CETRA[2014]

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA 2014

3rd International Conference on Road and Rail Infrastructure

28–30 April 2014, Split, Croatia

TITLE

Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY

Stjepan Lakušić

ISSN

1848-9850

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.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY

“Tiskara Zelina”, April 2014

COPIES

400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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

CETRA[2014]
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

ORGANISATION

CHAIRMEN

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

ORGANIZING COMMITTEE

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

All members of CETRA 2014 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. Vesna Dragčević, University of Zagreb
Prof. Isfendiyar Egeli, Izmir Institute of Technology
Prof. Rudolf Eger, RheinMain University
Prof. Ešref Gačanin, Univeristy of Sarajevo
Prof. Nenad Gucunski, Rutgers University
Prof. Libor Izvolt, University of Zilina
Prof. Lajos Kisgyörgy, Budapest University of Technology and Economics
Prof. Željko Korlaet, University of Zagreb
Prof. Zoran Krakutovski, University of Skopje
Prof. Stjepan Lakušić, University of Zagreb
Prof. Dirk Lauwers, Ghent University
Prof. Zili Li, Delft University of Technology
Prof. Janusz Madejski, Silesian University of Technology
Prof. Goran Mladenović, University of Belgrade
Prof. Otto Plašek, Brno University of Technology
Prof. Vassilios A. Profillidis, Democritus University of Thrace
Prof. Carmen Racanel, Technical University of Civil Engineering Bucharest
Prof. Tatjana Rukavina, University of Zagreb
Prof. Andreas Schoebel, Vienna University of Technology
Prof. Mirjana Tomičić-Torlaković, University of Belgrade
Prof. Audrius Vaitkus, Vilnius Gediminas Technical University
Prof. Nencho Nenov, University of Transport in Sofia
Prof. Marijan Žura, University of Ljubljana

DEFORMATIONAL PROPERTIES OF UNBOUND GRANULAR PAVEMENT MATERIALS

Andrea Načinović Margan, Željko Arbanas, Aleksandra Deluka-Tibljaš, Marijana Cuculić
Faculty of Civil Engineering, University of Rijeka, Croatia

Abstract

Selection of pavement materials takes very important role in pavement design procedure. The understanding of pavement structure behavior under cyclic loading is necessary in order to assure its serviceability during a predicted structure life. Unbound granular material layers in pavement structure represent a base for upper construction and their compaction and deformational behavior under cyclic loading have significant impact on the bearing capacity of upper layers and overall pavement construction. Unbound granular materials show complex behavior under cyclic loads with gradual accumulation of permanent deformation. Accumulation of a large number of small permanent deformation in unbound granular material usually affects on behavior of the sub-base layer and larger irreversible deformations in the upper layers of the pavement structure. Several analytical models have been developed to describe the development of the permanent deformations and behavior of unbound granular materials affected by these deformations. Recent studies and analyses are oriented on laboratory testing of different types of unbound materials under triaxial loading. These studies aim at developing analytical models which are more accurate in predicting deformation behavior of particular local materials under specific stress and moisture conditions.
The purpose of this paper is to present an overview of the models that describe permanent deformation in unbound granular materials and correlation between permanent deformation and number of load cycles. Particular emphasis in the analyses would be on models that can be applied on unbound pavement layers constructed of local materials used in Croatia.

Keywords: unbound granular material, pavement construction, permanent deformation, analytical models, triaxial loading

1 Introduction

Flexible pavement consists of one or more bound asphalt layer overlying one or more sub layers consisted of unbound granular material which are together compacted over a suitable soil subgrade and they are the most frequently used pavement type. These flexible road pavements deteriorate under effects of traffic load and weather over time. Because of that, selection of pavement materials takes very important role in pavement design procedure. The understanding of pavement structure behaviour under cyclic loading is necessary in order to assure its serviceability during a predicted structure life. Structure life of a pavement depends very much on the response and the quality of unbound granular layer material [1]. Unbound granular materials in sub-base and base layers have very important role in overall structural performance of the pavement and in general consisting crushed rock particles with certain amount of fines and different various water content [7]. Unbound granular layers in pavement structure have complex elastoplastic response under traffic loading. In this paper the idea is to present a short overview of the existing models for the description of performance of unbound layers and materials. Basic analyses of the factors influencing on that performance during time will be also presented.

2 Permanent deformations and appropriate behaviour models

Vehicles' wheeling causes repeated cyclic loads on pavement structures and two types of deformation, resilient and permanent deformations, occur (Fig.1.). Resilient deformations are recoverable part of deformations and they are related to the fatigue cracking of overlying asphalt layers. Permanent deformations are irreversible, very important accumulated plastic, non-recoverable deformations which may lead to rutting, one of the principal failure of flexible pavement structures. Accumulation of a large number of small permanent deformation in unbound granular material during each loading cycle usually can cause that failure or collapse of the sub-base layer and larger irreversible deformations like rutting in the upper layers of the pavement structure. These larger deformations accumulate during all service life [2,4,6]. Pavement design is made in the way that it can allow a very small number of a permanent deformation that does not threaten the stability of the pavements.

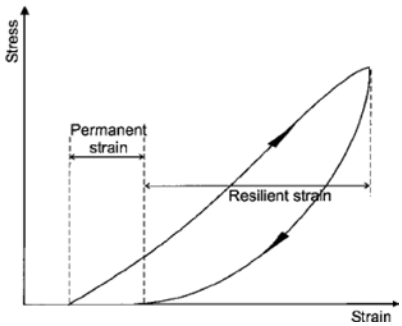

Figure 1 Strains in Granular Materials During One Cycle of Load Application [4]

Permanent deformation behaviour of unbound granular material is less studied than the resilient deformation because of influence of stress history on material behavior, difficulties in results of different laboratory test correlating, the complexity of the tests, so as complex and nonlinear constitutive relations [9, 10].
The most important and the best laboratory simulation of traffic loading to test the deformation properties is cyclic load triaxial testing [5]. Repeated load triaxial apparatus is device for cyclic load triaxial testing on prepared cylindrical specimen in order to investigate the mechanical behaviour of unbound granular material. Similar stress like in the field can be simulate with triaxial apparatus on prepared specimen – a cyclic vertical stress σ_1 and a cyclic horizontal stress σ_3 after that the corresponding deformations are measured. Unbound granular material under cyclic loading expose elastoplastic behavior by increasing of permanent deformation with load repetitions [7, 8, 9, 10]. Triaxial apparatus has a three controllers to generate back and air pressure and chamber in the partially saturated samples [1]. With repeated load triaxial test more information can be obtain from a single specimen because the experimental dispersion is reduced as is the amount of time and materials required [10].

2.1 Methods and models

The older method that is used for describing permanent deformations is empirical traditional method. Traditional design methods are based on experience with certain types of pavement material. That approach has a lots of disadvantages and limitations because of increases in traffic loads and growing transportation needs that resulted in rapid deterioration of road

networks. Because of that, nowadays, there is a strong desire to develop and study analytical methods and models to establish with more changes in loading and environmental conditions, construction techniques and materials [4]. Empirical models consider unbound granular material as linear elastic material with elastic moduli that is often determined on the empirical base [9]. Analytical models imply experimental approach application and mathematical characterization of behavior of unbound granular material under cyclic loading [3]. Models treat road pavement as a structure and they are based on analyzing the response of pavement layers and all structure under traffic cyclic load in certain environmental conditions [4]. The aim is to leave the traditional methods and develop an analytical model that can better describe permanent deformation behaviour. Analytical approach requires better understanding of the behavior and properties of the materials. A large number of tests in laboratories can enable development of models that can predict the permanent deformations. In laboratory it is possible to simulate the properties of material and response of unbound granular materials under cyclic traffic loading. Analytical pavement models can correlate deformations with layer thicknesses, layer material, conditions, traffic load which enable a prediction of permanent strain value at any loading cycle at any stress [2, 7].
Resilient response (Fig. 1.) is non-linear and these deformations can be interpreted using several models like Uzans and k-θ models [3, 5]. Irreversible, permanent deformations and strains are more complex and on their behaviour affect many factors such as stress, number of load cycles, grain shape, stress history, density, mineralogy, water/moisture content, fines content, etc. [5].

2.1.1 Impact of stress

Stress has a significant influence on the permanent deformations in unbound granular layers. Stress state similar to the stress in the field is simulated in triaxial apparatus. One of first significant conclusion that accumulation of axial permanent strain is related to deviator stress and confining pressure is given by Morgan (1966) [4].

Table 1 Equations that describe relationship between permanent strain and stress

Barksdale [13]	$\varepsilon_{1,p} = \dfrac{q/K \times \sigma_3^{\,n}}{1 - \left[\dfrac{(R_f \times q)/2(C \times \cos\phi + \sigma_2 \times \sin\phi)}{(1-\sin\phi)}\right]}$
Pappin [15]	$\varepsilon_{s,p} = (f\mathrm{nN}) \times L \times \left(\dfrac{q^0}{p^0}\right)_{max}^{2.8}$
Paute [14]	$A = \dfrac{\dfrac{q_{max}}{(p_{max} + p^*)}}{b \times \left(m - \dfrac{q_{max}}{(p_{max} + p^*)}\right)}$

Barksdale [13] relates the permanent strain to the ratio of repeated deviator stress and constant confining pressure with equation presented in Table 1. Expression depends on apparent cohesion C, angle of internal friction ϕ, constants K and n and constant relating the compressive strength to an asymptotic stress difference R_f. Pappin [15] also gives expression for accumulated permanent strain that depends on shape factor fnN, modified deviator stress q^0 and modified mean normal stress p^0, stress path length L. He also declares that the large permanent strains did not occur unless the material was stressed close to the static failure limit. At the University of Nottingham an experiment on five different specimens (aggregates) was carried out and none of listed equations and models seemed to give a satisfying explanation of the influence of stresses on accumulation of permanent deformation [7]. It was estimated that the non-linear model proposed by Paute (Table 1.) [14] the best fits the data at low levels of shear stress ratio when the material have almost total resilient behavior. The model is weak for high shear stress ratios when the accumulation of permanent deformations is progressive and cause deterioration [7]. Paute defines the hyperbolic expression for limit value of maximum permanent axial strain (A). Limit value A increases when the maximum shear stress ratio increases and it depends on parameters m (slope of the static failure line) and p* (stress parameter defined by intersection of the static failure line and the p-axis in p-q plane). It also depends on slope of static failure line m, maximum mean normal stress p_{max} and regression parameter b [14].

2.1.2 Effect of number of load applications, cycles

Some researchers [11-14] have followed another one approach trying to relate the value of permanent deformation with a number of load applications. Number of load traffic cycles is very important factor for deterioration of pavements. Cyclic traffic loading is also very often simulated in laboratories using triaxial apparatus test. In Table 2. is presented an overview of analytical models that offer good expression of the correlation between the strain and number of loading cycles [11-14].

Table 2 Equations that describe relationship between permanent strain and number of load cycles

Barksdale [13]	$\varepsilon_{1,p} = a + b \times \log(N)$
Sweere [12]	$\varepsilon_{1,p} = a \times N^{b}$
Khedr [11]	$\frac{\varepsilon_p}{N} = A \times N^{-m}$
Paute et al. [14]	$\varepsilon_{1,p} = A \times \left(1 - \left(\frac{N}{100}\right)^{-B}\right)$

Every equation is obtained on the bases of triaxial test results on differently prepared specimens. Barksdale [13] proposed an equation after tests with 10^5 load applications where strain depends on number of cycles N and a and b, constants for a given level of σ_1- σ_3 and σ_3. Swerre [12] proposed a non-linear model which depends on regression parameters a and b after 10^6 load cycles (N). Sweere's model equation is based on Korkiala-Tanttu's model (Eqn. (1) [16].

$$\varepsilon_p(N) = CN^b \frac{R}{A - R} \tag{1}$$

Difference between the Korkal-Tanttu's and Sweere's equations is in an effect of stress levels based on classic soil mechanics laws. C and b in eqn (1) are material parameters and R is shear stress ratio q/q_{f}., deviator stress/deviator stress at the failure [8]. Khedr [11] presented the model with conclusion that the rate of permanent strain accumulation decreases logarithmically with number of cycles where m is material parameter and A is material and stress-strain dependent parameter given as a function of shear stress ratio and resilient modulus.
Together with previously described studies that examined influence of stress on permanent strain accumulation an experiment that studied effect of load cycles on the same five specimens was carried out. Paute's non-linear model [14] fit the data the best and showed the least error in most cases in relation to others models that depend on number of load cycles [7]. Paute's model depends also on regression parameters A and B after $8x10^4$ load repetitions.

2.1.3 Effect of moisture content

Moisture is mostly related with the fines content of the unbound granular material. Adequate amount of water doesn't have a negative influence on unbound granular material behavior, but in combination with rapidly applied loads lied to high pore pressure and saturation. The effective normal stress is reduced by that pore pressure generation and can lead to the occurrence of permanent deformation. Haynes, Barksdale, Dawson and others concluded that combination of low permeability and high degree of saturation lead to lowering effective stresses and high pore pressure generation that lead to the lowering deformation resistance and stiffness [4].

2.1.4 Others Effects possible impacts

Other parameters that effect on deformations are stress history (Brown and Hyde 1975), density (Barksdale 1972, Allen 1973, Holubec 1969), fines content (Barksdale 1972, 1991, Thom and Brown 1988), aggregate type (Allen 1973), grain shape (Barksdale and Itani 1989, Janoo 1998), surface texture and mineralogy. Some models also give a correlation between static and cyclic loading tests (Gerrard 1975, Lentz and Baladi 1981) and correlation between resilient and plastic behavior (Veverka 1979 [5, 10].

3 Local source for unbound granular layers in Croatia

The aggregate type and mineralogy of origin are very important parameters for unbound granular materials. Crushed rock have to be resist on crushing under traffic loading. Unbound granular layers are mostly made of local stone materials. The construction of pavement structure can be accelerated if local materials are used. In Croatia, the aggregate used for pavement base and subbase is a crushed limestone aggregate that is local material with a good quality and parameters required in Technical Specifications [17].
Lekarp and Dawson studied the permanent deformation behaviour of five different aggregates and one of these was crushed limestone. Test that depends on number of cycles load show that Paute's model (Table 2.) the best fit the data. Test related to the effect of stress also shows that Paute's model (Table 1.) is the most appropriate model for limestone materials [6]. Khedr [11] was also studying crushed limestone material under repeated loading in triaxial apparatus. The conclusion was that the rate of permanent strain accumulation decreases logarithmically with the number of load repetitions according to the equation:

$$\frac{\varepsilon_p}{N} = A \times N^{-m} \quad (2)$$

where:

m material parameter;
A material and stress-strain parameter given as a function of shear stress ratio and resilient modulus.

At the University of Perugia and Marche Polytechnic a crushed limestone aggregate through was investigated under repeated loads in triaxial tests. They made tests on two mixtures: one was typical mixture for unbound layers according to the Italian Technical Specifications and the second was combination of the first with addition of a silty clayey soil fraction [2]. The results were analyzed and compared with a few known models proposed from Barksale, Sweere and Paute given in Table 2. Also is given a new linear-exponential model [2] is prosed as:

$$\varepsilon_p(N) = A + B \times N \quad (3)$$

where:

A constant expressing the variability of permanent strain accumulated during the first load cycles;
B strain rate per load cycle.

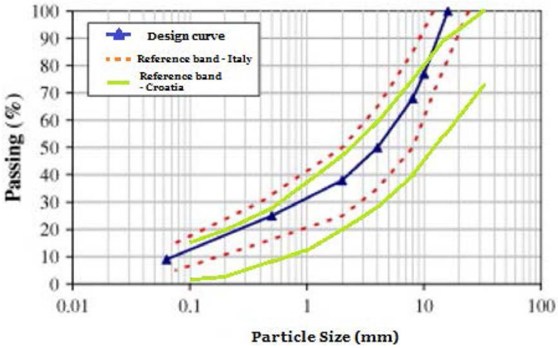

Figure 2 Design gradation for tested materials in reference band from Italy and Croatia [2, 17]

The determination coefficients R^2 which are obtained for every model provide that the highest value have a last model – greater than 0,95 [2]. Gradation of materials that have been tested are located in reference band in Italy but also in reference band in Croatia (Fig. 2.) and given model can be used for Croatians unbound layers although some more detailed analyses will help in estimating better permanent deformation behaviour in crushed limestone material.

4 Conclusion

In this paper an general overview of the most used models for the determination of permanent deformation behaviour in unbound pavement layer is presented. It can be established that the impact of stress and the number of load cycles have the most important effect on unbound granular material deformation behavior. Each model also has different influence factors such as cohesion, angle of internal friction, different material constants, shape factor, stress path length and regression parameter. Models that relate the permanent deformation with the number of load cycles mostly depend on the number of load cycles. Every model has several parameters like regression, material, stress-strain parameter which also have a major impact on deformation behavior. Results in the mentioned experiments that studied the impact of stress and the number of load cycles shown that Paute model fits the data best.

Crushed limestone is the mostly used local material in Croatia for pavement structures. In this paper an overview of a few analytical models that describe deformation behavior in that material like Paute's and Khedr's model are presented. Also, a linear- exponential model is given that can be used for Croatian unbound pavements' materials because that model the best fits the data with the determination coefficient greater than 0,95.

Analytical models are very complex because of the effect of a lot of parameters that impact on deformation behavior of unbound pavements' materials. It is necessary to conduct detailed analyses for crushed limestone locally used in Croatia in order to establish detailed models for the pavement constructions' design.

Reference

[1] Perez, I., Medina, L. & Romana, M.G.: Permanent deformation models for a granular material used in road pavements, Construction and Building Materials, 20, pp. 790-800, 2006.

[2] Cerni, G., Cardone, F., Virgili, A. & Camili, S.: Characterisation of permanent deformation behaviour of unbound granular materials under repeated triaxial loading, Construction ann Building Materials, 28, pp. 79-87, 2012.

[3] Cuculić, M., Arbanas, Ž. & Deluka-Tibljaš, A.: Deformacijske značajke nevezanih zrnatih materijala, Zbornik radova, Građevinski fakulet, 12, pp. 232-253, 2009.

[4] Lekarp , F., Isacsson, U. & Dawson, A.: State of the Art. II: Permanent strain response of unbound aggregates, Journal of transportation engineering, 126/1, pp. 76-83, 2000.

[5] Uthus, L.: Deformation Properties of Unbound Granular Aggregates, Thesis for the degree of philosophiae doctor, NTNU, Trondheim, 2007.

[6] Lekarp, F. & Dawson, A.: Analysis of permanent deformation behaviour of unbound granular materials, International Symposium on Thin Pavements, Surface Treatments, Unbound Roads, Canada, 1997.

[7] Lekarp, F. & Dawson, A.: Modelling permanent deformation behaviour of unbound granular materials, Construction and Building Materials, 12, pp. 9-18, 1998.

[8] Erlingsson, S. & Rahman, M.S.: Evaluation of Permanent Deformation Characteristics of Unbound Granular Materials from Multi-Stage Repeated Load Triaxial Test, TRB, 2013.

[9] Hornych, P. & Absamad, A: Selection and Evaluation of Models for Prediction of Permanent Deformations of Unobund Granular Materials in Road Pavements, Publication SAM-05-DE10. s.l., Competitive and Sustainable Growth (GROWTH) Programme, 2004.

[10] Gidel, G., Hornych P., Chauvin, J.J., Breysse, D. & Denis, A.: A new approach for investigating the permanent deformation behaviour of unbound granular material using the repeated load triaxial apparatus, Bulletin de Liaison des Laboratoires des Ponts et Chaussees, 233, pp. 5-21, 2001.

[11] Khedr, S.: Deformation characteristics of granular base course in flexible pavement, Transportation Research Record, 1043, pp. 131-138, 1985.

[12] Sweere, G.T.H.: Unbound granular bases for roads, PhD Thesis, University of Delft, 1990.

[13] Barksdale, R.: Laboratory evaluation of rutting in base course materials, Proceedings of the Third International Conference on Structural Design of Asphalt Pavements, London, pp. 161-174, 1972.

[14] Paute , J., Hornych, P. & Benaben, J.: Comportement mecanique des graves non traitees, Bull Liasion Laboratories Ponts Chaussees, 156, pp. 21-36.1988

[15] Pappin, J.W.: Characteristics of a granular material for pavement analysis, PhD. Thesis, Department of Civil Engineering, University of Nottingham, 1979.

[16] Korkiala-Tanttu, L.: A New Material Model for Permanent Deformations in Pavements, Proceedings of the 7th Conference on Bearing Capacity of Roads and Airfields, Trondheim, Norway, 2005.

[17] Opći tehnički uvjeti za radove na cestama, Hrvatske ceste – Hrvatske autoceste, Zagreb, 2001.