry of Land and Resources of the People’s Republic of China – Zhengding Base, Heibei Province’. The soil masses are from the same core by applying double spiral drilling method, which disturbed little by boring process. The diameter of the core is about 108mm. The basic physical properties of the samples are measured according to ‘*Specification of soil test (DT-82)*’, see Table 1. Because the grouting drilling caused the disturbance of the water content of the soil masses to some extent, the water content data are different from that in natural condition.

Table 1 Physical property indexes of soil samples

lithological characters	Clay	Clay	Sand soil	Sand soil	Silt	Silt
depth (m)	199	269	321	479	312	439
water content (%)	22.29	20.28	20.53	16.08	20.28	16.34
initial void ratio	1.186	1.045	1.173	0.971	1.147	0.895
specific gravity	2.74	2.74	2.64	2.65	2.69	2.69
bulk density (g/cm^3)	1.522	1.612	1.464	1.561	1.507	1.651
plasticity index	16.6	19.7	/	/	/	/
liquid index	-0.03	-0.29	/	/	/	/
liquid limit	39.4	45.7	/	/	/	/
plastic limit	22.8	26.0	/	/	/	/

2.2 Testing design

The testing is divided into two compression resilience processes, i.e. 200-400-800-1200 kPa and 1200-2800-3200, the maximum loadings are both less than the historical loadings of the soil masses, the purpose of which is to discuss the transformation characteristics of compression resilience after the unloading of the soil masses.

The KTG-800 automatic consolidometer is used to apply loading and unloading during the test. Self-weights of the six sets of sample are repeatedly loading and unloading in the range of P0+0.6 mPa, with loading stress not less than 400 kPa and repeated loading not less than twice. The unloading stresses of this set of samples are 1200-800 kPa, 1200-400 kPa and 3200-2800 kPa, respectively. The criteria for stability judgment during tests is ≤0.005mm per hour, above the precision of the national standard for soil tests, which is sufficient for the condition for studying deformation of the samples. The samples are compressed under the water-saturated condition.

According to the approximate formula, the overlying self-weight is the product of the volume weight and sampling depth. The loadings of 400 kPa, 800 kPa, 1200 kPa are significantly less than the compressive stress before unloading of the testing soil mass, while the loadings of 2800 kPa, 3200 kPa are closer to that. The testing procedure equals to the resilience-compression process of the regular compression-resilience test.

2.3 Method for data processing

The computation of the resilient compression modulus, soil mass void ratio, and correction of deformation under various grades loading are applied according to *Specification of soil test (DT-82)*.

3. Results and analysis

3.1 Comparison of compression deformations of the samples with the same lithology in different depth

The displacement is determined jointly by historical loading and lithology of soil mass. The samples are from the same bore hole, so the historical loadings of the samples above ground surface are deemed as the same. The historical loading increases with the depth.

Under the condition of 1200 kPa and 3200 kPa loadings, the deformations of the soil mass samples are 0.43~1.386 and 0.725~1.896, respectively. According to Figure 1 and Figure 2, in the whole compression-resilience processes, there are common properties in the soil masses with the same lithology: sand soil (321 m) > sand soil (479m); clay (199 m) > clay (269m); silt (312 m) > silt (439 m), indicating that the deformations of the shallow soil masses are bigger than that from the deep soil masses. E-log curves in Figure 3 indicate that during the resilient process, the void ratios in the same loading have the common properties: clay (199 m) > silt (312 m) > sand soil (321 m) > clay (269 m) > silt (439 m) > sand soil (479 m), the ratios of the soil masses decrease with depth, i.e. the ratios decrease in relation to the increase of the historical loadings, the deformations decline in correlation with the decrease of the compression resilience ability.

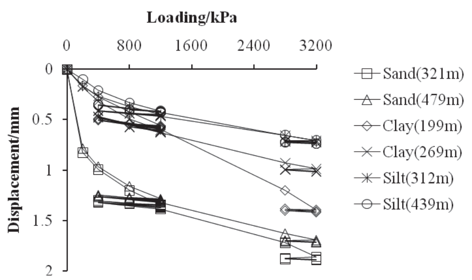

Fig.1 Displacement under different loadings

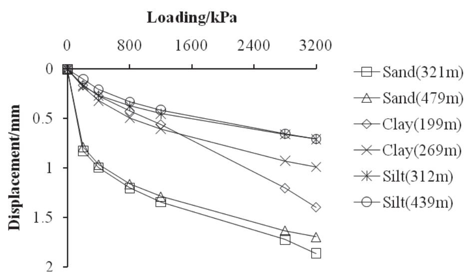

Fig.2 Correction of displacement under different loadings, this displacement means the soil deformation is stabilization by consolidation

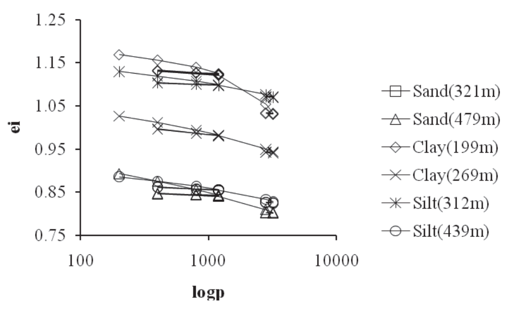

Fig.3 e-log curve

According to Figure 4 and Figure 5 denote the steady transformations of the last grade loading compressions in the two compression resilience processes of 200-400-800-1200 kPa and 1200-2800-3200 kPa, respectively. The figure shows that in the low loading condition of 1200 kPa, there are significant differences between sand and clay soil masses in different depth, i.e. shallow sand soil (321 m) > deep sand soil (479 m), shallow clay (269 m) > deep clay (199 m);the deformations of silt in different depth have no obvious variance. In the high loading condition of 3200 kPa, there are significant differences between sand soil and silt masses in different depth, i.e. shallow sand soil (321 m) > deep sand soil (479 m), shallow clay (199 m) > deep clay (269 m). It can be seen that the deformations of sand soil and clay are strongly influenced by their depth, i.e. the deeper, the more historical loading and the less deformation, but influence of the depth on the silt is relatively little.

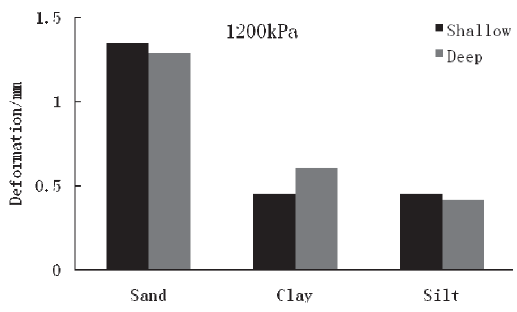

Fig.4 Comparison of the deformations of different soils under 1200 kPa

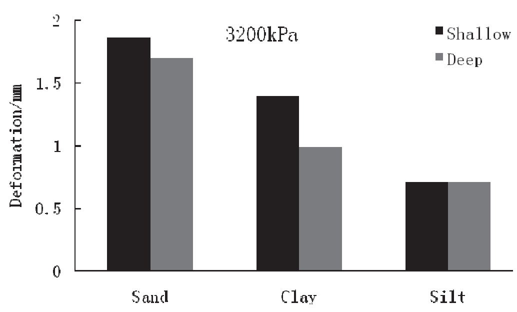

Fig.5 Comparison of the deformations of different soils under 3200 kPa

3.2 Comparison of soil mass compressive deformations with different lithology

It can been seen obviously that in the same loading condition, the relationship between deformations of different lithological soil masses is: sand soil > clay > silt, note that the historical variances caused by depth are neglected here. If the depth is considered, the void ratios in figure 3 show that the relationship are: clay (199 m) > silt (312 m) > sand soil (321 m) for shallow soils, clay (269 m) > silt (439 m) > sand soil (479 m) for deep soils, i.e. clay > silt > sand soil for void ratios of soils with different lithology. The lithology is an important factor that influences void ratio and deformation.

3.3 Comparison of compression resilience deformation characteristics of soil masses with different lithology

Figure 6 shows that the compression modulus of silt is apparently bigger than those of clay and sand soil. The compression modulus of clay is obviously bigger than that of sand soil under the condition of 200 kPa, but they are gradually close to each other along the increase of loading. Their relationship on compressibility are: silt > clay > sand soil, while on compression deformation are: sand soil > clay > silt.

From figure 7, figure8 and figure 9 we can see that the resilient modulus of clay is lower than those of sand soil and silt in resilient processes of 1200~800 kPa and 1200~400 kPa, reflecting that clay is relative plastic and the resilient moduli of sand soil and silt are close to each other. Under the condition of 1200~800 kPa, the resilient moduli are negative except clay (199 m) in the first resilience. According to the soil mass deformation stability criteria for the test, if we load pressure to 3200 kPa directly, the tested soil masses is not yet in the stable state of compression deformation, therefore silt and sand soil have no resilience. The second resilient process becomes normal, when the resilient moduli of silt and clay are close to each other, the modulus of clay lower than that of silt, the modulus of sand soil is apparently bigger than those of clay and silt, the resilience of sand soil is the lest and compression deformation is the most.

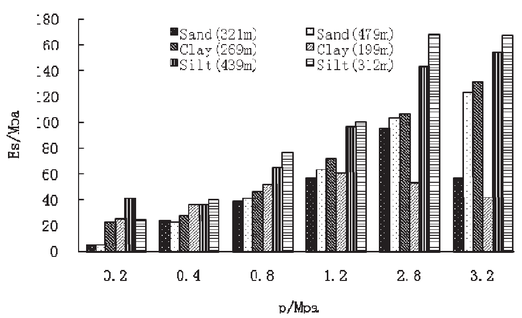

Fig.6 Comparison of the compression modulus of soils under different loadings

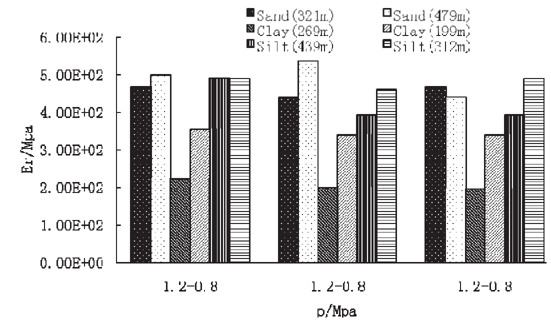

Fig.7 Comparison of the resilient modules of different soils in repeated spring-back process with 1.2～0.8 MPa

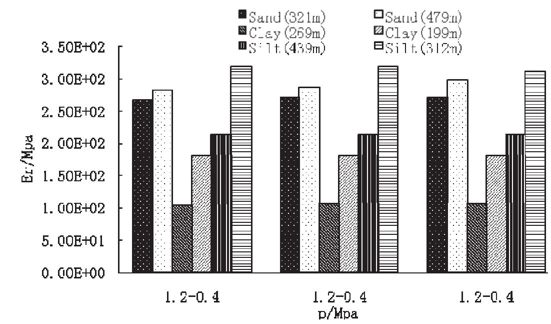

Fig.8 Comparison of the resilient modules of different soils in repeated spring-back process with 1.2～0.4MPa

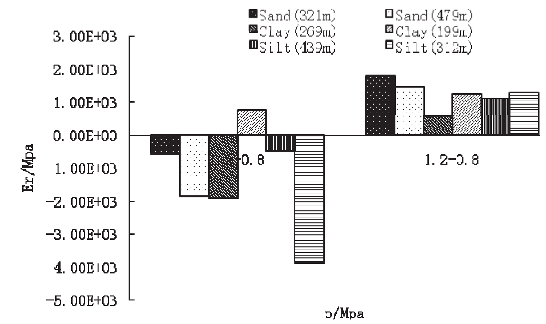

Fig.9 Comparison of the resilient modules of different soils in repeated spring-back process with 3.2～2.8MPa

3.4 Analysis of genesis of compression deformation

3.4.1 Sand soil

Under the loading condition, sand soil can be seen as skeleton construction formed by rigid grains, which is hard to generate grain deformation. The historical loading of sand soil is in positive, while the initial void ratio is in negative correlation with its depth (Table 1). The compression moduli of the loading conditions, except the 400 kPa condition, are increase with the depth, with which the compression deformations are decrease, however (Figure 5). Under the condition of 200~1200 kPa, sand soil is mainly in the process of changing void ratio. The 2800 loading do not reach the high loading condition before unloading, when the compression modulus of sand soil is close to that of clay, which possibly because the grain contact points abrade each other, then make the sand soil more compact.

3.4.2 Clay

The clay deformation include its slippage and breakage, which entail continuous media mechanics and micromechanics to analyse. Clay grains are agglomerates composed of numerous particles, which can be assumed as a rounded rigid-plastic body. In the case of no grain damages, the compression makes the rounded grains generate yield surfaces and form ellipses, the contact points move against each other. After removing the loading, the yield surfaces try to recover their original rounded forms. Therefore, clay is more resilient than silt and sand soil, the more loading, the more resilient. Clay may experience resilience after it is sampled and before it is tested. Under the low loading condition of 200~1200 kPa, historical resilience is included in compression deformation, so more historical loading of clay from deeper site causes more historical loading resilience, and then cause large deformation under low loading condition. The deformation of clay is significantly more than silt with approximate void ratio under the high loading condition of 2800~3200 kPa, which is a specific result for clay grains breakage. Compression deformation of shallow clay is apparently greater than deep clay. Because the historical loading of the deep clay is high, so are the grains, and the deep clay grains vulnerable to breakage are less than shallow clay grains, so the deformation is relative small. At the same time, there is grain slippage, so the compression of clay is the interactive result of grain slippage and breakage.

3.4.3 Silt

Silt grains aggregate tightly, without skeleton construction and plasticity. In this test, the silt compression is merely a changing void ratios process. Under the low loading condition of 200~1200 kPa, in aspect of the historical loading caused by lithology and depth, the void ratio of silt (312 m) is higher than silt (439 m), and the deformation of silt (312) is slightly bigger than silt (439); under the high loading condition of 2800~3200 kPa, the two sets of soil have no abrasion as sand soil has, nor breakage as clay has, so the deformation of the two silt under the condition are close to each other.

4. Conclusions

From the analyses above mentioned, we can see that the deep layer soil samples under test have the characteristics as follow:

(1)The deformation relationship of soils with different properties is: sand soil > clay > silt.

(2)Sand soil and clay are more vulnerable to deformation in shallower depth, and vice versa, while depth exerts little effect on silt.

(3)Deformation of sand soil includes pore compression in the initial stage and grain abrasion in the subsequent stages; the deformation of clay is the interactive result of grain slippage and breakage; the deformation of silt is pore compression.

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