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EFFECT OF PRIOR CYCLIC LOADING ON TRIAXIAL MONOTONIC EXPERIMENTS

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Abstract

Drained triaxial monotonic test is one of the most frequently used experiments in geotechnical engineering, mostly because its results are starting points for many research topics. This paper presents triaxial drained monotonic experiments on natural sand borrowed from the terraces of river Vardar, that passes through Skopje. This Skopje sand is highly uniform sand with only 2% fines, and a uniformity coefficient $C_u = 2$ with mean grain size of $d_{50} = 0.17$mm. It can be found at multiple places along the riverbank of Vardar River at different depths. Since this is an urban area, such sandy layers can be exposed to different sources of dynamic loads (traffic from roads, railways, factories, etc.) Knowing the fact that cyclic preloading has effects on the soil strength characteristics, these effects were investigated in the case of prior cyclic loading on consolidated drained triaxial compression monotonic test. The specimens were prepared using wet-tamping method at high range of different initial relative densities, then confined at three levels of initial effective stress $p_0 = 50$, 100 and 200kPa before shearing. The effect of the number of cycles and their amplitudes are also investigated not only on the curves of deviatoric stress q and volumetric strain ε_v versus axial strain ε_1 but additionally on the dependency curves that display the influence of the initial density I_{DO} and initial effective pressure p_0 on the peak friction angle φ_p, Young's modulus E_{50}, axial strain at peak ε_p and dilatancy angle ψ. The results indicate interesting outcomes concerning the physical behaviour of the investigated sand.

Keywords: Skopje sand, cyclic preloading, monotonic drained tests, initial density and pressure dependency

1. Introduction

Sand analysed in the paper can be found in multiple areas along the riverbank of Vardar river at different depths. Because the river passes through the urban city area these sandy layers are exposed to different sources of dynamic loading that can apply cyclic preloading on the sand. This calls for experimental data that will improve our understanding of the influence of cyclic preloading on the response to drained monotonic and cyclic loading for the investigated sand. For the purpose of the paper triaxial experiments were performed where specimens were prepared using a wet-tamping method [1] at different initial relative densities, then confined at three levels of initial effective stress p_0=50, 100, and 200kPa. Most of the monotonic drained tests without preloading are done in previous research [2,3], only now the database is enriched with additional experiments so that we can perceive the influence of cyclic preloading. This effect is presented throw the curves of deviatoric stress q and volumetric strain ε_v versus axial strain ε_1, but additionally on multiple dependency curves. Specimens are preloaded with 40 cycles with a shear strain amplitude of 0.01%. Cumulative strain from the preloading is at very low levels and doesn't change the specimen void ratio, which is probably the most important factor that needs to be fulfilled for a correct comparison to be made [4,5,6]. Additionally, the effect of the number of cycles and their amplitude is investigated. Tests with preloading of 20 cycles with the same amplitude and tests with 40 cycles but the double amplitude of 0.02% are performed for a void ratio range of Dr=45-55% to conclude if there is a real need for additional experiments.

2. Testing material and triaxial equipment

As mentioned before, the testing material represents natural fluvial sand so-called "Skopje sand" that consists mainly of silica oxides (around 78%) with particles of subangular shape. Because we are working with natural sand small differences in each borrowed batch are expected, so initial investigations are necessary to determine its physical properties (Table 1). The sand is highly uniform and has only 2% fines with a mean grain size of d_{50} = 0.17mm and a uniformity coefficient C_u = 2. The void ratios were determined using ASTM D4253-00 standards, e_{min} = 0.51 and e_{max} = 0.90, at mean pressure p = 0kPa.

Table 1 – Physical properties of Skopje sand

e_{max}	e_{min}	G_s	D_{10} (mm)	D_{50} (mm)	D_{60} (mm)	Cu	Cc	φ (o)	Fines (%)
0.95	0.51	2.615	0.095	0.26	0.19	1.8	0.8	33.5	2

The triaxial testing device used for the experiments presents a feedback-controlled cyclic triaxial system that can apply cyclic or dynamic loading to cylindrical soil specimens. This apparatus is a servo pneumatic system, with control on axial stress, confining pressure, and back pressure by incorporated Control and Data Acquisition System (CDAS). During the testing maximum of seven transducers in total are active. This includes measurements of the cell, back and pore pressure using pressure transducers, measurements of the applied axial load with submersible load cell and volume change of water entering or leaving the sample. Also, two axial transducers can acquire the deformations directly on the sample. All the data acquisition functions, critical control and timing are provided by the CDAS.

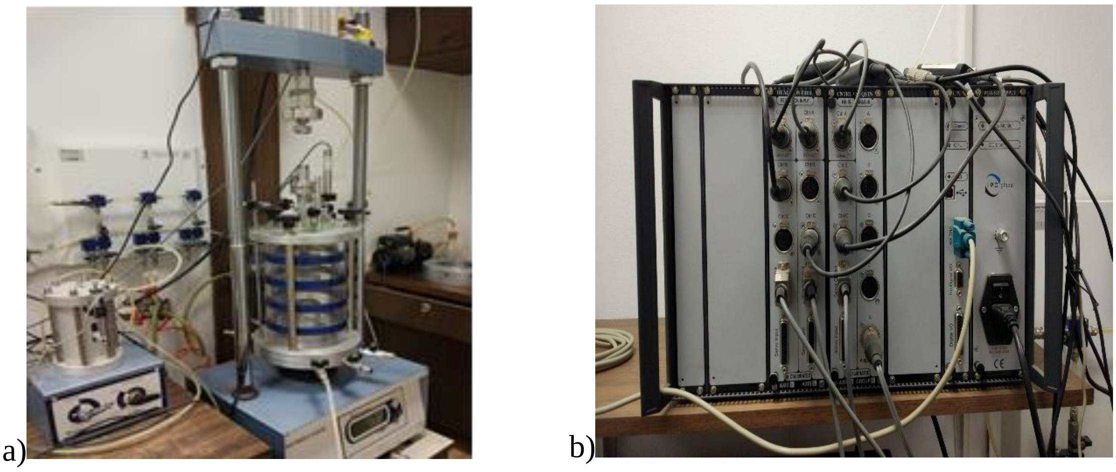

Figure 1. a) Triaxial and volume change equipment, b) Control and data acquisition system

As mentioned before all samples were reconstituted by wet-tamping in layers, using a three-piece steel cylinder lined with a rubber membrane. To speed up and achieve better saturation all samples were first saturated using CO_2 and only after with water up to B-value ≥0.95. The volume change was measured by pore-water volume change apparatus, while the specimens were axially strained at a rate of 0.2mm/min.

3. Results

Measured curves of deviatoric stress q and volumetric strain ε_v versus axial strain ε_1 from the drained monotonic triaxial tests are shown in the following figures and compared with the 40 cycles preloaded

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experiments grouped in three levels of densities. The increase of the deviatoric stress with the increasing effective pressure and density can be observed, as well as the increase of dilatancy. In terms of the comparison, it can be noticed that the preloading effects the response constantly and has a higher effect on the test with higher effective stress and usually lowers the peak deviatoric stress that the specimen can sustain.

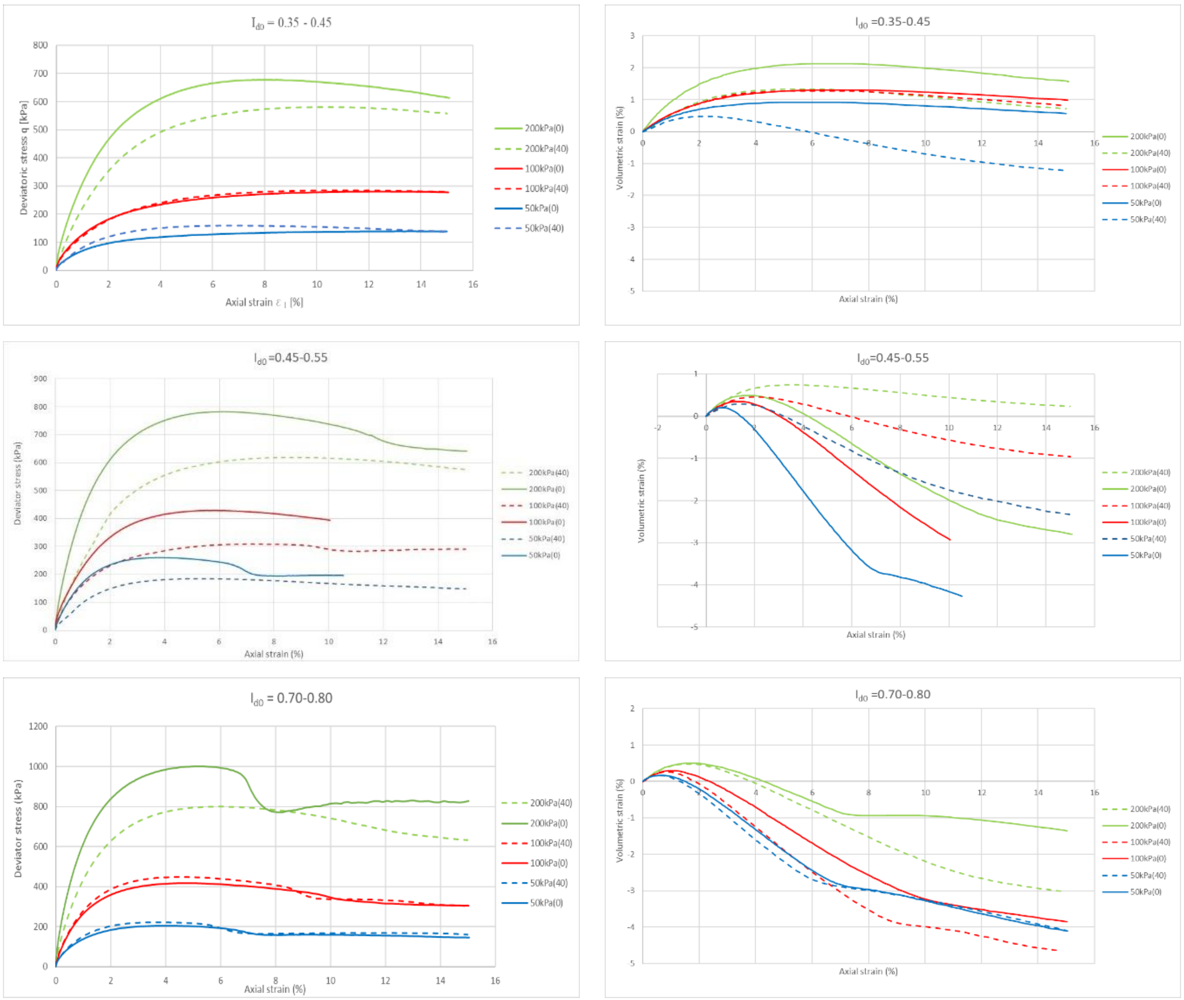

Figure 2. Comparison of deviatoric stress q and volumetric strain ε_v versus axial strain ε_1 as a result from drained monotonic triaxial tests

To investigate if there is an influence on the drained monotonic results from change in number of cycles applied in the preloading and their level of amplitude additional experiments were made. The number of cycles is lowered from 40 to 20 while in the second series of experiments the amplitude it is doubled from a shear strain of 0.01% to 0.02%. Again, the cumulative strain from the preloading is at a very low level that doesn't affect the initial void ratio of the specimens and the final results. All of the performed experiments were in the same range of initial densities I_{d0}=0.45-0.55 for three levels of effective stress, same as before, 50, 100 and 200kPa. From figure 3 can be noticed that the deviatoric stress q curve is not affected by the change in the number of cycles and their amplitude, at least not for the one that we are investigating. Further experiments will be made to find the limits where this is applicable and true.

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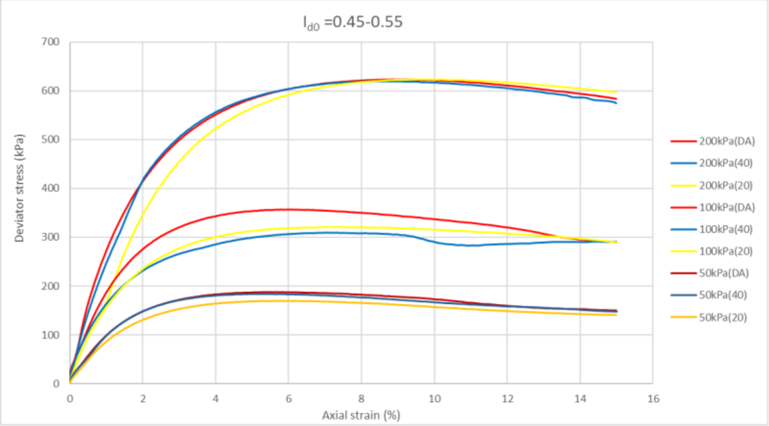
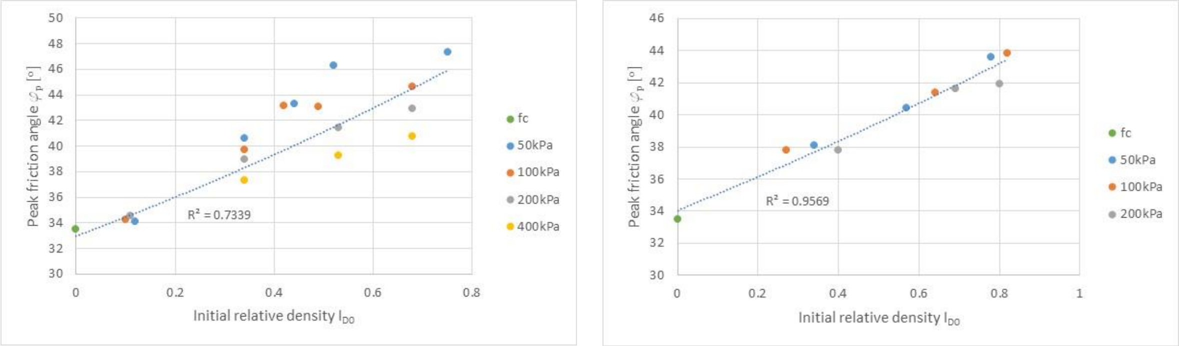


Figure 3. Effects of the number of preloading cycles and their amplitude to the deviatoric stress q versus axial strain ε_1 curve

Additionally, the effect of preloading is investigated on multiple dependency curves that mostly display the influence of the initial density I_{D0} and initial effective pressure p_0. Firstly we will look at the dependence of the friction angle. The critical friction angle φ_c that corresponds with the peak friction angle φ_p for zero initial density (I_{do}=0) has been determined from a loosely pluviated cone of sand, as an angle of repose, according to the procedure explained by Herle [7]. The measured critical friction angle together with all the peak friction angles derived from the drained monotonic triaxial tests are presented in Figure 4.



a) without preloading

b) with preloading

Figure 4. Peak friction angle φ_p versus initial relative density I_{DO}

The increase of the friction angle with the increase of the initial density can be observed on both trendlines, with or without applied preloading, together with a small decrease for higher initial effective pressures. A similar decrease in the friction angle as a consequence of the effective pressure is also noted in other researcher’s work [8,9]. When all results are placed on a single graphic (Figure 5) it can be noticed that higher peak friction angles are obtained for tests without preloading.

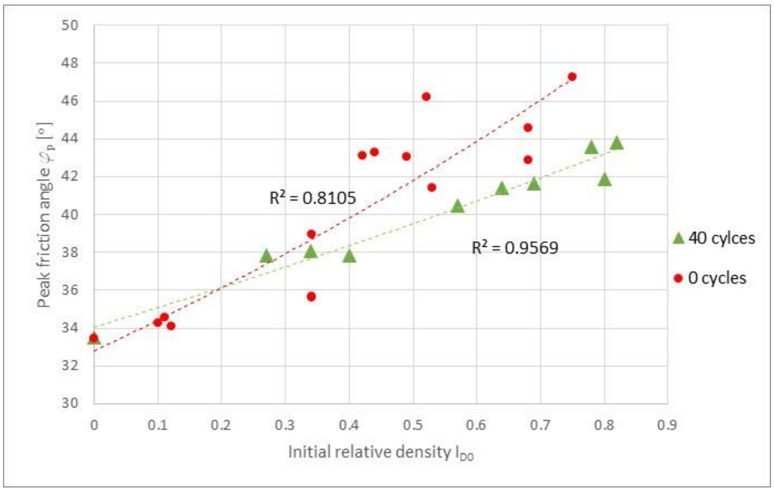
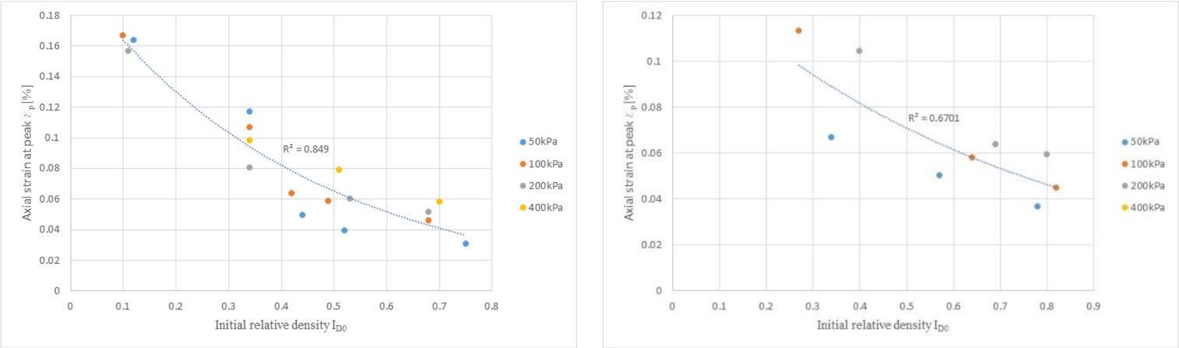


Figure 5. Summary graphic of peak friction angle φ_p versus initial relative density I_{DO}

The axial strains ε_p corresponding to the peak deviatoric stress from each experiment together with the initial relative densities are plotted in figure 6 for both types of experiments. Both plots reveal that in the case of higher initial densities the deviatoric peak occurs much sooner, also small pressure-dependence can be noted [10]. Both plots are combined in figure 7 where can be perceived that they follow almost the same trendline.



a) without preloading

b) with preloading

Figure 6. Axial strain at peak ε_p as a function of the initial relative density I_{DO}

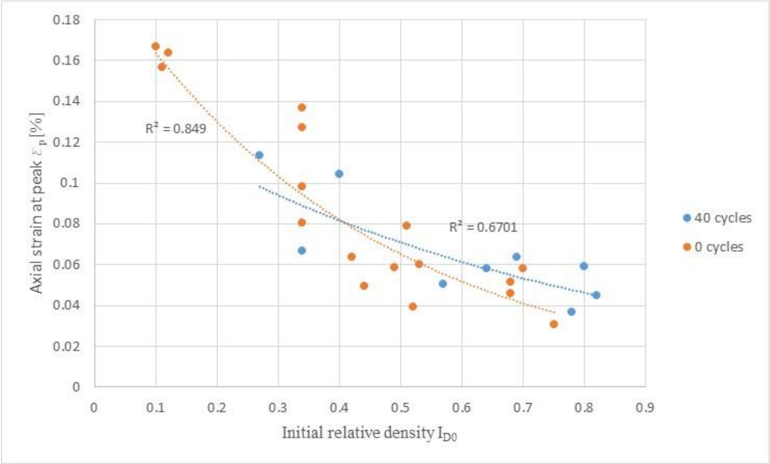


Figure 7. Summary graphic of axial strain at peak ε_p as a function of the initial relative density I_{DO}

Young's modulus E_{50} derived as a secant stiffness between q=0 and q= $q_{max}/2$ is presented as a function of the initial density I_{D0} in figure 8. In both cases the modulus increase with an increase of both initial density and effective pressure, with stronger pressure-dependence for a higher level of initial density. Preloaded experiments have significantly lower E_{50} values which is a common find in the literature [11] often cycle number and intensity dependant. The difference between the modulus is increased with the increase of both initial density and effective pressure.

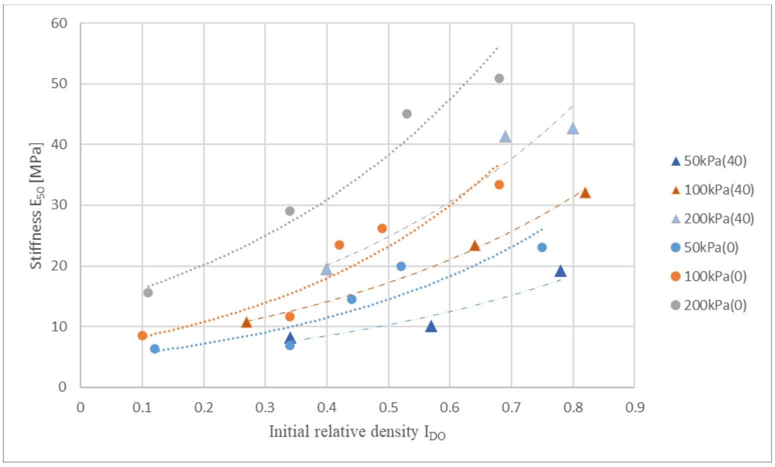


Figure 8. Summary graphic of Young's modulus E_{50} versus initial relative density I_{DO}

The last dependency curve that we will observe is the change of the dilatancy angle ψ as a function of the initial density I_{D0}. This angle can be recognized in the volumetric strain, ε_v, versus axial strain, ε_1, plots. In the case of triaxial conditions the two principal stresses are equal, $\sigma_2 = \sigma_3$, which implies that both mechanisms defined by the yield functions are simultaneously active [12]. Knowing the value of the increments of the volumetric strain $d\varepsilon_v$ and axial strain, $d\varepsilon_1$, the value of ψ in each step can be calculated using the equation (1):

$$\psi = \arcsin\left(\frac{\dfrac{d\varepsilon_v}{d\varepsilon_a}}{\dfrac{d\varepsilon_v}{d\varepsilon_a} - 2}\right); \qquad (1)$$

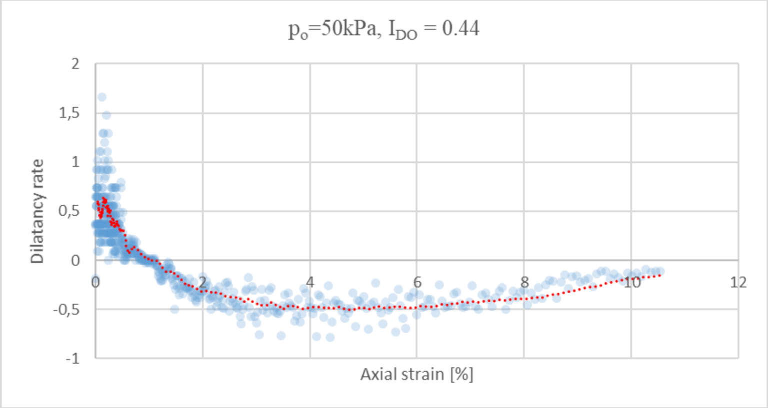
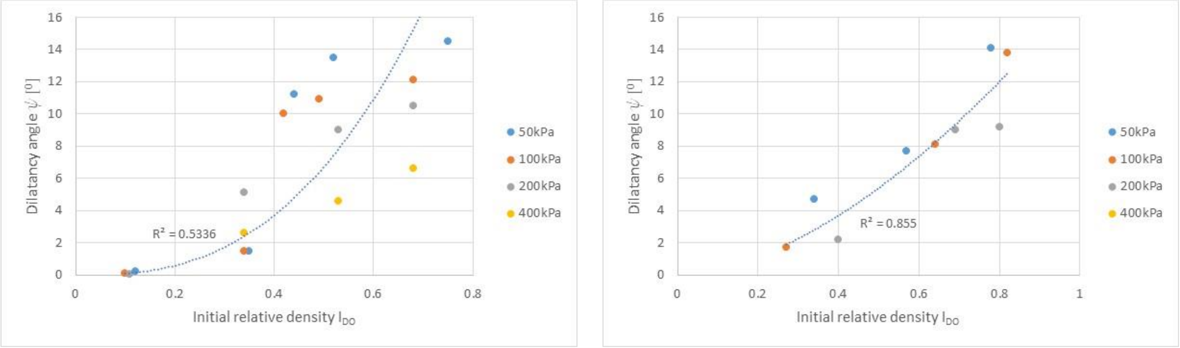


Figure 9. Dilatancy rate versus the axial strain from one experiment

Because there are jumps in the computed dilatancy rate from increment to increment acquired from the experiment to present a clearer trend, a smoothed curve, obtained by a moving average procedure is computed for each experiment (Figure 9). From the smoothed curve the maximum rate of dilatancy is attained which is coinciding with the deviatoric stress peak. Afterward using equation (1) the value of the dilatancy angle is computed and added to a graph versus the initial relative density (figure 10).



a) without preloading

b) with preloading

Figure 10. Dilatancy angle ψ as a function of initial relative density I_{DO}

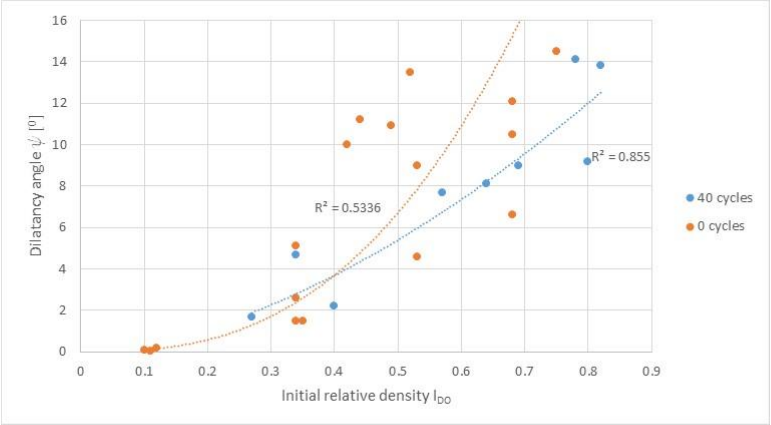


Figure 11. Summary graphic of dilatancy angle ψ as a function of initial relative density I_{DO}

The computed dilatancy angles are close to zero for low initial densities. The change of initial density and initial effective pressure in both cases have the same effect on the dilatancy angle as in the case of peak friction angle [13,14,15,16]. Preloaded samples demonstrate lower values of the dilatancy angles for similar initial densities, but more experiments are needed for the correlation to be proved.

5. Summary and conclusions

There are multiple studies published where Skopje sand is investigated to determine and establish its physical characteristic [2,3,17], but until this paper, there haven't been any experiments done using preloading. Since this type of sand can be found in the urban area of the city these types of experiments are necessary. Hopefully, this paper can act as a good foundation for further research on the subject.

From the curves of deviatoric stress q versus axial strain ε_a can be observed that cycling preloading often lowers the peak deviatoric stress that the specimen can sustain especially for tests done with higher initial effective stress, but no clear difference has been noticed when the number of preloading cycles and there amplitude is changed. The graph for Young's modulus E_{50} perfectly presents the effect of preloading where the difference between the modulus expands with an increase of both initial density

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and effective pressure. A small influence of the preloading has also been noted in the values of peak friction angles and dilatancy angles, usually lower then than one obtained from experiments without preloading, but still additional experiments are needed to make a clear conclusion or correlation between them.

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