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APPLICATION OF CYCLIC CBR TEST TO APPROXIMATION OF SUBGRADE DISPLACEMENT IN ROAD PAVEMENT

Wojciech Sas, Andrzej Głuchowski
Warsaw University of Life Sciences – SGGW

Abstract. The main aim of this paper was to approximate displacement of subgrade surface under cyclic loading. Soil specimens were loaded by force, which caused displacement to 2.54 mm. After that, specimens were loaded by the same force a number times. This procedure allowed to define the kind of displacement occurring under cyclic loading. An analysis of individual displacement was done on paper. Soil specimen was sandy clay and sandy clay stabilized by the addition of lime, the amount of which equals 8%. The additional aim was to prove that stabilization of cohesive soils with lime can marked increase stiffness of soil and to show various load-unload conditions of stabilized and non-stabilized sandy clay.

Key words: subgrade surface displacement, cyclic loading, CBR repeated test

INTRODUCTION

Unbound granular materials are widely used in Poland. Generally subbases are designed in accordance with Polish catalogue of typical structures of flexible and semi-rigid pavement [PCTSFSP 2001]. For this reason, pavements are models with constant material behavior where strains under acting stress are recoverable and well known.

In practice, after putting the road to service, many pavement subbases and subgrades fail during the first phases of exploitation, which causes ruttings to appear on the surface of roads and consequently turn out pavement from exploitation. When it comes to pavement design, the stress level must not be exceeded. If the stress exceeds the acceptable level, it will cause permanent deformation. Strain of pavement can be partially permanent also after compaction. It is only during the exploitation phase that the quality of pavement construction can be determined. However, destruction of pavements can be avoided, by fully understanding soil behavior under acting cyclic stress. Simulation of road traffic

Corresponding author – Adres do korespondencji: Wojciech Sas, Warsaw University of Life Sciences – SGGW, Faculty of Civil and Environmental Engineering, Water Center Laboratory, 6 Ciszewskiego St., 02-776 Warsaw, e-mail: wojciech_sas@sggw.pl

clearly shows how subbases and subgrades respond. After numerous load-unload cycles, granular materials exhibit resilient response. If pavement is loaded by constant force, eventually its strain will behave fully elastically.

On the other hand, first cycles are mostly consist of permanent deformation. The increase in load force causes new permanent deformation and new cycle of deformations of subbase layers. To obtain resilient response of pavements materials, surface deformation increases until fully elastic reaction occurs.

The most common subgrade soil layer in Poland, more or less, is clay or clayey soil. This material has poor bearing capacity properties and depends on moisture content. Because of that, almost every time, its quality has to be improved to acceptable values. One of the tools that make it possible is stabilization work.

Clayey soils are stabilized mostly by lime. It is proven, that adding lime to clayey can rapidly and highly increase bearing capacity and stiffness of this soil.

To measure the impact of a load on a compacted subgrade build from sandy clay and the size of displacement, a cyclic CBR test can be used.

By such test we can obtain parameters of displacement by forced load on specimen. For the purpose of this article we assume that compacted soil is loaded by force which that causes specimen penetration of 2.54 mm, by acting on this surface 50 times.

LITERATURE BACKGROUND

The term “resilient”describes a portion of energy that is put into a material while it is being loaded and later completely recovered when it is unloaded [Adu-Osei 2000].

Resilient response of granular materials in a pavement depends on its stress history, the current stress level and the degree of saturation. Being a typical granular material, soils do not respond fully elastically and they experience non recoverable deformation after each loading. After of numerous loads and sometimes even after applying force a number of times, non recoverable deformation are much smaller, compared to total deformation of specimen. These properties have impact on full elastic response of soil under cyclic loading [Brown 1996, Adu-Osei 2000]. Figure 1 shows the penetration of the sample in correlation to applied stress.

As it was mentioned above, displacement in soils caused by repeated stress is biggest in the first cycle. After that, repetition are much smaller. Resilient response can be obtain in a various level of following cycle.

In elastic theory, resilient response is a variant of linear elastic materials. Soils obey react to stress by three different ways: elastic – fully recoverable, plastic – non recoverable and visco-elastic – recoverable with time. These three strains are present in every cycle of load-unload cycle [Nazarian et al. 1996].

In pavement design, designers must prevent their constructions from becoming impaired in one of the many possible ways. One type pavement damages is routing. Ruts in pavements are caused by poor soil condition in subgrade, which is strongly linked with characteristic of permanent deformation. To avoid such problems, subgrade must be treated on equal terms with other pavement construction elements.

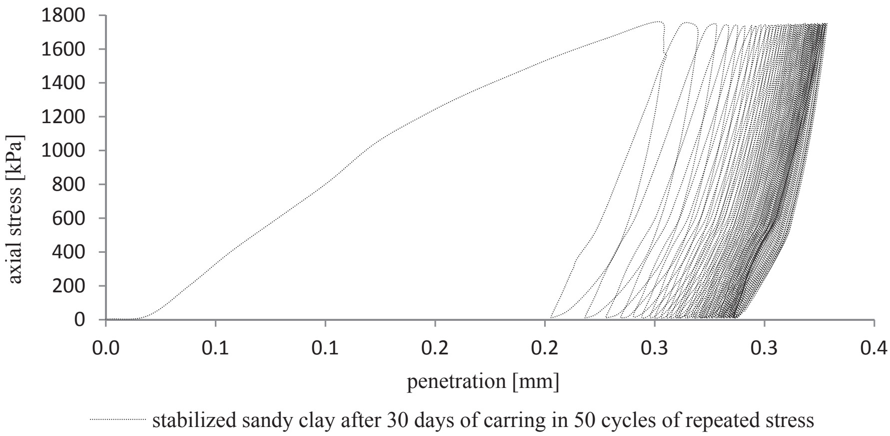

Fig. 1. Cyclic CBR test result for lime-stabilized sandy clay 30 days after stabilization

Permanent deformations are caused by plastic strains in granular materials. Applied stress is the main reason behind this process. Rising stress level causes bigger permanent deformations. In opposite to this, confining pressure increase causes plastic deformations to decrease.

However, subgrade soil resilient modulus estimation has lower impact on pavement work than M_R for asphalt concrete or for deep aggregate bases. These findings suggest that for practical use by the designers, resilient modulus could be estimated from empirical relations [Barksdale et al. 1997].

On the other hand, reliance on empirical equations can be dangerous for pavement. It is worth noting that subbases aggregate are stress sensitive and their performance depends on supporting ability of subgrade located at subbases layers. This observation was demonstrated in field research [Little 1999].

MATERIALS AND METHODS

Most of the subgrades in Poland are clayey soils, which do not meet the specification requirements of bearing capacity. Subgrade soils are classified by empirical properties to obtain bearing capacity [PCTSFSP 2001]. The most popular method to upgrade such soil properties as stiffness, elastic response or decrease permeability is stabilization [Little 1999]. In accordance with Eurocode 7, the soil was recognized as sandy clay [PN-EN 1997-2:2009] which was taken from road construction site. Proctor test for non-stabilized and stabilized soil was performed. Estimation of gradation curve was also undertaken. Figure 2 presents gradation curve for tested soil. Figure 3 shows results from Proctor test for non-stabilized and stabilized clay. Optimum moisture content was estimated as: 10.6% and 15.8% for non-stabilized and stabilized sandy clay respectively. Clay was stabilized by adding hydrated lime in the amount of 8%, and then was compacted with optimum moisture content. Stabilized soil maximum density reached by the Proctor method during compaction in CBR mould was 2.18 $g \cdot cm^{-3}$.

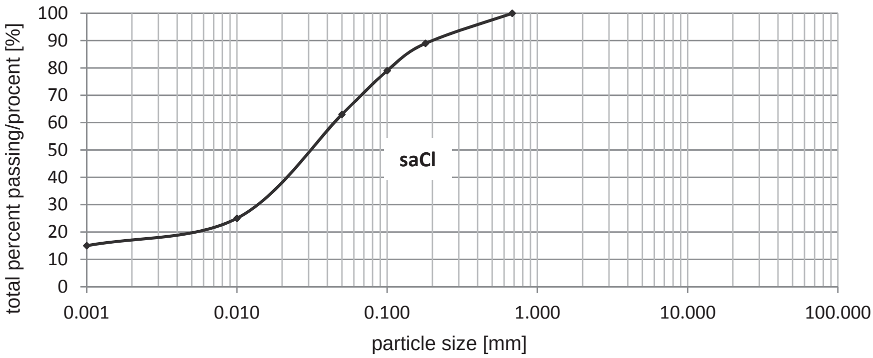

Fig. 2. Gradation curve for sandy clay

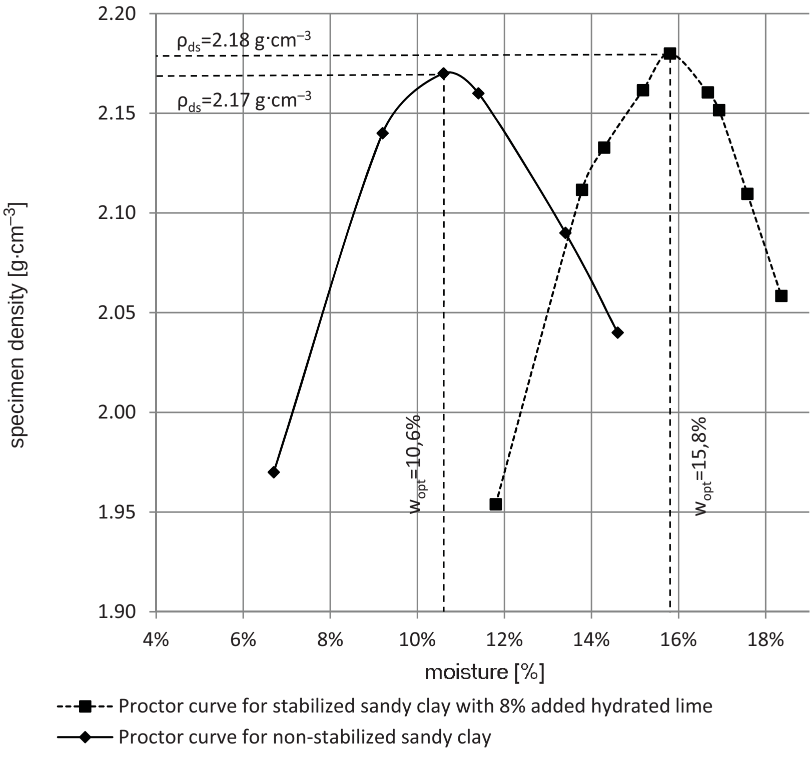

Fig. 3. Proctor test results for non stabilized and stabilized sandy clay

To evaluate parameters of plastic displacement of lime-stabilized sandy clay, cyclic CBR test was conducted. Principles of this test during the first step are the same as for usual CBR test. Sample was loaded by force of 0.05 kPa to keep contact with the plunger from the beginning of the test. Test starts under standard conditions; penetration velocity is 1.27 mm·min^{-1}, penetration depth amounts to 2.54 mm. After reaching 2.54 mm of penetration, sample was unloaded to 10 kPa. Peak stress obtained on 2.54 mm was used in next cycles as maximum applied axial stress. The specimens underwent 50 cycles of repetition. The aim of the test was to simulate displacement of subgrade surface by applying constant force and to observe plastic displacement behavior under cyclic loading.

Figure 4 presents propagation of wave from cyclic CBR test. Each wave underwent its peak stress from first load when stress of sample on penetration amounting to 2.54 mm was obtained. Test time was 13160 second for all specimens.

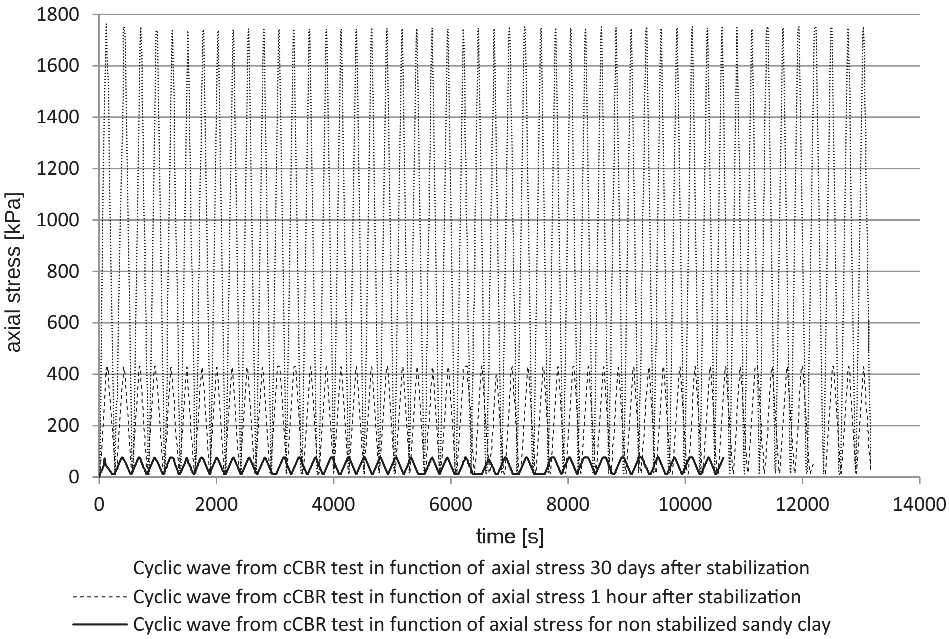

Fig. 4. Cyclic wave from cCBR test for sandy clay in various stage of stabilization

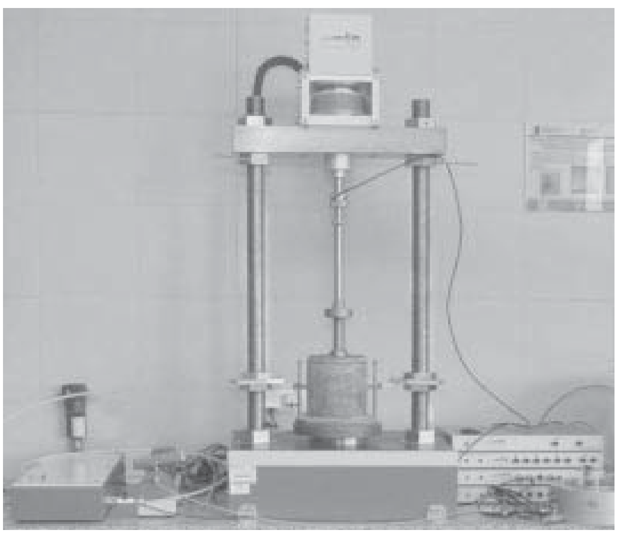

Fig. 5. Test equipment used to perform the cCBR test

Test equipment used to perform the cCBR test is presented in Figure 5. Detailed information about the performance of the test and analysis of obtained results were presented in another paper [Sas and Głuchowski 2012].

RESULTS

During the tests it was assumed that each specimen was loaded by force, which penetrated sandy clay to 2.54 mm depth. Prepared samples were stabilized and non-stabilized. Figure 6 presents axial penetration of the material in function of time.

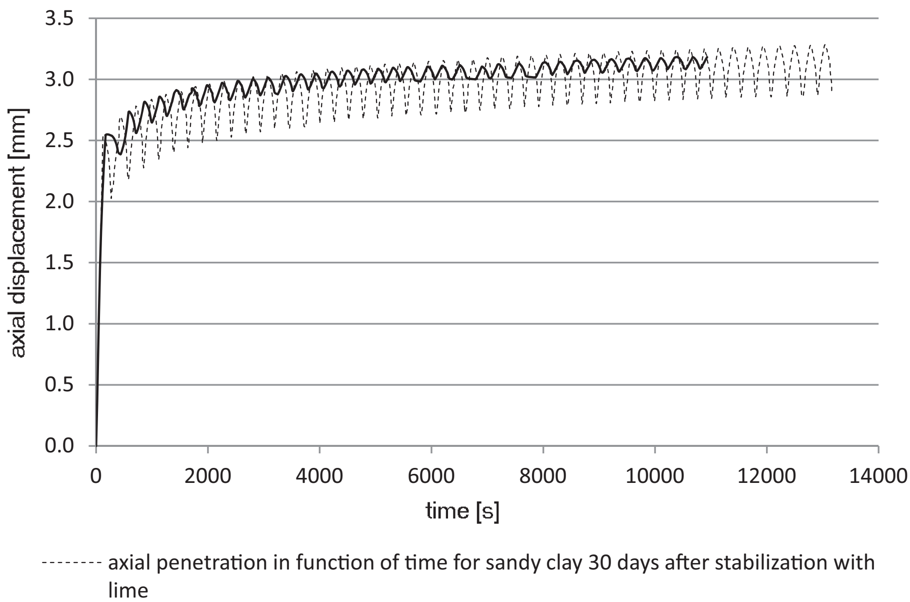

Fig. 6. Axial displacement of sandy clay in function of time

As it can be seen, for non-stabilized specimen the range of elastic displacement is noticeably smaller than for specimen stabilized by lime. Furthermore for first cycles, non--stabilized sandy clay exhibits fully plastic displacement, end of first load step is higher than end of second unload step. Only next cycles show elastic response of material. Last cycles of cCBR test are shown in Figure 7. Here we can see that plastic displacement of non-stabilized sandy clay constantly increases with time. With the increase of plastic displacement is followed by a decrease in elastic displacement. From this point forward, we can assume that an infinite number of cycle displacements will end with slightly smaller plastic and elastic displacement. In case of stabilized soil, the elastic response occurs from the beginning of the test. Additionally, soil shows the same range of total displacement. Last cycles of the test shown in Figure 7 give a picture of decreasing plastic strains. Because of constant growth of plastic displacement in flexible pavements, it is safer to predict invariable plastic displacement to design those constructions.

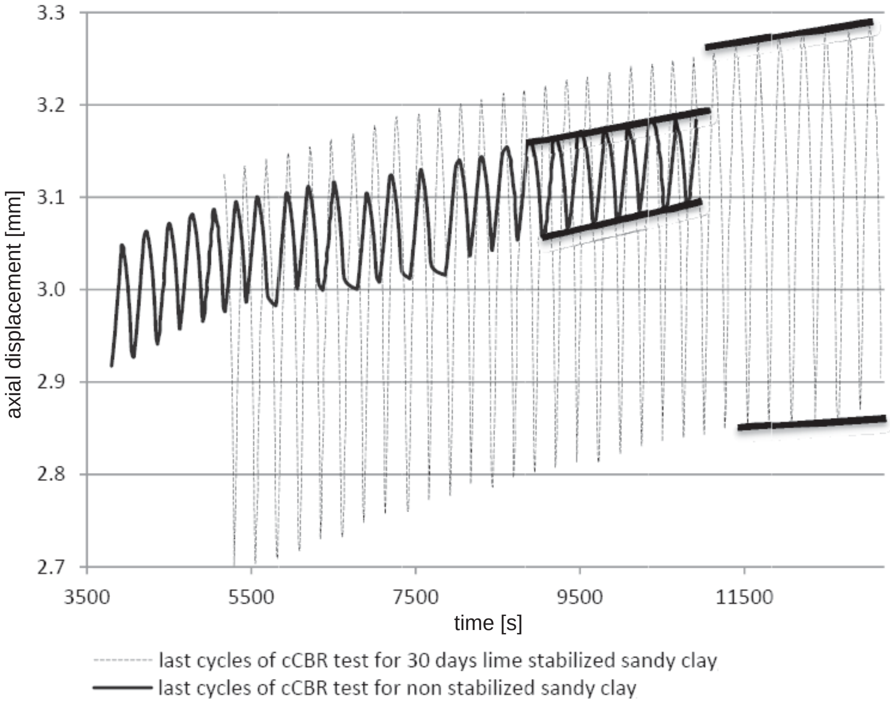

Fig. 7. Last cycles of the cCBR test in function of axial penetration and time

Total displacement of sample in function of time logarithm is shown in Figure 8. Predicted model of displacement was logarithm function. For trend estimation, coefficient determination (R^2) values was greater than 0.95. Such indicated function of total displacement tends to zero. Each specimen was loaded by another force, in this case we consider conditions of displacement caused by force which initially penetrated soil surface until 2.54 mm depth. Reloading by the same force numerous times creates bigger displacement in stabilized specimens than in non-stabilized sample. This leads to a following conclusion: stabilized sandy clay exhibits stronger non-linear elastic response than natural sandy clay and non-linear response is stronger for first few hours than in case of a specimen stabilized for longer period of time, in which case its elastic response is closer to non-stabilized sandy clay.

Figure 9 presents peak maximum and minimum of axial displacement in time logarithm. Plot indicates the growing displacement in load and unload phase of the cCBR test. At the same time in correspond to Figure 8, total displacement decreases as the test is being performed.

Figure 10 presents plot of components of total displacement. Last 15 cycles exhibit a large share of elastic displacement and small share of plastic displacement. It can also be seen that total displacement varies in followed cycles. Figure 10 corresponds with Figure 9. Total displacement tends to increase, but plastic displacement shares decrease, which results with elastic strain becomes the total strain. A number of repetitions causes the

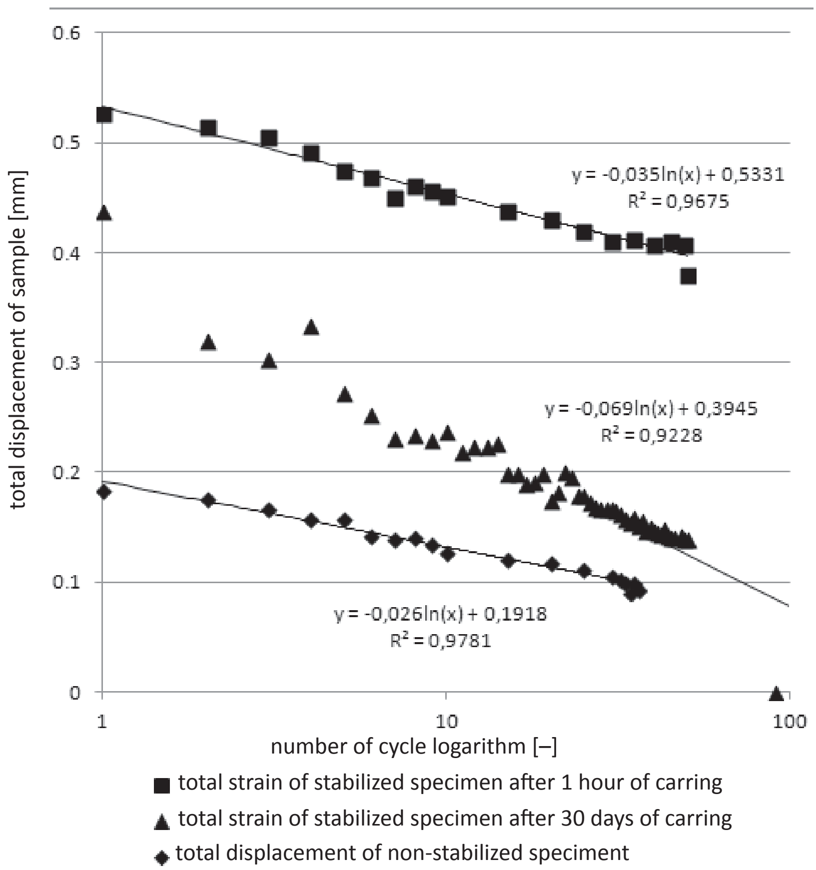

Fig. 8. Total displacement of samples in logarithm of cycles

occurrence of a decrease of elastic strain, consequently the material becomes more linearly elastic. It is clearly presented in Figure 9.

In order to describe the resilient response range of the material – in this case sandy clay – Figure 11 shows the results of the last load-unload cycle during the cCBR test. In linear elastic theory, material responds to load of force with linear strain. In case of heterogeneous material, such as soil, we are dealing with non-linear path of load-unload displacement. Because of that, resilient response is much greater in case of stabilized soils, than for non-stabilized sandy clay. That confirms conclusions reached during the discussion of Figure 8.

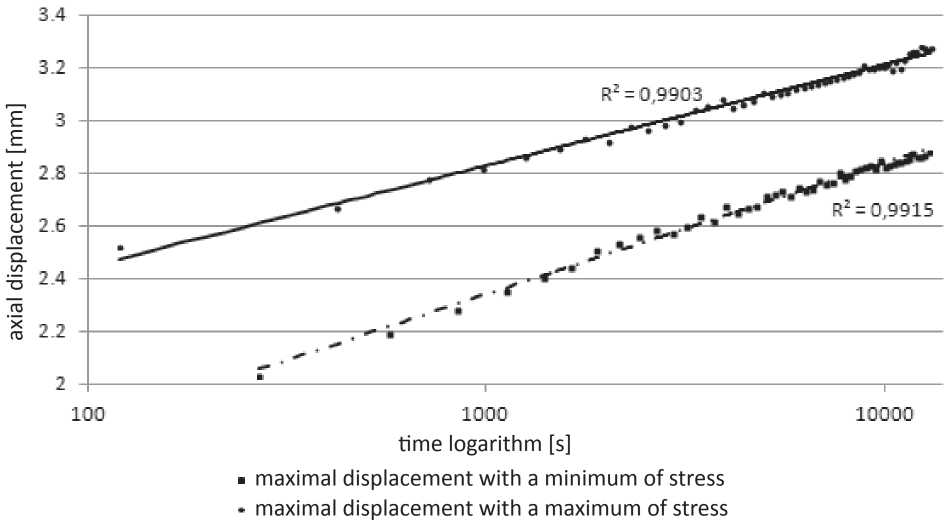

Fig. 9. Maximum and minimum displacement for tested sample

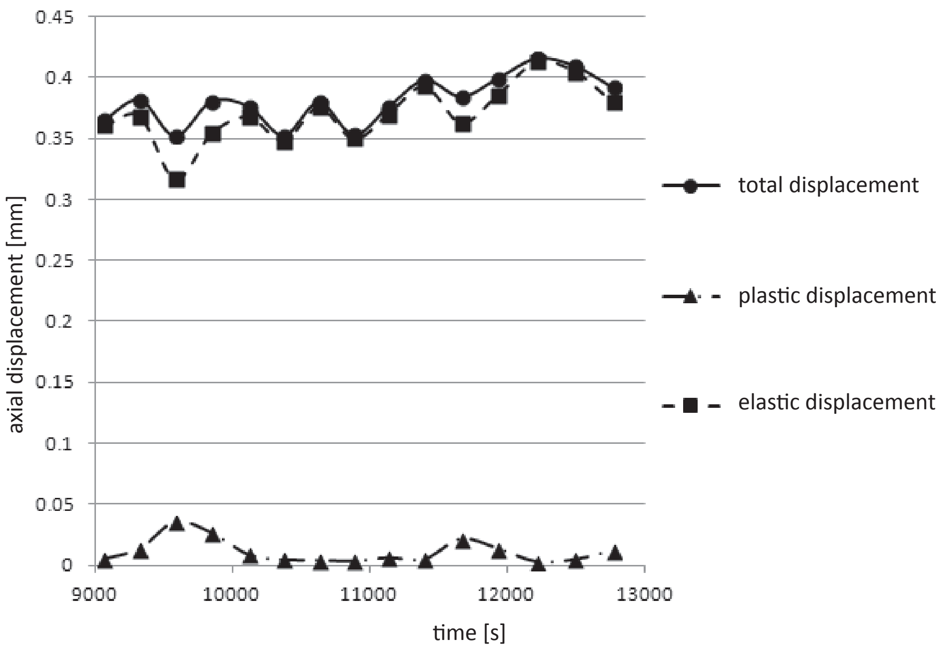

Fig. 10. Components of total displacement for the last 15 load-unload cycles

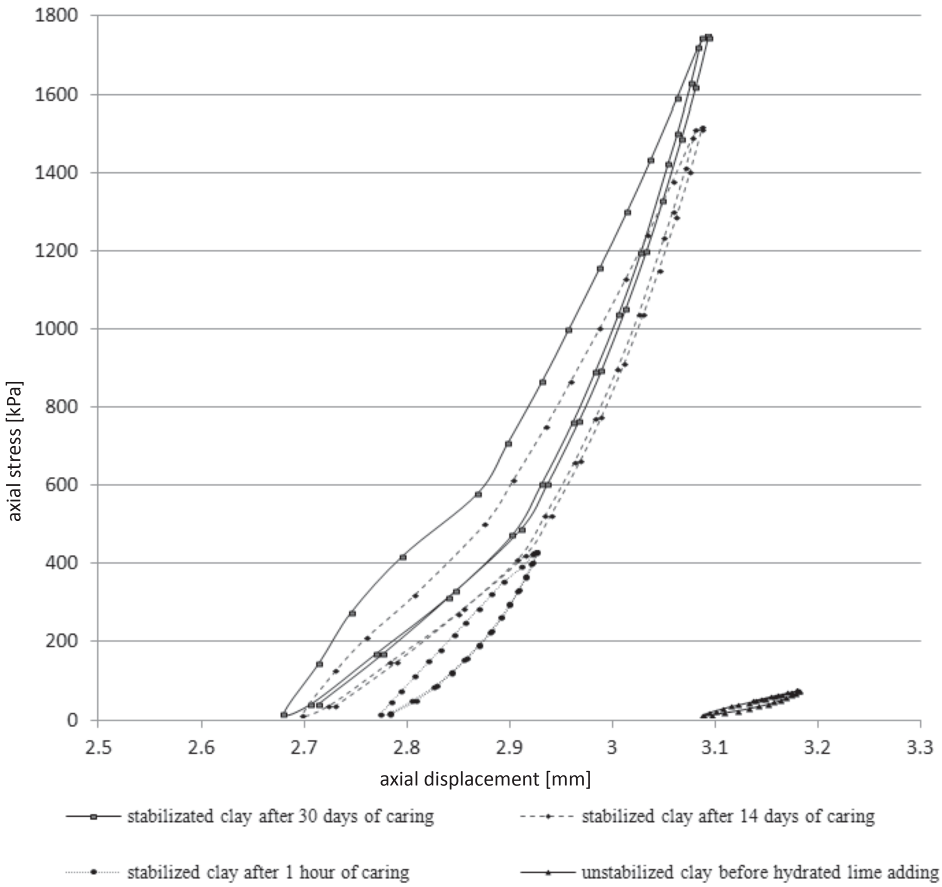

Fig. 11. Last cycle of cCBR test for stabilized and non-stabilized sandy clay

CONCLUSIONS

This paper presents the results of the cyclic CBR test. The main aim of this research was to approximate displacement in subgrade for soil forced by cyclic wave.

Research results lead to the following conclusions:

1. Stabilized soils exhibits stronger non-linear stress – strain relations under cyclic loading than the same sandy clay when it is non-stabilized.

2. Amount of plastic displacement decreases with time until it becomes the elastic deformation.

3. Total strain will increase even after total displacement becomes elastic.

4. Stabilized soils exhibit constant growth of displacement and invariable plastic resistance which is considered a desired behavior in case materials intended for design of flexible pavements.

5. Total resistance to penetration to 2.54 mm is clearly visible in case of stabilized and 30 days carried specimen, but not in case of non-stabilized soil.

REFERENCES

Adu-Osei A., 2000. Characterization of unbound granular layers in flexible pavements. Report ICAR/502-3, Texsas.

Brown S.F., 1996. Soil Mechanics in Pavement Engineering. Geotechnique 46, 383–426.

Barksdale R.D., Alba J., Khosla N.P., Lambe P.C., Rahman M.S., 1997. Laboratory determination of resilient modulus for flexible pavement design. NCHRP Web Doc 14 (project 1–28), Washington.

Little D.N., 1999. Evaluation of structural properties of lime stabilized soils and aggregates. The National Lime Association, Richmond.

Sas W., Głuchowski A., 2012. Methods of determination of the modulus of elasticity (E and Mr) from the repeated loading tests CBR. Przegląd Naukowy Inżynieria i Kształtowanie Środowiska 21 (3), 171–181.

Nazarian S. et al., 1996. Testing Methodology for Resilient Modulus of Base Materials. The Center for Geotechnical and Highway Materials Research, University of Texas AT el Paso.

PCTSFSP – Polish Catalogue of Typical Structures of Flexible and Semi-rigid Pavement, 2001. IBDM, GDDP, Warsaw.

PN-EN 1997-2:2009 Projektowanie geotechniczne. Część 2: Rozpoznawanie i badanie podłoża gruntowego.

ZASTOSOWANIE CYKLICZNYCH BADAŃ CBR DO WYZNACZANIA PRZEMIESZCZEŃ PODŁOŻA DROGOWEGO

Streszczenie. Celem artykułu było określenie przemieszczeń osiowych powstałych w wyniku działania siły cyklicznej przyłożonej na powierzchni podłoża gruntowego. Próbki zostały obciążone siłą, która spowodowała przemieszczenie powierzchni o 2,54 mm. Po tym badaniu próbki były obciążane wielokrotnie tą samą siłą. Ta procedura badawcza pozwoliła na zdefiniowanie rodzaju przemieszczeń w wyniku obciążenia cyklicznego. W artykule dokonano analizy poszczególnych przemieszczeń. Materiałem była glina piaszczysta z 8-procentowym dodatkiem wapna hydratyzowanego. Dodatkowym celem badań było udowodnienie wyraźnego zwiększenia sztywności gruntów kohezyjnych za pomocą stabilizacji oraz ukazanie różnorodnych ścieżek obciążenie – odciążenie dla stabilizowanej i niestabilizowanej gliny piaszczystej.

Słowa kluczowe: przemieszczenie powierzchni podłoża gruntowego, obciążenia cykliczne, cykliczne badanie CBR

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