

Settlement of foundation bases considering vibrocreep of sandy soils

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Abstract. Practice shows that the foundations of buildings located on a sandy base and transmitting dynamic loads to it receive undamped settlement, causing damage to structures and even the collapse of buildings, which best shows the relevance of the affected problem. The purpose of this work is to study and improve methods for quantifying the stress-strain state of sandy foundations operated under the influence of dynamic loads, taking into account the vibration creep of sandy soil. The authors conducted a laboratory study of the vibration creep of sandy soil under vibration on an experimental design of a soil dynamic ball viscometer and an analytical solution to the problem of foundation settlement under dynamic load. According to the results of laboratory studies, the authors have identified the relationship between the value of the viscosity coefficient η_0 and the intensity of tangential τ_i and mean stresses σ_m , which is later used in analytical calculation. Taking into account the propagation of static stresses according to the dependencies of Kolosov G.V., the propagation of vibrations in plan and depth according to the dependencies of Savinov O.A., the change in the viscosity coefficient depending on the intensity of vibration acceleration according to Barkan D.D., Ter-Martirosyan A.Z., Sobolev E.S., a quantitative assessment of the settlement of the base was carried out. The dependences obtained by the analytical method are consistent with the tray and field results of early studies by other authors.

Keywords: vibrocreep of sandy soil, dynamic load on the foundation, cyclic loading of the sandy base, viscosity of sandy soil, dynamic settlement

1 Introduction

Practice shows that the foundations of buildings located on a sandy base and transmitting dynamic loads to it receive undamped settlement, causing damage to structures and even the collapse of buildings, which best shows the relevance of the affected problem [1; 2; 3, pp.89-90; 4, p.210; 5, pp.138-144; 6, p.61, 73-75; 7, pp.1012-1013].

The change in the deformation and strength properties of sandy soils under the action of dynamic loads is an important aspect of predicting the stress-strain state of the foundations of construction objects [8, 9]. Early studies of the behavior of soils under the influence of

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dynamic loads were carried out by Casagrande A., Shannon W.L. as part of the construction of the Panama Canal [10]. An important contribution to the study of the process of vibration creep was made by the outstanding scientist Barkan D.D. [1, 2], having made the first experiments with the determination of the viscosity coefficient when the ball is immersed under the action of vibration in sandy soil. His initiatives were continued by no less outstanding researchers Savinov O.A., Ivanov P.L., Krasnikov N.D., Shechter O.Ya. and others, whose research was aimed at assessing the influence of relative density, humidity, intensity of vibration and static pressure on the compaction of sandy soil under dynamic influence [3, 4, 6]. A large amount of work was carried out in the field of assessing the effect of dynamic load on the strength of sandy soils under dynamic loading by Savinov O.A., Ivanov P.L., Kudrya V.I., Stavtitz L.R., Blekhman I.I., Dzhanelidze G.Yu., etc. [3, 5, 6, 7]. The work of V.A. Ilyichev, V.I. Kerchman, B.I. Rubin and V.M. Pyatetsky is of high interest in the subject area [5, pp.147-151; 7, pp.1012-1015; 11]. Bogolyubchik V.S., Goldstein M.N. and Khain V.Ya. conducted a large volume of tray tests with modeling the movement of foundations under the influence of dynamic load [12, 13, 14]. Scientists Chaney R.C., Fang H.Y. [15] conducted a study of the behavior of dry sandy soils under cyclic loading, as a result of which it was shown that with a small amplitude of dynamic load, axial deformation accumulates from cycle to cycle, and after a certain number of cycles, the hysteresis loop becomes closed, the sample stabilizes. As the results of Khosla V.K., Singh R.D. showed, with an increase in the amplitude of the dynamic stress σ_d or a decrease in the lateral compressive pressure σ_3 , the stable state of the soil is replaced by a slow accumulation of deformations (vibration creep) [16].

The work of Wang Z. and Zhang L. [17] shows the influence of the amplitude of cyclic deformation, lateral compressive load, the ratio of vertical and lateral static stresses, relative density, humidity and vibration frequency on the axial deformation and stiffness of sandy soil under the action of cyclic load. Publication by Wang K. et al. [18] contains a study of the effect of lateral compressive pressure on the intensity of axial and volumetric deformation of sandy soil under the action of cyclic loading. It is recorded that at a certain value of the compressing lateral pressure, the destruction of the sample with a significant expansion (dilatancy) does not occur, as it is fixed at lower values of σ_3 , but its compaction occurs with an increase in axial deformation and destruction of soil particles, which is also noted in the work of A.Z. Ter-Martirosyan [19, pp.53-54]. A wide range of modern studies of the vibration creep of sandy soils was carried out by Ter-Martirosyan Z.G., Ter-Martirosyan A.Z., Sobolev E.S. The authors found that additional deformations under cyclic and vibrational loads increase with increasing static tangential stresses and decrease with increasing mean stresses, therefore, these deformations depend on the degree of approximation to the limit state [19, pp.71, 73; 20, pp.74, 78; 21, pp.68-69, 79], additional deformation of vibration creep under vibration action increases with increasing frequency and has a damping character in time [20, c.78; 21, c.71].

The problems of foundation sedimentation were solved by Sobolev E.S. [22], Alzabeebee S. [23], Swain A., Ghosh P. [24], Vivek P., Ghosh P. [25], Wichtmann T. et al. [26], Wuttke F., et al. [27]. In the foreseeable field of publications, there are solutions to the problem of precipitation under dynamic influence on the base obtained numerically, and there are no solutions obtained analytically, where it would be possible to construct exact dependencies and mathematically analyze the influence of each factor of the calculation scheme separately. To try to fill this gap, the authors propose an analytical solution to the problem of the precipitation of a single foundation, to which a dynamic harmonic load is transmitted.

2 Methods

To assess the influence of stress state factors on the deformation of sandy soil in time under the action of vibration, a series of tests was carried out on an experimental design of a dynamic ground ball viscometer (patent № RU 2 775 356 C1; Fig.1).

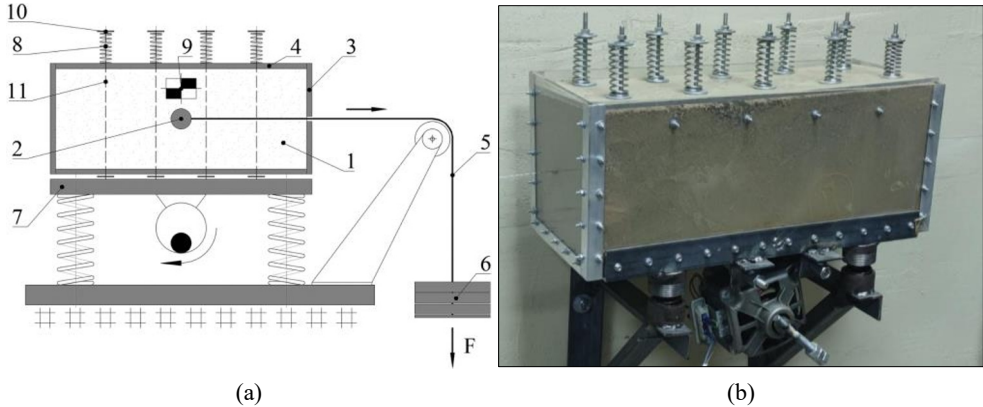


Fig. 1. The scheme of the ball-type dynamic viscometer device (a): 1 – a soil sample; 2 – a steel ball; 3 – a working chamber; 4 – a lid; 5 – a thin smooth steel cable; 6 – a load; 7 – a vibration platform; 8 – a group of springs; 9 – an accelerometer; 10 – fasteners; 11 – strands; photo of the assembled device (b).

A series of experiments was carried out where the viscosity coefficient η was measured at different values of the compression pressure forming the mean stress σ_m in the sample, and at different values of the load on the ball F , forming the intensity of tangential stresses τ_i . The viscosity coefficient according to the test results is determined by the formula (1).

$$\eta = \frac{F}{6\pi \cdot r \cdot \frac{s}{t} \cdot \left(1 + 2,1 \cdot \frac{r}{R_0}\right) \cdot \left(1 + 1,33 \cdot \frac{r}{h}\right)} \quad (1)$$

where F – the force under which the ball is set in motion;

r – the radius of the ball, m.;

R_0 – hydraulic cross-sectional radius of the working chamber, m.;

h – the length of the working chamber, m.;

s – the distance, m., to which the ball is moved during time t ;

t – the time, sec., for which the ball is moved at a distance s .

Taking into account the revealed dependences on the influence of the stress state level on the viscosity coefficient, the task is set on the development of precipitation over time of a single foundation with a width of $b_1=2 \cdot a_1$ at a depth of h_1 , transmitting pressure p_1 and $\Delta p \cdot \sin(\omega \cdot t)$ to the base, on a homogeneous non-saturated sandy base characterized by a specific gravity γ , an angle of internal friction φ , deformation modulus E , Poisson's ratio ν and viscosity coefficient η_0 at the manifestation of vibrocreep. The calculation scheme of the problem is shown below in Fig.2.

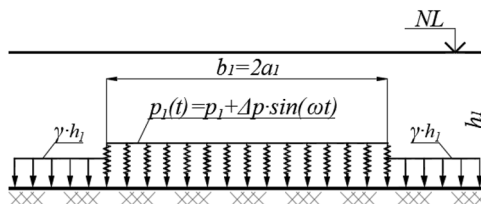


Fig. 2. The calculation scheme.

The foundation sediment consists of the static component s_{st} , determined in a known way [7], and the dynamic component s_{dyn} , determined by the formula (2). The stresses in the base are taken according to the dependencies obtained by Kolosov G.V. [28, pp.211-212]. To calculate the precipitation, the dependence obtained by Ter-Martirosyan A.Z. [19, pp.71; 21, pp.75-76] and Sobolev E.S. [20, pp.60-61, 78] in terms of the development of vibration creep in time and the influence of vibration acceleration is used.

$$s_{dyn}(t) = \int \varepsilon_z^{dyn} dz = \int \left[\frac{\tau_i}{\alpha \cdot \eta_0 \cdot e^{-\delta \cdot a} \cdot \frac{\tau_i^* - \tau_i}{\tau_i}} \cdot (1 - e^{-\alpha \cdot t}) \right] dz \quad (2)$$

where τ_i – the intensity of tangential stresses;
 τ_i^* – limiting tangential stresses;
 α – experimental rheological parameter of hardening [20, 21];
 δ – an experimental coefficient showing the dependence of viscosity on vibration acceleration of vibrations [20, 21];
 a – vibration acceleration of oscillation;
 η_0 – the viscosity coefficient before the start of vibration loading.

3 Results

Fig.3 below shows a graph of the dependence of the viscosity coefficient η on the load value F at different values of the compression pressure σ .

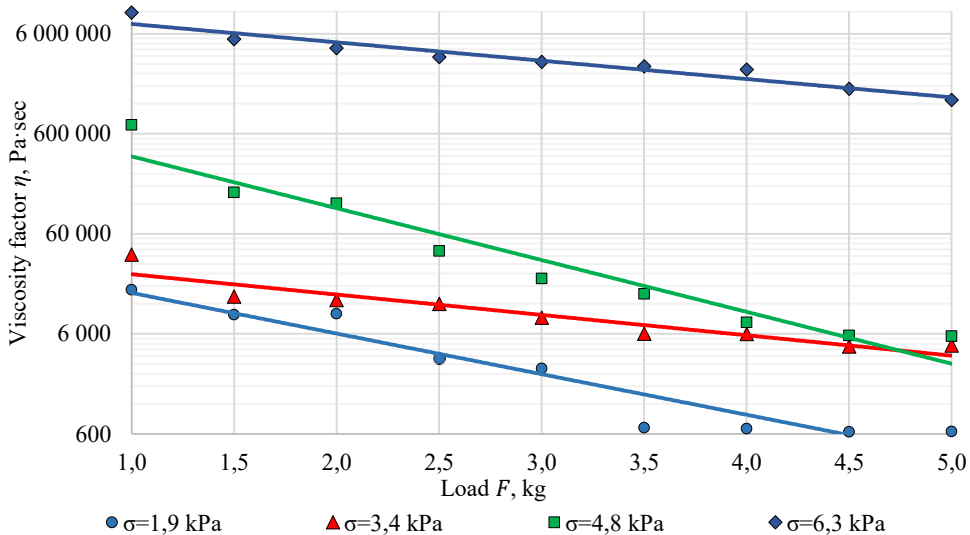


Fig. 3. A graph of the dependence of the viscosity coefficient η on the load value F at different values of the compression pressure σ .

Taking into account the increase in the viscosity coefficient with an increase in the mean stress σ_m , and a decrease in the viscosity coefficient with an increase in the intensity of tangential stresses τ_i , it seems possible to apply the Timoshenko dependence to describe the viscosity [28] (3).

$$\eta = \eta_0 \cdot \frac{\tau_i^* - \tau_i}{\tau_i} \quad \tau_i^* = \sigma_m \cdot tg \varphi \quad (3)$$

Fig.4-5 below shows the isofields of mean stresses σ_m and tangential stress intensities τ_i .

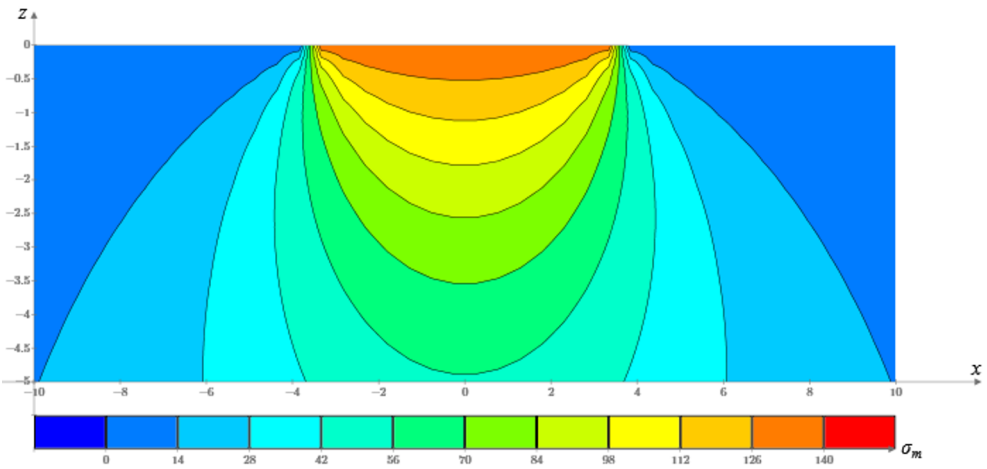


Fig. 4. Isofields of mean stresses σ_m in the sandy base at $a_l=3,6$ m и $p=160$ kPa.

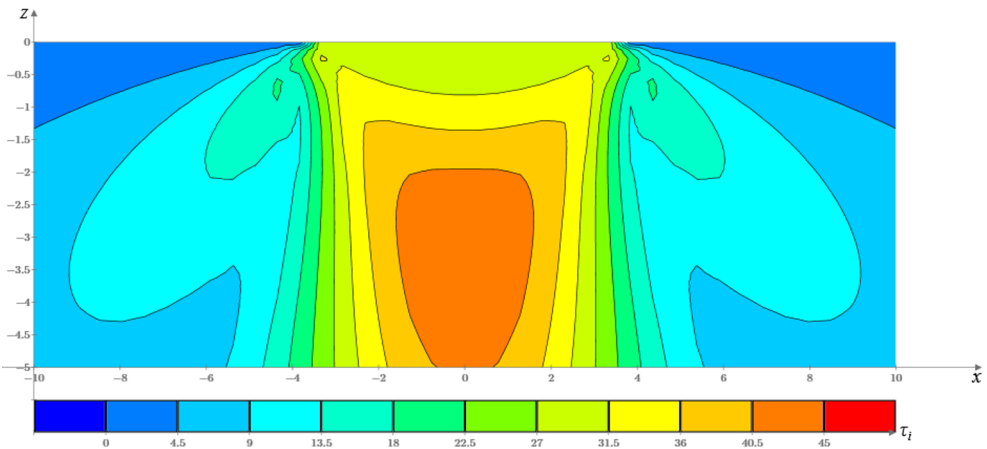


Fig. 5. Isofields of the intensity of tangential stresses τ_t in the sandy base at $a_l=3,6$ m and $p=160$ kPa.

Fig.6 shows a graph with a set of curves describing the precipitation over time.

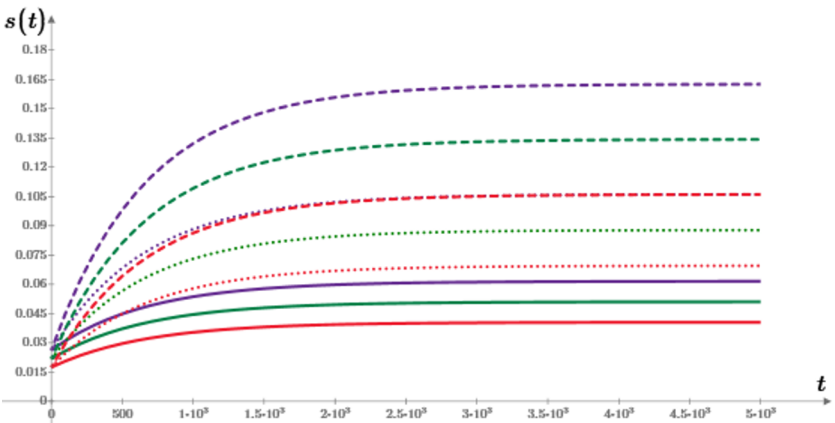


Fig. 6. Graph of the development of precipitation over the foundation time at the values of static load p_l and dynamic load Δp : (—) — $p=160$ kPa, $\Delta p=10$ kPa; (.....) — $p=160$ kPa, $\Delta p=20$ kPa; (- - -)

– $p=160$ kPa, $\Delta p=30$ kPa; (—) – $p=200$ kPa, $\Delta p=10$ kPa; (.....) – $p=200$ kPa, $\Delta p=20$ kPa; (---) – $p=200$ kPa, $\Delta p=30$ kPa; (—) – $p=240$ kPa, $\Delta p=10$ kPa; (.....) – $p=240$ kPa, $\Delta p=20$ kPa; (---) – $p=240$ kPa, $\Delta p=30$ kPa.

Fig.7 shows a graph of the dependence of the final precipitation of the foundation on the dynamic pressure under its base Δp at different values of static pressure p .

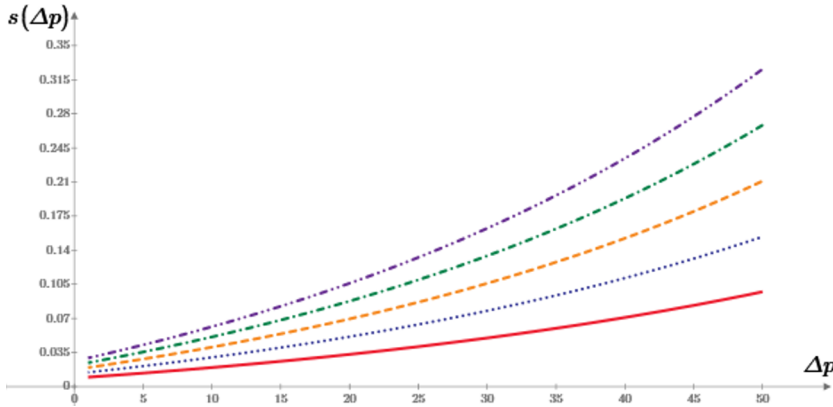


Fig. 7. Graph of the dependence of the amount of additional foundation precipitation on the value of the dynamic component of the load Δp at different values of the static component of the load p : (—) – $p=80$ kPa; (.....) – $p=120$ kPa; (---) – $p=160$ kPa; (—) – $p=200$ kPa; (---) – $p=240$ kPa.

4 Discussion

From the results of laboratory studies, it can be traced that the viscosity coefficient increases with an increase in the mean stress σ_m and decreases with an increase in the intensity of tangential stresses τ_i . The revealed dependence between the viscosity coefficient and the stress level (in particular, the magnitude of the average stress and the intensity of tangential stresses) is consistent with the results of previous researchers obtained by other methods, in particular Ter-Martirosyan A.Z. [21, pp.68-69], Sobolev E.S. [20, p.74], Khosla V.K., Singh R.D. [16].

Evaluating the family of curves shown in Fig.8, it can be traced that the foundation sediment under the action of dynamic load increases with the growth of static p and dynamic Δp components of the load. The analytical solution of the problem of foundation sedimentation under the action of dynamic loading on a homogeneous non-water-saturated soil base also corresponds to the results of large-scale field tests by V.A. Ilyichev, V.I. Kerchman, B.I. Rubin, V.M. Pyatetsky [5, pp.150-151; 11].

5 Conclusions

The proposed design of a ground dynamic ball viscometer allows to study the manifestation of viscosity in sandy soil under the action of vibration and to determine the viscosity coefficient. It has been experimentally established that the viscosity coefficient increases with an increase in the mean stress and decreases with an increase in the intensity of tangential stresses, which together can be described by the Timoshenko dependence.

Using the revealed dependence describing the effect of the stress state on the viscosity coefficient of sandy soil under the action of vibration, it was analytically established that the foundation sediment increases with an increase in the static and dynamic components of

the load on the foundation, which is consistent with the results of field observations of previous researchers.

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