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Determination of the Resilient modulus M_R for the lime stabilized clay obtained from the repeated loading CBR tests

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Abstract: *Determination of the Resilient modulus M_R for the lime stabilized clay obtained from the repeated loading CBR tests.* The main aim of this paper is to prove that CBR repeated test is useful to give an adequate like unconfined cyclic triaxial test parameters for design the pavement and subgrade soils. That parameter is the Resilient modulus (M_R) which is the elastic modulus based on the recoverable strain under repeated load. Resilient modulus (M_R), is an important parameter which characterizes the subgrade's ability to withstand repetitive stresses under traffic loadings. The 1993 AASHTO guide for design of flexible pavements recommends the use of M_R. The additional aim is connected with the concept of sustainable development. For many countries, where resources are at premium, it is very important that stabilized local soil can be used for road construction. For ensuring that stabilized clay can be used for pavement material standard compaction, CBR and repeated CBR tests were performed. In that paper parameter M_R of the subgrade lime stabilized clay soil by laboratory CBR repeated test were determined using for calculation formulas from triaxial cyclic test. Based on AASHTO empirical equation the static CBR values using back analysis was also calculated. Finally both values of CBR determined and calculated were compared.

Key words: repeated loaded CBR, Resilient modulus (M_R), bearing capacity of pavement.

INTRODUCTION

Pavements are civil engineering structures designed and explored for comfortable, safe and fast move of wheeled vehicles. Pavements are obey especially strange nature of road movement. Because of this reason foundation of road is a subject of continuously applied force which comes from load set from wheels. Although fact that roads are now commonly designed as stiff or half stiff with almost full elastic response from load force, they still are situated on heterogeneous soils. From this reason is still needed to entirely understand how subbase of pavements work under cyclic loading. By most of past decades design methods were based on empirical tests and equations which give an approximation of strain of pavements under set load. One of this kind methods is CBR test which is widely used even today (Vogrig et al. 2003). Currently large number of carried tests allow to simulate *in situ* conditions in road traffic laboratory. By triaxial tests done in cyclic load condition, it is possible to obtain mechanistic factors that better describe behaviour of subbase than empirical tests and equations (Nazarian et al. 1996). However number of test equipment such as CBR apparatus, is doubtless easier to obtain and cheaper to buy than sophisticated cyclic triaxial apparatus. Therefore attempts to find out method to obtain mechanistic properties of unbound and bond materials are desired. One of solutions of this problem may be cyclic CBR (cCBR) test which is using CBR apparatus in extraordinary way. By cCBR test method researchers are able to receive mechanistic factors such as Young modulus (E) or Resilient modulus (M_R) (Sas and Głuchowski 2012). Especially Resilient modulus (M_R) is desired in design of pavements. The other task included in that paper is lime stabilization of local natural material which is a subbase of road construction. The increasing of soil stiffness parameter like Resilient modulus (M_R) and bearing capacity CBR gives opportunity to use local stabilized clay soil for foundation of road construction. The other positive fact is, that in lime treated soil the ph value significantly increasing. That phenomena immobilizes heavy metals in soil what positively influence on soil and water environment.

LITERATURE BACKGROUND

Response of unbound subbase as nonlineal elastic material manifest their stress–strain behaviour in three ways:

- time-independent – elastic deformation recoverable after the remove of the load (ED),
- time-dependent – visco-elastic deformation recoverable after end of loading (VD), and
- plastic deformation during to the load–unload cycle, irrecoverable strain and is dependent on load frequency and rate, loading period (PD).

The deformation ED is a measure of the temporary Resilient modulus; deformation VD is a measure of visco-elastic properties, and deformation PD is a measure of creep and fatigue behaviour of the material (Nazarian et al. 1996). Resilient modulus is a distinctive soil factor and describe stress–strain response under cyclic loading in almost full elastic condition. To obtain such conditions it is indispensable to perform on tested soil numbers of load–unload cycles.

Theoretically Resilient modulus M_R is calculated from:

$$M_R = \frac{\sigma_d}{\varepsilon_n} \tag{1}$$

Parameter σ_d, the axial deviatoric stress, is:

$$\sigma_d = \frac{P}{A_i} \tag{2}$$

where P is the applied load and A_i is the original cross-sectional area of the specimen.

Parameter ε_a, the resilient axial strain, is calculated from:

$$\varepsilon_a = \frac{\Delta L}{L_i} \tag{3}$$

where ΔL is recoverable axial deformation along a gage length L_i (Araya 2011).

On Figure 1 behaviour of material forced by cyclic loading is presented. Observing the graph it is clear that under constant axial stress soil change their respond. By numerous of cycles soil behave full resilient respond where plastic strains is not present.

Presumably the most accurate method to obtain the permanent deformation potential and stability of lime of subbases and subgrades is a repeated load test or a rapid load test coupled with a stress ratio analysis (Little 1999).

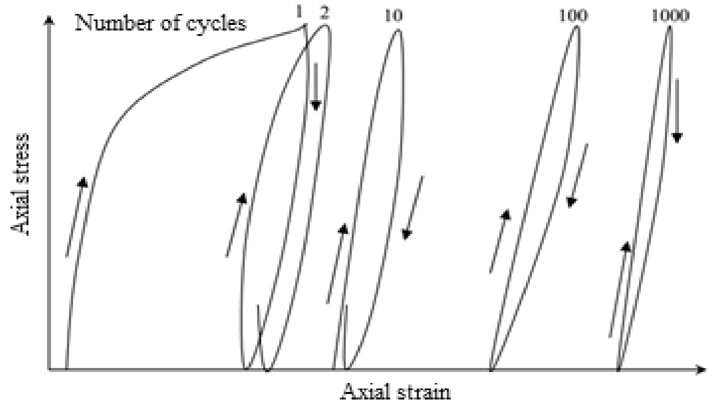

FIGURE 1. Schema of resilient response of granular material under cyclic loading (Araya 2011)

MATERIALS AND METHODS

For determination of California bearing ratio CBR and Resilient modulus M_R, tests were conducted on sandy clay according to PN-EN 1997-2:2009 soil which is characterized by sieve analysis. The result of sieve analysis test is shown on Figure 2. For determination of compaction possibilities: optimum moisture content and maximum dry density of natural and stabilized soil two standard proctor tests were done. First proctor test were done on non-stabilized clay material, second tests were done on 8% lime content stabilized clay samples. The results of proctor test for non-stabilized material is shown on Figure 3. For non-stabilized sandy clay the optimum moisture content and the maximum dry density of the sample are 10.6% and 2170 kg/m^3. The results of proctor test for 8% content hydrated lime stabilized material is shown on Figure 4. For stabilized sandy clay the optimum moisture content and the maximum dry density of the sample are 15.8% and 2180 kg/m^3. For CBR-cCBR tests, material was prepared with optimum moisture condition and standard proctor compaction energy 0.59 J/cm^3, applying 233 blows on specimen in 5 layers. Preparing of samples

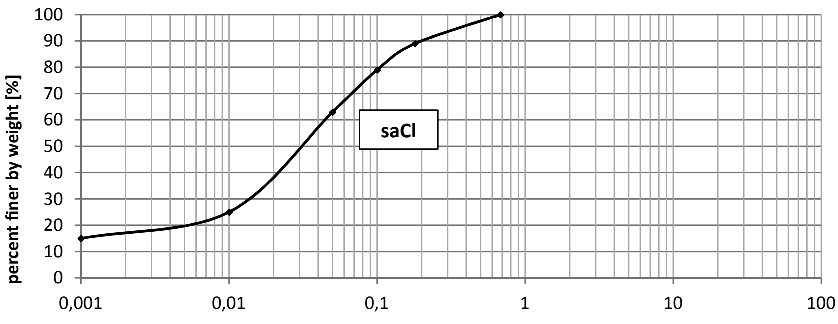

FIGURE 2. Particle size distribution of clay samples

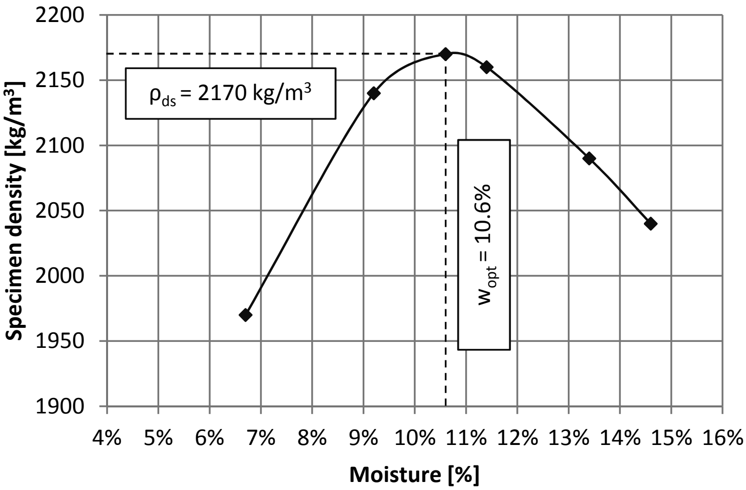

FIGURE 3. Proctor test for non-stabilized clay

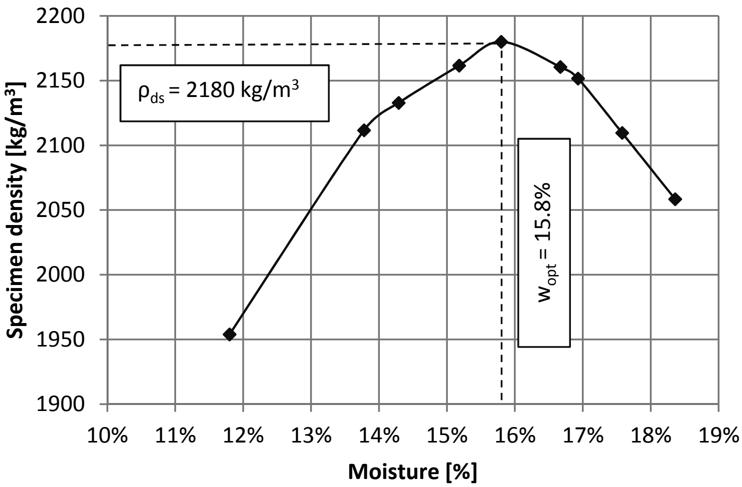

FIGURE 4. Proctor test for 8% lime content stabilized clay

was made in standard CBR mould and compacted using Proctor equipment. The energy of compaction was comparable for Proctor and CBR mould. CBR and repeated cCBR tests were done for non-stabilized and lime stabilized sandy clay. Stabilized specimens were tested after 1 hour, 14 days and 30 days of caring under constant condition of temperature and moisture of air. For test period stabilized samples were store in constant moisture room to keep them in the same moisture conditions.

Tests was conducted on cyclic triaxial base equipment modified and adaptated to perform cyclic CBR test. The test equipment used to perform CBR-

-cCBR tests are presented on Figure 5. Cyclic CBR test is a modification of standard CBR test which have the same start conditions as usual test. Specimen in standard CBR mould is placed under a plunger. The plunger must be loaded on specimen before test start by small force in range 0.05 kN. After preparing a sample and loading it by plunger, test is carry out until penetration of specimen reach 2.54 mm depth. After finishing this step, test was perform to unloading sample to force 10 kPa. This procedure is one cycle of loading–unloading step. To perform cyclic CBR test is needed to make around 50 to 100 cycles. After that, material behaviour will be mostly elastic. Test can be recognised as finished when plastic strain constitutes 3–5% of all soil strain.

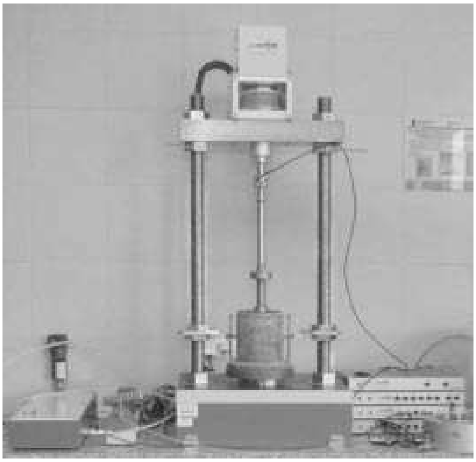

FIGURE 5. View on cyclic CBR test equipment

Basic results of the cCBR such as cyclic loading wave characteristics are presented on Figure 6 and Figure 7. Wave propagation in time and axial stress can be seen from the Figure 6. On Figure 7 cyclic wave propagation in time by axial strain can be observed. Figure 8 presents the results of CBR and cCBR – present dislocation of surface of tested soil under acting stress thrust by plunger. The first part of plot shows the maximum value of axial stress that is necessary for CBR calculation. The other part of plot shows

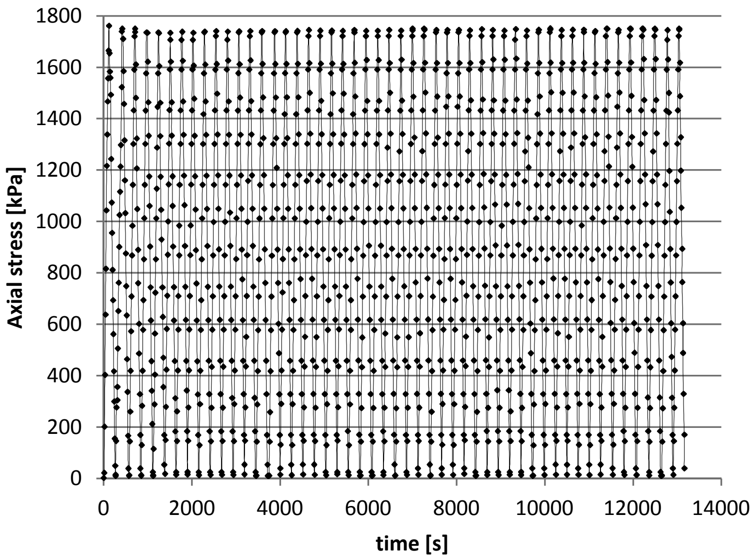

FIGURE 6. Cyclic wave propagation in time by axial stress of sample

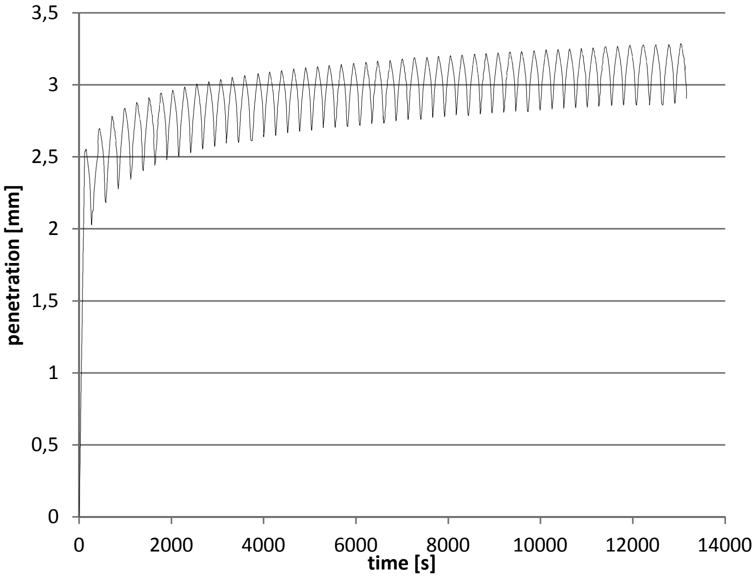

FIGURE 7. Cyclic wave propagation in time by axial strain of sample

number of loading–unloading steps of cycling that is necessary for Resilient modulus (M_R) calculation. Figure 8 shows also decrease of total sample dislocation to the moment when under the same stress dislocation is nearly invariance. At this moment performing of test is no longer necessary because resilient strain is already obtained. From this figure it can be also concluded that dislocation of sample was obtain earlier than resilient response of soil. That indicate dislocation of sample from constant stress is also constant and after that plastic strain have lower portion of total strain.

RESULTS AND DISCUSSION

Results from cyclic CBR test in function of stress and penetration of plunger for all tested samples has been presented on Figures 8a, 8b, 8c and 8d. From Figure 8a results for non-stabilized sandy clay are presented. Peak axial stress obtained on 2.54 mm penetration was 72 kPa, after 50 cycles of test the penetration plunger in the sample was 3.18 mm. Figures 8b, 8c, 8d presents the results for 8% lime stabilized sandy clay. On Figure 8b we can observe the results obtain on sample after 1 hour of caring. Maximum axial stress were 425.83 kPa on first loading and 2.78 mm penetration after 50 test cycles. Results the test on sample after 14 days of caring were 1647.53 kPa and 2.73 mm respectively what is presented on Figure 8c. Figure 8d presents the results of test on sample after 30 days of caring, the results were 1762.06 kPa and 2.70 mm. As was presented above stabilized soil have got explicitly higher stiffness which is caused by added lime. Also stiffness of stabilized soil increases in time, from 72 kPa to 1762.06 in 30 days which give 24.5 times more stiff. CBR values calculated from formula (4) are 1.04% and 25.54% respectively (Figs 8a, 8d).

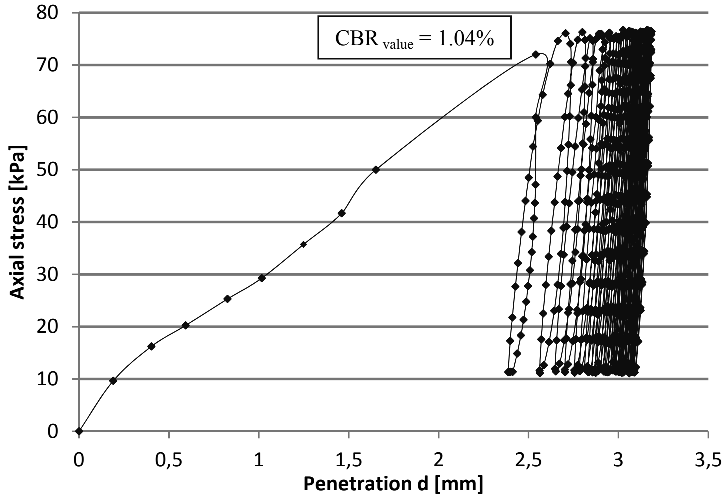

FIGURE 8a. Results from cyclic CBR test in function of stress and penetration of plunger for non--stabilized clay

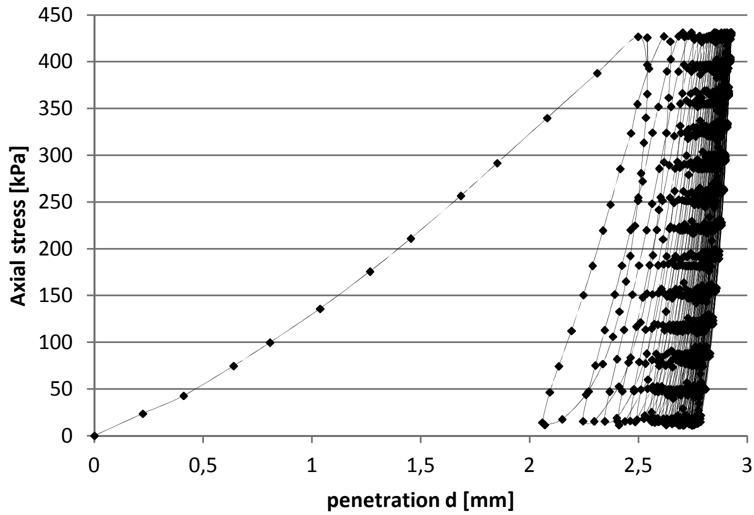

FIGURE 8b. Results from cyclic CBR test in function of stress and penetration of plunger for 1 hour stabilized clay

$$CBR_{2.54} = \frac{\sigma_p}{6900} \cdot 100\% \quad (4)$$

where: σ_p – axial stress, 6900 – standard axial stress crushed stone on 2.54 mm penetration depth. Based on results of "static" CBR and empirical equation proposed by AASHTO (5),

$$M_R = 10{,}340 \cdot CBR \quad (5)$$

values of Resilient modulus (M_R) were calculated. Results vary from 10.79 MPa for non-stabilized sandy clay to

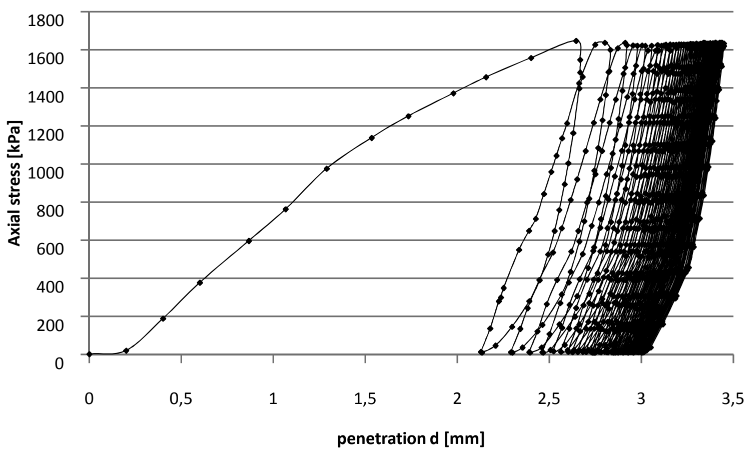

FIGURE 8c. Results from cyclic CBR test in function of stress and penetration of plunger for 14 days stabilized clay

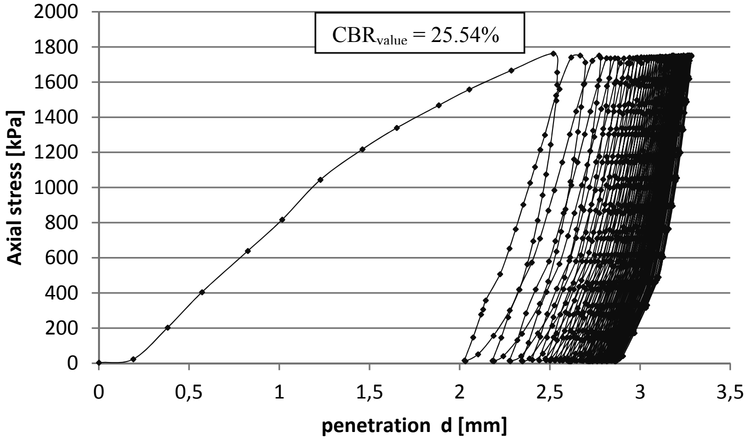

FIGURE 8d. Results from cyclic CBR test in function of stress and penetration of plunger for 30 days stabilized clay

264.05 MPa for 30 days carried stabilized soil sample. From Figures 8a to 8d we can observe variation of the elastic and plastic strain in function of time. On Figure 8a we can observe that first cycle have biggest impact on strain of clay. For non-stabilized sample the elastic strain was 0.07% of total strain in first cycle. For example elastic strain obtain from first cycle of lime stabilized clay after 1 hour was 0.24% (Fig. 8b). Stabilized clay after 30 days have elastic strain in range 0.26% (Fig. 8d).

Figure 9 present values of Resilient modulus M_R in logarithm of cycles. Last values of M_R, from cyclic tests when resilient respond of material was received, are showed on Table 1. Values of M_R were calculated from equations (1), (2), (3). The calculations of must be preceded

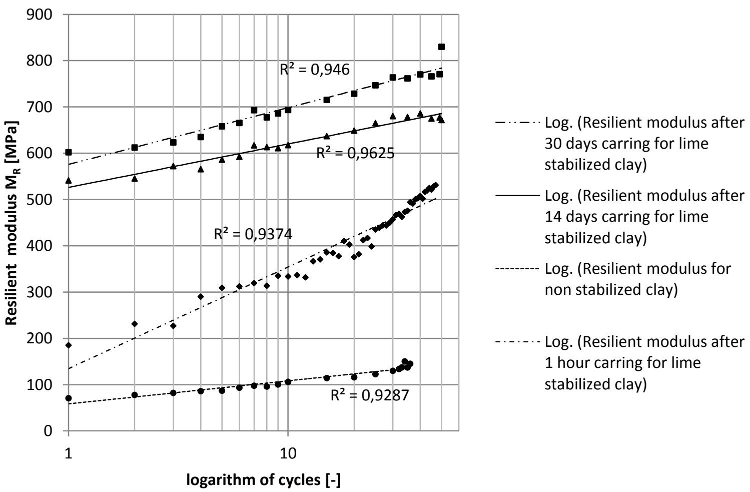

FIGURE 9. Resilient modulus M_R change for clay stabilized with lime during following cycles

TABLE 1. Value of resilient modulus after last cycle of tests

Sample details	Resilient modulus [MPa]
non-stabilized	145.26
stabilized period	
1 hour	531.42
14 days	671.72
30 days	830.09

by the analysis of stress–strain behavior of tested specimens. Resilient modulus is a measure of resilient strain after cyclic force load on surface of soil. Total resilient strain is a quotient of difference between elastic and plastic conservation in one cycle to total deformation of soil in one cycle. Stress effect on sample is a difference between maximal and minimal stress.

Because deficiency of testing Resilient modulus using different testing equipment like cyclic TRX and CBR, AASHTO gave an empirical equation (5) which can help to obtain Resilient modulus from CBR test. By this equation it is possible to determine range of Resilient modulus, but CBR test is a static loading of soil and because of that it is impossible to obtain exact M_R value from standard CBR test (literature). The main idea of cyclic loading CBR test is to limit imperfection of standard CBR procedure by adding to test cyclic phases of load and unload wave. As was mentioned Resilient modulus can be obtain from material which strain behavior is almost elastic. Figure 10 presents differences between CBR value calculated from Resilient modulus value obtain from first cycle of test and CBR value gain from static CBR test in this example from first load of specimens.

From the Figure 10 it is clear that results of CBR obtained directly in static conditions significantly differ from results obtained based on back analysis coming from Resilient modulus by using AASHOTO equation. This differences can influences on CBR results what consequently gives inflated values for

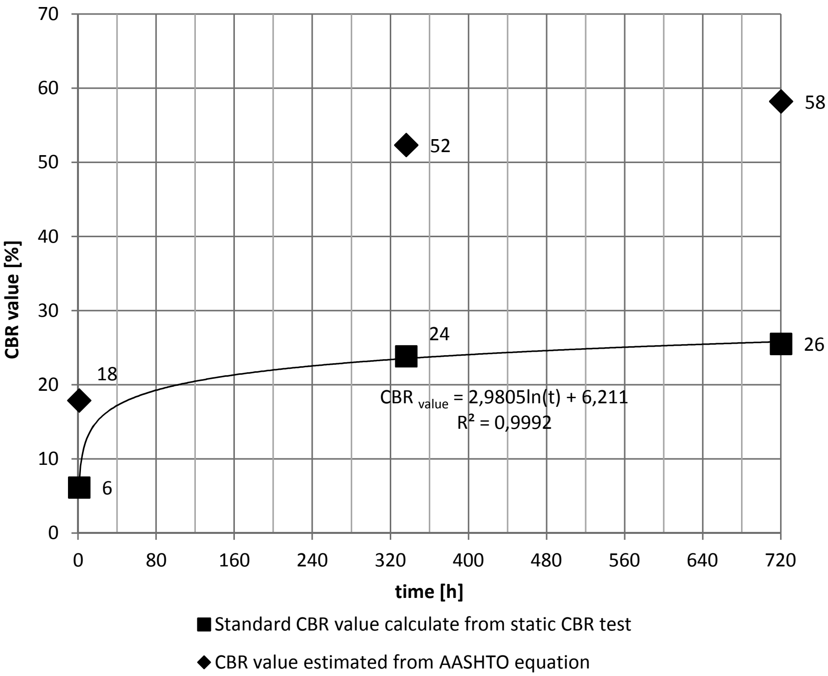

FIGURE 10. CBR values from static CBR test and obtain form M_R value from cyclic CBR test for stabilized sandy clay

pavement designing. Analysis of results presented on Figure 10 allows to give a correlation between CBR value calculate from static CBR test using presented formula on graph formula. Using that equation the predictable value of CBR according to time of lime stabilization of sandy clay can be made.

CONCLUSIONS

Cyclic deformations characteristic such as Resilient modulus M_R are key parameters for mechanic-empirical design of pavements. Undertaken tests showed that stabilization of poor soils such sandy clay can be good way to solve problem of subgrade in pavement design procedure. The reinforce of subgrade allow to use them for foundation of road construction according to PN-S-96011:1998. The minimal CBR value for subgrade is 25%. Also cyclic deformations can better describe material behavior and because of that can be more useful in road engineering. Tests proved that “static” CBR test as empirical test, use for obtaining material parameters such as bearing capacity and fortunate application in field can be questionable. The mentioned in paper differences of CBR values proved that empirical equations not fully give an adequate design parameters. For better understanding of resilient response of soils in needed to conduct more tests also witch cyclic CBR test. Additionally cyclic CBR test can be useful tool to obtain searched parameters and can be easily performed by laboratory crew without much experience training.

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Streszczenie: *Wyznaczanie modułu sprężystości M_R w warunkach cyklicznego obciążania z badań powtarzalnego CBR dla glin stabilizowanych wapnem.* Głównym celem niniejszej pracy jest wykazanie, że badanie CBR w warunkach powtarzalnego obciążania jest wiarygodnym testem do wyznaczania parametrów sprężystości podłoża gruntowego. Parametry te są następnie wykorzystywane do projektowania podbudowy i ulepszonego podłoża gruntowego. Jednym z parametrów jest powtarzalny moduł sprężystości (M_R) który opisuje odkształcenia sprężyste powstałe w wyniku cyklicznych obciążeń gruntu. Powtarzalny moduł sprężystości M_R, jest ważnym parametrem, który charakteryzuje zdolność podbudowy do odkształceń w wyniku powstających naprężeń od obciążenia ruchem drogowym. Podręcznik AASHTO 1993 do projektowania elastycznych nawierzchni zaleca stosowanie M_R. Celem artykułu jest także podjęcie problemu zasad zrównoważonego rozwoju. W wielu krajach, w których źródła odpowiednich kruszyw są oddalone od miejsca budowy, bardzo ważnym staje się wykorzystanie materiałów miejscowych poddanych zabiegom stabilizacyjnym. W celu potwierdzenia korzystnego wpływu stabilizacji na grunty spoiste o niekorzystnych parametrach wyjściowych wykonano badania CBR w warunkach statycznego obciążania i powtarzane badania CBR. W artykule wyznaczono parametr M_R dla gliny piaszczystej stabilizowanej wapnem hydratyzowanym za pomocą badania powtarzalnego CBR przy zastosowaniu równań opracowanych dla interpretacji badań trójosiowego ściskania w warunkach cyklicznego obciążenia. Na podstawie równania empirycznego AASHTO wyznaczono również wartości CBR a także wykorzystano analizę wsteczną wyznaczenia wartości CBR z otrzymanych z badań wartości M_R. W analizie wyników badań wartości te zostały ze sobą porównane wraz z komentarzem uzyskanych zależności.

Słowa kluczowe: badanie CBR w warunkach powtarzalnego obciążenia, moduł sprężystości w warunkach cyklicznego obciążania M_R, nośność podbudów drogowych.

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