BASES AND FOUNDATIONS, UNDERGROUND STRUCTURES

UDC 624.131.7

Tambov State Technical University
D. Sc. in Engineering, Prof. of Dept. of Structures of Buildings and Facilities
V. V. Ledenev
Master's student of Dept. of Structures of Buildings and Facilities
K. D. Chyong
Russia, Tambov, tel.: 8-960-670-60-30; e-mail: Skharlamov@inbox.ru

V. V. Ledenev, K. D. Chyong

STUDY OF CREEP OF SAND

Statement of the problem. Subgrade has perceived rheological properties, most importantly, creep. As a result, the number subbase displacements and their irregularities grow constantly in recent years. But this fact is not taken into account in calculations, this is why additional studies of structural strength and creep of sand are essential.
Results. Empirical relationships between displacements of models of sand subbase and loading conditions are obtained. It is shown that creep in sand subbase develops within a few months and years even. A degree of an increase in strength of sand with low moisture content with time resulting from structural strength formation is examined. It is found that a deformation rate depends largely on a loading level.
Conclusions. The data obtained allow us to develop more reliable methods to predict a deformation change with time.

Keywords: sand, creep, loading, foundation, rheological properties, empirical data, strength, deformation, forecasting.

Introduction

Creep in subgrade commonly occurring with varying speeds under adjacent slabs causes the subbase to settle unevenly. This results in the deterioration of operational properties of a structure and reduces its service life.

Creep of clay and frozen subgrade was a subject of many research efforts, e. g. [3, 6—8], whereas sand creep experiments are scarce [1—5, 8, 9].

The below results of the experiments are a follow up of those previously examined [2].

The experiments were conducted at the laboratory of Tambov State Technical University involving rigid steel stamps that were square and round shaped with $d_f = b_f = 10$ cm in four metal spatial trays of 50×50×50 cm in size. The model subgrade was fine grained quartz sand that was fiber compacted up to $\rho = 1.53$ g/cm^3 ($\varphi = 28°$; $c = 3$ kPa) in the air dry state. Stepwise increasing loads were transmitted to the handles. The force inclination angle was changed with respect to the vertical δ, eccentricity e (with respect to e its value is $e_o = 2e / d_f$ or $e_o = 2e / b_f$). All of the experiments led to the base deteriorating, i. e. when $F = F_u$, $\overline{F} = 1$ (loading level is $\overline{F} = F / F_u$). Movement of the stamp centre $\Delta(s, u, i)$ was determined according to the indices ИЧ-10. In the course of the experiment the temperature ($t = 16$ °C) and humidity ($\omega = 35$ %) in the basement of the building kept almost stable. Transport vibration was not known to have any effect.

A study was made of the function

$$s' = f\left(\overline{F}, \lambda_f, e_0, \delta, \rho, \omega, \varphi, b, \ldots\right). \quad (1)$$

1. Creep in sand

The experiments at $e_0 = 0.15$; $\overline{F} = 0.2$; 0.4; 0.6 and 0.7; $\delta = 0°$, $\lambda_f = b_f / h_f = 0$. Their outcome is shown in Fig. 1, 2 and 3.

As loading takes place at $e_0 > 0$, movement vectors s_t and u_t change with time, subgrade heaving i_t, their speeds s'_t, u'_t and i'_t go up as e_o of the ratio u_t/s_t increase.

At $\overline{F} \le 0.4$ settling was made stable after 75 days of observation; horizontal movement at $\overline{F} = 0.2$ did not increase after 75 days, while at $\overline{F} = 0.4$ the same happened after 95 days. At loading levels $\overline{F} \ge 0.6$ deformation was not shown to stabilize within the observation period.

The stamp heaving did not increase at $\overline{F} = 0.2$ and t > 75 days, $\overline{F} = 0.4$ and $t > 85$ days. No stabilization of deformation was observed for $\overline{F} = 0.2$ and 0.7. The stamp heaving at $e_0 = 0.15$ increased about 20 % compared to c $e_0 = 0$.

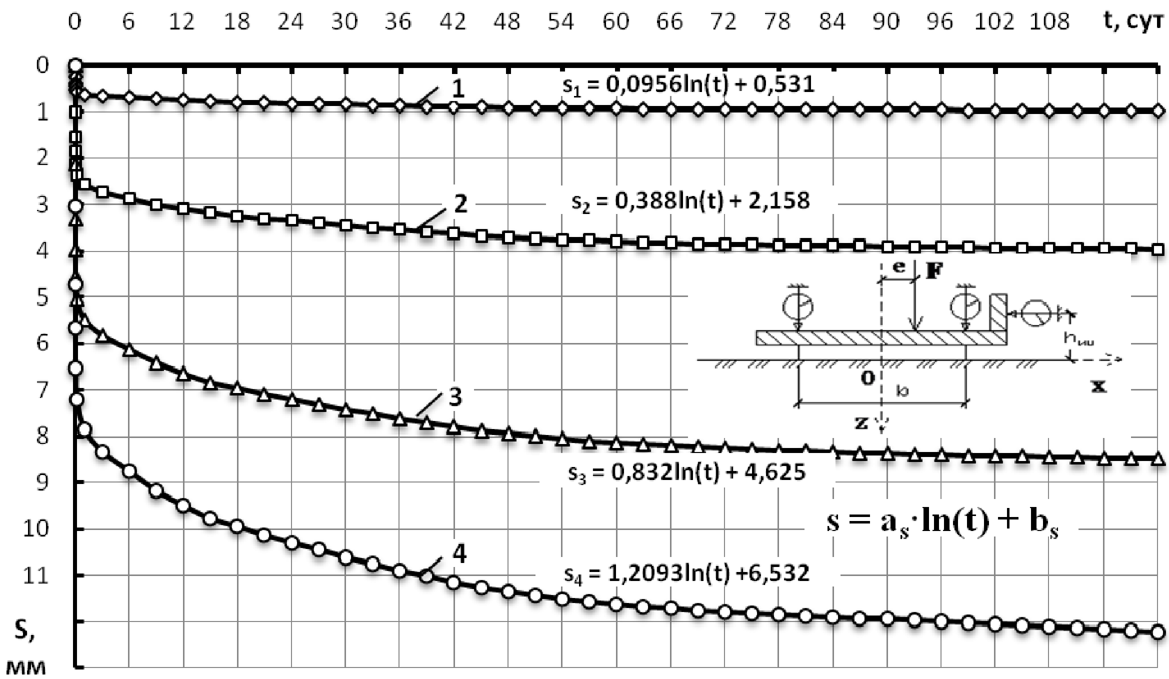

Fig. 1. Stamp settling in progress in time at e_0 = 0.15 and $\overline{F}$:
1 — 0.2; 2 — 0.4; 3 — 0.6; 4 — 0.7; сут — days; мм — mm

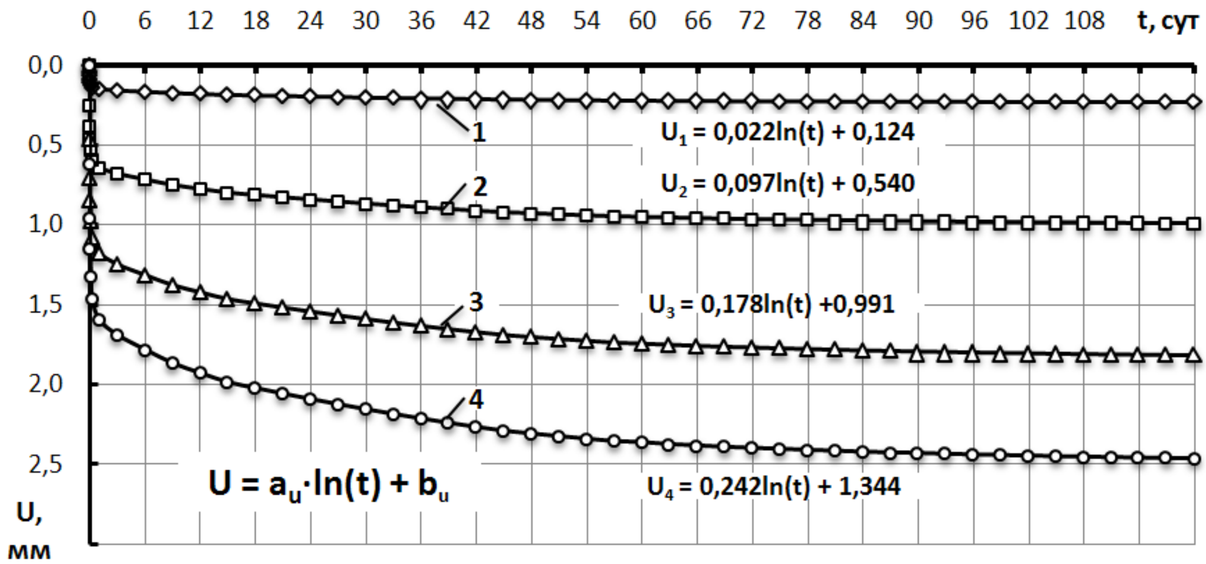

Fig. 2. Horizontal movement in progress in time at e_0 = 0.15 and $\overline{F}$:
1 — 0.2; 2 — 0.4; 3 — 0.6; 4 — 0.7; сут — days; мм — mm

The magnitudes of conditionally momentary movements at $\overline{F}$ = 0.2 … 0.7 are described by the equation

$$\Delta = \alpha_\Delta \, ln\,(t) + b_\Delta, \qquad (2)$$

where $\Delta = s, u, i$.

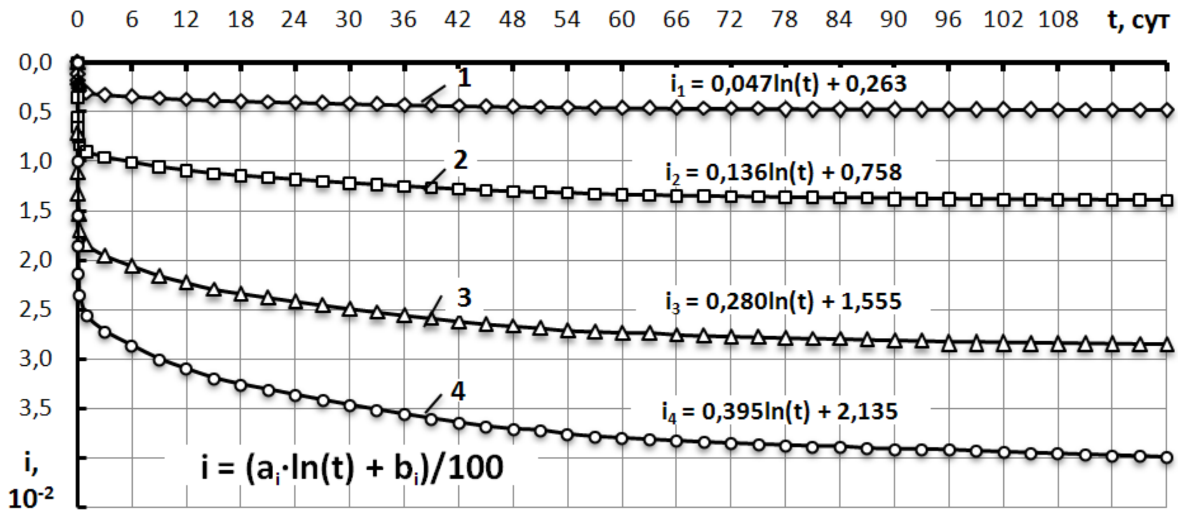

Fig. 3. Subgrade heaving in progress in time at e_0 = 0.15 and $\overline{F}$:

1 — 0.2; 2 — 0.4; 3 — 0.6; 4 — 0.7; сут — days

2. Experiments at e_0 = 0 and 0.15 at $\overline{F}$ = 0.9 and 0.95; δ = 0°, λ_f = 0

At $\overline{F}$ = 0.9, e_0 = 0 and 0.15 the heaving rate started going up at t > 10 days, which signifies the limiting condition (Fig. 4).

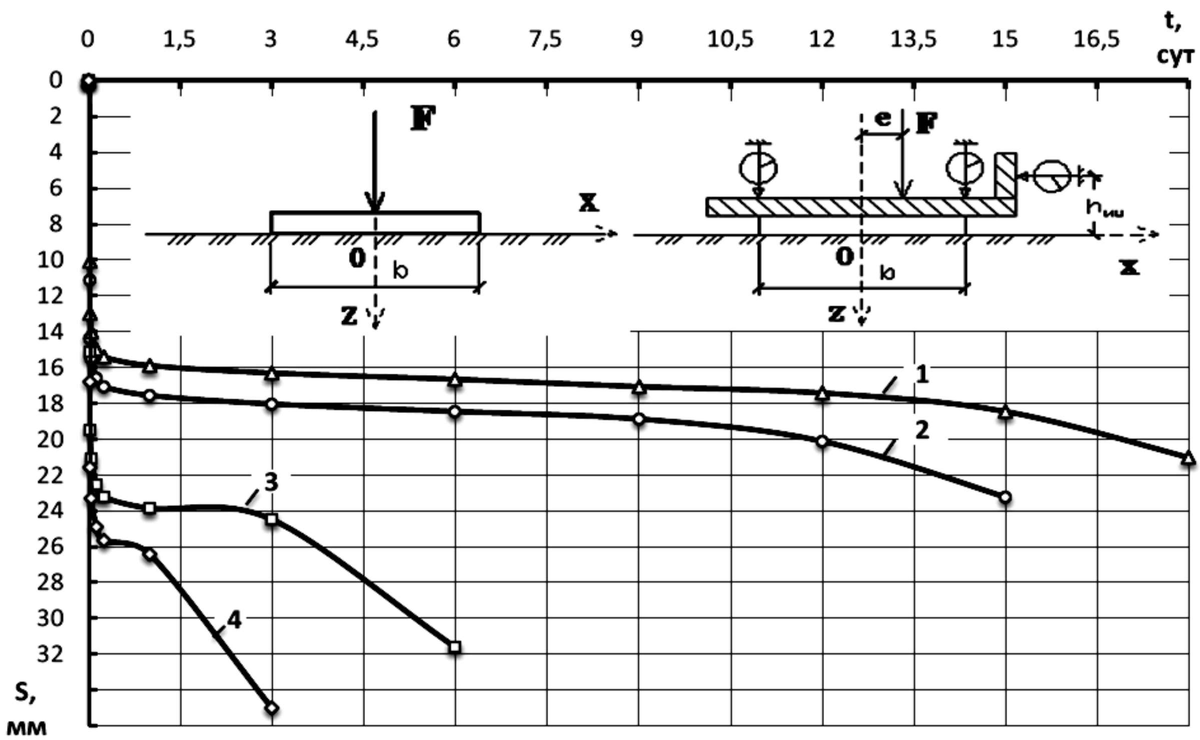

Fig. 4. Heaving in progress in time at e_0 = 0 (1, 3) and 0.15 (2, 4);

$\overline{F}$ = 0.90 (1, 2) and 0.95 (3, 4); сут — days; мм — mm

At $\overline{F}$ = 0.95 the heaving rates were on a sharp increase and in progress following 3 days (e_0 = 0) and days (e_0 = 0.15).

For e_0 = 0.15 the heaving magnitudes and their conditionally momentary components are significantly higher than at e_o = 0. This difference is on the increase as so does a loading level.

At $\overline{F}$ ≥ 0.95 the failure is in progress.

3. Study of reverse creep in sand

The experiments were made at $t_{раз}$ = 6 days and 21 days; $\overline{F}$ = 0.4 and 0.8.

The results are in Fig. 5 and 6 (heaving indices denote time, days, ageing at $\overline{F}$ = 0 (first) and unloading (second).

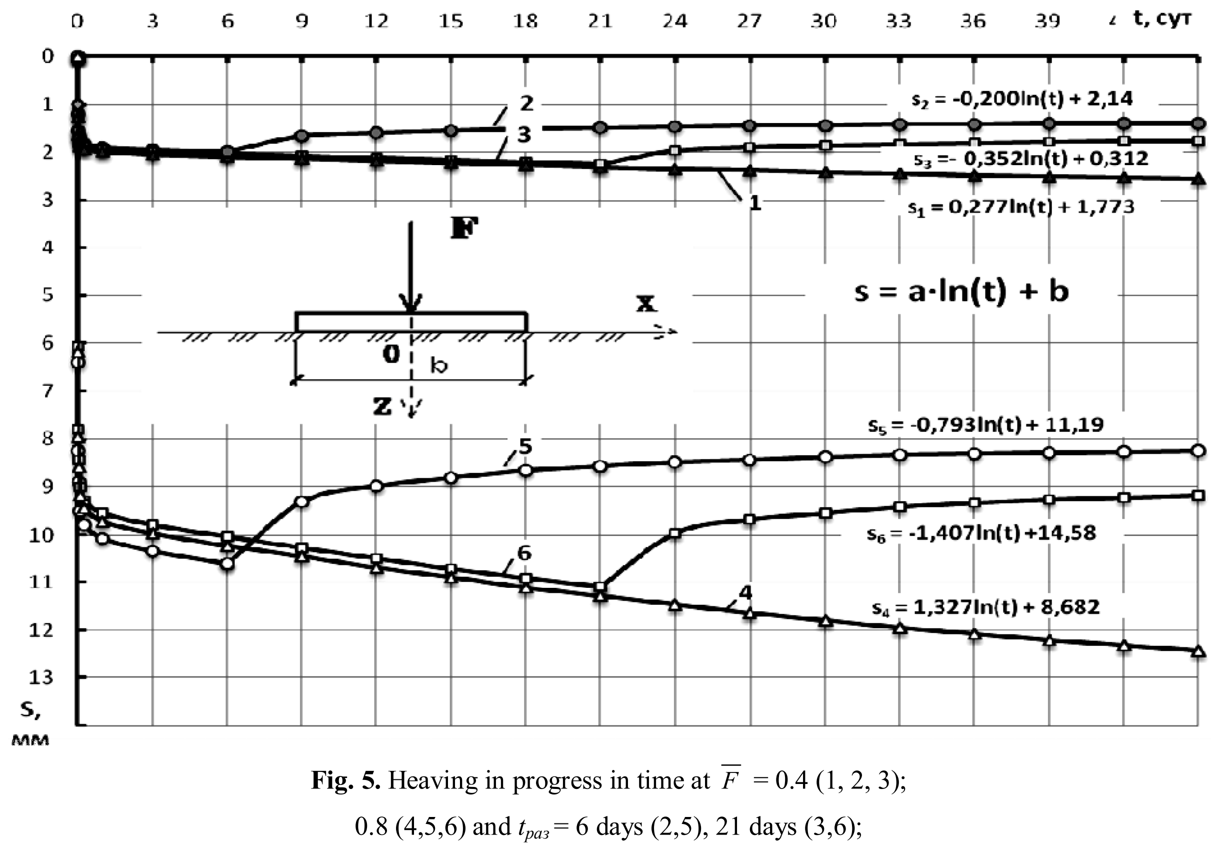

Fig. 5. Heaving in progress in time at $\overline{F}$ = 0.4 (1, 2, 3); 0.8 (4,5,6) and $t_{раз}$ = 6 days (2,5), 21 days (3,6); сут — days; мм — mm

In all the cases non-attenuating (in the accepted time intervals of 15 and 45 days) deformations of stamp heaving with decreasing speed were observed. At large loading levels the magnitudes of vertical movements (heaving) and their rates are higher.

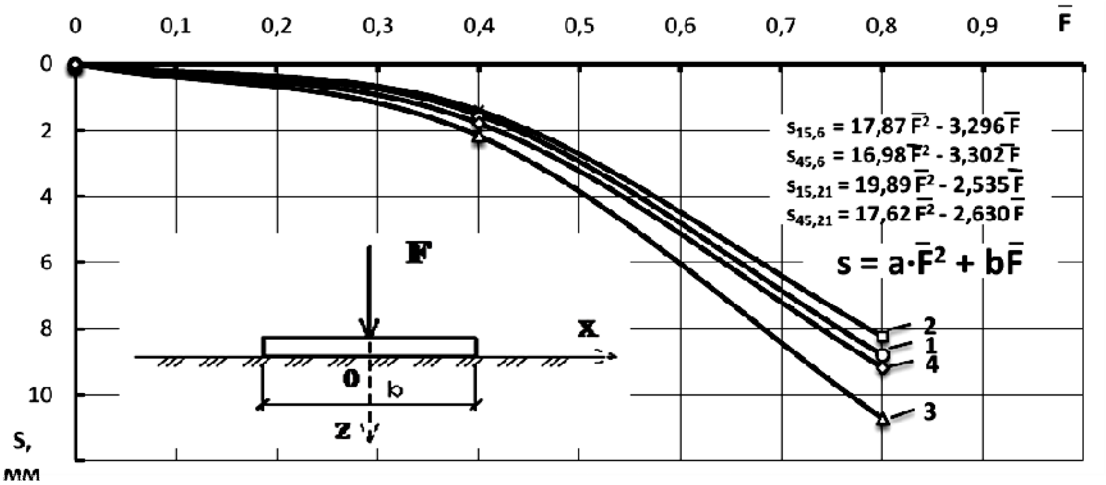

Fig. 6. Dependence of stamp heaving on the relative loading $\overline{F}$ at $t_{раз}$ = 6 days (1,2); 21 days (3,4) after 15 days (1,3) and 45 days (2,4); мм — mm

4. Creep under constant and stepwise increasing loading

Fig. 7, 8, 9 represent averaged values from four experiments. In three of them loading was brought up to the desired level: 0.4; 0.5; 0.6; the observations were carried out for 2 months at $\overline{F}$ = const. In the fourth experiment (the curves are crosshatched) the loading levels were increased after 21 days (0.4 → 0.5 → 0.6).

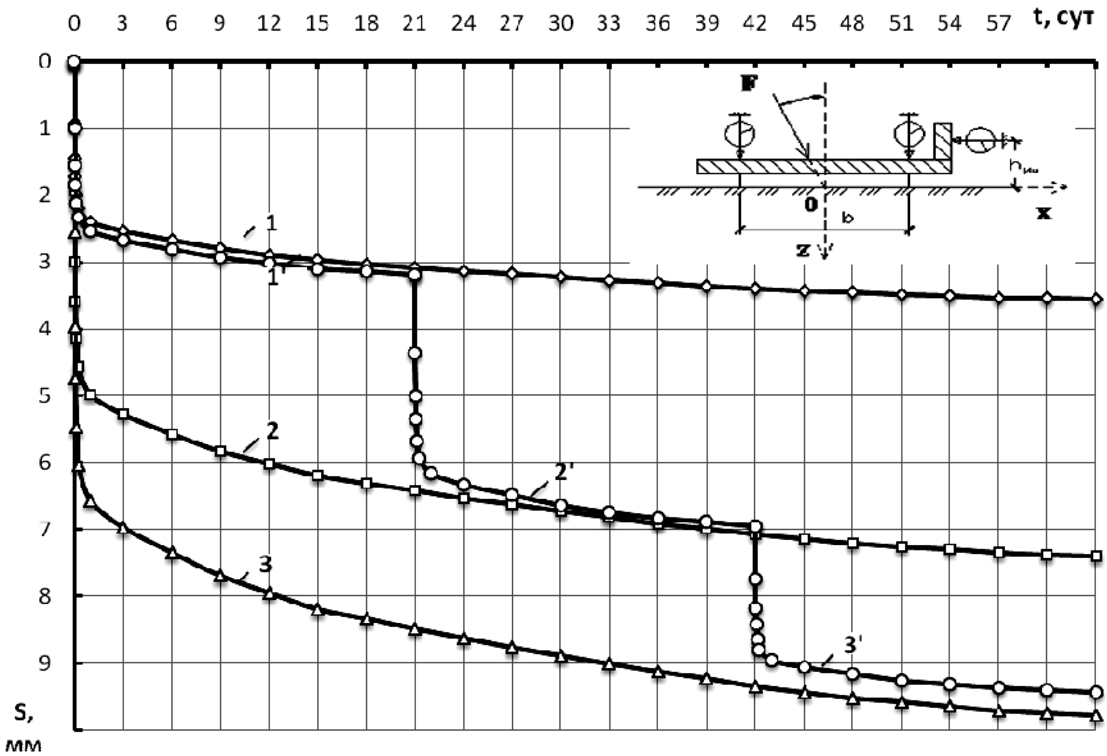

Fig. 7. Stamp heaving in progress in time at δ = 15° and $\overline{F}$: 0.4 (1, 1’); 0.5 (2, 2’); 0.6 (3, 3’); сут — days; мм — mm

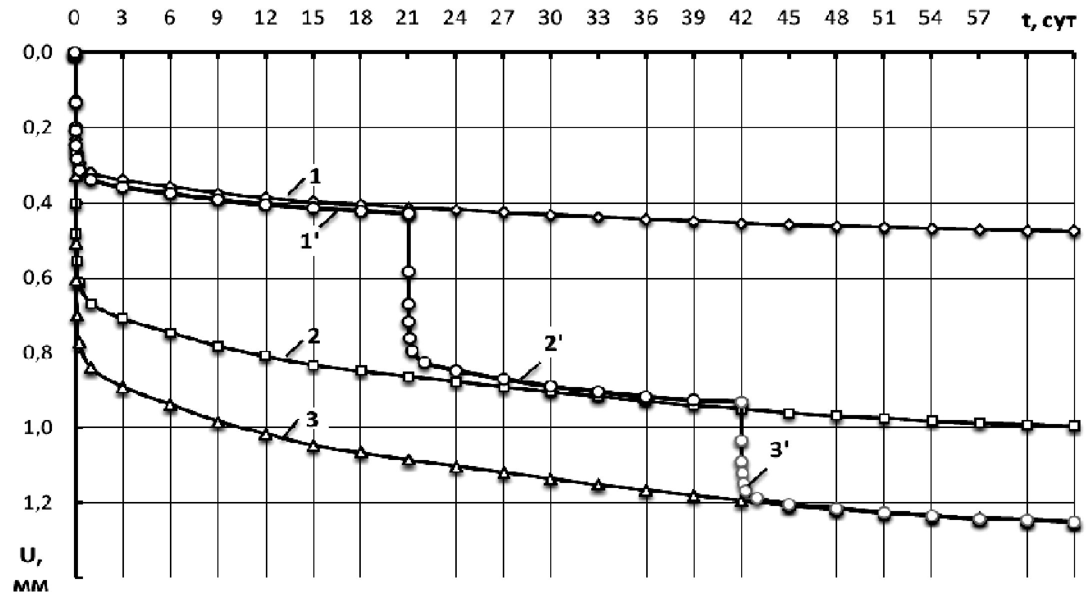

Fig. 8. Dependence of the horizontal movement on the loading at δ = 15° and $\overline{F}$:
0.4 (1, 1'); 0.5 (2, 2'); 0.6 (3, 3'); сут — days; мм — mm

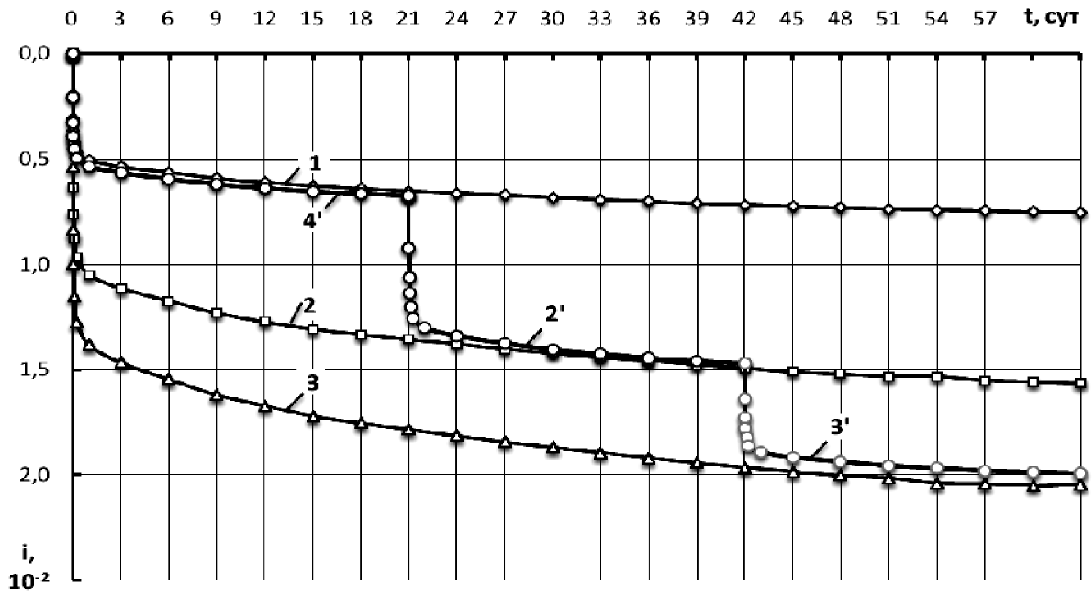

Fig. 9. Graphs of the dependence of heaving caused by the loading at δ = 15° and $\overline{F}$:
0.4 (1, 1'); 0.5 (2, 2'); 0.6 (3, 3'); сут — days

In all the cases non-attenuating movements were observed. The similarity of creep curves was noted. At δ = 15° the major type of movements is the vertical component of a heaving vector.

5. Influence of the relative embedding of the stamp

The experiments were performed at $\lambda_f = h_f / b$: 0; 0.5 and 1; b = 10 cm; e_0 = 0; δ = 0°; ρ = 1.53 g/cm^3; ω = 2.71 %; $\overline{F}$ = 0.4 and 0.8. The results are shown in Fig. 10 and 11.

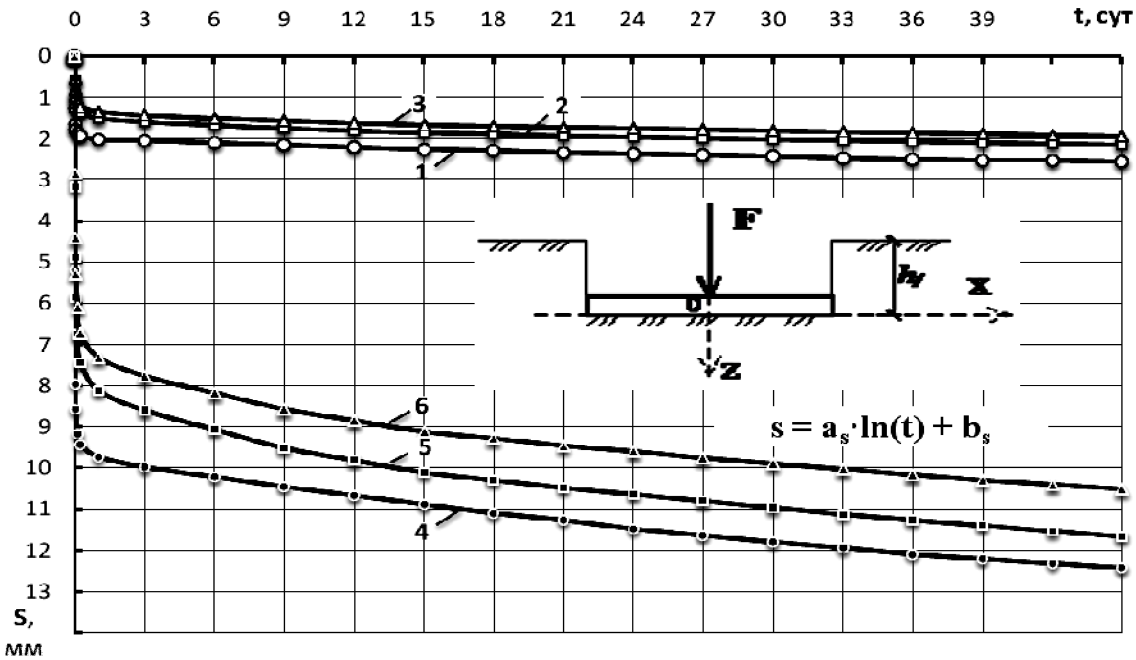

Fig. 10. Sand creep curves affected by the loading level $\overline{F}$: 0.4 (1,2,3); 0.8 (4,5,6), at the relative embedding of the stamp λ_f: 0 (1,4); 0.5 (2,5); 1 (3,6); сут — days; мм — mm

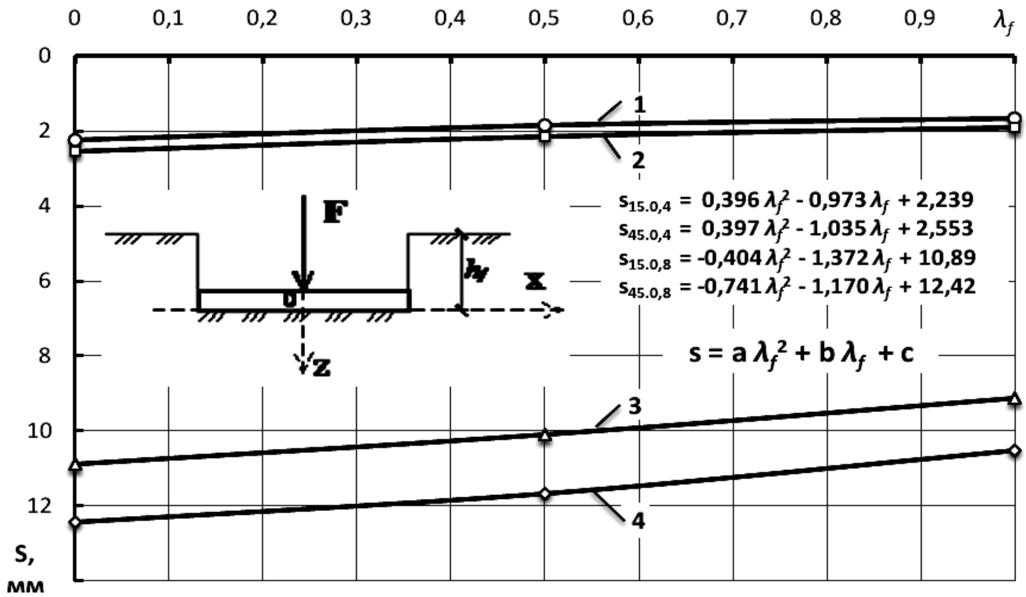

Fig. 11. Dependence of heaving of the stamp on the loading λ_f at $\overline{F}$: 0.4 (1,2); 0.8 (3,4); after t = 15 (1,3) and 45 days (2,4); мм — mm

In all the cases heaving was not seen to stabilize. The heaving rates in the time interval 15……45 days at $\overline{F}$ = 0.4 were 0.0190 mm/day, at $\overline{F}$ = 0.8–0.0995 mm/day. Creep curves of different λ_f are similar and the rates were almost identical in the course of the experiments.

6. Influence of the shape of the stamp

Square $b_f = 10$ cm, round stamps $d_f = 10$ cm were used in the experiment, the same with the rib around the circuit of 1 cm deep, cones with angles at the top of 30 and 45°. The experiments were held at $\overline{F} = 0.6$; $\lambda_f = 0$; $e_0 = 0$; $\delta = 0°$; $\rho = 1.53$ g/cm^3; $\omega = 2.71$ %. In all the cases the nature of interaction of models pressed into the subgrade and the subbase was different. The creep curves were however similar (Fig. 12).

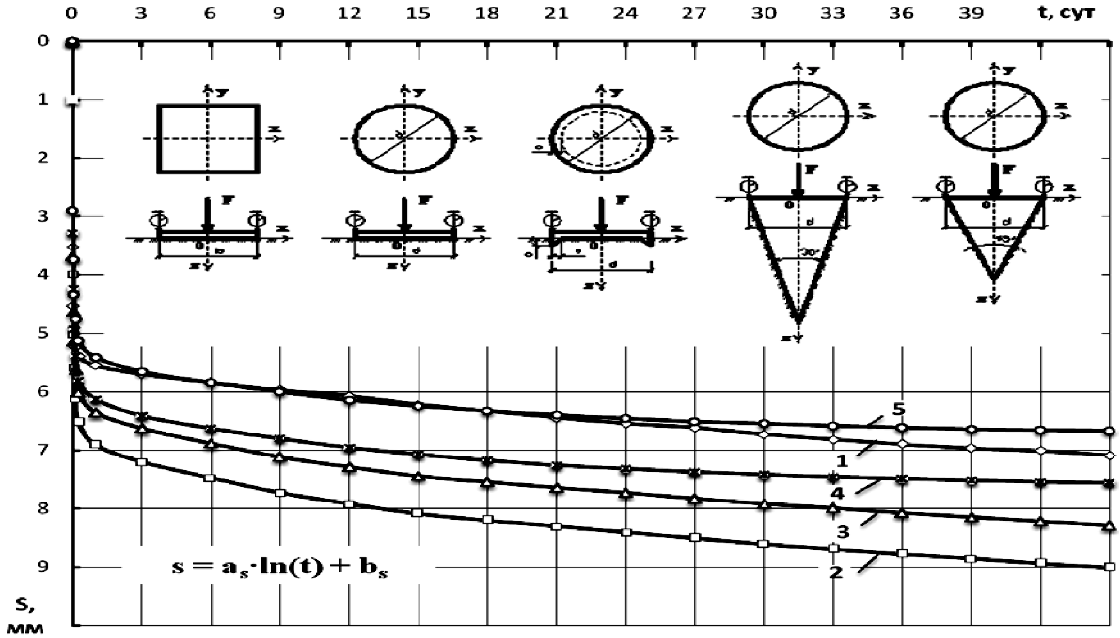

Fig. 12. Development of the stamp heaving in time:
1 — square one $b = 10$ cm; 2 — round one $d = 10$ cm; 3 — round one with ribs;
4 — cone with the top angle of $\alpha = 30°$; 5 — the same with the top angle of $\alpha = 45°$; сут — days; мм — mm

All the experiments found creep being non-attenuating at different deformation mechanisms of the subbase. A lower bearing capacity of the round stamp compared to the square and round one with ribs on the edges was proved experimentally.

Conclusions

1. It was shown necessary to study structural strength and creep of sand. The preliminary experiments found the magnitude of the failure loading F_u. The effect density, humidity, inclination angle force, parameters of reinforcing elements and loading application rate have on the bearing capacity of the subbase and creep deformation.
2. Curves of creep in sand were designed and functional dependencies were obtained. It is suggested that creep curves are described by a logarithmic function and equation coefficients by a power one. The observations of up to 6 months showed that movements of

the stamps at $\overline{F} > 0.3$ do not stabilize. Creep was most intense at $\overline{F} = 0.4\ldots0.7$ after first two months. Creep curves are shown to be similar for stamps of different shapes.

3. Breakage of particles at great contact strains as well as more contact laying at complex spatial movements of particles and elastic and plastic deformations were identified as the cause of creep deformation. Reverse creep curves under loading were drawn and functional dependencies were obtained as well. The experiments comprised two stages. A number of them were performed under varying creep strains and creep with stepwise increasing levels of strain. Both showed the similarity of the curves, i. e. movement magnitudes and their rates are similar.
4. A degree of increasing strength of low wet sand in time caused by emerging structural strength was researched.
5. The obtained data allow one to come up with viable methods to predict deformation development in time.

References

1. V. M. Antonov, V. V. Ledenev, "Research of Creep of Sand Foundation", in *Bases and Foundations,* N 23 (Kiev, 1990), pp. 3—6.
2. K. D. Chyong, V. M. Antonov, V. V. Ledenev, "Development of Sand Base Settlements in Time", in *Herald of the Central Regional Department of the Russian Academy of Architecture and Build Science*, N 8 (Tambov, 2009), pp. 155—160.
3. S. S. Vyalov, "Rheological Problems of Soil Mechanics" (Moscow, 1978) [in Russian].
4. V. V. Zhikhovich, "Creep of Sandy Soils Under One-Plane Shear", Bases, Foundations and Soil Mechanics, 1985, N 6, pp. 25—26.
5. V. V. Ledenev, *Bases and Foundations under Difficult Exposures* (Tambov, 1995) [in Russian].
6. S. R. Meschan, *Experimental Rheology of Clay Soils*, (Moscow, 1985) [in Russian].
7. Z. G. Ter-Martirosyan, *Rheological Parameters of Soil Mechanics* (Moscow, 1990) [in Russian].
8. L. Shukle, *Rheological Problems of Soil Mechanics* (Moscow, 1978) [in Russian].
9. V. V. Ledenev, V. M. Strulev, Azama Nilas, "The Influence of the Design of the Frame Foundation Footing on the Settlement and Bearing Capacity of Sand Base", Scientific Herald of Voronezh State University of Architecture and Civil Engineering. Construction and Architecture, 2010, N 3, pp. 23—31.