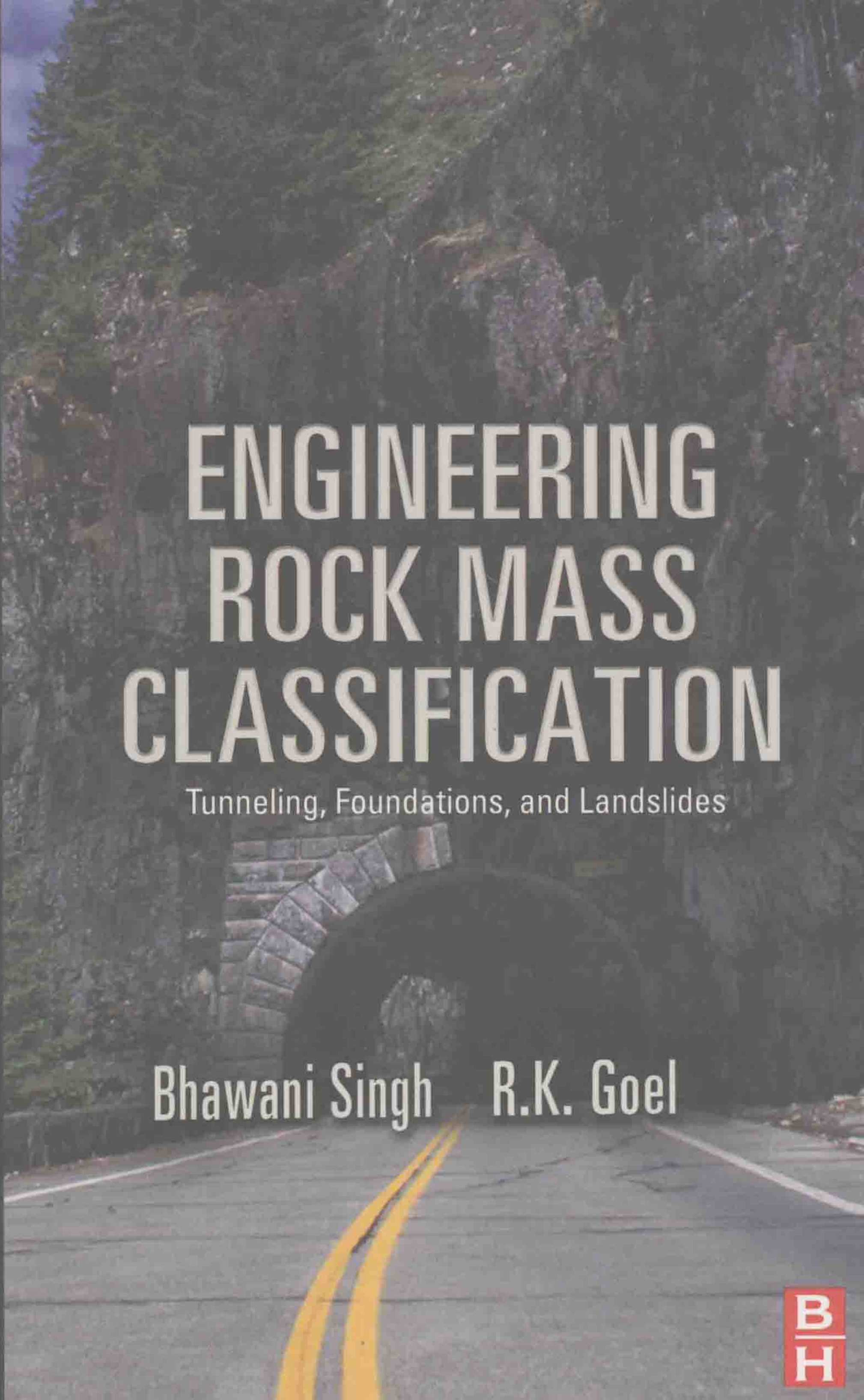

ENGINEERING ROCK MASS CLASSIFICATION

Tunneling, Foundations, and Landslides

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Engineering Rock Mass Classification

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Preface

The urgent need for this book, *Engineering Rock Mass Classification: Tunneling, Foundations, and Landslides*, was our motivation to write it. Many questions went through our minds: Is Classification reasonably reliable? Can it be successful in crisis management of geohazards? Can a single classification system be general enough for rock structures? Is classification a scientific approach? Laborious field research was needed to find answers to these vital questions.

By God's grace, scientists of the Central Institute of Mining and Fuel Research (CIMFR), IIT Roorkee, Central Soil and Material Research Station (CSMRS), Irrigation Research Institute (IRI), and the Norwegian Geotechnical Institute (NGI) came together. These God-gifted ideas and the reliable field data made our task of interpretation less tortuous. Consequently, several improvements in correlations have been possible and practical doubts were erased. At this point, consultancy works were started in the previously mentioned institutions. The success in consultancy further boosted our morale. Finally, the research work for this book was systematically compiled to help a new confident generation. The aim of this book is to generate more creative confidence and interest among civil, mining, and petroleum engineers and geologists. This book is a comprehensive revision of our book, *Rock Mass Classification—A Practical Approach in Civil Engineering*, and includes rock mass characterization, examples, and modern classifications.

Based on research, many classification approaches are scientific. Nevertheless, the scientific spirit of prediction, check, and cross-check should be kept alive; thus, many alternative classification systems have been presented here for particular rock structures. In feasibility designs of major projects, the suggested correlations in this book may be used. For final designs of complex openings, rational approaches are recommended. In the design of minor projects, field correlations may be used. The notation for uniaxial compressive strength of rock material in this book is q_c instead of σ_c. The engineering rock mass classification is an amazingly successful approach because it is simple, reliable, and time-tested for more than three decades.

Today the rational approach is becoming popular in consultancy on major projects. Our goal should be a reliable engineering strategy/solution of geological problems and not rigorous analysis. This should remove the prevailing dissatisfaction from the minds of designers. Thus, computer modeling may be the future trend of research at this time.

It appears that field testing and monitoring may always be the key approach to use in rock engineering projects, because all practical knowledge has been gained from interpretations of field observations.

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The Himalayas provide the best field laboratory to learn rock mechanics and engineering geology because of complex geological problems. Further, the hypnotic charm of the upper Himalayas is very healing especially to concerned engineers and geologists. Natural oxygenation on hill tracking charges our whole nervous system and gives a marvelous feeling of energy and inner healing. So, working in the majestic Himalayas is a twin boon.

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We are also deeply grateful to our beloved families for their sacrifice, love, deep moral support, and suggestions; and to all of our friends and students. We also thank Holy Teacher Dr. B. K. Saxena, former scientist, CBRI, Roorkee, for his kind blessings.

We wish to encourage all enlightened engineers and geologists to kindly send their important suggestions for improving this book to us.

Contents

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Chapter 1

Philosophy of Engineering Classifications

When you can measure what you are speaking about, and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts, advanced to the stage of science.

Lord Kelvin

THE CLASSIFICATION

The science of classification is called "taxonomy"; it deals with the theoretical aspects of classification, including its basis, principles, procedures, and rules. Knowledge tested in projects is called the "practical knowledge." Surprisingly the rating and ranking systems have become popular in every part of life in the twenty-first century.

Rock mass classifications form the backbone of the empirical design approach and are widely employed in rock engineering. Engineering rock mass classifications have recently been quite popular and are used in feasibility designs. When used correctly, a rock mass classification can be a powerful tool in these designs. On many projects the classification approach is the only practical basis for the design of complex underground structures. The Gjovik Underground Ice Hockey Stadium in Norway was designed by the classification approach.

Engineering rock mass classification systems have been widely used with great success in Austria, South Africa, the United States, Europe, and India for the following reasons:

1. They provide better communication between planners, geologists, designers, contractors, and engineers.
2. An engineer's observations, experience, and judgment are correlated and consolidated more effectively by an engineering (quantitative) classification system.
3. Engineers prefer numbers in place of descriptions; hence, an engineering classification system has considerable application in an overall assessment of the rock quality.
4. The classification approach helps in the organization of knowledge and is amazingly successful.
5. An ideal application of engineering rock mass classification occurs in the planning of hydroelectric projects, tunnels, caverns, bridges, silos, building complexes, hill roads, rail tunnels, and so forth.

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The classification system, in the last 60 years of its development, has been cognizant of the new advances in rock support technology starting from steel rib supports to the latest supporting techniques such as rock bolts and steel fiber reinforced shotcrete (SFRS).

PHILOSOPHY OF CLASSIFICATION SYSTEM

In any engineering classification system, the minimum rating is called "poor rock mass" and the maximum rating is called "excellent rock mass." Thus, every parameter of a classification plays a more dominant role as overall rating decreases, and many classifications are accurate in both excellent and poor rock conditions. Reliability may decrease for medium rock conditions. No single classification is valid for assessment of all rock parameters. Selection of a classification for estimating a rock parameter is, therefore, based on experience. The objective should be to classify the undisturbed rock mass beyond excavated faces. *Precaution should be taken to avoid the double-accounting of joint parameters in the classification and in the analysis. Thus, joint orientation and water seepage pressure should not be considered in the classification if these are accounted for in the analysis.*

It is necessary to account for fuzzy variation of rock parameters after allowing for uncertainty; thus, it is better to assign a range of ratings for each parameter. There can be a wide variation in the engineering classifications at a location. When designing a project, the average of rock mass ratings (RMR) and geological strength index (GSI) should be considered in the design of support systems. For rock mass quality (Q), a geometric mean of the minimum and the maximum values should also be considered in the design.

A rigorous classification system may become more reliable if uncertain parameters are dropped and considered indirectly. An easy system's approach (Hudson, 1992) is very interesting and tries to sequence dominant parameters at a site (see Chapter 27). This classification is a holistic (whole) approach, considering all parameters.

Hoek and Brown (1997) realized that a classification system must be non-linear to classify poor rock masses realistically. In other words, the reduction in strength parameters with classification should be non-linear, unlike RMR in which strength parameters decrease linearly with decreasing RMR. (Mehrotra, 1993, found that strength parameters decrease non-linearly with RMR for dry rock masses.) More research is needed on the non-linear correlations for rock parameters and rock mass characterization.

Sound engineering judgment evolves out of long-term, hard work in the field.

NEED FOR ENGINEERING GEOLOGICAL MAP

Nature tends to be heterogeneous, which makes it easy to predict its weakest link. More attention should be focused on the weak zones (joints, shear zones, fault zones, etc.) in the rock mass that may cause wedge failures and/or toppling. Rock failure is localized and three dimensional in heterogeneous rock mass and not planar, as in homogeneous rock mass.

First, a geological map on macro-scale (1:50,000) should be prepared before tunneling or laying foundations. Then an engineering geological map on micro-scale (1:1000) should be prepared soon after excavation. This map should highlight geological details for an excavation and support system. These include Q, RMR, all the shear zones, faults, dip and dip directions of all joint sets (discontinuities), highest ground water table

(GWT), and so forth along tunnel alignment. The engineering geological map helps civil engineers immensely. Such detailed maps prepared based on thorough investigation are important for tunnel excavations. If an engineering geological map is not prepared then the use of a tunnel boring machine (TBM) is not advisable, because the TBM may get stuck in the weak zones, as experienced in Himalayan tunneling. An Iraqi proverb eloquently illustrates this idea:

Ask 100 questions, but do not make a single mistake.

MANAGEMENT OF UNCERTAINTIES

Empirical, numerical, or analytical and observational approaches are various tools for engineering designs. The empirical approach, based on rock mass classifications, is the most popular because of its simplicity and ability to manage uncertainties. Geological and geotechnical uncertainties can be tackled effectively using proper classifications. Moreover, this approach allows designers to make on-the-spot decisions regarding supporting measures if there is a sudden change in the geology. The analytical approach, on the other hand, is based on assumptions and obtaining correct values of input parameters. This approach is both time-consuming and expensive. The observational approach, as the name indicates, is based on monitoring the efficiency of the support system.

Classifications are likely to be invalid in areas where there is damage due to blasting and weathering such as in cold regions, during cloudbursts, and under oceans. If the rock has extraordinary geological occurrence (EGO) problems, then these should be solved under the guidance of national and international experts.

According to Fairhurst (1993), designers should develop design solutions and design strategies so that support systems are ductile and robust, that is, able to perform adequately even in unknown geological conditions. For example, shotcreted and reinforced rock arch is a robust support system. The Norwegian Method of Tunneling (NMT) after 30 years, has evolved into a successful strategy that can be adopted for tunnel supporting in widely different rock conditions.

PRESENT-DAY PRACTICE

Present-day practice is a combination of all of the previously described approaches. This is basically a "design as you go" approach. Experience led to the following strategy of refinement in the design of support systems.

1. In feasibility studies, empirical correlations may be used for estimating rock parameters.
2. At the design stage, in situ tests should be conducted for major projects to determine the actual rock parameters. It is suggested that in situ triaxial tests (with σ_1, σ_2, and σ_3 applied on sides of the cube of rock mass) should be conducted extensively, because σ_2 is found to affect both the strength and deformation modulus of rock masses in tunnels. This is the motivation for research, and its presentation in this book is likely to prove an urgent need for in situ polyaxial tests.
3. At the initial construction stage, instrumentation should be carried out in drifts, caverns, intersections, and other important locations with the objective of acquiring field data on displacements both on the supported excavated surfaces and within the rock mass. Instrumentation is also essential for monitoring construction quality. Experience confirms that instrumentation in a complex geological environment is the key to success

for a safe and steady tunneling rate. These data should be utilized in computer modeling for back analysis of both the model and its parameters (Sakurai, 1993).

4. At the construction stage, forward analysis of rock structures should be carried out using the back analyzed model and the parameters of rock masses. Repeated cycles of back analysis and forward analysis (BAFA) may eliminate many inherent uncertainties in geological mapping and knowledge of engineering behavior of rock masses. Where broken/plastic zones are predicted, the borehole extensometers should reveal a higher rate of displacement in the broken zone than in the elastic zone. The predicted displacements are very sensitive to the assumed model, parameters of rock masses and discontinuities, in situ stresses, and so forth.
5. The principle of dynamic programming should be adopted. Construction strategy will evolve with time in every step to reach the goal quickly; for example, grouting may improve ground conditions significantly. Dynamic programming is essentially a "re-design while you go" evolutionary approach.
6. The aim of computer modeling should be to design site-specific support systems and not just analysis of the strains and stresses in the idealized geological environment. In a non-homogeneous and complex geological environment, which is difficult to predict, slightly conservative rock parameter values may be assumed for the purpose of designing site-specific remedial measures (lines of defenses) and for accounting inherent uncertainties in geological and geotechnical investigations.
7. Be prepared for the worst and hope for the best.

SCOPE OF THE BOOK

This book presents an integrated system of classifications and their applications for tunnels, foundations, and landslides in light of the field research conducted in India and Europe during the last three decades. This revised edition offers an integrated practical knowledge on the rock mass characterization for use in software packages along with extensive tables.

This text is a specialized book on rock mass classifications and is written for civil engineers and geologists who have basic knowledge of these classifications. The analysis and design of rock slopes is beyond the scope of this book (see Singh & Goel, 2002). There are several types of popular software for non-linear analysis, but they need an approximate solution to be useful, which is provided by the engineering rock mass classification.

This book is written to help civil engineers and geologists working on civil engineering jobs such as hydroelectric projects, foundations, tunnels, caverns, and rapid landslide hazard zonation.

Some engineers work under the assumption that a rock mass is homogeneous and isotropic, but this may not always be correct as shear zones are encountered frequently. Because of this, shear zone treatment is discussed in Chapter 2.

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