Practical relevance of collapse behaviour and microstructure of loess soils in Afghanistan

La signification pratique du comportement de collapsus et de la microstructure des sols de lœss en Afghanistan

C. Meier, C. Boley & Y. Zou

Institute for Soil Mechanics and Geotechnical Engineering, University of the Bundeswehr Munich, Germany

ABSTRACT

Since 2001, the NATO has been built Camps for ISAF troops in Afghanistan. Especially in the North of Afghanistan, Germany, as part of the NATO, is building camps in Mazar-e-Sharif, Kabul and Kunduz. The soil in this area mainly consists of alluvial loess from the surrounding mountains.

After heavy rains, extensive structural damage on buildings has occurred. Up to 10 cm settlements in buildings are the results of the water content plasticity of this kind of „soft-soil". In order to get more knowledge about collapse behaviour and to develop new foundations methods on loess soils, the Institute for Soil Mechanics and Geotechnical Engineering of the University of the Bundeswehr Munich, Germany, is instructed to carry out an extensive research programme.

RÉSUMÉ

Depuis 2001, l'OTAN a construit des camps pour les troupes de la FIAS en Afghanistan. La République fédérale d'Allemagne construit principalement des camps dans le nord du pays à Mazar-i-Charif, Kaboul et Koundouz. Le sol dans cette région se compose surtout de lœss alluvial provenant des montagnes environnantes.

Après de fortes pluies, des endommagements considérables des bâtiments se sont produits. Des tassements jusqu'à 10 cm dans les bâtiments sont le résultat de la sensibilité envers l'eau de cette sorte de sol mou. Afin d'apprendre plus sur le comportement de collapsus et de développer de nouvelles méthodes de fondation concernant les sols de lœss, l'institut de la mécanique des sols et de géotechnique de l'université de la Bundeswehr à Munich a été chargé d'effectuer un programme de recherche détaillé.

Keywords : loess soil, collapse behaviour, water content, settlement,

1 INTRODUCTION

After heavy rains, extensive structural damage on buildings in the area around Mazar-e-Sharif and Kunduz has often occurred. Up to 10 cm settlements of the buildings are the results of the water content plasticity of this kind of loess soil. These incidents, as well as similar problems during the building of the high speed railway in West China, show us the necessity of an extensive research program in this field of geotechnical engineering.

Up to now, a lot of research about loess soils and there settlement behaviour have been done by different scientists (Derbyshire 1995). But often chemical aspects are a bit neglected.

To get more knowledge about the settlement behaviour of loess soils, the research program is divided into three parts.

The first part is to understand the collapse behaviour under static loads. For this, modified compression tests were performed according to the Chinese standard GBJ 123-88. Particular attention was paid to changes in microstructure, because of loading and watering.

In a second step, which is also the second part of this study, the chemical properties were covered. Especially the chalk and salt content and its influence on the waterdepent susceptibility to collapse were analyzed.

The third step is the research of collapse behaviour under dynamic loads, with the objective of developing a new estimation method for earthquakes.

Up to now the first two steps of the study have been done and the results can be presented.

2 LABORATORY TESTING

To improve the understanding of the complex mechanical properties of this kind of soil, initial laboratory tests (index tests) were carried out. These tests are necessary to get an impression of the particle density of the soil, the bulk density of soil, the natural water content, grain size, liquid and plastic limit. To get the optimum water content with the associated density, compaction tests were made. The knowledge about the optimum water content bears relevance to the collapse behaviour under static, as well as under dynamic loads.

2.1 *Index tests*

The density ρ_s of soil particles of the loess soils from the three trial pits were determined according to Germany Standard DIN 18124. The test results are listed in Table 1 (MP = point of measuring and taking samples). The average value of the particle density is $\rho_s = 2.72$ g/cm³, which is the typical value of clay containing silt. The natural water content w of the samples were measured in laboratory. The values of natural water content are listed in Table 1 as well. The values of the natural water content w decreased with increasing depth. The average value of the natural water content is w = 4.77 %, which is a typical value of loess soils in dry areas. The bulk densities ρ of the undisturbed soil samples with natural water content were measured in laboratory. The dry densities ρ_d of the soil samples are calculated by bulk density ρ and natural water content w. Their values are also listed in Table 1. The dry density with the average value of ρ_d = 1.46 g/cm^3 is relatively low. The

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-738

calculated values of void ratio e of the most samples are higher than 0.8, which is relatively high for silts. The calculated degree of saturation S_r ranges between 10% and 30%. The liquid limit w_L and plastic limit w_P of the loess soils were determined in the laboratory according to Germany Standard DIN 18122. The liquid limit w_L ranges between 26% and 28%, the plastic limit w_P between 13% and 19%, thus the plasticity index I_P ranges between 8% and 14%. With the measured natural water content w, liquid limit w_L and plastic limit w_P the consistency index I_C was calculated. According to Germany Standard DIN EN 14688-2 the loess soils are in a "very stiff" state. The grain size fractions of the loess soils were determined according to Germany Standard DIN 18123. The grain size distribution curves of the loess soils are very similar. The fraction of silt grains is for all of the loess soils ranges between 56% and 70%. The sand grain fraction is above 16%. The rest is the clay fraction. The grain size fractions are the typical compositions of loess soils in middle Asia (Boley & Zou 2007).

Table 1. Optimum water content w_{opt} and maximum dry density ρ_{dmax}

		MP1*	MP2**	MP3*
density of soil grain				
ρ_s	[g/cm³]	2.73	2.72	2.71
water content				
w	[%]	5.00	8.13	4.41
wet density				
ρ	[g/cm³]	1.59	1.56	1.47
dry density				
ρ_d	[g/cm³]	1.51	1.45	1.41
void ratio				
e	[-]	0.80	0.88	0.94
degree of saturation				
S_r	[%]	17.93	22.95	11.50
liquid limit				
w_L	[%]	27.30	26.20	27.00
plastic limit				
w_P	[%]	13.50	14.50	18.20
plasticity index				
I_P	[%]	13.80	11.70	8.80
consistency index				
I_C	[-]	1.63	1.43	2.55
grain fractions:				
sand	[%]	16.50	70.00	13.50
silt	[%]	25.00	56.00	19.00
glay	[%]	17.00	69.00	14.00

*average values of 3-sample-testing
**average values of 2-sample-testing

2.2 *Compaction tests*

In order to determine the compaction properties of loess soils, compaction tests were performed in the laboratory according to Germany Standard DIN 18127. The optimum water content w_{opt} and the maximum dry density ρ_{dmax} of loess soils are listed in Table 2. The range for water content for the degree of compaction $D_{Pr} > 95\%$, obtained from the compaction curves is relatively large.

Table 2. Optimum water content w_{opt} and maximum dry density ρ_{dmax}

		MP1	MP2	MP3
w_{opt}	[%]	13.7	14.0	16.2
ρ_{dmax}	[g/cm³]	1.90	1.86	1.79
Ranges of water content for $D_{Pr} > 95\%$		10 – 18	10 – 18	12 – 20

3 COLLAPSE UNDER STATIC LOAD AND CHANGES IN MICROSTRUCTURE

Modified compression tests, so called collapse tests, were carried out, to identify the compaction behaviour as a function of changes in moisture content and load level.

To get an impression of what had happened to the microstructure of the soil, microscope pictures have been made before and after the collapse.

3.1 *Collapse tests*

In order to study the sensitivity of the loess soils in Mazar-e-Sharif to water, so called collapse tests were performed in laboratory according to Chinese Standard GBJ 123-88. For the tests, undisturbed loess samples with natural water content were compressed at first in an oedometer under different vertical pressures p. Then the samples were watered, and at the same time the vertical deformations of the samples were measured (Lutenberger, A.J. & Hallberg G.R. 1988). After watering the saturated samples were further compressed with increasing load (150, 200, 400, 800 kN/m²). The relative deformations of the samples before, during and after the watering in relation to the vertical pressures p were noted. Figure 1 shows the relative deformations ε_c (collapse deformation) during the watering in relation to the vertical pressure p for three different samples (MP1, MP2 and MP3). The collapse deformations ε_c increase with increasing vertical pressure p. The collapse deformations ε_c of the three samples for p = 200 kN/m² is larger than 7%. Thus, the loess soils belong to "highly collapsible loess soils" according to the Chinese Standard. The in-situ overburden pressure of the samples is p = 16.0 kN/m² approximately. The collapse deformation ε_c of the sample MP3 for p = 16.0 kN/m² is smaller than 1.5%, thus the sample is "not collapsible loess under overburden pressure" according to the Chinese Standard. Because the collapse deformation ε_c of the samples MP1 and MP2 for p = 16 kN/m² is larger than 1.5%, the two samples belong to "collapsible loess under overburden pressure" (Boley & Zou 2007).

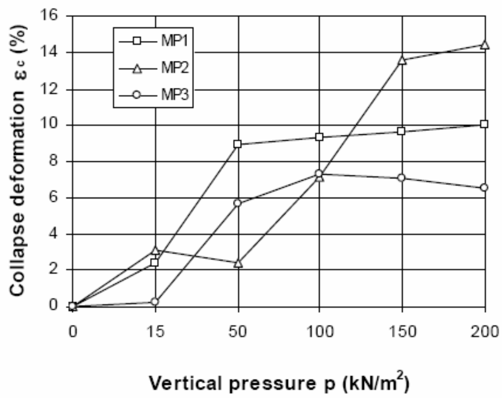

Figure 1. Collapse deformation of loess samples

3.2 *Microstructure*

The microstructure of the loess soils was observed under the microscope. The observed changes in structure are evidence of the collapse settlement.

Figures 2 show's the honeycomb structure of the loess soil before the collapse in the modified oedometer-test.

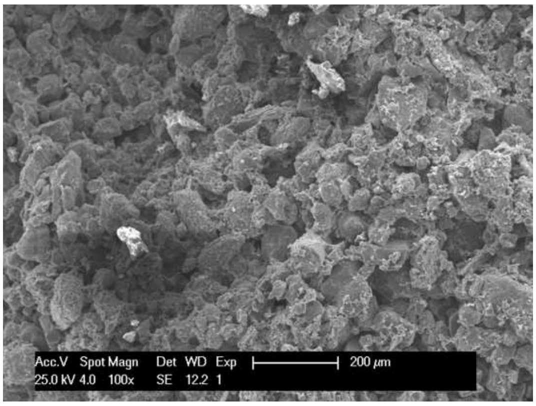

Figure 2. Loess sample before collapse; 100x magnification

Figure 2 shows a typical loess soil, which is characterized by an open structure with large pores. Bonding forces, which are responsible for the strength of the structure, are more mechanically than chemically founded (B. M. Schulz 2008).

After watering the sample under a defined load, the microstructure of the soil changed into a clearly denser system (Figure 3).

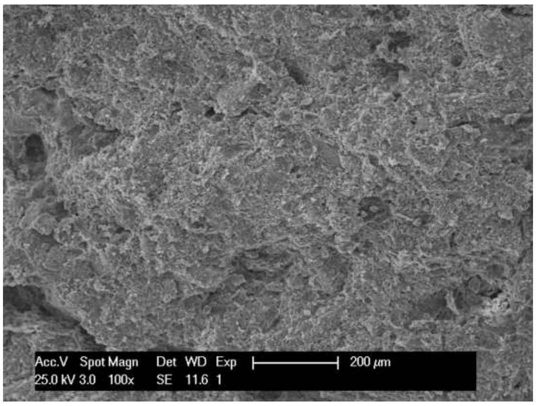

Figure 3. Same loess sample after collapse; 100x magnification

As can be seen in Figure 3, the poresystem of the loess has changed. Pores become smaller and the structure of the grains becomes more compressed.

At the beginning of the study, it was assumed that the main reason for the collapse is the dissolving of salt and lime (Figure 4) bounds by the added water.

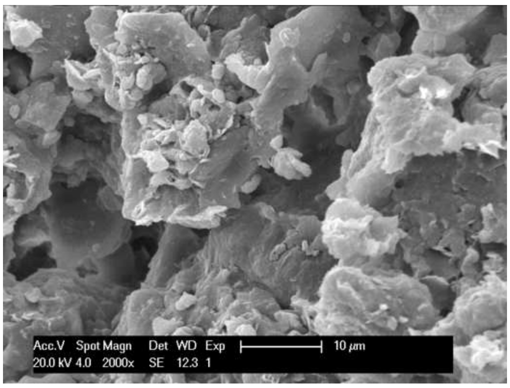

Figure 4. Loess with high salt and lime contents, 2000x magnification

To confirm or confute the theory, that the solution of salt and lime is responsible for the collapse deformation, further research was necessary.

4 CHEMICAL ANALYSES

In order to study the binding effects between silt grains the lime contents V_{Ca} of the loess soils were determined by laboratory tests according to Germany Standard DIN 18129. The lime contents V_{Ca} in the loess soils are listed in Table 3. Their values are above 23%, which is very high.

Table 3. Lime Content Vca

	MP1*	MP2**	MP3*
lime content Vca [%]	23.90	24.70	34.60

*average values of 3-sample-testing
**average values of 2-sample-testing

The results shown in Table 3 are based on an analyses, which measured the gassing. This gassing is the result of a chemical reaction between hydrochloric acid and lime. As it is known, lime is not the only soil component which reacts with hydrochloric acid. So it was necessary to confirm the reliability of the results (Table 3) on the basis of a second independent method.

For this the content of carbon dioxide was determined. Afterwards carbonate content was calculated with the help of molar masses.

$$\begin{aligned} MCO_2 &= MC + 2x\ MO \\ &= 12.0107\ g/mol + 2x\ 15.9994\ g/mol \\ &= \underline{44.0095\ g/mol} \end{aligned} \quad (1)$$

$$\begin{aligned} MCO_3 &= MC + 3x\ M \\ &= 12.0107\ g/mol + 3x\ 15.9994\ g/mol \\ &= \underline{60.0089\ g/mol} \end{aligned} \quad (2)$$

$$\begin{aligned} MCO_3 / MCO_2 &= 60.0089\ g/mol / 44{,}0095\ g.mol \\ &= \underline{\mathbf{1{,}36354}} \end{aligned} \quad (3)$$

From this follows:

$$CO_3 = 1.36354 \text{ x } CO_2 \quad (4)$$

With a determined CO_2 content of about 22.2%, the content of carbonate CO_3 comes to 30.27%, which confirms the results from the gassing test.

To figure out, if it is really lime ($CaCO_3$), comprehensive ion exclusion was necessary. Eluates were mixed for 24 hours and the negative and the positive ions were determined. Table 4 shows the results of the ion eclusion.

Table 4. Results of the ion exclusion

Kations	mg/Kg	Anions	mg/Kg
Ca	**1391**	Cl	407
Mg	195	F	13
Na	644	NO_2	27
Al	6	$\mathbf{SO_4^{2-}}$	**3778**
Fe	3	PO_4^{3-}	1
K	51		

As can be seen from the results, calcium (Ca) is the dominating kation. Because of the method, it was not possible to measure carbonate. Consequently sulfate (SO_4^{2-}) is the dominating anion but its content does not exceed the carbonate content. The result shows, that the salt content is not insignificant.

If the contained salt is easily water soluble, it would make a contribution to the collapse settlement, as it is common accepted. But to find out, how big the fraction of easily water soluble salt, minerals and other compounds is more research was necessary.

X-ray diffractometrical analysis was selected to get a detailed mineral disintegration of the loess soil. Afterwards the soil was dissolved in water (eluate) and X-ray diffractometrical analysis was made again. So it was possible to compare the results from the solid matter analysis with the eluate analysis to find out, if the salt fraction is easily soluble.

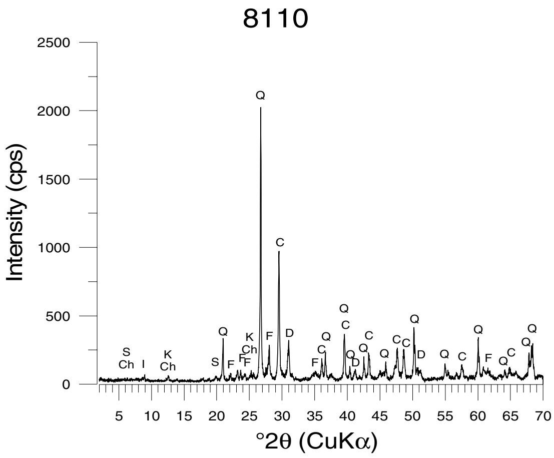

Figure 5. X-ray diffractometrical analysis of loess (sample: 08-110)

As can be seen in Figure 5, quartz crystal (Q) and calcite (C) are the dominating fractions. The sum of carbonate (predominantly calcite and dolomite) is about 37%. Other fractions are quartz crystal (16%), feldspar (16%). The sum of clay minerals, predominantly illite, muscovite, kaolinite and chlorite, is about 15%.

The result of solubility testing demonstrated, that just 2.1 weight per cent of this kind of loess soil is easily water soluble minerals.

5 CONCLUSIONS

From the above test results the following mechanical properties of the loess soils have been deduced:

- The natural water content with the average value w = 4.77% of the loess soils is relatively low. The dry density with the average value ρ_d = 1.46 g/cm³ of the loess soils is relatively low. The void ratio with the average value e = 0.87 is relatively large. The salt and lime contents with the average value V_{ca} = 24.3 is very high.
- Most of the grains in the loess soils are silt grains with sizes between 0.002 and 0.06mm. In the natural state the consistency index I_c is higher than 1. Thus, the loess soils with natural water content are in the semisolid state.
- The strength of the loess soils in their natural state with the friction angle φ = 29.5°, the cohesion c = 100.6 kN/m² and the average blow count of 20 is very high. After watering but without consolidation (collapse) the blow count is very low, thus, the strength is very low. After watering and consolidation the strength of the loess soils with the friction angle φ' = 34.9°, although the cohesion c' = 0, is also relatively high for silts.
- After watering and under certain pressure (i.e. 150kN/m²) the deformations (collapse) of the loess soils were very large. According to the Chinese Standard GBJ 123-88 the loess soils belong to "highly collapsible loess soils" and they can be considered as "collapsible loess under overburden pressure".
- The deformation modulus E_{vd} of the loess soils with natural water content ranges between 20 and 42 kN/m². The values of the modulus E_s of compressibility average 7000kN/m² for the pressure interval between 25 and 200 kN/m2. The values are not low for silts.

The unexpected result, that solely 2.1 weight per cent are easily water soluble, lead to the possibility that the collapse effect is based upon the dissolving of salt and lime bonding forces.

For further research, especially collapse under dynamic load, also mechanical and not chemical bonding forces will be considered.

REFERENCES

Boley, C. & Zou, Y. 2007. Geotechnical Report: Geotechnical Study on the Properties of the Loess Soils in Mazar-e-Sharif, Institute for Soil Mechanics and Geotechnical Engineering, University of the Bundeswehr Munich, unpublished; Munich: Germany

Boley, C. & Zou, Y. 2007. Geotechnical Report: Abschätzung erforderlicher Bodenkennwerte und Angabe benötigter technischer Daten für den Neubau der Unterkunftsgebäude im Camp Kunduz, Institute for Soil Mechanics and Geotechnical Engineering, University of the Bundeswehr Munich, unpublished; Munich: Germany

Boley, C., Zou, Y. 2007. Geotechnical Report: Geotechnical Study on the Properties of the Loess Soils in Mazar-e-Sharif, Institute for Soil Mechanics and Geotechnical Engineering, University of the Bundeswehr Munich, unpublished; Munich: Germany

Derbyshire, E. et. al. 1995. Genesis and Properties of Collapsible Soils

GBJ 123-88, Chinese Geotechnical Standard

Lutenberger, A.J. & Hallberg G.R. 1988, Stability of Loess, Engineering Geology, Vol. 25 pp. 247-261, Netherlands: Amsterdam

Scheidig, A. 1934. Der Löss und seine geotechnischen Eigenschaften, Dresden: Germany

Schulz, B.M. et. al. 2008 Numerische Studien zum Sackungsverhalten von Lockergestein unter dem Einfluss eindringenden Grundwassers, Geotechnik 31 (2) pp. 288 - 300