GEOLOGY AND ENGINEERING

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Geology and Engineering: their intimate association is shown here at the left abutment and emergency spillway of Williams Fork Dam, Grande County Colorado.

The insert shows the engineering geologic map of the migmatite coast rock, requiring engineering evaluation of its ability to anchor the dam and to pass the PMF overflow. Courtesy Denver Water Department.

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ABOUT THE AUTHORS

ROBERT F. LEGGET has over 50 years' experience in fieldwork, teaching, and research in civil engineering. After graduating from the University of Liverpool, he worked as a civil engineer in Scotland and Canada and taught at Queen's University (Kingston) and the University of Toronto. In 1947 he established the Division of Building Research for the National Research Council of Canada, serving as its director until his retirement in 1969. Mr. Legget is a former president of The Geological Society of America.

ALLEN W. HATHEWAY is a seventh generation Californian trained in geology (University of California at Los Angeles) and in geological and civil engineering (University of Arizona). Prior to joining the University of Missouri-Rolla faculty, he was with west coast and east coast geotechnical firms and taught (adjunct) at the University of Southern California and Boston University. He is past chairman of the Engineering Geology Division of The Geological Society of America and past president of the Association of Engineering Geologists. He is registered as a geologist, an engineering geologist, and as a civil and geological engineer.

PREFACE

This volume is intended to provide engineering students with an introduction to the practice of civil engineering and, concurrently, to the geologic input that is essential for all civil engineering work. *Every* site utilized for civil engineering structures or works is unique; there will be differences between even adjoining sites, due to the underlying geologic structure and stratigraphy. Accordingly, planning and design of every civil engineering project must start with a study of site and local geology.

Throughout the book, a main and continuing theme is the vital importance of *observation,* during site investigations, throughout the entire construction process, and in maintenance and regular inspection of completed facilities. *Observation* is far more than just seeing. "You see" said Sherlock Holmes to his friend Dr. Watson, "but you do not observe." Many of the Holmes adventures, by Conan Doyle, could well serve as supplementary reading to this book.

In consequence, treatment of the subject is entirely descriptive. Mathematics is an essential tool in the design process, a procedure in civil engineering that is entirely dependent upon assumptions made as to ground conditions at the design site. This book deals with the accuracy, or otherwise, of those assumptions upon which the success and safety of all structures depend. Computers now occupy a unique place in data management and structural design, but all that they make possible so effectively is ultimately dependent upon the *actual* geological conditions at the site. It is with these site conditions that this book is concerned.

The volume is at once a third edition of the first author's book of the same name (first edition 1939, second in 1962) and a major abridgement of the *Handbook of Geology in Civil Engineering* (by Robert F. Legget and Paul F. Karrow, McGraw-Hill, 1983) made with the agreement of the Publishers and Dr. Karrow. Treatment of the subject is therefore by means of carefully selected and usefully illustrative case histories. Essential references to more detailed accounts of the more important histories discussed are given at the end of each chapter. For convenience in use, these reference lists have been kept very short and, in general, include only periodicals (such as *Engineering News-Record*), which are available in all University engineering libraries. Since all the case histories (and many more) are to be found in the *Handbook* noted,

readers are directed to the much more detailed reference lists which it contains for those not given herein.

Metric units are used throughout the book (but always with Imperial units in parenthesis), in keeping with international practice. The authors, with great respect, must dissociate themselves from the spelling of *metre* as *meter* since the International Organisation for Standardisation (I.S.O.) has agreed that *metre* is the accepted spelling, and this is now in universal use except in the United States of America. Answers and questions for all chapters are contained in an accompanying booklet.

The authors are indebted to I. Noffke and M. Jacques for the expert typing of the final version of the text, and to all who so kindly assisted with the provision of illustrations for the *Handbook,* a selection from which now provides the illustrations in this text.

The authors venture to hope that as a by-product of the use of this book, some readers may come to appreciate that geology is indeed "the People's Science" (as was said over a century ago), a reminder that it can be studied by all and that even an elementary knowledge of the science can aid greatly in the appreciation of all scenery and especially of the beauties of the earth.

The proper use of geology as the starting point of all civil engineering achievement will become ever more important with the passing years and the gradual utilization of more favorable sites. Despite all the pressures that will come to bear on them through advancing technology and mounting demands, civil engineers should always remember the words of Francis Bacon, written as the modern world began to emerge:

NATURE, TO BE COMMANDED, MUST BE OBEYED.

Allen W. Hatheway

Robert F. Legget

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CHAPTER 1

THE CIVIL ENGINEER AND GEOLOGY

Every branch of civil engineering deals in some way with the surface of the earth, since the works designed by the civil engineer are supported by or located in some part of the earth's crust. The practice of civil engineering includes the design of these works and the control and direction of their construction. *Geology* is the name given to that wide sphere of scientific inquiry which studies the composition and arrangement of the earth's crust. This book is concerned with the application of the results of this scientific study to the art and practice of the civil engineer.

At the start of the nineteenth century, before engineering had become the highly specialized practice it is today, many civil engineers were also active geologists. William Smith is the outstanding example of these pioneers. Robert Stephenson combined geological study with his early work in railway construction, and other well-known figures in the annals of engineering history were also distinguished in geology.

Today there is widespread recognition of the vital importance of the science of geology to those who practice the art of civil engineering. Geology is commonly included as a basic subject in courses of training for civil engineering (it should be included in *every* civil engineering course); civil engineering papers contain frequent references to the geological features of the sites of works described; and soil mechanics, the generally accepted scientific approach to soil studies, provides a common meeting ground for civil engineer and geologist and a means of fostering their cooperation.

In the past, geological considerations frequently have been featured prominently in the study and discussion of failures of civil engineering works. In fact, to some engineers, geology may still be thought of as merely a scientific aid to the correct determination of the reasons for some of the major troubles that develop during or subsequent to construction operations. Although the assistance rendered by geologists and by the study of geological features in such "postmortem" considerations is valuable, the very fact that geological features may have had something to do with these failures suggests with abundant clarity that the best time to consult a geologist or study geological features is *before* design and construction begin. In this way, the science can serve the art in a constructive rather than merely a pathological manner. It will later be seen, as applications of geology are considered in some detail, that this constructive service of the science can not only prevent possible future troubles, but it can also suggest new solutions to engineering problems and can often reveal information of utility and economic value, even in preliminary work.

The more obvious effects of geological features on major civil engineering works may be seen in the underground railway services in London and New York. In London, because the city is built on a great basin of unconsolidated material (including the well-known London clay), tube railways, located far below ground level and built in clay that was easily and economically excavated, have provided an admirable solution to one part of the city's transportation problems. In New York, on the other hand, the surface of Manhattan Island on which the city is located is underlain to a considerable extent by Manhattan schist. Underground railways had to be constructed in carefully excavated rock cuts just below surface level, as innocent visitors to that great city learn if they happen to stand on a ventilation grating when a train passes in the subway below. Many similar instances of the profound effect of local geological characteristics upon major civil engineering works could be cited, but all would serve to emphasize the same point: how closely the science and the art are related and how dependent civil engineering work generally must be upon geology.

The science of geology stands in relation to the art of the civil engineer in just the same way as do physics, chemistry, and mathematics. The importance of the latter sciences to the civil engineer is never questioned; they are always considered the necessary and inevitable background to civil engineering training. It would be inconceivable for any engineer worthy of the name to be