PROCEEDINGS OF THE SECOND INTERNATIONAL SYMPOSIUM
ON HARD SOILS – SOFT ROCKS / NAPLES / ITALY / 12-14 OCTOBER 1998

The Geotechnics of Hard Soils – Soft Rocks

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OFFPRINT

A. A. BALKEMA / ROTTERDAM / BROOKFIELD / 1998

The Geotechnics of Hard Soils – Soft Rocks, Evangelista & Picarelli (eds) © 1998 Balkema, Rotterdam, ISBN 90 5809 018 3

A contribution to geotechnical engineering in HSSR of Adriatic coast area

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ABSTRACT: The results of engineering-geological, mineralogical, petrographical and geotechnical (laboratory and in situ) investigations of flysch layers are presented in the paper. These investigations were performed over the last fifteen years in the coastal areas of the Adriatic in the Republic of Croatia. The information collected enabled establishment of a number of correlations between mineralogical-petrographical composition and geotechnical properties of flysch layers. Further research is being carried aut with the aim of determining the influence of individual factors on weathering. In the research an emphasis was made on determining weathering criteria for HSSR.

1 INTRODUCTION

The complex of clastic Eocene sediments called flysch formations (Blašković 1985), is greatly represented in the coastal and insular regions of the Adriatic Sea and on a wider scale in some regions of the Mediterranean basin. Works in flysch are generally considered to be very complex because of the great spread of flysch formations and the heterogeneity of their engineering geological, mineralogical, petrographical and geotechnical properties (Magdalenić, 1980).

Due to frequent and great damage witnessed during construction and use of structures built in the Eocene clastic sediments of the Adriatic littoral and considering the planned construction of significant infrastructural, tourist and industrial structures, it was decided in 1983 to start the investigation project entitled; "Investigation of coastal flysch with the aim of enabling a more rational and economical construction" (Jašarević, 1986). These preliminary investigations, performed over a two year period and partly financed by the Ministry of Science of the Republic of Croatia, were completed by the end of 1987. The corresponding report covering the period between September 1985 and November 1987 was prepared (theme 12/84).

Preliminary investigations served as a basis for defining principal directions for future investigations and The Ministry of Science of the Republic of Croatia adopted and decided to finance over the 1987-1990 period one of the proposed investigation projects (theme 8/3: Stability of flysch slopes under static and seismic conditions). The results of investigations carried out in the scope of this were presented in a number of papers, three of which extensively cover this issue (Jurak et al.1987).

In the light of knowledge acquired and partly presented in the above mentioned papers, it was concluded that investigations may be continued as previously planned. However, a new qualitative element was introduced - structure on the slope. By such an unique approach to structures and flysch formations, it is possible to obtain much more rational and economical solutions, which are particularly concerned with the analysis of stability under seismic conditions. Numerical methods for stability analyses enable introduction of the structure/flysch environment interaction for an anisotropic medium of non-linear behavior (elastoplastic model). The Ministry of Science of the Republic of Croatia accepted to finance this investigation project over the 1991-1994 period (Project No. 2-11-292: The structure of flysch slope interaction under static and seismic conditions).

Part of the research results of the mentioned projects presented in this paper were presented at the International HSSR Symposium, Athens, 1993 (Jašarević et al. 1993).

The Society of Civil Engineers and Technicians - Zagreb in conjunction with the Croatian Society for Rock Mechanics and the Croatian Tunnelling Society organized, from 15-19 February, 1988, the seminar entitled "Investigation, design and construction in weak rocks" where lectures (approx. 200 pages) were presented by 20 renowned authors.

In the research performed after 1990, in Croatia, two authors worked on particular problems in soft rocks. In the dissertation, "Influence of Weathering on Use of Soft Rock Geotechnical Constructions" (Mišćević, 1996), the author looks at weathering and emphasizes:

..."Mechanical properties of soft rocks can be extrapolated between areas of hard soils and hard rocks. Accordingly, the problems in civil engineering works in these geotechnical materials are usually solved with theories from the established areas of soil and rock mechanics. However, soft rocks have some characteristics that can not be covered with these theories. One of those characteristics is weathering in the engineering period of time. This means changing of the mechanical properties due to environmental factors"...

In the dissertation, "Rock mass swelling and its influence on underground engineering structures" (Vrkljan, 1997), the author points out and proves the key hypothesis: a rock mass has the potential to swell only if it is exposed to prior desaturation (reduction of the water content). The second part of his hypothesis is related to the point that a rock mass with varying desaturation has varying (but similar) constitutive laws. Through the work, the difference between swelling potential and its value is explained. Swelling potential is defined as the ability of a rock mass to swell, in relation to the characteristics of the rock mass or its mineralogical composition and particle interaction. The swelling value is defined as the amount to which swelling potential is realized.

The International Society for Rock Mechanics (ISRM), with the aim of developing rock mechanics, initiated 26 commissions from 1967 to 1994. Results of work of these commissions are published as suggested methods (SM). Until now 4 SM have been published under this theme. An entire array of new works are being prepared which will likely shed more light on this area of science (HSSR) between foundation mechanics and rock mechanics.

2. ENGINEERING-GEOLOGICAL, MINERALOGICAL-PETROGRAPHICAL AND GEOTECHNICAL CHARACTERISTICS OF FLYSCH COMPLEXES IN ADRIATIC COASTAL AREA.

2.1 Engineering-geologic characteristics

The term flysch is defined in the Glossary of Geology issued by the American Geological Institute as:

- a marine sedimentary facies characterized by a thick sequence of poorly fossiliferous, thinly bedded, graded deposits composed chiefly of marls and sandy and calcareous shales and muds, rhythmically interbedded with conglomerates, coarse sandstones, and graywackes,
- an extensive preorogenic sedimentary formation representing the totality of the flesh facies deposited in different troughs, during the later stages of filling of a geosynclinal system, by rapid erosion of an adjacent and rising mountain belt,
- a term that has been loosely applied to any sediment with nearly all of the lithologic and stratigraphic characteristics of a flysch.

On the basis of the earlier preliminary lithologic, tectonic, structural and, to some extent, mineralogical-petrographical investigations (Blašković & Fritz, 1985), the decision was made (taking into account the possibilities of ensuring co-financing for some major structures) to perform detailed engineering geological, mineralogical, petrographical and geotechnical investigations in the following regions of the Republic of Croatia:

- clastites in the areas intensively disturbed by tectonic action (Bakar, Krk, Istria and Vinodol),
- disturbed clastites in the zone of the main tectonic contact with carbonate rocks (Dubrovnik, Split and Istria).

In making a basic geological map (M 1:100000), Blašković concludes the following about the greater

part of the Adriatic coastal area:
- in the make-up of the coastal and island areas of the Adriatic sea, complexes of Eocene clastic sediments have a significant presence;
- characterized by petrographical consistency and sedimentological properties, it is easily separated from limestone masses with which it is mostly in contact;
- considering the hydrological function of diferent of the complex, in an otherwise very permeable diferent region, they are richer in surface flows and sources of groundwater, both within flysch as well as in contact with carbonate masses;
- the relief, and also the rich vegetation canopy, contribute to the uniqueness of the clastic sediment area;
- significant differences in consequences from outside natural influences on clastic and carbonate masses extend to influences from various human actions.

2.1.1 General data about characteristics of clastic sediments

* In Istria, within the clastic complex two types can be identified: lower and upper. The lower one is varyingly spread, with a thickness of 0-200m, it is in the form of marl, with a more or less rich lime component, and rare and thin sand layers. The upper has a thickness of 400-600m, is far greater in area, consists mainly of properly alternating layers of marl and sand, and also has some layers of brachia, conglomerates, limestone of significantly varying thickness (20cm - 8m).

* In the Baker bay and Vinodol regions, within rhitmic, as much as it is possible to determine due to tectonic disturbances, marls dominate, sands and in particular rhytmic are less numerous.

* In the City of Split area, it is possible to separate clastic Eocene layers according to:
- thin, lower, mainly marl composition (40m),
- up to 800m thick group of layers characterised by proper rhythmic alternating classic and carbonate masses, rare layers of brachia, conglomerates, limestone of significant thickness, and
- locally limited occurrence, small thickness, mainly bold classic limestone sediments with marl buffers.

* In the City of Dubrovnik area, numerous levels of clastites called flysch occur. Through ordinary alternating sand and marl, this flysch contains a significantly increased volume of limestone conglomerates, particularly in the youngest level.

Taking into account the detailed investigations made over several years on the above localities, it may be stated from the engineering geological standpoint that all flysch formations have numerous common features although some differences have been observed. These differences are primarily due to successive sedimentation and development in several facies (Magdalenić et al. 1980).

The main properties of flysch are its great lithologic heterogeneity and anisotropy which is due to frequent vertical succession of various lithologic members. These successions and transitions of individual members are also frequent in the direction of sedimentation. For that reason, the flysch has many specific features while its common features greatly differ from physico-mechanical features of individual members. Sometimes they approach one, while in other instances they approach another member, but most frequently they correspond to features of the clayey part of the flysch as this flysch member imposes its properties on the entire series. The proportion of individual lithologic members in the sequence of layers is therefore quite significant (Magdalenić et al. 1980).

Shales, marls, siltites and sandstones are considered to be the most significant and the most frequent lithologic members of the flysch formations Limestones and conglomerates are less often represented.The specific nature of flysch terrains (particularly of older formations) is also due to the considerable tectonic damage causing more plastic formations like shales and marls to become faulted and often laminated, while the harder sandstones and limestones are crushed and divided into blocks (Magdalenić et al. 1980). These observations based on more recent investigations (Jašarević et al. 1987) are graphically presented in Figure 1A., 1B., 1C.

The engineering geological elements of the flysch slope structure (Fig.1A) confirmed on several localities (Fig.2) may be determined on the basis of detailed geological engineering mapping and investigations (surface excavations, trial holes, drill holes, geophysical measurements and in situ geotechnical investigations).

There are two boundary surfaces with respect to the described engineering geological elements. One of them is the discontinuity surface - the

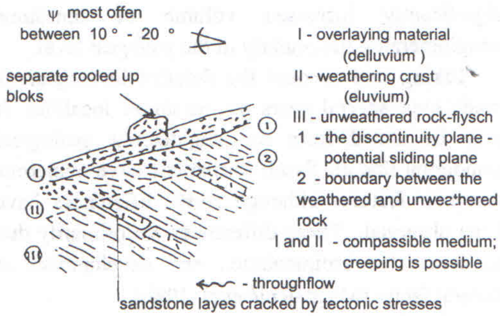

Figure 1A. Engineering geological elements in the flysch slope structure - a basis for geotechnical modeling on several sites along the Adriatic coast (Jašarević et al. 1987)

Figure 1B. Effect of erosion of slope made of flyschin the region of Istria.

cover/eluvium boundary, while the other is the delimitation surface with respect to the state of the rock - the eluvium/parent rock boundary. It is not a discontinuity surface but rather a gradual transition from one rock state into another. The first boundary surface may be defined as a potential slip plane. This potential characteristic is further enhanced by the cumulative process of mechanical suffosion which sometimes causes filtration of hypodermal

Figure 1C. Croatian investigations areas

water along the boundary plane between two genetically different formations (Jurak, 1987).

2.2 *Mineralogical and petrographical properties flysch formations*

Mineralogical and petrographical analyses of clastites and detritic limestones and the determination of their compositions are carried out through grading determination and microscopic analyses. In the case of clastites, it is especially significant to determine the binder or matrix composition, i.e. the content of clayey component.

Dispersive minerals of clay are a major component of some parts of the layer sequence. In order to precisely define the composition, features and behavior in a changed environment of such intercalations present in the sequence of layers, it is necessary to determine clay minerals through X-ray and thermal analyses (Magdalenić, 1980). The published data primarily concern the coarse clastic parts of the flysch. The information on fine clastic parts of the flysch is scarce and is presented in some papers such as (Jašarević, 1987.; Jurak, 1987) and (Crnković, 1985.; Simić, 1983.; Romana, 1983.), while the data concerning a few samples taken from several localities have not been published. A small number of samples have been analyzed so that the test results presented in Table 1, provide only a rough view of the mineralogical and petrographical characteristics of flysch formations. For instance, it may be noted that the proportion of phyllosilicates, typical clay minerals, in the weakly cemented (geologically loosely bound) flysch samples (clayey silt, silty clay) amounts to 50% or more. In the

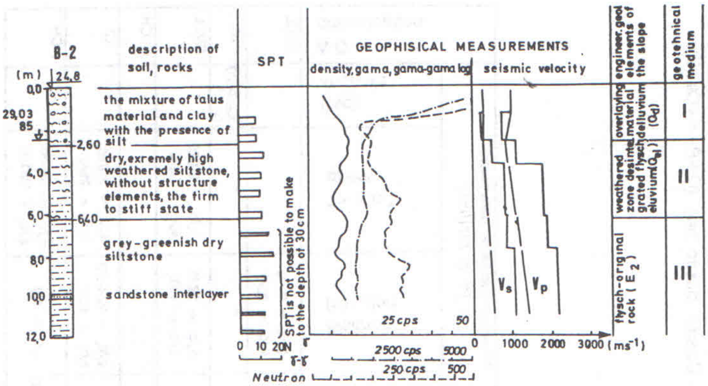

Fig. 2 Interpretation of results obtained by drilling, in situ testing and geophysical measurements at the trial hole situated in the region of Srebrena - Dubrovnik (Jašarević 1987).

cemented (geologically bound) sediments (sandstones), the proportion of phyllosilicates does not exceed 25%. The most represented phyllosilicates are mica minerals (muscovite and/or illite). All weakly cemented samples are characterized by the presence of vermiculite, chlorite-vermiculite mix and allophane. Chlorite and montmorillonite are present in small proportions. The kaolinite was found in all weakly cemented samples from the Rijeka region (the Bakar bay), while it was not discovered in samples taken near Dubrovnik. The samples from these two localities also differ in the proportion of calcite and quartz.

The information on the grading and mineralogical composition of flysch samples and different types of sediments is presented in Table 1. This information is derived from the published papers and available documents.

The following classification made according to (Barth et al.1983) provides proportions of carbonate and clayey sediments:

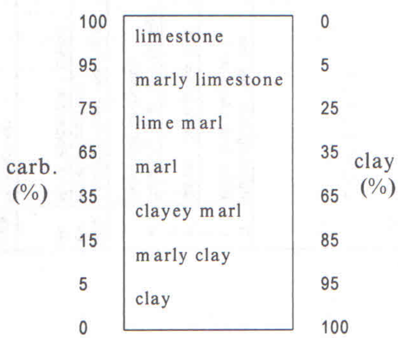

Fig. 3 Classification of carbonate and clayey sediments

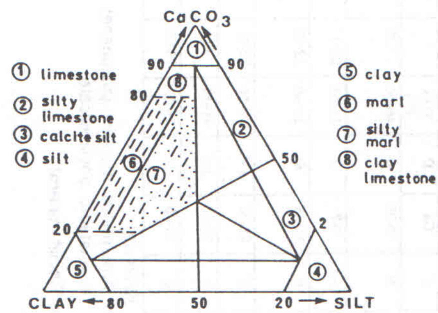

Fig. 4 Rock classification based on the calcite, clay and silt proportions (Konta, 1973)

The quantitative nomenclature and classification of rocks composed of calcite, clay and silt was presented by, Konta (1973).

According to that classification, marls contain 20-80% of clay, 20-80% of calcite and 10% of silt. Marls containing 20-80% of clay, 20-80% of calcite and 10-33% of silt are called "siltose marls", or "sandy-siltose marls" if they contain fine sand grains in addition to silt (Fig.4) (Tišljar,1987).

2.3 Some geotechnical properties of flysch formations

The engineering geological elements in the structure of flysch slopes were classified through engineering geological and geophysical investigations performed on several locations. This classification is the basis for establishing the geotechnical model. The following engineering geological elements were established using longitudinal and transverse wave velocities as shown in Tables 1-2, (Jašarević, 1987):

Table 1 - Mineral composition and grading of flysch samples including types of sediments (in approximate weight %)

	LOCALITIES	Grading (%) Gravel (%)	Sand (%)	Silt (%)	Clay (%)	MINERAL COMPOSITION Q	P	K	Ca	D	ΣGK (%)	T	Mo	C	C-V	KL	ANF	ΣFA (%)	Sediment type in situ test ⊗
Rijeka	Retaining wall near the Bakar bulk cargo port	-	20-45	50-70	4-8	20-30	8-15	⊕	18-25	0	46–70	22-30	<5	<5	0	⊕⊕	0	30–54	Sandy-clayey silt
Rijeka	Bakar - bulk cargo port	5-8	15-65	30-70	7-12	24-34	10-13	0–8	3-7	0	34–52	22-27	<5	<5	⊕⊕	0	0	48–66	Clayey-sandy silt
Rijeka	Retaining wall next to highway near Orehovica	0-3	10-48	40-70	10-30	13-16	3-6	0	15-18	⊕	31–40	22-25	0	10-15	0	5	25-35	60–69	Sandy-clayey silt ⊗
Dub-rov-nik	Landslide near the Župa Hotel- Srebreno	1-2	2-30	30-80	20-45	12-14	5-9	0	25-38	1–2	50–56	22-26	<5	≈5	⊕⊕	0	⊕⊕	44–50	Silty clay Clayey silt
Dub-rov-nik	Hotel Epidaurus - Cavtat	3-6	2-5	73-78	14-17	16-18	7-9	0	16-20	2–3	41–50	22	0	0	⊕⊕	0	⊕⊕	50–59	Clayey silt ⊗ Silt
Alg-eria	Hydropower tunnel - Harbil	-	2-4	29-35	59-61	13-15	⊕	0	15-20	2	30–37	18-35	⊕	<5	0	10	⊕⊕	63–70	⊗ Silty clay (Miocene marl)

Q = Quartz Ca = Calcite Mo = Montmorillonite KL = Kaolinite ΣFA (%) - Phyllosilicate
P = Plagioclase D = Dolomite C = Chlorite ANF = Amorphous material (allophane) + unstable phyllosilicate ΣGK (%) - Coarse clastic part (Q+P+K+Ca+D)
⊕ Small mineral content K = Feldspar T = Tincilit mineral
⊕⊕ Considerable mineral content V = Vermiculite

Tabele 3. Results of geotechnical laboratory and in situ investigations

	LOCALITY	$CaCO_3$ content (%)	Natural water content (%)	Liquid limit (%)	Plastic Limit (%)	Plasticity index (%)	Consistency index	Clay activity $A = \frac{I_P}{<2\mu m}$	Natural volume weight (Mg/m3)	Bulk density of dry sampl.(Mg/m^2)	Specific weight (Mg/m3)	Uniaxial compr. strength KN/m2	Axial strain (%)	Shearing resistance parameters ϕ /°/ c /kN/m²/ Triaxial	Bischop (circular)	"In situ" direct	Back analysis	A-C classification
Rijeka	Retaining wall near the Bakar bulk cargo port	11-20	6-10	31-38	18-12	12-18	1,400 1,80	1,5- 3,00	2.36- 2,55	-	2.74- 2,77	125 225	3,2 1,0	-	ϕ_v/c_v = 32/0 ϕ_r/c_r = 23/0	-	-	CI/CL
Rijeka	Bakar - bulk cargo port	11-36	6-10	29-34	14-21	16-19	0.70- 1,30	0,80- 2,70	2,32- 2,34	-	2,72- 2,74	-	-	-	-	-	ϕ_r/c_r = 25/20	CL
Rijeka	Retaining wall next to high-way near Orehovica	15-16	4-10	33-38	18-19	15-20	1,50- 1,90	1,13- 1,33	-	-	2,70- 2,72	-	-	-	ϕ_v/c_v = 27/0 ϕ_r/c_r = 15/0	ϕ_v/c_v = 30/20 ϕ_r/c_r = 28/0	-	CI/CL
Dub-rov-nik	Landslide near the Župa Hotel - Srebreno	8-20	11-15	40-44	7-20	23-33	0,90- 1,15	0.50- 1,65	2,11- 2,22	-	2,64- 2,72	-	-	-	-	-	-	CI/CH
Dub-rov-nik	Hotel Epidaurus - Cavtat	15-27	7-12	38-40	17-18	20-23	1,25- 1,56	1,21- 1,49	2,21- 2,24	2,00- 2,05	2,68- 2,69	240	1,75	-	ϕ_v/c_v = 22-25/0 ϕ_r/c_r = 15/0	ϕ_v/c_v = 30/20 ϕ_r/c_r = 28/0	-	CI
Alge-ria	Hydropower tunnel - Harbil	4-10	13-14	73-79	17-22	51-61	1,06- 1,15	0,85- 1,00	2,12- 2,27	1,82- 1,99	2,55- 2,71	512	2,10	ϕ_v/c_v=38/150	ϕ_r/c_r = 6/0	ϕ_v/c_v = 19/245 ϕ_r/c_r = 15/150	-	CH

Table 2. Results of geophysical measurements

I. overlaying mat. delluvium	Vp=700-900 (m/sec)	Vs=240-330 (m/sec)
II. degraded flysch -eluvium	Vp=900-1700 (m/sec)	Vs=370-800 (m/sec)
III. flysch - original rock	Vp=1800-2400 (m/sec)	Vs=700-1200 (m/sec)

It was determined according to grading, liquid limits and plasticity indexes that no marked differentiation exists among these engineering geological elements.

No significant variations of physicomechanical properties are expected within the unweathered flysch complex, except in parts characterized by the presence of sandstones and microbreccias, where variations are due to non-homogeneity of composition. The most marked variability of physicomechanical properties will be noted in the overlaying material (delluvium) as such properties depend on the dominant rock mass fraction and on the binding strength.

Disturbed and undisturbed samples taken from drill holes and trial holes were submitted to geotechnical testing in the laboratory. The grading and the mineralogical-petrographical composition is presented in Table 1, while the laboratory and insitu testing results are given in Table 3.

The liquid limit is a very significant indicator of clay properties because it indirectly points to the behavior of materials and to the presence of individual minerals in the flysch. Consequently, when the liquid limit is high, we also have the high water absorption capability and the small shear resistance, while the content of montmorillonite - which is the carrier of swelling potential - becomes dominant.

In fine-grained fractions, particular importance is given to particles composed of minerals having foliated structure such as kaolinite, illite and montmorillonite. It was established that they have negative electric charge at the surface of particles so that they absorb positive ions (H+) and other cations in water solution.

The swelling is a complex process. The effects of swelling and the value of swelling pressures depend on the presence of clay minerals in soil, on the structure and composition and on the physiochemical properties. Montmorillonite swells the most while kaolinite is characterized by the lowest swelling potential. According to (Seed et al 1962) the tested samples have low to high swelling potential, while only samples from Harbil (Algeria) have a very high swelling potential (Fig.9).

Insitu testing (direct shearing of blocks, approx. dim.: 50 X 50 X 50 cm) was performed according to ISRM recommendations on three localities as shown in Table 1. and Table 3. The tested blocks are characterized by a wide grading range and mineralogical composition which can best be seen on correlational diagrams.

3 EXISTING CLASSIFICATIONS OF ROCK MASS WITH EMPHASIS ON HSSR

Engineering classifications based only on "mineralogical-petrographical" characteristics are not only relatively small in number but are also unreliable because they do not take into account geotechnical properties which are important for the estimation of engineering characteristics of rock mass. Therefore, the shown "Classification according to the role of carbonate and clay" (Barth et al., 1939) (Fig.3) is proved invalid by our research shown in section 4, where according to weathering time ($T < 6000$ min), foundations include all types of rock mass in which the carbonate content is $CaCO_3 < 72\%$. According to the same classification, limestones are with more than 95% $CaCO_3$ and according to our research those are rock masses of carbonate complexes with $CaCO_3 > 78\%$

"Classification of rock mass based on related effects of carbonates, clays and powder", according to Konta (1973) in the so-called, three-component division, is not confirmed by our research, especially for limestones where the boundary value is $CaCO_3 > 78\%$ for "hard rocks" and not 90% as is shown on the diagram (Fig.4).

From the prior comparison we can identify conflict between the classification diagrams Fig.3 and Fig.4 for the greater part of separated sediments from clay to marl through to limestone.

Soft rocks have been traditionally viewed as materials which have existed on the fringes of soil mechanics and rock mechanics as is shown in Figure 5.

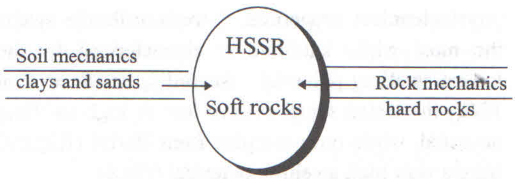

Figure 5. The current view of soft rocks in geomechanics (Johnston & Novello, 1993)

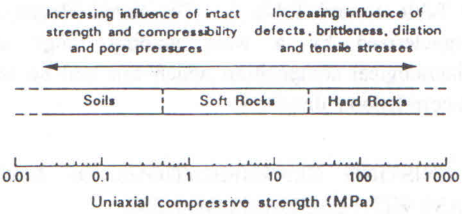

Figure 6. The continuous geotechnical spectrum

It has been argued that soils and rocks share many similarities which are linked through the behaviour of soft rocks. It seems quite reasonable to suggest, therefore, that soft rocks do not simply exist on the fringes of soil mechanics and rock mechanics, but are in fact the central component of a continuous spectrum of materials which extends from soft clays and loose sands to hard rocks as is illustrated in Figure 6. (Johnston & Novello, 1993).

Uniaxial compressive strength which is determined on relatively small samples with certain relationships between diameter and height is not a representative indicator for the estimation of behavior of rock mass due to the presence of discontinuities. "Classification based on the relationship between modulus of deformability (Et) and axial compressive strength" was performed by Deere and Miller (1966). Relationships between moduli of individual types of rock mass fall into particular areas as is shown in Figure 7:

Ⓐ Very high modulus ratio (> 500)
Ⓑ High modulus ratio (200 - 500)
Ⓒ Medium modulus ratio (100 - 200)
Ⓓ Low modulus ratio (50 - 100)
Ⓔ Very low modulus ratio (< 50)

Strength classification

A Very high strength (> 250 MPa)
B High strength (100 - 250 MPa)
C Moderate strength (50 - 100 MPa)
D Medium strength (25 - 50 MPa)
E Low strength (5 - 25 MPa)
F Very low strength (< 5 MPa)

Test results of deformability modulus and uniaxial compressive strength for rock mass carbonate complexes and flysch in the area of Split are generally between 200:1 to 650:1 (Fig.7).

"Engineering classification of rock mass "RMR"" (Bieniavski, 1973) was initiatted based on six parameters of rock mass:

- uniaxial compressive strength
- rock quality index of the(RQD) core,
- separation of discontinuities,
- properties of discontinuities,
- situation of groundwater,
- orientation of discontinuities.

The basic shortcoming of this classification is that it does not contain the parameter of "stability" of rock material. Stability is the resistance of the exposed rock surface material to changes due to outside influences such as: change in moisture, temperature. Sensitivity of rock materials to such influences is evident in the breakdown and erosion of surface material and can have negative consequences for engineering structures which are built on or in unstable rock mass.

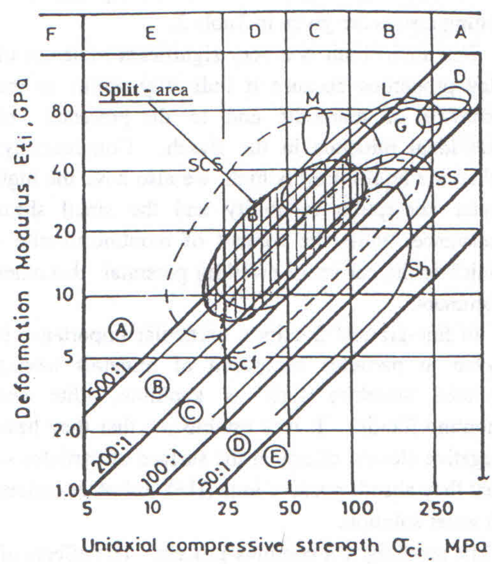

Figure 7. Modulus of deformability - axial strength of individual types of rock mass.
(Deere and Miller, 1966.)

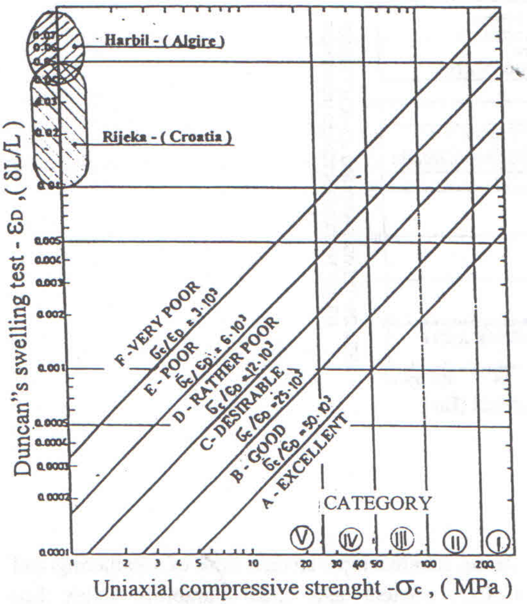

Figure 8. Geodurability classification, diagram (ε_D - σ_C)

Looking at the weathering mechanism in clays, marls, and loose sands, and the elimination of influential parameters (Olivier, 1979), a classification was made in which two parameters, Duncan's coefficient of free swelling $\varepsilon_d = \Delta l/l$, where Δl is the change in length of the sample after taking in moisture and "l" is the initial length of the sample, and the other parameter is the uniaxial compressive strength of σ_c

On Figures 8-9, the geodurability classification is shown with data for testing samples of flysch - Eocene clastic sediments in the area of Rijeka Bakar, Orehovica and Algiers (Harbil).

"Engineering classification "Q"" (Barton et al. 1974) is based on the following six parameters:

RQD - rock quality index
Jn - number of joint systems
Jr - joint roughness index
Ja - crack alteration index
Jw - joint pore - water reduction factor
SRF - stress- reduction factor

The first member - RQD represents the total structure of rock mass or the approximate relative size of block.

The second member - Jr/Ja gives shear strength between the blocks.

The third member Jw/SRF gives so-called active pressure, and the measure is the pressure of water and the parameter SRF which represents:
- loading of the affected zone,
- tension in healthy rock mass,
- swelling pressure.

In general, values of SRF range between approx. 1 for undisturbed competent rock mass to 10 or 20 for large pressures on crushed rock mass or for large pressures on rock mass under swelling.

4 SUGGESTED CLASSIFICATION APPROACH FOR WEATHERING TIME

Through the analysis of existing classifications with an emphasis on HSSR (section 3) the following can be noticed:

* Existing engineering classifications based on geological facts and mineralogical-petrographical characteristics have not successfully solved the classification problems for rock mass of the HSSR type, with an emphasis on stability, which is significant for application for geotechnical structures (foundations, earthfills, excavations, tunnels, etc.).

* Also, engineering classifications which are technically most acceptable (RMR and Q) have not satisfactorily solved the stability classification of rock mass of the HSSR type. In conjunction with these classifications, simple steps for the classification of rock mass according to stability were not created.

* Considering the many years of positive global experience in the application of classification steps RMR and Q, the simplest and optimal solution is to supplement these steps with additional steps, putting an accent on weathering determination, hence, solving the special requirements of the HSSR rock types.

In this section relatively simple steps with respect to stability were looked at for the classification of rock mass of the HSSR type. For the estimation of weathering time (STWP-Start time of weathering process) they include mineralogical-petrographical composition through carbonate ($CaCO_3$) content along with confirmation of durability index Id_2.

The variability of the factors that affect the stability of rock mass has had an effect on today's

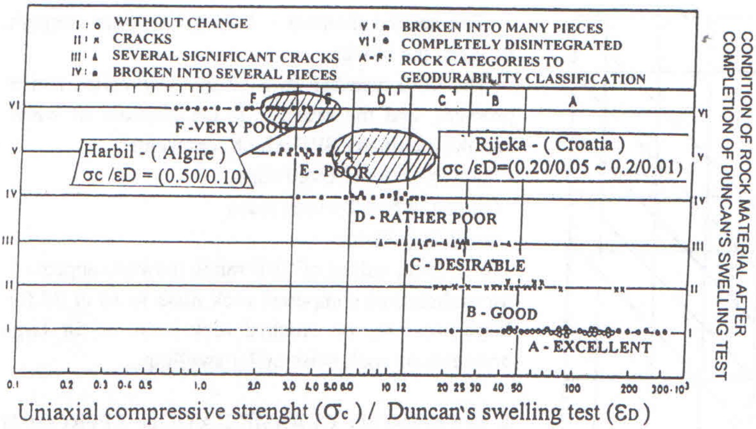

Figure 9. Geodurability classification, diagram ($\sigma_C / \varepsilon_{D}$ - weathering)

level of scientific knowledge in this field. It has made necessary for engineering tests to be such that they estimate the stability of rock mass in the most simple way. All tests, except weathering simulation (modeling of weathering), represent indirect measurement of certain characteristics which are related through experience to the stability of rock material. However, simulation tests also have drawbacks: they do not indicate directly the characteristics of the material or affecting factors which have influence on weathering. Tests have to be simple and must allow simulation of registered conditions in natural settings (Mišćević, 1996).

According to observations made in natural settings, the weathering process in flysch layers can be described as reduction of the material into small fragments. In natural settings the wetting-drying process dominates in affecting speed weathering. In laboratory conditions an attempt was made at simulating this process by submerging an unevenly shaped sample of material such that on one end the sample was continuously wet, and on the other it was naturally drying. The test showed that capillary rise occurred along present discontinuities on the samples, and that after a particular time separation occurred, that is, complete weathering of the sample took place.

The observed start time of the weathering process in laboratory conditions can be placed into groups: several hours, several days and several weeks, or months. Statistically analysed results indicate a strong relationship between time of weathering and $CaCO_3$ content and slake durability index Id_2. (Fig.10, Fig. 11, Fig.12)

In the paper (Mišćević, 1996) determined values (Split area) are shown (Fig.11) without results with high values of $CaCO_3$ and Id_2 in order to be comparable with aur laboratory.In these tests we did have not large values of $CaCO_3$ and Id_2 .

When laboratory tests and in situ observations are compared, it can be concluded that the mainly physical process occurs along primary cracks that are present along with the creation of new secondary

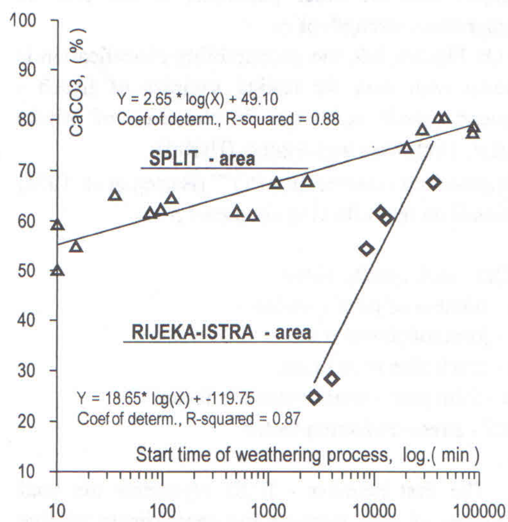

Fig. 10 $CaCO_3$ - weathering time

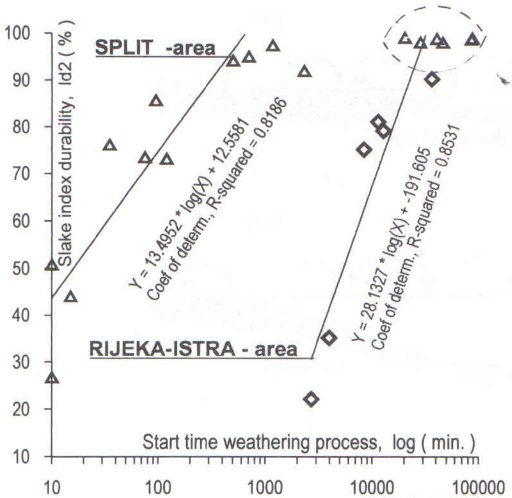

Fig. 11 Slake durability index - weathering time

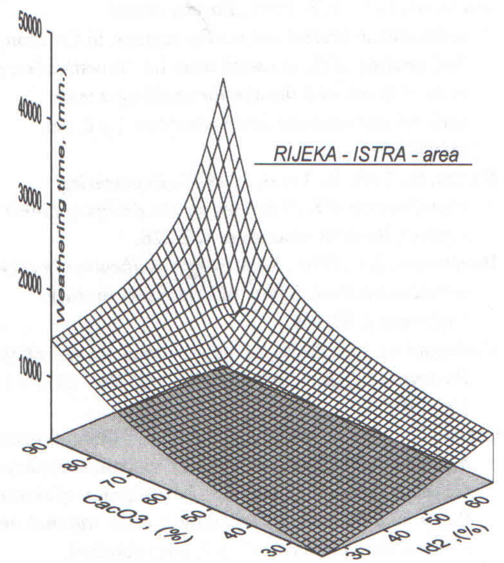

Fig. 12 Diagram for prediction of weathering time

cracks. Primary cracks are the consequence of breaks in the layering process, petrifaction and earlier tectonic occurrence (Fig.13). It is important to emphasize, with respect to prevented width widening in "in situ"conditions as well as circulation of groundwater, that results of the proposed laboratory tests for stability on HSSR are encouraging and it is necessary to continue with them in conjunction with "in situ" measurements on structures (Fig. 14, Fig. 15).

Fig. 13 Capillary rise on the discontinuities of the specimen.The specimen is partially submerged

In one project in the proximity of town, Rijeka, for purposes of construction of storage space, earth filling was done with flysch layers with a level height of up to H=20.0 m. From the settelment diagram (Fig. 14) of filled material of clastic sediments a large difference in results can be observed between laboratory and "in situ" tests. This difference is the cosenquence of conditions of prevented horizontal widenning in "in situ" conditions as well as a cosenquence of drainge of underground water. Results of weathering time in laboratory conditions cannot be directly applied on the forecasting of the weathering process in "in situ"

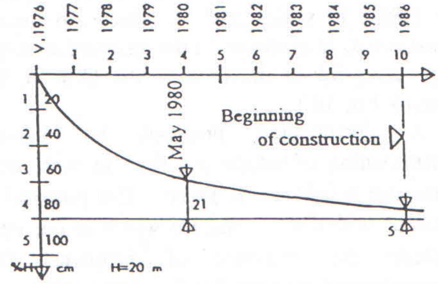

Fig. 14 Prediction of settlement of fill and beginning of structure construction (Pavlovec & Sabolić, 1980).

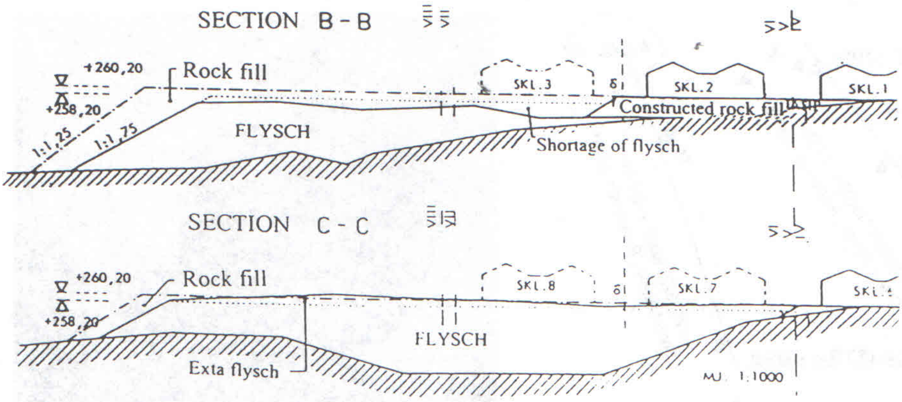

Fig. 15 Characteristic section profiles

conditions. This is why it is suggested that before designing structures test be performed in "in situ" conditions, with aim of determining correlations with results of laboratory tests.

5 CONCLUSION

* The research (laboratory and in situ) performed mainly in the areas of map and Split, confirms the hypothesis that rock mass of the HSSR type has various geotechnical characteristics and consistencies (of weathering) with time which depend on individual locations (Fig. 10, Fig. 11 (Blašković, 1988).
* In various construction projects (earth fills, excavations, foundations, tunnels) the classification of HSSR rock mass is very important, especially with regards to weathering characteristics because this has a significant influence on the selection of a technological approach for construction and structure stability.
* Determination of weathering time is significant for HSSR in which and on which structures are constructed, as is shown in the analyzed example of high earth fill in the area of the City of Rijeka (Fig.14, Fig. 15).
* A documented proposal for laboratory determination of weathering time in rock mass of carbonate complexes is given. The proposal is in function with $CaCO_3$ and Id_2 which in our opinion indicate the influence of significant factors (mineralogical-petrographical composition and geotechnical properties) on stability time (weathering) of HSSR.

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