ANALYSIS OF PAVEMENT STRUCTURES

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Gifted to my beloved wife, Nibedita

List of Symbols

a	Radius of circular area or equivalent tire imprint
A	Area
a_{st}	Cross-sectional area of a single steel bar
A_{st}	Cross-sectional area of steel per unit length
B	Width of a concrete slab
BF	Body force
C_{crp}	Creep compliance
C^h	Heat capacity
D	Flexural rigidity of a plate
E	Young's modulus or elastic modulus
E'	Storage modulus
E''	Loss modulus
E^*	Complex modulus
E_d	Dynamic modulus
E_{rel}	Relaxation modulus
f	Coefficient of friction
g	Acceleration due to gravity
G	Shear modulus
h	Layer thickness
I_1	First stress invariant ($= \sigma_1 + \sigma_2 + \sigma_3$)
I_2	Second stress invariant
I_3	Third stress invariant
k	Modulus of subgrade reaction
k^{td}	Coefficient of thermal diffusivity
k_s	Spring constant
k_{ss}	Slider constant
l	Radius of relative stiffness

L	Length of a concrete slab
M	Moment
M_R	Resilient modulus
M_c	Unit cost of maintenance
M_u	Unit road user cost
n	Number of repetitions applied
$\boldsymbol{N}$	Number of traffic repetitions a material/pavement can sustain
P_a	Atmospheric pressure
q	Pressure
Q	Concentrated load
Q_h	Heat flow per unit area
r	Discount rate
R	Reliability
S	Structural health of a pavement
t	Time
T	Temperature
$\boldsymbol{T}$	Number of expected traffic repetitions
T_t	Temperature at the top surface
T_b	Temperature at the bottom surface
T_∞	Temperature at infinite depth
u	Displacement along X direction (Cartesian coordinate)
u_r	Displacement along R direction (cylindrical coordinate)
U	Universal gas constant
v	Displacement along Y direction (Cartesian coordinate)
V	Shear force
v_θ	Displacement along tangential direction (cylindrical coordinate)
V_o	Speed
x	Distance along X direction
y	Distance along Y direction
z	Distance along Z direction
z_s	Gap between two adjacent concrete slabs
α	Coefficient of thermal expansion
α_T	Time shift factor
β	An angle
γ	Engineering shear strain

δ	Phase angle
ΔH	Apparent activation energy
ϵ	Strain
ζ	Dummy variable for time
θ	An angle in cylindrical polar coordinate system
η_d	Viscosity of the dashpot
μ	Poisson's ratio
ρ	Density of the material
σ	Normal stress
σ^c	Confining pressure ($= \sigma_3$)
σ_d	Deviatoric stress
σ^S	Tensile strength
σ^{TA}	Axial stress component due to temperature
σ^{TB}	Bending stress component due to temperature
σ^{TN}	Nonlinear stress component due to temperature
ω	Displacement along Z direction (for both Cartesian and cylindrical coordinates)
ω_f	Angular frequency
τ^b	Bond strength

Preface

This is a simple book.

This book is about pavement analysis. A pavement is a multi-layered structure, made of a number of layers placed one over the other. These layers can be made of asphaltic material, cement concrete, bound or unbound stone aggregates, etc. These materials show complex mechanical response with the variation of stress, time, or temperature. Thus, understanding the performance of an in-service pavement structure subjected to vehicular loading and environmental variations is a difficult task.

However, this is a simple book. This book presents a step-by-step formulation for analyses of load and thermal stresses of idealized pavement structures. Some of these idealizations involve assumptions of the material being linear, elastic, homogeneous and isotropic; the load being static; the thermal profile being linear and so on.

Significant research has been done on analysis and design of pavements during the last half-century (some of the fundamental developments are, however, more than hundred years old) and a large number of research publications are already available. However, there is a need for the basic formulations to be systematically compiled and put together in one place. Hence this book. It is believed that such a compilation will provide an exposure to the basic approaches used in pavement analyses and subsequently help

the readers formulate their own research or field problems—more difficult than those dealt with in this book.

The idea of this book originated when I initiated a post-graduate course on *Characterization of Pavement Materials and Analysis of Pavements* at IIT Kanpur. This course was introduced in 2007; that was the time we were revising the post-graduate course structure in our department. I must thank my colleague Dr. Partha Chakroborty for suggesting at that time that the Transportation Engineering program at IIT Kanpur should have a pavement engineering course with more analysis content. I also should thank him for his constant encouragement during the entire process of preparing this manuscript. One of our graduate students, Priyanka Khan, typed out portions of my lectures as class-notes. Those initial pages helped me to overcome the inertia of getting started to write this book. That is how it began.

This book has eight chapters. The first chapter introduces the sign convention followed in the book and mentions some of the basic solid mechanics formulations used in the subsequent chapters. The second chapter deals with the material characterization of various pavement materials. It introduces simple rheological models for asphaltic material. Beams and plates on elastic foundations are dealt with in the third chapter—these formulations form the basis of analysis of concrete pavement slabs due to load. The fourth chapter covers the thermal stress in concrete pavement, and it provides formulations for axial and bending stresses due to full and partial restraint conditions. The fifth chapter starts with the analysis of elastic half-space, and enlarges it to an analysis of multi-layered structure. A formulation for thermo-rheological analysis of asphalt pavement is presented in the sixth chapter. The seventh chapter discusses the pavement design principles where pavement analyses results are used. Finally, the last chapter discusses some miscellaneous topics which include analysis of a beam/plate resting on elastic half-space, analysis of dynamic loading conditions, analysis of composite pavement, reliability issues in pavement design, and the inverse problems in pavement engineering.

Since this book provides an overview of basic approaches for pavement analysis, rigorous derivations for complex situations have been deliberately skipped. However, references are provided in appropriate contexts for readers who want to explore further. I must place a disclaimer that those references are not necessarily the only and the best reading material, but they are just a representative few.

A number of my former and present students have contributed to the development of this book. They have asked me questions inside the classroom and outside. Discussions with some of them were quite useful, while others helped me to cross-check a few derivations. Dr. Pabitra Rajbongshi, Sudhir N. Varma, Vivek Agarwal, Pranamesh Chakraborty, Syed Abu Rehan, and Vishal Katariya are some of these students. I must also thank my former colleague, Dr. Ashwini Kumar, for the useful discussions with him on plate theories. I also thank all the people with whom I have interacted professionally from time to time for discussing various issues related to pavement engineering. I want to thank all the authors of numerous papers, books and other documents whose works have been referred to in this book.

I am most grateful to my parents for their care and thought involved in my education. I thank my father, Dr. Kali Charan Das, for teaching me formulations in physics using first principles. I thank my Ph.D. supervisor Dr. B. B. Pandey for training me as a researcher in pavement engineering. I also wish to thank my colleagues for the encouragement, and my Institute, IIT Kanpur, for providing an excellent academic ambiance.

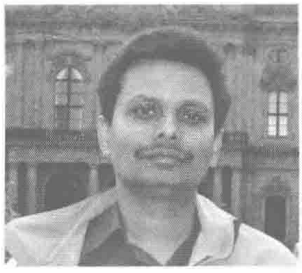
I thank CRC Press and Taylor & Francis staff members, especially Dr. Gangandeep Singh and Joselyn Banks-Kyle for remaining in touch with me during the development of the manuscript and Karen Simon during the production process. I must thank my family members for bearing with me, and especially my daughter Anwesha for sacrificing her bedtime stories for months, while I was finalizing the manuscript.

Care has been taken as far as possible to check for editorial mistakes. If, however, you find any, or wish to provide your feedback on this book please drop me an e-mail at adas@iitk.ac.in.

This book now must go for printing.

Animesh Das

About the Author



Animesh Das, Ph.D., is presently working as a professor in the Department of Civil Engineering, Indian Institute of Technology Kanpur. He earned his Ph.D. degree from the Indian Institute of Technology Kharagpur. Dr. Das's areas of interest are pavement material characterization, analysis, pavement design, and pavement maintenance. He has authored many technical publications in various journals of repute and in conference proceedings. He has co-authored a textbook titled *Principles of Transportation Engineering* published by Prentice-Hall of India (currently, PHI Learning), and he co-developed a web-course titled *Advanced Transportation Engineering* under the National Programme on Technology Enhanced Learning (NPTEL), India. Dr. Das has received a number of awards in recognition of his contribution in the field, including an Indian National Academy of Engineers Young Engineer award (2004) and a Fulbright–Nehru Senior Research Fellowship (2012–13), etc. Details of his works can be found on his webpage: http://home.iitk.ac.in/∼adas.

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