LABORATORIJSKO ISPITIVANJE SLIJEGANJA NASIPA OD LAPORA UZROKOVANO RASPUCAVANJEM ZRNA

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Predrag Miščević, Ph.D.
University of Split, FCEAG
Vlastelica Goran, Ph.D.
University of Split, FCEAG
Nikolić Mijo, Ph.D.
University of Split, FCEAG

Sažetak: Nasip izrađen od zrna dobivenih drobljenjem meke stijene može biti podložan dodanom slijeganju uzrokovanim raspucavanjem zrna unutar strukture nasipa. Ovo dodatno slijeganje nije uzrokovano promjenom stanja naprezanja unutar nasipa i ne može biti procijenjeno standardnim metodama proračuna na osnovi modula stišljivosti izmjerenog nakon zbijanja nasipa. Raspucavanje zrna je uzrokovano procesom rastrošbe, koji je u mekim stijenama kao što je lapor, uglavnom uzrokovan procesom sušenja i vlaženja. Ako su zrna u strukturi nasipa podvrgnuta sušenju i vlaženju, rezultat je usitnjavanje zrna do razine raspada u materijal koji se može opisati kao tlo. Usitnjeni materijal odvaja se od zrna i popunjava makro pore u strukturi nasipa što za posljedicu ima dodatno slijeganje nasipa. Uzorci za ispitivanje su izrađeni od drobljenog lapora u laboratorijskim uvjetima. Ispitivanje je provedeno sa modificiranim edometarskim uređajem. Izmjerene veličine se mogu iskoristiti u svrhu procjene dodatnog slijeganja nasipa uzrokovanog rastrošbom.

Ključne riječi: Meka stijena; Rastrošba; Lapor; Slijeganje; Nasip

LABORATORY INVESTIGATION OF EMBANKMENT SETTLEMENT CAUSED BYMARL GRAINS DETERIORATION

Abstract: Embankments made of crushed soft rock grains can be susceptible to additional settlement caused by deterioration of the grains inside the embankment. This additional settlement is not caused by the change of the stress state inside embankment and cannot be predicted by standard calculating methods with the embankment modulus of deformability measured after compaction of the embankment. The deterioration of the grains is mainly caused by the weathering process which is, in soft rocks such as marl, mainly induced by the wetting and drying processes. If marl grains in an embankment are subjected to the wetting and drying process, the result is breakage of the grains, as well as decomposition into soil material. Disintegrated material then fills the macropores of the embankment grain structure and gradually causes additional settlement. The samples were made of crushed marl in laboratory conditions. A test was conducted with modified oedometer apparatus. Measured values can be used for estimating the additional settlement caused by the weathering.

Key words: Soft rock; Weathering; Marl; Settlement; Embankment

1. INTRODUCTION

The properties of soft rock weathering are insufficiently investigated when using crushed soft rock for construction of embankments. If the crushed soft rock material placed in an embankment is subjected to cyclic change of water content, the material properties dependent on the weathering process become very significant in analysis of settlements and embankment stability. When grains in an embankment structure disintegrate fast due to weathering into finer particles that can move within embankment structure voids (macropores) as a result of gravity and water flow effects, the consequence is an additional settlement of the embankment (Wang et al. 2013). These settlements cannot be explained or calculated by the deformation properties determined on compacted embankment (Oldecop & Alonso, 2003). The described process can lead to unexpectedly large settlements, or/and embankment slope slippages due to reduced shear strength of the material in the embankment. Marls from the flysch deposits of the coastal belt in Dalmatia (Croatia) are a goods example of soft rock in which the described problem is observed, but similar soft rock materials are also used in other areas for construction of embankments (Cardoso & Maranha das Neves 2012, Cardoso et al. 2012).

As a consequence of weathering, mechanical properties of marl can change within a relatively short period from several months to several years (Alonso et al. 2010a; Calcaterra & Mario Parise 2010, Yin et al. 2016). This period can be analyzed as the engineering period or the structure durability period.

The main process causing the disintegration and cracking of marl is the water content alternation process, drying and wetting (Erguler & Ulusay 2009). The weathering process is a simultaneous action of many mechanical and chemical weathering processes (Ciantia et al. 2015, Miščević 1998a & 1998b, Gökçeoğlu et al. 2000, Miščević & Vlastelica 2011, Pineda et al. 2014a, Pineda et al. 2014b, Tugrul 2004, Alavi Nezhad Khalil Abad et al. 2015, Alavi Nezhad Khalil Abad et al. 2016). Just as an example, it is possible to mention the chemical process of gypsum formation from components in marl itself, which weakens the structure of marl, and simultaneously causes mechanical deterioration in cracks since gypsum has a considerably greater volume than the volume of the components involved in the process (Hawkins 2012 & 2015, Oldecop & Alonso 2012). All together, if marl is exposed to weathering, it changes its mechanical properties, which ultimately results in disintegration of initial embankment grains into smaller particles (Gautama & Shakoor 2013, Son & Chang 2009, Tschernutter 2011, Miščević & Vlastelica 2012, Zhang et al. 2012). A completely degraded material can be described as soil with silt-sized particles (Sadisun et al. 2005). Since compressive strength of soft rock is relatively small in comparison with hard rocks (Tziallas et al. 2013) fracturing of grains in the embankment structure can also be a consequence of stress states (Pinyol et al., 2007). Such a process is particularly pronounced when marl is weakened by the weathering process.

2. LABORATORY SIMULATION OF SETTLEMENT

2.1 Testing apparatus

Considering that there is no standard apparatus for testing settlement due to embankment grain deterioration, a device in the form of a testing cylinder was made. The cylinder is basically conceived as a standard edometer for testing soil samples, but modified for testing purpose (Zhang, et al. 2011, Zhang, et al. 2015), or without the possibility of applying load in vertical direction. The device and its section are shown in Figure 1.

The cylinder has an internal diameter of 26 cm and height of 14.95 cm. The upper plate can freely move vertically. The plate is perforated with the purpose of more efficient sample wetting and drying. On top there is a removable rigid frame holding a dial gauge with a precision of 0.002 mm for measuring the vertical displacement of the top plate. The frame is removed in the drying stage to prevent the measuring device from being damaged. The frame has three fixed attachment points in order to minimize the effect of frame removal and replacement on the measurement accuracy. The valve for water discharge after the sample wetting stage is at the bottom of the cylinder. In order to prevent fine particles from being washed out from the sample, filter paper is placed in the valve inlet zone. Each test was carried out simultaneously with two identical cylinders for the same crushed marl samples, with the purpose of confirming the measured results.

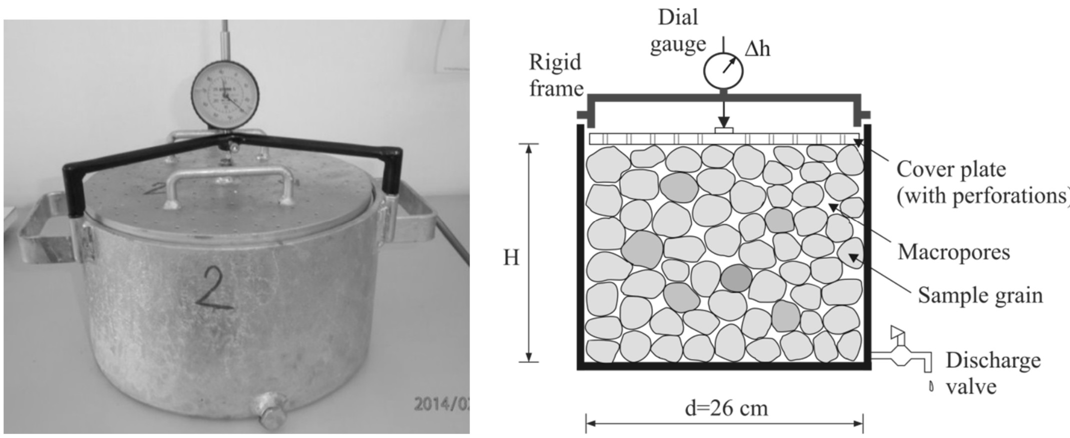

Figure 1. Testing cylinder

2.2 Sample preparation

Marl samples used in this investigation were taken from the wider area of the Split city. The geological characteristics of the area are described in the paper Miščević and Vlastelica, 2011. The test samples were prepared by mechanical crushing of marl in the natural water content state. The properties of marl used for individual test samples are shown in Table 1.

Table 1. Properties of marl used for test samples

	sample 1	sample 2	sample 3
carbonate content	63.18 %	59.33 %	64.40 %
dry unit weight of marl (γ_{rd})	23.44 kN/m^3	22.99 kN/m^3	21.40 kN/m^3
slake durability index (I_{d2})	84.01 %	95.45%	86.9%

Test samples 1 and 2 had a uniform grain size distribution with grain sizes from 20 to 37.5 mm. The uniform grain size distribution was chosen in order to carry out a test with large volume of macropores. The material for test sample 3 was obtained by mixing the materials after initial crushing and sieving marl samples in the ratio: 30% of grains from 20 to 37.5 mm in diameter, 30 % of grains from 10 to 20 mm in diameter, 20% from 4 to 10 mm and 20% from 2 to 4 mm. A view of the surface of test samples 1 and 3 is shown in Figure 2, left after placement (before the test) and right after the test. Samples were placed without compaction in order to avoid additional mechanical fragmentation of test samples.

The upper surface of test samples was manually leveled as much as possible. Namely, grain peaks on the upper surface take the weight of the upper plate, and regardless of how small the plate weight is, deterioration of these peaks at the beginning of the tests contributes the most to the vertical displacement.

When the top plate was placed, settlement was observed in a period of 24 hours in order to confirm that there was no displacement as a consequence of the plate load. The test was intended to investigate the deformation resulting from the deterioration of grains within the test sample rather than the deformation resulting from a change in stress states within the test sample.

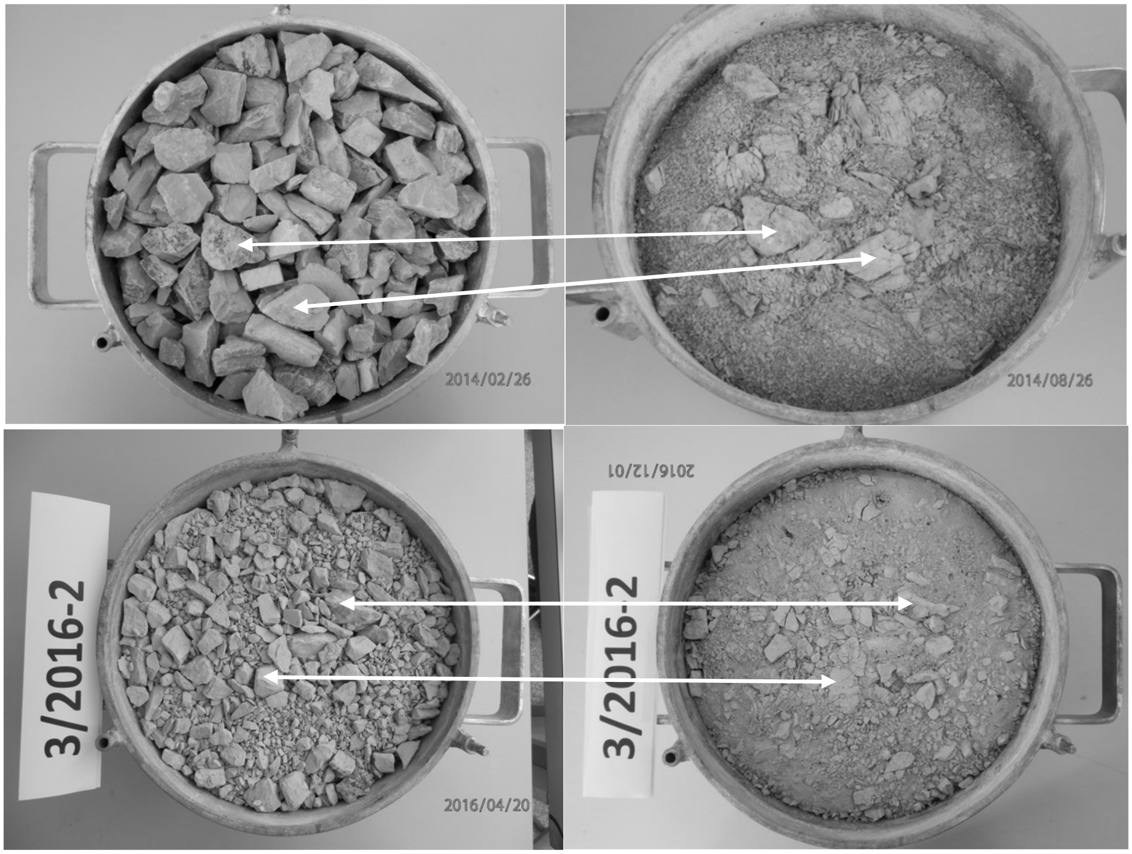

Figure 2. A view of the upper surface of test samples: 1- above, 3- below; before the test (left) and after the test (right)

2.3 Simulation of the weathering process

The weathering process was simulated under laboratory conditions with drying and wetting cycles. The wetting stage consisted of: closing of the discharge valve, filling the cylinder with demineralized water to eliminate the possibility of chemical processes caused by substances dissolved in water; keeping water in the cylinder for 2 hours; draining water through the valve at the bottom of the cylinder until the water is discharged. The drying stage consisted of: drying in dryer oven for at least 42 hours at a temperature of 105° C; cooling the cylinder at room temperature for at least 4 hours. For the sample size used, the drying period was defined as the period in which the water content of the sample decreased to less than 2%.

The described simulated weathering procedure indirectly included the effect of heating and drying on the weathering process. The intention was to speed up the weathering, because otherwise testing would require a period of several years due to long drying at room temperature. In real embankments, the temperature change magnitude is small because the interior of the embankment is protected from warming by sunlight.

2.4 Test results

Change in height of each of the two probes of each test sample was measured after every drying and wetting stage. The measured changes in height of both probes are shown: in Figure 3 for test sample 1, in Figure 4 for test sample 2, and in Figure 5 for test sample 3.

The swelling potential of each test sample can be seen on the presented graphs as the increase in height after the wetting stage. The periods on the graphs with no measured data are the periods of vacations. The interruptions of tests did not affect the final values.

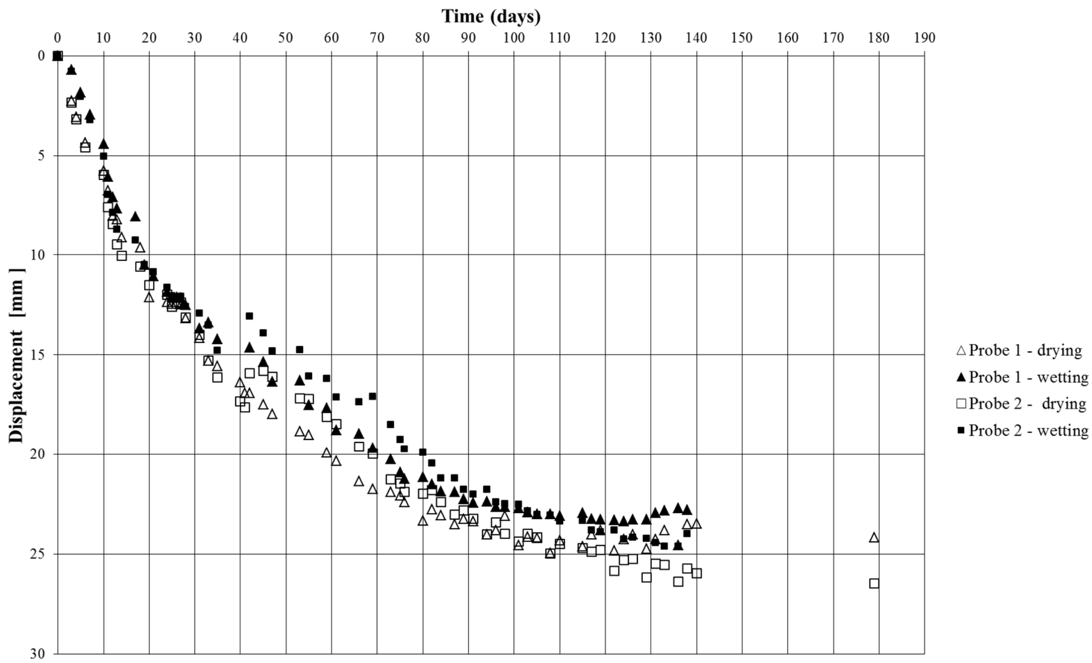

Figure 3. Change in height of test sample 1 (probes 1 and 2) after drying stageand wetting stage

If the top surfaces of test samples before and after the tests (Figure 2) are compared, it is possible to observe the zones that can be identified as initial grains in the structure before the beginning of the tests (examples are marked on the figure with arrows connecting views of grains before and after the tests). Most of the initial grains were disintegrated into smaller particles but can still be recognized on the surface as higher density zones. A part of the material is separated from the initial grains and transported by the action of gravity or water flow (in the stage of water draining from the cylinder) into surrounding macropores. This process decreases the volume of macropores. The transported parts of grains are further deteriorated by the action of weathering, and completely degraded marl can be observed as a material with silt-sized particles. For the test sample volume (cylinder) with dry unit weight of marl that forms grains in the structure, "macroporosity" is defined as "specific gravity" of the material forming the structure ($\gamma_{d,marl} \Rightarrow \gamma_s$).

The test samples with greater dry unit weight of the sample placed at the beginning of the tests have lower macroporosity, which causes lower additional settlement due to deterioration of initial grains.

On the analyzed test samples, the settlement was 17% of the initial sample height for sample 1 (average of two probes of the same test sample), 22% for sample 2, and 14% for sample 3. The macroporosity of the test samples at the beginning of the tests was n=0.52 for sample 1, n=0.49 for sample 2 and n=0.41 for sample 3. This leads to the conclusion that a lower initial macroporosity results in a lower additional settlement caused by deterioration of grains.

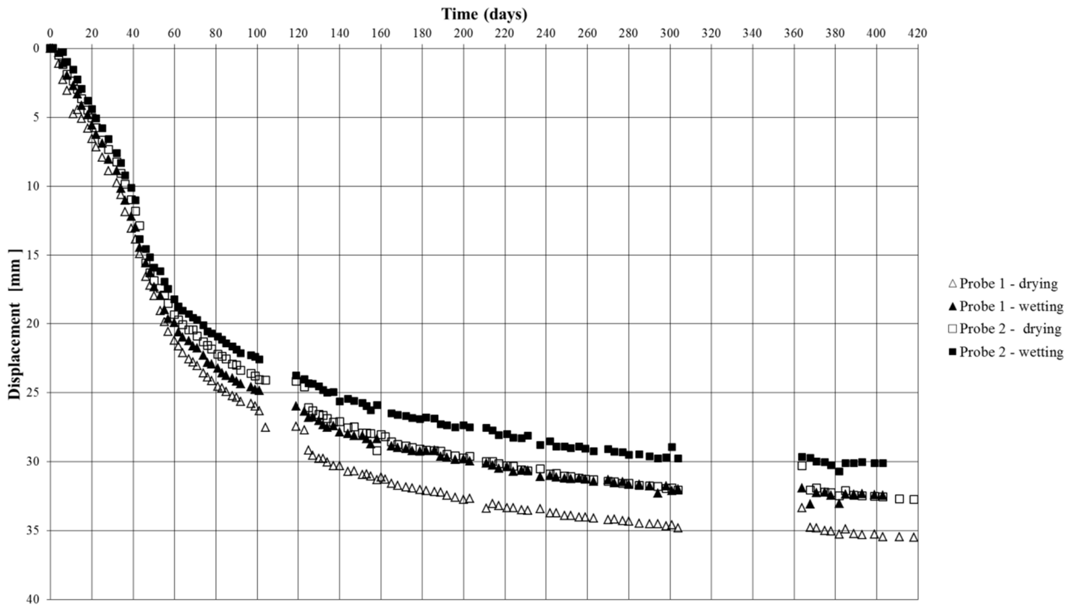

Figure 4. Change in height of test sample 2 (probes 1 and 2) after drying stageand wetting stage

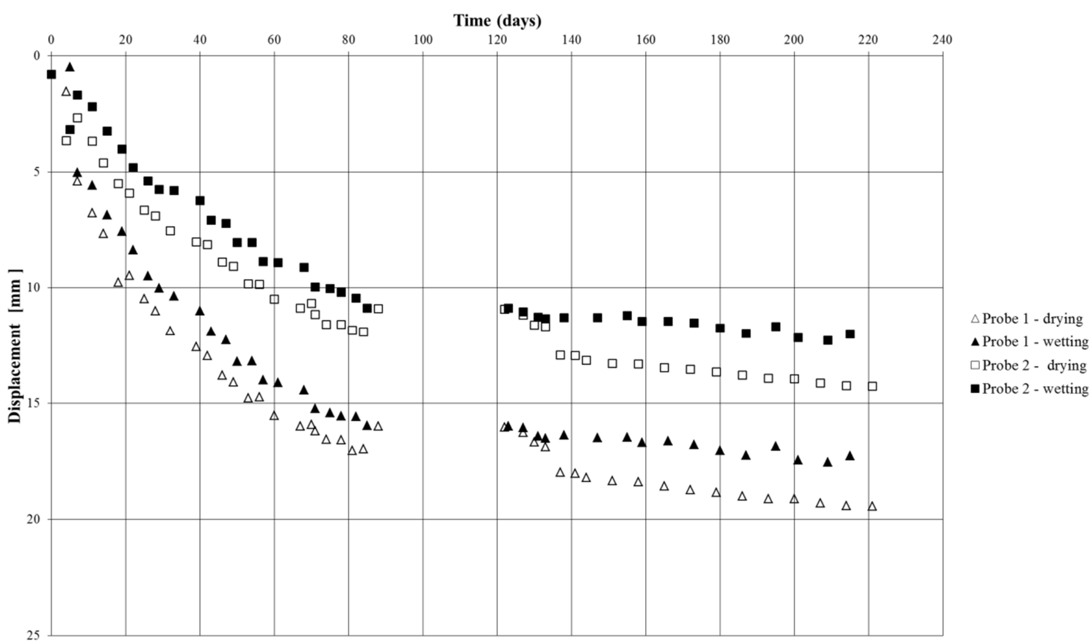

Figure 5. Change in height of test sample 3 (probes 1 and 2) after drying stageand wetting stage

3. CONCLUSIONS

Embankment made of crushed soft rock is susceptible to additional settlement due to deterioration of grains in the embankment structure. For grains of marl, the primary cause of deterioration is the weathering process resulting from changes in the water content within the embankment (drying and wetting). This settlement cannot be determined by compressibility of embankment layers measured after placement of material into the embankment.

The settlement caused by deterioration of grains in the embankment structure is very long due to the slow change of water content in a real embankment. The time required to achieve this settlement was several months even under laboratory "accelerated" water content change conditions on a relatively small volume of test samples. Under real conditions, this is a process that lasts for years, which is confirmed by examples from practice.

In order to reduce the effect of this additional settlement, it is necessary to place crushed marl with well-graded grain size distribution so as to achieve the lowest possible macroporosity of the placed embankment structure. The tested examples of marl samples indicate that the effect of grain deterioration on settlement reduces with reduction of macroporosity. A likely explanation is the fact that fragments separated from grains in a low macroporosity structure cannot be transported within the structure and so there is no change in structure volume that leads to the effect of additional settlement. This assumption, in order to be confirmed, requires further research with test samples of lower macroporosity.

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