THE INOVATION OF CBR TEST FOR THE DESIGN OF LOW CAPACITY ROAD PAVEMENTS CONSTRUCTIONS

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Abstract

Some of road design procedures use an empirical approach. It means that the relationship between design inputs and pavement performance are known from experience. Empirical design methods can range from extremely simple to quite complex. The simplest approaches of pavement structural designs are based on CBR test. Value of this well known method depend on different effects, like preparing of the CBR samples moisture content of the material degree of compaction etc. The authors deal with influence of these parameters in relation to CBR values and possibility to determine resilient modulus from CBR test for low capacity roads.

Keywords: resilient modulus, cyclic CBR test, degree of compaction, moisture content, road pavement design, finite element method

1 Introduction

The design methods of flexible pavement are based on a simple comparative test CBR (*California Bearing Ratio in %*). In this test is determined the force required for penetrating a piston into the depth of 2.5 and 5.0 millimeters of analyzed material and compared with the force needed for penetrating the same piston in the standard crushed rock reference material. Full pavement design procedure should have to take into the account wide range of the design elements e.g. initial conditions, pavement geometry, traffic, material properties, climatic conditions, response model, performance model etc.
A response model is the computing algorithm which will supply the response of the structure to a given load in terms of stresses, strains and displacements. It is a fundamental element in the pavement design procedure. There are three basic widely used "layered" methods: the Method of Equivalent Thicknesses (MET), Layered Analytical Models (LAM) and Finite Element Models (FEM).
The emergence of the first roads design methods is dated back to the U.S. of 1930s, when the first empirical layered method based on knowledge of soil bearing capacity using the CBR value was developed. The original CBR based design method was based on tests made on a variety of existing crushed stone pavements judged to have reached a critical structural condition. Since the middle 1950s methods using the CBR value to determine the design modulus of elasticity E_p (MPa) began to emerge.
With the development of numerical models based on finite element method (FEM) allowing analyzing the stress-strain behaviour of the pavement more accurately, raised the requirement to prepare the corresponding deformation characteristics. These characteristics must respect the dynamic and cyclic character of the load and also the plastic and elastic deformation depending on the current moisture content and degree of compaction. The values of modules obtained from the CBR test do not comply with these requirements. The CBR test

does not record either the character of the deformation behaviour of material or frequency of transport. Therefore other possibilities of determining the deformation characteristics are looked for and developed; in our case the characteristics for design of low capacity road pavements at present.

2 The parameters affecting the CBR values

The basic characteristics of natural granular materials and subbase that affect the values of bearing capacity and parameters of deformation are moisture content and degree of compaction. Their influence is in the existing designing methods expressed by safety factors and empirical recommendations. They are, however, during laboratory tests of determining CBR or E_{def} values (deformation modulus in [1]) not directly considered. These laboratory values of bearing capacity and values of derived elasticity modules are not directly usable in numerical models. The dependence of elasticity modulus (from plate loading test) on the degree of compaction is clearly shown in figure 1.

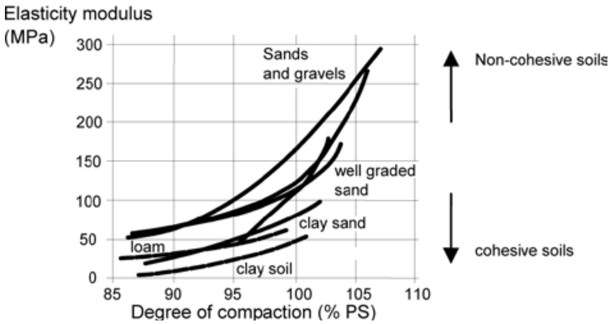

Figure 1 The dependence elasticity on degree of compaction of the soils [2].

Questions of a change of degree of compaction and moisture content of materials were checked in laboratories of Geostar Company and Mendel University in Brno.

2.1 Effect of compaction method of the sample

Previous standard for sample preparation for the CBR test in the Czech Republic [3] allowed static compaction. At present, the sample can be prepared only by using dynamic compaction - standard or modified Proctor energy [4]. According to practical experiences gained from performing these Proctor tests significant changes of the bulk density in the height of the sample may occur.
The experiments show in the rings on the bottom of the container increased the soil up to 3.6% in bulk density. Because this side of the sample is consequently tested by the penetration in the CBR test, it is evident that it leads to overrated results. However, if the samples were prepared by static compaction, the bulk density had less variance and bulk density values on the tested surface showed minimal difference from the required values.

2.2 Influence of moisture content on the CBR and the bulk density values

To verify the dependence between moisture content (w in %), bulk density (ρ_d in kg.m^{-3}) of soil sample and CBR values, CBR values at unsaturated samples by varying soil moisture content were experimentally measured. Figure 2 shows the trend of CBR parameter with increasing moisture content in comparison to bulk density.

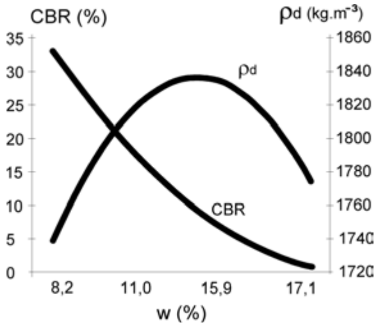

Figure 2 The example of dependence of CBR values and the bulk density on the change of moisture content [5].

3 Character of traffic load deformations

Deformations in road construction layers and in the subgrade due to cyclic dynamic traffic loadings can occur when particles of soil move from their original location [6]. Then a part of these particles will take a new permanent location. After repeated loading, shakes and dynamic effects induce next particles moving again. The emergent deformation u_N by repeated loads grow in a logarithmic dependence on the number of repeated load N according to the equation (1). Parameters α, β depend on the type of soil, load size and loading method (number of loads, the time between load and unload, loading rate growth).

$$u_n = \alpha + \beta \log N \tag{1}$$

During cyclic loading occur changes of strain-deformation response and physical properties in the early stage due to changes in microstructure. Material resistance to cyclic plastic deformation can increase cyclic hardening, decrease cyclic softening or a superposition of both processes may occur. These phenomena are often neglected in practice. From several tests with different amplitude of deformation can be obtained cyclic deformation curve (Fig. 3). Deformation modulus is then expressed in equation (2).

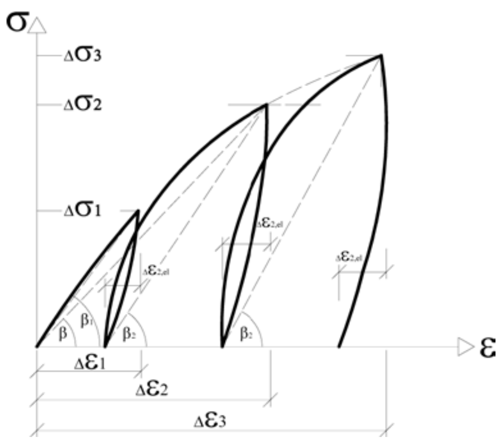

Figure 3 Cyclic loading diagram

$$E_{def,c} = \frac{\Delta\sigma_2}{\Delta\varepsilon_2 - \Delta\varepsilon_1 + \Delta\varepsilon_{2,el}} = tg\beta_2 \quad (2)$$

The design of pavement construction has to respect the specifics of deformation and define them by appropriately determined deformation modulus. The notation and methodology of the acquisition of this modulus have not been clearly specified.

4 Determination of deformation modulus M_R

American Association of State Highway and Transportation Officials deals with the design of road pavements on a long-term basis and based on new researches recommends replacing by this time used "strength" parameters (CBR) by cyclic modulus of elasticity (Resilient Modulus - M_R) [7]. The M_R value is able to define the real situation and the behaviour of the subgrade and materials of road construction layers better.

Latest and most advanced method to determine the M_R value of non-cohesive pavement materials is the triaxial compression test, which is governed in the Czech Republic by the standard CSN EN 13286-7 [8]. Characteristics obtained from this functional test are regarded as the most representative for the subsequent numerical models based on finite element methods (FEM). Testing of non-cohesive materials and bond mixtures in cyclic triaxial equipment can model conditions simulating real stress state of materials in the pavement construction during repeated dynamic loads. It is possible to observe both the flexible and plastic behaviour of the material and determine the value of resilient modulus at different levels of stress intensity. Another option to use the triaxial compression test is determination of permanent deformation caused by different levels of stress intensity (simulating different environmental influences) or determining parameters for predicting the plastic deformation of materials [8].

The resilient modulus M_R is analogous to elastic modulus used in the theory of elasticity. It is defined (eq. 3) as the ratio of stress intensity deviator σ_d to the elastic deformation ε_r.

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad (3)$$

Tests in a cyclic triaxial appliance to determine the M_R value are time-consuming. Initial costs of buying equipment are high and thus an obstacle to common use. Laboratory procedures required to implement the repeated triaxial tests on representative samples in commercial laboratories are not frequent. M_R values can be recommended for the road pavements of highest importance [9]. For minor and low volume roads are sought simpler and more affordable solutions. One of such solution may be a cyclic CBR test.

5 Cyclic CBR test, possibilities of using

The cyclic CBR test is an innovative and simple tool for assessing the deformation behavior and resilient modulus of subgrade and unbounded materials. It is not substitute for cyclic triaxial testing, whose principle is based, but gives the usable value resilient and deformation characteristics of subrage and unbounded material in particular for tertiary roads pavements [10].

Cyclic CBR test follows the standard laboratory CBR test. There is progressively implemented 50 to 80 cycles of loading and unloading on the sample. In each cycle is measured decrease in plastic deformation until its complete disappearance. The soil has only elastic deformation of which is then calculated so-called effective resilient modulus E_{eff} (MPa) which is also used for mathematical modelling and design of low capacity roads pavements.

The sample is prepared and the test carried out according to the criteria for equipment for standard CBR applying the load at a rate 1.27mm.min^{-1}. Repeated loading to a depth of penetration of 10mm is performed to reduce plastic deformation to zero (Fig. 4).

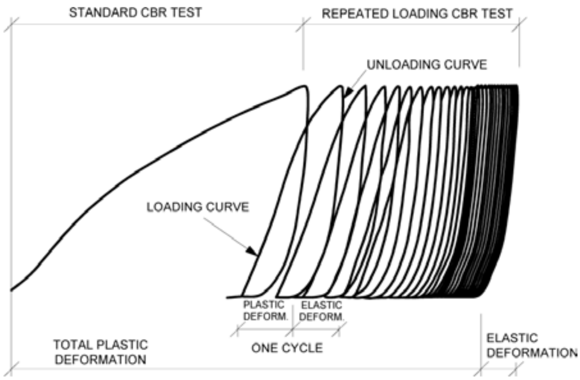

Figure 4 Course of cyclic CBR test (modified by [10])

Obtained effective resilient modulus E_{eff} also referred to as $M_{R,\,CBR}$ calculated from the settled elastic deformation at the end of loading reflects the total stiffness of the sample rather than an elasticity modulus (eq. 4).

$$E_{eff} = C1\left(1-\mu^{C2}\right)\sigma_0 \frac{a}{w^{C3}} \tag{4}$$

Where: E_{eff} = effective resilient modulus (MPa); w = elastic deformation (mm);
a = radius of pushing thorn; σ_o = strain below a thorn; μ = Poisson number of material; C1, C2, C3 constants [10].

6 Discussion and conclusion

Global development of design techniques for road pavements construction is moving from empirical to numerical modelling methods. Prerequisite for the use of numerical models is the provision of appropriate input parameters of deformation characteristics compatible with the finite element method. Given the high requirements for equipment to implement functional tests in routine practice are considered also alternative procedures and methods for determining the desired deformation characteristics.

The possibility of obtaining the resilient modulus from a simple cyclic CBR test is currently being tested in the laboratory of the Department of Landscape Management at Mendel University in Brno in cooperation with Geostar Company. Simultaneously this obtained modulus $M_{R,\,CBR}$ is tested for reliability analysis of pavements of tertiary roads and low loaded roads in numerical model based on finite elements method.

Monitoring of deformation behaviour of soils during cyclic loading of CBR equipment was started. It also included a determination of dependence of CBR values and resilient modules provided by the cyclic CBR test on moisture content. Figure 5 shows the development of plastic and elastic deformation after 60 load cycles. For the laboratory measurements was used CL soil from the subgrade with moisture content 10.9 %.

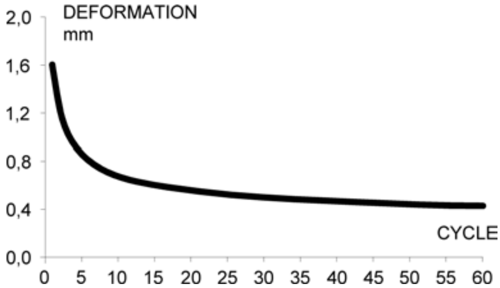

Figure 5 The development of plastic and elastic deformation after 60 load cycles [11]

Figure 6 Apparatus for determining $M_{R,CBR}$ (laboratory of Mendel University in Brno)

Gradual verifying of cyclic CBR test results has shown that the test is likely to be suitable for simple determination of changes of deformation characteristics of materials.

After first tests when was established bulk density for sample preparation for CBR the possibility of sample preparation by static pressing should be considered. Then the resulting CBR values would be based on the real bulk density changing with moisture content.

Performance of the sample in the CBR apparatus maybe more realistic describes the real behaviour of materials in the road pavements than the sample in cyclic triaxial equipment. The sample in triaxial equipment is cyclically loaded in a sort of "oedometer with a flexible case" - a membrane. The stiffness of the membrane is given by reinforcing lateral pressure σ_3. The value of the pressure chamber requires an accurate calculation using simulating numerical methods in order to realistically model real stress of the material in the pavement layer. The sample in CBR test also has a solid case but the ratio of its diameter to the diameter of the piston allows the emergence of lateral deflection and deformation of the test sample surface. The cyclic CBR test is a simple and rapid test to obtain good estimates of $M_{R,CBR}$ values for fine-grained materials and very probably also for coarser materials used in unbounded layers of pavements. This test does not replace the cyclic triaxial test but it is easier alternative for obtaining the required resilient characteristics. Moreover, if necessary it is possible easily modify degree of compaction and moisture content of materials in this test.

Acknowledgments

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