CETRA[2012]

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – **EDITOR**

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA 2012
2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

TITLE
Road and Rail Infrastructure II, Proceedings of the Conference CETRA 2012

EDITED BY
Stjepan Lakušić

ISBN
978-953-6272-50-1

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Katarina Zlatec · Matej Korlaet

COPIES
600

A CIP catalogue record for this e–book is available from the National and University Library in Zagreb under 805372

Proceedings of the
2nd International Conference on Road and Rail Infrastructures – CETRA 2012
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA 2012

2nd International Conference on Road and Rail Infrastructure

7–9 May 2012, Dubrovnik, Croatia

ORGANISATION

CHAIRMEN

Prof. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering
Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Maja Ahac
Ivo Haladin
Saša Ahac
Ivica Stančerić
Josipa Domitrović

All members of CETRA 2012 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. Ronald Blab, Vienna University of Technology, Austria
Prof. Vesna Dragčević, University of Zagreb, Croatia
Prof. Nenad Gucunski, Rutgers University, USA
Prof. Željko Korlaet, University of Zagreb, Croatia
Prof. Zoran Krakutovski, University Sts. Cyril and Methodius, Rep. of Macedonia
Prof. Stjepan Lakušić, University of Zagreb, Croatia
Prof. Dirk Lauwers, Ghent University, Belgium
Prof. Giovanni Longo, University of Trieste, Italy
Prof. Janusz Madejski, Silesian University of Technology, Poland
Prof. Jan Mandula, Technical University of Kosice, Slovakia
Prof. Nencho Nenov, University of Transport in Sofia, Bulgaria
Prof. Athanassios Nikolaides, Aristotle University of Thessaloniki, Greece
Prof. Otto Plašek, Brno University of Technology, Czech Republic
Prof. Christos Pyrgidis, Aristotle University of Thessaloniki, Greece
Prof. Carmen Racanel, Technical University of Bucharest, Romania
Prof. Stefano Ricci, University of Rome, Italy
Prof. Tatjana Rukavina, University of Zagreb, Croatia
Prof. Mirjana Tomičić–Torlaković, Univiversity of Belgrade, Serbia
Prof. Brigita Salaiova, Technical University of Kosice, Slovakia
Prof. Peter Veit, Graz University of Technology, Austria
Prof. Marijan Žura, University of Ljubljana, Slovenia

COMPARISON OF THE LABORATORY AND FIELD TESTS USED FOR PAVEMENT DESIGN

Lenka Sevelova[1], Jaroslav Hauser[2], Alice Kozumplikova[3]
1 Department of Landscape Management, Mendel University in Brno, Czech Republic
2 Geostar, spol. s r.o., Czech Republic
3 Department of Environmentalistics and Natural Resources,
Mendel University in Brno, Czech Republic

Abstract

Many present empirical design methods are based on CBR tests of underlying soils – pavement subgrade. On site testing consists of different methods, and obviously there are problems with comparing these two approaches. The authors deal with the comparison of testing, carried out both on site and in a laboratory, performed to determine deformation characteristics of the materials. These are consequently verified for use in numerical FEM models. The results of this comparison are presented.

Keywords: CBR tests – California Bearing Ratio, subgrade, pavement, FEM

1 Low volume road design methodology/design principle

During the design of forest roads/low volume roads we need to respect many specifics of this construction type that arise from the differences in transport of wood and the terrain demands of accessed forest areas. The transport of wood is done in the terrain with low bearing capacity value, unfavourable water regimen and higher longitudinal inclinations. In comparison with public roads, smaller speeds of transport units cause higher static effects and also increase load effects.
Forest roads belong to purpose–built or local communications with regard to traffic loads and in accordance with the existing technical regulations; they are designed as non–rigid roads covered with asphalt layers or unbounded materials, exceptionally they are designed as rigid.
According to the Czech technical directive TP 170, the existing analytical design method for non–rigid pavements is classified as theoretical–empirical It is based on the n–layer elastic half–space principle. The design characteristics are subsoil parameters, climatic conditions and traffic loads. A pavement subgrade depends on the type of soil and climatic factors, and is characterized by the CBR bearing ratio under optimal CBR_{opt} and saturated CBR_{sat} conditions. Load bearing capacity of the active zone is defined by three subsoil types PI to PIII with minimal values of the deformation modulus $E_{def,2}$ that must be achieved during soil acceptance during construction (see Tab. 1).

Table 1 The subsoil type table for TP 170 catalogue sheets

Subsoil type	P I	P II	P III
Subsoil frost susceptibility	non–susceptible	slightly susc. to susceptible	susceptible
Min. deformation modulus $E_{def,2}$	90 MPa	60(45) MPa	45(30) MPa
Design elasticity modulus E_{np}	120 MPa	80 MPa	50 MPa
CBR_{sat} (acc. to standard CSN 73 6133)	50 %	30 %	15 %

2 Subgrade characteristics and pavement designs according to the Czech Transport Ministry TP 170 Directive Method

Generally, cyclical moisture content change processes occur during the year in pavement subsoils in dependence on climatic and hydrogeological territorial conditions. A water regimen defines the change progression and the degree of moisture content distribution in the subsoil, and also the ground water character in the soil and its knowledge is necessary in the TP methodology in order to determine the CBR load bearing capacity.
The CBR load bearing capacity ratio is, according to TP 170, done on samples under optimal - CBR_{opt} and saturated CBR_{sat} moisture content. To determine CBR values under design conditions we need to consider a specific water regimen. The CBR design conditions are necessary to determine the design subsoil elastic modulus and the subsoil types PI to PIII.
Favourable (diffuse)

$$h_{pv} > h_{pr} + 2h_s \quad CBR_{opt} \tag{1a}$$

Unfavourable (pendular)

$$\begin{gathered} h_{pr} + h_s < h_{pv} > h_{pr} + 2h_s \\ CBR_{pen} = CBR_{opt} - 0{,}6\left(CBR_{opt} - CBR_{sat}\right) \end{gathered} \tag{1b}$$

Very unfavourable (capillary)

$$h_{pv} < h_{pr} + h_s \qquad CBR_{sat} \tag{1c}$$

where
- h_s is the height of capillary rise (m) that is, according to TP 170, determined from the grain size curve with the grains ‹ 0.02 mm
- h_{pr} is the depth of freeze–through (m) that is determined from the frost index Im , according to CSN 73 6196 or TP 170 from the relationship h_{pr} = 0.05 Im0.5
- h_{pv} is the depth of ground water from the surface (m).

In exceptional cases, and only for cohesive fine–grained soils, the water regimen can be roughly determined from the consistency number I_c . The subsoil types are differentiated according to the frost susceptibility of soils and their load bearing capacity that is currently declared by two different parameters. According to the TP design methodology the plain active zone bearing capacity is given by the minimum deformation modulus $E_{def,2}$ obtained from the static loading plate test. This parameter is used to check compression during acceptance of ground plain according to Tab. 2. At the same time the subgrade load bearing capacity is expressed by the CBR ratio value obtained from a laboratory test under design conditions.

Table 2 The required minimum deformation modulus values Edef,2 at the pavement plain

Required modulus of deformation $E_{def,2}$ (MPa)	Subsoil characteristic (acc. to USCS)
30	Silty and clayey soils ML, MH, CL, CH
45	Mechanically improved fine–grained silty and clayey soils ML, MH, CL, CH Sands and gravels SP, SW, SM SC, GM and GC, meeting CBR ≥ 15%,
60	SP, GM a GC at design CBR ≥ 15 % Active zone made of soil improved by bond mixture at CBRsat ≥ 10 %
90	Rock loose material, modified rock underbed, GW and GP soils, Soils improved by adding bonding agent at CBRsat ≥ 50 %

Pavement design follows the knowledge of the above mentioned characteristics that include the design level of breakage, design situation given by the design period, climatic conditions, subsoil characteristics, and the design elastic modulus. The design elastic modulus E_{pd} is determined based on the knowledge of CBR value from the water regimen conditions (1a-c), and from the relationship (2).

$$E_{pd} = 17.6\ CBR^{0.64}\ (MPa) \tag{2}$$

The equation (2) was taken over from England, where this relationship was verified on certain types of clayey and silty soils. That is why in CR field measurements we use CBR 2 % to 12 %. For the values higher than CBR 30 % we introduce a constant E_{pd} modulus value of 150 MPa. The design elasticity modulus Epd is defined for the behaviour of subgrade under the pavement at moisture content that corresponds to the design water regimen and for short period loads occurring during vehicle passage.
The CBR value thus became a basic parameter for the construction dimensioning of pavements. Especially designs of non–rigid pavement were and still are derived from the subsoil CBR value.
The earth body and active zone are designed for specific load capacity values according to TP and CSN 73 6133, and the design is limited by regulations on possibilities of use of specific materials for the given level of breakage. The load capacity values are unequivocally defined by the deformation transformation modulus $E_{def,2}$ that is checked at the subgrade and in other construction layers during construction. The rules concerning protection against breakage and pollution by moving of construction machinery and storage of construction materials apply to the active zone surface. This protection also applies to water drainage. Tab. 2 specifies minimum values of CBR load capacity ratio in saturated conditions and the $E_{def,2}$ deformation modulus, at which the soil for the active zone can be used without improvement. Relationships of both parameters were the subject of several studies (for example Pospisil, 2003) already; however, unambiguous and suitable correlations between both parameters were not definitely proven. According to the active zone control study performed by the Construction Faculty of the University of Zilina values of the parameters that define load bearing capacity within the construction quality checking are significantly higher than the considered project values. This discrepancy and the term confusion of deformation modulus and elasticity modulus lead to inadequate over dimensioning of pavements. Conclusions of this study recommend unification of the criteria for evaluation of earth plain load bearing capacity and unambiguous specification of characteristics used for design and quality evaluation.

3 Some problems during determination of California Bearing Ratio – CBR

So called CBR (California bearing ratio) bearing ratio is currently used for determination of soil bearing capacity of subsoil and individual road construction layer materials. The CBR test was developed in California in nineteen thirties as a material characteristic of road building materials, and its use expanded into the evaluation of soils in road subsoil strata; In CR this is done according to the European standard /1/.

The CBR test for determining the load bearing capacity should simulate soil behaviour in the road construction as faithfully as possible; therefore the surface of a test sample is loaded by metal surcharge collars, whose weight should substitute the effects of the load imposed by a future road. According to /1/ a surcharge collar weighing 2 kg erroneously represents an extra road load of 700 mm, instead of correct 70 mm.

The effect of this extra load on transport communications was investigated in our laboratories. In most cases we have found significant decrease of CBR /4/ and /5/ values of up to 50% both on original soils and soils improved by hydraulic binders while using the correct number of collars. We have also investigated the rise and fall of a sample surface while exceeding the soil load bearing capacity, which is mostly the case with CBR tests – see /2/. The original assumptions of behaviour of all samples as circular bases during the CBR tests were not confirmed.

4 Static Plate Load Tests – SZZ

The most important parameter of the soils and subgrades of pavements is so called deformation modulus $E_{def,2}$ that is determined by the static load test from the second load cycle. As was mentioned above, in CR this parameter is used for the subgrade and road construction layer quality evaluation within control tests on site. This test is also sometimes used to determine elasticity modulus.

The circular plate load tests belong to basic field tests for determination of deformation parameters of subsoil and unbounded construction layers. According to the way the test is arranged and used elasticity theory, the test can be used to determine the total deformation static modulus $E_{SZZ,c}$, elasticity static modulus $E_{SZZ,e}$, instantaneous deformation modulus E_o or the foundation reaction modulus K. The main use of the static plate load test (SZZ) is the determination of 'the load bearing capacity' of the loaded layer using the deformation modulus $E_{def,2}$.

The general procedure of the load test lies in the application of load through a circular plate to the foundation and determination of the corresponding deformations. The circular plate dimensions correspond to the construction purpose. A plate with the 300 mm diameter is used for road construction in CR. For transport construction purposes the tested surface is gradually loaded to the effective stress value of 500 kPa and the secant deformation modulus is determined from the approx. interval of 150 to 350 kPa. However, if a deformation of 5 mm is achieved, the test is brought to a halt, and the deformation modulus is recalculated for the interval of 0.3 to 0.7 multiple of the stress that corresponds to the 5 mm deformation.

5 Subsoil model behaviours after loading for FEM

The knowledge of deformation characteristics of used construction materials and soils that will participate in the interaction of the construction and subsoil system is crucial for the construction design. The basic deformation characteristic is the elasticity modulus that is, according to the Hook's law, defined as the original secant modulus (Fig. 1). For natural materials that are used for line constructions, where permanent deformations predominate over the elastic ones, the deformation transformation modulus that is defined as the secant modulus (Fig. 1) is used to describe mechanical behavior. The secant modulus E_{50} is defined for the reference stress at 50% stress during breakage, and is used to calculate areal foundations.

Transformation characteristics that depend on instantaneous structural properties cannot be derived from the subject matter, but they have to be derived from suitably selected experimental measurements. Current geotechnical procedures offer many tests and modulus values derived from them. During deformation of foundations and unbounded materials there is both soil compression, i.e. decrease in volume, and shear movement with consequent squeezing of material along originating shear planes. Therefore it is necessary to know the geotechnical characteristics, the modulus and the Poisson's number and the strength characteristic properties given by the angle of internal friction and cohesion. Suitable definition of physical and mechanical materials used for road construction is a basic task for the subgrade quality evaluation, strength and load bearing capacity determination, and last but not least, the determination of road thickness. These properties are given by the strength and deformation characteristics that determine the bearing capacity of materials to resist outside forces and deformation.

The subsoil material and construction layer characteristics are empirically defined for the purpose of road design, or they can be obtained during laboratory tests. Their selection and methods of determination change according to the requirements of calculation model developments. For a few decades a 'classical' design of road construction composition based on CBR values originated from the laboratory tests of broken subsoil materials was used, although non–rigid roads were rarely broken due to the loss of strength of their subgrade.

CBR is a soil and unbounded road layer characteristic used for both determination of the bearing capacity of subgrade, and also it is a base of the current design methods for road construction dimensioning in order to determine the subsoil modulus. Characteristics are sought and relationships defined, with which we can obtain the design CBR elasticity modulus E_p (MPa). Among the most known is the median design subsoil modulus E_{pn} obtained from nomograms, or for example the following relationships (TP 170; 2004). At the same time the correlation between CBR and the deformation modulus $E_{def,2}$ is monitored and sought, for example in /6/.

$$E_p = 10\ \mathrm{CBR}(\mathrm{MPa}) \quad \text{for CBR} < 5\ \% \tag{3}$$

$$E_p = 17.6\ \mathrm{CBR}^{0.64}(\mathrm{MPa}) \quad \text{for CBR} > 5\ \% \tag{4}$$

6 Results

Different methods of deformation moduli preparation using finite element method numerical modelling are used for material models and differ in their approach to simplification of strongly inhomogeneous soil environment, and with more or less accuracy describe the behaviour of materials after loading. Figs. 1 to 5 document the realistic distribution of stress under the plunger during modelling of CBR test using FEM. FEM was also used to create a behavioural model of subgrade on site during loading by the static load test. Results for the stresses of 500 kPa and 1250 kPa are shown in Figs. 6 and 7.

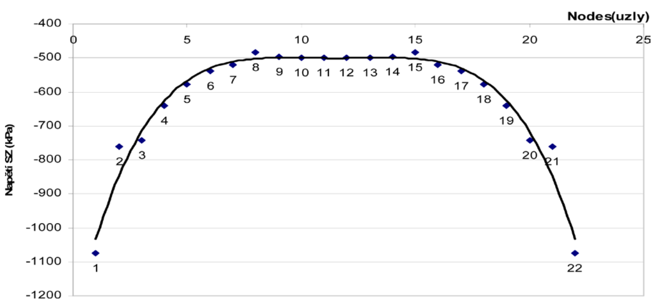
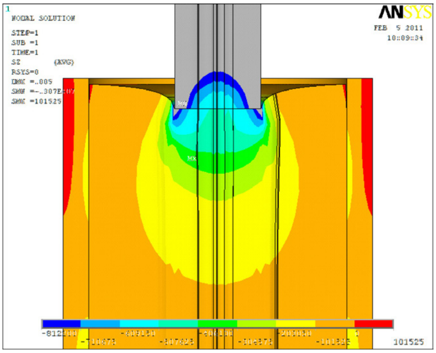


Figure 1 The stress under the penetration plunger during the simulation of CBR test using the FEM model.



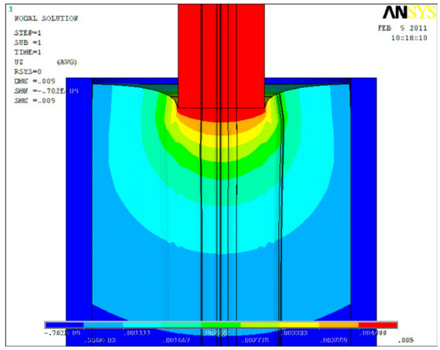
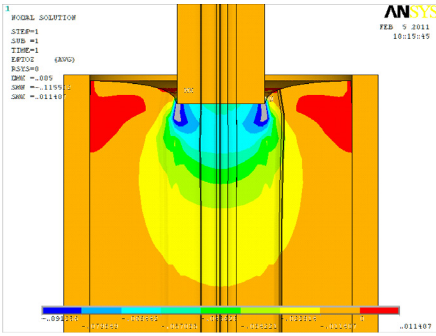


Figure 2 The vertical direction stress SZ.

Figure 3 The vertical deformations UZ.



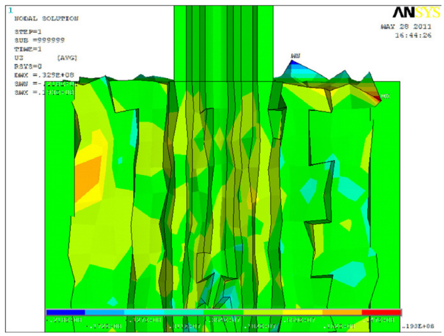
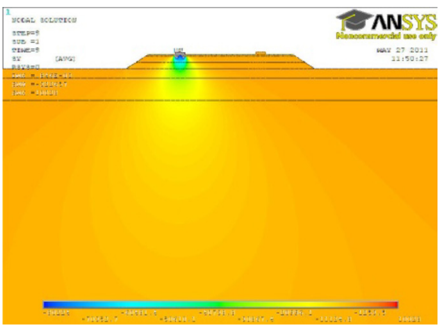


Figure 4 The relative deformations in the vertical direction during 3 mm penetration.

Figure 5 The relative deformations in the vertical direction during 10 mm penetration.



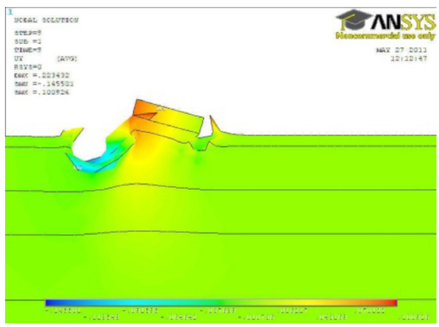


Figure 6 The vertical stress in the underbed during 500 kPa stress.

Figure 7 The breakage of the model during the 1250 kPa stress.

During the calculation of maximum stress applied during this test, and equal to 500 kPa, the model shows the resulting deformations very similar to the actually measured values – see Fig. 6. If the subgrade is loaded by the stress value equal to the stress under the penetration plunger in the CBR testing equipment (Fig. 7), the model collapses similarly as it broke after exceeding of the 1st load capacity limit.

7 Conclusions

Based on the comparison of two approaches, and thus obtained stress values and deformations from CBR and the load test on site, we can see that it is impossible to derive deformation and elasticity modulus values from the CBR test. According to our results we have breakage of the sample by shear during the CBR test, and also a significant decrease of CBR values occurs during the use of surcharge collars that substitute for the weight of the road, with concurrent sinking of the sample surface.

During the evaluation of transport construction subgrade we performed the determination of deformation and elasticity modulus found after the cyclical loading of the samples. Contrary to the original findings of prof. Molenaar that designed the CBR cyclical test, effective stresses at the penetration plunger tip will have to be modified during further tests, in order not to exceed real stresses caused by transport of tested material located in the road construction. Maximum stresses will be derived for various materials and used as the maximum for CBR cyclical tests.

Acknowledgements

The work was supported by the Technology Agency of Czech Republic as the project TA01020326 'Optimization of design and realization of low capacity road pavements'.

References

[1] CSN EN 13286 – 47 (2005). Test method for the determination of California bearing ratio, immediate bearing index and linear swelling.

[2] Hauser, J., Sevelova, L., Kozumplikova, A. (2010). Parametry CBR a IBI materialu do zemnich konstrukci dopravních staveb, in 38. konference se zahranicni ucasti Zakladani staveb Brno 2010 - Sbornik prispevku. 1. Ed. Brno: Sekurkon, s.r.o., p 60-65. ISBN 978-80-86604-51-0.

[3] Hauser, J., Kozumplikova, A., Sevelova, L. (2011). Zkoušky CBR a IBI při navrhování zemního tělesa a konstrukčních vrstev dopravních staveb. [CD-ROM]. in Geotechnicke problemy liniovych stavieb. Bratislava, p 101-108. ISBN 978-80-227-3504-9.

[4] Hauser, J., Kozumplikova, A., Sevelova, L. Zkousky CBR a IBI podlozi a nestmelenych podkladnich vrstev vozovek, Asfaltové vozovky Ceske Budejovice (2011).

[5] Hauser, J., Kozumplikova, A., Sevelova, L. (2012). The influence of the Soil Treatment On the CBR Test values, International Conference on Ground Improvement and Ground Control (ICGI 2012) in print

[6] Pospisil, K. Predvidatelnost modulu pretvarnosti, Geotechnika magazine 1/2003.