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EXPERIMENTAL INVESTIGATIONS

DEPENDENCE OF THE DYNAMIC MODULUS OF SOIL DEFORMATION ON IMPACT FREQUENCY

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Laboratory experiments on clayey soils under dynamic triaxial compression were conducted to establish a nonlinear relationship between the dynamic modulus of soil deformation and the frequency of impact. The most significant increase in the dynamic modulus of soil deformation is observed under an increase in frequency from 5 to 10 Hz. In comparison with fluvioglacial soils, the dynamic deformation modulus in glacial loams grows slower under an increase in frequency. This confirms the dependence of the obtained relations on the genesis of soils. The research results were used to develop vibration protection systems for high-precision equipment in high-tech industries.

Introduction

In the design of buildings and structures erected taking dynamic effects into account, determination of their optimal stiffness represents a principal research task. The dynamic characteristics of structures are determined by their inherent stiffness, the stiffness of their constituting nodes, and, importantly, by the stiffness of their foundation. In addition, the dynamic properties of the foundation largely determine the shape and frequency spectrum of vibrations of the entire structure [1]. The required safety of construction facilities can be ensured only on the basis of a quantitative assessment of the reliability of the structure–foundation system [2].

Dynamic properties are particularly significant in the design of industrial facilities where high-precision equipment is installed. This imposes stringent requirements on the vibration protection of structures in the fields of microelectronics production, photonic integrated circuits manufacturing, etc.

The dynamic modulus of deformation is known to be the defining mechanical characteristic of structures under dynamic impact [3–5]. When designing low-frequency vibration protection systems for high-precision equipment [6], it is necessary to establish the dependence of the dynamic modulus of soil deformation E_d (MPa) on the prevailing frequencies of dynamic impact.

Research into the influence of dynamic impact frequency on soil stiffness indicators has been carried out since the late 1980s [7–9]. It was shown [10, 11] that soil stiffness, characterized by the modulus of deformation, increases along with an increase in the frequency of dynamic impact. It was also noted that low-plastic clayey soils are less sensitive to variations in stiffness under dynamic impact [12].

The results of tests in a dynamic triaxial compression installation across a wide range of loading frequencies showed [13] that soil stiffness increases with an increase in the frequency of loading, while damping decreases. It was also noted that this effect is more pronounced in highly plastic clayey soils.

Of particular interest are the results of undrained tests of dusty clayey and sandy soils [14] under cyclic loading and direct shear conditions. It was shown that at deformations higher than 0.01%, when the behavior of soils becomes nonlinear, the impact frequency has a significant effect on soil stiffness. Thus, one loading cycle of clayey soils (from 0 to 1% strain) increases their stiffness by about 10%.

Numerous studies [15–18] note that the effect of dynamic loading frequency weakens along with an increase in the number of loading cycles and a decrease in the impact amplitude. Hence, the effect of loading frequency becomes more noticeable at a small number of loading cycles [19]. At the same time, clayey soils

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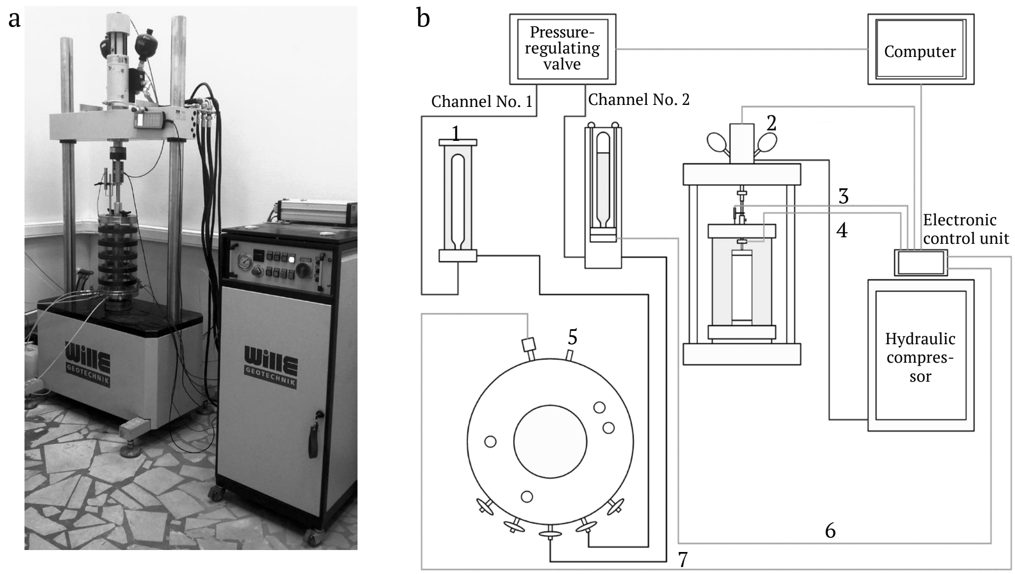

Fig. 1. Triaxial compression installation: a) a general view, b) a schematic diagram; 1) media separator, 2) rod displacement sensor, 3 and 4) external and internal displacement sensors, respectively, 5) safety valve, 6) volume change sensor, 7) pore pressure sensor.

exhibit a higher level of cyclic strength at higher frequencies, while the highest shear deformations and excess pore pressure are generated at lower frequencies [20].

In the present study, we set out to establish empirically the relationship between the dynamic modulus of soil deformation and the frequency of dynamic impact. To that end, we carry out laboratory tests of clayey soil specimens under triaxial compression.

Materials and Methods

Dynamic triaxial tests were carried out in the stress-strain control mode according to the consolidated undrained scheme with pore pressure monitoring. Testing was conducted using certified and verified equipment manufactured by the APS Antriebs-, Pruf-, und Steuertechnik (Wille Geotechnik, Germany). This equipment complies with GOST 12248.3 and consists of a servohydraulic load frame with a maximum axial force of 63 kN, a triaxial compression chamber, a servohydraulic drive control unit, a data processing unit for pressure and displacement sensors, an air pressure control unit, and a control computer. The force sensor is designed for a maximum axial force of 25 kN (Fig. 1).

Testing in the automatic mode (GEOsys software) implemented a given loading trajectory followed by measuring the vertical axial force, vertical displacement of the upper die, pressure in the chamber, pore fluid pressure, and volume change of the specimen.

Prior to testing, the specimens were placed in the compression chamber and subjected omnidirectional pressure equal to the natural pressure at a given depth. The consolidation stage was carried out under open drainage conditions. Following the completion of consolidation, the minimum static deviatoric load of 10 kPa was applied to the specimen due to the technical features of the installation. Subsequently, the stage of dynamic vertical loading with an amplitude of 30 kPa was carried out. The frequency of dynamic impact was taken equal to 2, 10, and 40 Hz; the number of cycles was 500 [21].

The dynamic deformation modulus E_d was determined according to [21] based on the dependence of axial stress σ'_1 on the relative axial strain ε (Fig. 2):

$$E_d = \Delta\sigma'_1 / \Delta\varepsilon_{\max}.$$

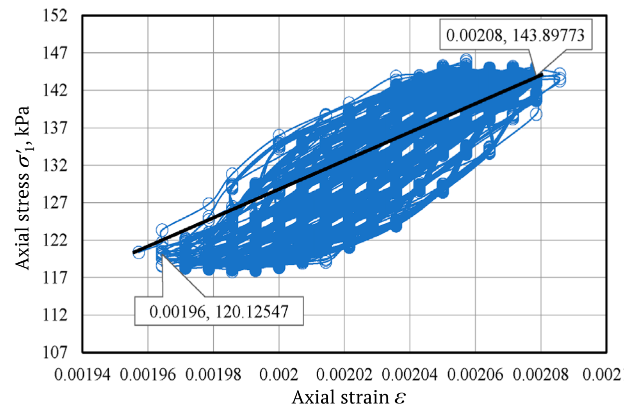

Fig. 2. Determination of the dynamic modulus of soil deformation based on the results of dynamic triaxial compression (semisolid loam, borehole No 2, borehole depth 4.5–5 m, dynamic frequency 2 Hz).

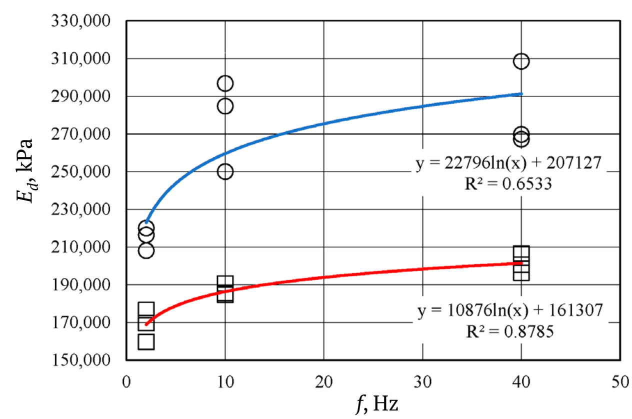

Fig. 3. Experimental determination of the dynamic modulus of soil deformation E_d depending on the frequency of dynamic impact *f*; ○) EGE-3 and □) – EGE-2.

TABLE 1

Test No.	Borehole No.	Depth of specimen collection, m	Description of the engineering geological element (EGE)	Loading frequency *f*, Hz	Dynamic deformation modulus E_d, kPa	
4	5	2.1-2.4	EGE-2 fluvioglacial loam brown, semisolid, with rare gruss inclusions (f,lgQIIms)	2	159 577	168 590
5	5	2.4-2.7			176 541	
6	6	2.2-2.5			169 652	
10	6	2.5-2.8		10	190 593	186 904
11	6	2.8-3.1			185 525	
12	7	2.1-2.4			184 594	
16	7	2.4-2.7		40	206 501	201 131
17	7	2.7-3			200 637	
18	7	2.7-3			196 255	
1	2	4.2-4.5	EGE-3 glacial loam brown, semisolid, sandy, with crushed stone and gruss inclusions (gQIIms)	2	220 025	214 814
2	2	4.7-5			208 009	
3	2	7.3-7.6			216 407	
7	2	7.7-8		10	249 987	277 151
8	3	3.7-4			284 682	
9	3	6.7-7			296 785	
13	3	7.7-8		40	267 126	281 797
14	3	8.7-9			308 542	
15	3	9.7-10			269 724	

Results and Discussion

The test results (Figs. 2 and 3, Table 1) allowed us to obtain a nonlinear dependence of the dynamic modulus of soil deformation on the frequency of impact. As a first approximation, the shape of the dependence can be assumed to be logarithmic; however, this conclusion requires further clarification by additional tests on similar soils.

An increase in the frequency of dynamic impact from 5 to 40 Hz leads to an increase in the dynamic deformation modulus from 210 to 290 MPa. The most significant changes are observed in the range from 5 to 10 Hz.

In glacial loams, the dynamic modulus of deformation was found to grow slower along with an increase in frequency compared to fluvioglacial soils. This indicates that the dependencies obtained are related to the genesis of soils.

The results obtained can be used at the preliminary stage of design of vibration protection systems for determining the regularities of changes in the dynamic modulus of soil deformation depending on the frequency of impact.

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