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NEW PROPOSED GSI CLASSIFICATION CHARTS FOR WEAK OR COMPLEX ROCK MASSES

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Abstract

The paper deals with the geotechnical classification of weak and complex rock masses. The complexity of these geological material demands a more specialized research and geological characterization due to the special features of their rock mass types regarding both their structure and their lithological characteristics. The weak and complex rock masses under consideration, often heterogeneous and containing rocks of extremely low strength, have in most cases undergone highly tectonised disturbance resulting in the destruction of their initial structure, while weathering can be another particular feature. The geotechnical types and their characterization of rock masses that can be developed in flysch, molasse, brecciated limestone, ophiolites and disturbed or weathered gneiss are studied here. In order to describe these masses in a quantitative way and provide numerical values to engineering design, new or revised rock mass classification diagrams are introduced within the general concept of the GSI system, or specific projections inside the existing GSI diagram are proposed The fundamental source for this research was data from the design and construction of 62 tunnels of Egnatia Highway appropriately assessed, processed, correlated and associated with field work.

Key words: *rock mass classification,GSI,weak rock mass, flysch-molasse,ophiolites, gneiss*

1. Introduction

The last decades there has been a rapid development on almost all the stages of a geotechnical design in engineering construction. Analysis and computational methods are the fields where great advance has been made. However, regardless the great capabilities offered by the present computational tools, the results are still encountering uncertainties due to the difficulties in defining design parameters. Hence, the basic attention should be focused on the definition of the geotechnical parameters and on the engineering geological behaviour of the rock mass.

Estimation of rock mass properties can be achieved by one of the following methods: a) laboratory testing, b) in situ testing, c) use of rock mass classifications (GSI, RMR, Q, etc.) and d) back analysis. However, in laboratory, samples are not representative of the rock mass due to the disturbance, jointing and the heterogeneity of most formations. Additionally, it is often not realistic or always feasible to carry out in situ tests. Back analysis, is the best way to estimate the geotechnical parameters, but only when construction has started, by evaluation of the deformation measurements and it can be used to validate or modify the parameters used. To estimate reasonable geotechnical parameters for the design before engineering construction, where back analysis is not possible, there is no option but to rely upon the use of a rock mass classification scheme - system of rock mass quantification that is correlated with the basic parameters needed for the design. These systems must cover a wide range of geological conditions, including the weak and complex ones which have more particularities. Though, in order to avoid the by-pass of basic geological and mechanical principles, these “numbers” must be also supported by the engineering geological behaviour, namely the type and mechanism of failure that “fits” best to the rock mass according to the engineering project.

The base of this research was a database named “Tunnel Information and Analysis System” (TIAS) established in the frame of the PhD research of the author (Marinos, 2007). Through this data base, a great number of geological, engineering geological and geotechnical data from the design and the construction of 62 tunnels of Egnatia Highway in Northern Greece were processed. These data, in conjunction with relevant field work, was evaluated by numerous correlations and observations and a result of this research was the extension or re-evaluation of the geotechnical classifications in the field of weak and complex rock masses. The rock masses presented in this paper are those of flysch, molasse, particular cases of limestones, ophiolites and disturbed – weathered gneiss.

2. Geotechnical classifications

The demand for rock mass classification becomes perceptible when laboratory testing was not adequate to cover the geotechnical perspectives of a rock mass. After Terzaghi’s 1946 classification for loads on tunnels, in the middle of 70’s the RMR (Bieniawski, 1973) and Q (Barton et al., 1974) classification systems were introduced. These systems were developed in order to provide tunnel support requirements for simple failure mechanisms controlled by sliding and rotation of intact rock blocks, through a rating of rock masses. Though, with the rapid growth of calculation and design tools, where progressive failures and temporary support measures can be analysed, the need for solid rock mass parameters became more than ever required. The failure criterion created by Hoek and Brown in 1980 to estimate the rock mass strength parameters is thus strongly connected to the Geological Strength Index (GSI), covering a wide range of geological conditions, including some weak rock masses like foliated and sheared (Hoek et al., 1998). The system was also extended to heterogeneous rock masses, such as flysch by Marinos and Hoek (2001).

3. Geotechnical classification of weak and complex rock masses

The weak rock masses that are examined in this study are generated by tectonical compression or weathering. Cases, where the decreasing of the quality is expressed on the rock mass scale and not necessarily on the primary low intact rock strength is thus presented. The initial intact rock strength before any disturbance can be either low or high. A complex rock mass is referred here as the one that displays evident lithological, structural and geotechnical heterogeneities and non -uniformities in macroscopic scale (scale of meters). The great number of geotechnical investigations and the experiences gained from tunnelling in Greece offered plenty of data concerning the engineering geological conditions of several formations and thus enabled their distinction in rock mass types and their quantification. As a result, new or revised GSI charts for weak and complex rock masses are presented in this paper based on PhD results (PhD, Marinos, 2007). In particular, these diagrams are for heterogeneous rock masses such as flysch, molassic formations, disturbed and weathered gneiss and projections for ophiolites and limestones.

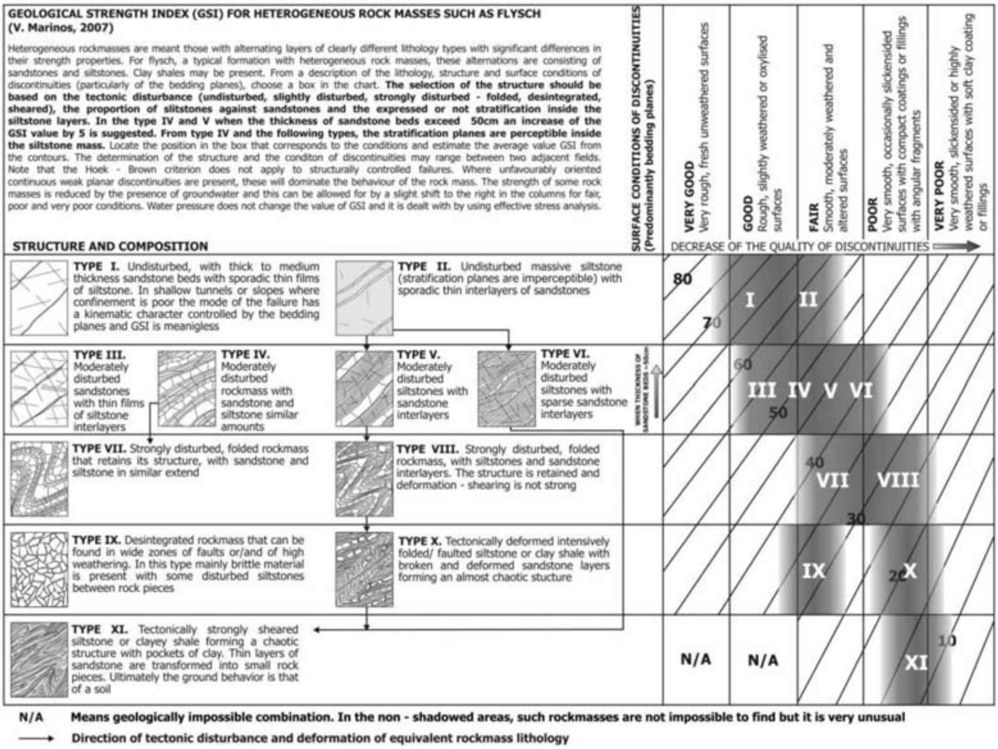

Fig. 1: A new GSI classification chart for heterogeneous rock masses such as flysch.

3.1. Geotechnical classification of heterogeneous rock masses such as flysch

Flysch formations are generally characterized by diverse heterogeneity, presence of members with low strength geomaterial and tectonically disturbed structures. In order to investigate the rock mass properties of flysch, 12 tunnels driven in various geological environments were examined. Flysch formations are classified here to 11 rock mass types (I to XI) according to the siltstone-sandstone participation and their tectonic disturbance.

A new GSI diagram for heterogeneous rock masses such as flysch is presented, where a certain range of GSI values for every rock mass type is proposed (figure 1). The 2001 chart (Marinos and Hoek, 2001) is been revised here with modifications in values and with additions of new types often met in nature. In the new diagram, GSI values are increased from 10 to 35 units for the "Blocky" to "Undisturbed" structures, respectively, particularly for the siltstone type. The high presence of siltstone beds does not decrease the GSI value, but only in the highly disturbed forms. When rock mass is undisturbed or slightly disturbed, independently of siltstone or sandstone predominance, GSI ratings have to be considered much higher. This was confirmed in tunnel construction, where lighter temporary support categories (correlated with high GSI values) were implemented and experienced marginal measured deformations. Hence, the selection of the structure should be initially based on the tectonic disturbance (from undisturbed to sheared rock masses), then on the proportion of siltstones against sandstones and finally on the expressed or not bedding stratification inside the siltstone layers. One more addition in the GSI chart is the

Table 1. Suggested proportions of values for each flysch rock type to be considered for the "intact rock" property determination (σ_{ci} and m_i) (based on Marinos and Hoek, 2001)

Flysch type	Proportions of values for each member of rock type to be considered for the weighted "intact rock" property determination
I, III	Use values for sandstone beds
II	Use values for siltstone or shale
IV	Thin beds: Reduce sandstone values by 10% and use full values for siltstone Thick beds: Use equivalent values for siltstone and sandstone beds
V	Reduce sandstone values by 20% and use full values for siltstone
VI	Use values for siltstone or shale
VII	Reduce sandstone values by 20% and use full values for siltstone
VIII	Reduce sandstone values by 20% and use full values for siltstone
IX	Use equivalent values for siltstone and sandstone beds according to their participation
X	Reduce sandstone values by 40% and use full values for siltstone
XI	Use values for siltstone or shale

bedding thickness consideration of the competent sandstone beds. In the type IV and V (slightly disturbed structures) when the thickness of sandstone beds exceeds 50cm, an increase of the GSI value by 5 is suggested. It is noticed that for the non disturbed types anisotropy is present due to the bedding planes and in analysis this fact should be taken into consideration.

In addition to the GSI values, it is necessary to consider the selection of the "intact" rock properties σ_{ci}, m_i and E_i for the heterogeneous rock masses considered as a unit. A 'weighted average' of the intact strength properties of the strong and weak layers is proposed in Table 1.

3.2. Geotechnical classification of molassic rock masses

Molasse is quite different from flysch, although both are consisting of same lithological types, since molasse is formed after the orogenesis, and did not suffer from compressional tectonics. The proposed GSI chart for molasses can be of general application to all formations consisting from alternations of sedimentary rocks not associated with significant tectonic disturbance, though this chart was based on the observations from the excavation of 12 tunnels along the Egnatia highway in molassic formation. The GSI chart for molasses has already been published (Hoek et. al. 2004) but is included in this paper in order to be compared and distinguished from the flysch chart.

As the molasse strata were formed after the main orogenesis, the deterioration of the quality of their rock mass is limited. Only in few cases the molassic formations may be deformed and present thrusts due to the final advance of tectonic napes but such a decrease of their quality is localized.

The siltstone (or marly) members are very vulnerable to weathering and a development of fissility parallel to the bedding when these rocks are exposed or are close to the surface may be developed. Thus in outcrops they appear thinly layered and when they alternate with sand-

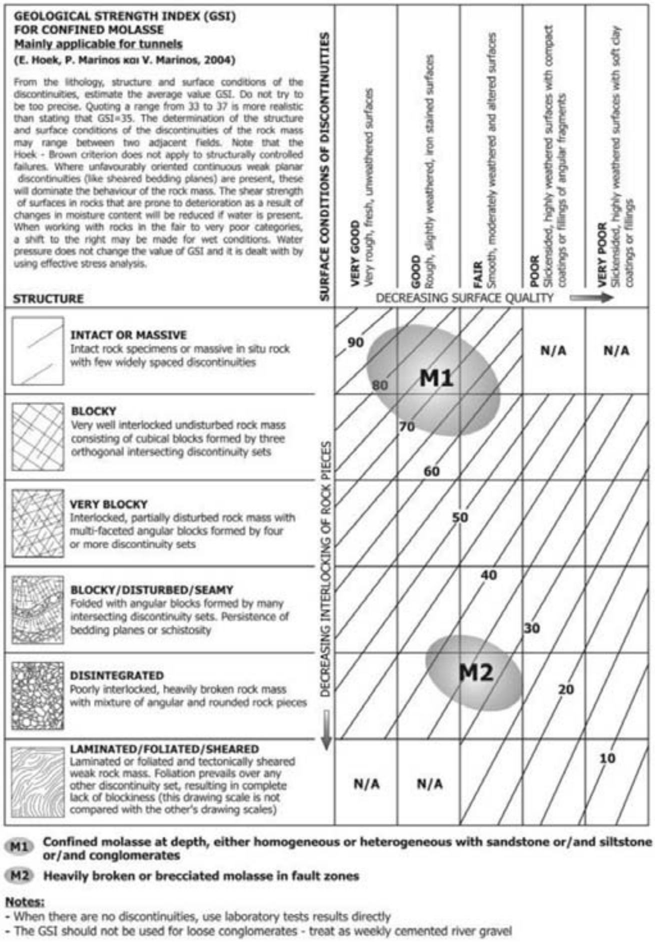

Fig. 2: GSI classification chart for molassic rock masses in depth (applicable for tunnels)

stones, their appearance resemblances to flysch. This appearance in outcrops can be misleading when considering the behaviour of these molassic rocks in a confined underground environment in which the process of air slaking is restricted and the rock mass is continuous and massive without any sign of stratification or schistosity inside the siltstone beds.

As a result, molassic rock masses have dramatically different structure when they outcrop or are close to the surface as compared to those confined in depth, where bedding planes, especially the siltstone ones, do not appear as clearly defined discontinuity surfaces. In such cases the use of the fundamental GSI chart reproduced in Fig. 2, is recommended and the zone designated M1 of a value of 50–60 or more is to be applied. If no discontinuities are present, GSI values are very high and the rock mass can be treated as intact with engineering parameters given by direct laboratory testing. When fault zones are encountered in depth, the rock mass may be highly broken but it will not have been subjected to air slaking. Hence the fundamental rock GSI chart given in Fig. 2 can be used but the GSI value will lie in the range of 25–40 as shown by the selected area M2.

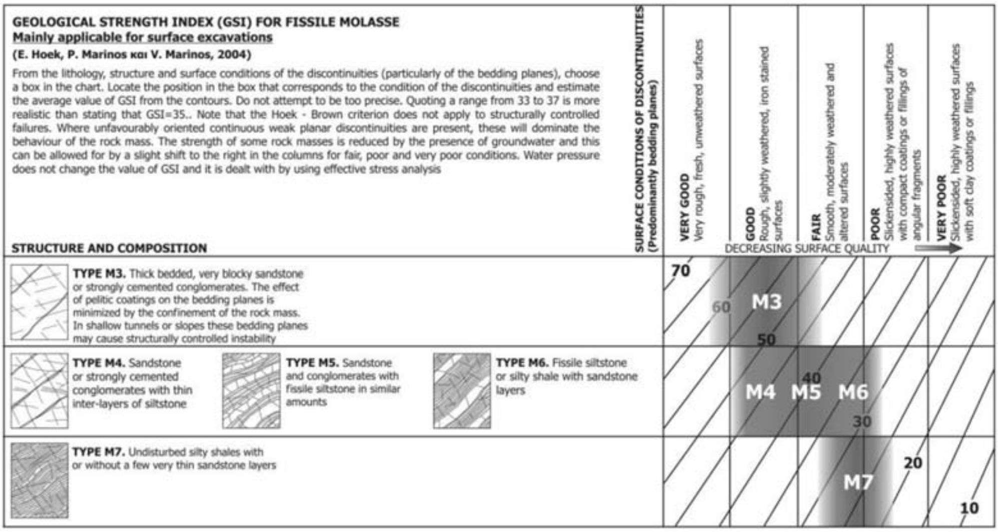

Fig. 3: GSI classification chart for molassic rock masses in surface (applicable for surface excavations)

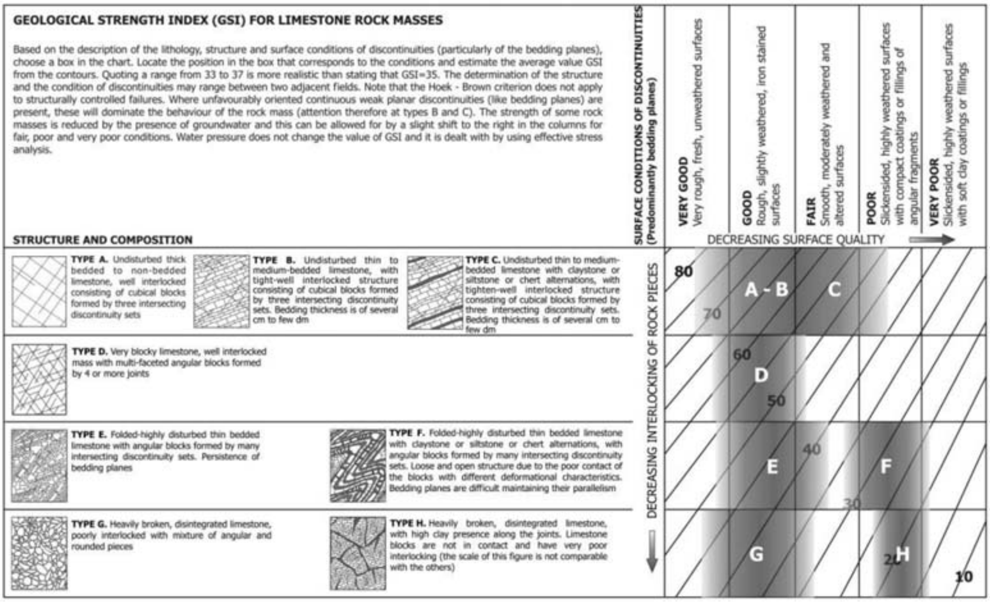

Fig. 4: GSI classification chart for limestone rock masses, including tectonically disturbed rock masses, with or without claystone, siltstone or chert intercalations.

In surface, the heterogeneity of the formation is discernible and similarities exist with the structure of some types of flysch. Hence the GSI chart for heterogeneous rock masses such as flysch can be used with the exclusion of sheared and disturbed types and with a slight shifting to the left of the flysch chart categories, as the molasse is always less disturbed. This version of the chart, for fissile molassic rocks (M3–M7 designations), is presented in Fig. 3.

3.3. Geotechnical classification of brecciated limestone formations

Limestones, in general, are neither weak nor complex formations. Though, if they are depressed in great areas by thrusting and tectonic rugs, poor rock masses can be produced. The rock mass is disintegrated with no remains of the initial structure due to the brittle behaviour of the limestone blocks. Two tunnels in heavily fractured limestones and three others in normal geotechnical conditions were examined in this study.

The rock mass quality may thus be poor to very poor because of the disintegrated structure which is characterized as heavily broken with a mixture of angular and rounded pieces (type G in fig.4). The RQD of such rock mass is zero (RQD=0) although a good frictional strength may be present. Cohesion is absent except if cemented material is present. In these cases the GSI value ranges from 30-45. In case of heavily broken limestone, with high clay presence along the joints (type H), where the pieces are not in contact and have very poor interlocking, the friction properties of the rock mass is significantly reduced. The rock mass is characterized as disintegrated with very poor surface condition with GSI values between 15 and 25.

Thin to medium bedded limestones, when are tectonically undisturbed (unfolded-slightly fractured) they present highly tight structure (type B) with "sewed" bedding planes. In such cases, rock mass is characterized as "Blocky" with "Good" to "Fair" surface conditions and is thus rated form 55 to 70. These values were confirmed after tunnel excavation where very light support measures were applied (GSI design value >55). In design analysis in low stress environment structural instability will be the failure process and the GSI is not applicable. In high stress GSI can be approximately used taking into account however the anisotropy provoked by the bedding planes.

In case of claystone or siltstone intercalations in a folded-highly disturbed rock mass, the structure is less tight due to the poor contact of the blocks with different deformational characteristics (the plastic members are sheared and the limestone beds are broken and cannot follow the same deformation pattern) and the parallelism between the bedding planes is limited.

3.4 Geotechnical classification of ophiolitic rock masses

Ophiolites often associated with subsequent overthrusts, contain a variety of rock types with geotechnical qualities varying from excellent to fair, becoming poor to very poor when serpentinisation is extensive and/or shearing present. The main included types are peridotites, gabbros, peridotites more or less serpentinised, serpentinites, schisto-serpentinites, sheared serpentinites, pillow lavas and chaotic masses in ophiolitic melanges. A high degree of serpentinisation together with the intensity of shearing may result to a mass where is difficult to identify any initial texture or fabric. This study is based on field data from outcrops, cuts in slopes, borehole cores and tunnel excavations (7 from Egnatia Highway) and from various significant ophiolitic complexes and melanges in northern and central Greece. A GSI chart is already published (Marinos et al 2005), but it is reproduced here together with the other new charts in order to include all charts of complex rock masses in the same paper, but also since an other type of rock mass is added.

Peridotites are strong and behave as typical brittle materials. Their tectonic disturbance is expressed in terms of intersecting joint sets. The range of GSI for peridotitic types of rock masses in an ophiolitic complex is shown in Fig. 5 (areas I and II). Serpentinisation can be present on the surface of discontinuities and the conditions of the joints are dramatically reduced to poor

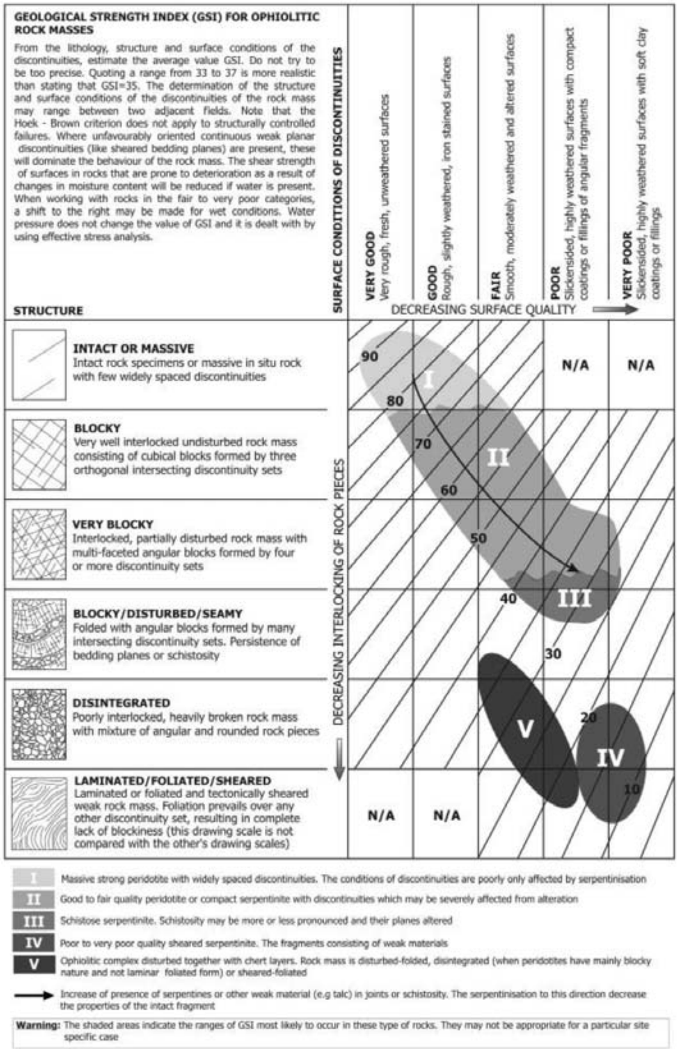

Fig. 5. GSI classification chart for ophiolitic rock masses

or very poor with coatings of “slippery” minerals such as serpentine or even talc. When the rock mass is jointed or fractured the GSI values drop as low as 35, not only due to a disturbed structure but also because of the conditions of the discontinuities, which become smooth and slippery due to serpentinisation. In a disturbed peridotitic mass, the serpentinisation process often loosens and disintegrates parts of the rock itself, not only contributing to lower GSI values but also reducing the intact strength values. Such disturbed peridotites fall in the lower bound of area II of the GSI diagram of Fig. 5.

If the process of serpentinisation is due to autometamorphism and/or associated with tectonic thrust, the rock mass is poor, with a schistose disturbed structure which may reduce the GSI to values to 30 or less (area III in the GSI diagram of Fig. 5). In the sheared zones of serpentinites there is a lack of blockiness, which allows the rock to disintegrate into slippery laminar pieces

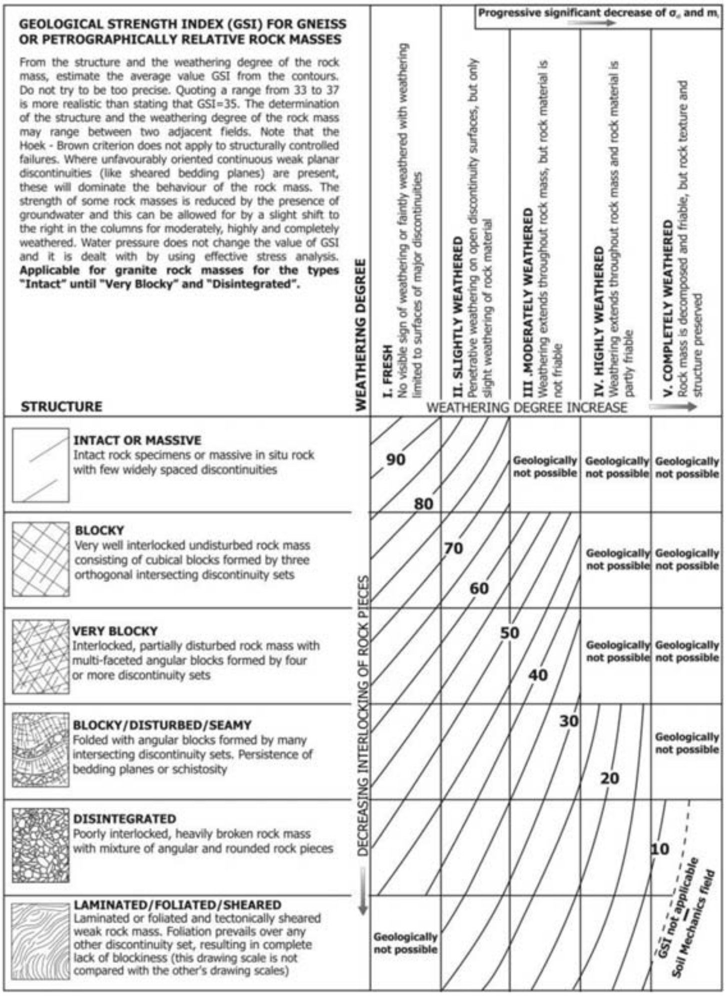

Fig. 6. GSI classification chart for gneiss or petrographically similar rock masses

and small flakes of millimeters in size. GSI values can drop to less than 20 (Fig. 5, area IV).

When the serpentinisation, due to weathering, has affected all the mass, in addition to the reduction of the intact strength there is a dramatic disintegration of the structure of the rock mass too.

In ophiolitic melanges, where rocks of the ophiolitic sequences are mixed in complete disorder with other rocks of various origins (flysch formations, chert and other), the rock mass is disturbed-folded or disintegrated (when peridotites have mainly blocky nature and not laminar – foliated form) or sheared-foliated and, thus, low to very low GSI values are assigned (area V in Fig.5).

3.5 Geotechnical classification of tectonically disturbed and weathered gneiss rock masses

Fresh gneiss forms evidently very competent rock masses with minor problems in geotechnical works. However, in certain geological conditions gneiss can produce poor to very poor rock masses. This environment is produced by intensive and sequent tectonic disturbance and thus weathering and alteration is favored in various degrees and depths.

In such conditions, the intact rock and rock mass strength present a wide range in values and the behaviour in ground works can be from simple to extremely problematic. Six tunnels along the Egnatia highway were investigated in a gneissic environment. In a disturbed tectonically environment, the complexity in gneiss rock mass, due to intense weathering (alteration of feldspars to clayey minerals) and fracturing, is characterized by erratic geometry to all directions. Here, the simple common case that the fracturing and weathering is gradually reduced with depth does not exist.

Thrust zones with brittle deformation encounter highly broken and weathering geomaterial, which can have significant thickness (up to 10m) consisting of remains of friable pieces in a texture governed mainly by clayey-sandy weathered product. On the other hand, gneiss rock masses can also be deformed in a ductile like manner when the initial structure is schistosed under high stresses (structures recognized along the base tunnels in Alps).

A decrease in the GSI value is proposed for the gneissic rock masses in order to consider more appropriately the weathering effect. By the comparison of the classifications and the temporary support categories between the design and the construction records, it was shown that this decrease lies to around 10 units. However, the use of this numerical difference must be carefully done due to construction issues, like for example the procedure to connect a classification value with the support category selection. Of course, this difference could also be due to the application of heavier support demand due to frequent over-brakes, like chimney type failures and not due to stress controlled problems. Nevertheless, the wide application of heavier support systems between similar geotechnical conditions, corresponding to a difference of 10 units, in all the tunnels and the geological concept described before, agreed to this diversity.

The new GSI chart is thus proposed for gneiss or rock masses with similarities in weathering, as the granite. This chart maintains the basic structures but the surface conditions of joints are replaced by the weathering grades (from Fresh-grade I to Completely Weathered- grade V, Brown, 1981). This is associated with a new calibration and the substitution of the straight lines of the fundamental chart with curved lines, bended to the left side of the chart.. As the weathering degree increases to the right, bending is increased as well. In the first column, where the rock mass is not weathered (category I), the calibration lines remains the same and GSI values do not change. The Decrease in GSI values starts from "Slightly weathered" (category II) rock masses and becomes higher (around 10 units) in "Completely weathered" rock masses (category V) with a "Blocky-Disturbed" or "Disintegrated" structure. However, a number of unfeasible geologically conditions (e.g. "Very Blocky" and "Highly weathered" rock mass) must be excluded from the GSI chart.

4. Conclusions

This paper deals with the geotechnical classification of weak and complex rock masses such as flysch, molasse, gneiss (in its disturbed form), ophiolites and particular cases of limestones The complexity of these geological material imposed a more specialized research for their geological characterization due to the special features of their rock masses regarding both their structure and their lithological characteristics. The weak and complex rock masses analysed had either undergone highly tectonised disturbance resulting in the destruction of their initial structure or/and weathering. They include in many cases an inherent heterogeneity with members of low strength.. The experience gained by the recent excavation of 62 tunnels in the Greek territory, under particularly difficult geological conditions, provided a great number of data, which were processed in a geotechnical database. From their assessment and analysis a number of new charts of the Geological Strength Index (GSI) are proposed, extending its application in the quantitative description of the geological material for engineering purposes.

5. Acknowledgments

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6. References

Barton, N.R., Lien, R., Lunde, J., 1974. Engineering classification of rock masses for the design of tunnel support. Rock Mechanics, 6(4), pp. 189-239.

Bieniawski, Z.T.,1973. Engineering classification of jointed rock masses. Trans South Afr. Inst. Civ. Eng. 15, pp. 335-344.

Brown, E.T., 1981. Rock characterization, testing and monitoring—ISRM suggested methods. Pergamon, Oxford, pp.171-183.

Hoek, E., Marinos, P. and Benissi, M., 1998. Applicability of the Geological Strength Index (GSI) classification for very weak and sheared rock masses. The case of the Athens Schist Formation. Bulletin of Engineering Geology and the Environment, 57(2), pp. 151-160.

Hoek, E., Carranza-Torres, C., Corkum, B., 2002. Hoek - Brown failure criterion - 2002 edition. In: Bawden H.R.W., Curran, J., Telesnicki, M. (eds). Proceedings of NARMS-TAC 2002, Toronto, pp. 267-273.

Hoek, E., Marinos, P., and Marinos, V., 2004. Characterization and engineering properties of tectonically undisturbed but lithologically varied sedimentary rock masses. International Journal of Rock Mechanics and Mining Sciences, 42(2), pp. 277-285.

Marinos, P., Hoek, E., 2000. GSI: a geologically friendly tool for rock mass strength estimation. In: Proceedings of the GeoEng2000 at the international conference on geotechnical and geological engineering, Melbourne, Technomic publishers, Lancaster, pp. 1422-1446.

Marinos, P., Hoek, E., 2001. Estimating the geotechnical properties of heterogeneous rock masses such as flysch. Bulletin of Engineering Geology and the Environment, 60, pp. 82-92.

Marinos, P., Hoek, E., Marinos, V., 2005. Variability of the engineering properties of rock masses quantified by the geological strength index: the case of ophiolites with special emphasis on tunnelling. Bulletin of Engineering Geology and the Environment, 65(2), pp. 129-142.

Marinos P. V. (2007). "Geotechnical classification and engineering geological behaviour of weak and complex rock masses in tunneling", Doctoral thesis, School of Civil Engineering, Geotechnical Engineering Department, National Technical University of Athens (NTUA), Athens, July (in greek).

Stille, H., Palmstroem, A., 2003. Classification as a tool in rock engineering. Tunnelling and Underground Space Technology, 18, pp. 331-345.