Stresses and Deformations in Stabilized Loess

Contraintes et Déformations dans un Loess Stabilisé

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SYNOPSIS In conection with the clarification of some questions concerning the mechanical model of the collapsible loess subsoils, field experiments were carried out with round and square plates with areas from 0,04 to 4 m^2. The experiments were made on a typical clayey loess and on a stabilized with portlandcement loess subsoil. By means of earth pressure cells the stresses in depth under the plates were determined. It was established that the stabilized layer changes the mechanical model of the subsoil, redistributes the stresses and increases considerably the bearing capacity.

INTRODUCTION

The investigation of the stress-strain behaviour of natural stabilized loess subsoils under loading with big plates is most reliable, because it is carried out under conditions closest to the actual condition of the subsoil under real foundations. Due to the fact that the tests "in situ" are too labour consuming, there are still few data allowing reliable conclusions about the behaviour of loess subsoils under loading.

The experiments carried out in the Soviet Union provide data about the condition of a loess subsoil at natural and artificially increased water content beneath big rigid plates (Goloubkov et al, 1968;Lomize et al, 1969;Tsytovich et al, 1979) for loads of normal use from 200 to 300 kPa. The aim of the present study is the investigation of:

(i) the deformation state of natural loess subsoils, caused by loads of normal use.

(ii) the stress-deformation state of the same subsoils under loads exceeding the limit of proportionality between stresses and deformations.

(iii) the influence of a stabilized upper layer on the distribution of stresses and settlements in a subsoil of natural loess.

THE PLATE LOADING TEST

On two sites plate-loading tests were carried out on a natural and on a stabilized by portlandcement loess subsoil. Some physical indices for the soils on each of the test sites are presented in Table I.

TABLE I

Physical Indices of Soils

Type of soil	Depth	kg/m^3	kg/m^3	I_d %	%
Site I Sindel(nat.) Macroporous clay	0,0-1,5	1680	1400	12	20
Clayey loess	1,5-3,1	1830	1500	14	22
Site II Russe(stab.) Loess	1,5-4,0	1660	1450	6,1	17

At site I two tests were carried out on two levels: on elevation 0,00 in the soil layer and on depth 1-1,5 in clayey, heavily macroporous loess. In the tests a set of round rigid plates with areas 0,071; 0,2 and 0,3 m^2 and square plates with areas 1,50 and 4,00 m^2 were used. The loading of the small plates was realized by means of a hydraulic installation. A specially made frame, loaded with 100 kN served as a counter-weight (Fig.1)

The big plates were loaded with packs of sheet steel with a single weight of 25 kPa up to 250 kPa (Fig.1). A final settlement of no more than 0,0001 m per 2 hours was wated for at each loading step.

On the same site also tests with plates of 4,00 and 24,00 m^2 on a bi-layered subsoil, consisting of a cement-soil layer and a natural loess layer, were carried out (Minkov et al, 1979).

The stabilized layer was performed according to the regular technique (Instructions, 1976; Minkov et al, 1976) from cement-soil mixture with 5% cement and a thickness of a 1,5 and 2,00 m.for the different sections. The modulus of deformation of this layer was determined by additional place tests with area of the plate 0,3 m^2. After a rest of 28 days the material had the following charac-

Fig.1 General view of the two plates' positions - Site I

Fig.2 General view of a plate with an area of 24 m^2 - Site I

Fig.3 General view of the plate position on Site II, A = 4 m^2

teristics: density 1700 kg/m^3; uniaxial compressive strength 1,0 MPa; tensile strength at bending 500 kPa; cohesion 300 kPa and modulus of deformation from 82 to 95 MPa.

On Site II loading of typical loess at natural water content was realized (Table I). The subsoil was loaded with a rigid steel plate with an area of 4,00 m^2 by means of 8 jacks, each one having a loading capacity of 500 kN and all of them connected by a hydraulic system in two circles. The reactive efforts were transmitted by a steel supporting construstion to 6 anchors (Fig.3) 0,2 m in diameter and with a depth of 11,00 m. The anchors were widened in order their bearing capacity to be increased (Fig.3).

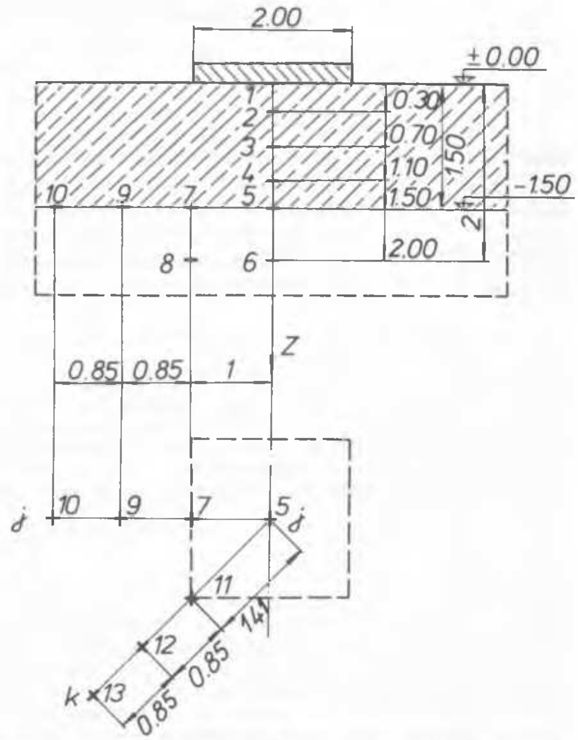

Fig.4 Position of earth pressure cells under the plate with A = 4 m^2, Site I

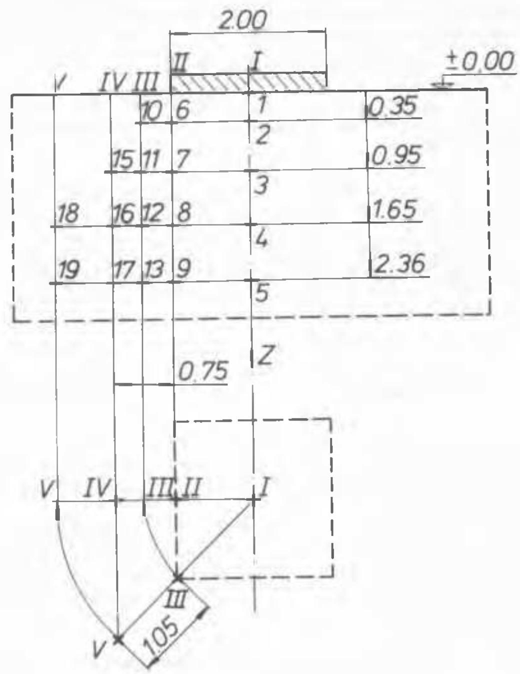

Fig.5 Position of earth pressure cells under the plate with A = 4 m^2, Site II

The vertical settlements were determined by a system of indicators with an accuracy of 0,01 mm, the indicators being mounted on a reference frame. A precise leveller served to control the data of the vertical deformations of the plate itself and for estimating the deformation of the subsoil surface outside the plate. For determining the distribution of the vertical stresses in depth, earth-pressure cells were used, having a hydraulic converter 7 cm in diameter, 1 cm in height and a loading range from 0,1 to 1 MPa at a modulus of deformation 2,5 GPa. The earth-pressure cells were inserted in vertical boreholes according to schemes enabling an actual idea of the distribution of the vertical stresses in depth and aside from the plate (Fig.4,5) to be got. The contact stresses were determined in the following way: on the leveled ground surface the plate instrumented with earth-pressure cells with a diameter of 8 cm and a height of 14 mm was installed. The building-in of the reading equipment was done according to a worked out and checked procedure (Jellev, 1978). The indications of the earth-pressure cells were recorded with a universal tensometrical equipment.

TEST RESULTS AND INTERPRETATION

The investigation of the strain behaviour of the natural loess subsoil at site I with plates having areas from 0,04 to 4,00 m^2 enabled the estimating of the scale effect on the modulus of deformation of loess (Fig.6,7). The diagrams on Fig.8 referring to subsoils with different deformational characteristics show, that the values for the modulus increase insignificantly at plate areas larger than 0,3 to 0,5 m^2.

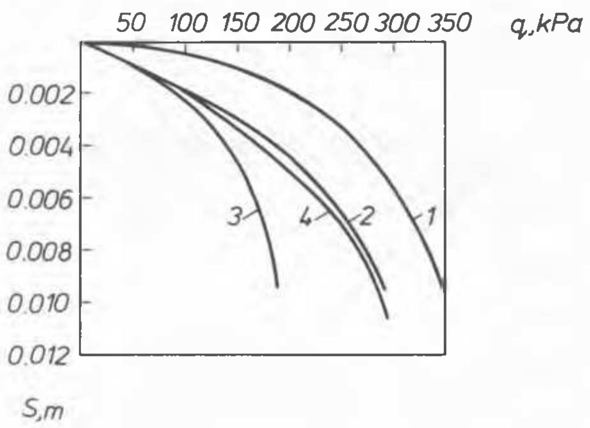

Fig.6 Settlement-loading relationship at Site I
1-plate-A=0,04 m^2,elev= 0,00; 2-A=0,20 m^2, 0,00; 3-A=0,20 m^2, -1,50; 4-A=0,30 m^2, -1,50

The analysis of the settlement-stress relationships (Fig.7,9) for plates with A=1,5 and 4,00 m^2 shows that loess subsoils deform like other structurally underconsolidated subsoils. After a linear section of the loading-settlement relationship, a rapid settlement occurs, disturbing the linearity. However, there is no presence of the typical for clayey soils pushing out and loss of bearing capacity. This means that in case the only criterion for a safe design will be the size of allowed settlements, respectively the danger of collapse deformations at increase of the water content.

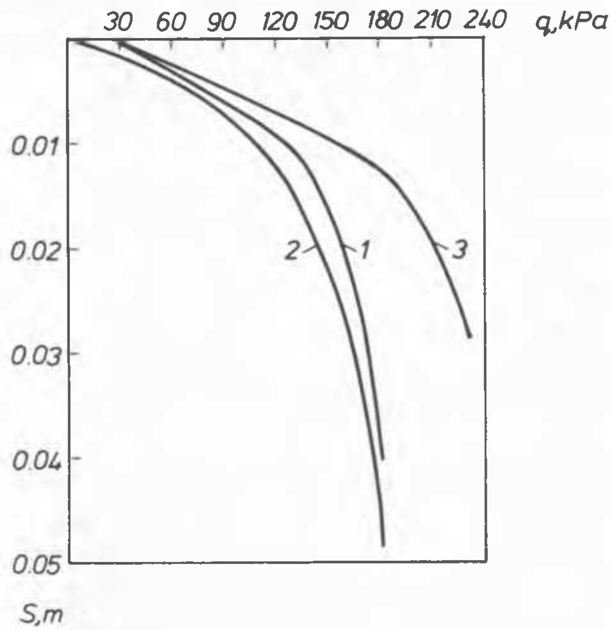

Fig.7 Loading-settlement relationship, Site I
1-plate-A=4 m^2,elev. 0,00; 2-A=4 m^2, -1,50; 3-A=1,5 m^2, -1,50

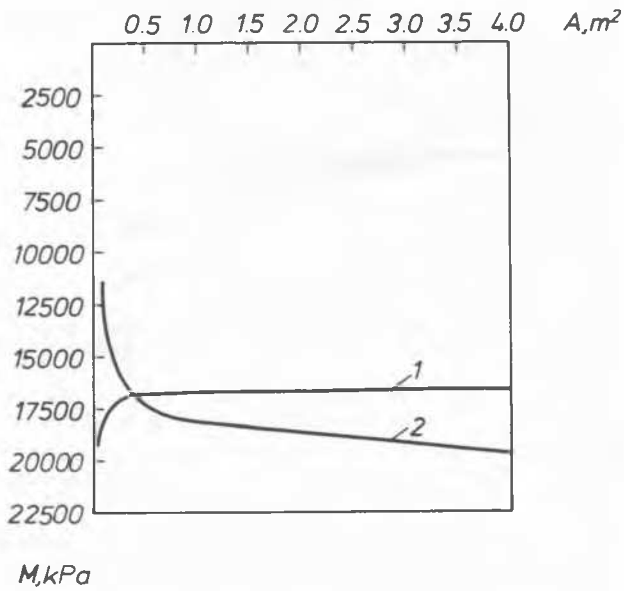

Fig.8 Modulus of deformation-plate area relationship
1 - tests on elevation 0,00; 2 - on elev. -1,5

The studies of other authors (e.g. Goldstein et al, 1970) show that for this type of subsoil the deformations develop mainly in a soil volume li-

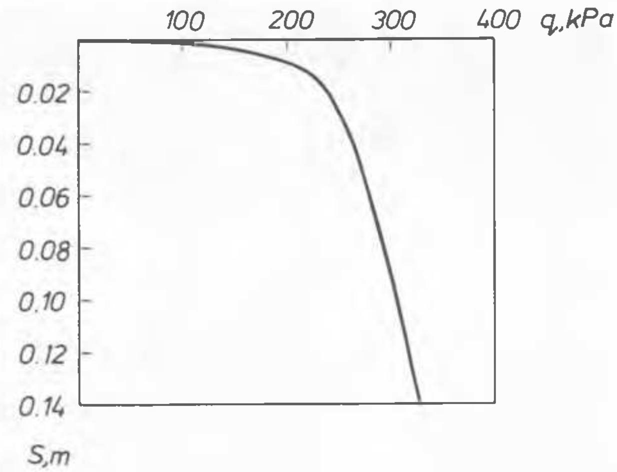

Fig.9 Settlement-loading relationship, Site II

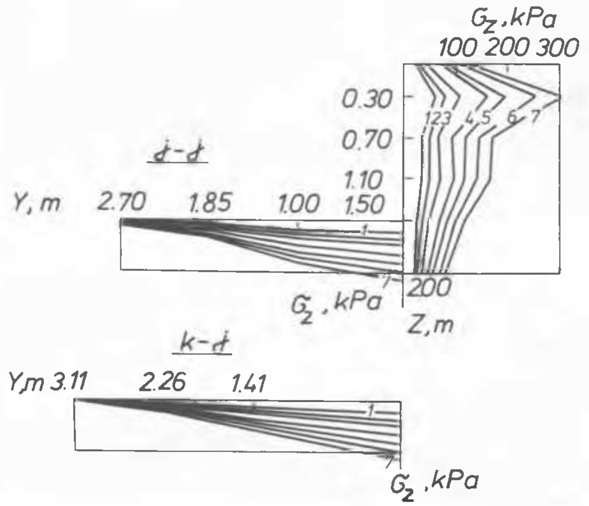

Fig.10 Vertical stresses under a plate with A = 4 m^2; Site I
1-q=58,7 kPa; 2-q=85,6 kPa; 3-q=113 kPa; 4-q= 147 kPa; 5-q=172 kPa; 6-q=199 kPa; 7-q=238 kPa

mited by the plate area and the depth of the active zone. For the loading test with a rigid plate (A=4,00 m^2) was found out that the additional stresses are distributed to a depth equal to 1,1 the diagonal of the plate(Fig.10,11).

Fig.12 shows the experimental loading-settlement relationships for a two-layered subsoil at a ratio of the deformation moduli $\frac{M_1}{M_0}=\frac{950}{120}=8$ and thickness of the upper stabilized layer H=1,5 and 2,0 m.

The settlements of the plate on the bi-layered subsoil are from 3 to 6 times smaller when H = 1,5 m and from 5 to 11 times smaller when H = 2,00 m for loads from 140 to 180 kPa, compared with those on the natural one.

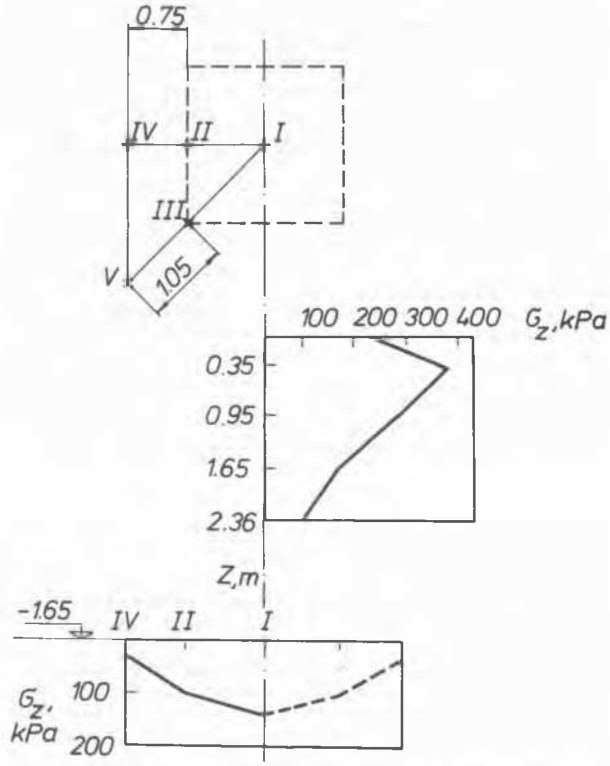

Fig.11 Vertical stresses under a plate with A=4 m^2; Site II, q=310 kPa
a - in the vertical I
b - in the horizontal at elev.-1,65

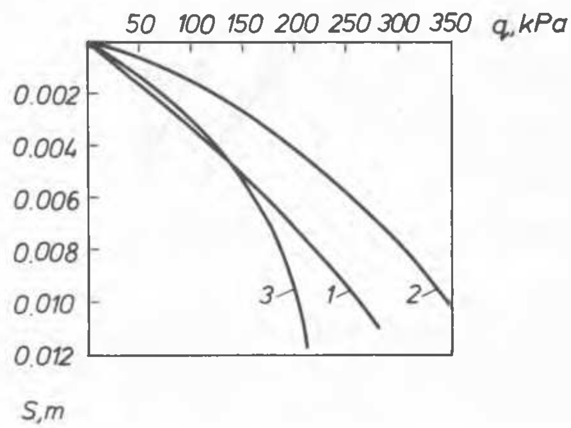

Fig. 12 Settlement-loading relationship, Site I, stabilized upper layer
1-A=4 m^2, h=1,5 m; 2-A=4 m^2, h=2,0 m; 3-A=24 m^2, h=2,0 m

In the case of stabilized bi-layered subsoil an area outside the plate above 5 times larger than the plate itself is affected, while at the natural subsoils the deformations spread on an addi-

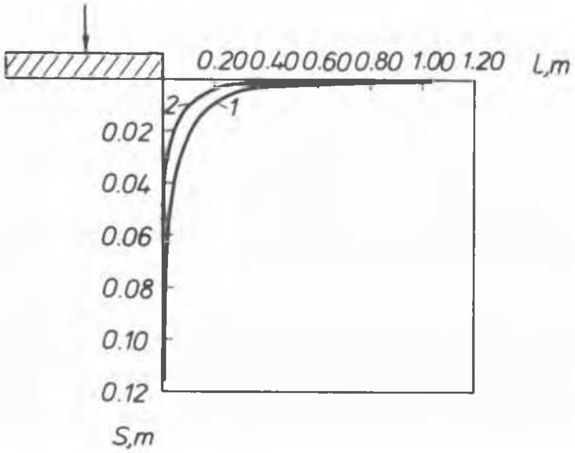

Fig.13 Distribution of deformations on the surface outside the plate($A=4\ m^2$),Site II
1-q=310 kPa; 2-q=117 kPa

ditional area of about only 1/5th of the size of the plate (Fig.13).

The comparison of the values for the vertical stresses at the boundary between the two layers with the corresponding values from the diagram for distribution of stresses in the natural subsoil for plate loads above 200 kPa, shows once again the big influence of the upper stiffer layer on the stress-strain state of the subsoil (Fig.10,11). While for the bi-layered subsoil the stresses at 1,5 m depth spread aside at least one time the size of the plate, for the natural base they remain within the limits of the plate.

Most of the analytical methods for determining the deformations of the bi-layered subsoil give results, which cause an overdimensioning of the upper layer thickness. The application of the method of Burmister (1945) for correcting the settlement factor in cases when foundations with cement-soil cushions are considered, gives settlement values which differ from those obtained in the experiments up to 10%.

CONCLUSION

The investigation of the stress-strain state of a natural loess subsoil under big plates shows that large reserves of bearing capacity are present. The loading of the loess subsoil beyond the limit of proportionality between stresses and strains is possible if the actual settlements do not exceed the permissible ones and no danger of severe moistening of the soil exists.

By means of direct measurements of the stresses in the subsoil once more the major redistributing effect of the stabilised upper layer was ascertained. So under application of an accessible technique a bi-layered subsoil with total bearing capacity, several times increased, can be produced.

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