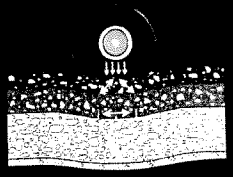


4th INTERNATIONAL CONFERENCE BITUMINOUS MIXTURES AND PAVEMENTS

4ο ΔΙΕΘΝΕΣ ΣΥΝΕΔΡΙΟ ΑΣΦΑΛΤΙΚΩΝ ΜΙΓΜΑΤΩΝ ΚΑΙ ΟΔΟΣΤΡΩΜΑΤΩΝ

PROCEEDINGS *VOLUME I*

ΠΡΑΚΤΙΚΑ *ΤΟΜΟΣ 1*

EDITOR: PROF. A. F. NIKOLAIDES
ΕΠΙΜΕΛΕΙΑ: Α. Φ. ΝΙΚΟΛΑΪΔΗΣ

THESSALONIKI, APRIL 2007
ΘΕΣΣΑΛΟΝΙΚΗ, ΑΠΡΙΛΙΟΣ 2007

Proceedings of the 4th International Conference on Bituminous Mixtures and Pavements, Thessaloniki, April 2007

Πρακτικά 4ου Διεθνούς Συνεδρίου Ασφαλτικών Μιγμάτων και Οδοστρωμάτων, Θεσσαλονίκη, Απρίλιος 2007

Bituminous Mixtures and Pavements

Ασφαλτικά Μίγματα και Οδοστρώματα

Editor: A.F. Nikolaides

Επιμέλεια πρακτικών: Αθ. Φ. Νικολαΐδης

ORGANIZING COMMITTEE

Chairman: Prof. Nikolaides A.F., A.U.Th.

Μέλη:
Woodside A., Prof. University of Ulster, United Kingdom
Uddin W., Assoc. Prof., University of Mississippi, U.S.A.
Colwill D., O.B.E., ex-TRL, United Kingdom
Pyrgidis Chr., Assoc. Professor, A.U.Th.
Kimoundris A., Assistant Professor, A.U.Th.
Dalaveras A., Assistant, A.U.Th.
Bizani K., A.U.Th.
Manthos E., A.U.Th.
Sarafidou M., A.U.Th.

SCIENTIFIC COMMITTEE

Chairman: Prof. Tsohos G., A.U.Th.

Μέλη:
Al-Nageim H., Prof., John Moor University, United Kingdom
De Winne E., Prof., Ghent University, Belgium
Eliou N., Assist. Prof., University of Thessaly, Greece
Evdorides H., Dr., Lecturer, University of Birmingham, United King
Fatseas G., Gen. Director, Quality of Public Works, Ministry of EPPI
Fortes R.M., Prof., Mackenzie University, Sao Paolo, Brazil
Grabowski W., Prof., University of Poznan, Poland
Khalid H., Dr., University of Liverpool, United Kingdom
Kokkalis A., Assist. Prof., Dimocretio University of Thrace, Greece
Lafon J., LRPC Toulouse, France
Losa M., Assoc. Prof., University of Pisa, Italy
Mintsis G., Prof., A.U.Th., Greece
Mohammad L., Prof., Louisiana State University, U.S.A.
Mouratidis A., Prof., A.U.Th, Greece
Nicholls J.C., Dr., TRL, United Kingdom
Pereira P., Prof. Minho University, Portugal
Santagata E. Prof., Polytechnic of Torino, Italy
Woodward D., Dr., Reader, University of Ulster, United Kingdom
Zoorob S., Senior Research Officer, University of Nottingham, Unite

Organizers:

HIGHWAY ENGINEERING LABORATORY,
DEPARTMENT OF CIVIL ENGINEERING, AUTH

TRANSPORT & ROAD ASSESSMENT CENTRE (TRAC)
UNIVERSITY OF ULSTER, UK

CENTRE FOR ADVANCED INFRASTRUCTURE TECHNOLOGY
(CAIT), UNIVERSITY OF MISSISSIPPI, USA

Sponsors

SPANOS Industries

NETOIL S.A.

AEIFOROS

BITOUMINA S.A.

ATLANTIS

SHELL

RESEARCH COUNCIL OF AUTH

SIM S.P.A.

ESHA S.A.

HUESKER

DYNAPAC

AKTIS S.A.

EGNATIA ODOS S.A.

SET 978-960-91849-2-2
ISBN 978-960-91849-3-9

PREFACE

The papers contained in this Volume were presented at the 4th International Conference on Bituminous Mixtures and Pavements that took place in Thessaloniki, Greece in April 2007. The papers reflect the most up to date advances in highway materials technology and engineering.

Today, more than ever, the engineers are facing the challenge, not only to design and construct the pavements properly and economically but also to make them last as long as possible. This implies a thorough understanding of materials behavior, appropriate use of them in the continuously changing environment of the project, and implementation of improved technologies and methodologies.

The papers cover the recent developments worldwide in the areas of pavement materials, pavement design, construction and maintenance, recycling, surface characteristics and other related subjects in highway engineering.

The distinguished Members of the Scientific Committee worked hard, and with matchless colleague zeal, providing invaluable work by reviewing the papers. I thank them a lot for their outstanding work.

The Organizing Committee, the heart of the Conference, worked with great enthusiasm in order to ensure the success of the Conference. My gratitude is also extended to every single one of them, personally.

Also, I would like to thank the Sponsors for their kind contributions that made possible to organize this Conference at a low participation fee.

Finally, I thank the Authors for their high scientific level contribution, the Participants for attending the Conference and in general all those who worked and contributed to the success of this Conference.

Thessaloniki 19/4/2007

Prof. A. F. Nikolaides
President of the Conference

VOLUME I

ΤΟΜΟΣ I

Table of Contents

Περιεχόμενα

1st and 2nd Plenary Sessions

Συνεδρία Α΄ και Β΄με όλα τα μέλη παρόντα

1. Aschuri I., Woodward D., Woodside A., UK
MODIFICATION OF ASPHALT CONCRETE USING FLY ASH AND WASTE PLASTIC 3

2. Uddin W., USA
A METHODOLOGY FOR ESTIMATING SEASONAL NONLINEAR MODULUS VALUES FOR DESIGN AND EVALUATION OF ASPHALT PAVEMENTS 13

3. Nicholls J.C., Carswell I., Williams J.T., Gibb M. UK
SERVICE LIVES OF THIN SURFACING SYSTEMS IN THE UK..... 25

4. Hassan M. M., Khalid H. A., Artamendi I., UK
USE OF RHEOLOGY TO STUDY BINDER PERMANENT DEFORMATION 33

5. Νικολαΐδης Α.Φ., GR
ΠΡΟΩΡΗ ΚΑΤΑΣΤΡΟΦΗ ΕΥΚΑΜΠΤΩΝ ΟΔΟΣΤΡΩΜΑΤΩΝ ΣΤΗΝ ΕΛΛΑΔΑ: ΤΙ ΦΤΑΙΕΙ..... 43
Nikolaides A.F., Premature failure of flexible pavements in Greece: What is to blame

6. Fortes R.M., Merighi J.V., Bandeira A.A., Pereira de Silva J.A., Balestra P.B., Bichoff R., Brazil
A PROPOSAL FOR A SYSTEM OF PAVEMENT MANAGEMENT IN BUS CORRIDORS OF SAO PAULO 59

Session I: Pavement Materials
Συνεδρία Ι: Υλικά Οδοστρωμάτων

1. Sengoz B., Topal A., Tanyel S., Turkey
ENGINEERING PROPERTIES OF SBS MODIFIED BITUMEN FOR PAVING MIXES..... 73

2. Topal A., Şengoz B., Isikyakar G., Turkey
BLENDING PROPERTIES OF EVA BASED POLYMER MODIFIED BITUMEN 83

3 Νικολαΐδης Α.Φ., Μάνθος Ε., Σαραφείδου Μ., GR
ΤΡΟΠΟΠΟΙΗΜΕΝΗ ΜΕ SBS ΚΑΙ ΚΟΙΝΗ ΑΣΦΑΛΤΟΣ ΟΔΟΣΤΡΩΣΙΑΣ: ΙΔΙΟΤΗΤΕΣ ΚΑΙ ΣΤΑΤΙΣΤΙΚΗ ΑΝΑΛΥΣΗ ΑΠΟΤΕΛΕΣΜΑΤΩΝ 93
Nikolaides A.F., Manthos E., Sarafidou M., SBS modified and conventional bitumen: Properties and statistical analysis of results

4. Nigen-Chaidron S., France
RHEOLOGICAL CHARACTERIZATION OF BITUMINOUS BINDERS FOR SPECIFICATION PURPOSES. 109

5. Lo Bianco A, Madonia G., Italy
ESTREMOPHILOUS BACTERIA FOR ACHIEVING COHESIVE STRENGTH IN THE AGGREGATES FOR UNBOUND LAYERS OF ROAD PAVEMENTS 119

6. Zoorob S.E., Phillips P., UK
BACTERIAL DEGRADATION OF HYDROCARBONS WITH IMPLICATIONS FOR ASPHALTS, PART 1: EVIDENCE OF LARGE SCALE BIODEGRADATION 135

7. Zoorob S.E., Phillips P., UK
BACTERIAL DEGRADATION OF HYDROCARBONS WITH IMPLICATIONS FOR ASPHALTS, PART 2: ATTACK MECHANISMS. . 145

8. Grabowski W., Wilanowicz J., Slowik M., Sobol T., Poland
FUNCTIONAL PROPERTIES OF BAGHOUSE FILLERS FROM A DUST EXTRACTOR INSTALLED IN AN ASPHALT PLANT 155

9. Nicholls J. C., Lay J., Reid J.M., UK
THE POTENTIAL USE OF CEMENT KILN DUST (CKD) AS FILLER IN ASPHALT. 165

10. Bogdanski B., Slowik M., Poland
ASSESSMENT OF POLISH ROAD AGGREGATES PROPERTIES CONSIDERING EUROPEAN STANDARDS REQUIREMENTS 177

11. Ribeiro R.C., Correia J.C.J., Seidl P., Soares J.B., Brazil
THE INFLUENCE OF DIFFERENT MINERALS ON THE MECHANICAL RESISTANCE OF ASPHALT MIXTURES 187

10. Νικολαΐδης Α.Φ., Μάνθος Ε., GR
ΙΣΟΔΥΝΑΜΟ ΑΜΜΟΥ ΑΔΡΑΝΩΝ ΥΛΙΚΩΝ ΟΔΟΠΟΙΙΑΣ ΜΕ ΤΗΝ ΕΥΡΩΠΑΪΚΗ ΚΑΙ ΑΜΕΡΙΚΑΝΙΚΗ ΠΡΟΔΙΑΓΡΑΦΗ ΚΑΙ ΑΠΟΤΕΛΕΣΜΑΤΑ ΜΠΛΕ ΤΟΥ ΜΕΘΥΛΕΝΙΟΥ 199

Nikolaides A.F., Manthos E., Sand equivalent of road aggregates tested with European and American standards and methylene blue results

11. Chikyala V., Puppala A., Bauman S., USA
COMBINED LIME AND CEMENT TREATMENT OF EXPANSIVE CLAY 215

Session II: Pavement design, construction and maintenance
Συνεδρία II: Σχεδιασμός, κατασκευή και συντήρηση οδοστρωμάτων

1. Nicholls J.C., Hassan K.E., James D., Badr A.S.M., Calder A.J.J., UK
CRACK BRIDGING OF CRC PAVEMENTS WITH THIN ASPHALT SURFACINGS 229

2. Oliveira J.R.M., Zoorob S., Thom N., Pereira P.A.A., Portugal
A SIMPLE APPROACH TO THE DESIGN OF PAVEMENTS INCORPORATING GROUTED MACADAMS 239

3. Losa M., Marvogli M., Leandri P. Bacci R., Italy
STRUCTURAL ANALYSIS OF ASPHALT PAVEMENTS ON COLLECTOR RURAL ROADS 251

4. Cope M., Allen B., Zoorob S.E., UK
A STUDY OF THE EFFECT OF BITUMEN / VEGETABLE OIL BLENDS ON ASPHALT MIXTURE PERFORMANCE 261

5. Bandeira A.A., Merighi J.V., Fortes R..M., Brazil
CONTACT MECHANICS TECHNIQUES APPLIED TO STUDY 3D PAVEMENT STRUCTURE DESIGN 271

6. Momm L., Barra B.S., Brazil
EMPIRICAL MECHANISTIC EVALUATION OF ASPHALT PAVEMENT STRUCTURES COMPARING COMPUTERIZED TOOLS AND LABORATORY FATIGUE TEST DATA 283

7. Μουρατίδης Α., GR
ΚΑΤΑΣΚΕΥΗ ΚΑΙ ΣΥΜΠΕΡΙΦΟΡΑ ΒΡΑΧΩΔΩΝ ΟΔΙΚΩΝ ΕΠΙΧΩΜΑΤΩΝ 293
Mouratidis A., Construction and performance of rock embankments in highway engineering

8. Ravaioli S., Italy
ASPHALT IN RAILWAY APPLICATIONS A 30 YEARS OLD EXPERIENCE IN ITALY 307

9. Toraldo E., Lambrugo S., Italy
THE OPTIMIZATION OF PHOTO CATALYTIC MORTARS FOR ROAD PAVEMENTS 315

10. Καρακαϊδού Ι., GR
ΤΟ ΝΟΜΙΚΟ ΠΛΑΙΣΙΟ ΤΗΣ ΣΥΝΤΗΡΗΣΗΣ ΚΑΙ ΛΕΙΤΟΥΡΓΙΑΣ ΟΔΩΝ ΣΤΗΝ ΕΛΛΑΔΑ 327
Karakaidou I., The legal framework of the maintenance and operation of Greek highways

11. Εναγγελίδης Δ,. GR
ΟΔΗΓΙΕΣ ΚΥΡΙΑΣ ΣΥΝΤΗΡΗΣΗΣ ΟΔΟΣΤΡΩΜΑΤΩΝ ΚΑΙ ΜΕΤΡΗΣΕΙΣ ΤΩΝ ΧΑΡΑΚΤΗΡΙΣΤΙΚΩΝ ΤΟΥΣ ΣΕ ΤΜΗΜΑΤΑ ΤΗΣ ΕΓΝΑΤΙΑΣ ΟΔΟΥ 343
Evangelidis D., Pavement maintenance guidelines and pavement measurements in Egnatia Odos Motorway

Session III: Bituminous mixtures
Συνεδρία ΙΙΙ: Ασφαλτικά μίγματα

1. Mohammad L., Saadeh S., USA
LABORATORY EVALUATION OF ASPHALT MIXTURES USING SIMPLE PERFORMANCE TESTS 357

2. Ciampa D., Olita S., Italy
FATIGUE RESISTANCE OF ASPHALT CONCRETES: THEORETICAL AND EXPERIMENTAL APPROACH THROUGH THE UNIBAS-M.P.T. DEVICE 367

3. Beckedahl H.J., Sivapatham P., Germany
RESISTANCE AGAINST FATIGUE OF ASPHALT PAVEMENTS WITH DIFFERENT COMPACTION DEGREE 379

4. De Winne Ir.E., De Winne Ir.P., Belgium
COLD MIX ASPHALT SURFACINGS: EXPERIENCES IN BELGIUM 389

5. Agostinacchio M., Olita S., Italy
PERFORMANCE COMPARISON OF DIFFERENT TYPES OF POROUS TWIN-LAYERS FOR HIGH ROAD SAFETY STANDARD 401

6. Νικολαΐδης Α.Φ., GR
ΛΕΠΤΗ ΕΠΙΦΑΝΕΙΑΚΗ-ΑΝΤΙΟΛΙΣΘΗΡΗ ΣΤΡΩΣΗ: ΠΡΩΤΕΣ ΕΦΑΡΜΟΓΕΣ ΜΕΓΑΛΗΣ ΚΛΙΜΑΚΑΣ ΣΤΗΝ ΕΛΛΑΔΑ 411
Nikolaides A.F., Thin surfacing: First large scale applications in Greece

7. Bolzan P.E., Horst E., Kohl A., Argentina
SMA DOUBLE LAYER SOLUTIONS (SMA -DLS) FOR BOTH URBAN AND HIGHWAYS PAVEMENT PRESERVATION 425

8. Nicholls J.C., Jordan R.W., Hassan K.E., Williams J.T., Badr A.S.M., UK
ASPHALT SURFACING TO BRIDGE DECKS 435

9. Giacobi C., Layerle E., France
OPTIMIZATION OF THE SERVICE LIVES OF HIGHWAY SURFACE COURSES 447

10. Taherkhani H., Collop A. C., Iran
RECOVERY BEHAVIOUR OF ASPHALTIC MATERIALS 455

11. Οικονόμου Ν, Μαυρίδου Σ., .Καζακόπουλος Α., GR
ΜΕΛΕΤΗ ΤΡΟΠΟΠΟΙΗΜΕΝΩΝ ΑΣΦΑΛΤΟΜΙΓΜΑΤΩΝ ΜΕ ΦΘΑΡΜΕΝΑ ΕΛΑΣΤΙΚΑ ΟΧΗΜΑΤΩΝ 465
Oikonomou N., Mavridou S., Kazakopoulos A., Study of asphalt mixtures modified with tire rubber

12. Praticò F.G., Ammendola R., Moro A., Italy
ASSESSING THE ROLE OF MIX PROPERTIES ON THE CHEMICAL RESISTANCE OF BITUMINOUS FRICTION COURSES..... 479

13. Hassan M M., Khalid H.A., UK
INCINERATOR BOTTOM ASH AGGREGATES IN BITUMINOUS MIXTURES 489

14. Agostinacchio M., Ciampa D., Diomedi M., Italy
ELECTRIC ARC FURNACE SLAG IN HIGH MODULUS ASPHALT CONCRETE FOR WEARING-COURSE LAYER: MIX DESIGN AND MECHANICAL PROPERTIES EVALUATION 499

15. Yusof M.A.W., Zoorob S.E., UK
POTENTIAL FOR INCORPORATING TIN SLAG IN ASPHALT MIXTURES, PART 1: MATERIAL CHARACTERIZATION..... 509

16. Yusof M.A.W., Zoorob S.E., UK
POTENTIAL FOR INCORPORATING TIN SLAG IN ASPHALT MIXTURES, PART 2: ASPHALT MIX PERFORMANCE 519

Author Index
Ευρετήριο Συγγραφέων

4th INTERNATIONAL CONFERENCE
BITUMINOUS MIXTURES AND PAVEMENTS
Thessaloniki, Greece, 19-20 April 2007

A SIMPLE APPROACH TO THE DESIGN OF PAVEMENTS INCORPORATING GROUTED MACADAMS

J. R. M. Oliveira *
Lecturer, University of Minho, Guimarães, Portugal
S.E. Zoorob
Senior Research Officer, University of Nottingham, UK
N.H. Thom
Lecturer, University of Nottingham, UK
P. A. A. Pereira
Professor, University of Minho, Guimarães, Portugal
* University of Minho, Department of Civil Engineering, Azurém, 4800-058 Guimarães, Portugal, joliveira@civil.uminho.pt

ABSTRACT
Grouted macadams form a semi-flexible class of composites whose behaviour lies somewhere between concrete and conventional asphalt materials, having both excellent rut resistance and a degree of flexibility. This paper presents a series of pavement design computer simulations, based on results obtained from laboratory fatigue and stiffness tests on grouted macadam and conventional asphalt mixtures. The design variables explored include the application of grouted macadams both as surface and binder/base course layers. Comparisons were made with conventional asphalt surface and base course constructions. The resultant stresses, strains and fatigue lives were determined based on four classes of pavement foundations with increasing bearing capacity. In order to simulate traffic loading more realistically, the fatigue characterisation tests carried out on the grouted macadam mixtures incorporated and examined the effect of rest periods on fatigue performance. This paper discusses key findings and includes results in the form of design charts for both composite types. The main conclusion drawn from this project was that the incorporation of grouted macadams is likely to provide an economical solution in many pavement design circumstances owing to their superior stiffness and fatigue characteristics.

KEY WORDS: Pavements, grouted macadam, design, fatigue, shift factors.

1. INTRODUCTION

The design of flexible and flexible composite pavements has traditionally been carried out by using design charts whereby the thickness of each layer is obtained as a function of the design traffic [1, 2]. Furthermore, this approach has recently been used in a revision of the design methodology [3, 4] in order to improve the pavement design principles to respond to the evolution of traffic characteristics. Thus, following the same principles, several design charts should be developed for pavements incorporating grouted macadams, which show enhanced properties when compared with conventional asphalt mixtures.

The results obtained in the present study allow a comparison between conventional bituminous mixtures and grouted macadam mixtures. The following sections describe the approach used and present the design charts obtained for pavements with surface or base courses incorporating grouted macadams.

2. DESIGN PRINCIPLES CONSIDERED

The mean annual temperature at low altitudes across England varies from about 8.5 °C to 11 °C [5]. However, pavement design is traditionally carried out at a reference temperature of 20 °C [2, 4]. In the present study, the fatigue life equations were obtained from laboratory tests carried out at 20 °C, by Oliveira [6], which have shown that fatigue life of grouted macadams is not susceptible to temperature variations between 0 and 20 °C. Therefore, temperature has more influence on the value of stiffness used for design, which also depends on the loading frequency. According to the Highways Agency [4], pavement design should be carried out at a reference condition of 20 °C and 5 Hz. Indirect Tensile Stiffness Modulus (ITSM) and four-point bending tests carried out at 5 Hz, by Oliveira [6], have shown similar stiffness results for the same temperature. Increasing the frequency in four-point bending tests resulted in increased stiffness moduli.

In this study, the value of stiffness chosen for pavement design was obtained from tests carried out at 10 Hz, being the same frequency used for determining the fatigue lines. Thus, 8000 MPa (which is a conservative value) has been used in the calculations. Nonetheless, this may be assumed as an adequate value to use in pavement design, since Oliveira [6] obtained similar values in ITSM tests (corresponding to a frequency of approx. 5 Hz) carried out at 20 °C, in 2-year-old specimens.

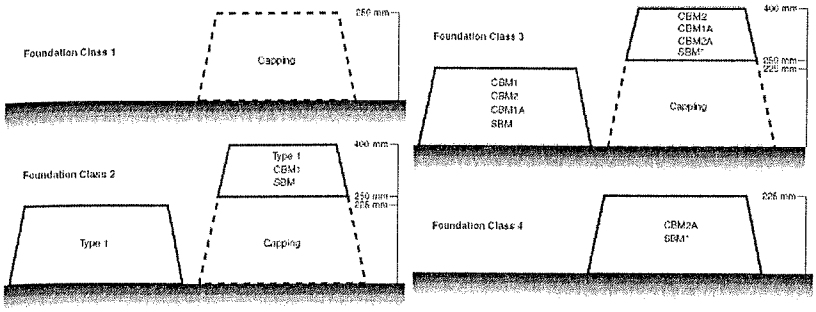
In this investigation, four pavement foundation classes were considered (Figure 1), as suggested by Nunn [3], on top of which one or two new layers would be applied. The design characteristics to be used for each foundation are shown in Table 1. Some of the results obtained in this study are based on pavement response calculations carried out using a multilayer linear elastic analysis computer program – BISAR 3.0 [7].

itionally been
each layer is
this approach
4] in order to
tion of traffic
design charts
ıdams, which
ılt mixtures.
ison between
ıixtures. The
design charts
ating grouted

ıes from about
arried out at a
ıe fatigue life
C, by Oliveira
ıot susceptible
ıture has more
epends on the
vement design
5 Hz. Indirect
carried out at
for the same
sts resulted in

ı was obtained
or determining
has been used
quate value to
s in ITSM tests
ı °C, in 2-year-

ere considered
wo new layers
foundation are
are based on
r linear elastic



* Material class CBV12 or superior class (BS EN 14227-2)

Figure 1: Example designs for foundation classes 1 to 4 on 5% CBR subgrade [3]

Table 1: Design characteristics of pavement foundations

Foundation Class	Stiffness (MPa)	Poisson's Ratio
1	50	0.35
2	100	0.35
3	200	0.35
4	400	0.35

The grouted macadam layer was used in the calculations in two different positions, either as a surface course or as a base/binder course. A Dense Bitumen Macadam (DBM50) base course and a Hot Rolled Asphalt (HRA) or Stone Mastic Asphalt (SMA) surface course were considered as comparative materials to the grouted macadam, respectively used as base or surface course. Their mechanical properties are summarised in Table 2, according to the values obtained by Oliveira et al. [8] and specified in the new HD26/06 [4].

Table 2: Mechanical properties of considered materials

Material	Stiffness (MPa)	Poisson's Ratio
Grouted Macadam	8000	0.25
DBM50	5400	0.35
HRA or SMA	3100	0.35

2.1 Relationship between laboratory results and field performance

A major difficulty with fatigue testing is developing a meaningful relationship between the results of laboratory tests and field performance. Laboratory tests usually use sinusoidal loading and fixed strain or stress amplitude during a single test, whereas in practice, the mode of loading is randomly distributed, including rest periods and the effects of lateral wander of vehicles. Temperature variations in the asphalt layer and healing effects, due to intermittent loading, also influence the field performance of asphalts. In order to take these effects into account, correction factors (also known as shift factors) are usually applied. However, determination of the correct shift factor is fairly complicated, since it

depends on the type of test, mode of loading, testing temperature and type of mixture [9, 10].

The ultimate value used in the present investigation was 45, which resulted from a previous study [11]. This value concurs with that suggested by Ekdahl and Nilsson [12] for flexible pavements. Nevertheless, the shift factor of 45 is still considered a conservative value due to the particular behaviour of grouted macadams, in terms of crack propagation [11].

2.2 Fatigue life predictions

The fatigue life calculations of the grouted macadam layer were made according to the laboratory results obtained by Oliveira [6], and multiplied by the shift factor mentioned above, which resulted in Equation 1. On the other hand, the fatigue life of bituminous mixtures was calculated according to the fatigue criterion specified by Powell et al. [1] and Nunn [3], which represents the field performance of asphalt mixtures (Equation 2).

$$N = 2.7 \times 10^{-9} \cdot \varepsilon_t^{-3.9718} \quad (1)$$

$$N = 4.169 \times 10^{-10} \cdot \varepsilon_t^{-4.16} \quad (2)$$

where:

N = Number of equivalent standard axle loads (ESALs);

ε_t = Tensile strain induced at either surface or underside of bound layers.

3. DESIGN OF PAVEMENTS WITH GROUTED MACADAM SURFACE COURSES

As previously stated, four pavement foundations were used in a multilayer linear elastic analysis to study the response of each structure to the application of a standard wheel load (40 kN). In this case, a conventional bituminous base (DBM50) was used on top of the foundation, over which a 40 mm thick surface course was applied (comprising either a conventional (HRA or SMA) or a Grouted Macadam mixture).

The response of the pavement was analysed from two perspectives: failure of the base by fatigue (maximum strain at the bottom of the layer); failure of the surface course by fatigue (surface originated cracking). The latter is a result of tensile strains developed under the side of the tyre, near the pavement surface, which assume significant values in pavements with thick bound layers. In order to determine the maximum strain, a mesh of points was created, as illustrated in Figure 2, since its location can change slightly with changes in base thickness.

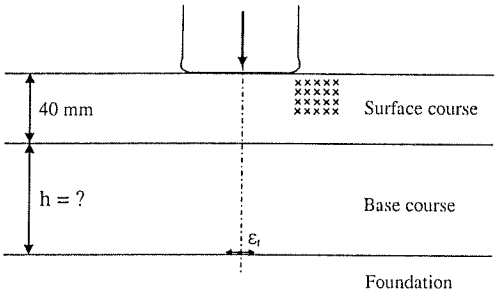


Figure 2: Typical pavement structure used in BISAR to determine the critical tensile strains induced by a standard wheel load

Several iterations were made for each surface course, increasing consecutively the thickness of the bituminous base, and determining the expected fatigue life of both base and surface course, according to the obtained tensile strains.

The results of this study are presented in the following figures, on a comparative basis, in terms of the material used in the surface course. Thus, Figures 3 and 4 represent the design of the base and the influence of its thickness on the appearance of surface cracking.

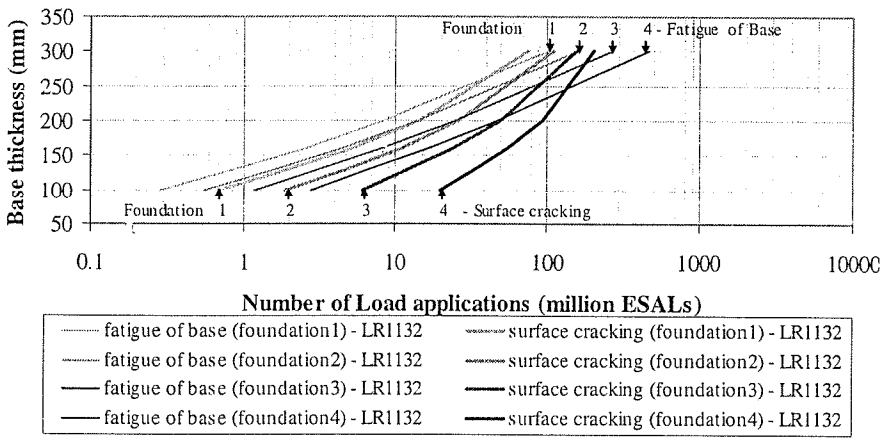


Figure 3: Design of base under a 40 mm HRA or SMA surface course, for both the traditional fatigue criterion and the appearance of surface cracking

From Figures 3 and 4, it can be observed that for thicker pavement bases, when a bituminous surface course (HRA or SMA) is used, the critical failure criterion is the fatigue of the surface course. The same cannot be applied if a grouted macadam surface course is used instead, due to lower values of strain occurring at the surface as a consequence of its higher stiffness, and due to the extended fatigue life of the mixture itself.

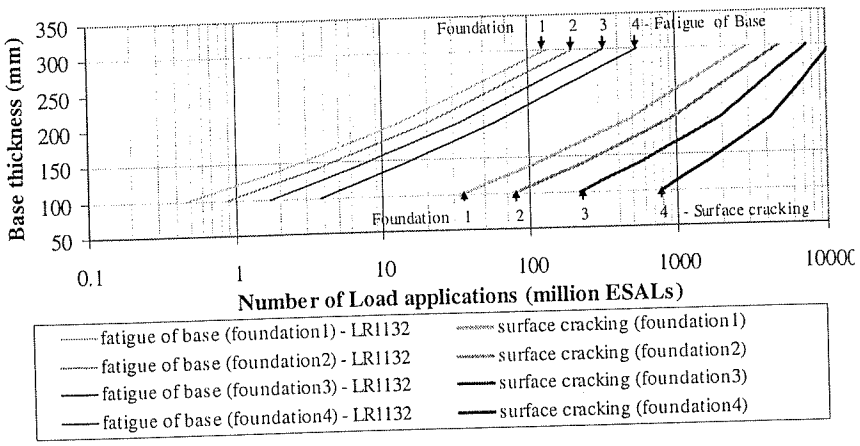


Figure 4: Design of base under a 40 mm Grouted Macadam surface course, taking into account the traditional fatigue criterion and the appearance of surface cracking

In Figures 5 and 6, a comparison is made between the results obtained for both types of surface course, and their influence on the design of the base thickness is presented. The benefits of using a grouted macadam surface course are evident from the analysis of these figures, although more significantly in terms of fatigue cracking originated at the surface than in terms of fatigue of the bituminous base. Nonetheless, a longer fatigue life can be expected from pavements incorporating grouted macadam surface courses.

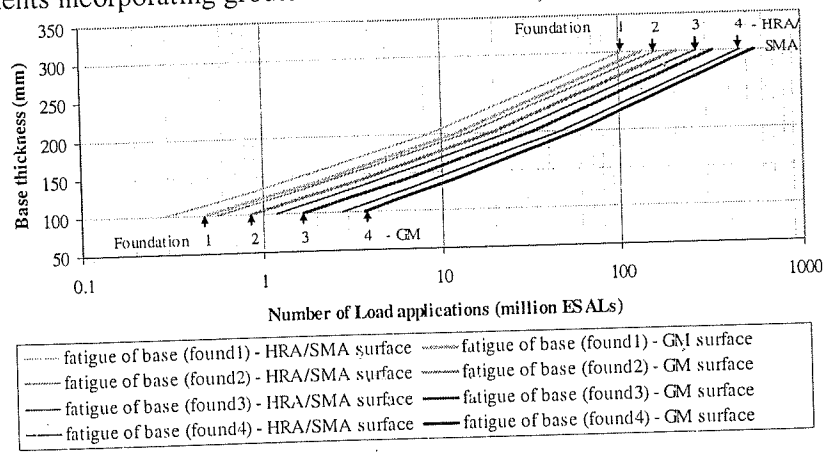


Figure 5: Influence of the type of surface course on the design of the base, considering the traditional fatigue criterion (at the underside of the base)

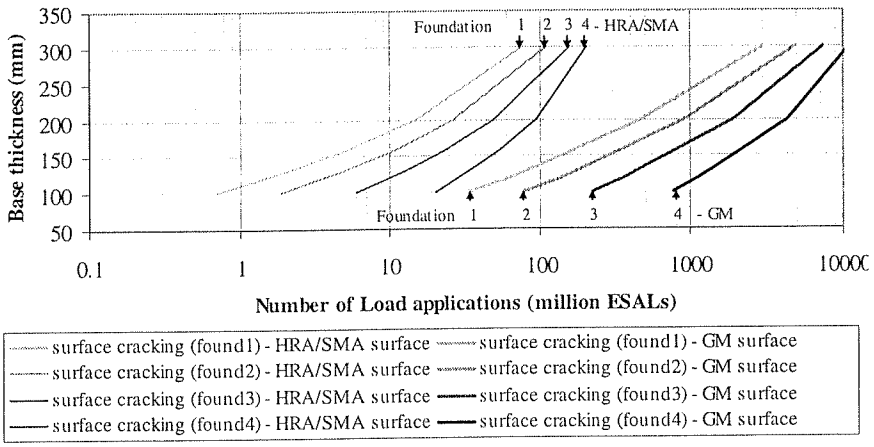


Figure 6: Influence of the type of surface course on the design of the base, considering fatigue of the surface course (surface cracking)

4. DESIGN OF PAVEMENTS WITH GROUTED MACADAM BASE COURSES

A methodology similar to that described in the previous section was used to study the design of pavements incorporating grouted macadam base courses. In this case, the material used in the surface course was a traditional HRA or SMA mixture. The results are shown in Figures 7 and 8, respectively for the standard grouted macadam mixture and for a stiffer grouted macadam (e.g., resulting from a reduced binder content), with a Stiffness Modulus of 12000 MPa, as those obtained by Oliveira et al. [8].

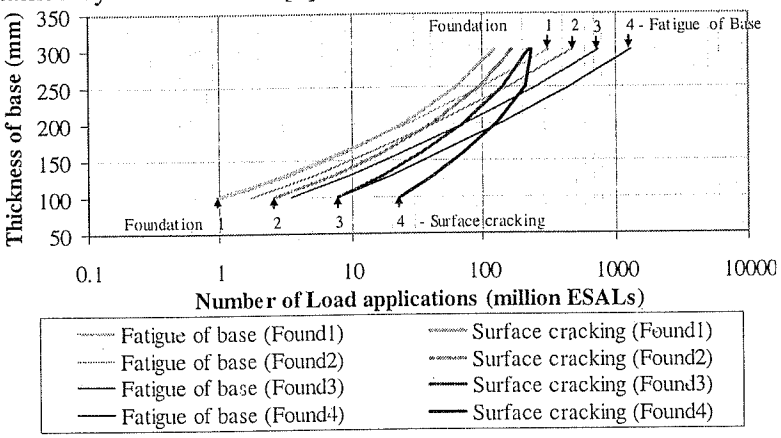


Figure 7: Design of a standard grouted macadam base course under a 40 mm HRA or SMA mixture, considering fatigue of base and surface cracking

As it can be observed from Figure 7, surface cracking (fatigue of the bituminous surface course) is the critical design criterion for pavements with bases thicker than 200 mm. In the case of a stiffer grouted macadam, particularly for pavements with less stiff foundations, surface originated cracking can be even more critical, as shown in Figure 8. For the case of Foundation Class 1 (50 MPa), the thickness of the base is always governed by fatigue of the surface course, whereas for the other foundation classes the critical criterion can be either of them (surface cracking for pavements with bases above 150 mm thick). Nonetheless, an extended fatigue life can be observed for pavements incorporating grouted macadam base courses, and this is most evident for stiffer grouted macadam bases.

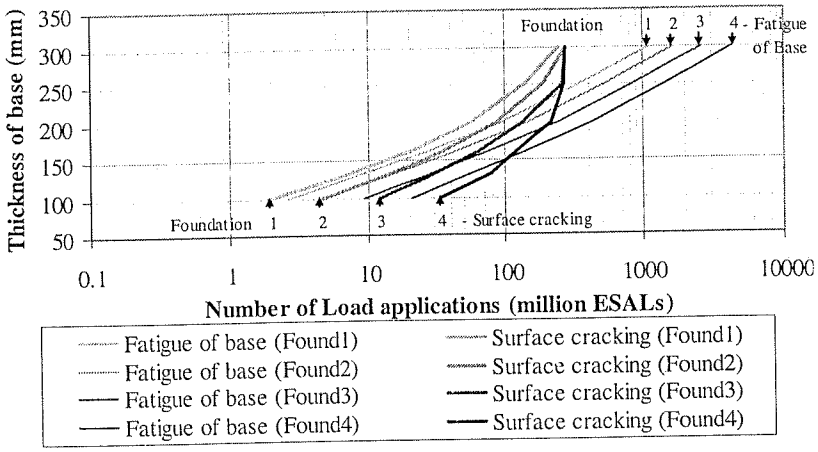


Figure 8: Design of a stiffer grouted macadam base course under a 40 mm HRA or SMA mixture, considering fatigue of base and surface cracking

A comparison with the results obtained for pavements with bituminous base courses (from Section 3) is made in Figures 9 and 10, using the standard grouted macadam mixture. Again, pavements incorporating grouted macadam mixtures show extended fatigue life, which could even be longer if a stiffer grouted macadam mixture is used.

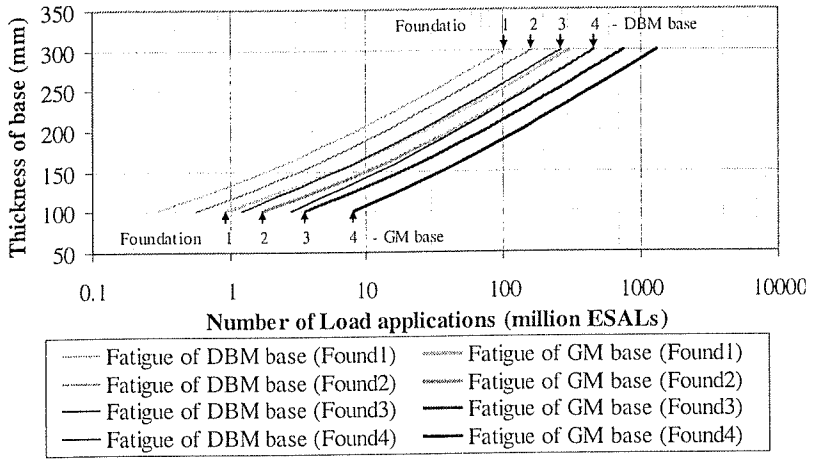


Figure 9: Influence of material type on the fatigue life of the base

One issue that may arise from this pavement design study is the feasibility of constructing grouted macadam layers thicker than 200 mm. Contec [13] claim that they have achieved 210 mm, but full grout penetration may become more difficult to obtain in such thick layers. Thus, the application of consecutive layers may be necessary in order to obtain pavements with up to 300 mm thick base courses (e.g., 150 + 150 mm).

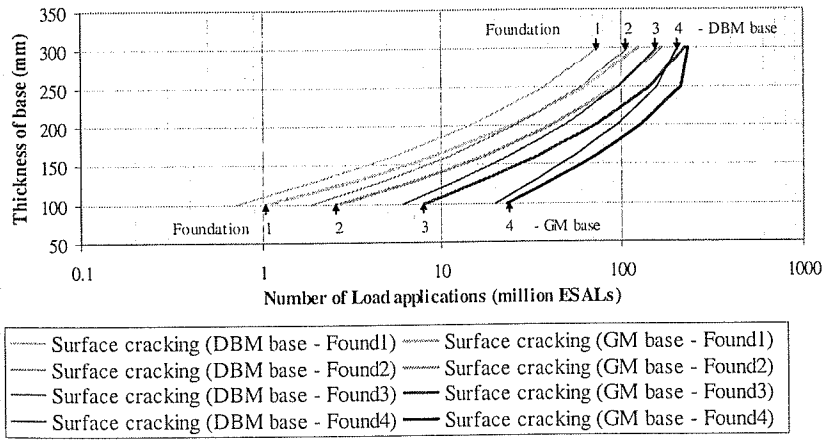


Figure 10: Influence of base material on the fatigue of the surface course

5. CONCLUSIONS

The main conclusions that can be drawn from this study are presented as follows:

i) extended fatigue lives for pavements incorporating a grouted macadam surface course can be obtained if the same base thickness is used, in comparison with HRA or SMA surface courses. Alternatively, a lower base thickness is necessary to obtain the same fatigue life;
ii) surface originated cracking may be significant in pavements with thick bound layers;
iii) a different application of grouted macadam, as a base course, was also studied. Design charts have been developed for two types of grouted macadam: the standard mixture (8000 MPa) and a stiffer mixture (12000 MPa). Both mixtures have shown better performance than traditional DBM50 mixtures, with reduced base thickness or extended fatigue life resulting from the stiffer grouted macadam mixture, as expected;
iv) a particular issue that should be highlighted is the dominance of surface cracking above a certain base thickness (200 mm and 150 mm, respectively, for the standard and the stiffer grouted macadam mixtures). Thus, only the surface layer would need to be subjected to future maintenance operations.

REFERENCES:

[1] Powell, W. D., Potter, J. F., Mayhew, H. C. and Nunn, M. E., *The structural design of bituminous roads,* TRRL Laboratory Report 1132, Transportation and Road Research Laboratory, Crowthorne, 1984.
[2] Highways Agency, *Design Manual for Roads and Bridges*, HD 26/01 - Volume 7 - Section 2 - Part 3 - Pavement Design, London, 2001.
[3] Nunn, M., *Development of a more versatile approach to flexible and flexible composite pavement design*, TRL Report TRL615, TRL Limited, Crowthorne, 2004.
[4] Highways Agency, *Design Manual for Roads and Bridges*. HD 26/06 (Draft 4) - Volume 7 - Section 2 - Part 3 - Pavement Design, London, 2006.
[5] MetOffice, *Mean annual temperature in the UK.* <URL:http://www.metoffice.com/climate/uk/location/england/> [Accessed 2 December 2005].
[6] Oliveira, J. R. M., *Grouted Macadam: Mechanical Characterisation for Pavement Design*, PhD Thesis, University of Nottingham, Nottingham, May 2006.
[7] Shell International Oil Products BV, *BISAR 3.0 – BItumen Stress Analysis in Roads*, User Manual, The Hague, 1998.
[8] Oliveira, J., Thom, N. H. and Zoorob, S., Fracture and Fatigue Strength of Grouted Macadams, *Proceedings of the 10th International Conference on Asphalt Pavements*, Quebec, 2006.
[9] Rao Tangella, S. C. S., Craus, J., Deacon, J. A. and Monismith, C. L., *Summary Report on Fatigue Response of Asphalt Mixtures,* Prepared for Strategic Highway Research Program, Project A-003-A, Institute of Transportation Studies, University of California, Berkeley, 1990.

[10] Shell International Petroleum Company Ltd., *Shell Pavement Design Manual*, London, 1978.

[11] Oliveira, J. R. M., Pais, J. C., Thom, N. H. and Zoorob, S., *A Study of the Fatigue Properties of Grouted Macadams*, (Paper submitted to the International Journal of Pavements in October, 2006).

[12] Ekdahl, P. and Nilsson, R., How may the variation of traffic loading effect measured asphalt strains and calculated pavement service life? *7th International Conference on the Bearing Capacity of Roads, Railways and Airfields (BCRA)*, Trondheim, 2005.

[13] Contec ApS, *The new generation semi-flexible wearing course.* <URL:http://www.confalt.com> [Accessed 8 August 2005].

The Proceedings contain the papers presented at the 4th International Conference on Bituminous Mixtures and Pavements that took place in Thessaloniki, Greece, in April 2007. The Proceedings consist of two Volumes and contain 83 papers in total, from international and national experts. The papers presented reflect the most up to date advances in highway material technology and engineering.

Volume I contains 46 contributions and is divided into four parts: part one contains papers in the plenary sessions. The rest of the parts contain papers per session: Pavement materials, Pavement design, construction and maintenance and Bituminous mixture.

Volume II contains 37 contributions and is divided into four parts, as the number of sessions: Highway and pavement management systems and network operation systems, Pavement recycling, geotextiles, safety at works and effects of roadworks to the environment, Pavement assessment and surface characteristics and Specifications, road safety, street furniture and road marking materials.

Τα Πρακτικά περιέχουν τις επιστημονικές ανακοινώσεις που παρουσιάσθηκαν στο 4ο Διεθνές Συνέδριο Ασφαλτικών Μιγμάτων και Οδοστρωμάτων το οποίο έλαβε χώρα στη Θεσσαλονίκη, τον Απρίλιο 2002. Τα Πρακτικά αποτελούνται από δύο Τόμους και περιέχουν συνολικά 83 ανακοινώσεις, από ξένους και Έλληνες επιστήμονες. Οι επιστημονικές ανακοινώσεις που παρουσιάζονται αντανακλούν τις πλέον πρόσφατες προόδους στην τεχνολογία των υλικών και της μηχανικής στην Οδοποιία.

Ο **Τόμος Ι** περιέχει 46 ανακοινώσεις και χωρίζεται σε τέσσερα μέρη: το πρώτο μέρος περιέχει ανακοινώσεις από Συνεδρίες σε ολομέλεια. Τα άλλα μέρη περιέχουν ανακοινώσεις ανά Συνεδρία: Υλικά οδοστρωμάτων, Σχεδιασμός, κατασκευή και συντήρηση οδοστρωμάτων και Ασφαλτικά μίγματα.

Ο **Τόμος ΙΙ** περιέχει 37 ανακοινώσεις και χωρίζεται σε τέσσερα μέρη, όσα και οι Συνεδρίες: Συστήματα διαχείρισης και λειτουργίας οδοστρωμάτων και οδικών δικτύων, Ανακύκλωση, χρήση γεωυφασμάτων, ασφάλεια έργων και περιβαλλοντικές επιπτώσεις έργων οδοποιίας, Μέθοδοι αξιολόγησης οδοστρωμάτων και επιφανειακά χαρακτηριστικά και Προδιαγραφές, οδική ασφάλεια, εξοπλισμός οδού και υλικά διαγράμμισης.

SET 978-960-91849-2-2
ISBN 978-960-91849-3-9