Researteh of the Seismic Properties of Clay Soils for Seismic Microzoning

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Abstract. The paper presents the results of seismoacoustic studies of soils on the example of samples of unsalted Sarmatian clays from the Northern black sea region. Samples of natural addition and humidity, as well as corresponding samples of soil particles were studied. Regression dependences of the longitudinal wave velocity on some indices of physical and mechanical properties of Sarmatian clays are revealed. The values of elastic wave propagation velocities determined as a result of ultrasonic investigations are used to calculate the increment of the seismic score and to map seismic microzoning, which is extremely important for ensuring the safety of construction in seismic areas. The obtained results can be used for seismic microzoning of any areas composed of clay swollen soils.

1. Introduction
In Russia, areas with seismicity of 7 points and above cover more than 2 million km². This is more than 12% of the total territory of the country. Over 1,300 cities and towns are located in these areas. In particular, on separate sites, the territory of the southern part of the Russian platform belongs to such seismic zone (according to SP 14.13330.2011 "Construction in seismic areas") [2]. In this regard, special attention in the design and construction of buildings and structures should be paid to a detailed study of the engineering-geological conditions of construction sites [3], because the construction of such sites requires the study of the seismic properties of soil bases and perform seismic microzoning. Seismic observations are carried out in the form of a set of studies, one of which is the laboratory ultrasound transmission of clay soil samples [4-8] for the purpose of a detailed study of the velocity characteristics and attenuation parameters. The true values of elastic wave propagation velocities determined as a result of ultrasonic investigations are used to Refine the data obtained by other methods and, as a result, to calculate the increment of the seismic point and to make a map of seismic microzoning.

2. Methods of work
The studies were carried out by means of ultrasonic scanning of samples, which was performed by serial pulse flaw detector UKB-1M with sensor frequencies of 60-100 kHz. Cylindrical samples were
x-rayed. The sensor and receiver were located along the axis of the specimen at a distance of 10 cm. After scanning on the same sample were carried out penetration research and shear testing method the consolidated slice. From the same monolith (rock sample) experiments on free swelling were carried out, the humidity of the swollen soil was determined and its transmission was carried out [8-11]. For tests there were samples of so-called Sarmatian clays, which are widespread in the South of Russia, Ukraine and Moldova [12-16]. The properties of soil samples considered in this example are presented in table 1.

Due to the fact that seismoacoustics properties of clay soil in a large measure depend on the degree of agregirovannosti – the nature of the structural relationships between the solid dirt particles, the specially prepared samples of pastes – analogues of the respective samples are clays. For this, the samples were dried, milled and sifted through a sieve with mesh size 1.0 mm. Powder was filled with water in the quantity necessary to give it the moisture of the sample – analogue, and compacted in the compactor to a density of a sample – analogue.

**Table 1.** Physical and mechanical properties of Sarmatian clays subjected to ultrasonic transmission.

| No. sample's | Physical property | Mechanical property |
|--------------|------------------|------------------|
|              | $\rho_0$ g/cm$^3$ | $\rho_d$ g/cm$^3$ | $W$ | $n$ | $S_r$ | $K_d$ | $\varepsilon_{0.1}$ MPa | $c$ MPa | $\varphi$ | $P_m$ MPa |
| 1            | 2.05             | 1.67             | 0.23 | 0.39 | 1.00 | 1.03 | 2.18          | 2.86 | 18       | 7.9       |
| 325          | 2.04             | 1.67             | 0.22 | 0.39 | 0.96 | 0.94 | 1.60          | 2.48 | 7        | 4.4       |
| 330          | 2.08             | 1.68             | 0.24 | 0.39 | 1.00 | 0.83 | 1.50          | 1.34 | 10       | 4.5       |
| 332          | 1.99             | 1.58             | 0.26 | 0.43 | 0.96 | 1.10 | 1.38          | 1.25 | 8        | 8.5       |
| 333          | 1.91             | 1.48             | 0.29 | 0.46 | 0.94 | 0.91 | 1.25          | 1.09 | 10       | 5.5       |
| 334          | 1.98             | 1.53             | 0.29 | 0.45 | 1.00 | 0.94 | 1.50          | 1.31 | 10       | 7        |
| 335          | 1.94             | 1.48             | 0.31 | 0.16 | 0.99 | 0.98 | 1.38          | 1.25 | 8        | 6.7       |
| 338          | 2.12             | 1.77             | 0.20 | 0.36 | 0.99 | 1.05 | 2.38          | 2.08 | 18       | 6.8       |
| 340          | 2.1              | 1.74             | 0.17 | 0.37 | 0.82 | 1.18 | 2.25          | 1.82 | 22       | 8.9       |
| 347          | 2.02             | 1.62             | 0.25 | 0.41 | 0.98 | 0.90 | 1.60          | 1.46 | 11       | 4.1       |
| 348          | 2.10             | 1.67             | 0.23 | 0.39 | 0.98 | 1.04 | 1.55          | 1.33 | 14       | 6.3       |
| 351          | 2.20             | 1.86             | 0.18 | 0.32 | 1.00 | 1.06 | 2.30          | 1.88 | 24       | 8.9       |
| 400          | 2.04             | 1.63             | 0.25 | 0.41 | 1.00 | 0.98 | 1.35          | 0.93 | 21       | 6.3       |
| 406          | 2.08             | 1.67             | 0.24 | 0.39 | 1.00 | 0.98 | 1.75          | 1.49 | 15       | 8.1       |
| 437          | 2.03             | 1.67             | 0.21 | 0.40 | 0.91 | 1.00 | 1.83          | 1.42 | 22       | 7.8       |
| 438          | 2.07             | 1.72             | 0.20 | 0.38 | 0.94 | 1.03 | 2.50          | 1.93 | 30       | 8.08      |
| 448          | 2.13             | 1.75             | 0.22 | 0.37 | 1.00 | 1.04 | 2.05          | 1.69 | 22       | 8.1       |

Such studies together with tests of swollen soil allow to predict the seismic properties of "structurless" Sarmatian clays in areas of intensive weathering and landslide formation.

3. **Research results and their analysis**

A feature of geological sections of the soil thickness composed of dispersed rocks is their relatively weak differentiation in the propagation velocities of elastic waves. This conclusion, already formulated by V. N. Nikitin [17], is confirmed scientific results. For a group of samples of Sarmatian clays of the Northern black sea region [12-16], with very different indicators of their physical and mechanical properties, given in table 1, the values of the velocities of longitudinal waves $V_p$ from 1300 to 1840 m/s are obtained in table 2.
Table 2. The rate of passage of longitudinal waves through the samples of Sarmatian clays natural addition \( (V_{p1}) \), ground paste \( (V_{p2}) \) and swollen soil \( (V_{p3}) \).

| No. sample's | Velocity of longitudinal waves, m/s | \( \frac{V_{p1}}{V_{p2}} \) | \( \frac{V_{p1}}{V_{p3}} \) | Indicators swellings |
|--------------|----------------------------------|----------------|----------------|-------------------|
| 1            | 1730                             | 3.1            | 0.31           | 0.09              |
| 325          | 1400                             | 2.1            | 0.34           | 0.15              |
| 330          | 1300                             | 1.9            | 0.29           | 0.15              |
| 332          | 1800                             |                | 0.46           | 0.14              |
| 333          | 1570                             |                | 0.34           | 0.05              |
| 334          | 1670                             | 1.5            | 0.40           | 0.16              |
| 335          | 1630                             | 1.3            | 0.41           | 0.13              |
| 338          | 1700                             | 1.4            | 0.33           | 0.22              |
| 340          | 1840                             | 1.5            | 0.40           | 0.28              |
| 347          | 1300                             | 1.1            | 0.30           | 0.10              |
| 348          | 1600                             | 1.4            | 0.29           | 0.09              |
| 351          | 1700                             |                | 0.29           | 0.09              |
| 400          | 1625                             | 1.9            | 0.26           | 0.01              |
| 406          | 1680                             | 2.0            | 0.32           | 0.17              |
| 437          | 1550                             | 1.9            | 0.30           | 0.13              |
| 438          | 1700                             |                | 0.27           | 0.06              |
| 446          | 1720                             | 1.8            | 0.31           | 0.16              |

Correlation analysis of the dependence of \( V_{p} \) on physical properties indicates the absence of such a connection. Correlation coefficients with most physical properties do not exceed \( r = 0.4 \).

It is known that the bound water on the properties is close to a solid body, in particular, on speed of propagation of elastic waves. The decrease in the density of the skeleton at swelling and decompaction of the clay leads to an increase in humidity of up to \( 0.26 – 0.40 \) and has the effect of reducing the longitudinal wave velocity of \( 1.1 \) to \( 1.5 \) times and is \( 1000 - 1680 \) m/s. (Y. I. Olyansky, E. V. Schekochikhina [6,7,18]).

Due to the fact that the strength of structural bonds has a determining effect on the velocity of elastic waves, the velocity of \( V_{R} \) in soil pastes (at natural humidity) was analyzed [19,20]. It is established that the velocity \( V_{p} \) in the destruction of structural bonds of crystallization (concrete) type is reduced in average 2 times in total \( 670 - 1100 \) m/s correlation of the velocity \( V_{p} \) of characteristic values of mechanical properties of clays of medium and high. The highest values of the correlation coefficients with the indicators: the specific resistance of penetration \( P_{mn}, r = 0.98 \) (Figure 1 (a)); coefficient of natural compaction \( K_{d}, r = 0.78 \) (Figure 1. (b)); shear forces \( \tau_{0,1}, r = 0.62 \) (Figure1 (c)).
Figure 1. Graphs of the dependence of the velocity of longitudinal waves $V_p$ from the values of the listed properties Sarmatian clays of the Northern black sea: a) from the specific resistance of penetration $P_m$; b) from the ratio of natural compaction $K_d$; c) from the shear forces $\tau_{0.1}$.

Since all indicators of the physical properties of rocks are closely interrelated and the change of any one of them inevitably entails a change in the other, the velocity of elastic waves can be used to indirectly determine a number of indicators of engineering-geological properties of rocks. For
Sarmatian clays, they can be used to determine the specific resistance of penetration, shear force and compaction index.

There is also a significant decrease in the velocity of longitudinal waves during the disintegration of clay rocks, which can take place on steep slopes under the influence of exogenous processes (cyclic swelling and shrinkage in particular). The fall of the $V_p$ velocity in this case is on average 2 times, which leads to an increase in the amplitude of the oscillation and can contribute to an increase in the area under seismic microzoning.

4. Conclusions

The obtained results of ultrasound studies in General do not contradict the data of other authors and are compared with the studies of V.A. Vasiliev [8] for the Central ancestral clays of the Caucasus. And can be used in the performance of work on seismic micro-zoning of territories composed of Sarmatian clays in the Northern black sea and Central Caucasus. In addition, the obtained data can be useful in the implementation of seismic microzoning of other areas where clay swollen soils are common.

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