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Variation of Shearing Characteristics of Loess Soil after Irrigation

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Abstract: At Heifangtai terrace in China, farmland reclamation and settlement started in 1960's and irrigation farming began in 1968. Following to the irrigation, ground subsidence and landslides have occurred. The ground subsidence was due to collapse of loess soil caused by applying irrigation water. However, the effect of the collapse and the wetting on shear characteristics are still not clear. In order to investigate changes in the shear characteristics of loess soil when wetted, direct shear box test using the undisturbed and remolded samples of Malan loess soil was conducted. The results of the undisturbed soil showed decrease in both cohesion and internal friction angle occurred by wetting, while little change in the strength parameters was observed for the remolded soil. For the undisturbed soil, the cementating material is considered effective to the unsaturated cohesion, which disappears in the saturated state. The irrigated soil showed the different unsaturated strength parameters from the non-irrigated soil. Nevertheless, the may be strongly affected by the soil water content.

Key words: **Collapse; Loess soil; Direct shear box test; Cohesion; Internal friction angle; Cementation; Landslides**

灌溉后的黄土剪切特征变化

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摘 要:在中国甘肃省的黑方台阶地上从上世纪60年代开始出现人类定居和开垦活动,并自1968年发展为灌溉农业。随着灌溉的进行地面已出现沉陷和滑坡。地表沉陷是由灌溉水的充填引起黄土结构崩塌造成的。然而崩塌和湿润化对剪切特征的影响目前还不清楚。为了研究湿化后的黄土剪切特征的变化,进行了对马兰黄土未经扰动和重塑土样的直接剪切盒测试。结果显示未扰动土样的粘合力和内摩擦角在湿润化后都下降了,而所观察到的重塑土的弹度参数只有少许变化。未扰动土的不饱合粘合力,据认为其受胶结物质的影响,在饱合后消失了。经灌溉的土的不饱合强度参数与未灌溉土相比表现出差异,它们可能受土壤水分的强烈影响。

关键词: 崩塌; 黄土; 直接剪切盒测试; 粘合力; 内摩擦角; 胶结; 滑坡

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0 Introduction

Heifangtai is a river terrace of the Yellow River located about 60 km west of Lanzhou, the capital of Gansu province, China. It belongs to a temperate arid/semi-arid climate zone, where precipitation is 316.3 mm/year, evaporation is 1 689 mm/year and average temperature is 8.4 ℃. In 1960, about 2 000 people migrated to the Heifangtai from constructing the Liujiaxia hydro power station. Then, the Chinese government carried out the farmland reclamation and settlement for the immigrants. Irrigation began in 1968, but since then , many ground subsidence in the farmlands and landslides at the edge of the terrace have happened. It was a serious problem for farmland conservation and disaster prevention since the ground subsidence and landslide have broken the irrigation canals and farmers' residence.

Collapse of the loess soil by applying the irrigation water is considered responsible for the ground subsidence at Heifangtai. Collapse settlement was caused by increate in soil water content which could weaken the bonding force between soil particles. Collapsible soils are often described as loose granular soils with large void ratio and the soil structure temporary held with clays or some cementating materials[5]. Malan loess soil in Heifangtai is also the collapsible soil and accumulates 40~50 m in thickness at surface layer [3].

On the other hand, changes in the shear characteristics when wetted and collapsed, are necessary for the slope stability analysis at Heifangtai. However, little is known about it. In this paper, changes in the shear characteristics of the Malan loess soil by wetting are studied by using direct shear box test.

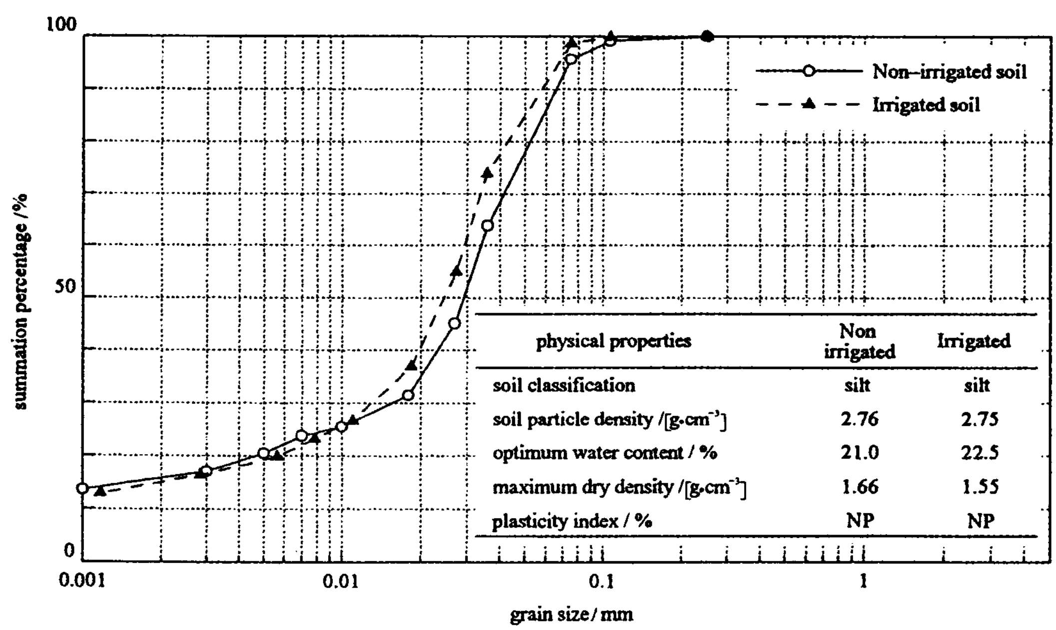
1 Materials and Methods

1.1 Soil sample

Two soils were sampled at Heifangtai. One was sampled at farmland that has been already collapsed by the irrigation water(hereafter called 'irrigated soil'). Another was sampled at unused land that doesn't have both irrigation and collapse history except for the collapse by rainwater(hereafter called 'non-irrigated soil'). Undisturbed sample and remolded sample were prepared. Some of physical properties of two soils are shown in Fig. 1. The physical properties were almost same between the two.

1.2 One-dimensional response-to-wetting test

In order to investigate the collapsibility of the Malan loess soil, one-dimensional response-to-wetting test was conducted by using an oedometer.



physical properties	Non irrigated	Irrigated
soil classification	silt	silt
soil particle density /[g·cm⁻³]	2.76	2.75
optimum water content / %	21.0	22.5
maximum dry density /[g·cm⁻³]	1.66	1.55
plasticity index / %	NP	NP

Fig. 1 Physical properties of the Malan loess soil.

Remolded specimen of the non-irrigated soil of 30 mm in height and 75 mm in diameter was used for the test. The soil was compacted with mass water content of 5%(= w) with a rammer. Compaction energy was 552 kJ/m^3. Loading pressure of 50.2, 101, 202, 404, 808 kN/m^2 were applied and collapse upon wetting was measured under each loading pressure. The procedure was as follows:

(1) After the specimen was set in the ring, the first loading pressure (50.2 kN/m^2) was applied.

(2) Compression under unsaturated state with each loading pressure was repeated with compression period of 3 hours. After compression under a certain loading pressure level was completed, distilled water was introduced into the specimen from the lower end through the porous plate, and the collapse settlement was caused. Water percolation was continued for 24 hours to attain complete saturation, at the same time, the vertical displacement of collapse settlement was recorded.

(3) After the wetting for 24 hours, consolidation was stared under the following loading pressure. The consolidation was repeated until the last loading pressure(808 kN/m^2) was applied.

1.3 Direct shear box test

Direct shear box test was performed for the remolded specimen of the non-irrigated soil and the undisturbed specimen of both the irrigated soil and non-irrigated soil. For both undisturbed and remolded specimen, the unsaturated shear strength and the saturated shear strength after wetting was measured. Compaction energy for the remolded sample and the specimen size were the same as the ones for the one-dimensional response-to-wetting test. Shearing rate was 0.173 mm/min and the specimen was sheared until the horizontal displacement reached 8.75 mm. Space between upper and lower shear box was 0.3 mm.

1.3.1 Unsaturated direct shear box test

In unsaturated state , the specimen was compressed under the applied confining stress for 12 hours, and then sheared.

1.3.2 Saturated direct shear box test(CD-test)

The specimen was compressed for 12 hours under the confining stress, and then, in order to attain complete saturation, CO_2 gas was permeated through the specimen for 20 minutes under the inlet air pressure of 5.0 Pa prior to water saturation. Following to CO_2 gas treatment, distilled water was supplied from the lower end of the specimen, which caused the collapse settlement. The percolation of the water was continued for 24 hours. After the water percolation, tensiometer was inserted into the specimen to measure pore water pressure. The shearing rate was slow enough to satisfy the drained condition, which could be checked by the change in the pore water pressure at the shearing process.

2 Results and discussion

2.1 One-dimensional response-to-wetting test

Fig. 2 is the result of the one-dimensional response-to-wetting test using the remolded specimen of the non-irrigated soil, and it shows the collapse settlement upon wetting under the various loading pressure. p_w in Fig. 2 is the loading pressure applied when the soil was wetted. The coefficient of collapsibility δ_s is used as the index of the collapsibility[2]. The equation for the coefficient is as follows

$$\delta_s = \frac{h_p - h'_p}{h_0}$$

Where h_p is the sample height under a loading pressure, h'_p is the sample height under a loading pressure in saturated state, and h_0 is the original sample height. Normally, the coefficient is applied for only undisturbed soil. If the coefficient is larger than 0.015, the soil is distinguished into collapsible soil. In this one-dimensional response-to-wetting test, the coefficient was from 0.023 to 0.153. Therefore, the remolded specimen of the non-irrigated soil is considered to have the great collapsibility.

The compression yielding stress p_y for 'no-wetting' curve was p_y = 205 kN/m^2. The degree of collapse settlement was large around the compression yielding stress. The all compression curves af-

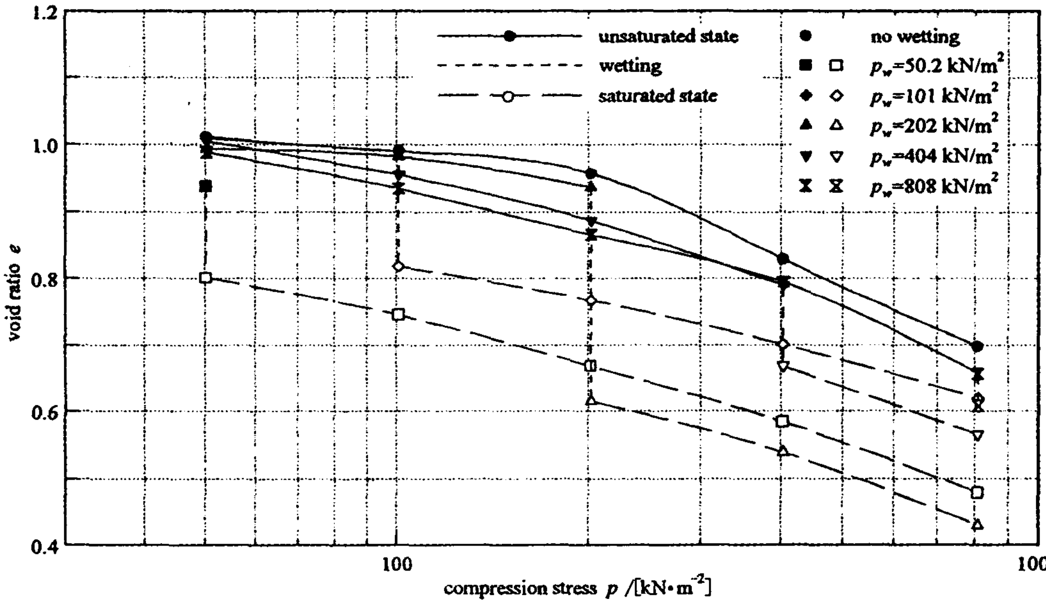


Fig. 2 e-log$p$ curves for the one-dimensional response-to-wetting test using the remolded specimen of the non-irrigated soil.

ter wetting approximately traced the same curve and no yielding stress was observed in the curves after wetting. This is considered the typical behavior of the Malan loess soil[1].

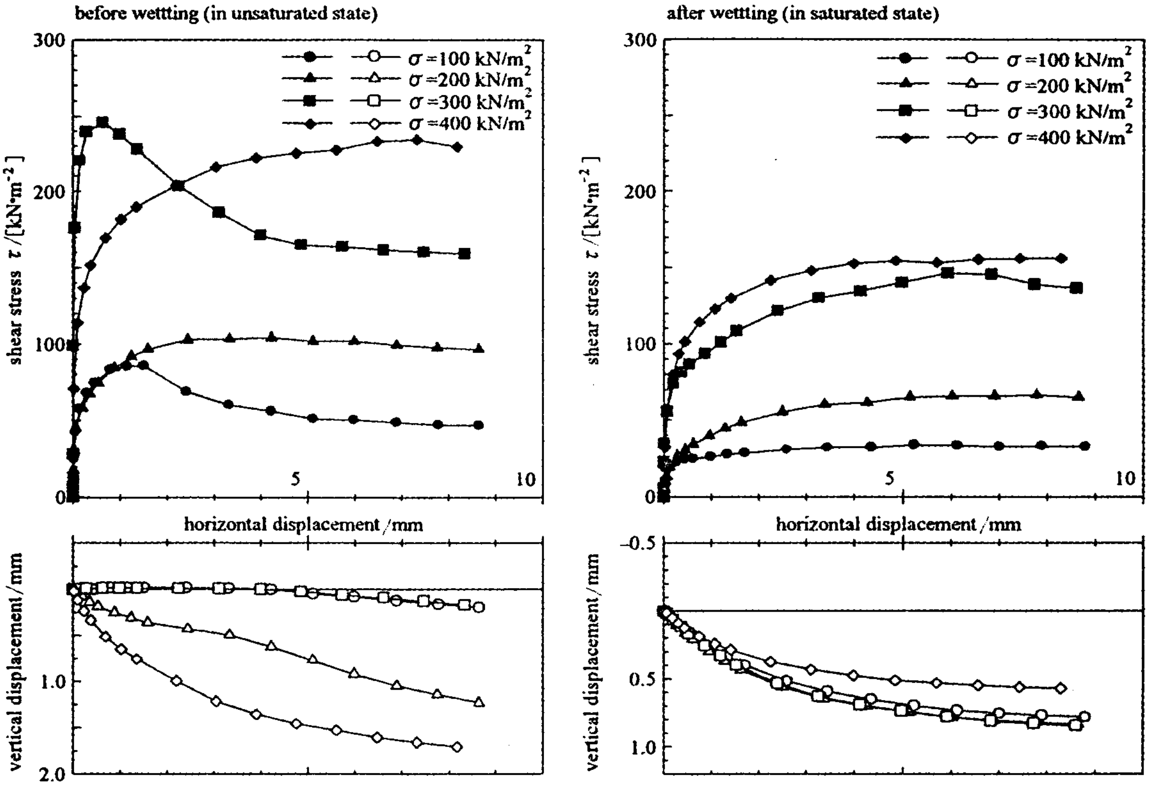
2.2 Direct shear box test

2.2.1 Undisturbed shear strength

Fig. 3(a) and Fig. 3(b) are the results of the undisturbed specimen of the non-irrigated soil. The mass water content in unsaturated state corresponds to the natural water content, which is 1% ~6%(=w_n), and the value in saturated state after wetting was 23%~27%(=w). In unsaturated state without wetting (Fig. 3(a)), the shear stress-horizontal displacement curves had the peak strength with the confining stress of 100, 300 kN/m^2. Under these confining stresses, the vertical displacement had been kept around zero until the residual strength was achieved. In saturated state after wetting (Fig. 3(b)), no peak point existed and all shear stress curves showed slightly plastic hardening. The residual strength in saturated state was smaller in comparison with the one in unsaturated state. The disappearance of the large peak strength by comparison the unsaturated soil with the saturated soil was the remarkable change in the shear stress-horizontal displacement curve. The peak shear strength isn't considered due to the effect of overconsolidation because the confining stress was in normally consolidated region. On the other hand, the Malan loess soil includes much calcium carbonate, which can affects the shear strength as cementating material. Therefore, the peak strength under unsaturated state considered due to the effect of the cementation.

Fig. 4 is the result of the undisturbed specimen of the unsaturated irrigated soil with the natural mass soil water content of 15%~16%(=w_n). The behaviors of shear stress and dilatancy were almost same to the ones of the saturated non-irrigated soil, which was plastic hardening. In addition, no peak strength such as the unsaturated non-irrigated soil was observed.

In Fig. 3(a), (b) and Fig. 4, only the unsaturated non-irrigated soil had the large peak strength. The peak shear strength is considered due to the effect of the cementation as mentioned above. The cementating effect on shear strength is thought to disappear by attaining water saturation, because the peak strength wasn't observed for the saturated non-irrigated soil and the unsaturated irrigated soil. The saturated non-irrigated soil was artificially wetted before shearing, and the unsaturated irrigated soil had been already wetted by applying the irrigation water for many years. Hence,



(a) in unsaturated state (w=1～6%) (b) in saturated state (w=23～27%)

Fig. 3 Shear stress-vertical displacement-horizontal displacement curve for the undisturbed specimen of the non-irrigated soil .

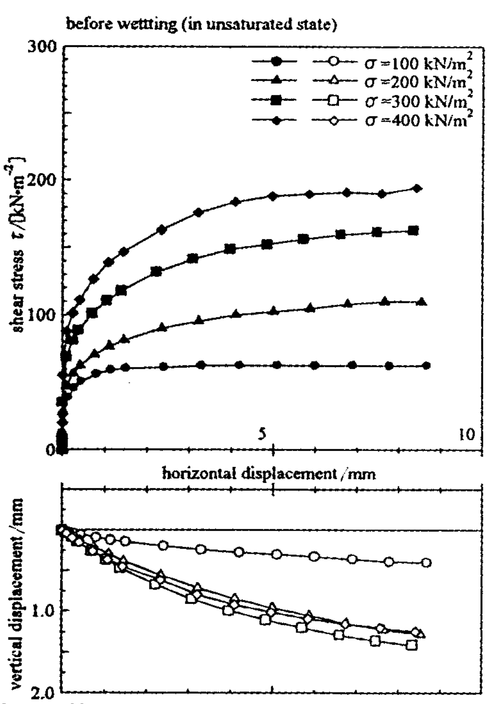


Fig. 4 Shear stress-vertical displacement-horizontal displacement curve for the undisturbed specimen of the irrigated soil in unsaturated state(w=15%～16%).

these two soils had lost the effective cementation on shear strength by wetting before shearing.

Fig. 5 shows the Coulomb's failure lines by the direct shear box test for the undisturbed specimen of the non-irrigated soil and the irrigated soil. For the non-irrigated soil, the line of the peak strength had larger cohesion than the residual strength by 20.1 kN/m^2, while the internal friction angle was similar between the peak strength and the residual strength. Therefore, the cementating effect contributes to only the cohesion of the peak strength in unsaturated state. In saturated state after wetting, both the cohesion and the internal friction angle got smaller than the ones before wetting (in unsaturated state).

In comparison the unsaturated non-irrigated soil with the unsaturated irrigated soil(Fig. 5), the internal friction angle of the irrigated soil was smaller, while the cohesion was similar between the two soils. However, the value of nature water content was different (the mass water content of the irrigated soil was higher than the non-irrigated soil by 10% ~ 15%), so the difference of water content may affects the cohesion. For the Malan loess soil, the strength parameters are significantly affected by water content[4].

2.2.2 Remolded shear strength

The results of the direct shear box test for the remolded specimen of the non-irrigated soil are Fig. 6(a), 6(b) and 7. In Fig. 6(a) and 6(b), the shear strength under saturated state was smaller than the unsaturated strength. Nevertheless, the behavior in the shear stress-horrizontal displace-

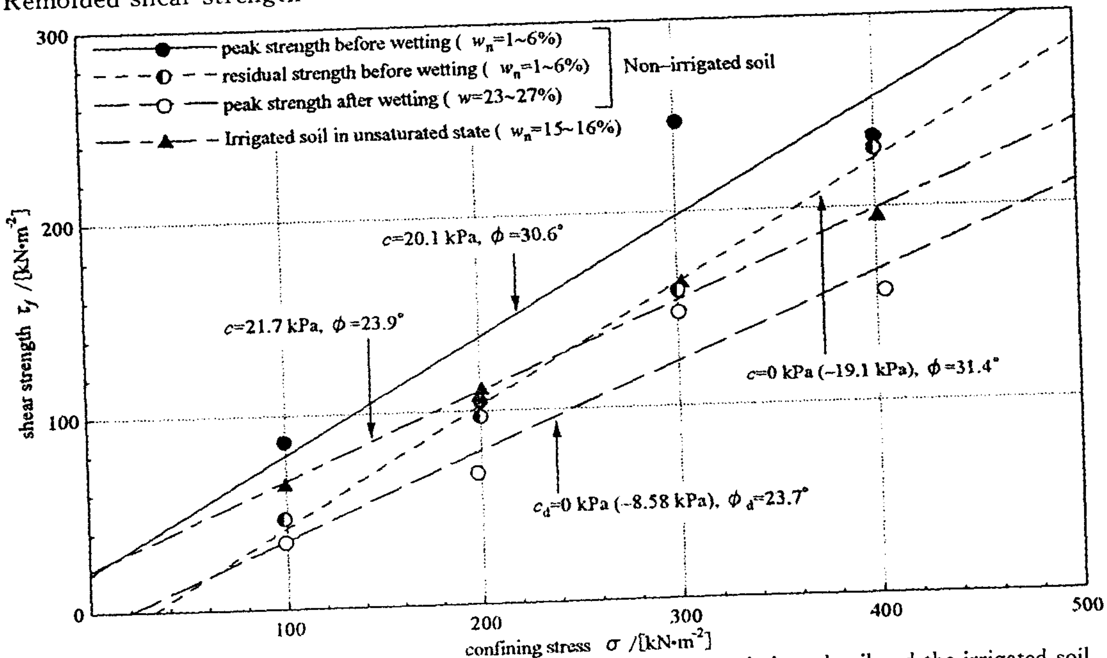


Fig. 5 Coulomb's failure lines for the undisturbed specimen of the non-irrigated soil and the irrigated soil.

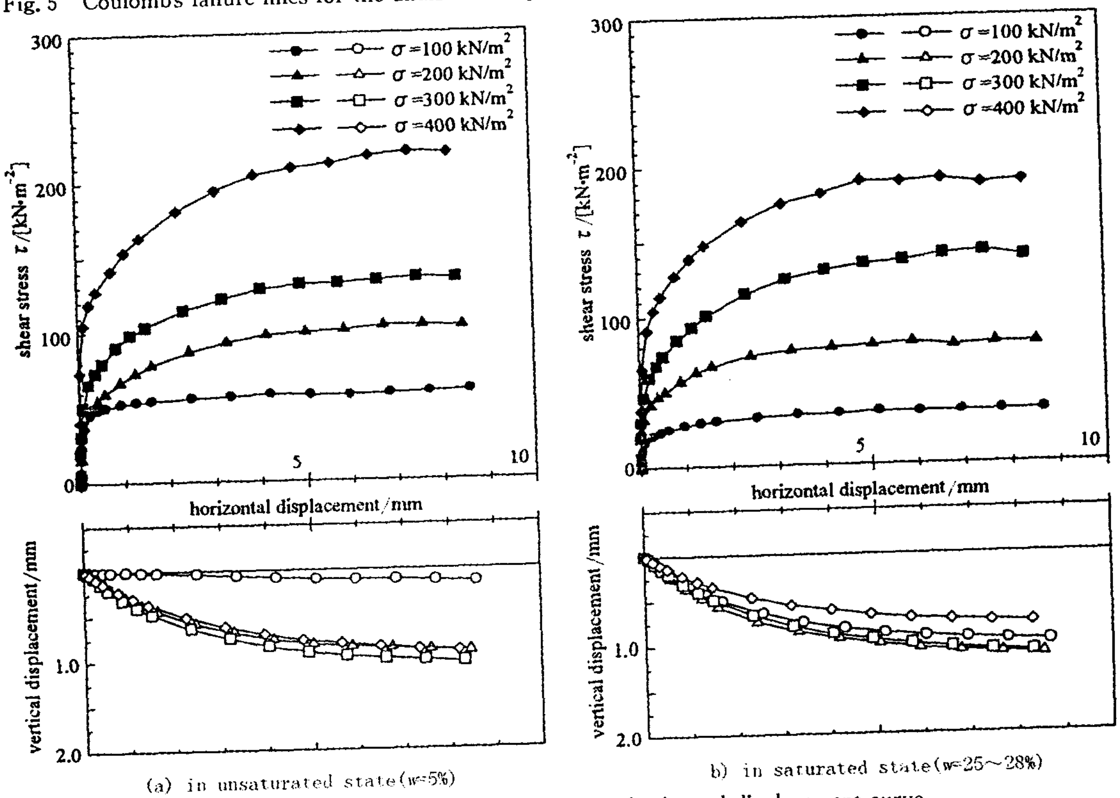


Fig. 6 Shear stress-vertical displacement-horizontal displacement curve for the remolded specimen of the non-irrigated soils.

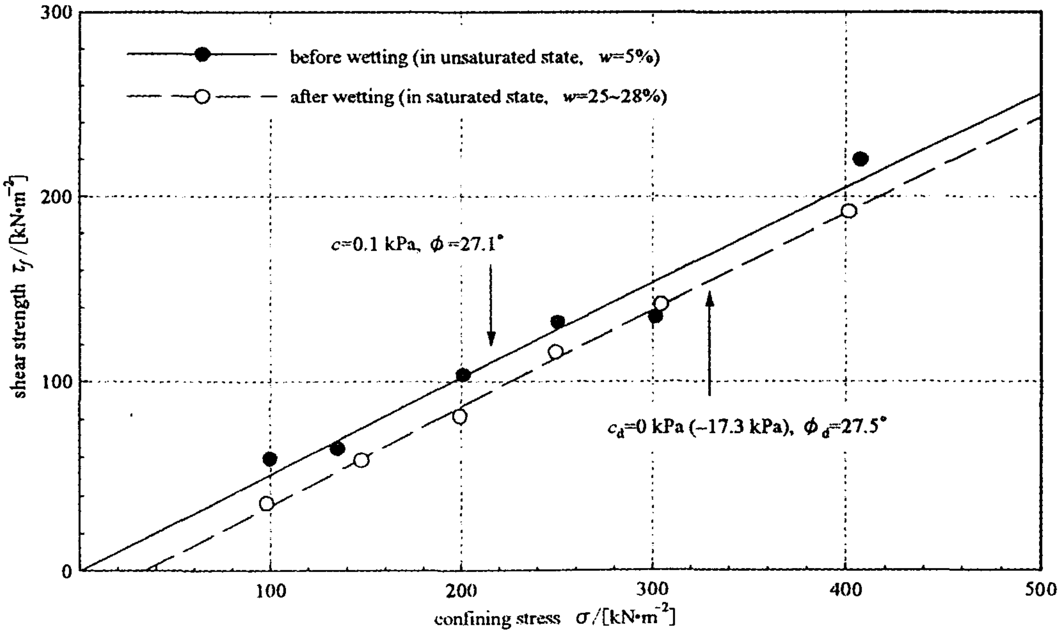


Fig. 7 Coulomb's failure lines for the remolded specimen of the non-irrigated soil.

ment curves of both the saturated soil and the unsaturated soil was similar, and there was no noteworthy difference between the two condition about the strength parameters(Fig. 7).

3 Conclusion

For the undisturbed Malan loess soil, changes in the shear characteristics by wetting are observed.

(1) Both the cohesion and the internal friction angle of the unsaturated soil are larger than the two of the saturated soil.

(2) The remarkable peak strength exists in unsaturated state, which is considered due to the cementating material in the Malan loess soil and it contributes to only the cohesion. This cementating effect disappears by wetting.

(3) The internal friction angle of the unsaturated irrigated soil was smaller compared with the unsaturated non-irrigated soil, while the cohesion was similar. However, there is the difference of natural water content between the two, and it may affect the strength parameters.

From these conclusion, the value of the strength parameters is considered capable of decreasing by attaining water saturation such as applying irrigation water.

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