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Measurement and Applications

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Introduction

The fundamental equations

The transport properties of concrete measure the ability of fluids to move through it. The equations for them were first documented by the end of the nineteenth century (Fick 1855; Darcy, 1856) and applied to concrete by the middle of the twentieth century (Powers *et al.*, 1954). However, they remain difficult to measure, particularly if the common *in situ* tests are used.

Interest in these properties has increased as many structures built in the second half of the twentieth century have suffered durability problems, particularly corrosion of reinforcement. This corrosion was investigated by Knudson (1907) and was soon discovered to be caused by chloride transport through the cover layer (Rosa *et al.*, 1912). All of the major deterioration mechanisms are controlled by the transport properties. This is the main application for them and is discussed in Chapter 13. Other applications in waste containment are discussed in Chapters 14 and 15.

This book is intended to give an improved understanding of the transport mechanisms that take place during testing. The particular emphasis of the work is to show how the fundamental transport properties may be obtained. Two different types of solution to the equations are presented: analytical solutions and computer models. In general, it is found that analytical solutions are useful up to a point, but full solutions require a computer model. In many cases, the analytical solutions are only used to check the computer models by running them for a special case.

The work will be of interest to researchers who are measuring or modelling durability of concrete structures and to practitioners who are evaluating concrete structures or designing containment structures for fluids or wastes and require to know the permeability as part of the design. The analysis methods which are presented may also be used to confirm the reliability of any individual test.

The importance of this work was stated by Whitmore and Ball (2004) as follows:

> 'According to a recent study completed by the US Federal Highway Administration, the annual direct cost of steel corrosion to the US economy is estimated at $276 billion, or 3.1% of the US Gross Domestic Product. If indirect costs such as loss of productivity are included, the annual cost is conservatively estimated at $552 billion, or over 6% of GDP. While these

statistics are specifically related to the overall cost of corrosion, some estimates indicate that up to 30% of this total is related to corrosion in concrete structures.'

It is shown in Chapter 13 that this corrosion is directly controlled by the transport properties.

Computer codes

The computer code that was used for the models in this book is written in the Basic computer language. This language has been in use for at least 40 years and has been made far easier to use by being adopted as the macro language in Microsoft Excel. The way in which the fundamental equations are expressed as code is explained in Chapter 2. Due to the improvements in processing speed of common computers, very little attempt is made to optimise the code, but they all still run in a few minutes.

These simple programmes are quick to develop and very versatile. In recent work, the author has also used them to model heat evolution in concrete. The reader is referred to Walkenbach (2010) for a guide on how to write programmes in Excel. The full spreadsheets, including the code in the macros for the two main programmes, are free to download from the author's website (http:www.claisse.info/Landfill.htm and http:www.claisse.info/Coulomb.htm) for use as examples of the type of code used.

The derivation of equation (6.2) in Chapter 6 was an excellent example of using analytical methods in combination with numerical modelling. The author used numerical computer modelling while Dr Harris (lead author of the paper – see Appendix 1) used analytical methods. Work continued until agreement was reached. This is an approach that the author recommends. In particular, computer code should be checked with analytical solutions even if this can only be done for special cases as described in section 2.3.

Structure of this book

The fundamental equations are presented in Chapter 1. Chapter 2 explains how simple computer programmes can be written to use the equations in models. Chapters 3, 4 and 5 look at the surface tests for transport, showing analytical solutions for the transport equations and discussing how the tests can be improved to obtain values for the permeability. Chapters 6, 7 and 8 discuss gas migration and, in particular, how it is affected by moisture. Chapter 9 presents data showing factors affecting the measurement of water permeability at high pressure. Chapters 10, 11 and 12 are about electrical tests. It is shown that the commonly used solution to Fick's law is highly inaccurate in these tests even if there is no applied voltage. Finally, Chapters 13, 14 and 15 discuss applications of which the most common is durability of reinforced concrete in Chapter 13.

Experimental data

The experimental data and analytical derivations presented in this book have been taken from a number of journal papers published by the author. These papers are listed in Appendix 1 and full copies are available on the author's website (http:www.claisse.info/Publish.htm).

Summary of contents

This book explains:

- What the transport properties are and how they move ions and fluids through concrete.
- How to write computer models for the transport processes.
- How to choose a method to measure surface absorption of concrete – and how much of the sample it actually tests.
- How to prepare the concrete surface for testing – particularly if it is wet.
- How water vapour moves during the drying of concrete.
- How porosity affects the transport processes.
- What happens in the concrete if you apply a voltage for rapid testing of chloride migration.
- Why chloride migration generates a voltage in a test even if you don't apply one – and why this affects the results.
- How transport properties control the durability of structures.
- How to use transport properties to model waste containment structures.
- How to prepare cracked samples for permeability testing that don't fall apart (see photograph on front cover).

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