THE FLEXIBLE
PAVEMENT ENGINEERING

MODULE

THE FLEXIBLE PAVEMENT ENGINEERING

MODULE

WAN MOHD NAZMI WAN ABDUL RAHMAN

Penerbit
Universiti Malaysia Pahang Al-Sultan Abdullah
Kuantan
2024

First Published, March 2024

Cataloguing-in-Publication Data
Perpustakaan Negara Malaysia
A catalogue record for this book is available from the National Library of Malaysia
ISBN 978-629-7641-04-1

Published By
Penerbit
Universiti Malaysia Pahang Al-Sultan Abdullah
Lebuh Persiaran Tun Khalil Yaakob,
26300 Gambang, Kuantan,
Pahang Darul Makmur.
Tel: 09-431 5034

Printing
PNC Printing
No.2, Tingkat Bawah, Taman Damai Indah,
Peramu, 26600, Pekan, Pahang Darul Makmur
Tel: 09-425 2010

ACKNOWLEDGEMENTS

All praise and thanks are due to Allah the Almighty who sustain me throughout the whole process and enable me to complete this book. This book, *The Flexible Pavement Engineering Handbook,* is based on the author's humble experience engaging in Engineering Laboratory III (Highway and Geotechnical).

The author would like to thank the Faculty of Civil Engineering Technology for technical support and for giving permission to complete this book.

PREFACE

The first edition of ***The Flexible Pavement Engineering Handbook*** informs the basic theory of pavement engineering and provides the overview of important background information on road pavement material. This book is an ideal resource to introduce all Malaysian, particularly who is involved in road pavement engineering, regarding road pavement material.

Each chapter goes through a detailed description of the term in pavement engineering (chapter 1), bitumen and aggregate (chapter 2), flexible pavement (chapter 3), asphalt mixture (chapter 4) and asphalt mixture testing (chapter 5). With this book, readers will quickly setup-to-speed on the most recent in road material, especially in pavement engineering. This volume will be useful in giving professionals a method to evaluate the road pavement material.

TABLE OF CONTENTS

CHAPTER 5 ASPHALT MIXTURE TESTING

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

S_{mix}	Stiffness Modulus
F	Peak Value of the Applied Vertical Load
z	Amplitude of Horizontal Deformation
h	Mean Thickness of the Test Specimen
v	Poison's Ratio
σ	Horizontal Tensile Stress at Specimen Centre
P	Load Applied at Centre of Sample
t	Specimen Thickness
ΔH	Horizontal Deformation
Ω	Specimen Diameter
G_{mb}	Bulk Specific Gravity
W_a	Mass of Asphalt Mixture Sample in Air
W_w	Mass of Asphalt Mixture Sample in Water
W_{sat}	Mass of Asphalt Mixture Sample in Saturated Condition
G_{mm}	Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
P_b	Bitumen Content
G_{se}	Effective Specific Gravity of Aggregate
G_b	Specific Gravity of Bitumen
G_{sb}	Bulk Specific Gravity of Aggregate
MC	Moisture Content of Sample
W	Original Wet Weight of Sample
D	Dry Weight of Sample

σ_{max}	Maximum Tensile Stress
$\acute{\varepsilon}_{ini}$	Initial Tensile Strain
S_{mix}	Stiffness Modulus
N_f	Number of Cycle to Failure
R^2	Coefficient of Determination
N_c	Number of Cycle at Critical Crack

LIST OF ABBREVIATIONS

AASTHO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AI	Asphalt Institute
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BC	Bitumen Content
BS	British Standard
HMA	Hot-Mix Asphalt
ITFT	Indirect Tensile Fatigue Test
ITSM	Indirect Tensile Stiffness Modulus Test
ITST	Indirect Tensile Strength Test
LAAV	Los Angeles Abrasion Value
OBC	Optimum Bitumen Content
PI	Penetration Index
PWD	Public Work Department
RLAT	Repeat Load Axial Test
SP	Softening Point Test
VFB	Percentage of Voids in Aggregate Filled with Bitumen
VMA	Percentage of Voids in Mineral Aggregate
VTM	Percentage of Voids in Total Asphalt Mixture

CHAPTER 1

BASIC PAVEMENT ENGINEERING TERM

This section discusses the pavement engineering term that will be widely used after this chapter. This term is also to remind or give a clear meaning to avoid any confusion and misunderstanding (Thom, 2008).

1.1 DENSITY, UNIT WEIGHT AND SPECIFIC GRAVITY

The density of material is the mass per unit volume (kg/m^3). For instance,

Water	=	1000 kg/m^3
Rock	=	2500 - 3000 kg/m^3
Soil (rock particles + water + air)	=	1500 - 2000 kg/m^3
Crush rock pavement layer	=	2200 kg/m^3
Asphalt mixture and Concrete	=	2400 kg/m^3

However, in pavement engineering, we prefer using unit weight rather than density, because most materials in pavement engineering are statics and the effect of density is to generate weight due to gravity. This is defined as the weight per unit volume and expressed in N/m^3 or more popular as kN/m^3. For example, the pavement layers tend to have 18 to 24 kN/m^3 of unit weights.

Specific gravity is a convenient relative measure. The upper and lower specific gravity are a ratio of the material densities to water i.e specific gravity of water is 1. For instance, the bitumen being marginally denser than water has a specific gravity of 1.02 to 1.03.

1.2 STRESS, PRESSURE AND STRAIN

Stress and pressure are similar, defined as force divided by area and expressed in N/m^2 or Pascal (Pa). However, in pavement engineering term, stress is more commonly used because it deals with solid but pressure usually relates to liquid and gases. Therefore, the contract stress occurs as load from the wheel applied on road surface is divided by the contact area. This will be approximately equal to the air pressure within the tyre. For example, the vertical contact stress and the tyre pressure of a typical heavy goods vehicle wheel are both around 600kPa. However, due to the way flexible pavement spreads the load from the wheel, the vertical stress at the top of the subgrade may be less than 10 kPa (Thom, 2008).

Strain describes the degree to which a material deforms. It is also defined as the change in a dimension divided by the original magnitude of that dimension and it has no units because it is a relative change. In contrast, we prefer using percentage if strains are large but we usually use microstrain ($\mu\varepsilon$) if strains are very small, like strains generated within pavement under wheel load. The 1$\mu\varepsilon$ is a strain of 10^{-6} or a change of one millionth in the original dimension. The detail relationship between load destruction in pavement, stress and strain is shown in Figure 1.

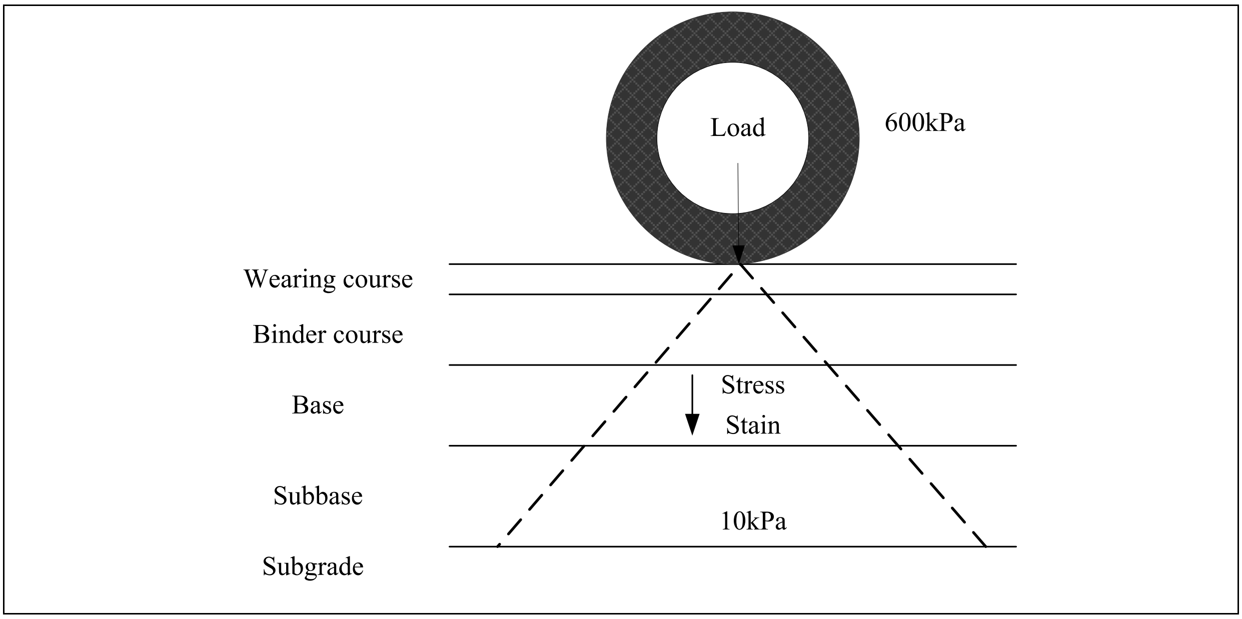

Figure 1.1: Example of load distribution in flexible pavement

1.3 ELASTIC MODULUS, RESILIENT MODULUS AND STIFFNESS MODULUS

The elasticity of civil engineering material is shown in Figure 1.2. This figure also reveals a sample of civil engineering material with length (L) and cross section area (ab), subjected to a direct normal load (P) in tension in the x direction. The civil engineering material could be applied in concrete, soil or asphalt mixture. This uniaxial loading causes a direct stress $\sigma = P/ab$ and strain $\varepsilon x = x/L$. The elastic modulus (also called Young's Modulus or resilient modulus or stiffness modulus), E, is defined as illustrated in equation 1.1.

$$E = \frac{\sigma}{\varepsilon} \qquad (1.1)$$

where:
E = Elastic modulus
σ = Applied stress
ε = Resultant strain

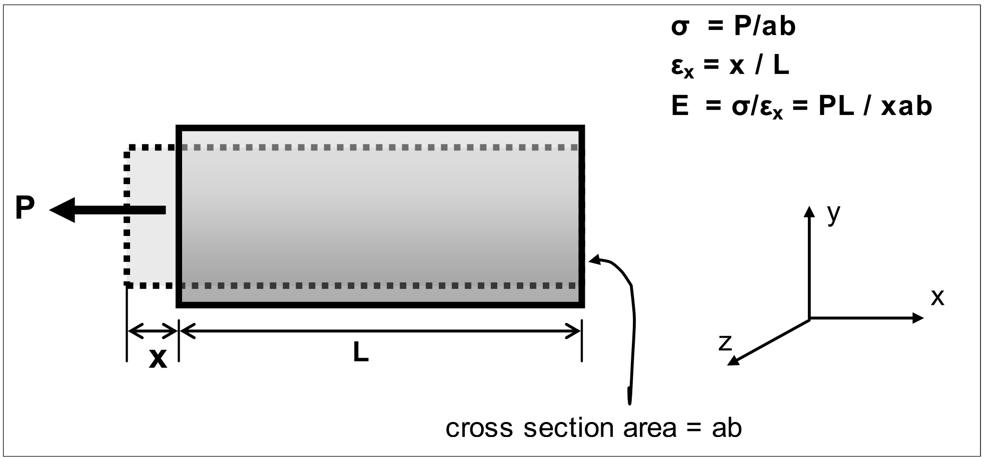

Figure 1.2: Elasticity of civil engineering material
Source: Sunarjono (2008)

The unit of stress in elastic modulus is N/m^2 or Pa. It can be seen in Figure 1.2 as the material is loaded, the civil engineering material is not only getting longer, but it also decreases its cross-sectional area. As a result, the deformations in the y and z directions occur when divided by the corresponding dimensions, a and b, and yield strain εy and εz. The ratio of these strains to εx is defined as 'Poisson's Ratio (v)'. The Poisson's Ratio is dimensionless and generally ranges from 0.1 to 0.5. A value of 0.5 implies that no volumetric change is taking place, since increasing dimension in the x direction is compensated by decreasing dimension in the two other directions. For asphalt mixture, Poisson's Ratio is around 0.35 (Sunarjono, 2008).

In conclusion, the elastic modulus is used in concrete or steel because it is assumed that the behaviour of the concern material is linear. In contrast, the unbound material or soil is significantly non-linear and stress dependent, because it separates out elastic behaviour from plastic component where strains are non-recoverable. Therefore, for unbound material or soil, we prefer using resilient modulus. Asphalt mixture is a viscoelastic material. This material could be viscous or elastic, and it depends on temperature and loading rate. Thus, in pavement engineering, we prefer to use stiffness modulus because asphalt hss non-linear behaviour, and asphalt stiffness varies depending on temperature and loading rate (Thom, 2008).

REFERENCES

American Association of State Highway and Transportation Officials. 1982. *Resistance to abrasion of small size course aggregate by use of the Los Angeles machine.* AASTHO T96-7: 1982. Washington: AASTHO.

American Association of State Highway and Transportation Officials. 2005. *Bulk specific gravity of compacted hot mix asphalt using saturated surface-dry specimens*. AASTHO T166 (05) : 2005. Washington: AASTHO.

American Association of State Highway and Transportation Officials. 2015. *Theoretical maximum specific gravity and density of hot mix asphalt*. AASTHO T209 :2015. Washington: AASTHO.

American Society for Testing and Materials. 1993. *A guide for fatigue Ttesting and the statistical Analysis of Fatigue Data*. STP No. 91. Pennsylvania: ASTM.

American Society for Testing and Materials. 2013. *Standard specification for viscosity-graded asphalt cement for use in pavement construction.* ASTM D3381 : 2013. Pennsylvania: ASTM.

Asphalt Institute. 2001. *Superpave Mix Design*. Superpave^{TM} Series No.2 (SP-2). Third Edition. USA: AI.

British Standards Institution. 1990a. *Testing aggregate – part 112: method for determination of aggregate impact value (AIV)*. BS 812-112: 1990. London: BSI.

British Standards Institution. 1990b. *Testing aggregate – part 110: method for determination of aggregate crushing value (ACV)*. BS 812-110: 1990. London: BSI.

British Standards Institution. 1990c. *Testing aggregate – part 110: method for determination of ten percent fines value (TFV)*. BS 812-111: 1990. London: BSI.

British Standards Institution. 1996. *Method for determining resistance to permanent deformation of bituminous mixtures subject to unconfined dynamic loading*. DD 226: 1996. London: BSI.

British Standards Institution. 2000. *Bitumen and bituminous binders- specification for paving grade bitumens*. BS EN 12591: 2000. London: BSI.

British Standards Institution. 2004a. *Bituminous mixtures- test methods for hot mix asphalt- part 26: stiffness*. BS EN 12697-26: 2004. London: BSI.

British Standards Institution. 2004b. *Bituminous mixtures- test methods for hot mix asphalt- part 24: resistance to fatigue*. BS EN 12697-24: 2004. London: BSI.

British Standards Institution. 2007a. *Bitumen and bituminous binders- determination of needle penetration*. BS EN 1426: 2007. London: BSI.

British Standards Institution. 2007b. *Bitumen and bituminous binders- determination of the softening point- ring and ball method*. BS EN 1427: 2007. London: BSI.

Brown, S.F. 1994. *Properties of road layers in bituminuous mixtures in road construction.* pp 43-63. London: Thomas Telford.

Brown, S. F. 2000. *Residential course on bituminuous pavements, materials, design and evaluation*. Lecture notes. School of Civil Engineering, University of Nottingham.

Cooper, K.E. and Brown, S.F. 1989. Development of a simple apparatus for the measurement of the mechanical of asphalt mixes. *Proceedings of Eurobitument Symposium*, pp 494-498.

Halstead W.J. 1985. Relation of asphalt chemistry to physical properties and specification. *J. Assoc. of Asphalt Paving Technology*. **54**: 91-117.

He G.P. 2006. *Study the use of reclaimed asphalt pavement (RAP) with foamed bitumen in Hong Kong*. PhD Thesis. The Hong Kong Polytechnic University, Hong Kong.

IPC Global. 2013. IPC Global product overview. http://www.ipcglobal.com.au/images/stories/products/products/pdfs/IPC_Product, (19 March 2013).

Kingham, I. R. 1973. Failure criteria developed from AASHO road test data. Highway research board, Special report 140, *Proceeding of a Symposium on Structural Design of Asphalt Concrete Pavements to Prevent Fatigue Cracking*. pp 183-196.

Peterson J.C. 1984. *Chemical composition of asphalt as related to asphalt durability state of the art*. Transportation Research Record. (999): 13-30. USA: TRR.

Public Work Department. 1992. *A guide to visual assessment of flexible pavement surface condition*. First Edition, JKR 20709-2060-92. Malaysia: PWD.

Public Work Department. 1985. *Manual on pavement design*. First edition, Technical Guide (Road) 5/85. Malaysia: PWD.

Public Work Department. 2008. *Standard specification for road works*. First edition. JKR/SPJ/2008. Malaysia: PWD.

Read J M. 1996. *Fatigue cracking of bituminous paving mixtures*. PhD Thesis. University of Nottingham, UK.

Read J and Whiteoak D. 2003. *The shell bitumen handbook*, Fifth edition. UK: Thomas Telford.

Roberts, F.L, Kandhal, P.S, Brown, E.R, Dah-Yin Lee and Kennedy, T.W. 1996. *Hot mix asphalt materials, mixture design and construction*. Second edition. Maryland: NAPA Education Foundation.

Sunarjono Sri M.T. 2008. *The influence of foamed bitumen characteristics on cold-mix asphalt properties*. PhD Thesis. University of Nottingham, UK.

Tapkin S. 2007. The effect of Polypropylene fibres on asphalt performance. *J. Building and Environment.*

Thom N. 2008. *Principle of pavement engineering*. First edition. UK: Thomas Telford.

Widyatmoko, I., 2002. *Performance of bituminous and bydraulic materials in pavements* edited by S.E. Zoorob, A.C. Collop & S.F. Brown, NCPE, the University of Nottingham, UK.

Wright H. Paul and Dixon K. Karen. 2004. *Highway Engineering*. Seventh edition. New York: Wiley.

AUTHOR'S BIOGRAPHY

Wan Mohd Nazmi Wan Abdul Rahman is a senior lecturer in Universiti Malaysia Pahang. He is currently attached to the Faculty of Civil Engineering Technology. His research interest includes Pavement Engineering, Road Safety and Traffic Engineering.