Tunnelling and Underground Space Technology 78 (2018) 159–167

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Long-term behaviour of complex underground structures in evaporitic rock mass – Experiences gained from calculations and geotechnical observations

Gunter G. Gschwandtner[a,*], Robert Galler[b]

[a] iC-Consulenten, Bergheim, Austria
[b] Chair of Subsurface Engineering, Montanuniversität, Leoben, Austria

ARTICLE INFO

Keywords:
Geotechnics
Underground structure
Numerical simulation

ABSTRACT

The assessment of the stability of underground structures is an interdisciplinary effort combining tasks from various special fields. In addition to geotechnical engineering and geology, hydrogeology in particular plays a major role in the determination of long-term behaviour of the structure and the surface area. With regards to the stability of underground structures in evaporitic rock mass, a non-negligible factor is the influence of water, both rainwater and groundwater. The resulting leaching process affects the surrounding rock mass, gradually reducing its strength. The first part of this paper presents an approach for the determination of long-term behaviour of a complex underground structure based on an underground gypsum mine. For this purpose a numerical model was developed, which is based on the geological, hydrogeological and geotechnical conditions, including an implementation of the leaching process. Based on the calculation result a geotechnical monitoring program was developed to observe the long-term behaviour. The second part of this paper presents the aggregated data from a surveying period of four years and compares it with the simulation results.

The information gained from the prediction of the long-term behaviour and the regular comparison with the result of the long-term monitoring program can provide a basis for risk evaluation, making it possible to reduce potential risks for the surface area at an early stage, especially in inhabited areas.

1. Introduction

The impact of mining activities and the construction of underground structures constitute a risk potential for the population as well as for property values. In recent decades the problems of stability and subsequent use have increased in the areas of abandoned mines especially in the area of leachable rocks (gypsum, salt, etc.) and karstic rock. These abandoned mine sites and areas in leachable rocks are stable during the comparatively short active excavation activity of raw materials, but become unstable due to the complex "aging process" (Auvray et al., 2004, 2008; Colak, 2002; Hoxha et al., 2000, 2006; Jim et al., 2004; Meer et al., 1995, 1997, 1999, 2000; Gschwandtner, 2013) which can lead to far-reaching restrictions or hazards in populated areas like settlements.

Examples of such occurrences are mining works of Volterra in Italy (Olgaard et al., 1995), Pingyi in Shandong China (Zhu, 2004), Livry Gargan and Grozon in France (Auvray et al., 2004), Xinglong in Hebei China (Li, 2007), Shaodong in Hunan China, Steighorst in Germany (Friedrich et al., 2008), as well as a former underground gypsum mine in Austria.

2. Assessment of the structural stability for complex underground structures

Due to a mostly limited amount of geological and rock mechanical data and the complex long-term material behavior of the rock mass, it is difficult to make a reliable and detailed prediction regarding the stability of old abandoned mine structures.

However, to get a rough idea regarding the long term stability of complex underground mines, a detailed investigation program is necessary. Together with analytical and numerical calculations weakened and hazard zones should be able to be detected.

It is inevitable to combine the information from various subject areas in order to create an understandable and clear concept for the evaluation of existing data for the determination of stability (Fig. 1.) The areas of expertise required for the analysis can basically be divided into the following four sectors:

i. Geology
ii. Hydrogeology
iii. Geotechnics/rock mechanics

* Corresponding author.
E-mail address: g.gschwandtner@ic-group.org (G.G. Gschwandtner).

https://doi.org/10.1016/j.tust.2018.04.030
Received 28 November 2017; Received in revised form 20 April 2018; Accepted 25 April 2018
0886-7798/

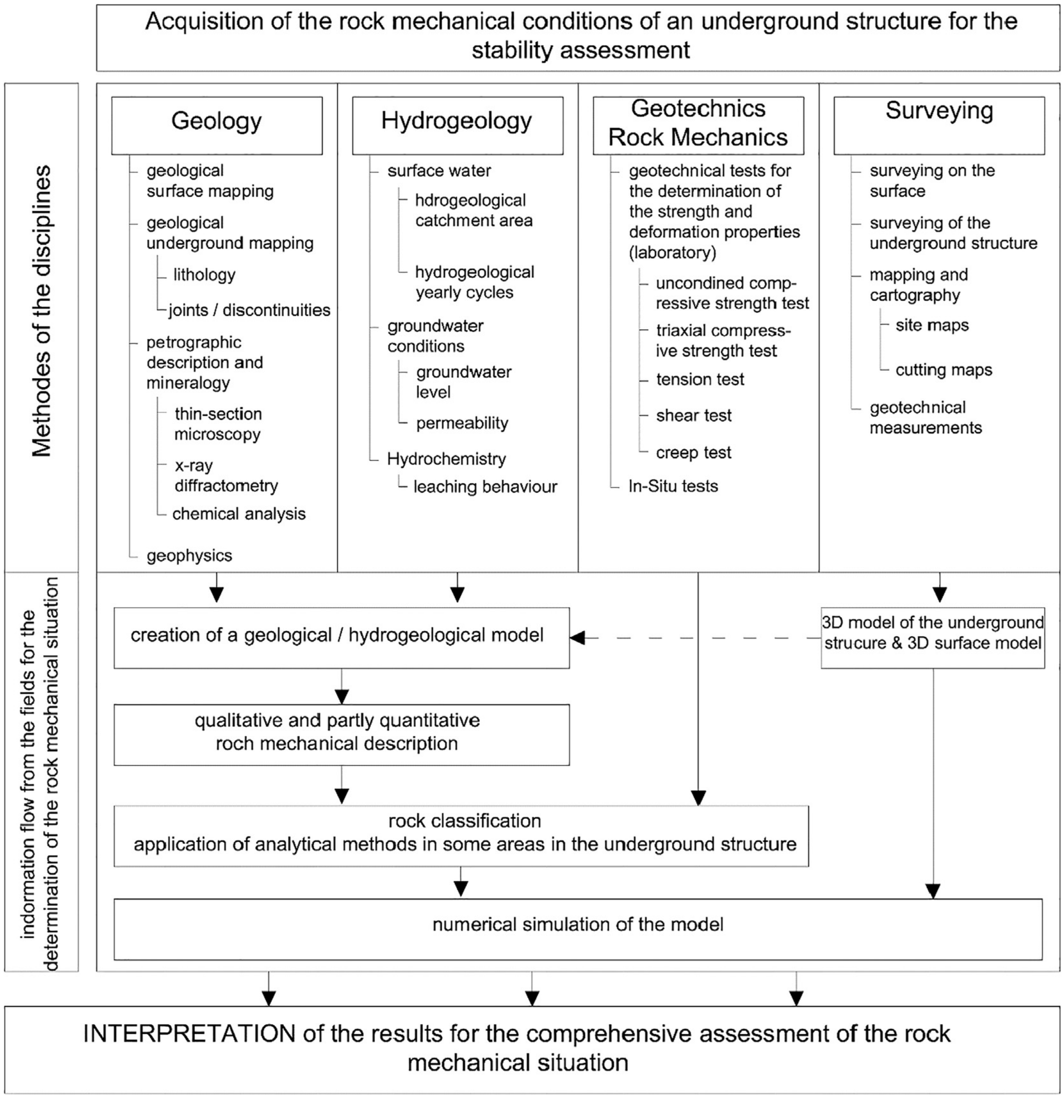

Fig. 1. Overview of the subject areas including investigation methods (Gschwandtner and Galler, 2011).

Table 1
Overview of geotechnical parameters of dolomite and Haselgebirge (MIN, Max, Mean, Median) (Gschwandtner, 2013).

Parameter	Unit	Dolomite				Haselgebirge			
		MIN	*MAX*	*Mean*	*Median*	*MIN*	*MAX*	*Mean*	*Median*
Density	g/cm^3	2,16	2,71	2,40	2,33	2,21	2,51	2,30	2,29
Elastic-modulus	GPa	8,12	87,90	55,87	53,60	4,44	44,64	14,84	10,16
Deformation-modulus	GPa	1,46	88,70	50,13	40,60	0,22	39,53	9,09	2,52
UCS	MPa	2,85	78,58	34,04	21,9	1,00	19,14	5,06	3,57
Friction angle	°	25,22	47,60	35,22	30,59	20,78	30,11	26,30	27,00
Cohesion	MPa	3,36	15,10	7,57	4,21	1,37	6,30	2,89	2,31
Tensile strength	MPa	0,33	3,17	1,51	1,31	0,16	1,91	0,52	0,43

iv. Surveying including geotechnical monitoring

Numerical calculations are mostly based on two-dimensional plain-strain crosscuts or highly simplified three-dimensional models. Older “grown” underground mines usually have highly complex structures. Such conditions can only be inadequately represented by two-dimensional simulations.

Simplyfied three-dimensional calculations can be used for the simulation of excavation works as well as for the calculation of stress transitions at the face area in tunnel constructions or even for the simulation of mining sequences in the mining industry. These models use existing symmetry planes to reduce the number of elements and thus the computation time. Long stretched structures can therefore be reduced to a half or quarter model. However, in all cases where the underground structure does not have an elongated geometry and no symmetry plane, real 3D modeling has to be used.

Meanwhile mining companies started to create models of their underground deposits including the compilation of the whole geometric dimensions of the underground structure as well as the implementation of geological data from mapping as well as drilling work. These data