Swell-shrink Behavior and Soil Improvement of Compacted Expansive Soil

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1. INTRODUCTION

Under the natural undisturbed conditions, some clayey soils show certain swelling-shrinkage, but their swelling grades are low. When being disturbed, compacted and then used for the embankment and roadbed, their natural structures are destroyed and cementing bonds broken, the water contents decrease the dry densities become high and the swelling-shrinkage increase. By this they may become high swelling grade expansive soil. The purpose of this study is to investigate the swelling-shrinkage mechanism and effect of lime-treatment on this type of compacted expansive soil.

2. SOIL DESCRIPTION AND TEST METHODS

In this study, investigated expansive soils are selected in nearly the same locations of Ning-Lian Highway, China. They are alluvial sedimented and overconsolidated soils. Table 1 shows their physico-mechanical properties. Compacted specimens were prepared according to Modified Proctor compaction tests, and their physico-mechanical properties are also tabulated in Table 1. To do the swelling pressure test, the specimen of 60x20 cm disc size was placed in an oedometer consolidation cell. The test procedure consisted of putting porous stone on the top and bottom of the laterally confined samples, applying a vertical stress to the samples under 100% degree of saturation. Swelling percentage under 50 kPa (δ_{ep50}) is also measured using oedometer under 100% degree of saturation. In both of the tests, the samples were allowed to fully swell for at least 2 days to complete swell. Total swelling percentage (δ_{ps}) is calculated as : $\delta_{ps} = \delta_{ep50} + \lambda_s (w-w_s)$, in which λ_s is the soil shrinkage coefficient, w is the nature water content and w_s is the shrinkage limit.

Table 1 Physico-mechanical properties of selected undisturbed and compacted soils

Soil type	Water content, w (%)		Liquid limit, LL (%)		Plastic index, PI		Dry density ρ_d (g/cm^3)		Organic matter
	U	C[1]	U	C	U	C	U	C[2]	(%)
Grey soil	34.2	19.5	51	55	23	24	1.33	1.74	0.2
Black soil	43.9	24.5	58	60	32	34	1.30	1.60	trace
Greyish-yellow soil	27.4	20.0	43	43	19	20	1.54	1.71	1.5
Yellow silty soil	25.8	14.2	32	33	15	16	1.61	1.63	trace

U--undisturbed soil C--compacted soil 1-- optimum water content 2-- maximum dry density

3. SWELL-SHRINK BEHAVIOR AND CONSIDERATION OF MECHANISM

(1) Behavior

From Table 2, it can be seen that under undisturbed conditions, swelling-shrinkage indexes of these soils are low except for the Yellow silty soil, whereas they become higher when remolded and compacted. Swelling pressure of a type of soil named Grey soil increases by 27 times varying from 22kPa to 587kPa, while that of so called Black soil increases by 39 times ranging from 10 kPa to 385 kPa. The swelling pressure of Greyish-yellow soil increase by about 7 times changing from 40 kPa to 276 kPa. Only the Yellow silty soil remains no-expansive even after remold and compaction. Another indication is that the swelling percentage under 50 kPa of undisturbed soil is below zero and it increases above zero (except for the Yellow silty soil) after being compacted. After being compacted δ_{ps} of the undisturbed soils become relatively higher, δ_{ps} of the Grey soil being the largest one, while that of Yellow silty soil being the lowest one. According to Li (1992), for soil with δ_{ps} greater than 0.7%, it should be considered as expansive one. Therefore these compacted soils are expansive soils excluded Yellow silty one.

Table 2. Comparison of swelling-shrinkage indexes between compacted and undisturbed soils

Soil Type	δ_{ep50} (%)		δ_{ps} (%)			P (kPa)			SWC	
	U	C	U	C	U/C	U	C	U/C	U	C
Grey soil	-0.7	11.8	4.3	11.8	3.0	22	587	27	moderate	high
Black soil	-1.9	7.3	7.3	7.5	1.0	10	385	39	high	high
Greyish-yellow	-1.2	5.5	2.9	6.2	2.0	40	276	7	low	high
Yellow silty soil	-3.7	-0.5	-0.7	-0.4	1.0	6	7	1	non	non

δ_{ep50}--swelling percentage under 50kPa, δ_{ps} --total swelling percentage, P--swelling pressure, SWC--swelling classification

(2) Change of dry density and water content

From Table 1, it can be seen that dry densities of undisturbed soils are larger while water contents are lower compared with the compacted ones. The swelling of soil is due to a moisture film forming around the particles as a result of reaction between the clay particles and water. As the thickness of moisture film increases, the volume of the soil increases also. This phenomenon varies depending on the conditions of dry density and water content. For a specimen with low water content, formation of the moisture film is easy and it reaches maximum thickness in a short time. However, when the dry density is high, there are more clay particles per volume of soil which is benefit to the swelling, and thus the reactions between particles and water are more serious. The dry densities of compacted soils are higher and their water contents are lower. On the contrary, undisturbed soils have no such performances. Thus it is clear that degree of water saturation plays important roles in soil swelling.

(3) Change of microstructure

After long complicated natural events, undisturbed clay soil mass develops certain structure strength and strong connection form among soil particles. This can partly suppress the swelling. On the contrary, in laboratory compacted soils have been ground, remolded and compacted, their original structures are destroyed, natural structure strength low down and thus factors suppressing swelling are removed, which makes them easy to swell. Table 3, which well describe the microstructure differences between compacted and undisturbed soils can explain the phenomena rather clearly. To get the Scanning Electronic Microscope (SEM) photographs, all the specimen were prepared by the freeze dry method using the freeze-vacuum-sublimation desiccator. From Table 3, it can be seen the microstructures of compacted soils are mainly of turbulent or turbulent-orientation aspect with higher structural particle orientation and their pores distribute homogeneously and form rows of channels. When soils immerse into water, water can penetrate easily along these channels which makes aggregated particles react with water sufficiently. As for the microstructures of undisturbed soils, most of the pores are micro ones and they do not distribute homogeneously. So water penetrates into soil with difficulty. Microstructure of Yellow silty soil does not vary obviously before and after compact, therefore the swelling-shrinkage properties do not differ much.

Table 3. Comparison of microstructures between compacted and undisturbed soils

Soil type	Undisturbed soil	Compacted soil
Grey soil	turbulent fabric	turbulent-orientation fabric
Black soil	aggregate fabric	turbulent-orientation fabric
Greyish-yellow soil	matrix fabric	turbulent fabric
Yellow silty soil	aggregate-skeletal fabric	aggregate-skeletal fabric

4. SOIL IMPROVEMENT

To reduce the swelling, 8 wt. percentage lime is added into the compacted expansive soil specimens and homogeneously mixed. Under the laboratory conditions with 20°c temperature and 22% humidity, twenty-four hours are allowed to pass for sufficient reaction between the lime and expansive soil specimens. To do the swelling test, the water content of the mixture is allowed to reach an optimum, and the dry density of the specimen is also permitted to reach a maximum. For the unconfined compression test after seven days soaking in water, each specimen is formed into a ϕ4xH5cm cylinder. From Table 4, it is clear that the improvement in the Grey soil is the best. The improvement in the Black soil is relatively poorer, still belonging to the category of expansive soil. The reason for this may be that the organic matter content of the Black soil is 1.5%, which is as much as 7 times that of the Grey soil. Among the soils, the improvement in the Yellow silty soil is the poorest. With sufficient reaction between the compacted expansive soil and the lime, a change in the exchange cation causes the aggregation of the clay particles, and the microstructure becomes more dense compared with the untreated compacted expansive soil (Li, 1992). Therefore the physical and mechanical properties of the compacted expansive soil are improved.

Table 4. Comparison of swelling-shrinkage indexes between pre and post-treatment of compacted soils

Soil type	δ_{ep50} (%)		δ_{ps} (%)		P (kPa)		q_{u7d} (kPa)		SWC	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Grey soil	11.8	-0.4	11.8	-0.4	587	30	CP	893	moderate	high
Black soil	7.3	0.3	7.5	1.25	385	134	CP	423	high	high
Greyish-yellow	5.5	-0.3	6.2	-0.4	276	37	CP	1191	low	high
Yellow silty soil	-0.5	-0.5	-0.4	-0.2	7.5	10	CP	101	non	non

Pre--prior to lime treatment, Post-posterior to lime treatment, q_{u7d}--unconfined compress strength after 7 days soaking in water, CP--collapse, P--swelling pressure

5. CONCLUSIONS

Based on the analysis above, several conclusions can be obtained:(1) The breakdown of the cementing bonds is one of the reasons why compacted expansive soils show higher swelling abilities and pressure compared with the undisturbed soils; (2) The initial water content plays an important role in the swelling abilities and pressure of the compacted expansive soil; (3) The compacted expansive soils show higher structural element orientation as compacted with that of undisturbed soils, and this rearrangement of the particles is another factor affecting the swelling abilities and swelling pressure. In terms of practical applications, careful attention should be paid to such soils in engineering works. Improvement by lime treatment can ameliorate swelling damage.

REFERENCE

1) LI Sheng-lin et al.. Study on the engineering geology of expansive soils in china, Jiangsu Science and Technology Publishing House, pp129-140, 1992 (in Chinese).