RESILIENT MODULUS OF PAVEMENT MATERIAL FROM ORGANIC MATTER ENRICHED PUMICE

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KEYWORDS

Pavement material, Pumice, Organic, Cyclic triaxial testing, Resilient modulus

ABSTRACT

Green areas in connection to densely build up areas are often desired. These can be made, e.g. on top of garage basements or buildings. In order to integrate layers where planting is possible ("growth layers"), and layers with a certain stiffness that would enable some traffic such as e.g. parking, special material is required.

The currently presented materials are made from pumice mixed with organic matter, where the pumice shall provide the required stiffness, and the added organic material shall provide the requisite fertility. Besides having an appropriate stiffness, the pumice also enhances the performance of the growth layer with respect to moisture transport and oxidation of the layer.

Four materials, including clean pumice and pumice enriched with organic matter, are tested in order to determine resilient modulus as a measure of stiffness. The tested material is in variable grain size of up to 20 mm.

In the first, conditioning phase the specimens were exposed to 20 000 cycles. Subsequently, cyclic phases at different cell pressures were performed in order to determine the resilient moduli as a function of overlaying stress and the cyclic load.

The article presents the results and comparison of the cyclic triaxial tests on clean and organic enriched pumice-based pavement materials.

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1. INTRODUCTION

Natural pumice is a porous stone that can soak up to 50 % of water and still include more than 25% of air. While the use of pumice for soil stabilization is well documented in landscaping and horticulture, the material is also used for soil improvement in road building (e.g. Çimen et al. 2015 [9]). Based on this, it is presumed that an organic-enriched pumice-based material can have resilient moduli sufficient to sustain light traffic, while being able to support growth of plants with respect to nourishment, moisture transport and oxidation of the layer. This would allow for use of the present material where planting and some traffic such as e.g. parking are simultaneously desired.

The tested pumice-based materials are composed of pumice gravel in variable grain sizes of up to 20 mm, and organic matter. Both clean pumice and organic-enriched materials are tested.

Preliminary testing of the material included limited determinations of grain density cf. DS/EN 17892-3 [1], grain size distributions cf. DS/EN 17892-4 [2] (proprietary data), and maximum dry density and water content by means of vibration table cf. DS/EN 13286-5 [3].

Mineralogy of the tested pumice has not been determined. In general, pumiceous sands and gravels are siliceous materials with lower specific gravity than silica sands, typically up to 2.5 (Asadi et al. 2017 [5], Pender et al. 2006 [8], Chaney et al. 2001 [6]). Specific gravity of the presently tested clean pumice is 2.38. It is underlined by e.g. Chaney et al. 2001 and Pender et al. 2006, that due to the closed porosity of pumice, typical grain size and the very procedure of testing may influence the test value.

Vibration table test of clean pumice at full saturation resulted in a soft, low density, structureless specimen. The test at natural water content resulted in a firm, high density specimen. Specimens for subsequent cyclic triaxial testing are therefore built in by tamping the material at natural water content to 95% of the maximal dry density determined in the vibration table tests.

The grain size distribution testing prior to, and after the vibration table test on clean pumice showed an increase in the content of fines from about 4% to about 10%, attributed to particle crushing.

One cyclic triaxial test was performed on material that was also including a fraction of scoria. Scoria is material that is typically denser and with a higher strength than pumice, with larger pores and thicker pore walls. Variety of uses of scoria for e.g. landscaping, horticulture and roadbeds is documented by Dehn and McNutt 2015 [7].

Finally, it should be noted that the tests were carried out over a span of several years and without a scientific purpose.

2. CYCLIC LOAD TRIAXIAL TEST FOR UNBOUND MATERIAL

Testing program and sample conditioning

Four drained cyclic triaxial tests were conducted on materials summarized in Table 1 in order to determine resilient moduli. Note that Test 2 has been rerun in the resilient phase due to technical issues.

Table 1. Overview of materials for drained cyclic triaxial testing

Test no.	Material	Fraction [mm-mm]	Organic content [%]	Dry density [g/cm^3]	Saturation [%]	H/D [mm/mm]
1	Clean pumice	0-10	0	0.84	100[a]	140/70
2	Pumice with organic content	0-18	15	0.59	n.a.	200/100
3		10-20	10	0.51	100[a]	200/100
4	Pumice with scoria and organic content	0-7 (scoria) 10-18 (pumice)	10	0.72	49[b]	200/100

[a] Estimated and referring to the open pores space.

[b] Calculated based on the material crushed after test.

Conditioning of specimens was carried out at the effective axial stress of about 170 kPa and constant cell pressure (confining stress) of 70 kPa; 20 000 cycles was carried out with the cyclic stress deviator of 200 kPa corresponding to the low stress level of the Method B of DS/EN 13286-7 [1]. Characteristic permanent axial strain cf. Annex C of DS/EN 13286-7 is presented in Table 2.

Table 2. Characteristic permanent strain based on the conditioning phase

Test no.	Permanent axial strain		
	end of conditioning, $\varepsilon_1^{p}{}_{(20000)}$ [%]	after 100 cycles, $\varepsilon_1^{p}{}_{(100)}$ [%]	characteristic $\varepsilon_1^{c} = \varepsilon_1^{p}{}_{(20000)} - \varepsilon_1^{p}{}_{(100)}$ [%]
1	1.50	n.a.	<1.50
2	1.24	0.61	0.63
3	1.98	0.72	1.26
4	2.89[a]	2.37[a]	0.52

[a] >1 % occurring during the first cycle of conditioning

Following DS/EN 13286-7, materials 1, 2 and 3 have been validated for repeated loading for resilient testing as the axial strain of 2 % was not exceeded in the conditioning phase. In the Test no. 4, a significant portion of axial strain (>1%) occurred during the first conditioning cycle. This was considered to be an effect of bedding, and consequently, the material is validated for resilient testing.

Study of resilient modulus

The testing was conducted principally following the Constant confining pressure procedure (Method B of DS/EN 13286-7). At each confinement stress, 100 cycles were applied at each of several cyclic deviator stress levels (hereafter "series"). In order to comply with 100 cycles requirement, Test 2 has been rerun after initial series at 20 and 35 kPa confinement stress that were carried out with 41 to 47 cycles. An example of stress conditions for all series in Test 1 is plotted against double amplitude cyclic axial strain at the end of each series in Figure 1. Double amplitude cyclic axial strain and cyclic stress deviators are defined in Figure 2.

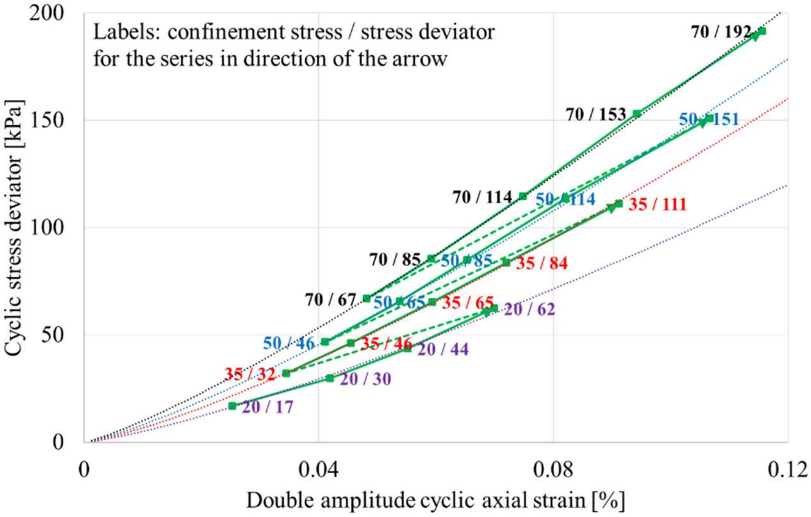

Figure 1 Testing levels and resilience example from the test on clean pumice (1)

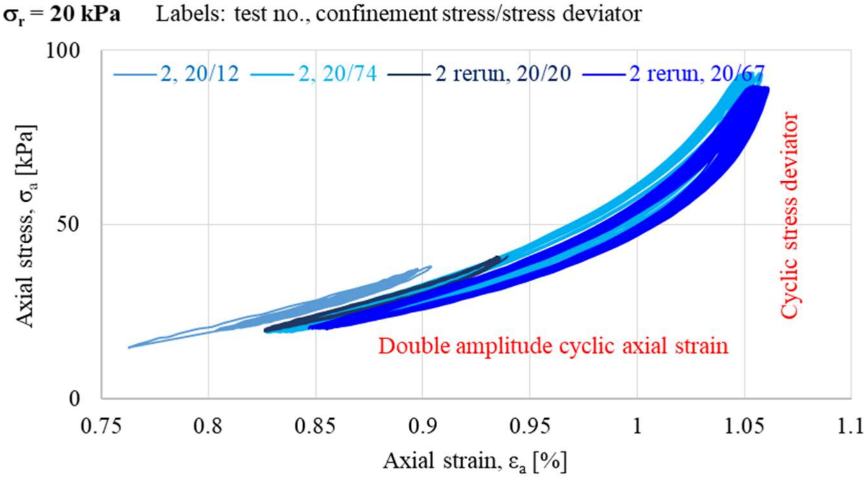

Figure 2 Possible effect of rerun depicted on selected series within Tests 2 and 2,rerun.

Following the standard, all four tests have been carried out at the confinement stress levels of 20, 35, 50 and 70 kPa, see Figure 3. In addition, Test 4 has been carried out at confinement stress levels of 100 and 150 kPa. All the series carried out at constant confinement stress levels are marked with arrow lines in Figure 3. Double amplitude cyclic axial strain in Figure 3 is measured in the last cycle of every series against the applied cyclic stress deviators. Upon the last cyclic state at constant confinement pressure, the tests continued at the next confinement state; this is indicated with dotted lines in Figure 3.

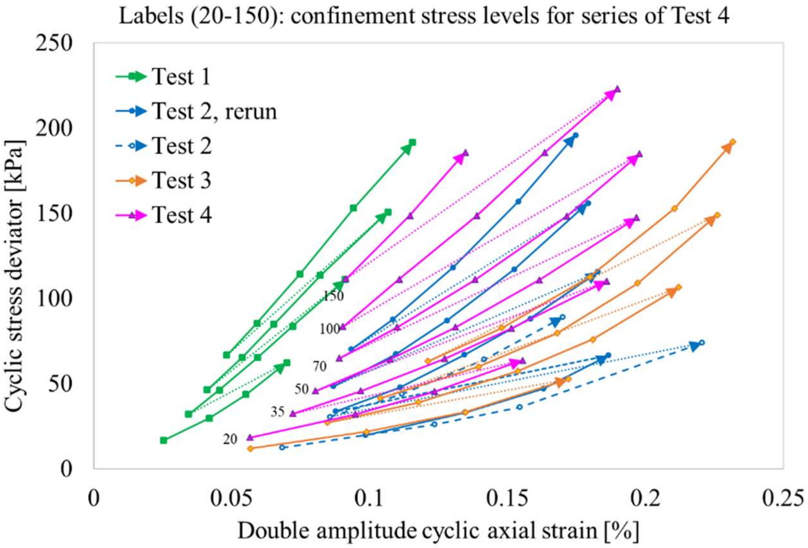

Figure 3 Simplified stress strain paths.

3. RESULTS AND DISCUSSION

As depicted in Figure 2, the stress strain response during the resilient cycling is typically nonlinear, with a small hysteresis. Similar is observed both for clean pumice and pumice enriched with organic material.

Resilience for the clean pumice (Test 1) can be seen on Figure 1 showing the final stress-strain states for each of the series in the space of cyclic stress deviator and double amplitude cyclic axial strain. Figure shows that all strain development curves originate at 0, indicating that the full unload of specimen to no confinement and no cyclic deviator state results with full reversal of strains, thus confirming resilience.

Resilient modulus, E_r, is defined as a ratio of cyclic deviator stress to resilient strain. The resilient strain is a measure of deformation occurring during elastic loading, i.e. fully reversible. The variation of E_r within the space of the elastic loading and occurring resilient strain may take any trend while depending on the load level or other factors causing elastic nonlinearity. E_r is determined as a function of confinement pressure and the cyclic stress deviator and presented in Figure 4.

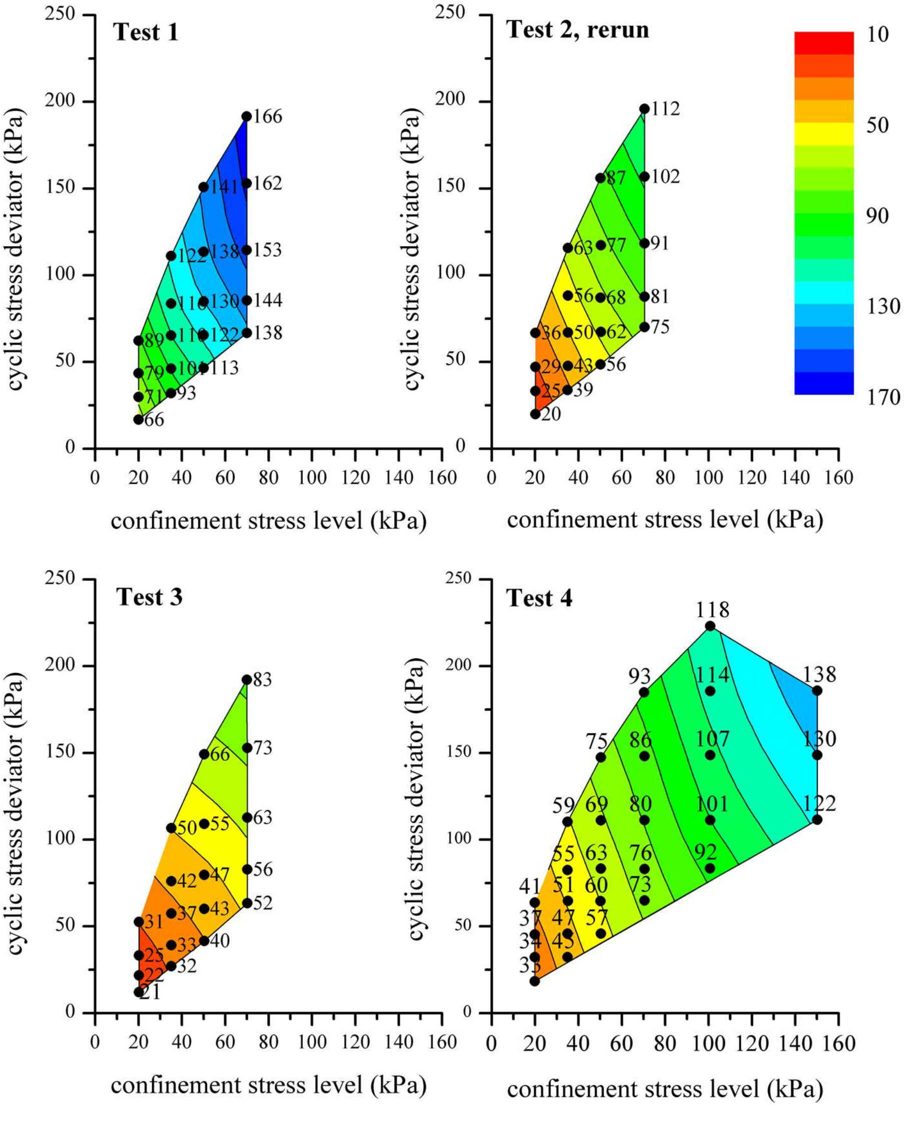

Figure 4 Resilient moduli contours as function of cyclic stress deviator and confining stress level. Labels: Er test results

The reduction of E_r increase with increasing confining pressure in clean pumice (Test 1) is found in overall agreement with the results of Asadi et al. 2017 [5].

A comparison of the four materials is presented in Figure 5, per confinement stress level. The clean pumice in Test 1 has the highest stiffness. For all the tests with organic material, E_r is significantly lower. At higher confinement stresses, the nonlinearity of E_r against the cyclic deviator stress is the highest in clean pumice. The lowest increase of E_r with cyclic stress deviator is seen in pumice enriched with scoria and organic matter (Test 4).

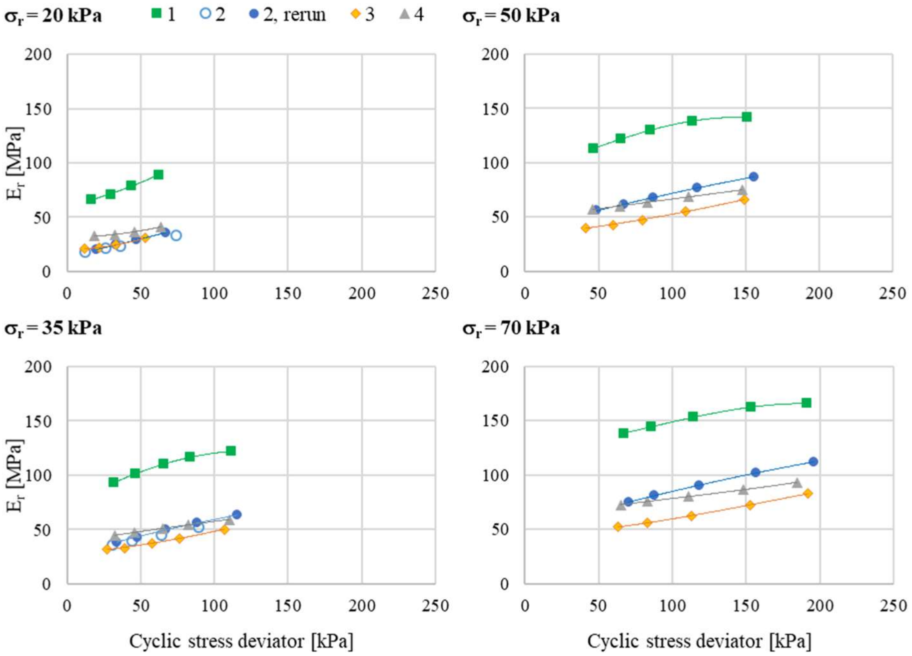

Figure 5 Resilient moduli as function of cyclic stress deviator per confining stress level, σ_r, ranging from 20 to 70 kPa

A possible effect of a rerun is observed on a medium coarse specimen with 15 % organic material (Test 2 and Test 2,rerun). Figures 2 and 3 show that the moduli in the series at 20 and 35 kPa confinement increased in the rerun, possibly at the expense of increased average axial strain. However, the evaluation of E_r may also be influenced with the lower number of cycles in the series of the original run of Test 2.

4. CONCLUSIONS

The four presented tests showed that the testing standard DS/EN 13286-7 is generally applicable for testing of resilient modulus on clean pumice gravel and pumice enriched with organic material.

Testing showed nonlinear stress strain response in resilient loading cycles, and confirmed the resilience of cyclic strain.

The highest E_r moduli are evaluated for clean pumice gravel, which is finer than the gravel used in samples enriched by organic materials. At low confinement stress of 20 kPa, there is no significant difference in E_r between the Tests 2 and

3, whereas Test 4 on the material enriched with scoria showed higher moduli. Generally, the lowest E_r moduli are evaluated for the coarsest material (Test 3).

Characteristic permanent strain based on the four tests generally classifies materials in Class C3 cf. DS/EN 13286-7 Annex C.

ACKNOWLEDGEMENT

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