Application of Classification Scheme Developed by Marinos and Hoek for Determination of Geotechnical Properties of Flysch Masses of Northwest Caucasus

Bondarenko N. A.
Department of Regional and Marine Geology
Kuban State University
Krasnodar, Russia
nik_bond@ mail.ru

Lyubimova T. V.
Department of Regional and Marine Geology
Kuban State University
Krasnodar, Russia
tv_luy@yandex.ru

Selivanova A. V.
Department of Regional and Marine Geology
Kuban State University
Krasnodar, Russia
selivanova_a@bk.ru

Abstract—**This article describes the experience of applying the Geological Strength Index (GSI) methodical approach for determining the strength characteristics of flysch masses of the Northwest Caucasus during the construction of technological tunnel. The results of the work are given according to the ranked system and the selected indexes are validated. The article also describes the possible types of deformations of the structure.**

Keywords—rock mass rating; geotechnical characteristics; flysch; geological strength index

I. Introduction

As it is known, the southern slope of the Northwest Caucasus is characterized by complex engineering and geological conditions, which are defined by dissected mountainous terrain, sedimentary masses with a persistent specific rhythmic structure, and high seismicity. To date, extensive material has been accumulated on the study of the structure of flysch sequences of the Black Sea coast. The results obtained earlier by the authors [1, 2] showed that the specific structure of flysch sequences, i.e. presence of rocks both with high and low indicators of physical and mechanical properties, is a significant factor in the formation of engineering and geological conditions of the territory. However, no large-scale or comprehensive engineering and geological studies of flysch strata have been done.

When dealing with heterogeneous and weathered rock masses such as flysch, it is very difficult to obtain an undisturbed sample from a well to carry out uniaxial compressive strength tests in the laboratory. Almost every sample obtained from rock masses under these conditions will contain fractures along the bedding surface, schistosity or cracks. Consequently, any laboratory tests performed on core samples will show understated strength values. Intensification of the pace of construction has revealed an urgent need to study hard rocks, since it is necessary to know the parameters which characterize natural flysch masses in general for making optimal design decisions and safe operation of buildings and structures.

Methods for assessing physical and mechanical properties of flysch rocks currently used in Russia often do not cover the complexity and diversity of geological factors and have several disadvantages, the most significant of which are:

1) selection and subsequent processing of data on the type of rock prevailing in the mass;

2) use of classifications which are based on the separation of rocks in the mass according to their material composition and difficulty of mining.

Thus, flysch is not considered as a specific rock mass for which special techniques of engineering and geological data processing and classification should be developed.

In Western countries, starting from the middle of the twentieth century, the most effective method for studying rock masses was rating rock classification by the stability criterion based on empirical data (Table I) taking into account both the structure of the rock mass and its physical and mechanical properties [3 6]

The most famous classifications in Russia are listed in Table II. The classification developed by N. S. Bulychev is the most consistent with the rating or categorical classifications of rocks.

Indicator of rock mass fracturing in N. S. Bulychev's classification is similar to Rock Quality Designation RQD in Deere's classification. There is a close correlation between these indicators. It should also be noted that RQD was introduced in GOST 25100-2011 as part of approximation of domestic and foreign regulatory documents [7].

TABLE I. OVERVIEW OF FOREIGN CLASSIFICATIONS OF ROCK MASSES

Year	Author (criterion)	Brief description
1879	Ritter	The author proposed to use a common approach to rock masses for choosing tunnel support based on experimental data
1946	Terzaghi	Classification of rock masses (a brief description and possible rock pressure consequences)
1950	Steeny	Geological classification
1958	Loffer	The author suggested taking into account the time of stability
1964	Deere (RQD)	Classification by fracturing according to core drilling data. The author introduced Rock Quality Designation (RQD), %, – the ratio of the total length of the sound core pieces longer than 10 cm to the length of the drilled interval in the well.
1972	Wickham (RSR)	For the first time a rating indicator taking into account several factors affecting the stability of the rock masses was introduced.
1973	Beniawski (RMR)	The classification is used for choosing tunnel support and determining stable distances when making decisions for open and underground works. The classification uses 6 parameters: uniaxial compressive strength; RQD; crack spacing; fracture conditions;
1974	Barton (Q/NGI)	The classification is used for choosing tunnel support and determining stable distances when making decisions for open and underground works.

TABLE II. OVERVIEW OF CLASSIFICATIONS OF ROCK MASSES DEVELOPED IN OUR COUNTRY

Classification (author)	Brief description
M. M. Protodiakonov	The concept of "rock hardness" was introduced. It was proposed to test a rock sample for its compressive strength (kg/cm^2) in the rock hardness coefficient scale. The value of the coefficient was determined as one hundredth of the compressive strength.
V. V. Rzhevsky	The classification is based on the relative difficulty of drilling index based on the labor indicator and physical characteristics of rocks – compressive σ_{com} and shear σ_{sh} strength and density (ρ).
N. S. Bulychev	Classification of rocks by their stability. The category of rock is determined by an indicator calculated on the basis of a number of dimensionless coefficients reflecting in points the influence of various factors.

It can be concluded that all existing classifications of rock masses have evolved from classifications based on scoring approaches as classifications developed from the standpoint of a hierarchical block model of a rock mass have been created. In the case of hard rocks Hoek-Brown behavior model is the closest. The insight on its features is provided in the article. [8]. The subsequent development of this approach led to the development and application of special classifications, one of which was the classification developed by E. Hoek and V. Marinos for flysch deposits [9].

For the first time the Geological Strength Index methodical approach was tested by the authors of this article on flysch masses at the construction sites of tunnels No. 3, 3a, 4, 4a, 6, 6a, 7, 7a, 8, 8a in the city of Sochi, which are part of the relief road of Kurortny prospekt. Comparison of information obtained during engineering surveys along the tunnel route with the data obtained from the classification developed by V. Marinos and E. Hoek showed good convergence, including the cases of recorded emergencies arising during construction.

Thus, the adaptation of the methods for integrated assessment of geotechnical properties of flysch rock masses of the southern slope of the Northwest Caucasus using the Geological Strength Index is timely and has scientific novelty.

II. METHODS AND MATERIALS

According to the applied classification, flysch masses are divided into 11 types (I-XI) by the ratio of pelitic rocks to sandstone, tectonic dislocation and degree of weathering. For each case the range of values of the strength index, which varies from 0 to 100, is determined. According to the structural and textural features and the mode of occurrence, a block is selected in the summary table (Fig. 1). For this purpose, the degree of tectonic disturbance of the rock mass (undisturbed, moderately disturbed, strongly disturbed) and the ratio of pelitic rocks to sandstone are taken into account.

I type flysch, represented by layers of sandstone of high or medium thickness with separate thin layers of pelitic rocks, has the greatest strength. Further, as the share of sandstone decreases, the type of flysch increases, and, accordingly, the value of the strength index becomes lower [10].

The subsequent data processing was carried out in the RocData 5.0 program and developed by E. Hoek and V. Marinos. The calculation in the program is made separately for the rocks which form the flysch mass.

In the RocData 5.0 program the following parameters were selected in the drop-down windows:

- σc (uniaxial compressive strength of an undisturbed sample from the rock mass);

- geological strength index (GSI);

- constant mi;

- the degree of disturbance of the rock mass D;

- deformation modulus E was calculated (the calculation was made according to the formula $E = MR\sigma c$, where the value of the modulus of elasticity MR was selected from the drop-down list according to the type of rock);

- scope of calculations (tunnels, slopes, general case), depth was specified (for tunnels);

- specific gravity of the rocks, maximum principal stress $\sigma_3 max$ was calculated.

Simultaneously with the calculations the program automatically generated dependency graphs: principal effective stresses and normal stress-shear stress (Fig. 2).

Table with generalized strength characteristics was formed for each type of rock of the flysch. The final calculation of geotechnical characteristics for the entire flysch mass was made taking into account the proportions of the rocks which form the flysch mass (Table III).

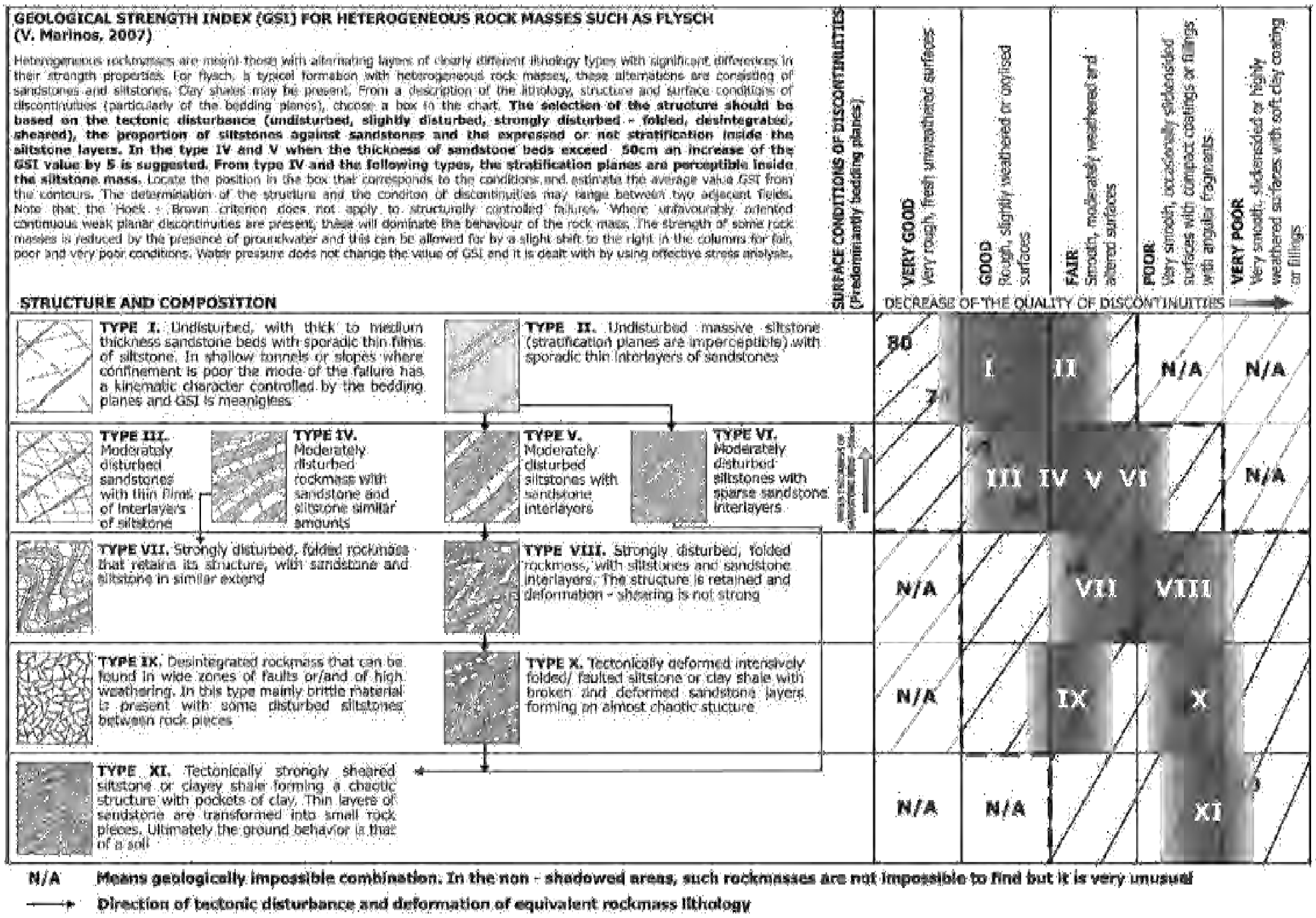


Fig.1. Summary table of the values of Geological Strength Index [20]

TABLE III. THE PROCEDURE FOR CALCULATING THE GEOTECHNICAL CHARACTERISTICS FOR THE ROCK MASS ACCORDING TO THE TYPE OF FLYSCH

Type of flysch	**Proportions for calculating the strength characteristics of the flysch mass**
I, III	Use the values for sandstone
II	Use the values for pelitic rocks
IV	Reduce the values for sandstone by 10% and use the complete values for pelitic rocks
V	Reduce the values for sandstone by 20% and use the complete values for pelitic rocks
VI	Use the values for pelitic rocks
VII	Reduce the values for sandstone by 20% and use the complete values for pelitic rocks
VIII	Reduce the values for sandstone by 20% and use the complete values for pelitic rocks
IX	Use the values for pelitic rocks and sandstone according to their proportion
X	Reduce the values for sandstone by 40% and use the complete values for pelitic rocks
XI	Use the values for pelitic rocks

III. RESULTS

The rock masses that make up the Upper Cretaceous carbonate flysch formation on the Black Sea coast from Novorossiysk to Gelendzhik were chosen as the object of study. This is mainly the interbedding of calcareous and clay marls, limestones, less often sandstones and siltstones. The suites are characterized by rhythmical structure of thin layers, with the exception of Kunikov suite, which is an example of flysch with a rhythmical structure of medium layers.

The type of flysch and its corresponding strength index were determined on the basis of the ratio of pelitic rocks to sandstone which form flysch cyclites of the suites and taking into account the factors of engineering and geological conditions (Table IV).

Further data processing is given in view of the axis of the technological tunnel (Fig. 3).

The calculation data for all suites were summarized in Table V. It was found that the geotechnical characteristics change for the worse depending on the ratio of pelitic rocks to sandstone, depth of the tunnel route, degree of tectonic dislocation of rocks, weathering and watering depths.

So the highest geotechnical characteristics can be traced in the Ananur suite (well 4, tunnel depth 328.5 m). Stability and strength of the rock mass are controlled by the high content of sandstone, which provides a reinforcing effect for the entire mass, silicification, lack of water in the rocks, and location of the mass, most of which is outside the zone of tectonic disturbances.

TABLE IV. CLASSIFICATION OF THE ROCK MASSES BASED ON GSI

Stage	Series	Suite	Type of flysch		GSI
Campanian	Upper	Kunikov (K_2*кn*)	II	MARL	65
	Lower	Penay (K_2*pn*)	VIII		30
		Aheya (K_2*ah*)	V		45
Cenomanian		Ananur (K_2*an*)	IV		55

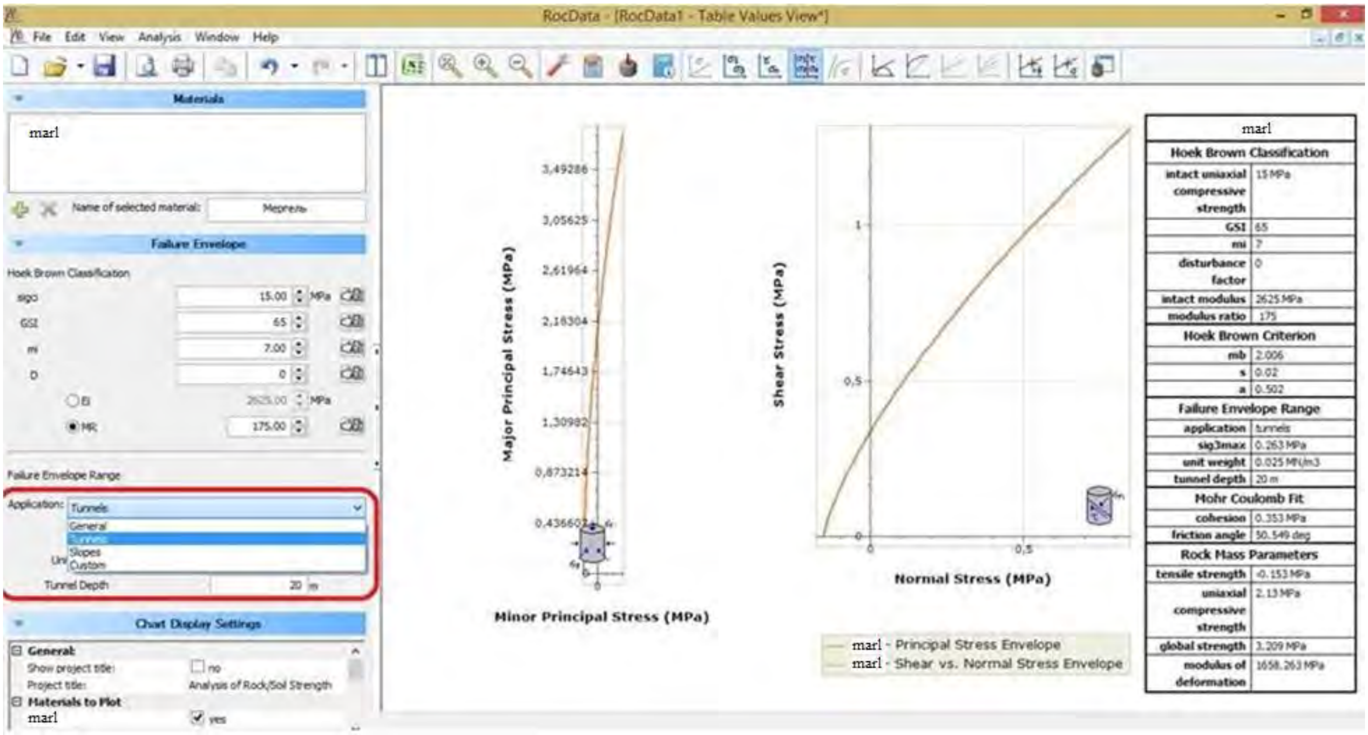


Fig. 2. Plotting dependency graphs: principal effective stresses and normal stress-shear stress

The Aheya suite (well 3, tunnel depth 116 m) is characterized by lower geotechnical characteristics due to its location in the fractured zone of the rocks and the water content.

Kunikov suite is characterized by the highest type of flysch and GSI; depth of the tunnel is 20 m near the South portal and the rock mass is located outside the zone of tectonic disturbances. However, the ratio of pelitic rocks (95%) to sandstone (5%) contributes to a significant reduction of overall geotechnical characteristics.

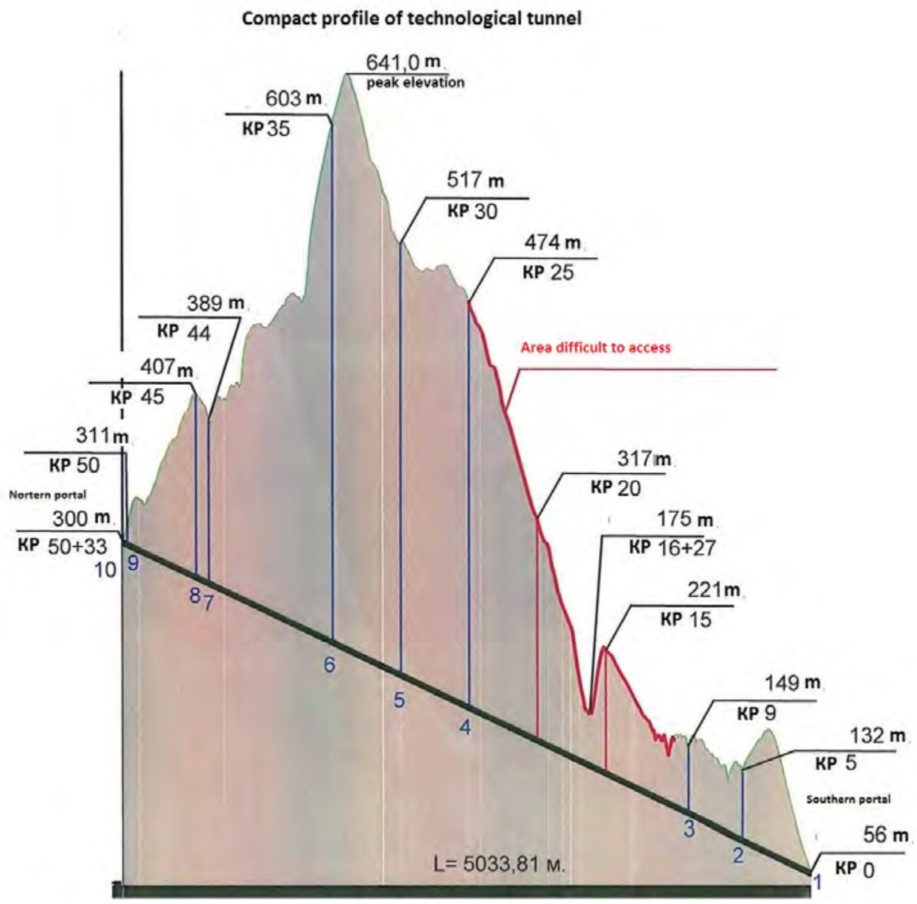
Panay suite (well 2, tunnel depth 96 m) is the strongest and most stable among all the suites according to the ratio of sandstone to pelitic rocks. But its location in the fractured zone, a deep weathering zone (50-100 m), increased water content in the mass and strong dislocation of rocks – all contribute to low values of geotechnical characteristics. All of the above factors put Penay suite in the fourth place as having the worst geotechnical characteristics.

Further, according to [11], the condition of the rock mass and the possible types of its deformations were determined, and general recommendations were given on the average cut spacing and the optimal support or each type of flysch that forms the tunnel section.

The results were also summarized in Table VI.

IV. CONCLUSION

Analysis of domestic and foreign experiences in the development and application of different classifications for evaluating the strength characteristics of natural rock masses shows that the practice of drawing up the classifications to determine characteristics of rock masses is not developed in our country. The reasons for this probably lie in the lack of confidence in linking the qualitative and quantitative indicators of the state of the masses – it is believed that this approach is characterized by a subjective attitude. Another reason is isolation of our country in the period of formation and development of standards for determining geotechnical characteristics: GOSTs, SNiPs, GESNs and other regulatory documents were created in our country, while in Western countries the development of rating classification systems was actively pursued.



№ bore-hole	KP	Amount of bore-holes	Depth of bore-holes
1	0	2	20
2	5	1	86+10 =96
3	9	1	106+10=116
4	25	1	318,5+10=328,5
5	30	1	386+10=396
6	35	1	428+10=438
7	44	1	120+10=130
8	45	1	151+10=161
9	50	1	29,9+10=39,9
10	50 +33	2	15,5 25
Total amount		12	1 785,9

Fig. 3. Compact profile of the technological tunnel

The advantages of the rating classification based on Geological Strength Indicator developed by E. Hoek and V. Marinos and the RocLab 5.0 program include:

- highly specialized nature of the classification developed for flysch which takes into account the maximum number of variations in the ratio of the pelitic rocks to sandstone in the flysch masses, tectonic dislocation and the degree of weathering of rocks;

- availability of the base which is theoretically substantiated and expressed in the form of calculations (the Hoek-Brown criterion). On the basis of it, the subsequent development of the E. Hoek and V. Marinos's classification, i.e. the system for evaluating flysch rock masses using qualitative and quantitative indicators, became possible;

- the classification makes it possible to assess the strength characteristics of the entire rock mass, and not by the prevailing rock; it is used in the case when it is impossible to carry out full-fledged field or laboratory tests.

The use of the classification developed by E. Hoek and V. Marinos allowed us to differentiate the route of the technological tunnel in terms of tunneling difficulty and expected deformations, determine the most appropriate cut spacing for a given type of flysch and formulate recommendations on the construction features of temporary support. It has been found that during the usage of the technological tunnel under consideration the following phenomena may occur:

- formation of dangerous zones characterized by stress-strain state of the rocks of the roof;

- a sharp increase in groundwater inflow into the tunnel;

- deformations of the support.

In this connection, the organization of geotechnical monitoring is recommended.

Application of the E. Hoek and V. Marinos's classification and subsequent processing of data in the RocLab 5.0 program should not completely replace the "work of a geological engineer", i.e. the complex of works on engineering and geological surveys for each specific object should be of top priority. But, like any innovation, the rating classification based on Geological Strength Index developed by E. Hoek and V. Marinos will most likely be met with caution by organizations conducting engineering surveys on the Black Sea coast of the Northwest Caucasus, first of all, because this method is not formalized in the regulatory documentation.

TABLE V. CLASSIFICATION OF THE ROCK MASSES IN VIEW OF GSI

Suite	Interval of suites'contacts with tunnel axis	Rock proportions in suite, %	Static level of underground water, m	Physical conditions of rocks	Complications	GSI	Hoek-Brown classification		Intact uniaxal compressive strenght		Mohr-Coulomb fit		Rock mass parameters	
Kunikov (K_2kn)	KP0-KP0+26	Limestone, marl - 35 Argillacios marl - 55 Aleurolite - 5 Sandstone - 5	Bore-hole 1/1 -6.6 Bore-hole 1/2 - 12.5	fissured	no	II	σci, MPa	15	Application	Tunnel	C, MPa	0,35	σt, MPa	-0,153
							GSI	65	$\sigma_3$max	0,263			σc, MPa	2,130
							mi	7	ϒ	0,025	ϕ,°	50,5	σcm, MPa	3,209
							Ei, MPa	2625	H,м	20			Erm, MPa	1658,3
							MR	175						
Penay (K_2pn)	KP3+12 – KP5+31	Limestone, marl - 25 Argillacios marl - 30 Aleurolite - 15 Sandstone - 30	69	fissured to crushed	fissured area	VIII	σci, MPa	43	Application	Tunnel	C, MPa	0,37	σt, MPa	-0,009
							GSI	30	$\sigma_3$max,MPa	1,98			σc, MPa	0,328
							mi	7-17	ϒ	0,024-0,026	ϕ,°	54,74	σcm, MPa	3,487
							Ei, MPa	10325	H,м	96			Erm, MPa	454,4
							MR	395						
Aheya (K_2ah)	KP5+31 – KP 11+39	Limestone, marl - 70 Argillacios marl - 15 Sandstone - 15	84,5	fissured		V	σci, MPa	43	Application	Tunnel	C, MPa	0,78	σt, MPa	-0,060
							GSI	45	$\sigma_3$max,MPa	2,48			σc, MPa	1,928
							mi	7-17	ϒ	0,025	ϕ,°	73,17	σcm, MPa	7,648
							Ei, MPa	10325	H,м	116			Erm, MPa	2309,2
							MR	395						
Anaur (K_2an)	KP 24+15 – KP 26+26	Argillacios marl - 20 Aleurolite -30 Sandstone - 25 Mudstone -25	no	no		IV	σci, MPa	61,5	Application	Tunnel	C, MPa	1,69	σt, MPa	-0,130
							GSI	55	$\sigma_3$max,MPa	6,82			σc, MPa	2,988
							mi	7-17	ϒ	0,022-0,026	ϕ,°	66,07	σcm, MPa	9,653
							Ei, MPa	19912,5	H,м	328,5			Erm, MPa	4027,13
							MR	622,5						

TABLE VI. GENERAL CHARACTERISTICS OF THE ROCK MASS AND RECOMMENDATIONS ON TUNNEL SUPPORT

Suite	Type of flysch according to Marinos and Hoek (GSI)	Condition and possible types of deformations of the mass		Recommendations
Kunikov (K_2kn)	II	- strength of the undisturbed sample – from low to medium; moderately fractured structure	- the state of the rock mass is controlled by the low strength of pelitic rocks and the depth of excavation; - limited deformation can occur at great depth; at shallow depth the tunnel is stable, and depending on the orientation of the axis of the tunnel and fractures faults and pinching-out can occur.	- cut spacing of 2-3 m; - installation of anchors to support unstable areas and control deformation; - light steel frames for weathered masses.
Penay (K_2pn)	VIII	- the mass is strongly deformed; - strength of the undisturbed sample – from low to medium; - orientation of the fractures contributes to the formation of faults and landslides; - low permeability.	- isotropic behavior of the mass; - due to the low strength of the pelitic rock deformations begin to occur at an average thickness of overlying layer; - local block weakening and sliding; - extensive deformations (collapses) are expected only in weathered layers at a very shallow depth.	- cut spacing of 1.5-2 m; - dense network of anchors to control the deformation; - steel structure to enhance the rigidity and strength of the supporting frame; - measures to strengthen the lining; - permanent or temporary inverted arch.
Aheya (K_2ah)	V	- medium fractured structure, schistose near the surface; - strength of the undisturbed sample – from low to medium; - bedding configuration and shear strength of pelitic rocks contribute to the formation of inrush and pinching-out; - blocks of rocks of small or medium size.	- the state of the mass is close to isotropic; - deformations can occur within a limited area under overlying rocks of average thickness; - at shallow depth the tunnel is stable, but depending on the orientation of the fractures faults and inrush can occur; - closer to the surface and weathering zone landslides may occur due to excessive excavation.	- cut spacing of 1.5-2 m; - systematic installation of anchors to support unstable areas and control deformation; - light steel structures to enhance the rigidity and strength of the supporting frame; - pile lining in case of a weathered structure to avoid collapses; - measures to strengthen the lining.

Ananur (K_2an)	IV	- medium fractured structure; - strength of the undisturbed sample – medium; - presence of pelitic rock with schistose surface contributes to unstable condition; - blocks of rocks of medium size (1–2 m x 3 m)	- anisotropic condition of the rock mass; - occurrence of shifts and pinching out; - condition is controlled by the orientation of faults relative to the axis of the tunnel; - in case of horizontal bedding and low thickness of the layer problems may arise with exceeding the excavation spacing.	- cut spacing of 1.5-2 m; - systematic installation of anchors to support unstable areas and control deformation; - pile lining in case of a weathered structure to avoid collapses.

References

[1] T.V. Lyubimova and A.V. Ovchinnikov, "Changes in the physical and mechanical properties of carbonate flysch marls due to weathering," Geology, Geography and Global Energy, vol. 60. p. 12, 2011.

[2] T.V. Lyubimova and N.A. Bondarenko, "Petrophysical properties of rocks of the Upper Cretaceous flysch formation on the Black Sea coast of the Northwest Caucasus," South Russian Journal of Geology, Geography and Global Energy, vol. 3 (16), pp. 156-162, 2006.

[3] Z.T.Beniawski, "Engineering rock mass classification," Wiley: New York, 1989, pp. 224-251.

[4] J. Jacubec and D.H. Laubscher, "The MRMR rock mass rating classification system in mining practice," Brisbane, 2000, pp. 413-421.

[5] D.H. Laubscher, "A geomechanics classification system for the rating of rock mass in mine design," J Sth Afr Inst Min Met, vol. 90(10), pp. 257-273, 1990.

[6] D.H. Laubscher and J. Jacubec, "The MRMR Rock Mass Classification for jointed rock masses," Foundations for Design, Brisbane, vol. 3, pp. 475-481, 2000.

[7] GOST 25100-2011. Soils. Classification.

[8] I.E. Sas and A.V. Bershov, "On the features of the Hoek-Brown rock behavior model and the assignment of its initial parameters," Engineering surveys, vol. 13, pp. 42-47, 2015.

[9] E. Hoek, "Estimating the Geotechnical Properties of Heterogeneous Rock Masses such as Flysch," Bull. Eng. Geol. Env., vol. 60, pp. 85-92, 2001.

[10] V. Marinos, "Geotechnical classification and behavior of weak and complex rocks for tunneling," School of Civil Engineering, Geotechnical Engineering Faculty, National Technical University of Athens (NTUA), Athens, 2007, pp. 112-136.

[11] V. Marinos, "Tunnel behaviour and support associated with the weak rock masses of flysch," Science Direct, Journal of Rock Mechanics and Geotechnical Engineering, vol. 6, pp. 227-239, 2014.