

Национална конференция с международно участие „ГЕОНАУКИ 2022“  
National Conference with International Participation “GEOSCIENCES 2022”

## Evaluation of the frost resistance of fresh granodiorites from the Plana pluton in the region of the village of Gorni Okol, Bulgaria

### Оценка на мразоустойчивостта на свежи гранодиорити от Планския плутон в района на с. Горни Окол, България

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**Abstract.** This paper presents the changes in physical and mechanical parameters of fresh granodiorites from the Plana pluton after freezing. Laboratory studies were carried out to evaluate the properties of the granodiorites, such as determining the strength, density and water absorption of the rock material. A total of 39 samples at various weathering grades were tested at a wide range of density and water absorption values in the dry and saturated state. The results revealed that the absorption of water is highly dependent on the weathering grade. From the laboratory tests, reductions of rock material strength from various weathering grades with regard to density and water absorption are suggested. After carrying out a certain number of freeze-thaw cycles of the fresh granodiorites, their strength indicators also decrease.

**Keywords:** geotechnical parameters, PLT, granodiorites, Plana Mountain, Plana pluton.

### Introduction

Water absorption is one of the most important parameters influencing the rock material strength. A small increase in the water absorption values may lead to a marked reduction in strength and deformability. This effect is important for safety and stability of slopes and underground openings. Several researchers have studied the effect of moisture content on the engineering properties of rock (Mohamad et al., 2011; Tianshu Bao et al., 2022, etc.). An indicator of the quality of rocks can also be their ultrasonic wave velocities (Iliev, 1968; Tchakalova, Dobrev, 2020).

Rocks are exposed to various degradation processes but generally freeze-thaw cycles are considered to be one of the major factors in their decay. The frost resistance of rocks is a complex phenomenon. Different intrinsic properties (e.g., porosity and mineral composition) as well as extrinsic properties (e.g., presence of salts, temperature variation,

humidity) influence the frost resistance of a stone. Cyclic freezing and thawing is considered one of the most powerful causes of deterioration of rocks features.

The study area covers part of the Plana Mountain, near the villages of Dolni and Gorni Okol (Sofia region) (Kanev, 1989; Nikolov, Yordanova, 1997), where igneous rocks (coarse-grained granodiorites and quartz monzodiorites) of the Upper Cretaceous Plana pluton are omnipresent (Iliev, Katskov, 1990). The Plana pluton (part of the Central Sredna Gora Magmatic Area) built up most of the Plana Mountain, part of the northern slopes of the Verila Mountain as well as the western parts of the Shumnatitsa hills (Boyadjiev, 1971; Dabovski, 1975; Kamenov et al., 2009). The total area of the pluton is about 400 km<sup>2</sup>.

Weathering, erosion, landslides, etc. are widely developed among the physical-geological processes in the Sredna Gora Region (Kamenov, Iliev, 1963; Kamenov et al., 1963; Iliev-Broutchev, 1994). The

significant tectonic rework and crushing of rocks in the area (Georgiev et al., 2009) have facilitated the intensive weathering processes. The depth of penetration of these processes is closely dependent on the composition and structure of the rocks, exposure of the slope and relief forms, and above all, on the tectonic cracking. All this determines the great unevenness in terms of the thickness of the weathering zone and the unfavorable changes in the physical and mechanical properties of the rocks. The degree of rock weathering reflects the development of erosion processes.

In previous studies, the physical and mechanical properties of granodiorites from the Plana pluton, including the point load strength  $Is(50)$  were determined by Ivanov et al. (2018).

## Methodology

Some physical and mechanical parameters of the studied rocks were determined, such as density, specific density, point load strength, frost resistance under BDS EN (Bulgarian standard European norms). The absorption of water at atmospheric pressure was determined for each test body (BDS EN 13755). The point load method (PLT) was used to evaluate the strength parameters (Dobrev et al., 2002; Ilov, 2009) of granodiorites from the Plana pluton. The point load test was carried out, using the test method of cylindrical bodies (drill core), axial load, which meet the requirements specified in the ASTM D 5731 – 08 standard.

Thirty-nine specimens with a diameter of 90–94 mm and a height of about 30–35 mm were examined. With these dimensions, the equivalent diameter  $De$  is approximately 62 mm. According to the specified standard, the corrected value of the point load index  $Is(50)$  is the value of the point load index  $Is$  that would be obtained in a diametrical test with  $D = 50$  mm. Four specimens each of unweathered (fresh) granodiorite were tested in air-dry, water-saturated and water-saturated post-freeze state for 28 cycles at  $-20$  °C and thawing in water to  $20$  °C. The test method for determination of susceptibility of natural stone to frost deterioration is standardized with CEN standard EN 12371.

Longitudinal and transverse seismic wave velocities ( $Vp$ ,  $Vs$ ) were also determined by sounding in laboratory conditions according to the ASTM D2845 standard.

## Results

The results of the performed laboratory tests of the rock samples are shown in Figure 1 and Table 1. The obtained correlation dependences (Ivanov et al., 2018) between the Corrected Point Load Strength Index  $Is(50)$  in water-saturated state and the density of rock samples in an air-dry state (Fig. 1a) and between the Corrected Point Load Strength Index  $Is(50)$  in water-saturated state and water absorption ( $Ab$  - water absorption at atmospheric pressure) (Fig. 1b) are supplemented with new data.

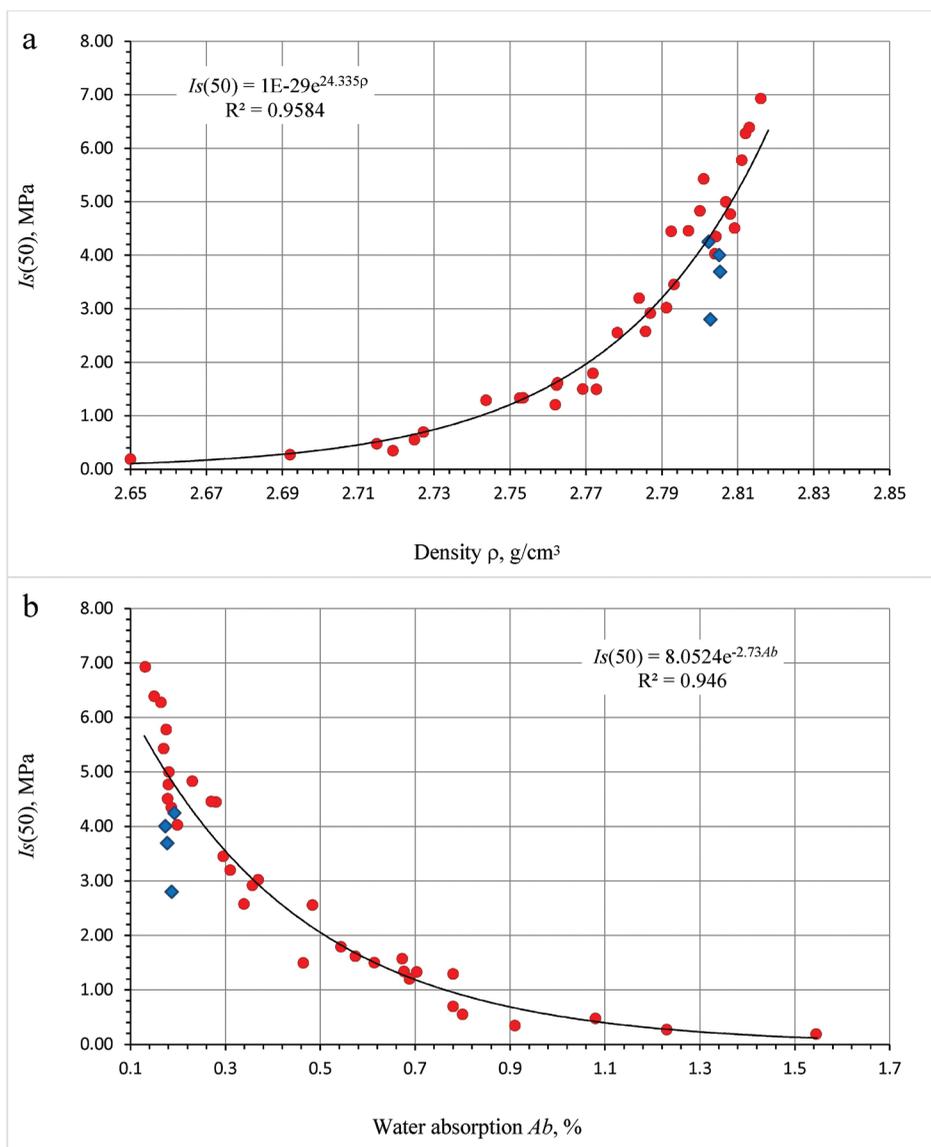
According to data from the laboratory analyses, the granodiorites have the following average parameters: bulk density  $\rho_n = 2.77$  g/cm<sup>3</sup> (2.65–2.82 g/cm<sup>3</sup>) in an air-dry state and 2.79 g/cm<sup>3</sup> (2.68–2.81 g/cm<sup>3</sup>) in the water-saturated state; uniaxial compressive strength  $UCS = 56.8$  MPa (19.3–121.7 MPa); tensile strength in the water-saturated state  $\sigma_t = 3.72$  MPa. For the corrected point load index  $Is(50)$  in the water-saturated state, the mean values were 2.95 MPa (0.19–6.93 MPa).

The obtained empirical dependence shows a very high correlation between the values of the bulk density in the air-dry state and the corrected point load index  $Is(50)$  in the water-saturated state, with a coefficient of determination  $R^2 = 0.958$  (Fig. 1a). Slightly weathered to unweathered (fresh) rock samples with a high density above 2.80 g/cm<sup>3</sup> are characterized by the highest strength values. The weakest are those with high water absorption and with a bulk density below 2.73 g/cm<sup>3</sup>. The correlation between water absorption at atmospheric pressure and corrected point load index  $Is(50)$  also shows a very high correlation  $R^2 = 0.946$  (Fig. 1b).

After freeze-thaw cycles, the  $Is(50)$  point load strength of the rock decreased from 5.44 MPa to 3.69 MPa (Table 1). The seismic wave velocity also decreases from 5305 m/s to 5185 m/s for  $Vp$  and from 2375 m/s to 1875 m/s for  $Vs$ . No significant

Table 1. Determination of frost resistance (BDS EN 12371) for unweathered (Fresh) granodiorites from the Plana pluton

Condition (state)	$Ab$ , %	$\rho_n$ , g/cm <sup>3</sup>	$\rho_n^w$ , g/cm <sup>3</sup>	$Is(50)$ , MPa	$Vp$ , m/s	$Vs$ , m/s
Water-saturated	0.186	2.804	2.810	4.49	5305	2345
Air-dry	0.178	2.806	2.811	5.44	5285	2375
Water-saturated after freezing	0.182	2.804	2.809	3.69	5185	1875



**Fig. 1.** Point load strength of granodiorites from the Plana pluton: (a) Relationship between Corrected Point Load Strength Index in water-saturated state and the density of rock samples in an air-dry state; (b) Relationship between Corrected Point Load Strength Index and the water absorption of rock samples. Note: values obtained after freeze-thaw are shown with a blue diamond.

change was observed in the rock density and water absorption.

## Conclusions

The research carried out shows that the slightly weathered and fresh granodiorites from the Plana pluton have good physical and mechanical indicators. The point load strength decreases with decreasing density (respectively increasing water absorbency) of the studied granodiorites. A very high correlation dependence is established between the studied indicators.

The performed study of the frost resistance of the granodiorites (after 28 freeze-thaw cycles)

shows that the values of the strength indicators and the velocity of the seismic waves ( $V_p$ ,  $V_s$ ) decrease. The change in rock density and water absorption is negligible because the tested rock is unweathered and has low porosity.

*Acknowledgments:* This work has been carried out in the framework of the National Science Program “Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters”, approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-279/03.12.2021).

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