Long-term vibration laboratory tests of sandy soils

A Z Ter-Martirosyan and E S Sobolev

Department «Soil mechanics and geotechnics», Moscow State University of Civil Engineering (National Research University), 26 Yaroslavskoye Shosse, Moscow 129337, Russia

E-mail address: e.s.sobolev@mail.ru

Abstract. The presented work examines the features of testing at the laboratory of the Moscow State University of Civil Engineering "Research and Education Center" Geotechnics "on a triaxial device with the ability to create dynamic loads (vibration stabilometer). Information on the course of cyclic tests of sandy soils is given, their analysis is carried out and formulated the main conclusions about the effect of the duration of vibration loading on the final stress-strain state of the soil mass.

1. Introduction

During the design, construction and operation of industrial, civil, hydraulic engineering and transport structures in connection with the constant increase in the intensity of technogenic dynamic impact, construction in seismically active areas, in water areas and in other special situations, it is necessary to take into account the vibration effects on the foundation soils to assess their interaction with the underground part of structures, in order to determine possible additional deformations.

The experience in the construction and operation of the listed types of structures and high-rise buildings with a developed underground part shows that long-term cyclic and vibration effects lead to the accumulation of additional deformations in the soils of the bases and, ultimately, to additional precipitation and rolls of the foundations of structures, and sometimes to loss of stability, for example, during dynamic liquefaction of water-saturated sands.

2. Research method

To take into account the vibration creep of soils, the vibration creep coefficient \( K_{vc} \) is used, which reduces the value of the static modulus of total deformation. This approach to predicting the vibrational creep of soils can be called quasi-static, since it is carried out within the framework of conventional static methods for calculating the settlement of the foundations of structures.

The values of the vibration creep coefficient for the studied soils were calculated by the following formula:

\[
K_{vc} = \frac{\Delta \varepsilon_s}{\left(\Delta \varepsilon_s + \Delta \varepsilon_g\right)}
\]

where \( \Delta \varepsilon_s \) and \( \Delta \varepsilon_g \) - strain increments from static and dynamic loading in a given stress range.

The soil deformation modulus, taking into account the vibration creep deformation, should be determined by the formula:

\[
E_{vc} = E_s \times K_{vc}
\]
where $E_s$ – Young modulus based on static test results, in kPa; $K_c$ – vibration creep coefficient.

One of the fundamental issues in the field of vibration creep assessment is the choice of test conditions: frequency, number of cycles and time. In most cases, the frequency is taken as the most typical for each site (for example, the vibration frequency of an electric machine, transport impact, etc.). The test is carried out until the full stabilization of deformations during vibration creep, which is assessed by the absence of increments of vertical deformation. However, given the laboriousness and high cost of such tests, it is necessary to develop an acceptable method for assessing the test time, as well as the need to conduct tests at different frequencies.

The mechanism of vibrational creep of dispersed soils is currently not fully understood. Many researchers [9, 11] believe that the vibration creep coefficient depends on the frequency of exposure, based on the fact that the conditions of interaction of particles change at different frequencies, and, consequently, their creep resistance. However, this theory needs additional experimental confirmation, since at the moment there are not enough test data at various frequencies.

In addition, consideration of the phenomenon of vibration creep from the point of view of energy [2, 3, 6] spent on overcoming internal friction leads to the conclusion that the manifestation of vibration creep will only be affected by the number of cycles with equal amplitude, regardless of frequency. However, in the case of soil, rheological processes associated with pore water and rigid bonds of various natures between particles are important, and these processes are always a function of time. Thus, the time between individual cycles will have a significant impact on the development of additional deformations due to vibration creep.

The purpose of this work is to study the parameters of vibration creep by analyzing the effect on vibration creep of the number of cycles and the frequency of exposure based on the experience of testing in the REC "Geotechnics" MSUCE soils for solving production problems.

3. Laboratory research

For testing, equipment manufactured by APS Antriebs-, Pruf- und Steuertechnik GmbH "Wille Geotechnik" (Germany) was used, which is a servo-hydraulic load frame with a maximum axial force of 63 kN, a triaxial compression chamber, a control unit for a servo-hydraulic drive, a data processing unit from pressure sensors and displacement, air pressure control unit, media separator, burette with differential volumetric deformation sensor and control computer. The general view of a three-axis device with the ability to create dynamic loads (vibration stabilometer) is shown in figure 1.

During testing in automatic mode (software GEOsys 8.7.8) [16], the specified loading path is realized.

The tests were carried out in type A chambers, designed for specimens 140 mm high and 70 mm in diameter. Top and bottom dies are made of stainless steel. Porous plates of pressed steel chips and filter paper were placed between the dies and the sample. Latex casings were used, 0.5 mm thick.

Samples of sandy soil of a given density ($\rho = 2.02$ g/cm$^3$), close to natural, were placed in the chamber of a triaxial device, after which they were completely saturated with water. After the completion of water saturation, a comprehensive pressure was applied to the sample, equal to the domestic one at a given depth, and the stage of consolidation was carried out under open drainage conditions. Compression pressure was 500 kPa. After stabilization of volumetric deformations, a deviatorial load was applied to the sample, equal to the additional pressure from the structure at the sample depth (150 kPa).

After the application of all acting loads and stabilization of deformations, the drainage was closed, and a vertical vibration load with a frequency of 20 and 50 Hz was applied to the sample. The number of cycles was $180 \times 10^3$ (at a frequency of 20 Hz) and $300 \times 10^3$ (at a frequency of 50 Hz), which represents about 2.5 hours of dynamic loading. The amplitude of the cyclic vertical loading was 30 kPa, which was 4.5% of the total vertical load.

Thus, in the course of the last stage of testing, the values of additional deformations of the sample were obtained due to the action of the load of a given frequency in the conditions of consolidated-undrained triaxial compression. After processing the test reports, the values of the vibration creep coefficient were obtained at the stage of vibration loading.
Figure 1. General view of the installation of triaxial compression with the possibility of vibration loading.

The results of the tests performed are presented in figures 2 and 3. The graphs show the dependences of the development of relative vertical deformations during the period of vibration loading on the number of cycles at frequencies of 20 and 50 Hz, respectively.

Figure 2. Dependence of the development of relative deformations on the number of vibration loading cycles with a frequency of 20 Hz.
Figure 3. Dependence of the development of relative deformations on the number of cycles of vibration loading with a frequency of 50 Hz.

Based on the results of the tests carried out, trend lines were plotted using the least squares method, which made it possible to compare the results for frequencies of 20Hz and 50Hz (figures 4 and 5, respectively).

Figure 4. Dependence of relative deformations on loading time in seconds for testing four soil samples at a frequency of 20 Hz.
Figure 5. Dependence of relative deformations on loading time in seconds for testing four soil samples at a frequency of 50 Hz.

4. Conclusions

With the joint analysis of the obtained curves, the following general conclusions can be drawn:

- additional deformation during vibration creep increases with increasing frequency;
- regardless of the frequency and number of cycles in the same soil, deformation stabilization occurs in the same time;
- logarithmic equations of the trend line for the same soil differ exclusively in the free term. This allows us to conclude that the law of deformation development due to vibration creep will be identical for the same soil. Despite the fact that the logarithmic dependence does not allow obtaining complete stabilization of additional deformations, it can be assumed that it has a damping character, because at $t \to \infty$, $\varepsilon \to 0$.

Based on a detailed analysis of the performed dynamic tests of sandy soils, the following main conclusions can be drawn:

- Stabilization of relative deformations during vibration tests of sandy soils under conditions of triaxial compression at a frequency of 20 Hz and an amplitude of deviatorial loading of 30 kPa (4.5% of the total vertical load) occurred on average after 4500 s.
- Stabilization of relative deformations during vibration tests of sandy soils under conditions of triaxial compression at a frequency of 50 Hz and an amplitude of deviatorial loading of 30 kPa (4.5% of the total vertical load) occurred on average after 4000 s.
- When carrying out dynamic tests of sandy soils in a vibro-stabilometer, the time of vibration loading plays a decisive role, since it is a factor that takes into account both the frequency and the number of cycles in the form

$$t = \frac{N}{f}$$

(3)

where $t$ - time of vibration loading, s; $N$ - number of vibration load cycles; $f$ - vibration loading frequency, Hz.

- The vibration creep of each individual soil can be described by a general law that is unchanged for different frequencies in the form:

$$\varepsilon(t) = \alpha \times \ln(t) - \beta$$

(4)

where $\varepsilon(t)$ - additional relative deformations at the stage of vibration loading; $\alpha$ - rheological coefficient; $\beta$ - constant value.
References

[1] Abramova T T 2016 Protection of soil masses from dynamic and seismic loads Symvol Nauki 4 pp 41-9
[2] Voznesensky E A 1999 Dynamic instability of soils (M: Publishing group URSS)
[3] Abramova T T and Voznesensky E A 2015 Modern methods of managing properties of soils on the sites exposed to high dynamic loads Geotechnics 4 pp 6-25
[4] Standard GOST 12248-2010 Soils. Methods for laboratory determination of strength and deformability characteristics 2012
[5] Standard GOST 20522-2012 Soils. Methods for static processing of test results 2013
[6] Ishihara K 2006 Behavior of soils during earthquakes (S.-Pb: DIA)
[7] Sobolev E S, Ter-Martirosyan A Z and Morev D S 2019 Experimental studies of elastic shear waves speeds in soil-cement depending on density Geotechnics 11 (3) pp 6-12
[8] Technical report Determination of the vibration creep coefficients of sandy soils at the facility: Construction of the highway Drozhzhino - Bobrovo - Lopatino at the address: MO, Leninsky municipal district, Bultnikovskoe rural settlement. - M.; MGSU, 2013.
[9] Ter-Martirosyan A Z, Mirny A Yu, Sidorov V V 2013 Laboratory testing of soils at the Moscow State University of Civil Engineering (MGSU-MISI) (M: Engineering Survey magazine) issue # 8
[10] Ter-Martirosyan A Z 2010 Residual deformations and stresses in the soil environment under the action of a cyclic load. Collection of scientific papers of the XXIII International Interuniversity Scientific and Practical Conference of Young Scientists, Doctoral and Postgraduate Students "Construction - Formation of the Living Environment", 14-21.04.2010 Moscow pp 815-9
[11] Ter-Martirosyan Z G 2009 Soil mechanics (Moscow: ASV)
[12] Ter-Martirosyan Z G, Ter-Martirosyan A Z 2009 Creep deformations of soils under cyclic and vibration effects Proceedings of the XVIII Polish - Russian - Slovak seminar "Theoretical foundations of construction" Moscow - Arkhangelsk 01-05.07.2009 (Warsaw) pp 473-80
[13] Ter-Martirosyan Z G, Ter-Martirosyan A Z 2008 Residual stresses in soils under cyclic loading Proceedings of the XVII Polish - Russian - Slovak seminar "Theoretical foundations of construction" Warsaw 02-06.06.2008 (Zilina) pp 278-83
[14] Ter-Martirosyan Z.G. 1990 Rheological parameters of soils and calculations of the foundations of structures (Moscow Stroyizdat)
[15] Ter-Martirosyan Z G, Nikolaev A P and Ter-Martirosyan A Z 2008 Residual deformations and stability of soil masses under seismic impacts Scientific and technical journal "Vestnik MGSU" pp 41-7
[16] Operational documentation for a set of equipment for testing in triaxial compression 63kN APS GmbH "WilleGeotechnik" 2012 (Germany Göttingen-Rosdorf)