Geotechnical properties of collapsible soils
Les propriétés géotechniques des sols collapsibles

V.RIZKALLAH, Professor of Geotechnical Engineering, Civil Department, University of Hannover, FRG
K.KEESE, Geologist, Civil Department, University of Hannover, FRG

ABSTRACT: The collapsibility of soils depends on several factors strongly affecting each other. A major effect is the internal unit fabric. It has been observed that soils which are suspectible to collapse are well-sorted, fine-grained clastic sediments as well as porous soils with a relatively low cohesion. Such sediments derive mainly through aeolian processes. In this paper the collapsibilty degree of low-cohesive sediments from Lower Saxony (Germany) is investigated and evaluated. Test conditions and processing of samples are precisely discribed and so enable to compare the results obtained in this research work with those published. Error effects occuring during laboratory performance when using an oedometer, mainly the side wall friction between sample and sample ring, are explained and their influence on collapsibility behaviour is discussed.

INTRODUCTION

Under surcharge conditions some soils do not only display the process of settlement but show deformation if water is added. Settlement of soils caused by sudden break down of grain-fabric under a constant surcharge and water access is defined as "collapse".

This test program is performed to investigate the collapsibility behaviour of aeolian, low-cohesive sediments. Collapsibility tests conducted by other authors showed that large samples are more suitable (e.g. Hellweg 1981). This is in contradiction to previous works which recommended small sample sizes in order to keep the side friction between sample and ring as low as possible and to reduce the lost of effective surcharge.

A new compression apparatus which enables to measure the effective load at the bottom of sample has been constructed. It allows to assess the degree of collapsibility as well as the influence of side wall friction as a function of sample dimensions.

INVESTIGATED SOIL

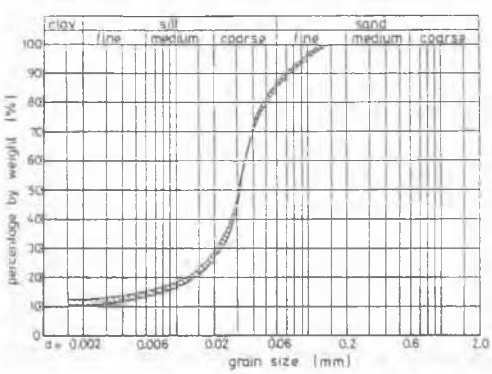
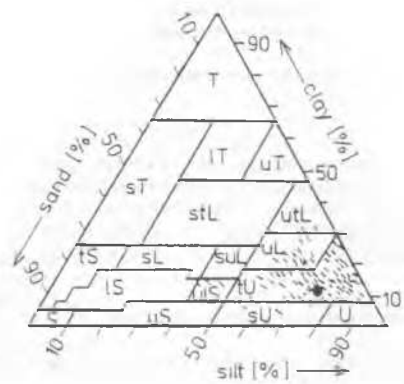


Fig. 1: Grain-size distribution of the investigated loess loam

The investigated soil consists of an aeolian sediment deposited during the Weichselian glacial period. Compared to autochthonous, young deposited loess it possesses a relatively low carbonat content due to weathering. Therefore it is usually defined as loess loam.



where: T;t = clay;clayey
L;l = loam;loamy
U;u = silt;silty
S;s = sand;sandy

Fig. 2: Triangular soil classification chart according to a proposal of german bureau for soil investigation; comparison of loesslike soils (`) with the investigated soil (•).

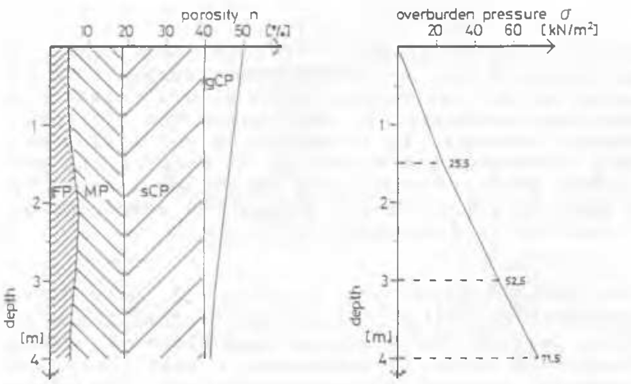
Due to the slight clay content it was not possible to determine the consistency of the soil I_c (liquid and plastic limits, plastic index). Soil characteristics are summarized in Table 1.

In order to assess the stratification of the soil (density in natural state) undisturbed samples were taken from 1,2 and 3,5 m below ground level.

Pore volume (n) and pore-size distribution are recorded as a function of the overburden pressure (σ) and the depth in Fig. 3.

Water content	w	0,137 - 0,22
Porosity	n	0,44 - 0,46
Min porosity	min n	0,40
Max porosity	max n	0,57
Density	D	0,65 - 0,76
Saturation	S_r	0,43 - 0,74
Unit weight of wet soil	γ [kN/m³]	16,5 - 18,3
Unit weight of dry soil	γ_d [kN/m³]	14,5 - 15,0
Unit weight of solids	γ_s [kN/m³]	26,67
Lime content	V_{ca}	0,005
Loss of ignitation	V_{gl}	0,015
Coefficient of uniformity	U	18
Curvature index	C	7

Tab. 1: Soil characteristics of soil



where: FP = fine-pores (< 0.02 µm)
MP = medium-pores (0.02 µm - 10 µm)
sCP = small coarse-pores (10 µm - 50 µm)
gCP = great coarse-pores (>50 µm)

Fig. 3: Influence of overburden pressure (σ) on pore-size distribution

It has been noted that the values of FP, MP and sCP, which represent primary porosity, do not depend on surcharge. Decreasing of void ratio with depth depends only on reduction of secondary porosity (= gCP).

MATERIAL, EQUIPMENT AND PROCEDURE

Within the frame of this research and based on the experience of common triaxial cells a new oedometer with a fixed ring was developed. The apparatus enables to measure the real stress acting on bottom of porous stone disc (p_u) and therefore determine the lost of stresses due to side wall friction (s. Fig. 4). Safety glass was used for the sample ring. The degree of settlement and collapse as well as acting load (p_u) were recorded electonically as absolute values and function of time.

According to the high number of tests and large sample size (V_{max} = 1357 cm3) disturbed samples had to be used. The diameter was 7,9 and 12 cm, the relation diameter to height (D/H) 4,2 and 1.

Initial sample porosity of n = 0,45 corresponds to the natural porosity of a sample laying 1,5 m below ground level (s. Fig. 3). In order to determine the behaviour of collapsibilty as a function of initial water content (w) and surcharge during wetting (σ_w) both parameters were varied as follows:

w = 0.02, 0.04, 0.06, 0.08, 0.10, 0.15, 0.19
σ_w = 30, 60, 100, 200 kN/m²

The initial water contents were obtained by two different ways, either by air drying of the "wet" soil or by drying the sample completly and adding the necessary amount of water.

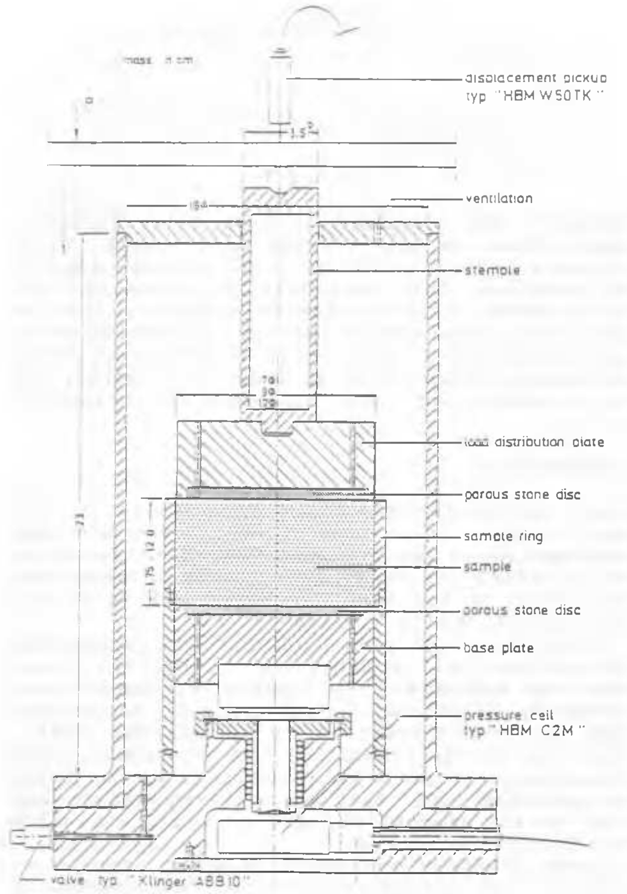


Fig. 4: Schematic section showing new developed oedometer

The shear strength of the soil and the friction between sample and ring material was determined in the shear box apparatus (10x10 cm).

RESULTS AND DISCUSSION

Results of all shear tests are summarized in Table 2 and shown in Fig. 5.

w	φ'	$φ_w'$	δ'	$δ_w'$	c'	c'_w	c'_p	c'_{pw}
	[°]				[kN/m²]			
0.19	33	33	22.0	22.0	9	0	1	0
0.15	32	33	21.5	22.0	11	0	2	0
0.10	32.5	32.5	22.5	22.5	9	0	1	0

Tab. 2: Influence of water content (w) on the results of the shear tests

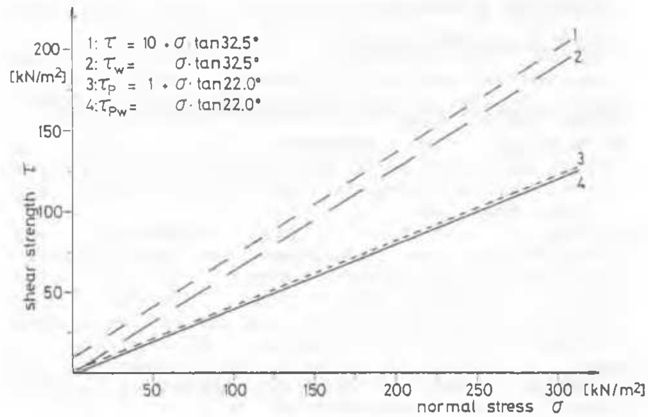


Fig. 5: Results of shear tests

It was found that the angle of internal friction and friction between sample and sample ring do not depend on initial water content. These results and observations are different to those published from Potyondi 1961.

Applying the equation

$$\tau_R = \sigma' \cdot (1 - \sin \varphi') \cdot \alpha \cdot \tan \varphi' \quad (1)$$

$$k_0 = 1 - \sin \varphi' \quad (2)$$

$$\mu = \alpha \cdot \tan \varphi' \quad (3)$$

with: τ_R = residual shear strength
σ' = effective stress
φ' = angle of internal friction of drained soil
k_0 = coefficient of rest earth pressure according to Jaky
μ = coefficient of friction

and the results of the shear tests, it is not necessary to estimate the value of α (in general $\alpha \approx ½$). The value α may be determined by using the angle of wall side friction (δ')

$$\mu = \tan \delta' \quad (4)$$

Fig. 6 shows tendencies of settlement behaviour of the soil as a function of sample dimension. In case of a constant diameter but increasing height of sample, the relative settlement decreases respectively.

The influence of initial water content is significant. The settlement increases when water content increases and sample height is constant. Pore volume decreased by 5 % at the state of maximum settlement (s' = 0,08). The value corresponds to secondary porosity (=gCP).

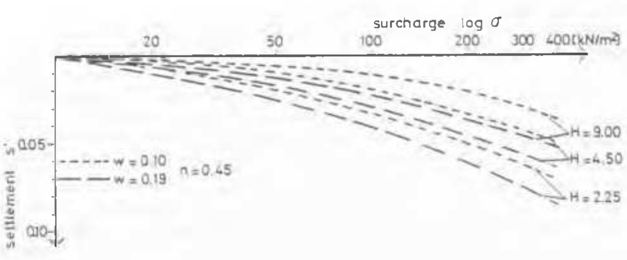


Fig. 6: Influence of water content (w) and height of sample (H in cm) for constant porosity (n) and sample diameter (D = 4,5 cm) on the settlement (s') of loess loam

Fig. 7 demonstrates results of the collapsibility tests. The behaviour of subsidence seems to be comparable to the behaviour of settlement under same performance conditions.

In addition Fig. 7 shows the influence of water content versus surcharge during wetting.

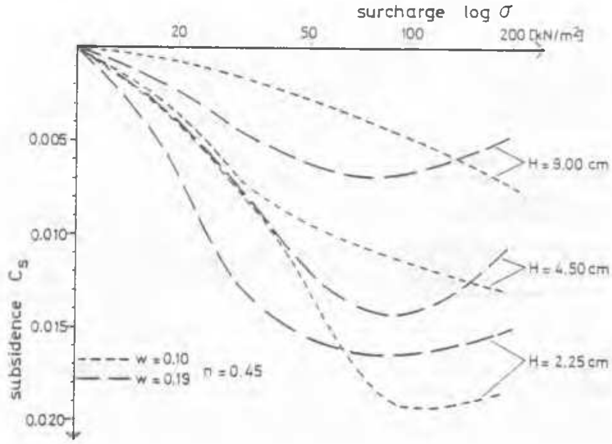


Fig. 7: Influence of water content (w), surcharge by wetting (σ_w) and height of sample (H) for a constant porosity (n) and sample diameter (D = 4,5 cm) on the coefficient of subsidence (Cs)

In case of a water content of w = 0,19 the maximum subsidence was already observed for a surcharge of about 80 kN/m². Considering a water content of w = 0,10 the maximum subsidence was not even observed till a surcharge of 200 kN/m².

The absolute coefficient value of subsidence C_s = 0.02 is relatively small. This is significant for the degree of danger for foundations in collapsible soils.(s. Tab. 3).

Coefficient of subsidence C_s	Degree of danger
0,00 - 0,01	No problem
0,01 - 0,05	Moderale trouble
0,05 - 0,10	Trouble
0,10 - 0,20	Severe trouble
› 0,20	Very severe trouble

Table 3: Coefficient of subsidence (Jennings/Knight 1975)

Fig. 8 illustrates the relative loss of effective stress as a function of sample height.

Measured values were compared with those calculated according to the theoretical approach of Muhs and Kany (1954). The coefficient of friction was determined to $\mu = \tan \delta'$ = 0,4 (see Tab. 3) considering a coefficient of earth pressure at rest $k_0 = 1 - \sin 33° = 0,46$.

Fig. 8 illustrates that this approach can be applied only for sample height with D/H = 4 (Fig.8, curves 1).

It seems to be evident that if the relation D/H (sample diameter/sample height) decreases, no satisfactory correspondence between measured and calculated results was obtained (see Fig. 8, curves 2 and 3). In case of D/H = 1 there is no more linearity observed whenever surcharge is smaller than 200 kN/m².

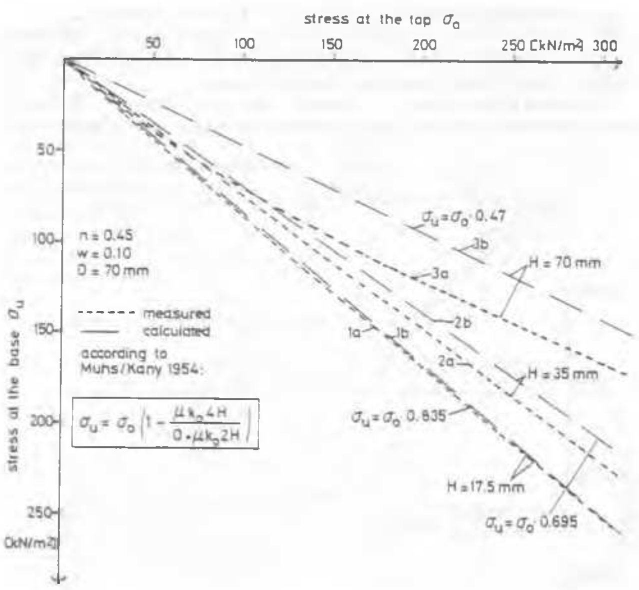


Fig. 8: Comparison of measured values by oedometer tests with those calculated by the formula of Muhs/Kany (1954)

SUMMARY AND CONCLUSIONS

The conducted tests with loess loam showed that the results were affected by the following characteristics:

- Amount of settlement and coefficient of subsidence decrease when sample height increases.
- Coefficient of subsidence dependends on initial water content and surcharge during wetting.
- Initial water content seems to have no significant influcence on shear strength.
- The total amount of settlement and collapsibility is not constant.
- The maximum coefficient of subsidence depends mainly on water content.
- Friction between sample and sample ring increases when the proportion D/H decreases.
- Mobilization of total friction depends on the amount of settlement.

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