ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 63 47 Number 2, 2015

http://dx.doi.org/10.11118/actaun201563020405

INFLUENCE OF ENVIRONMENTAL HUMIDITY ON MECHANICAL PROPERTIES OF NATURAL AND RECYCLED UNBOUND MATERIALS

Aleš Florian[1], Lenka Ševelová[2], Jaroslav Žák[1]

[1] Department of Civil Engineering, The Institute of Technology and Businesses in České Budějovice, Okružní 10, 370 01 České Budějovice, Czech Republic

[2] Department of Landscape Management, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

FLORIAN ALEŠ, ŠEVELOVÁ LENKA, ŽÁK JAROSLAV. 2015. Influence of Environmental Humidity on Mechanical Properties of Natural and Recycled Unbound Materials. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 63(2): 405–409.

Low volume roads are widely used all over the world. To improve their quality a FEM computer simulation of their behavior is proposed. The input information about mechanical properties of individual materials is crucial for obtaining results as exact as possible. Among others, the mechanical properties are generally dependent on the state of stress and on humidity conditions. For this purpose the cyclic-load triaxial machine testing of cyclic-load performance of materials seems to be a promising test method. The test specimens can be prepared with different amounts of water. Thus modulus of elasticity (Young modulus) of different materials including recycled ones can be measured under the different conditions of horizontal and vertical stresses and under the different humidity conditions.

Using the proposed testing procedure the modulus of elasticity of materials used in the newly built low volume road is obtained under the different state of stress as well as humidity conditions set to standard, dry and fully saturated level. Also recycled materials which are able to replace the traditional materials in the pavement are tested. Obtained values of modulus of elasticity can be used in a FEM study of the newly built road.

Keywords: low volume road, pavement, triaxial test, Young modulus, unbound materials

INTRODUCTION

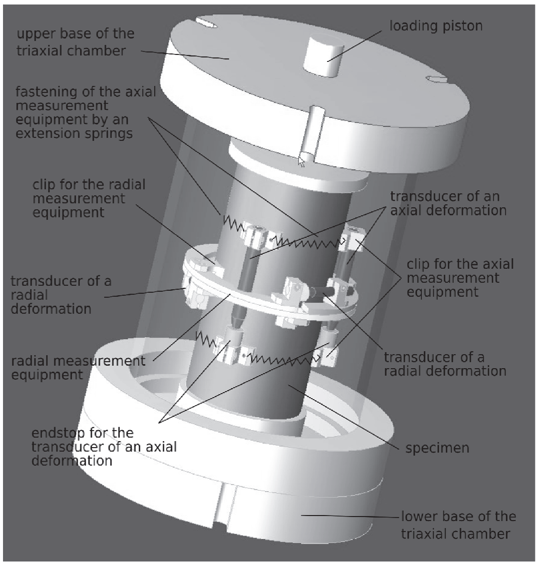
Pavement structures in the Czech Republic including low volume roads are designed according to the technical recommendation TP 170 (2010). The traditional design method is based on the knowledge of traffic load and material characteristics of particular materials. These parameters are defined empirically or are obtained from traditional laboratory tests which unfortunately are not able to respect the real behavior of pavements. Therefore it is very difficult and time consuming to put new materials (including recycled materials) into practice or to change traditional thickness of structural layers, see e.g. Hornych and Abd (2004), Saeed *et al.* (2001), Werkmeister *et al.* (2003).

To improve the quality of low volume roads the computer simulation of their behavior using FEM model is proposed Ševelová and Kozumplíková (2010). To obtain the most accurate results from such a model it is necessary to work with the exact values of the modulus of elasticity (Young modulus) of individual materials. Generally, the values presented in standards and regulations are not the desired values of the modulus of elasticity, but rather different deformation moduli. The reason is simple – the traditional standard tests used in geotechnical as well as pavement design practice are not able to determine the desired modulus of elasticity.

Cyclic-load triaxial testing is an innovative laboratory test method. By simulating both the vertical loading and the horizontal pressure caused by individual crossings of vehicles as well as self-weight of the structure, the real stress conditions in corresponding layers of the structure can be obtained. Although the method was included in EN 13286-7 (2004), it has not been used in practice very often up till now. The success of the proposed test method in a practical use is dependent on the knowledge of loading effects. The vertical and horizontal stresses produced in particular layer materials are necessary inputs. The horizontal stress cannot be obtained experimentally by long-term measurements on real pavements because it is both time and money consuming process with a low efficiency.

The mechanical properties of materials are dependent not only on the stress conditions but also on the humidity conditions. The test specimen can be prepared with different amount of water and thus the humidity influence can be studied too.

The values of modulus obtained from triaxial testing can be used as input values for FEA of the pavement behavior under different humidity conditions.



1: *Triaxial chamber with specimen and measurement equipment*

MATERIALS AND METHODS

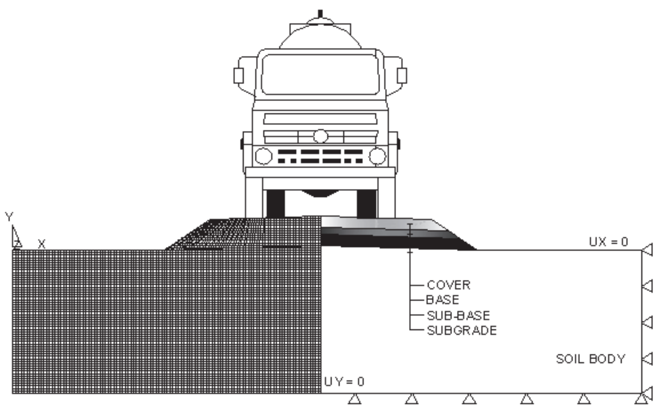
Cyclic-load Triaxial Test

The cyclic-load triaxial test is able to simulate the real traffic loading and stress conditions in a pavement during its whole lifetime. The triaxial test consists of repeating short-time vertical pulses together with constant or variable confining horizontal pressure on a cylindrical specimen of dimensions 200 mm high and 100 mm diameter. The vertical pulses on the specimen simulate passing of wheels and the confining pressure simulates the horizontal stress conditions in a particular layer of a pavement. The specimen is placed in the triaxial chamber between two porous slabs which drains off the water, see Fig. 1. The specimen deformations are measured by linear variable displacement transducers (LVDT). The deformation in vertical direction is measured by three LVDTs in order to measure a possible tilt of the specimen. The horizontal deformations are measured by two mutually perpendicular LVDTs to deal with possible anisotropic deformations. The outputs of triaxial test are modulus of elasticity, progress of permanent deformation, and Poisson coefficient.

To make the triaxial test of structural materials more reliable we have to know the range of vertical stress and horizontal pressure for a particular layer as well as humidity conditions.

Low Volume Road Analysed

The triaxial testing is performed for materials used in the newly built multi-purpose low volume road (forest road and ski track). The road has two lanes (the lane width of 3 m) with the total width of 7 m, see Fig. 2. It is designed according to ČSN 73 6133 (2010) and TP 170 (2010). It consists of three structural layers (non-rigid cover, base, sub-base) and the subgrade soil with no added binders. In the original project (natural variant) only materials from natural resources are used. The cover layer consists of a mixture of mechanically compacted aggregates of 100 mm thickness, the base layer is made from gravel fractions 16–32 of 150 mm



2: *Model of pavement structure*

I: *Structural layers of natural and recycled variant of low volume road*

Layer	Thickness [mm]	Poisson Coeff. [-]	Natural Variant	Recycled Variant
Cover	100	0.3	Mechanically Compacted Aggregates	Recycled Bitumen
Base	150	0.3	Gravel	Recycled Concrete
Sub-base	150	0.3	Coarsely Crushed Stone	
Subgrade		0.25	Soil	

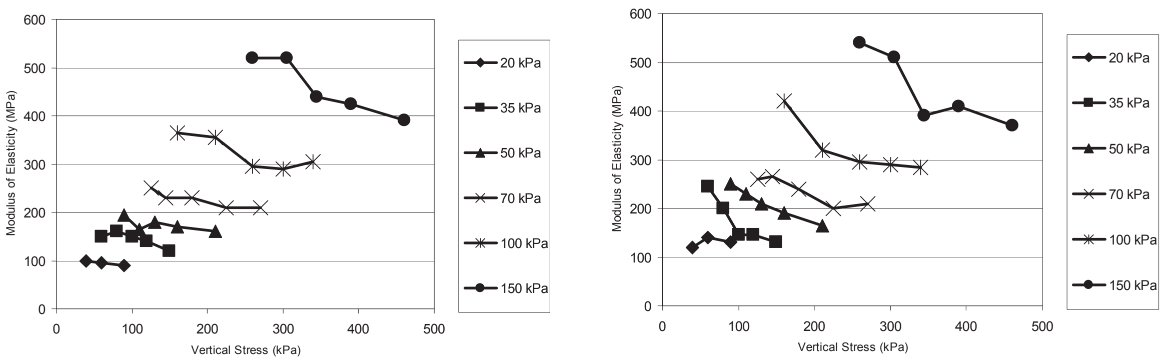
thickness and the sub-base is made from coarsely crushed stone fractions 32–63 of 150 mm thickness, see Tab. I. In the alternative project (recycled variant) for cover as well as base layer the recycled materials instead those from natural resources are proposed. The cover layer consists of mechanically compacted recycled bitumen material of 100 mm thickness, the base layer is made from recycled concrete fractions 0–16 of 150 mm thickness and the sub-base is the same as in the natural variant, see Tab. I.

RESULTS OF TRIAXIAL TEST OF MATERIALS

The measurement of behavior of individual natural and recycled materials using the triaxial test was performed at a constant chamber pressure (horizontal stress) set to 20, 35, 50, 70, 100, 150 kPa, and 10 000 loading cycles. Testing of one material specimen lasted approximately four hours. After completion of testing, the specimen was removed and from the center of specimen the humidity was set. Up until now testing of the cover and base materials of recycled variant and the base and sub-grade materials of natural variant has been finished Karásková (2012).

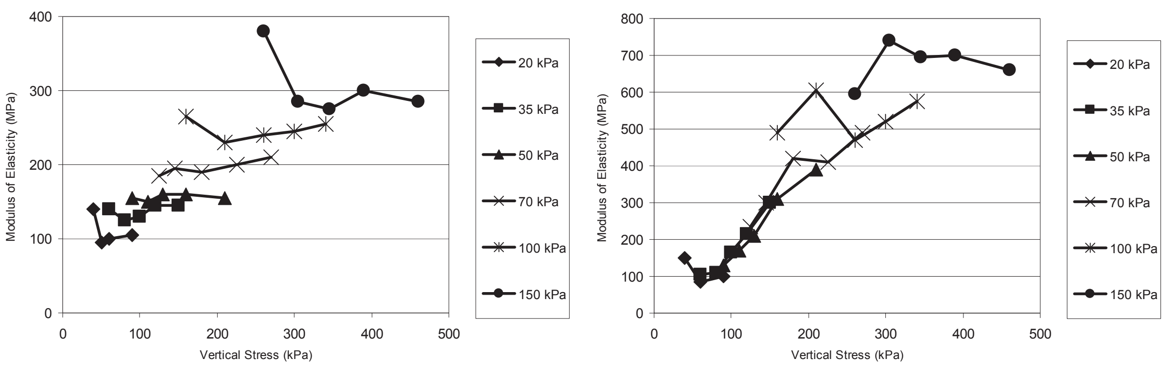
First of all, the modulus of elasticity was determined for the standard humidity level and for different horizontal stress levels (20, 35, 50, 70, 100, 150 kPa). The results are shown for natural materials in Fig. 3. and for recycled ones in Fig. 4. It is clearly shown how the modulus of elasticity of unbound materials (recycled as well as natural materials) significantly depends on the state of stress (horizontal and vertical stress) in which the material is located.

Then more detailed testing of the modulus of elasticity was performed for three different humidity levels and the most probable state of stress in which the individual material in the structural layer may occur. For example, for the sub-grade material horizontal stress of 20 kPa and vertical



(a) Base material (b) Subgrade material

3: *Modulus of elasticity under different horizontal and vertical stress conditions, natural materials*



(a) Base material (b) Cover material

4: *Modulus of elasticity under different horizontal and vertical stress conditions, recycled materials*

II: *Modulus of elasticity, natural materials, dry humidity level*

Layer	w– [%]	E [MPa]	Mean Value E [MPa]
Subgrade	1.6	339.0	***263.3***
	1.8	194.0	
	1.8	257.0	
Base	1.9	251.0	***248.3***
	1.8	269.0	
	2.2	225.0	

III: *Modulus of elasticity, natural materials, standard humidity level*

Layer	w– [%]	E [MPa]	Mean Value E [MPa]
Subgrade	10.0	137.0	***146.7***
	10.0	158.0	
	10.0	145.0	
Base	6.0	182.0	***247.0***
	6.0	318.0	
	6.0	241.0	

IV: *Modulus of elasticity, natural materials, saturated humidity level*

Layer	w– [%]	E [MPa]	Mean Value E [MPa]
Subgrade	11.6	66.0	***66.0***
	10.5	81.0	
	11.0	51.0	
Base	6.5	169.0	***171.7***
	7.0	151.0	
	6.3	195.0	

V: *Modulus of elasticity, recycled materials, dry humidity level*

Layer	w– [%]	E [MPa]	Mean Value E [MPa]
Base	7.4	181.0	***170.3***
	6.4	170.0	
	6.2	160.0	
Cover	0.8	1285.0	***1391.0***
	0.7	1497.0	
	1.0	2035.0	

VI: *Modulus of elasticity, recycled materials, standard humidity level*

Layer	w– [%]	E [MPa]	Mean Value E [MPa]
Base	10.0	166.0	***149.5***
	10.0	314.0	
	10.0	133.0	
Cover	3.0	459.0	***455.0***
	3.0	1800.0	
	3.0	451.0	

VII: *Modulus of elasticity, recycled materials, saturated humidity level*

Layer	w– [%]	E [MPa]	Mean Value E [MPa]
Base	12.7	126.0	***126.7***
	14.2	156.0	
	10.5	98.0	
Cover	3.9	1040.0	***393.5***
	5.0	527.0	
	4.0	260.0	

stress of 75 kPa was further assumed. Similarly, for the base material horizontal stress of 50 kPa and vertical stress of 150 kPa and for the cover material horizontal stress of 100 kPa and vertical stress of 250 kPa were assumed. The humidity was set to standard humidity level (w), to dry humidity level (w–) and to saturated humidity level (w+). The testing was performed with three samples each time. Results are shown in Tabs. II–VII. It could be seen that the modulus of elasticity decreases with increasing humidity and vice versa.

CONCLUSION

Testing of materials in triaxial testing machine under different humidity as well as stress conditions allows to obtain the values of modulus of elasticity that respect real conditions in real pavements. Depending on the actual state of stress of materials under the standard humidity level, the modulus of elasticity of the subgrade material used in the newly built road can be expected in the interval 120–540 MPa, while for the base material the modulus of elasticity can be expected in the interval 90–520 MPa for the case of natural materials. In the case of recycled materials the modulus of elasticity can be expected in the interval 100–380 MPa for the base material and for the cover material the modulus of elasticity can be expected in the interval 90–740 MPa. It is seen that the modulus of elasticity decreases with increasing vertical stress in the case of natural materials. Recycled materials show different behavior. For the base material (recycled concrete) the modulus of elasticity is more or less independent on the vertical stress intensity with the exception of the highest intensity of 150 kPa, when it decreases with increasing vertical stress. For the cover material (recycled bitumen) the modulus of elasticity increases with increasing vertical stress with the exception of the high intensity over 100 kPa, when it is more or less independent on the vertical stress intensity.

Up until now realized tests show that the modulus of elasticity decreases with increasing humidity and vice versa. Also it is found that the dry conditions acting on the structural materials of the pavement generally do not cause as significant changes in the mechanical properties as rain or high moisture. Depending on the actual humidity level, the mean value of modulus of elasticity of the subgrade material can be expected in the interval 65–265 MPa, while for the base material the modulus of elasticity can be expected in the interval 170–250 MPa for the case of natural materials. In the case of recycled materials the mean value of modulus of elasticity can be expected in the interval 125–170 MPa for the base material and for the cover material the modulus of elasticity can be expected in the interval 390–1395 MPa.

Acknowledgement

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

REFERENCES

CEN. 2004. *Unbound and hydraulically bound mixtures – Part 7: Cyclic load triaxial test for unbound mixtures*. EN 13286-7.

HORNYCH, P. and EL ABD, A. 2004. Performance-based specifications: Selection and evaluation of models for prediction of permanent deformations of unbound granular materials in road pavements. In: *SAMARIS Draft report*, SAM-05-DE10, 2004.

KARÁSKOVÁ, R. 2012. *Performance testing of recycled materials in roads.* MSc. Thesis. Brno: Brno University of Technology.

MINISTRY OF TRANSPORT. 2010. *Design of pavement structures*. TP 170.

SAEED, A., HALL, J. W. JR. and BARKER, W. 2001. *Performance – Related Tests of Aggregates for Use in Unbound Pavement Layers*. NCHRP report 453.

ŠEVELOVÁ, L. and KOZUMPLÍKOVÁ, A. 2010. Numerical Model for Parametric Studies of Low Volume Roads. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, LVIII(5): 361–367.

ÚNMZ. 2010. *Road earthwork – design and execution*. ČSN 73 6133.

WERKMEISTER, S., NUMRICH, R., DAWSON, A. R. et al. 2003. Design of granular pavement layers considering climatic conditions. In: *Transportation Research Board, 82th Annual Meeting*. Washington D.C.

Contact information

Aleš Florian: Ales.Florian@seznam.cz
Lenka Ševelová: lenka.sevelova@mendelu.cz
Jaroslav Žák: jzax@seznam.cz