



David Muir Wood

CIVIL ENGINEERING

A Very Short Introduction

OXFORD

David Muir Wood

常州大学图书馆藏
CIVIL
ENGINEERING

A Very Short Introduction

OXFORD
UNIVERSITY PRESS

OXFORD

UNIVERSITY PRESS

Great Clarendon Street, Oxford, OX2 6DP,
United Kingdom

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship,
and education by publishing worldwide. Oxford is a registered trade mark of
Oxford University Press in the UK and in certain other countries

© David Muir Wood 2012

The moral rights of the author have been asserted

First Edition published in 2012

Impression: 2

All rights reserved. No part of this publication may be reproduced, stored in
a retrieval system, or transmitted, in any form or by any means, without the
prior permission in writing of Oxford University Press, or as expressly permitted
by law, by licence or under terms agreed with the appropriate reprographics
rights organization. Enquiries concerning reproduction outside the scope of the
above should be sent to the Rights Department, Oxford University Press, at the
address above

You must not circulate this work in any other form
and you must impose this same condition on any acquirer

British Library Cataloguing in Publication Data

Data available

Library of Congress Cataloging in Publication Data

Data available

ISBN 978-0-19-957863-4

Printed in Great Britain by
Ashford Colour Press Ltd, Gosport, Hampshire

Civil Engineering: A Very Short Introduction

VERY SHORT INTRODUCTIONS are for anyone wanting a stimulating and accessible way in to a new subject. They are written by experts and have been translated into more than 40 different languages. The series began in 1995 and now covers a wide variety of topics in every discipline. The VSI library contains nearly 400 volumes—a Very Short Introduction to everything from Indian philosophy to psychology and American history—and continues to grow in every subject area.

Very Short Introductions available now:

- | | |
|---|---|
| ACCOUNTING Christopher Nobes | ARCHITECTURE Andrew Ballantyne |
| ADVERTISING Winston Fletcher | ARISTOCRACY William Doyle |
| AFRICAN HISTORY John Parker and
Richard Rathbone | ARISTOTLE Jonathan Barnes |
| AGNOSTICISM Robin Le Poidevin | ART HISTORY Dana Arnold |
| ALEXANDER THE GREAT
Hugh Bowden | ART THEORY Cynthia Freeland |
| AMERICAN HISTORY Paul S. Boyer | ASTROBIOLOGY David C. Catling |
| AMERICAN IMMIGRATION
David A. Gerber | ATHEISM Julian Baggini |
| AMERICAN POLITICAL PARTIES
AND ELECTIONS L. Sandy Maisel | AUGUSTINE Henry Chadwick |
| AMERICAN POLITICS Richard M. Vellely | AUSTRALIA Kenneth Morgan |
| THE AMERICAN PRESIDENCY
Charles O. Jones | AUTISM Uta Frith |
| ANAESTHESIA Aidan O'Donnell | THE AVANT GARDE David Cottington |
| ANARCHISM Colin Ward | THE AZTECS David Carrasco |
| ANCIENT EGYPT Ian Shaw | BACTERIA Sebastian G. B. Amyes |
| ANCIENT GREECE Paul Cartledge | BARTHES Jonathan Culler |
| THE ANCIENT NEAR EAST
Amanda H. Podany | THE BEATS David Sterritt |
| ANCIENT PHILOSOPHY Julia Annas | BEAUTY Roger Scruton |
| ANCIENT WARFARE Harry Sidebottom | BESTSELLERS John Sutherland |
| ANGELS David Albert Jones | THE BIBLE John Riches |
| ANGLICANISM Mark Chapman | BIBLICAL ARCHAEOLOGY Eric H. Cline |
| THE ANGLO-SAXON AGE John Blair | BIOGRAPHY Hermione Lee |
| THE ANIMAL KINGDOM Peter Holland | THE BLUES Elijah Wald |
| ANIMAL RIGHTS David DeGrazia | THE BOOK OF MORMON Terryl Givens |
| THE ANTARCTIC Klaus Dodds | BORDERS Alexander C. Diener and
Joshua Hagen |
| ANTISEMITISM Steven Beller | THE BRAIN Michael O'Shea |
| ANXIETY Daniel Freeman and
Jason Freeman | THE BRITISH CONSTITUTION
Martin Loughlin |
| THE APOCRYPHAL GOSPELS
Paul Foster | THE BRITISH EMPIRE Ashley Jackson |
| ARCHAEOLOGY Paul Bahn | BRITISH POLITICS Anthony Wright |
| | BUDDHA Michael Carrithers |
| | BUDDHISM Damien Keown |
| | BUDDHIST ETHICS Damien Keown |
| | CANCER Nicholas James |
| | CAPITALISM James Fulcher |
| | CATHOLICISM Gerald O'Collins |

- CAUSATION Stephen Mumford and Rani Lill Anjum
- THE CELL Terence Allen and Graham Cowling
- THE CELTS Barry Cunliffe
- CHAOS Leonard Smith
- CHILDREN'S LITERATURE Kimberley Reynolds
- CHINESE LITERATURE Sabina Knight
- CHOICE THEORY Michael Allingham
- CHRISTIAN ART Beth Williamson
- CHRISTIAN ETHICS D. Stephen Long
- CHRISTIANITY Linda Woodhead
- CITIZENSHIP Richard Bellamy
- CIVIL ENGINEERING David Muir Wood
- CLASSICAL LITERATURE William Allan
- CLASSICAL MYTHOLOGY Helen Morales
- CLASSICS Mary Beard and John Henderson
- CLAUSEWITZ Michael Howard
- CLIMATE Mark Maslin
- THE COLD WAR Robert McMahon
- COLONIAL AMERICA Alan Taylor
- COLONIAL LATIN AMERICAN LITERATURE Rolena Adorno
- COMEDY Matthew Bevis
- COMMUNISM Leslie Holmes
- COMPLEXITY John H. Holland
- THE COMPUTER Darrel Ince
- THE CONQUISTADORS Matthew Restall and Felipe Fernández-Armesto
- CONSCIENCE Paul Strohm
- CONSCIOUSNESS Susan Blackmore
- CONTEMPORARY ART Julian Stallabrass
- CONTEMPORARY FICTION Robert Eaglestone
- CONTINENTAL PHILOSOPHY Simon Critchley
- CORAL REEFS Charles Sheppard
- COSMOLOGY Peter Coles
- CRITICAL THEORY Stephen Eric Bronner
- THE CRUSADES Christopher Tyerman
- CRYPTOGRAPHY Fred Piper and Sean Murphy
- THE CULTURAL REVOLUTION Richard Curt Kraus
- DADA AND SURREALISM David Hopkins
- DARWIN Jonathan Howard
- THE DEAD SEA SCROLLS Timothy Lim
- DEMOCRACY Bernard Crick
- DERRIDA Simon Glendinning
- DESCARTES Tom Sorell
- DESERTS Nick Middleton
- DESIGN John Heskett
- DEVELOPMENTAL BIOLOGY Lewis Wolpert
- THE DEVIL Darren Oldridge
- DIASPORA Kevin Kenny
- DICTIONARIES Lynda Mugglestone
- DINOSAURS David Norman
- DIPLOMACY Joseph M. Siracusa
- DOCUMENTARY FILM Patricia Aufderheide
- DREAMING J. Allan Hobson
- DRUGS Leslie Iversen
- DRUIDS Barry Cunliffe
- EARLY MUSIC Thomas Forrest Kelly
- THE EARTH Martin Redfern
- ECONOMICS Partha Dasgupta
- EDUCATION Gary Thomas
- EGYPTIAN MYTH Geraldine Pinch
- EIGHTEENTH-CENTURY BRITAIN Paul Langford
- THE ELEMENTS Philip Ball
- EMOTION Dylan Evans
- EMPIRE Stephen Howe
- ENGELS Terrell Carver
- ENGINEERING David Blockley
- ENGLISH LITERATURE Jonathan Bate
- ENVIRONMENTAL ECONOMICS Stephen Smith
- EPIDEMIOLOGY Rodolfo Saracci
- ETHICS Simon Blackburn
- THE EUROPEAN UNION John Pinder and Simon Usherwood
- EVOLUTION Brian and Deborah Charlesworth
- EXISTENTIALISM Thomas Flynn
- THE EYE Michael Land
- FAMILY LAW Jonathan Herring
- FASCISM Kevin Passmore
- FASHION Rebecca Arnold
- FEMINISM Margaret Walters
- FILM Michael Wood
- FILM MUSIC Kathryn Kalinak
- THE FIRST WORLD WAR Michael Howard
- FOLK MUSIC Mark Slobin
- FOOD John Krebs
- FORENSIC PSYCHOLOGY David Canter
- FORENSIC SCIENCE Jim Fraser
- FOSSILS Keith Thomson

FOUCAULT Gary Gutting
 FRACTALS Kenneth Falconer
 FREE SPEECH Nigel Warburton
 FREE WILL Thomas Pink
 FRENCH LITERATURE John D. Lyons
 THE FRENCH REVOLUTION
 William Doyle
 FREUD Anthony Storr
 FUNDAMENTALISM Malise Ruthven
 GALAXIES John Gribbin
 GALILEO Stillman Drake
 GAME THEORY Ken Binmore
 GANDHI Bhikhu Parekh
 GENIUS Andrew Robinson
 GEOGRAPHY John Matthews and
 David Herbert
 GEOPOLITICS Klaus Dodds
 GERMAN LITERATURE Nicholas Boyle
 GERMAN PHILOSOPHY
 Andrew Bowie
 GLOBAL CATASTROPHES Bill McGuire
 GLOBAL ECONOMIC HISTORY
 Robert C. Allen
 GLOBAL WARMING Mark Maslin
 GLOBALIZATION Manfred Steger
 THE GOTHIC Nick Groom
 GOVERNANCE Mark Bevir
 THE GREAT DEPRESSION AND THE
 NEW DEAL Eric Rauchway
 HABERMAS James Gordon Finlayson
 HAPPINESS Daniel M. Haybron
 HEGEL Peter Singer
 HEIDEGGER Michael Inwood
 HERODOTUS Jennifer T. Roberts
 HIEROGLYPHS Penelope Wilson
 HINDUISM Kim Knott
 HISTORY John H. Arnold
 THE HISTORY OF ASTRONOMY
 Michael Hoskin
 THE HISTORY OF LIFE
 Michael Benton
 THE HISTORY OF
 MATHEMATICS Jacqueline Stedall
 THE HISTORY OF MEDICINE
 William Bynum
 THE HISTORY OF TIME
 Leofranc Holford-Strevens
 HIV/AIDS Alan Whiteside
 HOBBS Richard Tuck
 HORMONES Martin Luck
 HUMAN EVOLUTION Bernard Wood
 HUMAN RIGHTS Andrew Clapham
 HUMANISM Stephen Law
 HUME A. J. Ayer
 HUMOUR Noël Carroll
 THE ICE AGE Jamie Woodward
 IDEOLOGY Michael Freeden
 INDIAN PHILOSOPHY Sue Hamilton
 INFORMATION Luciano Floridi
 INNOVATION Mark Dodgson and
 David Gann
 INTELLIGENCE Ian J. Deary
 INTERNATIONAL
 MIGRATION Khalid Koser
 INTERNATIONAL RELATIONS
 Paul Wilkinson
 INTERNATIONAL
 SECURITY Christopher S. Browning
 ISLAM Malise Ruthven
 ISLAMIC HISTORY Adam Silverstein
 ITALIAN LITERATURE Peter
 Hainsworth and David Robey
 JESUS Richard Bauckham
 JOURNALISM Ian Hargreaves
 JUDAISM Norman Solomon
 JUNG Anthony Stevens
 KABBALAH Joseph Dan
 KAFKA Ritchie Robertson
 KANT Roger Scruton
 KEYNES Robert Skidelsky
 KIERKEGAARD Patrick Gardiner
 THE KORAN Michael Cook
 LANDSCAPE ARCHITECTURE
 Ian H. Thompson
 LANDSCAPES AND
 GEOMORPHOLOGY
 Andrew Goudie and Heather Viles
 LANGUAGES Stephen R. Anderson
 LATE ANTIQUITY Gillian Clark
 LAW Raymond Wacks
 THE LAWS OF THERMODYNAMICS
 Peter Atkins
 LEADERSHIP Keith Grint
 LINCOLN Allen C. Guelzo
 LINGUISTICS Peter Matthews
 LITERARY THEORY Jonathan Culler
 LOCKE John Dunn
 LOGIC Graham Priest
 MACHIAVELLI Quentin Skinner
 MADNESS Andrew Scull
 MAGIC Owen Davies
 MAGNA CARTA Nicholas Vincent

MAGNETISM Stephen Blundell
 MALTHUS Donald Winch
 MANAGEMENT John Hendry
 MAO Delia Davin
 MARINE BIOLOGY Philip V. Mladenov
 THE MARQUIS DE SADE John Phillips
 MARTIN LUTHER Scott H. Hendrix
 MARTYRDOM Jolyon Mitchell
 MARX Peter Singer
 MATHEMATICS Timothy Gowers
 THE MEANING OF LIFE Terry Eagleton
 MEDICAL ETHICS Tony Hope
 MEDICAL LAW Charles Foster
 MEDIEVAL BRITAIN John
 Gillingham and Ralph A. Griffiths
 MEMORY Jonathan K. Foster
 METAPHYSICS Stephen Mumford
 MICHAEL FARADAY Frank A.J.L. James
 MICROECONOMICS Avinash Dixit
 MODERN ART David Cottington
 MODERN CHINA Rana Mitter
 MODERN FRANCE Vanessa R. Schwartz
 MODERN IRELAND Senia Pašeta
 MODERN JAPAN Christopher Goto-Jones
 MODERN LATIN AMERICAN
 LITERATURE
 Roberto González Echevarría
 MODERN WAR Richard English
 MODERNISM Christopher Butler
 MOLECULES Philip Ball
 THE MONGOLS Morris Rossabi
 MORMONISM Richard Lyman Bushman
 MUHAMMAD Jonathan A.C. Brown
 MULTICULTURALISM Ali Rattansi
 MUSIC Nicholas Cook
 MYTH Robert A. Segal
 THE NAPOLEONIC WARS
 Mike Rapport
 NATIONALISM Steven Grosby
 NELSON MANDELA Elleke Boehmer
 NEOLIBERALISM Manfred Steger and
 Ravi Roy
 NETWORKS Guido Caldarelli
 and Michele Catanzaro
 THE NEW TESTAMENT
 Luke Timothy Johnson
 THE NEW TESTAMENT AS
 LITERATURE Kyle Keefer
 NEWTON Robert Iliffe
 NIETZSCHE Michael Tanner

NINETEENTH-CENTURY
 BRITAIN Christopher Harvie and
 H. C. G. Matthew
 THE NORMAN CONQUEST
 George Garnett
 NORTH AMERICAN
 INDIANS Theda Perdue
 and Michael D. Green
 NORTHERN IRELAND
 Marc Mulholland
 NOTHING Frank Close
 NUCLEAR POWER Maxwell Irvine
 NUCLEAR WEAPONS
 Joseph M. Siracusa
 NUMBERS Peter M. Higgins
 NUTRITION David A. Bender
 OBJECTIVITY Stephen Gaukroger
 THE OLD TESTAMENT
 Michael D. Coogan
 THE ORCHESTRA D. Kern Holoman
 ORGANIZATIONS Mary Jo Hatch
 PAGANISM Owen Davies
 THE PALESTINIAN-ISRAELI CONFLICT
 Martin Bunton
 PARTICLE PHYSICS Frank Close
 PAUL E. P. Sanders
 PENTECOSTALISM William K. Kay
 THE PERIODIC TABLE Eric R. Scerri
 PHILOSOPHY Edward Craig
 PHILOSOPHY OF LAW Raymond Wacks
 PHILOSOPHY OF SCIENCE
 Samir Okasha
 PHOTOGRAPHY Steve Edwards
 PLAGUE Paul Slack
 PLANETS David A. Rothery
 PLANTS Timothy Walker
 PLATO Julia Annas
 POLITICAL PHILOSOPHY David Miller
 POLITICS Kenneth Minogue
 POSTCOLONIALISM Robert Young
 POSTMODERNISM Christopher Butler
 POSTSTRUCTURALISM
 Catherine Belsey
 PREHISTORY Chris Gosden
 PRESOCRATIC PHILOSOPHY
 Catherine Osborne
 PRIVACY Raymond Wacks
 PROBABILITY John Haigh
 PROGRESSIVISM Walter Nugent
 PROTESTANTISM Mark A. Noll

PSYCHIATRY Tom Burns
PSYCHOLOGY Gillian Butler
and Freda McManus
PURITANISM Francis J. Bremer
THE QUAKERS Pink Dandelion
QUANTUM THEORY John Polkinghorne
RACISM Ali Rattansi
RADIOACTIVITY Claudio Tuniz
RASTAFARI Ennis B. Edmonds
THE REAGAN REVOLUTION Gil Troy
REALITY Jan Westerhoff
THE REFORMATION Peter Marshall
RELATIVITY Russell Stannard
RELIGION IN AMERICA Timothy Beal
THE RENAISSANCE Jerry Brotton
RENAISSANCE ART
Geraldine A. Johnson
REVOLUTIONS Jack A. Goldstone
RHETORIC Richard Toye
RISK Baruch Fischhoff and John Kadvany
RIVERS Nick Middleton
ROBOTICS Alan Winfield
ROMAN BRITAIN Peter Salway
THE ROMAN EMPIRE Christopher Kelly
THE ROMAN REPUBLIC
David M. Gwynn
ROMANTICISM Michael Ferber
ROUSSEAU Robert Wokler
RUSSELL A. C. Grayling
RUSSIAN HISTORY Geoffrey Hosking
RUSSIAN LITERATURE Catriona Kelly
THE RUSSIAN REVOLUTION
S. A. Smith
SCHIZOPHRENIA Chris Frith and
Eve Johnstone
SCHOPENHAUER
Christopher Janaway
SCIENCE AND RELIGION
Thomas Dixon
SCIENCE FICTION David Seed
THE SCIENTIFIC REVOLUTION
Lawrence M. Principe
SCOTLAND Rab Houston
SEXUALITY Véronique Mottier
SHAKESPEARE Germaine Greer
SIKHISM Eleanor Nesbitt
THE SILK ROAD James A. Millward
SLEEP Steven W. Lockley and
Russell G. Foster

SOCIAL AND CULTURAL
ANTHROPOLOGY
John Monaghan and Peter Just
SOCIALISM Michael Newman
SOCIOLINGUISTICS John Edwards
SOCIOLOGY Steve Bruce
SOCRATES C. C. W. Taylor
THE SOVIET UNION Stephen Lovell
THE SPANISH CIVIL WAR
Helen Graham
SPANISH LITERATURE Jo Labanyi
SPINOZA Roger Scruton
SPIRITUALITY Philip Sheldrake
STARS Andrew King
STATISTICS David J. Hand
STEM CELLS Jonathan Slack
STUART BRITAIN John Morrill
SUPERCONDUCTIVITY Stephen Blundell
SYMMETRY Ian Stewart
TEETH Peter S. Ungar
TERRORISM Charles Townshend
THEOLOGY David F. Ford
THOMAS AQUINAS Fergus Kerr
THOUGHT Tim Bayne
TIBETAN BUDDHISM
Matthew T. Kapstein
TOCQUEVILLE Harvey C. Mansfield
TRAGEDY Adrian Poole
THE TROJAN WAR Eric H. Cline
TRUST Katherine Hawley
THE TUDORS John Guy
TWENTIETH-CENTURY
BRITAIN Kenneth O. Morgan
THE UNITED NATIONS
Jussi M. Hanhimäki
THE U.S. CONGRESS Donald A. Ritchie
THE U.S. SUPREME COURT
Linda Greenhouse
UTOPIANISM Lyman Tower Sargent
THE VIKINGS Julian Richards
VIRUSES Dorothy H. Crawford
WITCHCRAFT Malcolm Gaskill
WITTGENSTEIN A. C. Grayling
WORK Stephen Fineman
WORLD MUSIC Philip Bohlman
THE WORLD TRADE
ORGANIZATION Amrita Narlikar
WRITING AND SCRIPT
Andrew Robinson

Acknowledgements

Early versions of the text of this book have been read by Margaret Abel, Hugh Balchin, Carol Collins, Julia Elton, Ted and Virginia Khan, Adrian Mathias, Helen Muir Wood, James Sutherland, and Sue Vardy. I am immensely grateful to all of them, but especially to Julia and James, for the thoughtful and detailed comments that they provided. Whether they will feel that I have adequately reacted to their suggestions I cannot tell – the responsibility for the final text rests with me.

I am also very grateful to Andrew Muir Wood for providing excellent drawings for Figures 10, 18, 24 and 27.

David Muir Wood
Monikie
April 2012

Contents

List of illustrations xiii

Introduction 1

- 1 Materials of civil engineering 13
 - 2 Water and waste 50
 - 3 ‘Directing the great sources of power in nature’ 62
 - 4 Concept – technology – realization 80
 - 5 Robustness 101
 - 6 Civil engineering: looking forward 119
- Sources 131
- Further reading 133
- Index 137

List of illustrations

- | | |
|--|--|
| 1 Tower of Pisa 15 | 13 Structural action of Forth railway bridge 33 |
| 2 Todaiji temple, Nara 19 | 14 Sydney harbour bridge 35 |
| 3 Corbelling 21 | 15 Footbridge, Shirakawa 40 |
| 4 Striding arches, Moniaive 22 | 16 Nuclear power station, Torness 42 |
| 5 Blackfriars bridge 23 | 17 Footbridge, Aberfeldy 44 |
| 6 Arch bridge near Constantine 24 | 18 Airbus A380 45
Kindly provided by Andrew Muir Wood |
| 7 Chartres cathedral 25 | 19 Clywedog Dam 64 |
| 8 Prague cathedral 27 | 20 Taipei 101 72 |
| 9 Angkor Thom 28 | 21 Golden Gate bridge 75 |
| 10 Steel construction, NYC 30
Kindly provided by Andrew Muir Wood | 22 Elements of civil engineering design process 81 |
| 11 Buckling 32 | 23 Sydney Opera House 83 |
| 12 Forth railway bridge 33 | |

24 Bell Rock lighthouse **90**
Kindly provided by Andrew Muir Wood

25 *Shinkansen* **97**

26 Millennium footbridge,
London **99**

27 Ronan Point **103**
Kindly provided by Andrew Muir Wood

28 Taipei metro **106**

29 Heathrow Airport
Terminal 5 **124**

Introduction

In 1828, the Royal Charter of the Institution of Civil Engineers, drafted by Thomas Tredgold, defined the purpose of the Institution:

The general advancement of mechanical science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a civil engineer; being the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and light-houses, and in the art of navigation by artificial power, for the purposes of commerce; and in the construction and adaptation of machinery, and in the drainage of cities and towns.

Setting off on a camping trip in the hills the associated needs are evident. You need shelter from the elements and from potential predators. You need a supply of fresh water, food, and energy for cooking, heating, and light. There is some advantage in thinking ahead about 'waste disposal' and possibly the need for medical supplies. Wandering the wilderness has its attraction but more

frequently there will be some form of pathway in existence for you to follow. The pioneering people reaching the Americas or other unfamiliar lands had the same requirements. Interdependence encouraged the formation of settlements which became villages and then towns and cities. The benefits of scale and collaboration in provision of this infrastructure were obvious—common means of protection against predators (human or animal), common sources of clean water (no need for each household to have its own well), common strategies for disposal of waste (one man's waste disposal can become another man's pollution), common sources of energy, common networks of transport. The advantages of sharing skills and resources would have rapidly become apparent.

All these elements of infrastructure come under Tredgold's definition of 'civil engineering'.

The emergence of civil engineering

The term *civil engineering* has been used, and its meaning has evolved for rather more than 200 years. Chambers Dictionary defines an engineer as 'one who designs or makes, or puts to practical use, engines or machinery of any type, including electrical; one who designs or constructs public works, such as roads, railways, sewers, bridges, harbours, canals, etc; one who constructs or manages military fortifications, etc., or engines'. A civil engineer is 'one who plans and builds railways, docks, etc. as opposed to a military engineer, or to a mechanical engineer, who makes machines etc.'

'Engineer' comes from the Latin *ingenium* meaning skill, linked with the design and construction of clever devices (*engines*)—such as catapults—for inflicting damage in military campaigns. The term *civil engineering*, introduced to distinguish those working with non-military engines, seems to be almost an oxymoron. But the term now relates to that branch of engineering

which is concerned with the creation of the infrastructure of society: the *civil* implying this link with the citizen and with civilization. The techniques used for these *civil* projects have general application: civil engineers may well be working with the military on provision of buildings, roads, bridges, airfields—specifically *un-civil* engineering under the original meaning of the term.

Of course, even before the term *civil engineering* was coined, civil engineers were in existence even if they were then described using other terms. The person (or persons) unknown who organized the construction of the Great Pyramids, some 5000 years ago, must be called an engineer. He (probably a man) certainly had acquired, by observation and experience, the skills necessary to translate a concept into reality using effective technology. The Greeks (Anthemius of Thrales and Isidorus of Miletus) put in charge of the design of the church of Hagia Sophia (in Constantinople – Byzantium or Istanbul) by the Roman Emperor Justinian in around AD 600 were, like Christopher Wren 1000 years later, expected both to solve the day-to-day problems of detailed construction and also to plan the overall shape and form: they were civil engineers. The Greek word μηχανή (mechani) means ‘a machine, or a clever trick’. Odysseus had the attribute πολυμήχανος (polimechanos): ‘one who knew many tricks and could cope with difficult situations’. This would be a good description of an engineer, but today a mechanic would be expected to have a narrower range of skills than an engineer. Anthemius and Isidoros would have been described as ἀρχιτέκτονες (architektones): *master builders*. The potential for confusion of engineering and architecture is apparent. The inventiveness of cathedral builders such as Brunelleschi in devising special cranes for safely raising construction supplies would have qualified them for the description of *engineer* too. Words like *mechanic*, *engineer*, *architect* now resonate in a way which does not begin to think about their origins two or three millennia ago.

Much mediaeval engineering was based on geometric rules based on prior experience of successful structures. Scientific understanding developed slowly as people such as Galileo sought explanations for phenomena and began to apply mathematical concepts to the analysis of structural elements. The Industrial Revolution which began in Britain in the early 18th century produced both a large number of ingenious steam-powered machines, which replaced man-power in the new factories, and also a new building material—cast iron—which had a strength greater than the timber that it replaced in many bridges and large buildings. With care in the manufacturing process, there was a predictability and narrow variation of the mechanical properties which made its use more straightforward.

The cathedral builders (or engineers) organized themselves into a closed community, keeping the secrets of their experience within the community. The notion of engineering as a profession is a development from this but it occurred in different ways in different countries. The French, with an emphasis on Cartesian analysis and mathematical representation, made rapid progress in what we now see as the various branches of engineering mechanics, with state encouragement. The British, with an emphasis on observation and practice, and less desire for central control, developed a more autonomous profession. The national routes to the *formation* of engineers differ widely in the balances of practice and theory or of training and education.

In late 17th century France, the military engineer was given formal status by the creation of a *Corps des Ingénieurs du Génie Militaire* in 1690 by Maréchal Vauban. Vauban was famous for the design of fortifications, which usually consisted of masonry structures retaining compacted earth (within the remit of civil engineering today). In 1716, this was followed by the creation of the *Corps des Ingénieurs des Ponts et Chaussées* who were charged with the construction and maintenance of networks of communication (roads and bridges). The training of these latter