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Comparison of the resilient modulus and the Calfornia Bearing Ratio in case of stabilized soils

Comparaison du module de résilience et du CBR concernant les sols stabilisés

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ABSTRACT: The resilient modulus is an input parameter of the design of pavement structures. Its value can be determined by direct and indirect methods. The resilient modulus is measured directly by dynamical triaxial test meanwhile several methods exist to determine its value indirectly, among which the calculation from the CBR value is proposed mostly by the literature and practice. During the research dicussed in this paper the resilient modulus of stabilized loess soil was examined using dynamical triaxial and CBR tests. In case of the direct method, the influence of the deviatoric stress and the dosage of the binder on the resilient modulus was investigated. In the literature several correlations exist that were created to estimate the resilient modulus based on the CBR value of the soil. During the research the resilient modulus of the stabilized loess soil was determined also using these formulas. The results of the direct measuements showed a great coincidence with the data found in the literature. However the resilient moduli calculated from the CBR values were much higher than the ones got from the dynamical triaxial tests so it seems that the existing correlations cannot be used for stabilized soils, a new formula should be created for these cases.

RÉSUMÉ: Le module de résilience est un paramètre d‘entrée de la conception des structures de chaussée. Sa valeur peut être déterminée par des méthodes directes ou indirectes. Le module de résilience est mesurée directement par essai triaxial dynamique, cependant il existe plusieurs méthodes pour déterminer sa valeur indirectement parmi lesquelles la calculation basée sur la valeur CBR est la plus recommendée par la litérature et la practice. Dans le cadre de la recherche présentée par ce papier, le module de résilience d‘un sol de loess stabilisé a été examiné par des essais triaxiaux dynamiques et des essais CBR. Dans le cas de la méthode directe, l‘influence du tenseur déviateur et du dosage du liant sur le module de résilience a été examinée. Dans la litérature plusieurs corrélations existent qui ont été créées afin d‘estimer le module de résilience en utilisant la valeur CBR du sol. Pendant la recherche le module de résilience du sol de loess stabilisé a été déterminé en utilisant ces formules aussi. Les résultats des mesures directes sont en corcordance avec ceux qui ont été publiés dans la litérature. Cependant les modules de résilience calculés à partir des valeurs CBR étaient plus élevés que les résultats donnés par les essais triaxiaux dynamiques, alors il semble probable que ces formules ne peuvent pas être utilisées dans le cas les sols stabilisés pour lesquels une nouvelle formule doit être créée.

Keywords: resilient modulus; CBR, stabilized soil,

1 INTRODUCTION

The resilient modulus is the elastic modulus of the earthworks that can be taken into consideration during the design for dynamic loads. It is an input parameter of the design of pavement structures, therefore its value influences greatly the thickness and the span of life of the base and wearing course. The resilient modulus of the earthworks can be determined directly by cyclic triaxial test, which method is well spread but a bit complex and can be costly in proportion to the volume of the project. In addition to the direct measurements, several indirect methods are suggested by the literature to determine the value of the resilient modulus. During these procedures the M_R is calculated by different formulas based on another soil parameter, such as the California Bearing Ratio or the unconfined compression strength. In the practice the calculations based on the CBR value are the most commonly used and considered to be reliable. The indirect methods possess a lot of advantages: they can be accomplished on site and in the laboratory using less complicated tools and faster methods, hence they are more economical compared to the dynamic triaxial test. Obviously they have also disadvantages: the formulas are often established based on the results of specified sites and soils, therefore their validity is limited to given soils or value ranges, thus the scatter and the uncertainty of the calculated results is higher than expected. Despite these disadvantages it would be favorable if the value of the resilient modulus could be determined in a simpler way, but the existing correlations do not seem to be applicable to stabilized soils.

2 THE RESILIENT MODULUS

Soils, binderless and cohesionless mixtures with hydraulic binders have a nonlinear behavior during loading, the validity of Hooke‘s law is limited. In spite of that, the pavement design methods based on the principles of elasticity require the determination of the modulus values that characterize mostly the elastic behavior, such as the resilient modulus. According to its general definition, the resilient modulus is the quotient of the deviatoric stress and the elastic strain.

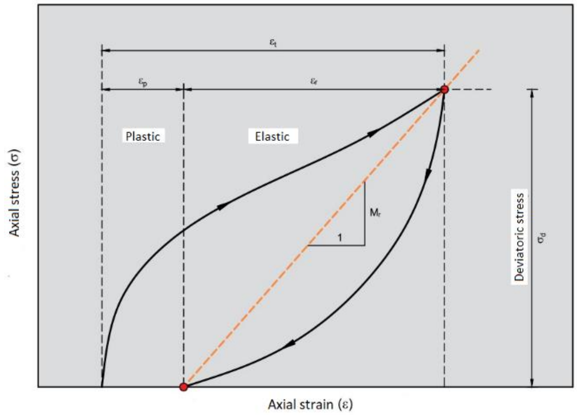

Figure 1. Interpretation of the resilient modulus

Basically it characterize the stiffness of the material and not the strength. Its value depends on the confining stress, therefore it can be determined applying different loads and confining pressures.

According to the literature natural soils the value of the resilient modulus varies in the range of 10-280 MPa. Special soils, such as lateritic soils are characterized by a significantly higher resilient modulus value that varies between the range of 70-600 MPa. Stabilized soils can be characterize by a resilient modulus varying between 40-350 MPa. However the soil becames more resistant to the humidity, thus relatively high resilient modulus values can be taken into consideration during the span of life of the earthworks. Stabilized lateritic soils possess much higher resilient modulus, but generally during the stabilization of this type of soil higher quantity of binder is applied.

3 THE RELATIONSHIP MR - CBR

To determine the resilient modulus indirectly, the literature mostly recommends the calculation based on the CBR value. The CBR test is simple and can easily be performed in the laboratory or even on site. For the calculation, several formulas exist, but unfortunatelly the validity of these correlations are limited to a given soil tpye or value range. Another significant problem is that if more formulas are applicable for a soil and for its CBR value, there is an important scatter and uncertainty in the calculated results.

Generally these formulas give the resilient modulus as the CBR value multiplied by a constant number, for example the most known correlation given by Heukleom & Klomp (1962):

$$M_R = 10.34 \cdot CBR \quad (CBR < 10) \qquad (1)$$

$$M_R = 9.79 \cdot CBR \quad (10 < CBR < 20) \qquad (2)$$

Where M_R is the resilient modulus (MPa) and *CBR* is the California Bearing Ratio (%).

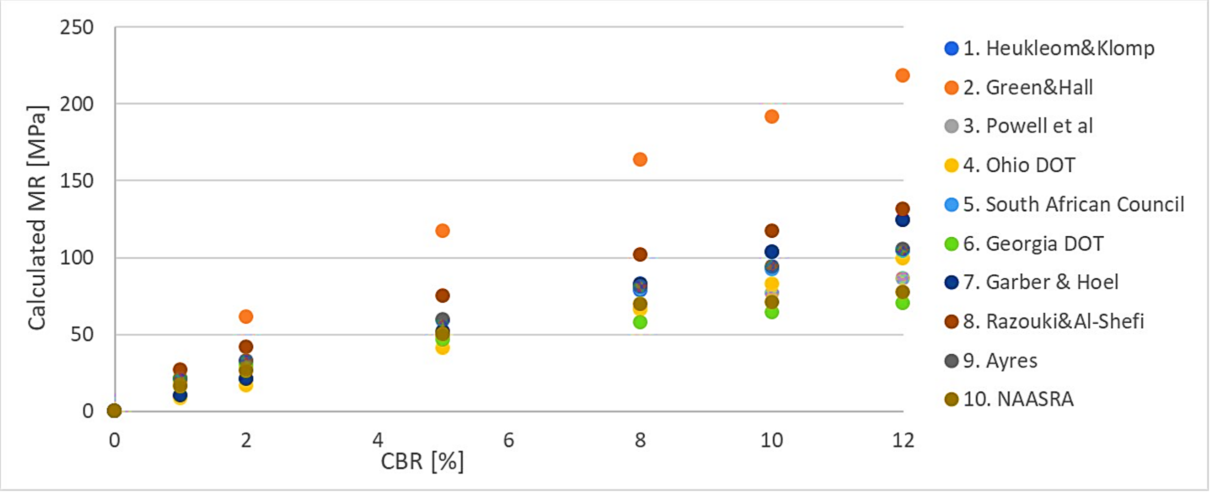

Figure 2. Calculation of the resilient modulus using different correlations

Other correlations suggest that the resilient modulus is a power function of the California Bearing Ratio, multiplied by a constant number, as given by the Georgia Department of Transportation:

$$M_R\ (MPa) = 21.48 \cdot CBR^{\,0.4779707} \qquad (3)$$

Where M_R is the resilient modulus (MPa) and *CBR* is the California Bearing Ratio (%).

Having examined different correlations it is noticeable that in case of higher CBR values, the range of the resilient moduli calculated with these formulas becames significantly greater. The highest calculated value can be 3-4 times bigger than the lower results. It means that it is difficult to decide which correlation gives the appropriate result if theoretically either formula is applicable.

4 LABORATORY TESTS AND DISCUSSION OF RESULTS

To examine the relationship between the resilient modulus and the California Bearing Ratio several tests were carried out applying a loess soil which is a tipical soil type in Hungary. The soil was stabilized using different binders: cement and cement-lime mixtures. The samples were prepared at the optimum moisture content. The dynamical triaxial and also the CBR tests were performed after 28 days of curing time.

Dynamic triaxial tests were carried out based on the AASHTO T307 method therefore the resilient modulus tests were executed applying 5 different deviatoric stresses and at the end of the test a loading step of 10000 cycles was performed with the highest deviatoric stress.

Figure 3. shows the results of the dynamic triaxial test performed applying 55 kPa deviatoric stress. It can be seen that a linear relationship can be established between the resilient moduli determined by the direct method and the CBR values. It has to be noted that a linear correlation could be justified only for a certain range of values, because for the low CBR a linear calculation method gives unreasonably high resilient modulus values. On the figure the measurement points of the same colour belong to the samples stabilized by the same binder but applying different dosage of the given binder.
The tendency discussed above could be observed in case of the other loading steps too.

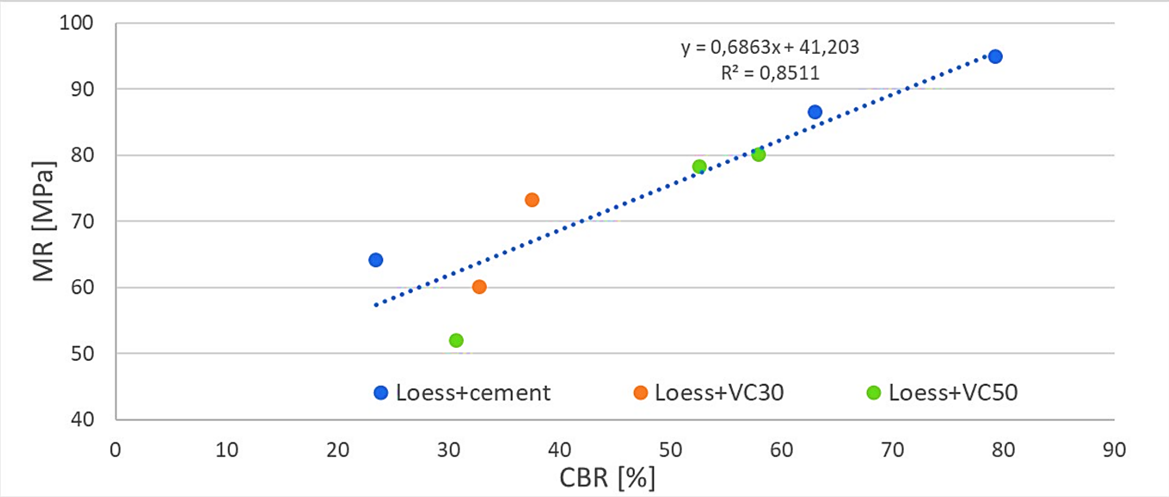

Figure 3. Relationship between the resilient modulus and the CBR value (55 kPa deviatoric stress)

Figure 4. and 5 show the results of the last step, where 10.000 cycles were apllied to the specimens to examine the change in the value of the resilient modulus. During the research the first 10 and the last 10 cycles were taken into consideration. It is noticeable that the fitting of the linear regression is slightly worse in case of the last 10 cycles, although some kind of correlation is clearly appears in the results.

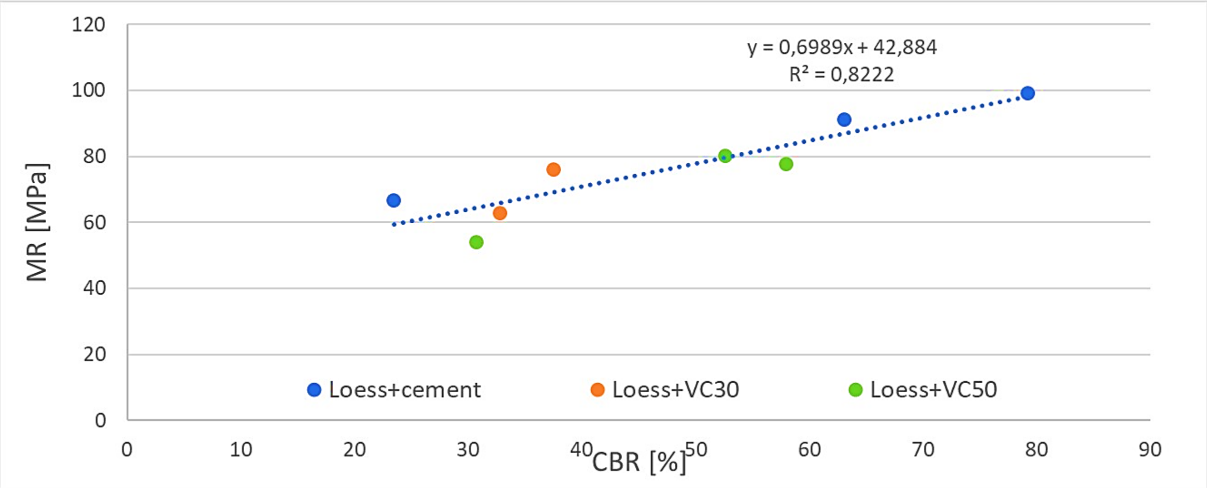

Figure 4. Relationship between the resilient modulus and the CBR value (the first 10 cycles of the 10.000 cycles loading)

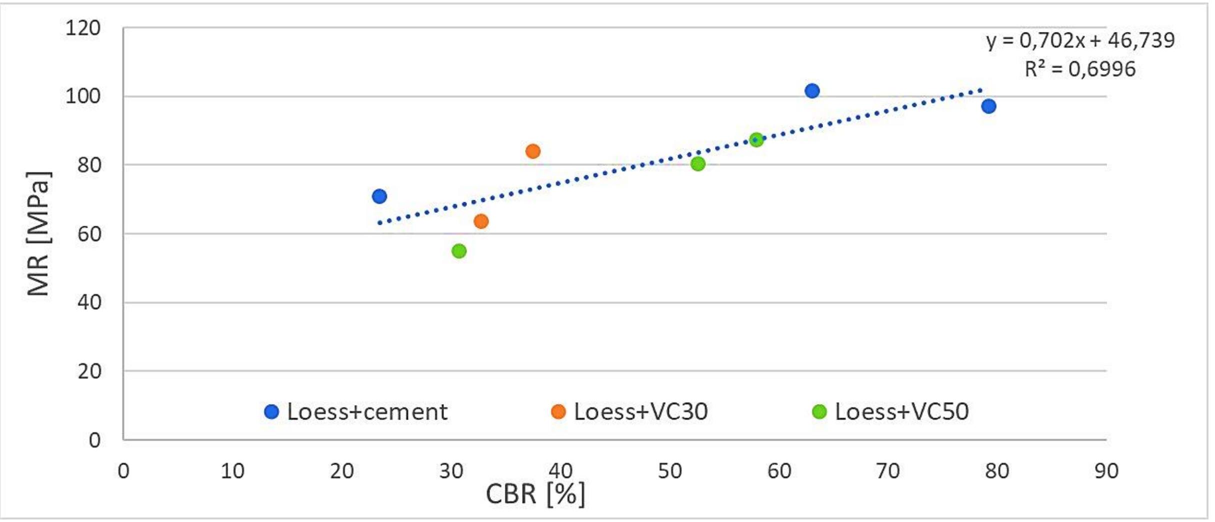

Figure 5. Relationship between the resilient modulus and the CBR value (the last 10 cycles of the 10.000 cycles loading)

As comparison the value of the resilient modulus was determined using also the indirect method. The M_R was calculated with ten different formulas suggested by the literature.

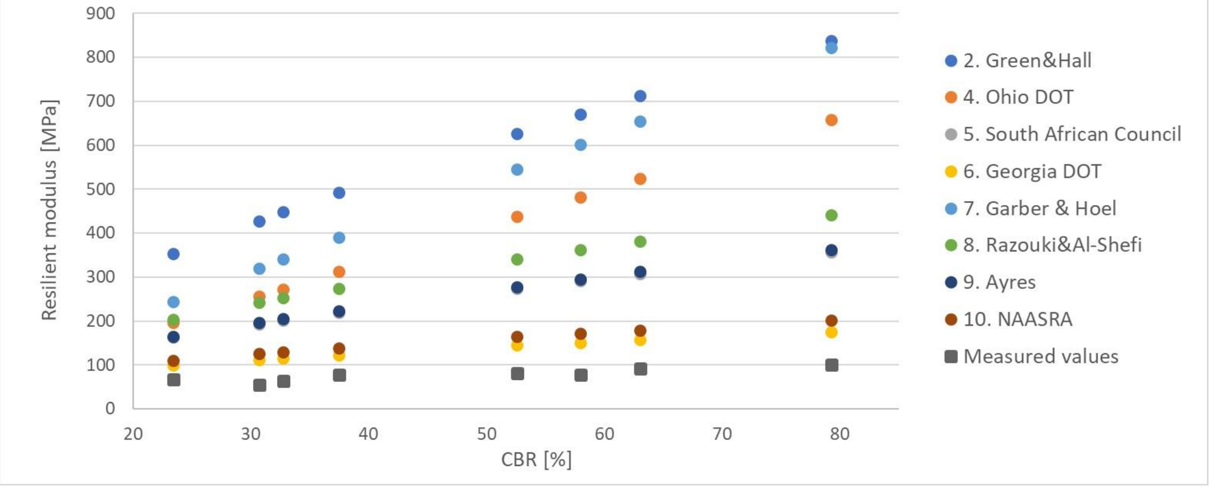

Figure 6. Comparison of the calculated and measured values

As shown in the figure 6. the resilient moduli calculated using the different correlations are higher than the directly measured values. For this type of soil, the formula given by the Georgia Department of Transportation provides the nearest results which are the lowest among the calculated values. Being the smallest values, these calculated resilient moduli are 1.5 – 2.0 times greater than the results provided by direct tests. On average these formulas give 3.0 – 4.0 (or in case of higher CBR values) 6.0 – 7.0 times higher results than the dynamical triaxial tests. It is important to notice that the scatter of the calculated results reach the 40 – 60 % of the average values in case of the calculated resilient modulus which means that the uncertainty of the results is very high.

5 CONCLUSIONS

In this paper the direct and indirect methods are compaired that can be used to determine the value of the resilient modulus. The resilient modulus is an important input parameter in the design of the pavement structures. It can be determined directly by dynamical triaxial tests, that is a complex and costly procedure. The literature recommends also several indirect methods that consist of the calculation of the resilient modulus based on different soil parameter. The most commonly applied parameter is the California Bearing Ratio. In the literature there are different formulas established to determine the M_R using the CBR value which are used even in the practice. The main disadvantage of these correlations is that their application is often limited to a given soil type or range of values, and they provide contradictory and unreasonably high values. Therefore it seems to be probable that another more convenable formula has to be developed in the future to stabilized soils. It has to be also investigated that the different measurement methods are sensible to certain parameters (for example the moisture content), and how this sensitivity could be evaluated or eliminated.

Even if the direct method can be very well used to determine the resilient modulus it would be favorable to elaborate a correlation between the resilient modulus and the CBR value, because with that the previous CBR data and experiences can be transfered to M_R.

The results of the direct method are in great coincidence with the resilient modulus values given by the literature, since the dynamical tests provided M_R values in the range of 50 – 120 MPa. The resilient moduli calculated are at least 1.5 – 2.0 times greater than the direct results.

According to the results of the laboratory tests carried out during the research presented in this paper, some kind of correlation exist between the resilient modulus and the CBR value. However the precision of this correlation and its validity concerning the range of value is yet to be determined. Further researches are necessary to precise the precise correlation that could be applied in the practise.

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