A STRUCTURAL DESIGN PROCEDURE FOR EMULSION TREATED PAVEMENT LAYERS

JOHANNES JACOBUS ERASMUS LIEBENBERG

A dissertation submitted in partial fulfilment of the requirements for the degree of:

MASTER OF ENGINEERING (TRANSPORTATION ENGINEERING)

In the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT
AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA, PRETORIA

JANUARY 2003

DISSERTATION SUMMARY

A STRUCTURAL DESIGN PROCEDURE FOR EMULSION TREATED PAVEMENT LAYERS

JJE LIEBENBERG

Supervisor: Professor AT Visser

Department: Civil and Biosystems Engineering

University: University of Pretoria

Degree: Master of Engineering (Transportation Engineering)

The use of bitumen emulsion treated pavement layers is well established and is becoming more popular in road building. Current structural design procedures include mainly empirical methods or methods derived from laboratory studies. No design method based on results from accelerated pavement testing of full scale pavements currently exists and no provision for emulsion treated materials exists in the South African Mechanistic Pavement Design Method or the TRH4 structural design guideline document on flexible pavements.

The need therefore existed to provide some guidelines on the structural design of emulsion treated materials based on accelerated pavement testing on a full-scale pavement. The aim of this research was to provide interim guidelines for the structural design from accelerated pavement testing supported by relevant laboratory testing.

A test section, constructed with an emulsion treated ferricrete, was subjected to Heavy Vehicle Simulator testing. Samples from the test site were tested in the laboratory to investigate the engineering properties of the material under different bitumen and cement contents. The laboratory study was used to determine parameters, which are important to the structural design procedure. Results from the laboratory study indicated that the cement content contributes towards the strength of the material, while the bitumen content contributes towards the flexibility of the material.

Results with the Heavy Vehicle Simulator indicated that the test section had a good resistance to permanent deformation. It was determined that the behaviour of the material was two-phased, similar to that of lightly cemented materials. During the first phase, the material demonstrates fatigue properties. The end of the fatigue life phase was defined to be when the resilient modulus of the material reduced to a value of 500 MPa. During the second phase, the material is in an "equivalent granular" phase with a reduced resistance to permanent deformation. The permanent deformation resistance behaviour of an emulsion treated material in its second phase is similar to that of unbound granular materials. The concept of the stress ratio was introduced to describe the permanent deformation behaviour.

Failure criteria for fatigue and permanent deformation were developed and presented as a transfer function that can be used in the South African Mechanistic Pavement Design Method. The transfer functions were developed for different road categories and a design procedure is proposed.

Finally, a design catalogue for emulsion treated base layers was developed from these transfer functions and is presented.

SAMEVATTING VAN VERHANDELING

STRUKTURELE ONTWERPMETODE VIR EMULSIE BEHANDELDE PLAVEISELLAE

JJE LIEBENBERG

Promotor: Professor AT Visser

Departement: Siviele en Biosisteem Ingenieurswese

Universiteit: Universiteit van Pretoria

Graad: Magister in Ingenieurswese (Vervoeringenieurswese)

Die gebruik van bitumen emulsie behandelde plaveisellae is goed gevestig en word al hoe meer populêr in die bou van paaie. Huidige ontwerpprosedures bestaan meestal uit empiriese metodes, of metodes ontwikkel uit suiwer laboratoriumstudies. Geen ontwerpmetode wat gebaseer is op volskaalse plaveiseltoetse bestaan tans vir emulsie behandelde materiale nie. Daar word ook nie voorsiening gemaak in die Suid-Afrikaanse Meganistiese Plaveiselontwerpmetode, of die TRH4, vir die gebruik emulsie behandeling nie.

Daar bestaan dus 'n behoefte na riglyne vir die strukturele ontwerp van emulsie behandelde materiale wat gebaseer is op volskaalse plaveiseltoetse. Die doel van hierdie studie was om voorlopige riglyne daar te stel vir die strukturele ontwerp van hierdie materialse wat verkry is uit die volskaalse plaveiseltoetse en relevante laboratoriumtoetse.

'n Toetsseksie van emulsie behandelde ferrikreet is gebou en onderwerp aan toetse met die Swaarvoertuignabootser. Monsters van die toetsseksie is in die laboratorium getoets om the invloed van verskillende sement en bitumen inhoude op die ingenieurseienskappe van die materiaal te ondersoek. Parameters wat belangrik is vir die strukturele ontwerp van emulsie behandelde materiale is in dié laboratoriumstudie bepaal. Resultate van die laboratoriumstudie dui aan dat die sement hoofsaaklik verantwoordelik is vir die sterkte van die materiaal, terwyl die bitumen bydra tot the buigsaamheid.

Die toetse onder die Swaarvoertuignabootser het daarop gewys dat die materiaal redelike goeie weerstand teen permanente vervormings besit. Dit is verder ontdek dat emulsie behandelde materiale 'n twee fase gedrag het wat soortgelyk is aan die van liggesementeerde materiale. Gedurende die eerste fase het die materiaal vermoeiingseienskappe getoon. Die einde van dié fase is gedefinieer wanneer die elastiese veerkragmodulus 'n waarde van 500 MPa bereik. Die tweede fase is 'n "ekwiwalente granulêre fase" waar die materiaal 'n verminderde weerstand teen permanente

vervorming het. Die permanente vervormingsgedrag van die materiaal is dieselfde as die van granulêre materiale. Die konsep van Spanningsverhouding, om die permanente vervormingsgedrag van die materiaal te beskryf, is voorgestel.

'n Swigtingsstandaard vir die vermoeiingsleeftyd en permanente vervorming is ontwikkel in die vorm van oorgangsfunksies, wat in die Suid-Afrikaanse Meganistiese Plaveiselontwerpmetode gebruik kan word. Die oorgangsfunksies is ontwikkel vir die verskillende kategorieë paaie in Suid Afrika.

Laastens is 'n katalogus ontwikkel vanaf die oorgangsfunksies wat die ontwerp van emulsie behendelde materiale kan vergemaklik. Die katalogus is ingesluit.

AAN: My ouers

Lieb en Elsie Liebenberg

ACKNOWLEDGEMENTS

I wish to express my appreciation to the following organisations and persons who made this dissertation possible:

a) This dissertation is based on a research project by Gautrans. Permission to use the material is gratefully acknowledged. The opinions expressed are those of the author and do not necessarily represent the policy of Gautrans.

b) Gautrans for the financial support on the laboratory and Heavy Vehicle Simulator testing

c) CSIR Transportek for the provision of data and the use of their facilities during the course of the study.

d) Stewart Scott (Pty) and the University of Pretoria for their financial support.

e) The following persons are gratefully acknowledged for their assistance, interest and guidance during the course of study:

   i) Dr. Fenella Long of CSIR Transportek.

   ii) Mr. Hechter Theyse of CSIR Transportek, .

   iii) Ms. Elsbieta Sadzik of Gautrans.

   iv) Mr. Bernoit Verhaeghe of CSIR Transportek for the opportunity to use the facilities at CSIR Transportek.

   v) Dr. Morris de Beer of CSIR Transportek.

   vi) Mr. Willie Diedericks of CSIR Transportek who operated the Heavy Vehicle Simulator, for his interest and devotion to the project

   vii) Mr. Philip Joubert of Stewart Scott (Pty)Ltd. for the opportunity to do this work.

   viii) Dr. Fritz Jooste for the software he developed in a very short time to assist in the development of the design catalogue.

f) Professor AT Visser, my supervisor for his guidance and support.

g) My family and friends for their encouragement, prayers and support during this study.

h) To God, my creator and saviour, who blessed me with the ability to perform this study.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway Transportation Officials
ASTM	American Standard Test Methods
CBR	California Bearing Ratio
COLTO	Committee of Land Transportation Officials
CSIR	Council for Scientific Industrial Research
CSRA	Committee of State Road Authorities
ETB	Emulsion treated base
GEMS	Granular emulsion mixes
GM	Grading modulus
HVS	Heavy Vehicle Simulator
ICL	Initial Consumption of Lime
ITS	Indirect Tensile Strength
LVDT	Linear Variable Displacement Transducer
MDD	Multi Depth Deflectometer
PI	Plasticity Index
SABITA	Southern Africa Bitumen and Tar Association
SAMPDP	South African Mechanistic Pavement Design Procedure
TRH	Technical Recommendations for Highways
UCS	Unconfined Compressive strength

LIST OF SYMBOLS

a'	structural coefficient for recycled layers used as base
a_1, a_2, a_3	AASTHO layer coefficients
B_V	Proportion of bitumen present in asphalt mix
c	Cohesion (kPa)
CDF	Cumulative damage factor (Miner's law)
c_{term}	Cohesion term
d	Thickness of asphalt layer (mm)
E	Modulus of elasticity (MPa)
e	natural logarithm = 2.718 281 828 46….
E_1	Elastic modulus of base layer (MPa)
E_2	Elastic modulus of subbase layer (MPa)
E_{bend}	Bending stiffness of beam (MPa)
E_i	Initial modulus of elasticity (MPa)
E^i_{bend}	Initial bending stiffness of beam (MPa)
FOS	Factor of safety
h_1	Thickness of base layer (mm or inches)
h_2	Thickness of subbase layer (mm of inches)
K	Constant indication moisture regime when calculating Factor of Safety
K_1, K_2	Constants describing stress sensitivity material
M_f	Final modulus (MPa)
M_R	Resilient modulus (MPa)
M_t	Modulus at specific time after construction @ 23°C (MPa)
N	Number of load repetitions
N_{c1}	Load repetitions to initiate crushing
N_{c2}	Load repetitions to advanced crushing
N_{eff}	Effective fatigue life

N_f	Number of load repetitions to failure
N_{ff}	Fatigue and fracture life
n_i	Damage of i^{th} load repetition
Ni	Number of load repetitions to crack initiation
N_{if}	Initial fatigue life
N_{PD}	Number of load repetitions to certain level of plastic strain
N_{std}	Number of load repetitions of standeard wheel load to certain level of distress
N_t	Total number of allowable load repetitions
N_x	Number of load repetitions of wheel load to certain level of distress
Pen	Penetration of recovered bitumen
p_f	normal stress (kPa)
π	pi = 3.141 592 653 59…
P_{std}	Standard wheel load (kN)
Px	wheel load (kN)
q_f	Shear stress (kPa)
RD	Relative density (%)
RF	Early cure reduction factor
S	Degree of saturation (%)
S	Sand equivalent value (#4 sieve to minus 200 mesh)
SF	Shift factor
SN	Structural number
SR	Stress ratio
t	Thickness of emulsion treated base layer (mm)
V_B	Bitumen content by volume (%)
V_V	Voids content (%)
σ_1^m	Maximum allowable major principal stress (kPa)
σ_1^a	Working or applied major principal stress (kPa)

σ	Applied stress from tri-axial test (kPa)
Θ	Bulk stress (kPa)
α	Factor depending on amount of filler voids present in asphalt mix
ϕ	Friction angle (degrees)
ρ	relative density (lb/ft^3 or kg/m^3)
ε	Resilient strain measured (ε)
τ	Shear stress (kPa)
σ_1	Major principal stresses (kPa)
σ_2	Intermediate principal stress (kPa)
σ_3	Minor principal stresses (kPa)
ε_b	Strain at break (με)
σ_b	Stress at break (kPa)
σ_d	Deviator stress (kPa)
ε_i	Induced tensile strain due to loading (με)
ε_m	Tensile strain in asphalt mixture (με)
σ_{max}	Maximum stress (kPa)
ε_{mix}	Bending strain repeatedly applied to asphalt mixture (με)
ε_p	Permanent (plastic) strain (ε)
ε_t	Horizontal tensile strain (με)
σ_t	Vertical compressive stress on top of base layer ≈ tyre contact pressure (kPa)
ϕ_{term}	Internal friction angle term (degrees)
ε_v	Vertical compressive strain (με)
σ_v	Vertical compressive strain (kPa)