Tunnels

Excavation and primary support

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Foreword of the President of the International Tunnelling Association - ITA
Mr. Martin Knights

It is my great pleasure to be invited to write a foreword to this book. It is a great gesture for HUBITG and ITA Croatia to complete this book on behalf of Prof.Hudec.

Croatia is a valid member of International Tunnelling Association – ITA. This year for the first time the Executive Committee of ITA will hold its regional meeting in Zagreb. There is much infrastructure to be built and replaced in Europe and the geography of Croatia presents many challenges for rail, road and water transport projects. This means an opportunity for ITA and ITA Croatia to demonstrate to the government and decision makers that tunnelling will offer many long lasting benefits. The benefits will include better environmental solutions, reduced construction and operation costs and responsible legacy for the future.

The principle challenges for ITA are to encourage young people to consider a carreer in tunnel engineering. ITA wants all member nations to ensure that the training and education is given to all those that want to play a part in our future. Croatia has an excellent tradition of well qualified engineers and we will encourage Croatia to maintain this tradition especially to ensure there will be tunnel engineers to create future infrastructure.

ITA wishes ITA Croatia continued success and we appreciate the active support that she gives.

London, May 15, 2009

Foreword of the President of the Croatian Chamber of Civil Engineers
Mr. Zvonimir Sever

Professor Mladen Hudec is an important person in the Croatian Civil Engineering of the last century who succeeded in achieving superior results in everything he engaged in. He was a man of great knowledge and wide interests. Yet, his greatest love were the underground structures. The book ″Tunnels - Excavation and Primary Support″ is the best evidence of the breadth of knowledge and expertise of professor Hudec in that field.

I have collaborated with professor Hudec for more than twenty years. These years are preserved still in my memory. He enchanted people with his spontaneity, kindness, loyalty and goodness of heart. He transferred his knowledge and experience to his co-workers unselfishly. I have learnt much from him myself, particularly in the field of hydrotechnical tunnel design.

The Croatian Chamber of Civil Engineers strongly supports publishing books from the field of Civil Engineering. During last five years the Chamber has supported in various ways publishing some twenty technical books. I hope that this book will encourage young people to direct their career to the tunnelling and the underground structures. In compliance with the current trend in the world to utilize underground spaces for reasons of protection of the environment, a lot is to be built yet in Croatia in this field.

Finally, I would like to thank dr. Davorin Kolić and mr. Svjetlan Hudec who have made praisworthy effort and prepared this book, which regrettably professor Hudec did not live to complete and publish himself.

Zagreb, May 20, 2009

HRVATSKA KOMORA INŽENJERA GRAĐEVINARSTVA

Preface

This book came about on the basis of the original manuscript and materials of Prof.Hudec dealing with tunnels and underground structures which he prepared for publishing. The basic structure of the book starting with the review of the evolution of underground construction methodology through history concentrates in the main body of the text on the analysis of the principal issues relevant for the tunnels constructed by conventional excavation methods. It is essential to become aware of these issues for the proper understanding of the underlying principles of the above mentioned construction methodology. For this purpose the excavation methodology is reviewed in detail and the various elements of primary supports presented which as a matter of fact is in compliance with the basic concept of the scope contemplated by Prof.Hudec to be covered by this book.

On the basis of such material the majority of the existing chapters were reviewed and where necessary supplemented and the new ones added related to the modern approach to the tunnelling and underground spaces technology. In this manner the originally devised work was reshaped but retained its basic concept concerning the subject matter, which is the methodology of excavation and primary support of tunnels and other underground spaces, as well as the level of coverage of such subject matter. Method of analysis of stress states and protection of loss of stability of parts of top heading is presented having application in tunnelling in hard rock material. Consequently, the book in the final form deals with the basics of the excavation and primary supports carried out by the conventional methods of tunnelling in rock masses.

In the first, introductory chapter of the book the differences are outlined between the modern and old methods of the excavation and support, the latter being the basis for the development of the new conventional methods of tunnelling and underground construction. The basic difference is also indicated that exists between the conventional tunnelling and the mechanised tunnelling methods which are recently finding wide application.

The history of tunnelling is outlined in the second chapter without going into too much detail by presenting four famous and outstanding examples of underground construction from the ancient times. The examples are chosen from the variety of writings on history of underground construction by Prof.Hudec over the number of years published in the Annual Review of the Faculty of Mining, Geology and Petroleum Engineering (RGN), University of Zagreb containing the same, and also many other examples of underground structures in much more detail and scope. These writings are indicated at the end of this book as part of the reference.

In the next chapters the development of conventional excavation methods is presented having origin from the mining technology, where all tunnel technology comes from. Over the time through the evolution of the methods, the excavation methodology was developed known today by the different names, but characterized in principle by multidrift excavation and protection against collapse by sprayed concrete and anchor application.

Development and application of conventional tunnelling method, which we call in this part of Europe as „New Austrian Tunnelling Method“, is described in chapter 8. This method has different names in different parts of the world its use being widespread all over the world (e.g.: SEM - “Sequential Excavation Method“ in North America; SCL – „Sprayed Concrete Lining“ method in Great Britain and South East Asia; „Spritzbetonbauweise“ in Germany and Switzerland; and „New Austrian Tunnelling Method“ – NATM in English or in German „Neue Österreichische Tunnelbauweise“ – NÖT frequented in Austria and many other countries in the world).
In chapters 9 and 10 the rock mass behaviour laws and stress analysis around excavation opening are presented. The approach is illustrated by algebraic expressions suitable for quick analyses and definition of stress state in principal stress directions. In addition, these two chapters may serve as a basis for determination of crown arch loss of stabilization through fallouts.

After defining the state of stress around an opening, and prediction of the possible susceptibility of crown arch to fallouts, the next chapters are devoted to review of the types and forms of primary support elements used today. Thus, in chapter 12 the anchors are presented, with different ways of their application and basic expressions for their dimensioning. Chapter 13 is devoted to the sprayed concrete and its application and in chapter 14 the application of the steel fibre reinforced sprayed concrete is introduced in basic form, much more details being specified in the guidelines for their application indicated in the reference section. The important aspect of the influence of fire on sprayed concrete is described in chapter 15, which gained in importance due to the problems occurred in practice and on account of the additional requirements on the safety of tunnels being imposed after a number of tunnel fire disasters during the last ten years. And finally, in the chapter 16 the forms and applications of primary support steel arches are described.

Several examples from the recent tunnelling practice are given in the concluding parts of

the book, followed by the application methods of support elements, with their characteristics being indicated in the tables which may be found useful for daily application in design and construction practice.
In any case, the book in this form as it is now may be successfully used for reference, and if used together with a number of guidelines indicated in the literature list as a practical manual.

In the next issues of this book new chapters are planned to be added covering areas of excavation and support of tunnels in weak, unstable material, monitoring and measurement of displacements of cross-sectional profile during excavation and application of primary support, application of the waterproofing lining layers and drainage details, construction of inner concrete lining and principles of tunnel ventilation.

Davorin Kolić, Svjetlan Hudec

Zagreb, May 15, 2009

PLAITWORK
The history carved in stone

The Croatian plaitwork is geometric shallow ornament specific for Early Croatian culture. In the Pre-Romanesque and early Romanesque period (from 9th to 11th century) the plaitwork ornamentation was used for decoration of Early Croatian churches, abbeys, sculptures, monuments, and artefacts. In modern times plaitwork pattern is popularly thought of as part of Croatian national identity.

Acknowledgement

We would like to thank all advertisers for their support during preparation and publishing of this book.

We would like to express thanks to the family of Prof.Hudec who provided the basic text issue, drawings and photos that made the basis for the work on finalizing and publishing this first book on tunnelling in Croatian language.

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Chapter 1
INTRODUCTION

Excavation of tunnels and underground caverns followed by the stabilization of the profile immediately after its excavation represents one of the most challenging and demanding civil engineering ventures. The latter phase, aimed at prevention of the collapse and excessive change of excavated form, is known as supporting. The substantial development in technology of excavation and support has occurred during the 19th century and in the first half of the 20th century (Kovari, 2002a, 2002b, 2002c) but the pressing need for more efficient and rapid construction of underground space and tunnels demanded the application of new materials and as a consequence of new technologies. The greatest advancement in the supporting technology was made in the second half of the 20th century. (Vandevalle, 1990; Whittaker-Frith, 1990).

The conventional tunnelling techniques, so called old methods have been almost completely abandoned and are rarely used in modern times, but nevertheless it is important to know their underlying principles. Although site investigation works are planned and carried out in advance with an aim of predicting geotechnical conditions of excavation and support, unexpected surprises in the underground are being encountered all the time. This is especially true for our local karstic areas characterised by the saying «the rule is that there is no rule in karst!» or «Expect the Unexpected!» The surprises that may be encountered are caverns, caves, vertical and horizontal dry or active water courses, open contacts of the geological units, cavities filled with deposits of softened material and larger or smaller rock blocks, and finally local fallouts and collapses. Standard solutions in such situations are often inadequate, so one has to resort to improvisations and non-standard solutions to cope with the difficulties and overcome seemingly unsolvable situations. For that purpose, conventional support methods which can be adapted to a variety of ground conditions, will

be presented first, and only then the contemporary support systems.
The basic difference between the old and new methods of support is in the function given to the support system. The old methods preferred wooden supports in form of so called mining timber, i.e. roundwood substantially shorter than standard sawn lumber. The excavation of tunnel profile in difficult geotechnical conditions is of cyclic nature, i.e. cycle of excavation followed by cycle of support placement. The supports are given only temporary function of supporting rock mass until being replaced by the permanent lining, made of stone or concrete blocks, or concrete lining cast in forms, and in many cases masonry lining of bricks. Wooden timbering should not be left in place behind the permanent lining, as the rotting of the timbers would create voids which could cause uncontrolled displacements of rock mass and cave ins or impacts on the liner. For that purpose it was necessary to remove timber on short sections prior to installing permanent lining. At that particular moment the rock mass on that section is left unsupported, which usually resulted in its being deformed, but at the same time the stresses in rock mass are reduced and the load on the permanent lining to be installed is reduced too. At first the lining takes very little load, the full loading is to take place during relaxation of the neighbouring section. The process of placing permanent supports, and consequently the whole cycle of the works is discontinuous and relatively slow.

Modern support methods treat support as a structural element to be left permanently in function, and not to be removed during lining installation. The main purpose of the support is to stop the process of deformation of rock mass induced by excavation of the underground structure. As a rule, the installation of the permanent lining is started after completed excavation of the whole length of the tunnel, or greater part of it. Both processes, i.e. that of excavation and support and the placement of the permanent lining, are continuous and independent of each other, and by using adequate machinery the works proceed much faster than those based on old methods. It is important to note that materials for support elements are durable and there is no need for them to be removed prior to installation of the permanent lining, and in addition all the loads are undertaken by the support which performs in this way a function of permanent structure. Working with the supports of durable material is much safer and by a wide margin faster. Besides, modern support methods enable full face excavation and support of larger tunnel profiles, and only in cases of exceptionally adverse geological conditions the excavation and support needs to be done in stages by multiple drifts (Frgić et al, 2003). Often the installation of the permanent lining can be omitted completely or in part, if the final function of the underground structure allows it.

According to the contemporary concepts, the support system is an independent structural element which is to ensure permanent and complete stability of the underground structure, and for this reason a review is included here of the calculation methods for sizing the

elements of the support system.
One issue that should be noted here is the excavation by tunnell boring machines (in Croatian practice usually called „moles“, TBM - Tunnel Boring Machine, Engl.; TVM – Tunnel-Vortriebs Maschine, Germ.) where the two stages are united, i.e. concurrent excavation and installation of the segmental tunnel lining is achieved. The function of the primary support is performed in part by the shield tail under the protection of which the permanent lining is installed. Complete profile, which is circular as a rule, is lined with pre-cast reinforced concrete segments.

Wood as a material for supports had some advantages. Forming mining timber by sawing and hewing is fast and adaptable to any situation at the site. Miners felt secure with timber, because sudden breaking seldom occurred. As a rule, overloaded timber buckles before breaking, letting loud cracking and creaking sounds, thus giving visual and audible warning of potential danger, and the support can be reinforced in time.

Structural elements of the new methods are rock bolts, dowels or anchor bars, shotcrete, fibre reinforced shotcrete, reinforced concrete, steel arches sets and steel props. Shotcrete lining adapts easily to the actual form of the excavated contour, and rockbolts too do not require accurate form of excavated profile. Tunnel support systems made of steel, however, are delivered to the site with exact dimensions determined on the basis of the ideal geometric conditions and it is more difficult to adapt them in case excavated profile varies significantly from the design profile.

There is a variety of conventional support methods, differing in the sequence and method of attack and the concept of the support system. Having in view that this section is intended only to give an outline of support principles used in exceptionally adverse geotechnical conditions, the heaviest types of supports will be presented for the following four excavation methods:

- Belgian method
- Old Austrian method
- German method
- Italian method

This section is illustrated with drawings of the solutions adopted for construction of the first tunnels in Croatia on Rijeka and Lika railway lines.

Chapter 2
HISTORY OF TUNNELLING

2.1 Introduction

Utilization of the underground spaces in the form of shelters, tunnels, burial chambers or other underground structures has started already in ancient times. We may find different well preserved underground structures all around the world. In this chapter a short review is given of some of the most popular and well known underground structures situated in Eqypt, India, Malta and Turkey. This review is only a small part of the material published by the author in the Annual Review of the Faculty of Mining, Geology and Petroleum Engineering (RGN), University of Zagreb and elsewhere in the period from 1996 to 2002. (Hudec 1996, 1997a, 1998b, 1999, 2000a, 2001, 2002).

2.2 Egypt

Searching for the beginnings of the underground geotechnics one should start with the Ancient Egypt in which many preserved remnants of the structures may be found and on which a lot of written and graphic documentary records are available along with the comprehensive literature. One of the areas which the existing literature is usually mentioning only in passing, but which is nevertheless important for the history of technology is the area of the underground construction. Since the time of the first written records of the Egyptian history many underground spaces were constructed and preserved. They are