Rock Mechanics and Engineering

Editor: Xia-Ting Feng

Volume 5: Surface and Underground Projects

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Rock Mechanics and Engineering

Foreword

Although engineering activities involving rock have been underway for millennia, we can mark the beginning of the modern era from the year 1962 when the International Society for Rock Mechanics (ISRM) was formally established in Salzburg, Austria. Since that time, both rock engineering itself and the associated rock mechanics research have increased in activity by leaps and bounds, so much so that it is difficult for an engineer or researcher to be aware of all the emerging developments, especially since the information is widely spread in reports, magazines, journals, books and the internet. It is appropriate, if not essential, therefore that periodically an easily accessible structured survey should be made of the currently available knowledge. Thus, we are most grateful to Professor Xia-Ting Feng and his team, and to the Taylor & Francis Group, for preparing this extensive 2017 "Rock Mechanics and Engineering" compendium outlining the state of the art—and which is a publication fitting well within the Taylor & Francis portfolio of ground engineering related titles.

There has previously only been one similar such survey, "Comprehensive Rock Engineering", which was also published as a five-volume set but by Pergamon Press in 1993. Given the exponential increase in rock engineering related activities and research since that year, we must also congratulate Professor Feng and the publisher on the production of this current five-volume survey. Volumes 1 and 2 are concerned with principles plus laboratory and field testing, *i.e.*, understanding the subject and obtaining the key rock property information. Volume 3 covers analysis, modelling and design, *i.e.*, the procedures by which one can predict the rock behaviour in engineering practice. Then, Volume 4 describes engineering procedures and Volume 5 presents a variety of case examples, both these volumes illustrating 'how things are done'. Hence, the volumes with their constituent chapters run through essentially the complete spectrum of rock mechanics and rock engineering knowledge and associated activities.

In looking through the contents of this compendium, I am particularly pleased that Professor Feng has placed emphasis on the strength of rock, modelling rock failure, field testing and Underground Research Laboratories (URLs), numerical modelling methods—which have revolutionised the approach to rock engineering design—and the progression of excavation, support and monitoring, together with supporting case histories. These subjects, enhanced by the other contributions, are the essence of our subject of rock mechanics and rock engineering. To read through the chapters is not only to understand the subject but also to comprehend the state of current knowledge.

I have worked with Professor Feng on a variety of rock mechanics and rock engineering projects and am delighted to say that his efforts in initiating, developing and seeing through the preparation of this encyclopaedic contribution once again demonstrate his flair for providing significant assistance to the rock mechanics and engineering subject and community. Each of the authors of the contributory chapters is also thanked: they are the virtuosos who have taken time out to write up their expertise within the structured framework of the "Rock Mechanics and Engineering" volumes. There is no doubt that this compendium not only will be of great assistance to all those working in the subject area, whether in research or practice, but it also marks just how far the subject has developed in the 50+ years since 1962 and especially in the 20+ years since the last such survey.

John A. Hudson, Emeritus Professor, Imperial College London, UK
President of the International Society for Rock Mechanics (ISRM) 2007–2011

Introduction

The five-volume book "Comprehensive Rock Engineering" (Editor-in-Chief, Professor John A. Hudson) which was published in 1993 had an important influence on the development of rock mechanics and rock engineering. Indeed the significant and extensive achievements in rock mechanics and engineering during the last 20 years now justify a second compilation. Thus, we are happy to publish 'ROCK MECHANICS AND ENGINEERING', a highly prestigious, multi-volume work, with the editorial advice of Professor John A. Hudson. This new compilation offers an extremely wide-ranging and comprehensive overview of the state-of-the-art in rock mechanics and rock engineering. Intended for an audience of geological, civil, mining and structural engineers, it is composed of reviewed, dedicated contributions by key authors worldwide. The aim has been to make this a leading publication in the field, one which will deserve a place in the library of every engineer involved with rock mechanics and engineering.

We have sought the best contributions from experts in the field to make these five volumes a success, and I really appreciate their hard work and contributions to this project. Also I am extremely grateful to staff at CRC Press / Balkema, Taylor and Francis Group, in particular Mr. Alistair Bright, for his excellent work and kind help. I would like to thank Prof. John A. Hudson for his great help in initiating this publication. I would also thank Dr. Yan Guo for her tireless work on this project.

Editor
Xia-Ting Feng
President of the International Society for Rock Mechanics (ISRM) 2011–2015
July 4, 2016

Contents

Slopes

Chapter 1

Discontinuity controlled slope failure zoning for a granitoid complex: A fuzzy approach

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Abstract: Kinematic analysis is one of the most used methods to evaluate potential failures such as planar, wedge and toppling in rock slopes. To analyze possible failure types, orientations of slope and discontinuity geometry with the friction angle of the discontinuities planes are used. In this study, kinematical analyses were evaluated to obtain discontinuity controlled potential failure types in the Gumushane Granitoid Complex which is exposed in Gumushane City and the surroundings. Unstable slope orientations for planar, wedge and toppling failure types were determined. The unstable orientations obtained from kinematic analyses were used to create Geographic Information System (GIS) based instability risk maps. The maps generated by the GIS were evaluated using the Fuzzy Interference System (FIS) method to produce instability risk maps for the study area.

1 INTRODUCTION

Stability analyses in rock slopes are carried out routinely in many engineering studies such as mining, construction and geotechnical projects. The main objectives of these stability analyses can be listed as follows:

- Determination of rock slope stability conditions,
- Researching the potential failure mechanisms,
- Determination of the factors that affect the stability of slopes,
- Carrying out optimum and safe slope designs,
- Determination and testing of different support and enhancement methods.

Various methods such as kinematic analyses, limit equilibrium method and numerical analyses are used today for evaluating rock slope stability. However, the potential failure type, terrain conditions as well as the weak and strong aspects of the preferred method should be taken into account when selecting the analysis method to be used.

In this study, kinematic analyses have been carried out to determine the possible failure types that might occur due to discontinuities in the area where the Gumushane Granitoid Complex is exposed (Figure 1) and to determine the orientations that such failures can occur. The results obtained from kinematic analyses have been evaluated

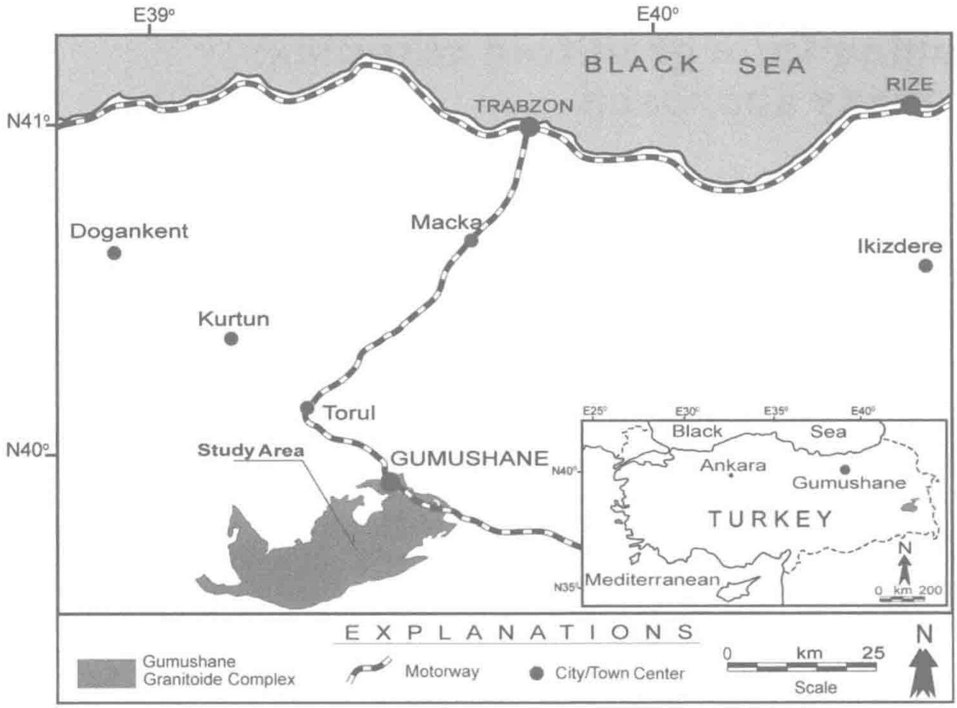

Figure 1 The location map of study area.

via Geographical Information System (GIS) and Fuzzy Inference System (FIS) methods and risk maps have been generated for the study area.

The studies have been carried out in three stages. In the first stage, the main orientations and the shear strengths of joints have been determined. To this end, orientation measurements were obtained from the joints and these joint orientations were evaluated using the Dips v5.1 (Rocscience, 2002) software after which the main orientations of joints were determined. Whereas the shear strength of the joints was determined according to the method suggested by Barton & Choubey (1977).

In the second stage, the results obtained from field and laboratory works were evaluated using Dips v5.1 (Rocscience, 2002) software and kinematic analyses were performed for planar, wedge and toppling failures to determine the orientations of unstable orientations of slope. In the final stage, the results obtained from kinematic analyses were used to generate GIS based instability risk maps and the obtained maps were evaluated according to the FIS method after which instability risk map was generated for the study area.

2 GEOLOGY OF STUDY FIELD

The Pontide Orogenic Belt of Turkey is located in the middle sections of the Alpine-Himalaya Orogenic Belt. The eastern portion of it, which is also known as the

Eastern Pontides, has been divided into Northern Zone and Southern subzones by researchers according to the lithological and structural properties of the exposed units. In the Southern Zone including the study area, metamorphic, magmatic and sedimentary rocks that have formed during time intervals varying from Late Paleozoic to Quaternary crop out in the study area (Figure 2).

The oldest rocks in the region are the Early Carboniferous Pulur and Kurtoglu Metamorphic Complexes aged Early Carboniferous (Topuz *et al.*, 2004, 2007). These metamorphic complexes include many different metamorphic rocks that vary in origin from continental rocks to oceanic rocks (Dokuz *et al.*, 2011, 2015).

Middle Carboniferous Kose-Gumushane Granitoid complexes that settle by cutting the Pulur-Kurtoglu Metamorphic Complex mostly consist of continental crust based granodiorite and granite and less of quartz diorite, quartz monzonite, spherulitic dacite

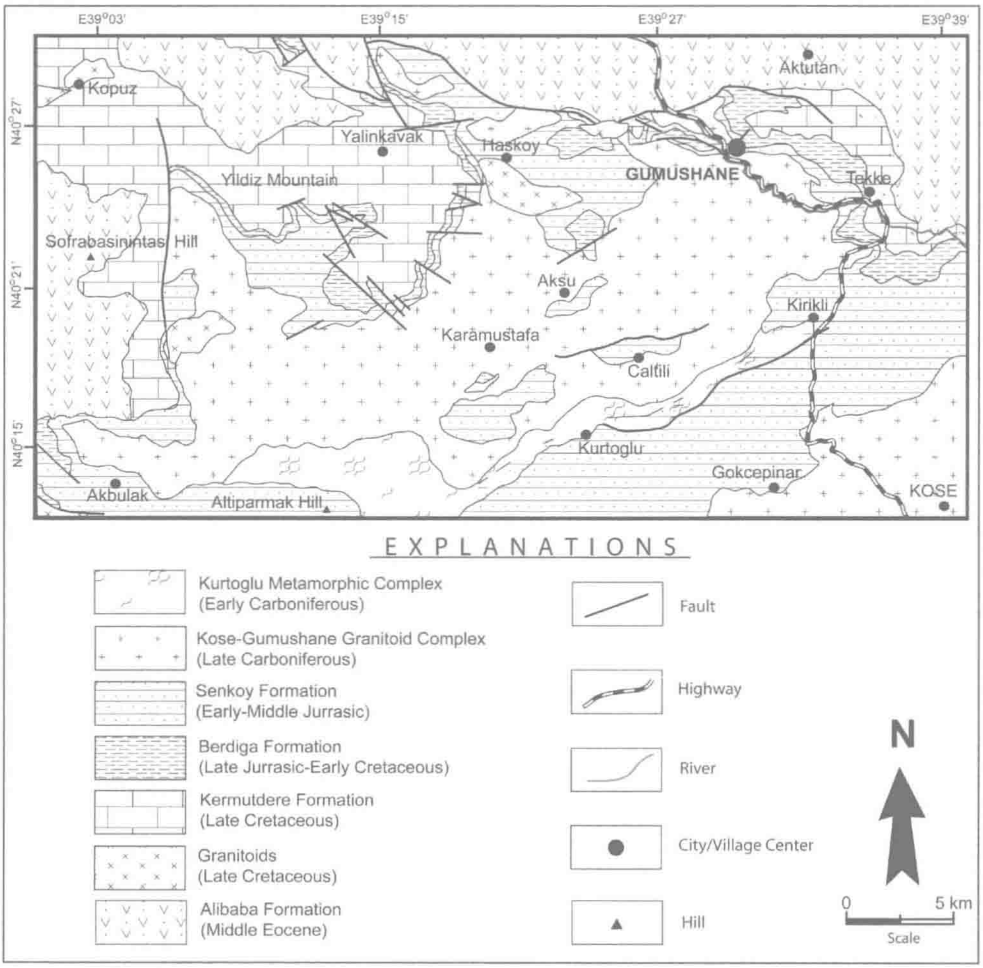

Figure 2 The geological map of study area.

and riolites (Topuz *et al.*, 2010; Dokuz, 2011). Aplitic dikes are also observed in granitic complexes. This study is focused on the Late Carboniferous Gumushane Granitoid Complex, which includes at least 4 or 5 well developed joint sets.

The Early-Middle Jurassic Senkoy Formation unconformably covers the Carboniferous basement rocks. It starts at the base with the basal conglomerate consisting of quartzite and granite pebbles and the carbonous intermediate level sandstones that are on top of them. Red limestones with macro-fossil (Ammonitico Rosso facies) lie on top of these (Kandemir & Yilmaz, 2009). Overlying is a sequence consisting of volcanic-clastic pebble, sandstone, siltstone and marl interbedded with various basic volcanic rocks (tuff, tuffite, andesite, spilitic basalt and pyroclastics) (Dokuz & Tanyolu, 2006). In places, cherty limestones and basalts are also observed within the unit (Dokuz *et al.*, 2006; Sen, 2007).

The Late Jurassic – Early Cretaceous aged Berdiga Formation that creates a key stratigraphic horizon in the Eastern Pontides conformably covers the Senkoy Formation unconformably. The unit begins at the base with medium to thick bedded and partly massive dolomitic limestones (Vörös & Kandemir, 2011). Upward it contains pebble, sandstone and siltstone and ends with dolomitic limestone (Koch *et al.*, 2008). Chert nodules are observed in places within the unit. The Berdiga Formation can easily be separated from the other sedimentary units in the region due to its hard topography, thick layered and massive structure and gray, off-white, yellowish and beige colors. The formation is conformably covered by the Late Cretaceous Kermutdere Formation.

The Late Cretaceous Kermutdere Formation attracts attention with its thin-medium bedding, light greenish color and soft topographic appearance (Saydam, 2002). The Kermutdere Formation starts at the base with yellow sandy limestone and upward continues with red micritic limestone, red sandstone, siltstone and marl as the guiding level (Saydam & Korkmaz, 2011). These rocks are covered by a turbiditic succession that consists of alternating gray pebblestone, sandstone, siltstone, marl and claystone sequences. In parts, micro conglomeratic levels are also observed within the unit in parts (Dokuz & Tanyolu, 2006).

There is also a second a granitic body inside the study area that cuts the Gumushane Granitoid Complex. This body radiometrically has not been dated yet, but its age is given as Late Cretaceous-Eocene based on the stratigraphical position of the similar intrusive bodies to the further north (Guven, 1993). Such intrusive bodies become dominant in the areas to the north (Kaygusuz *et al.*, 2008; Karsli *et al.*, 2010a).

The Middle Eocene is represented by Alibaba Formation, which starts at the base with sandstone and tuffite interbedded with nummulitic limestones. Upward the unit continues with andesite, basalt and associated pyroclastic rocks and ends with limestone, sandstone, marl tuff alternation (Arslan & Aliyazicioglu, 2001). The formation non-conformably covers the Kermutdere Formation as well as the Late Paleocene-Early Eocene adakitic stocks (Karsli *et al.*, 2010b, Dokuz *et al.*, 2013). Younger rocks are located at the northern zone of the Pontides (Aydin *et al.*, 2008).

The youngest units of the region are composed of Quaternary aged hill slope wash and alluviums. Slope wash has sprung forth from the older units that have been exposed and consists of elements with different dimensions and is exposed especially on the hills. Whereas alluvium consists of well-rounded elements at river beds with clay, sand, pebble and block dimension.

3 ORIENTATION AND SHEAR STRENGTH OF DISCONTINUITIES

Orientation of discontinuities and shear strength are two parameters that play important roles in the development of instabilities that develop due to discontinuity surfaces. These two parameters are used as input parameters in rock slope analyses such as kinematic analysis, limit equilibrium analysis. Hence, the main orientations of the discontinuities in the rock as well as shear strengths have to be determined.

3.1 Orientation

Discontinuity orientation is expressed as the position in space of a discontinuity surface and is defined by the dip and dip direction of the surface. The measurements taken directly from the rock mass using geologist compass is evaluated via the contour diagrams prepared to test this method using stereographic projection method and the main orientations of the discontinuity sets contained within the rock mass are determined. Generally, stereonets with lower hemisphere and equal-angle are used.

In this study, a total of 1797 orientation measurement taken from the joints of Gumushane Granitoide Complex were evaluated in accordance with the methods suggested by ISRM (2007) using Dips v5.1 software (Rocscience, 2002) and main orientations of the joint sets were determined (Figure 3, Table 1). As can be seen

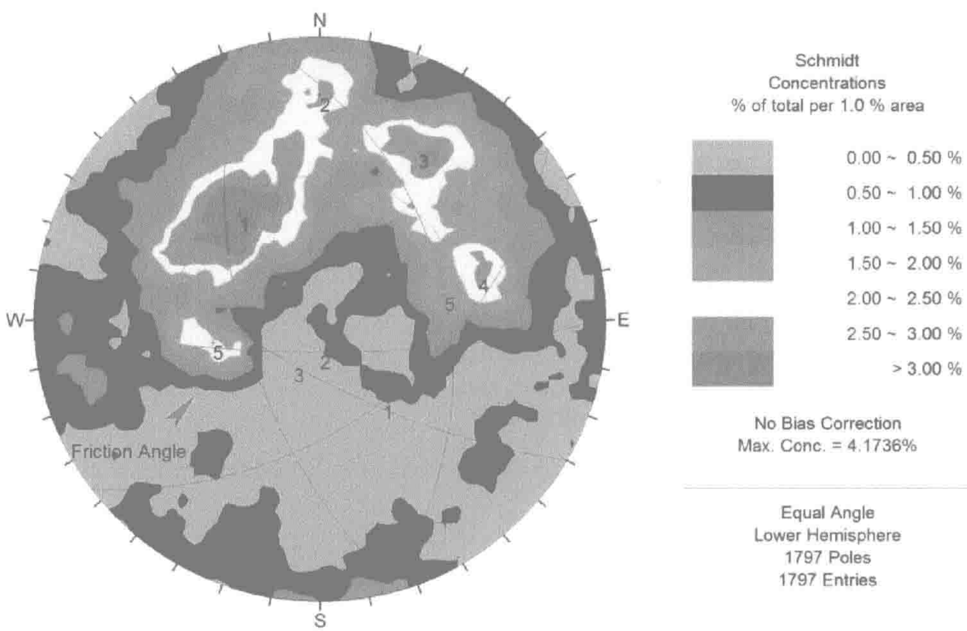

Figure 3 Stereographic projections of joint sets.