Rudarsko-geološko-naftni zbornik	Vol. 13	str. 47–55	Zagreb, 2001.

UDC 551.311.23:551.781.4(697.13)

Stručni članak

WEATHERING PROCESS IN EOCENE FLYSCH IN REGION OF SPLIT (CROATIA)

Predrag MIŠČEVIĆ and Tanja ROJE-BONACCI

Faculty of civil Engineering, University of Split, Department of geomechanics, Matice hrvatske 15, HR - 21000 Split, Croatia. E-mail: Predrag.Miscevic@gradst.hr

Keywords: Weathering, Flysch, Classification

The Eocene flysch in the region of Split (Dalmatia, Croatia) is characterized by the presence of layers with different characteristics. It mainly includes thin-layered marls, clayey marls, calcareous marls, clastic layered limestones, calcarenites and breccias. Those parts that can be described as the soft rocks or hard clays by the mechanical means, exposed to weathering reduce the durability within "an engineering time scale". The paper deals with the factors that influence the weathering process. The analyzed weathering is a combination of processes acting simultaneously. Most of these processes depend on the change of the water content, thus the weathering process mainly develops when a material is subjected to the wetting-drying process. On the base of these results form of degradation process is modeled. The weathering process can be mainly described as physical weathering combined with chemical weathering on the free surfaces and on the cracks walls, Erosion as a result of weathering, is the dominant geomorphic process on analyzed flysch terrain. According to the analysis, as the most appropriate due to the characteristics, the tests are chosen as index properties. Some of these tests are modified in order to adapt them to the determined characteristics of materials from flysch layers. The correlations between the measured values are used as the basis for the classification proposal of the analyzed material, according to its resistance to weathering processes. Roughly, three main groups of samples are recognizable: the first one with carbonate content more then 90% is not weathered at the engineers time scale; the second group with carbonate content from 75% to 90% include samples susceptiblé to weathering in engineers time scale; the third group with carbonate content less then 75% include samples in which the weathering occurs immediately after the exposition to the weathering factors.

Ključne riječi: Trošenje, Fliš, Klasifikacija

Eocenske flišne naslage područja Splita (Dalmacija, Hrvatska) karakterizira prisutnost slojeva različitih svojstava. Naslage uglavnom sadržavaju tanko uslojene lapore, glinovite lapore, kalcitične lapore, klastični uslojeni vapnenac, kalkarenite i breče. Oni slojevi koji se po mehaničkim svojstvima mogu opisati kao mekane stijene ili tvrda tla, imaju svojstvo da izloženi procesima trošenja značajno gube trajnost i to unutar "inženjerskog razdoblja vremena". U ovom radu razmatraju se čimbenici koji utječu na proces trošenja. Analizirano trošenje je kombinacija procesa koji djeluju istodobno. Većina tih procesa ovisi o promjeni vlažnosti, te se trošenje uglavnom razvija kada je materijal podvrgnut sušenju i vlaženju. Na osnovi rezultata ispitivanja utjecaja sušenja i vlaženja modeliran je proces degradacije svojstava. Trošenje može uglavnom biti opisano kao fizičko a usko je povezano s kemijskim i uglavnom se odvija na slobodnim površinama materijala i na zidovima pukotina u njemu. Erozija kao rezultat trošenja je dominantni geomorfološki proces na razmatranim flišnim naslagama. Na osnovi provedene analize odabrani su pokusi koji kao indeksni pokazatelji najbolje opisuju razmatrani proces trošenja. Neki od pokusa su dijelom modificirani kako bi se što bolje prilagodili ispitivanju materijala iz flišne naslage. Uočene korelacije između mjerenih rezultata poslužile su za izradu prijedloga klasifikacije predmetnih materijala s obzirom na njihovu podložnost trošenju. U osnovi, mogu se prepoznati tri glavne grupe uzoraka: uzorci koji sadrže više od 90% karbonata nisu podložni trošenju unutar inženjerskog razdoblja vremena; druga grupa su uzorci koji sadrže od 75% do 90% karbonata osjetljivi su na trošenje unutar inženjerskog razdoblja vremena; treću grupu čine uzorci sa manje od 75% karbonata u kojima se proces trošenja razvija neposredno nakon izlaganja faktorima trošenja.

Introduction

Eocene flysch in the greater Split area (Croatia) is marine sediment characterized by a layered structure, made of layers with different characteristics. The lithological components of the layers can be classified into various groups ranging from hard clays to hard rocks according to their mineralogic-petrographic and engineering-geological properties. The mineralogical-petrographical composition and faults in the structure of minerals and rocks directly influence the general physica-structural and physical-mechanical features of the flysch layers. The characteristics of the coarse clastic rocks mainly depend upon the composition of the binding agent (matrix), whereas the properties of marls and siltstone depend upon the quantity and types of the clay minerals of which they are composed. The Eocene flysch in the Split region is represented with calcareous breccias, breccia-conglomerates, calcarenites and detrital limestones bound by biocalcarenite and calcite cement, and marls. The marls are mainly composed of calcite and clay minerals (illite, illite-muscovite and montmorillonite) with some quartz, feldspars and plagioclase. Mainly there are the following series (Šestanović, Štambuk and Samardžija, 1994.):

- thin-layered marls, clayey marls and calcareous marls altering with thin-layered calcarenites (and marl clay in inter-layer fissures)
- marls with layers of various thickness (with marl clay in inter-layer fissures)
- clastic layered limestones
- calcarenites altering with calcareous breccias (and breccia conglomerates)
- calcareous breccias (and breccia conglomerates)
- calcarenites, breccias and marls repeatedly altering among themselves.

According to their physical-mechanical properties the majority of marl and marly layers can be classified as materials suceptible to a change in properties due to the weathering processes. The weathering process change the material with soft rock properties into a fine-grained material. In this paper the weathering of the soft rock is defined as *"degradation or deterioration of natural structural materials under the direct influence of the atmosphere, hydrosphere and man's activities within the engineering time scale"* (Fookes, Gourley and Ohikere, 1988). The term *"engineering time scale"* (i.e. a period ranging from a few years to a few decades) is used to distinguish this type of weathering from the weathering processes of hard rocks on a geological time scale. The paper is the study of causes, which lead to the weathering of these materials.

In the greater area of town Split in Dalmatia region (Croatia), the result of weathering process is constant degradation of natural slope surfaces and of artificially made slopes made with cuts for structures. An example of natural slope degradation in flysch formation is shown in Figure 1. Slope is located near the sea coast, and degraded material from the bottom of slope is constantly removed by wave erosion. Consequence of this process is recession of the coast line at a rate of approximately half of meter in 20 years. Figure 2. shows an example of an artificial slope in flysch formation made for a road construction. Slope surface erosion, as result of weathering, is not prevented by protective measures, so gravity and rain transport the degraded material on the road surface (being hazardous to the traffic).

Fig. 1. Photograph of a coastal cliff in flysch. Degraded material in the bottom of slope is constantly removed by sea (Trstenik, Split).
Sl. 1. Fotografija obalne stijene u flišu. Degradirani materijal u podnožju stijene stalno je uklanjan morem (Trstenik, Split)

Characteristics of degradation processes on marl

Generally, weathering includes two dominant processes, physical weathering which results in the disaggregation of rocks without mineralogical change, and chemical weathering resulting in the decomposition of the constituent minerals to stable or metastable secondary mineral products.

For the purpose of analyses of weathering process on flysch material, investigations were performed in laboratory conditions. The investigations were performed on three identical groups i.e. samples were broken into pieces, and every group was composed with one piece from each sample. Characteristics of materials the groups are composed of, are shown in Table 1.

Fig. 2. Photograph of an artificial slope cut for a road construction (Adriatic motorway near Kašel Gomilica)
Sl. 2. Fotografija umjetno zasječene kosine za izgradnju ceste (Jadranska autocesta kod Kaštel Gomilice)

The first group with natural moisture content (moisture immediately after excavation) was kept in a container without changes in humidity, while the temperature was the same as temperature of the air in laboratory. *The second group* was submerged in the container filled with water and kept under the same temperature conditions as the first group. *The third group* was subjected to the process of repeated wetting and drying in the laboratory conditions. Samples were dried in drying oven on temperature of 50°C for 20 hours, and after 4 hours of cooling on a laboratory air temperature, submerged into water for 24 hours.

After a period of six months, all samples from the first group were without any visible change. In the second group only samples with a carbonate content less than about 60% (see Table 1) were partly degraded.

In the third group all samples, that can be classificated as *marl, calcareous marl* or *marly limestone* (materials with carbonate content less then 95%), were completely degraded into a fine grained material. Samples with carbonate content greater than 95% (limestones, calcarenites) were without visible changes. Generally, from the analyses of degraded samples, the weathering process on marl, calcareous marl or marly limestone from flysch can be mainly described as physical weathering, combined with chemical weathering on the surface of samples and on the crack walls inside the samples i.e. all surfaces of material that could come into contact with water.

An example of the described process is shown in Figure 3. for the sample No. 14 from Table 1. The investigation was performed on a sample submerged partly with one side in the water for one month. The middle part of a sample was in a constant condition of wetting and drying, i.e. water capillary rose to that part and dried by an air. As a result of weathering, on the side submerged into water a crack along the sample can be seen (meaning physical degradation) (S c a v i a , 1995) as well as white powder on the surface as a result of chemical changes.

From the test results it can be observed that the weathering process mainly develops when a material is subjected to the wetting-drying process (M i š č e v i ć & R o j e - B o n a c c i , 1995). In fact, in this test the weathering was a combination of few processes acting simultaneously, but

Table 1 Characteristics of materials used to form groups
Tablica 1 Karakteristike materijala za formiranje skupina

sample number	carbonate content (%)	specific gravity (G)	slake durability index I_{d2} (%)	soaking of water w_{up} (%)	dry weight γ_d (kN/m^3)	free swelling of dissaggregaded sample (%)	beginning of decomposition t_{deco} (min)
1.	67.70	2.70	91.7	6.93	23.12	4.0	2300
2.	81.12	2.69	98.6	3.42	24.45	0.0	>200000
3.	61.73	2.71	93.9	8.29	23.69	3.0	500
4.	59.05	2.69	50.5	8.78	22.48	18.0	10
5.	60.84	2.70	94.8	7.89	23.22	4.0	700
6.	80.52	2.70	97.2	4.13	24.45	0.0	11500
7.	54.58	2.72	43.7	12.37	22.04	6.0	15
8.	99.75	2.72	99.0	0.88	25.95	0.0	-
9.	62.03	2.71	85.3	9.65	22.17	2.0	95
10.	74.37	2.70	98.9	3.15	24.55	0.0	20100
11.	61.39	2.65	73.1	10.45	22.23	2.0	75
12.	80.28	2.69	97.9	2.85	24.70	4.0	46000
13.	80.30	2.68	98.7	3.14	24.52	0.0	40320
14.	64.93	2.66	75.8	9.61	22.47	2.0	35
15.	77.92	2.70	97.9	4.16	24.21	1.0	28080
16.	67.29	2.69	97.2	4.80	23.75	2.0	1170
17.	75.55	2.69	93.9	4.48	24.21	0.0	150000
18.	99.75	2.73	99.4	1.38	24.98	0.0	-
20.	64.33	2.71	72.8	9.81	21.99	3.0	120
21.	49.79	2.69	26.4	20.78	21.01	6.0	10
22.	68.04	2.67	95.4	6.46	22.71	5.5	28000
23.	77.32	2.70	98.6	3.28	24.57	4.0	85000
24.	78.55	2.71	98.8	2.71	24.76	9.0	87000

mostly dependent on the change of the water content. For the analyzed samples the most exposed processes were:

• *Swelling of material on the surface* of samples as result of chemical reactions, mainly transformation of carbonate into gypsum. The gypsum has 99.9% larger volume compared to the volume of material before the start of a reaction. In the Figure 3. gypsum can be seen as a white powder on the surface of sample. Transformation into gypsum was proved by the change of SO_3 content (as a main component of gypsum) and by the weight loss procedure in the process of heating with controlled change of temperature. As an example, for the sample from Figure 3. the SO_3 content was 0.29% in intact soft rock (whole chemical analyses is shown in Table 2.), while the white powder on the surface had 4.41 % of SO_3. In the weight loss procedure during heating with controlled change of temperature, white powder lost 2.81% of weight on temperature between 140°C - 160°C which correspond to loss of water in gypsum. A diagram of the analyses is shown in Figure 4.

• *Swelling of clay minerals.* Some samples contain clay minerals that swell in contact with water, but because of calcite cement bonds that hold clay minerals, the process is mostly developed on samples surfaces and inside the cracks. The potential influence of swelling minerals is analyzed on disaggregated samples with the free swell test (G i b b s and H o l t z, 1956). Measured values of the free swell test on analyzed materials are shown in Table 1.

• *Disintegration* due to the quick soaking of water into cracks and fissures of a dried sample. This process is described as slaking, and measured with the so-called slake durability index. The measured values after a second cycle of the slake durability test (ISRM 1979) are shown in the Table 1.

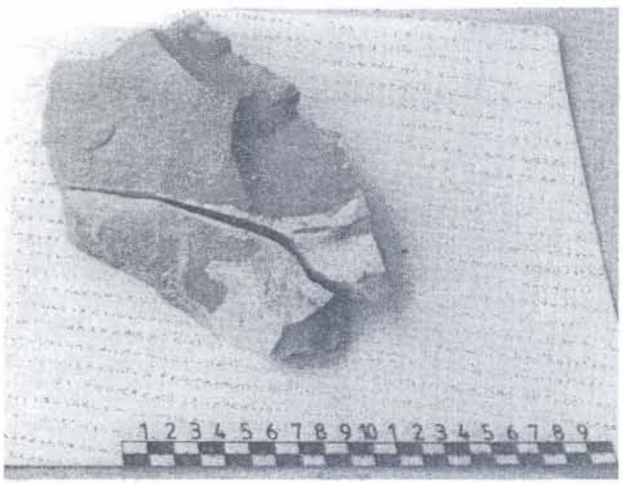


Fig. 3. Example of the simultaneous physical and chemical degradation
Sl. 3. Primjer istovremene fizičke i kemijske degradacije

• *Solubility* (resolving) is characteristic of samples with more than 40% of clay minerals. Because of smaller calcite content, calcite bounds are weaker and clay minerals resolve from matrix in contact with a water.

• *A change of volume* caused by temperature change also influences disintegration. This is a well known phenomenon, but was not analyzed in the paper because its influence is slower in time and it is not emphasized in the studied area. Nevertheless, the change of temperature (heating) can influence the moisture of materials, meaning it is a part of drying process.

Forms of degradation process

According to the laboratory investigations of the analyzed material, deterioration caused by the weathering can be described by two forms of degradation process:

1/ The first form is disintegration in smaller parts with the development of the cracks system. On samples with or without any cracks on the surface, under weathering process, new cracks develop and all cracks lengthen. In the

Table 2 Chemical composition of the sample from Fig. 3
Tablica 2 Kemijski sastav uzorka sa slike 3

Component	(%)
loss of weight by heating	32.80
SiO_2	16.22
Al_2O_3	4.86
Fe_2O_3	3.70
CaO	38.77
MgO	2.01
SO_3	0.29
non-melted rest	0.08
Alkali+neutral	1.27
Σ=	100.00

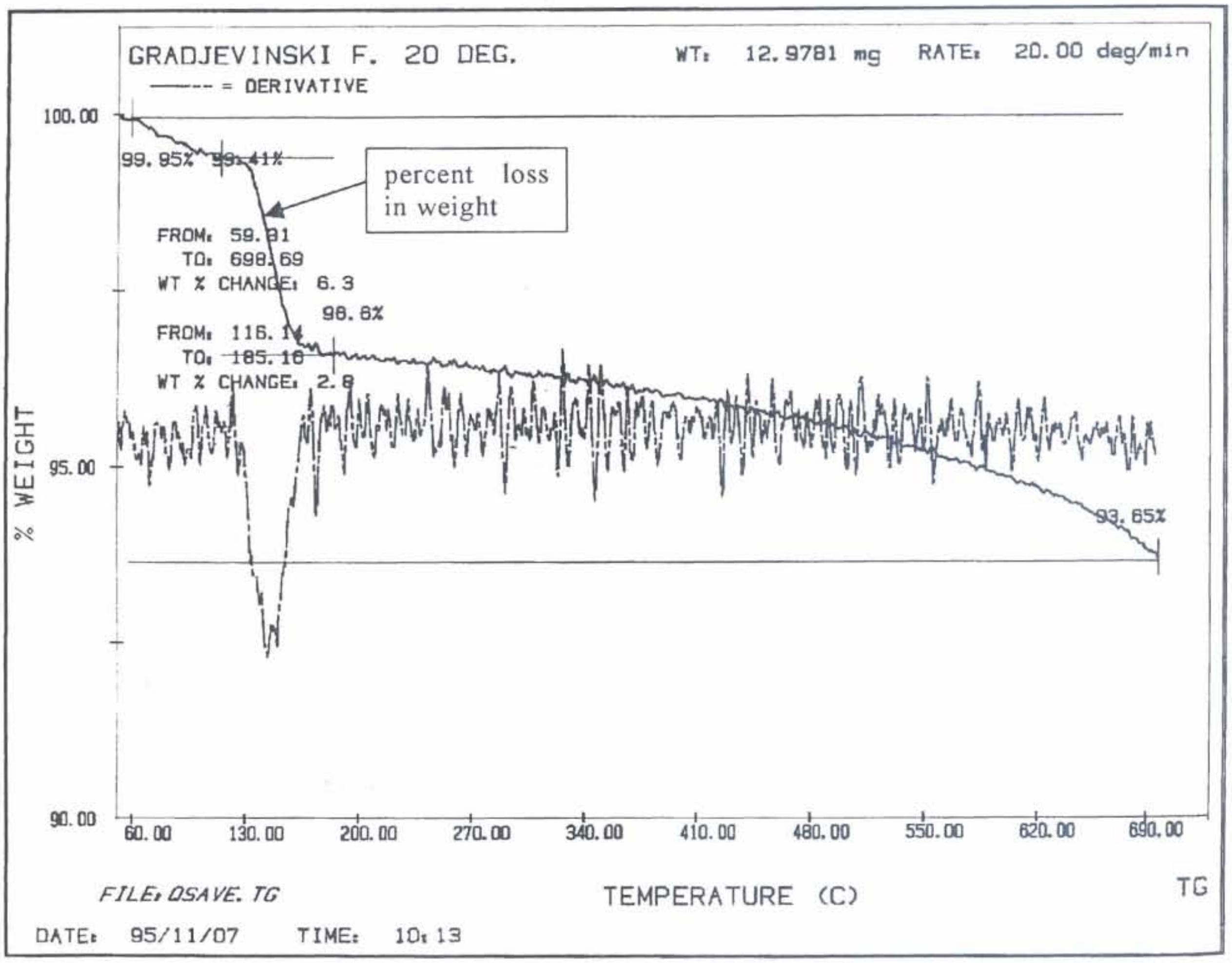


Fig. 4. Diagram of the weight loss in the process of heating with controlled change of temperature, for the white powder from sample in Figure 3.
Sl. 4. Dijagram gubitka mase zagrijavanjem uz kontrolu promjene temperature bijelog praška uzorka sa slike 3

process of wetting-drying, cracks develop as a result of simultaneous action of all previously described processes. An example of crack development is shown in Figure 5. on sample number 9 from Table 1. When the three-dimensional system of cracks is closed, a part is cut off from the sample (Fig. 6a). The process is usually developed near the surface, but can spread throughout the sample and break the sample into smaller pieces.

2/ The second form of degradation can be described as the exfoliation from the surface into depth (Fig. 6 b), (resulting eventually in a mass of small angular fragments and flat slivers which could readily be scraped loose by hand). Exfoliation is usually a result of decomposition of clay minerals, but it can be a result of all previously described processes acting on the surface of sample. An example of exfoliation is shown in Figure 7. on sample No. 17 from Table 1.

Depending on the characteristics of the unweathered material, a sample can simultaneously undergo both previously described forms of degradation processes. Consequently, the sample is usually broken into smaller parts which have larger surface area that can be in contact with water and the process of degradation is accelerated. The shape of the crack propagation and the dimensions of the cut particles depend mainly upon the mineral composition and the faults in the structure (O l i v i e r , 1979), but also depend on the surrounding stiffness of the cracks and the level of desiccation and moisturizing in the process of wetting-drying.

In laboratory conditions, the speed of weathering can be expressed as a function of wetting-drying cycles, depending on a level of desiccation and moisturizing. But in nature, velocity can not be expressed by a continuous time function. The reason is the fact that wetting-drying cycles in nature (and also the level of desiccation and moisturizing) depend on the weather, geological and morphological characteristics of the area, the changes of ground water level, etc.

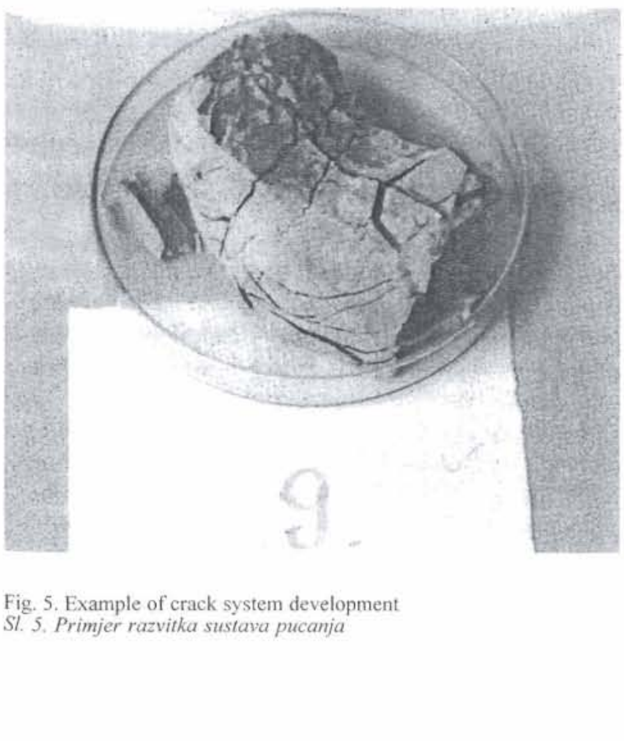


Fig. 5. Example of crack system development
Sl. 5. Primjer razvitka sustava pucanja

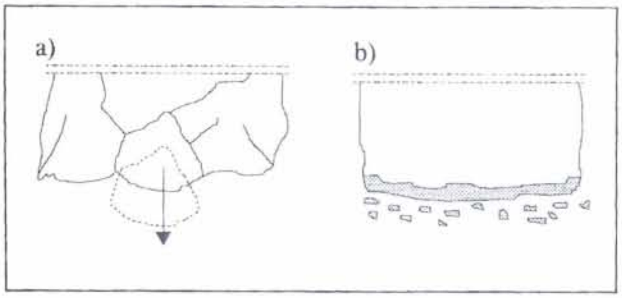


Fig. 6. Forms of degradation processes on the analyzed material
Sl. 6. Oblici degradacijskih procesa analiziranog materijala

Classification due to weathering within the engineering time scale

The drying-wetting process is the most influential process since it enables and speeds up chemical weathering as well as physical weathering. Hence, the proposal for classification of analyzed material is based on tests which stimulate the drying-wetting process in the best way (S a b a t a k a k i s , T s i a m b a o s and K o u k i s , 1993). The second criterion was applicability of test, because some examined samples disintegrated quickly when they came in contact with water, so it was impossible to obtain the shape required by the test. The following laboratory tests were performed:

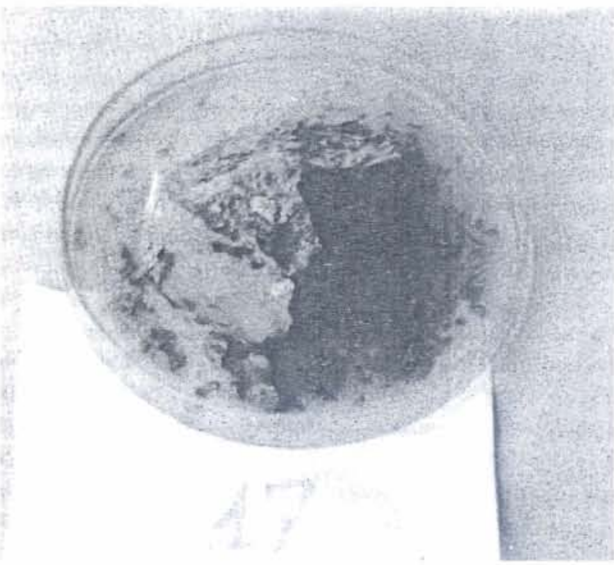


Fig. 7. Example of surface exfoliation
Sl. 7. Primjer površinskog ljuštenja

- dry weight $(\gamma_d = \rho_d \cdot g)$
- carbonate content (C)
- water absorption (w_{sl})
- slake-durability index (second cycle) (I_{d2})
- free swell test (Gibbs & Holtz 1956) (S_{sl})
- point at which decomposition begins (t_{deco}); a test proposed by the authors. The test is performed in the following way: a sample 10 cm in size, is air dried at a tempera-

ture od 20°C, and then one end of the sample is dipped into shallow water; the time period starting from the dipping of the sample to the beginning of fragment separation is measured.

The tests were performed on the previously described group of samples (Table 1) so that all lithological elements of the flysch which are susceptible to described weathering were represented. The group include two samples of limestone which are classified as hard rock. The results obtained on these two samples are used as "boundary points" at one end of the range of properties. Since the clay samples could not be tested in the proposed way, it was not possible to determine, using the suggested tests, the "boundary points" at the other end of the properties range.

The testing results were correlated, so that Figures 8a to 12a present the test results with correlation coefficient $R \geq 0.90$. Cluster analysis was performed for the selected correlations presented in Figures 8b to 12b. The figures present the results obtained by the clustering method which simulated the observed material behavior under natural conditions in the best way when considering the analyzed properties.

According to the correlation of the results presented in Figures 8 to 12 it can be concluded that there are three main groups. The *first group* includes the samples of rock on which the *weathering process*, as defined in this paper, is *not visible*. The *second group* includes samples of soft rock *susceptible to weathering in engineering time scale*. The *third group* contains samples *very susceptible to weathering*. The weathering process on these samples occurs immediately after the exposure of the material to weathering factors and the weathering time corresponds to the beginning of the engineering time scale. According to the analysis of results presented on the graphs, the groups can be characterized by properties presented in Table 3.

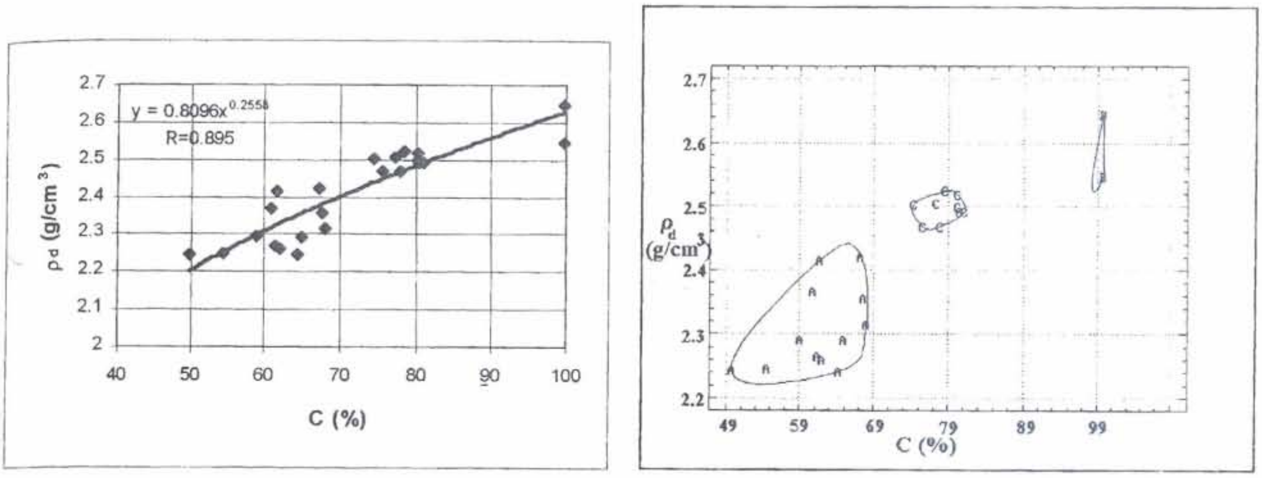
Concluding remarks

The materials from flysch layers that can be classified as a soft rock or hard clay (mainly marl, calcareous marl or marly limestone), are very susceptible to the repeated change of moisture. Cyclic wetting-drying is not the only, but is the main cause of the processes that together can be described as weathering process. The result of weathering process on these materials is degradation from material with soft rock characteristics into material with properties of a fine-grained material. The process can be described as a physical degradation combined with chemical changes on all material surfaces that can be in direct contact with water.

As a result of the described characteristics, the weathering process starts on the surface but because of crack system development it spreads throughout the material, from the surface into depth. For materials with carbonate content less than approximately 80% the process is relatively quick (in nature from few to tens of years). Because of thin layered structure of flysch, the degradation process follows a principle of the weakest bond in the chain: when the weak-

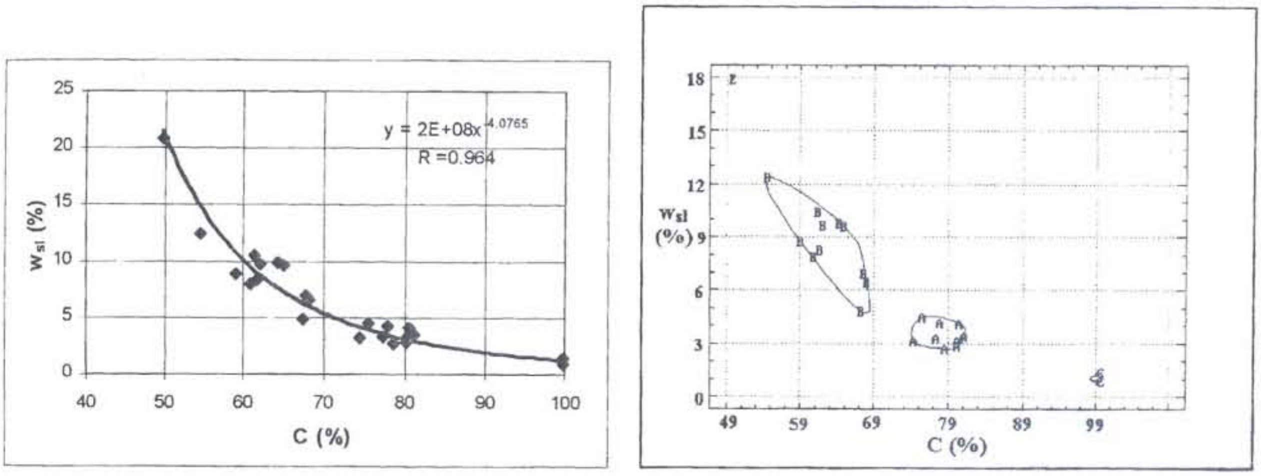
Table 3 Index parameters for the classification proposal
Tablica 3 Putokazni parametri za predloženu klasifikaciju

	Carbonate content C (%)	Slake durability index I_{d2} (%)	Water absorption w_{sl} (%)	free swell test s_{sl} (%)	Time of decomposition beginning t_{deco}
Rock material which can be considered as "classic" rock within the engineering time scale from the weathering standpoint.	> 90 %	> 95 %	< 3 %	-	-
Rock material susceptible to weathering although the weathering process within the engineering time scale is very slow.	75 % - 90%	90 % - 95 %	3 % - 6 %	0% -10 %	> 7 days
Rock material which can be entirely classified as "soft" or "not-durable" rock. It is susceptible to weathering during a relatively short period within the engineering time scale.	< 75 %	< 90 %	> 6 %	> 10 %	< 7 days



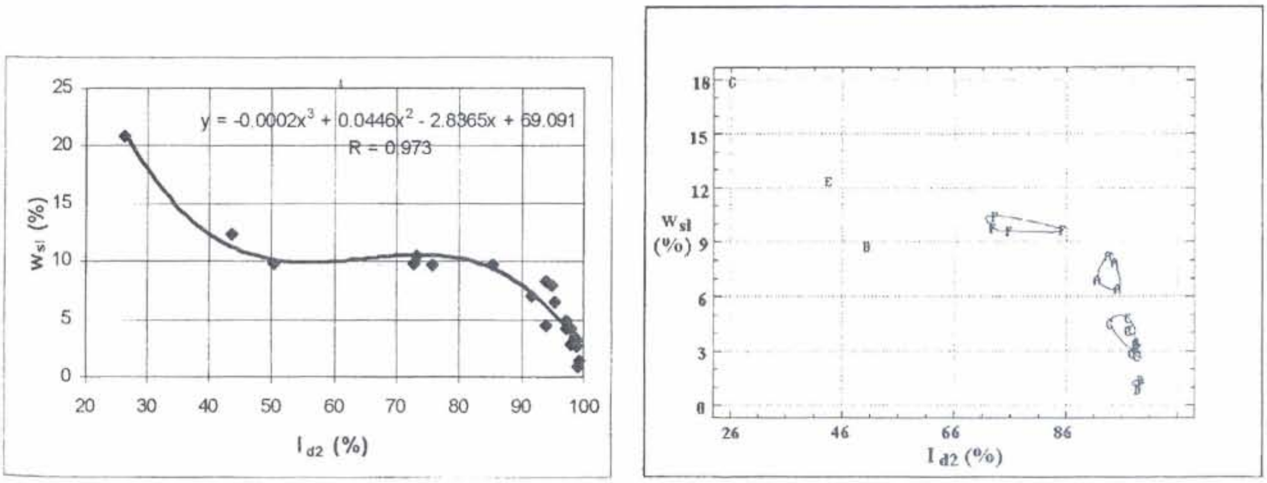
(a) (b)

Fig. 8. Dry density (ρ_d) vs. carbonate content (C); a) relationship, b) cluster analysis
Sl. 8. Suha volumenska masa (ρ_d) prema sadržaju karbonata (C). a) odnos b) cluster analiza



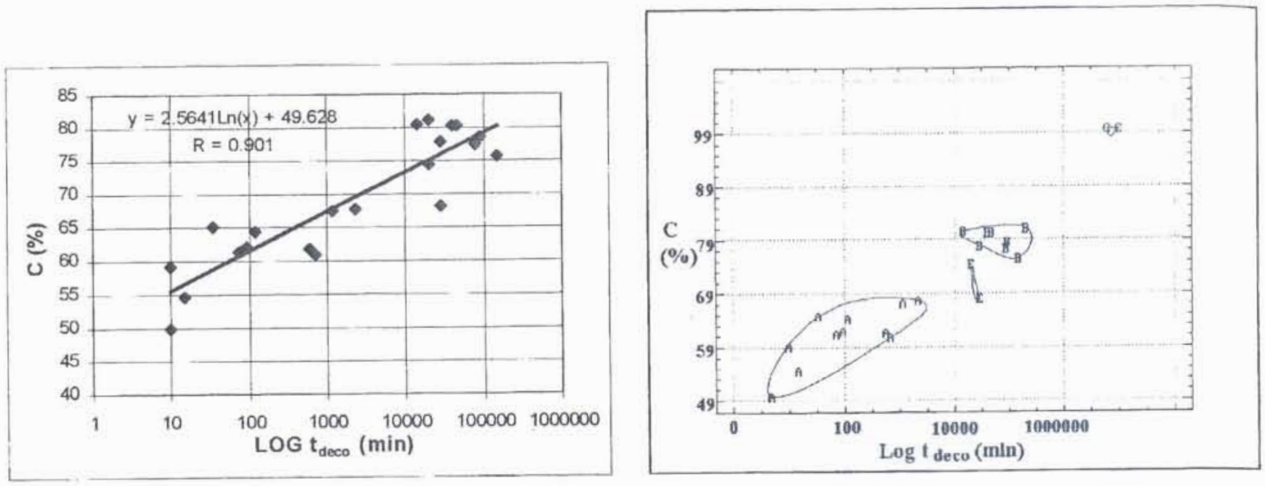
(a) (b)

Fig. 9. Absorption of water (w_{sl}) vs. carbonate content (C); a) relationship, b) cluster analysis
Sl. 9. Upijanje vode (w_{sl}) prema sadržaju karbonata (C). a) odnos b) cluster analiza



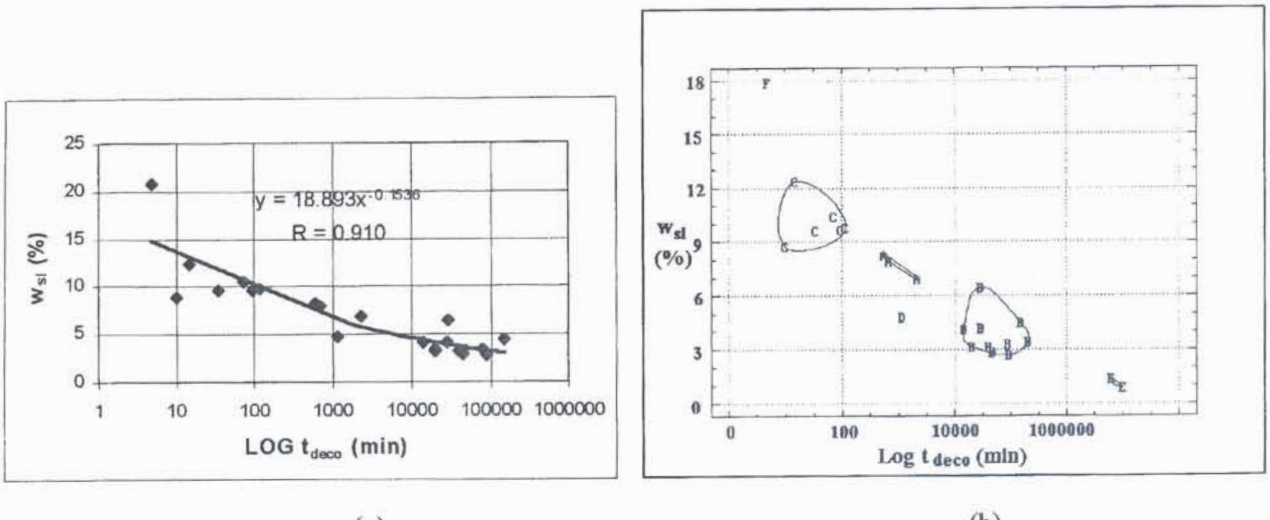
(a) (b)

Fig. 10. Absorption of water (w_{sl}) vs. slake-durability index (second cycle) (I_{d2}); a) relationship, b) cluster analysis
Sl. 10. Upijanje vode (w_{sl}) prema indeksu slejt durabiliti (I_{d2}). a) odnos b) cluster analiza



(a) (b)

Fig. 11. Carbonate content (C) vs. beginning of decomposition (t_{deco}); a) relationship, b) cluster analysis
Sl. 11. Sadržaj karbonata (C) prema početku dekompozicije (t_{deco}): a) odnos b) cluster analiza



(a) (b)

Fig. 12. Absorption of water (w_{sl}) vs. beginning of decomposition (t_{deco}); a) relationship, b) cluster analysis
Sl. 12. Upijanje vode (w_{sl}) prema početku dekompozicije (t_{deco}). a) odnos b) cluster analiza

est layer is degraded, surrounding layers collapse because there is no more lateral support, even they are hard rock.

All surfaces on flysch terrain exposed to wetting-drying are constantly eroded because of weathering. Erosion is the dominant geomorphic process in this kind of terrain. Effects of process depend on the dip of surface, orientation of layers in correlation to surface, and on a transportation processes.

Therefore analyzed process should be taken into account in civil engineering constructions. *Surfaces cut in the flysch terrain should be protected from the wetting-drying process to prevent constant erosion leading to environmental problems or even to overall unstability of a cut slope.*

Received: 2000-09-27
Accepted: 2001-10-23

REFERENCES

Fookes, P.G., Gourley, C.S. and Ohikere, C. (1988): Rock weathering in engineering time. *Quar. J. of Engin. Geology., Vol. 21,* 33-57, London.

Gibbs, H.J. & Holtz, W. G. (1956): Engineering properties of expansive clays. *Trans. Am. Soc. Civ. Eng. 121(1),* New York.

ISRM (1979): Suggested methods for determining water content, porosity, density absorption and related properties and swelling and slake-durability index properties. *Int. J. for Rock Mech. Min. Sci. & Geo. Abstr. 16,* 141-156, Oxford.

Johnston, I.W. & Novello, E.A. (1994): Soil mechanics, rock mechanics and soft rock technology. *Geotech. Eng., 107(1),* 3-9 London.

Maekawa, H. & Miyakita, K. (1991): Effect of repetition of drying and wetting on mechanical characteristics of a diatomaceous mudstone. *Soils and Foundation. 31(2),* 117-133, Tokio.

Miščević, P. & Roje-Bonacci, T. (1995): Prediction of additional settlement part caused by weathering of fill material. *Int. J. Engin. Mod. 8(1-2),* 37-44, Split.

Miščević, P. (1997): The investigation of weathering process in flysch terrains by means of index properties. In: Marinos, P.G., Koukis, G.C., Tsiambaos, G.C. & Stournaras, G.C. (editors): *Proc. Int. Sym. on Eng. Geology and Enviro., Athens, Greece,* Balkema, Vol. 1, 273-277 pp, Rotterdam.

Olivier, H.J. (1979): Some aspects of the influence of mineralogy and moisture redistribution on the weathering behaviour of mudrocks. *Proc. of the 4th Int. Con. on Rock Mech.,* Vol. 3, Theme 1, ISRM /Montreux/.

Richardson, D.N. & Wiles, T.T: (1990): Shale durability rating system based on loss of shear strength. *J. of Geotech. Engineering 116(12),* 1864-1881, New York.

Roje-Bonacci, T. (1998): Parameter changes after weathering of sof rock in flysch. Proc of Sec. Int. Sym. on Hard Soils-Soft Rocks, In: Evangelista, A., Picarelli, L. (editors) The Geotechnics of Hard Soils - Soft Rocks. ISSMGE, 799-804 pp, Naples

Sabatakakis, N., Tsiambaos, G. and Koukis, G. (1993): Index properties of soft marly rocks of the Athens basin, Greece. In: Anagnostopoulos, A. (editor): *Geotech. Enging. of Hard soils--Soft rocks.* Balkema. 275-279 pp, Rotterdam.

Scavia, C. (1995): A method for the study of crack propagation in rock structures. *Geotechnique. 45(3),* 447-463, London.

Šestanović, S., Štambuk, N. and Samardžija, I. (1994): Control of the Stability and Protection of Cut Slopes in Flysch. *Geologia Croatica. 47(1),* 139-148, Zagreb.

Šestanović, S. (1998): Engineering-geological Characteristics of Marl from Eocene Flysch in the City of Split, Croatia. Proc of Sec. Int. Sym. on Hard Soils-Soft Rocks, In: Evangelista, A. Picarelli, L. (editors) The Geotechnics of Hard Soils - Soft Rocks. ISSMGE, 311-314 pp, Naples