Deformability of Gypseous Soils

Déformabilité des Sols Gypseux

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SYNOPSIS The paper deals with the first field investigations of gypseous soils (soils with a gypsum content) subject to a static load and long-term wetting. The chief aims were to establish the nature of the development of suffosion settlement with time, to observe the variation in the hydrochemical conditions and soil properties during gypsum leaching, to determine the deformable zone in the base under test plates, and to work out various methodological questions.

Gypseous soils are widespread in semiarid and arid zones,and are often used as the natural foundation bases for buildings and structures. It is known that in the leaching of gypsum from a soil by percolation,the physicochemical and mechanical properties of the soil are changed with the development of suffosion settlement (Mikheev,Petrukhin and Kronik,1973). Very few laboratory compression-percolation investigations have been devoted to the study of gypseous soils,and no data whatsoever can be found in the literature on field tests of these soils under static loads.

The present authors were the first to conduct tests on gypseous soils under a static load (with test plates) and with long-term wetting of the foundation base.

Three experimental sites were selected for the tests with characteristic,widely differing soil conditions. The physicomechanical properties of the investigated soils are listed in Table 1.Testing time ranged from 180 to 440 days.

Square reinforced concrete blocks with an area of 5000cm^2 and a height of 0.7m were used as the test plates.These plates were put into test pits 2.0x2.0m in size at depths from 1.0 to 2.5m. The loads were applied by means of calibrated weights.The vertical displacement of the plates was measured by deflectometers and a surveyor's level. Depth marks were placed at 20cm intervals to measure the layer-by-layer strain of the soil stratum within the limits of the middle part of the test plate.Drainage holes were provided at the four corners of the test pit, and an observation well was bored directly adjacent to the test pit.

The soil was sampled before the beginning of an experiment,during the experiment and after disassembling the test plate device to determine its physicomechanical and chemical properties. Observations were carried out throughtout the experiment to register changes in the flow and chemical composition of the stream of water,and changes in the percolation properties of the soil.

Table 1 Physicomechanical Properties of the Investigated Gypseous Soils

Name	Unit mass, g/cm^3	Density, g/cm^3	Natural water content, %	Void ratio	Plasticity indices w_L	w_P	I_P	Angle of internal friction, deg	Cohesion, kg/cm^2	Gypsum content, %	Readily soluble salt content,%
Sandy loam of "gypsum horizon", Exper 1	1.36	2.42	2.0	0.82	32	30	2	-	-	55	2.9
Loam Exper.2	1.68	2.55	9.3	0.65	42	33	9	28	0.69	10	1.2
Exper.3	1.48	2.55	7.0	0.84	42	30	12	29	0.10	20	2.1
Grussy loam Exper.4 and 5	1.46	2.56	8.8	0.91	37	26	11	31	0.25	26	2.5

Tests were conducted in the following sequence. First the load was increased in steps up to the given maximum pressure and the settlement S_n of the test plate was determined for the natural water content. Then, after conditional stabilization of the settlement, the soil stratum was wetted and the subsident deformation S_s was determined. Further long-term wetting (at constant load) enabled the suffosion settlement S_ℓ to be determined.

The chief results of these experiments are listed in Table 2 and plotted in Fig.1 which shows the curves of relative piping settlement of the test plate (ratio of the absolute settlement S_ℓ to the depth h of the deformed zone) with respect to the amount of water used for wetting.

The test showed (see Table 2) that at natural water content and short-term wetting all of the investigated soils have low compressibility. The values of $S_{n/h}$ and $S_{s/h}$ do not exceed 0.01.

In the process of long-term percolation of water through the soil suffusion settlement develops. In Experiment 1 the test plate remained practically stationary during the first 50 days of wetting (Fig.1, curve 1). During this time only chemical suffosion occurred.

Subsequently, mechanical suffosion (piping) also began and the test plate was subject to continuous settlement at the average rate of 0.19 mm/day. Scours of a plan area from 20 to 30cm and depth from 30 to 40cm formed at the soil surface under the test plate

Table 2

Results of Long Term Static Tests on Gypseous Soils

Exper. No.	Test period, days	Wetting period, days	Water volume, m^3	Water consumption, litres/cm^2	Pressure, MPa	Gypsum content, %	Height h of deformed zone, m	Settlement: Total S_t		At natural water content S_n		After short-term wetting S_s		After long-term wetting S_ℓ	
								S_t, mm	$\frac{S_t}{h}$	$\frac{S_n}{h}$	$\frac{S_n}{S_t}$, %	$\frac{S_s}{h}$	$\frac{S_s}{S_t}$, %	$\frac{S_\ell}{h}$	$\frac{S_\ell}{S_t}$, %
1	180	161	1100	9.2	0.3	55	0.6	25.5	0.043	0.003	7.0	0.002	5.0	0.038	88.0
2	280	269	1400	11.7	0.3	10	0.6	9.1	0.015	0.002	13.3	0.001	6.6	0.012	80.1
3	440	30	760	6.3	0.2	20	1.0	21.2	0.021	0.002	9.5	0.003	14.3	0.016	76.2
4	360	140	930	7.8	0.3	27	1.0	116.0	0.116	0.007	6.0	0.003	2.6	0.106	91.4
5	230	110	630	5.3	0.2	25	1.0	66.5	0.067	0.007	10.4	0.009	13.4	0.051	76.2

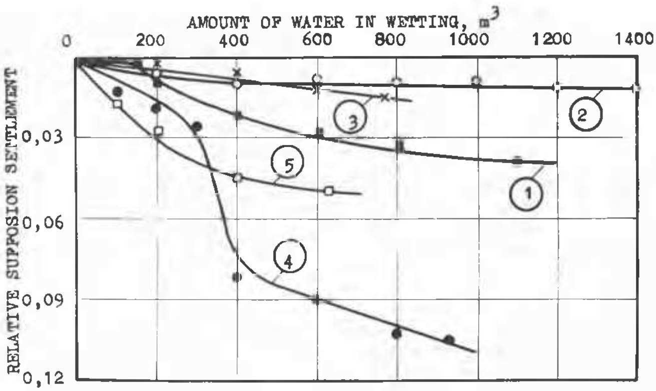

Fig.1. Dependence of the relative suffosion settlement on the amount of water in wetting. Figures in circles indicate the number of the experiment

and beyond its extent. Considerable tilting of the plate began after the soil had been wetted 160 days and this made it necessary to stop the experiment. Thus, the obtained values $S_\ell/h=0.038$ is not the limiting value since only 10% of the salts in the deformed layer had been leached out when the experiment ended.

Suffosion settlement of the test plate first proceeded at a rate of 0.04mm/day in Experiment 2. Then the settlement became stabilized and at the end of the experiment the value of S_ℓ/h equalled 0.015 (Fig.1, curve 2). Salt egress from the soil within the limits of the deformed zone was about 85% of the initial gypsum content.

In Experiment 3, test plate settlement developed continuously during the leaching of the gypsum and at a constant rate (Fig.1, curve 3). The obtained value $S_\ell/h=0.16$ is not the limiting one because settlement had not been stabilized by the end of the experiment, and only 30% of the gypsum had been removed from the deformed zone.

In the initial stage, suffosion settlement of the test plates in Experiments 4 and 5 (Fig.1, curves 4 and 5) proceeded in practically the same way at a rate of 0.3 mm/day. Subsequently, the settlement of the plate in Experiment 4 increased drastically and became about twice that of the plate in Experiment 5. This is probably due to the different pressures at the bottom of the test plates. In addition to chemical suffosion at the base of the test plates, particles were also carried out mechanically, leading to the formation of scours in the soil. Here the initial stage consisted mainly of gypsum leaching and, further on, mechanical piping was predominate. The experiments were stopped when considerable tilting of the test plates occurred and the base had lost its stability. The amount of salts leached from the deformed zone ranged from 35 to 55%.

Thus, the combined action of chemical suffosion and mechanical piping in soils of the "gypsum horizon" and in gypseous grussy loams leads, at first, to considerable settlement. Further gypsum leaching and the carrying out of soil particles lead to a loss of stability of the soil base.

As is evident from Table 2, the compressibility of the investigated soils upon long-term watering is determined mainly be suffosion settlement which constitutes from 76 to 91% of the total settlement of the soil.

Observation of the depth marks indicated that the height h of the deformed zone under the test plates ranged from 0.6 to 1.0m, i.e. $h=(1$ to $1.5)L$, where L is the length of a side of the test plates. Fig.2 shows a typical diagram of the variation with time in the layer-by-layer deformation under the test plate in Experiment 4.

Observation of the amount of the dense residue of filtrates in the well indicated that in most cases in the path of percolation from the test pit to the observation well, maximum saturation of the water with gypsum (about 2 g/litre) is reached.

After finishing the experiments and digging control test pits in investigated soils con-

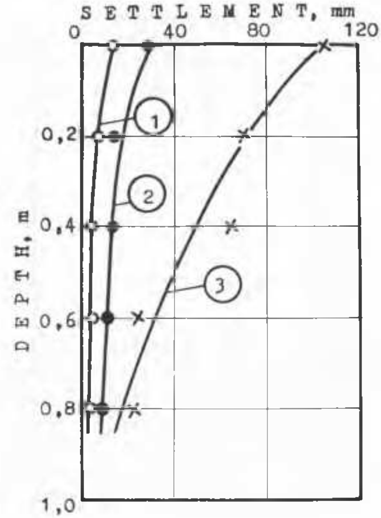

Fig.2. Curves indicating the layer-by-layer deformation with time of the soil under the test plate in Experiment 4. Figures in circles indicate: 1-deformation after 10 days of wetting, 2-after 46 days, and 3-after 140 days.

taining from 20 to 27% gypsum (Experiments 3,4 and 5), the zone of practically complete gypsum removal was very definitely determined visually because it displayed a marked increase in microporosity and jointing (fracturing). This zone could not be established either visually or in laboratory investigations in soil with a gypsum content of 10% (Experiment 2).

Salts leached from the soil are carried out by the water and deposited, as a rule, beyond the limits of the deformed zone. The front of complete desalination of the soil gradually moved downward at a rate of about 1 mm/day in Experiment 3 and about 6 mm/day in Experiments 4 and 5. A typical diagram is given in Fig.3 showing the change in gypsum content of the soil after 140 days of wetting. The diagram shows a reduction in gypsum content at a depth up to 0.6 m and a certain increase at depths from 0.8 to 1.0m.

On the basis of the aforesaid, it is more correct, in many cases, to relate the value S_ℓ with the zone of practically complete salt removal h_A rather than with the whole zone h being deformed.

The experiments showed that the percolation properties of the soil base under test plates increases with time. This is due to the leaching of the gypsum and increase in soil porosity, as well as to the development, in many cases, of mechanical piping.

Experiments for determining the soil strength under field conditions by the "air hole" method (before the test plate experiment and following its completion) showed

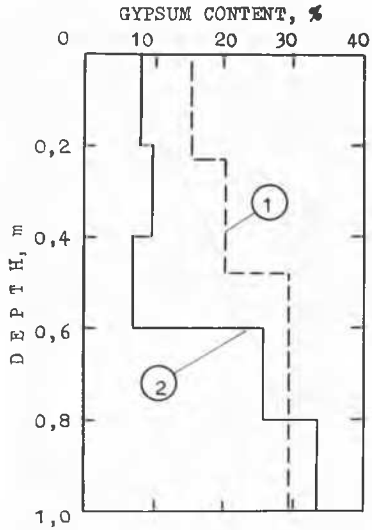

Fig.3. Gypsum content of the soil with depth before the experiment (1) and after 140 days of wetting (2).

that in the initial state the angle of internal friction and cohesion of a loam with a gypsum content of 20% (Experiment 3) have average values of 37° and 0.99 kg/cm². After leaching out the gypsum, these values are reduced to 31° and 0.09kg/cm², respectively. The results obtained confirm laboratory investigations which show that the strength of gypseous soils is reduced when the gypsum is leached out.

CONCLUSIONS

Long-term plate tests of gypseous soils with wetting of the soil base under the plate yielded the following results. In the natural state and after short-term wetting, the investigated soils have low compressibility. Upon long-term wetting, suffosion settlement is developed which reached 0.05 to 0.1 in grussy loams. Under the combined action of chemical suffosion and mechanical piping, the soil base loses its stability. Suffosion settlement constitutes from 76 to 91% of the total settlement of the test plate. Soil strength is reduced as a result of gypsum leaching. The depth of the zone being deformed is from 1 to 1.5 times the length of a side of the test plate.

REFERENCES

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