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Uniaxial compressive strength and durability of sandstones and marls with varying moisture content

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Abstract

The compressive strength of sedimentary rocks varies significantly with moisture content. In this study, Point Load Tests (PLT) and corresponding Uniaxial Compressive Strength (UCS) correlations were determined for marl and sandstone samples with varying water contents, tested in two pilot areas in the northern Adriatic.

The specimens were collected from the coastal zone where cyclic wetting and drying occurs, influencing the mechanical stability of the rock mass. Samples were tested in their in situ condition, after 24 hours, and after one week of wetting. PLT on irregular samples and Slake Durability Test were performed in the Geotechnical Laboratory at the Faculty of Civil Engineering, University of Rijeka following the standardized procedures.

Marls testing results indicate a clear reduction in UCS with increasing water content, while Slake Durability Tests revealed high resistance to low disintegration of marls under cyclic environmental conditions. On the other hand, sandstone samples have shown varying behaviour, depending on the period of sampling, initial water content and moisture penetration regimes. The results indicate that the mechanical properties of the rock mass are significantly affected by its heterogeneity and the environmental conditions in which it occurs. Furthermore, they emphasize the need to account for additional controlling factors to improve the interpretation of index test results and to validate the mechanical behaviour of surface materials exposed to marine environmental conditions.

Keywords

Uniaxial Compressive Strength, Point Load Test, water content, Slake Durability Testing.

1 Introduction

1.1 Geological context

Research is performed on two pilot areas: Havišće Bay in the Kvarner area (Fig.1B), and Brovinje Bay on the Istrian Peninsula (Fig.1C). According to the geological map of the Republic of Croatia (CGI, 2009), pilot areas are built in Liburnian deposits, foraminiferal limestones and siliciclastic rocks (flysch) of Paleogene age (Vlahović and Velić 2009). Havišće Bay is partly built-in stable limestone rock, and unstable flysch rock mass on the other hand. The cover consists of decomposed marls and more resistant sandstone fragments weakly attached to the slope material or separated underneath the slope. Brovinje Bay is mostly formed of thick layered marls of varying weathering degree (Fig. 2).

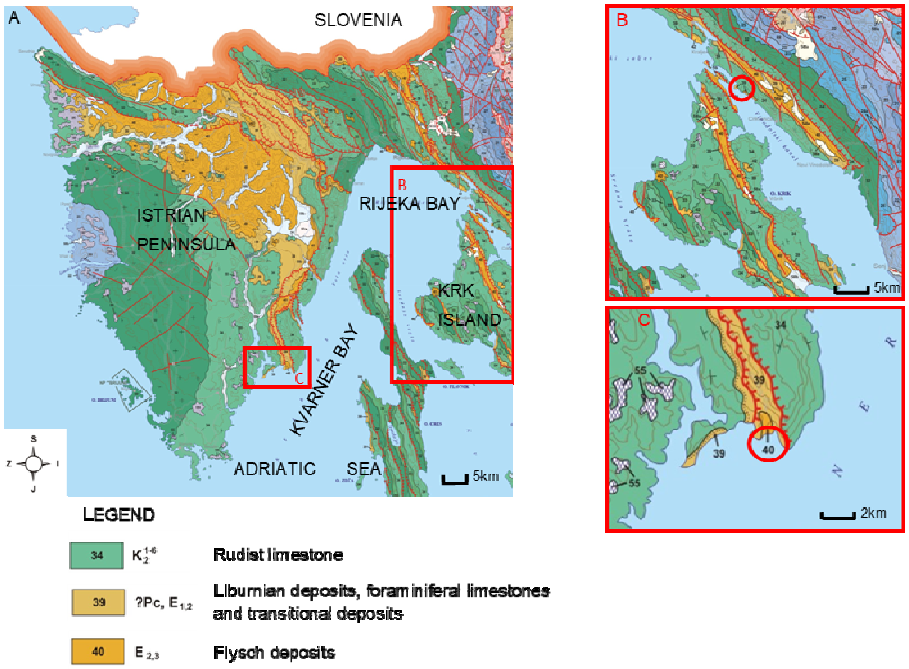


Fig. 1 Pilot area locations on the geological map of the Republic of Croatia Scale 1:300,000 (CGI, 2009).

1.2 Sampling locations

The rock samples were collected at three locations in Havišće Bay, and two locations in Brovinje Bay. All the samples were transported in plastic bags to the laboratory and protected from changing in humidity, kept in laboratory conditions, until the testing. First samples were taken in June: Brovinje marls (L1BJ and L2BJ) and Havišće sandstones (L1HJ, L2HJ, L3HJ). Second sampling of Havišće sandstones was repeated in October (L1HO, L2HO) to study the seasonal effect on the testing properties.

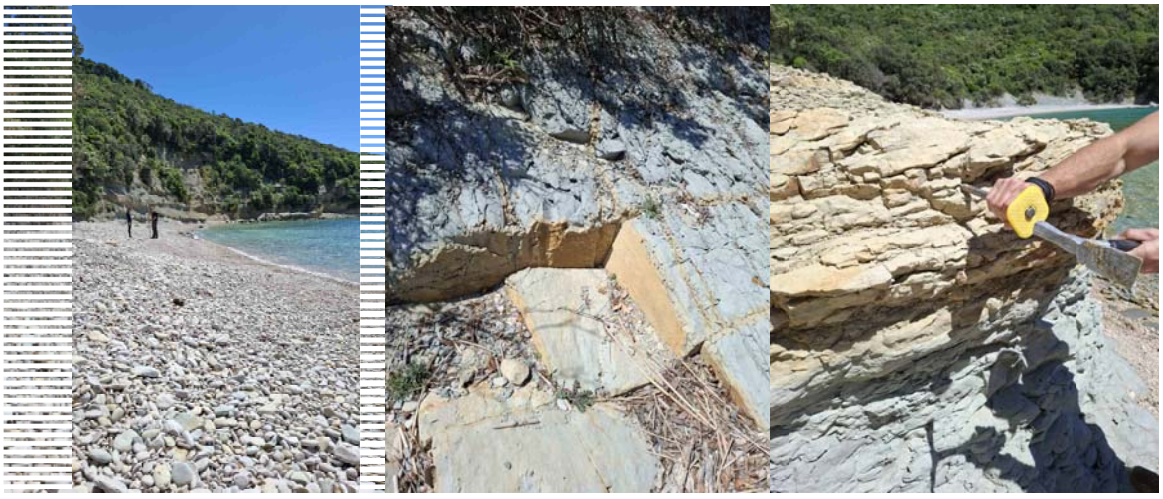


Fig. 2 Brovinje Bay pilot area (left) with visible marls outcrops (middle -L1BJand right photo- L2BJ).

The Brovinje Bay (Fig.2) samples were taken at one sheltered location (L1B) and another location exposed to waves and wind (L2B). Homogeneous marl rock blocks of varying colour were detached using chisel and a hammer (light olive grey to light bluish grey at L1B, and greyish orange to pale

yellowish brown at L2B). Havišće Bay (Fig 3.) samples are mostly homogeneous sandstones, superficially orange to yellowish brown colour, and mostly grey inside. First group of sandstone samples were blocks weakly bound on the unstable and partly collapsed slope (L1HJ/L1HO), another group was collected at the base of the slope (L2HJ/L2HO), and the last one from the weakly bound cover layer (L3HJ). It is important to emphasize that the sandstones samples were highly heterogeneous and that the samples differed from one another in terms of their degree of weathering and mineralogical composition.



Fig. 3 Havišće Bay pilot area (left) with visible sandstone outcrops (middle-L1H and right photo-L2H and L3H).

2 Laboratory and field testing

Uniaxial Compressive Strength was estimated based on a *Point Load Test(PLT)* and ISRM (1985) standardized procedure for irregular sample testing, which corresponds to in situ water content, water content after 24h and 7 days wetting. One part of the samples was also tested after 24 hours of drying. Digital PLT apparatus, from the Geotechnical laboratory, at the Faculty of Civil Engineering in Rijeka was used to perform the testing. The mean value of $I_{s(50)}$ was calculated by deleting the two highest and lowest values from 10 or more valid tests, and calculating the mean of the remaining values. Used index-to-strength conversion factor (β) is 21.4 for marls (Lashkaripour 2002) and 21.9 for sandstones (Singh et al. 2012). Field identification testing of marl rock, was also performed on the Brovinje site using geological and *Schmidt hammer*. At both sampling locations, it was determined that more than one blow of geological hammer was required to fracture the rock, corresponding to strong rock (R4) i.e. uniaxial compressive strength 50-100 MPa (Brown, 1981). L type Schmidt hammer, and the ISRM (1981) suggested procedure were used to calculate the rebound number Rn. The *Slake Durability Test* procedure was carried out in accordance with the ASTM standard (2004) and repeated for the desired number of cycles (n) to determine the durability index I_{dn}. Slake durability index values that are taken after three or more cycles of slaking and drying may be useful for evaluating rock durability so five cycles were applied to each sample from Brovinje site.

3 Results

3.1 Brovinje marls

Obtained mean UCS at Brovinje marls at both testing locations at natural humidity and after 24h wetting is shown in Table 1. PLT testing has shown that the samples were superficially quite soft during the testing, and the cone penetrated into the samples up to over 7mm before cracking. It is visible that moisture penetrated only a small part of the cross-section, mainly at the edges, to a few millimetres (Fig.4.). The natural humidity of the taken samples was 1.5% and 1.57% (at L1BJ, and L2BJ), while the moisture content after 24h of wetting increased to 2,5% and 1,9% correspondingly. It was determined that after a 24h wetting process, the UCS for samples from L1BJ decreased around 2%, and for samples from L2BJ around 3,7%, what confirms that it is necessary to test a larger number of samples to draw precise conclusions. According to the field testing, the average Schmidt rebound number is Rn=27,8, what taking into account the Sight et al. (1983) relation, gave the estimated UCS value of 55.6 MPa.

Table 1. Comparison of strength properties for the marl samples tested at Brovinje site.

Sampling location	**UCS (MPa)- natural humidity**	**UCS (MPa)- 24h wetting**
L1BJ	33,53	32,86
L2BJ	47,05	45,32



Fig. 4 Wet samples after breaking: a) L1BJ; b) L2BJ.

The results of the performed Slake Durability Tests at Brovinje marls are presented in Table 2, The remained samples were not fragmented and appeared to be low degraded after two and five cycles, corresponding to high I_{d2} and I_{d5} values. According to Gamble's classification (1971), the sample from L1BJ can be classified as very high durable, and the rock mass atL2BJas high durable.

Table 2Results of the Slake Durability Testsat two locations samples from Brovinje site.

No. of cycle	**I_d, L1BJ (%)**	**I_d, L2BJ (%)**
1st cycle	99.18	96.45
2nd cycle	*98.57*	*95.71*
3rd cycle	98.27	95.24
4th cycle	97.99	94.87
5th cycle	97.45	94.27

3.2 Havišće sandstones

It can be noticed that some samples, apparently of greater weathering degree, cracked irregularly due to PLT testing, because of barely visible microcracks. More worn brownish areas inside some samples were visible. The cone in the wet samples was significantly indented during testing (up to 30mm), and some samples began spalling near the surface at higher pressures. The natural humidity of the samples at location L1HJ was 0,97%, on the location L2HJit was 0,76%, and on the location L3HJ 0,94%. The moisture content of the samples after 24 h of wetting increased, and was 2,29%, 2,09% and 1,49% correspondingly. The UCS values increased after 24h drying from 75,10MPa to 111,52 MPa (48,5%) at L1HJ, and from 66,21 MPa to 86,34 MPa (30,4%) at L2HJ. The mean UCS value obtained from natural humidity samples at L3HJ is 56.50 MPa. The results of the post-drying testing at L3HJ were not considered as relevant (only 4 samples were tested). After 24h of wetting the results show that the UCS values decreased expectedly (Table 3). Compared to dry samples the strength decreased for 46,4% at the L1HJ, and 42,9% at theL2HJ. The samples from L3HJ after 24h wetting the UCS value was similar as natural water content value (57,37 MPa), but, again, it wasn't considered as relevant because few samples were tested.

Sandstone samples collected in October show mean UCS value of 55MPa at L1HO and 54,13 MPa at the L2HO. The natural humidity of the samples at L1HO was 1,68%, while the natural humidity on the L2HO was 1,41%. The moisture content of the samples after 24h of wetting increased, and was 2,19% for the L1HO and 2,23% for the L2HO. After 7 days of wetting the moisture content increased to 2,64% and 2,70% for locations L1HO and L2HO correspondingly. The sandstone specimens show a clearly defined darker zone, indicating water penetration after wetting. The penetration front is irregular but well delineated, forming a lens-shaped to asymmetric saturated zone. Water ingress is partial, not fully saturating the specimen, which suggests heterogeneous cementation or grain packing and capillary-controlled flow through the intact rock pores (Fig. 5A). Dark brownish zones on the

failure surface indicate on the presence of the mineralogically distinct, iron-oxide–rich or more fine-grained layer in some samples (e.g., Fig. 5B).

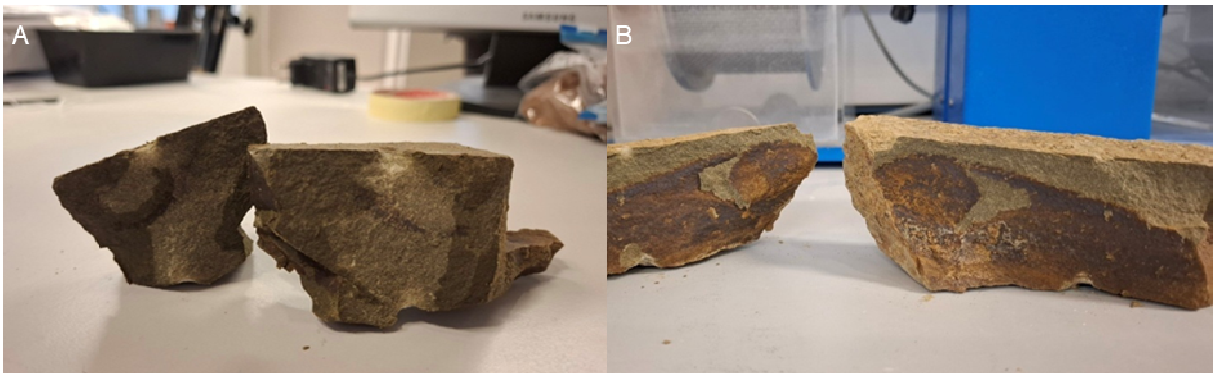


Fig. 5 Sandstone sample after testing: a) different water penetration patterns; b) dark brownish traces on the failure surface.

While it was expected that increased moisture content would result in a reduction of the PLT Index, the results obtained at the L1HO did not confirm these expectations. After 24h wetting, the results show that the UCS values increased to 68,70MPa at location L1HO and to 67,41MPa at the location L2HO (Table 3).

Table 3. Comparison of strength properties for the samples tested in June and October.

Sampling location	**UCS (MPa)-natural w**		**UCS (MPa)-24h wetting**		**UCS (MPa) - 7 days wetting (2 cycles of drying and wetting)**	**UCS (MPa) - 7 days wetting (one cycle of drying and wetting)**
	June	October	June	October	October	October
L1H	75,10	55,00	59,82	68,70	86,61	74,55
L2H	66,21	54,13	49,34	67,41	66,94	54,30

In comparison with the testing performed in June, the natural water content in October at L1H andL2H was around 1% larger than in the case of the specimens tested in the summer period. The samples collected in June show significant change in water content after the 24h wetting, while the samples collected in October show lower water content change after 24h wetting. Since only the group of samples collected in October was exposed for the 7-day wetting, it cannot be compared to sampling in June, and it can be concluded that the water content after 7 days of wetting increased from the natural state for both locations (Table 4).

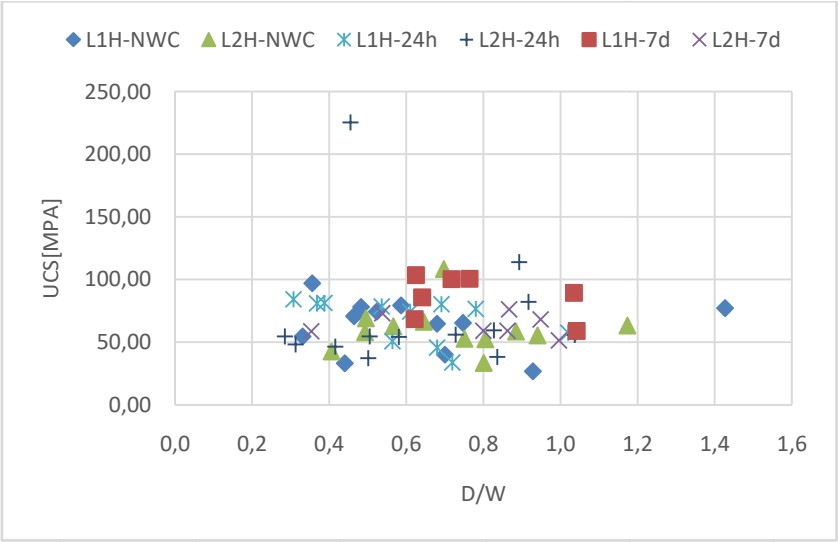


Fig. 6 Sandstone mean UCS values considering different D/W ratio.

Different specimen slenderness (hight/width ratio D/W) for all tested samples in June and October(same location and wetting conditions) wasanalysed (Fig. 6). Ratios lower than 0.3 and greater than 1.0 were not considered (according to the ISRM recommendations). Generally, it can be concluded that the tested group of samples doesn't show dependence of the mean UCS value of the D/W ratio.

Table 4. Changes in water content during different periods and wetting processes.

Sampling location	w (%)-natural		w (%)-24h wetting		w (%)-7 days wetting
	June	October	June	October	October
L1H	0,97	1,68	2,29	2,19	2,64
L2H	0,76	1,41	2,09	2,23	2,70

4 Conclusions

The performed testing indicates on the basic strength and durability properties of marls and sandstones at the pilot areas. The estimated marls UCS decreased with the increase in water content, and the samples were classified as very high to high durable. The sandstones collected and tested in June (L1HJ and L2HJ), have shown increase in UCS values after 24h of drying and expectedly decreased UCS values after short-term wetting (24 h), i.e., classical weakening effect, as predicted in the rock mechanics theory. What was surprising, samples tested in October after 24 h /7 days wetting have shown UCS equal or higher than in the natural condition. The corresponding irregular and mostly surface water penetration may be the cause of the obtained results. The results indicate that the heterogeneity of the investigated samples affected the test outcomes. However, the number of samples is insufficient to draw robust conclusions. It can be seen that the water ingress was partial and did not fully saturate the specimen, suggesting a heterogeneous moisture distribution and a failure surface comprising both wetted and non-wetted areas (Fig 5a). Another influencing factor can be the period of sampling and the corresponding natural water content, since the samples in October were taken after a rainy period, unlike the sampling in June 2025, after a dry and hot period. Other factors, that have not been considered systematically in this analysis, and that might have influence on the PLT results, are mineralogical composition, lamination, grain-size bands and other. It can be concluded that more samples with systematic consideration of all influencing factors should be considered to draw further conclusions and to validate the influence of the marine environment on the mechanical characteristics of the surface materials in parts of the bay more or less exposed to drying and wetting process.

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