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Research paper

Analysis of strain anisotropy and hydroscopic property of clay and claystone

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ABSTRACT

The paper presents an analysis of laboratory and field investigations of the anisotropy of natural early Permian claystone deformation behavior. Strain anisotropy in geotechnical engineering is of interest when calculating settlements and the ground base bearing capacity of a building foundation. The authors carried out pressuremeter tests, static stamp tests on claystone having an area of 600 cm^2 and a number of laboratory odometer tests of modern hard clay and claystone samples cut parallel and normal to stratification, as well as numerical modeling of these tests. The results obtained from the experiments and numerical modeling of claystone anisotropy deformability are reported and discussed. A number of the field and laboratory experiments made it possible to study the strain anisotropy of claystone in comparison with modern hard clay in the vertical and horizontal directions. In particular, modern clay shows less deformation under loading in the vertical direction than in the horizontal one. As for claystone, it shows less deformation under loading in the horizontal direction. The ratio is obtained to determine the parameters of the Jointed Rock model realized in the PLAXIS software package. The results of numerical modeling are in good agreement with the tests, thus supporting the numerical methods realized in the Jointed Rock model as a practical tool for the analysis of the soft rock stress–strain behavior. The mechanical properties of claystone are sensitive to water content and atmospheric air. Much attention is paid to the fulfillment of engineering and geological surveys, development of design documents, and foundations on claystones.

1. Introduction

One of the basic assumptions of soil mechanics is that soil is an isotropic linearly deformable material. Soils can be considered as a linearly deformable body at small stress changes, taking the relationship between the common strains and stresses as linear dependence. At present, many methods of calculation used in practice are based on the principle of linear deformability and in this case it is rightful to use the theory of elasticity and engineering methods for calculating foundation settlement. However, natural soils are not anisotropic and they behave like linear elastic materials under relatively small loads. But even in this case, residual deformation occurs under unloading. Therefore, when determining relative deformation the modulus of general deformation (hereinafter referred to as the modulus of deformation) is used. It considers both plastic and elastic soil deformations and depends on the applied load.

Investigations of clay strain anisotropy have been carried out in many countries since the beginning of the last century. Zhiwei and Jidong (2012) and Salager et al. (2013) noted that most natural clays were inherently transverse anisotropic due to the settlement accumulation process. Experiments showed that the properties of clays usually depended on the direction in which they were measured. That feature of mechanical behavior (and also of other aspects, such as filtration, thermal conductivity) was resulted from micro- and macro-structural factors. Specific directions were defined microscale in the course of clay formation (for example, deposition) considering the structure, texture, crystallography or grain sizes; whereas they were defined large scale using lamination and cracks. It was pointed out that clay soils had transversely isotropic strain anisotropy. That model was described by five deformation parameters, the main of which was the modulus of deformation. The previous researches, such as Biarez (1961), Barden (1963), Eftimie and Botez (1969), Lam and Tatsuoka (1988), and Nishimura et al. (2007) carried out research into soil deformability. Among Russian researchers Goldstein and Lapkin (1972), Pisanenko (1976), Lekhnitskiy (1977), and Bugrov and Golubev (1993) can be mentioned. Anisotropic deformability is clearly observed in soils and soft rocks having a layer structure. However, in the works of Shutenko (1968), Grechko et al. (1976) and others it is pointed out that strain anisotropy is typical for homogeneous clays too. Biarez (1961) showed that the deformability of modern clays was more defined in the plane

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of stratification (in the horizontal plane). However, there are several papers pointing out that soft rocks have less compressibility in the plane of stratification (Shutenko, 1968; Grechko et al., 1976; Pisanenko, 1976).

There have been no methodology and special equipment for determining the deformation characteristics of anisotropic soft rocks in Russia so far. Goldstein and Lapkin (1972) used an odometer to study the anisotropic deformation characteristics of clays. Grechko et al. (1976) used a triaxial device and Pisanenko (1976) used the compression type of a triaxial device. Zhang et al. (2012) performed claystone compression tests in parallel and perpendicular directions with respect to bedding planes. Hoxha et al. (2007), Fityus and Buzzi (2009), and Zhang et al. (2012) studied clayey rock deformability under partly saturated conditions. It was shown that clayey rocks became more ductile and the elastic modulus decreased when the water content increased. Such effects were inherently related to the modification of clayey rock microstructure. For instance, the drying and wetting processes could alter the distance among clay particles and lead to the change in mechanical properties of clay aggregates (Robinet, 2008).

Current analytical solutions for determining the stress–strain state of anisotropic ground bases are overly complex and designed for simple loading schemes. At the present time, to determine the stress–strain state of bases, numerical methods are widely used. These methods are not dependent on the types of ground bases and a loading scheme, but they require the application of deformation and strength parameters, many of which are not defined in the course of standard engineering and geological investigations. In this paper much attention has been given to the tests for determining these parameters.

Today the development of high-rise construction in the world has led to the use of deep lying clays as the bases of building foundations, including early Permian claystones (Ponomaryov and Sychkina, 2014). Argillite or claystone is a soft rock that consists of clay particles consolidated by means of the cement of ferrous and carbonate composition. This soft rock occurs widely in the European part of Russia, Western Europe and North America. As studied macroscopically, claystone is a dense massive rock of brown color and consists of clay material with carbonate impurities, uniformly impregnated with iron oxides. The microscopic study of claystones in plane-parallel thin sections and polished sections by Kuznetsov and Ignatiev (1951) showed that the rock was composed of clastic grains of 10^{-4}–10^{-3} cm in diameter, cemented by the dispersed mass of a clay-chloritic substance, carbonates and iron hydroxides (Fig. 1).

The thermal characteristics of clay stone indicate the presence of montmorillonite, chlorite, gypsum, dolomite, and calcite in them (Kuznetsov and Ignatiev, 1951). Film and cement substances (montmorillonite, chlorite, carbonates and iron hydroxides) can amount up to 70% of the rock mass. According to Gainanov (1972), the character of the relations among particles in claystone combines a full-crystal and film type of cementation. Thus, the structure of claystone is characterized by the availability of pelitic and fine aleurite clastic particles filmed and cemented into a homogeneous mass. Clastic material is homogeneous by its mineral composition. High hygroscopicity of up to 110 °C is typical for it. Claystone solubility depends on the content of carbonates, but it increases when applying cardonic of up to 500–1000 mg/l. The physical properties of claystone are determined by the significant content of montmorillonite in a state of old colloid. With the loss of natural moisture montmorillonite shrinks and microcracks appear in the rock. Immersion of claystone in such a state into water causes uneven expansion and its wedging by water into small pieces along horizontal stratification planes (Fig. 2).

Consequently, water saturation and weathering lead to the significant worsening of the deformation properties of these clays. It is important to know the real modulus of claystone deformation for the forecast of building foundation settlement. Earlier the authors gave the value for the settlement prediction of building foundations on claystone (Ponomaryov and Sychkina, 2014). Timely consideration of the specific behavior of claystone under water saturation at the stage of geological and engineering surveys, development of design documents and construction will make it possible to subsequently eliminate special measure expenses to restore the strength and deformation properties of foundation bases.

The total thickness of deposits, including Permian claystones and sandstones, is approximately 350 m. Claystone is marine clay deposited during the Permian period (more than 290 Ma ago). Permian claystone experienced a complex history of loading (Ponomaryov and Sychkina, 2012). It consisted of a long continental period and accumulation of alluvial clays and sands above them. Usually such a history of loading and texture indicates anisotropic mechanical properties.

In this paper, the results of claystone deformability in different planes are used to determine the numerical solution parameters of the Jointed Rock model. Thus, the obtained model parameters were implemented for the prediction of the stress–strain state of claystones when carrying out laboratory and field tests. Besides, the method of calculating the modulus of deformation of Permian claystones considering their anisotropic deformability was improved. To do that the following problems were solved:

1) the methodology was described, the field and laboratory experiments for the anisotropy coefficient calculation were done, and the results of strain anisotropy degree determination for claystone and modern hard clay under natural moisture and total water saturation were compared;

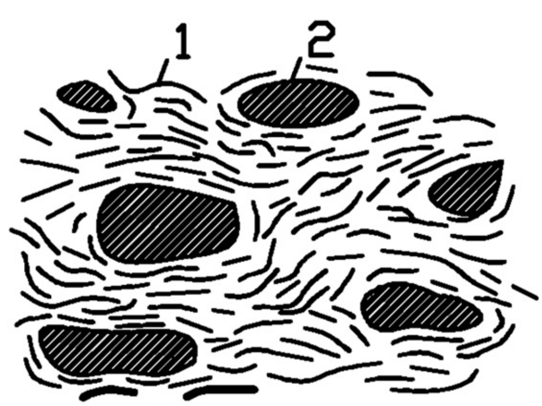

Fig. 1. Orientation of clay particles in claystone: 1 — clay particles and 2 — clastic particles.

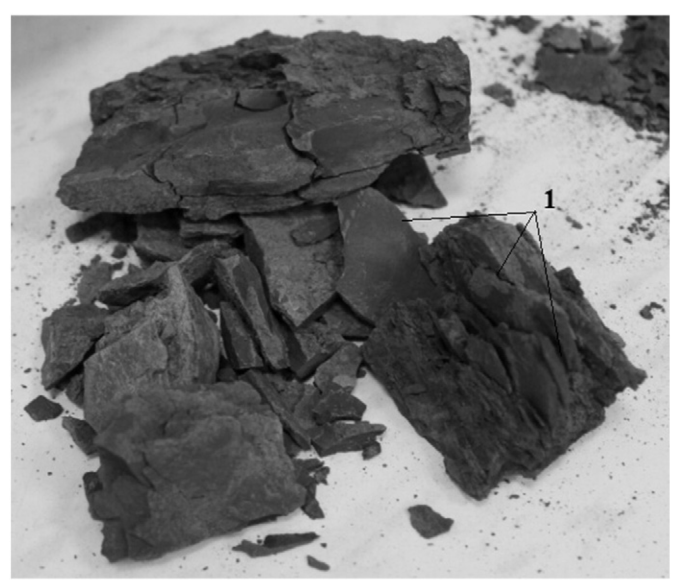

Fig. 2. Claystone destroyed along horizontal stratification planes: 1 — horizontal stratification planes.