ice
Institution of Civil Engineers
publishing

Principles of Pavement Engineering

Second edition

Nick Thom

ice
Institution of Civil Engineers
publishing

Principles of Pavement Engineering

Second edition

Nick Thom
University of Nottingham, UK

Published by ICE Publishing, One Great George Street, Westminster, London SW1P 3AA.

Full details of ICE Publishing sales representatives and distributors can be found at: www.icevirtuallibrary.com/info/printbooksales

First published 2008
Second edition published 2014

Other titles by ICE Publishing:

ICE Manual of Construction Materials.
M. Forde (ed.). ISBN 978-0-7277-3597-3
Portland Cement, Third edition.
G. Bye. ISBN 978-0-7277-3611-6
The Shell Bitumen Handbook, Fifth edition.
J. Read and D. Whiteoak. ISBN 978-0-7277-3220-0

www.icevirtuallibrary.com

A catalogue record for this book is available from the British Library

ISBN 978-0-7277-5853-8

Commissioning Editor: Rachel Gerlis
Production Editor: Imran Mirza
Market Specialist: Catherine de Gatacre

Typeset by Academic + Technical, Bristol
Printed and bound by CPI Group (UK) Ltd, Croydon CR0 4YY

Principles of Pavement Engineering

Foreword

I have known the author for over 30 years, and we have shared the same professional background in pavement engineering, so I can say with confidence that Nick Thom is not only extremely knowledgeable about the subject, but also writes (and indeed presents) in an engaging and approachable style. That is why I would recommend this book to any student of pavement engineering, whether for a first introduction (as would be the case for a university module) or for a more detailed understanding of the subject (as a reference to support decision making concerning design and maintenance of pavements in practice).

Although often overlooked by those not closely involved in the discipline, the study of pavements incorporates some fundamental aspects of civil engineering. A pavement is a structure, which is constructed on natural or man-made ground; it must be capable of spreading the design load over that ground, typically, for many years and for millions of load applications; a fundamental understanding of materials, in both bound and unbound states is required, especially when the structure is being assessed for a change in use; and the presence of water can have a significant negative impact on durability and/or the expected performance. Accordingly, Part 1 introduces the reader to the principles.

Many standards, manuals, and codes of practice have been developed over the last 30 years, but pavement engineering is still as much of an art as a science. That is good, since the over standardisation of a subject can stifle innovation; but the author reminds us in the introduction that 'the pavement industry deals in high-volume low-cost materials', so pavement engineers must be flexible in the use of locally available materials, especially if taking sustainability into account. Part 2 provides guidance on materials, and the often conflicting properties (e.g. fatigue cracking resistance vs. deformation resistance) that require the application of both knowledge and judgement if satisfactory performance is to be achieved in situ.

Having identified material properties, and with an understanding of test methods, the reader can then consider Design (Part 3). Several design guides have been developed and revised over the last few decades (typically, for specific applications, such as highways, or ports, or airports – see References) and these are excellent. However, Part 3 provides important background to the considerations around which those guides have been developed. These are particularly important when innovative materials or combinations of materials are to be used, or an investigation into premature pavement distress is required.

This brings the reader to Maintenance (Part 4) and the challenge of extending the life of a pavement structure to achieve the required serviceability levels in future. Perhaps more than anywhere, this is where the pavement engineer must use judgement, and take account of constraints – such as time restrictions (around routine traffic movements) when access is available to carry out work, or retaining finished levels (to adjacent structures). Part 4 provides the framework around which such considerations can be made.

The scope of this book is comprehensive, not only covering the common forms of pavement construction, but also more unusual pavements. This second edition also demonstrates that there is still much to learn on the subject, with additional material on rubber modified and warm mix asphalt; the testing of unbound materials and the influence of water in pavement foundations; and sections on pothole development and repair strategy. In addition, many of the calculation sheets have been expanded to improve clarity, and the section on SAMI's and geogrids now includes example predictions.

The general public takes our roads, ports, airports, hardstandings, cycleways, bridge surfacings, etc. for granted, and often feel inconvenienced when maintenance or renewal is required; they may not even be aware of the structure 'below their feet' that is performing such an essential function. Yet this infrastructure is vital to the economic wellbeing of any country. *Principles of Pavement Engineering* does justice to the complexity of this subject – but in a way that will both inform and interest the reader.

Robert Armitage
Director, URS Infrastructure and Environment Ltd

Acknowledgements

In no way is this book an individual effort. It could never have been written if it were not for the research that has been, and continues to be, carried out by numerous individual researchers at the University of Nottingham, ensuring that I have at least had the opportunity to access up-to-date knowledge across a range of subjects. For this second edition, while there are still too many to record in full, I would particularly identify Oluwaseyi Oke, Olumide Ogundipe and Tao Lu, as well as reiterating my thanks to academic colleagues at the Nottingham Transportation Engineering Centre: Stephen Brown, Andrew Dawson, Gordon Airey, Tony Parry and James Grenfell. I also owe considerable thanks to colleagues in industry, notably Bachar Hakim, Martyn Jones and Daru Widyatmoko of URS Infrastructure and Environment UK Ltd and Andrew Cooper of Cooper Technology, who have either directly or indirectly given me access to ongoing developments as well as making me aware of some of the key challenges facing practitioners. My thanks also go to Robert Armitage of URS for kindly agreeing to write the foreword to this book.

Contents

ice
Institution of Civil Engineers
publishing

Part 1

Principles and practicalities

Principles of Pavement Engineering
ISBN 978-0-7277-5853-8

http://dx.doi.org/10.1680/ppe.58538.003

Chapter 1
Introduction

When all is said and done, the pavement industry deals in high-volume, low-cost materials. In the UK alone, there are approximately 14 000 km of trunk road and motorway with a surface area of some 250 km^2, around 10% of which has to be resurfaced each year. In the USA, this figure can be multiplied by about six. And these are not figures that can be dramatically reduced while motor vehicle transport remains such a key factor in the economy. The choice of materials is, therefore, limited to those that can be easily and cheaply produced in large quantities – which inevitably means the raw materials of the earth, namely *rock*, *sand* and *clay*. Any additive used to give extra quality – such as bitumen or cement – has to be used relatively sparingly; otherwise society just could not afford it – to say nothing of the environmental cost of such additives. The job of the pavement engineer, therefore, is to maximise the potential of these cheap, readily-processable materials. The unit cost of the bulk materials may be relatively low, but the quantities required are very high indeed, which means that a modest saving per square metre can multiply up to a very substantial saving overall. To put it another way, if the life of a road pavement can be extended by 10%, this represents a very large contribution to the local economy.

1.1. The long history of the paved highway

It is impossible to know where or when the wheel was invented. It is hard to imagine that Stone Age humans failed to notice that circular objects such as sections of tree trunk rolled. The great megalithic tombs of the third millennium BC bear witness to ancient humans' ability to move massive stones, and most commentators assume that tree trunks were used as rollers; not quite a wheel but a similar principle! However, it is known for certain that the domestication of the horse in southern Russia or the Ukraine in about 4000 BC was followed not long afterwards by the development of the cart. It is also known that the great cities of Egypt and Iraq had, by the late third millennium BC, reached a stage where pavements were needed. Stone slabs on a rubble base made an excellent and long-lasting pavement surface suitable for both pedestrian usage and also traffic from donkeys, camels, horses, carts and, by the late second millennium BC, chariots. Numerous examples survive from Roman times of such slabbed pavements, often showing the wear of tens of thousands of iron-rimmed wheels. Traffic levels could be such that the pavement had a finite life.

Even in such ancient times, engineers had the option to use more than simply stones if they so chose – but only if they could justify the cost! Concrete technology made significant strides during the centuries of Roman rule and was an important element in the structural engineer's thinking. Similarly, bitumen had been used for thousands of years in Iraq as asphalt mortar in building construction. Yet neither concrete nor asphalt was used by pavement engineers in ancient times, for the excellent reason that neither material came into the cheap, high-volume category. As far as the pavement engineer was concerned, economics dictated that the industry had to remain firmly in the Stone Age. Even in the days of Thomas Telford and John Loudon Macadam – the fathers of modern road building in the UK – the art of pavement construction consisted purely of optimising stone placement and the size fractions used.

Times have moved on; the massive exploitation of oil has meant that bitumen, a by-product from refining heavy crude oil, is now much more widely available. Cement technology has progressed to the stage where it is sufficiently cheaply available to be considered in pavement construction. However, there is no way that pavement engineers can contemplate using some of the twenty-first century's more expensive materials – or, at least, they can be used only in very small amounts. Steel can only be afforded as reinforcement in concrete and, even in such modest quantities, it represents a significant proportion of the overall cost. Plastics find a use in certain types of reinforcement product; polymers can be used to enhance bitumen properties; but always the driving force is cost, which means that, whether we like it or not, Stone Age materials still predominate.

1.2. Materials for pavement construction

In introducing the various building blocks from which pavements are constructed, it will not be possible to avoid entirely the use of technical terms such as 'load', 'strength' and 'stiffness'. Definitions of these terms can be found in Chapter 4.

1.2.1 Soil

Every pavement, other than those on bridges, self-evidently includes soil. The most basic design requirement of any pavement is that the underlying soil is adequately protected from applied loads. Thus, no pavement engineer can avoid the need to understand soil. The following list features some key facts.

- Soils vary from heavy clays, through silts and sands to high-strength rocky materials.
- Soils are not usually consistent along the length of a road or across any pavement site.
- Soils are sensitive to water content to differing degrees.
- Water content will vary during the life of a pavement, sometimes over quite short timescales, in response to weather patterns.
- Some soils are highly permeable; some clays are virtually impermeable.

All this leads to one thing – *uncertainty*. However clever one tries to be in understanding and characterising soils, it is quite impossible to be 100% sure of the properties at a given time or in a given location.

This uncertainty makes life considerably harder. Nevertheless, it is necessary to categorise each soil type encountered in as realistic a way as possible, and there are two fundamental areas in which soil behaviour affects pavement performance. These are

- *stiffness* under transient (i.e. moving wheel) load
- resistance to accumulation of deformation under repeated load, likely to be related to *shear strength*.

The various means of testing, measuring and estimating these properties are covered in Part 2 of this book, as are the possibilities of soil improvement by using additives such as cement and lime.

1.2.2 Granular material

Granular material is unbound material with relatively large particle sizes, and includes natural gravel, crushed rock and granulated industrial by-products such as slag from steel production. Soils are technically granular materials, albeit often with a very small particle size (2 μm or less for clay), but the key difference is that a soil is not, in general, 'engineered' in any way. A granular pavement layer, on the other hand, will be selected and quite possibly deliberately blended to give a particular combination of particle sizes. It can also be mixed with a predetermined amount of water. One would therefore naturally expect that much of the uncertainty inherent in soil properties is removed in the case of a granular material. However, it may still be difficult to predict performance accurately, as different material sources, most commonly different rock types, might be expected to exhibit slightly different properties due to their different responses to crushing or their differing frictional properties. Nevertheless, a granular material will be a much more controlled and predictable component than the soil. Even the water-content variation of a granular material will be a little more predictable, in both magnitude and effect, than in the case of soil.

However, the properties of granular material of interest to the pavement engineer are actually more or less the same as those of soil, namely

- *stiffness* under transient load
- resistance to accumulation of deformation under repeated load, related to *shear strength*.

1.2.3 Hydraulically-bound material

Nowadays, the availability of Portland cement, and substitutes such as fly ash or ground granulated blast-furnace slag, means that it can be economical to use such a binding agent to strengthen a granular material. These binders are known as 'hydraulic' binders, as they require the presence of water for the cementing action to take place. Cement technology is a vast subject in its own right and involves several different chemical reactions, the most important of which are the conversion of tricalcium silicate (*c*. 50% of Portland cement) and dicalcium silicate (*c*. 25%) into hydrates (forming strong solids) by reaction with water, also generating calcium hydroxide and heat. The first reaction is rapid; the second is slower. The reader should refer to specialist literature for details.