Safety in Mines Research Advisory Committee

Final Project Report

Numerical Modelling of Mine Workings: Annual Update 1999/2000

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Executive Summary

The SIMRAC project GAP629 has two aspects. Firstly, the production of an updated edition of the guidebook *Numerical Modelling of Mine Workings*. The original document was launched to the South African mining industry in April 1999. Secondly, the maintenance of an Internet web site containing information about the guidebook and currently available numerical modelling software packages. Since both the updated edition of the guidebook and the web site are deliverables for this project, this report only describes how these objectives were achieved and does not repeat the content of either deliverable.

The work undertaken to update the guidebook took the form of enhancements and correction of errors in the original document, and the writing of entirely new sections of text. A summary of this work is presented in tabular format. Many of the minor enhancements and changes made to the document have not been included in the aforementioned table as they are too numerous.

The Internet web site has been redesigned as it was discovered that the original layout of the site was not conducive to easy maintenance. Visitors to the site can gather information regarding both currently available software packages and the content of *Numerical Modelling of Mine Workings.* It is also possible to download freeware and individual chapters of the guidebook via this site. The current design facilitates easy maintenance of the web site.

A corrected and enhanced edition of the guidebook is now available for use by rock mechanics engineers in the South African gold and platinum mining industries. To compliment this, an internet web site providing a facility for the interaction between rock mechanics engineers and numerical modelling experts is now readily accessible.

Acknowledgements

Table of Contents

List of Figures

List of Tables

1   Introduction

On the 14th April 1999 the first edition of the *Numerical Modelling of Mine Workings* was launched to the mining industry. (This document was one of the deliverables for GAP415.) The event, which was held at Miningtek, was attended by over 70 industry representatives. The occasion was deemed a success as it provided an opportunity to promote both the guidebook and SIMRAC. To date, of the order of 100 copies of the guidebook have been distributed to both SIMRAC contributors and non-SIMRAC contributors.

The purpose of this project, GAP629, is to ensure that the content of the aforementioned guidebook is current, correct and informative. This aim was achieved through two enabling outputs:
1.   to update the guidebook *Numerical Modelling of Mine Workings*, and
2.   to maintain the internet web site.
Since an updated edition of the guidebook and the internet web site constitute the deliverables of this project, this report will only briefly discuss the work that went into the production thereof. It is not the intention of this report to repeat the contents of either the guidebook or the web site.

The work undertaken to create an updated edition of the guidebook took the form of enhancements and correction of errors to the original document, and the writing of entirely new sections of text. A summary of this work is presented in a tabular format. Many other minor enhancements and changes were made to the document but they have not been included in this table as they are too numerous.

The Internet web site has been redesigned it was discovered that the original layout of the site was not conducive to easy maintenance. The current design now has a more logical structure, is comprehensively cross-referenced, and facilitates easy maintenance of the site. Visitors to the site can gather information regarding both currently available software packages and the content of *Numerical Modelling of Mine Workings.* It is also possible to download freeware and individual chapters of the guidebook via the site.

1.1 Problem Statement

During 1997 and 1998, under GAP415, the first edition of *Numerical Modelling of Mine Workings* was compiled. This document is aimed at addressing many of the problematic issues related to the numerical modelling of rock mechanics problems that have arisen over the past few decades. These issues include:
- Identifying the numerical modelling program best suited to solving the problem at hand.
- The meaning of the various input parameters and what values to assign to these parameters.
- Correcting ambiguities presented in other currently available texts and to cull incorrect and misleading information.
- Collation of valuable information relating to the use of numerical modelling to solve mine design problems in the South African gold and platinum industries.
A full discussion of these and other associated problems is presented in the final report for GAP415.

The guidebook needs to be maintained such that its content is current, correct and informative. Due to the dynamic nature of the software industry, it is necessary that this document be updated frequently. Feed back from users has helped identify where corrections need to be made, enhancements included and new material introduced.

1.2 Objectives of this Project

This project set out to continue to help solve the problem of the inappropriate use of numerical modelling when investigating mine design problems. The project has two deliverables:
1. an updated edition of the guidebook *Numerical Modelling of Mine Workings*, and
2. a web site with information regarding the guidebook and currently available numerical modelling software packages.

1.2.1 Updated Edition of *Numerical Modelling of Mine Workings*

The enhancements made to *Numerical Modelling of Mine Workings* have taken on the form of the inclusion of additional information and correction of errors to the original document, and the inclusion of entirely new sections. A summary of these enhancements is presented in a tabular format. Many other enhancements and minor changes were made to the document but have not been included in the aforementioned table as they are too numerous.

1.2.2 Internet Web Site

When work commenced on updating the Internet web site it was discovered that the original layout of the site was not conducive to easy maintenance. In response to this problem a decision was taken to redesign the web site using a more logical structure to facilitate easy updates in future. The web site contains information on both the guidebook and currently available numerical modelling software packages that are applicable for the South African gold and platinum mining industries. Visitors to the site are also able to download freeware and the individual chapters of the guidebook. In order to download the guidebook a visitor needs to have a password which will issued upon receipt of a nominal charge.

2 Updated Edition of *Numerical Modelling of Mine Workings*

Enabling Output 1: Updates to the current edition of the guidebook *Numerical Modelling of Mine Workings* will incorporate feedback from industry and information regarding new software releases. (This document is an evolving reference that requires ongoing maintenance.)

Milestone Date: 03/2000
Actual Date: 09/1999

2.1 Updates to Volume I: Principles of Numerical Modelling

The changes made to Volume I of *Numerical Modelling of Mine Workings* have taken on the form of enhancements and correction of errors to the original document as well as the inclusion of entirely new sections. Since an updated edition of this document is a deliverable for this project, the text comprising the new and amended sections of the guidebook are not repeated within this report, however, Table 2-1 contains a summary of these changes. Many other minor enhancements and changes have been made to the original document but are not included in the table as they are too numerous.

The entries in Table 2-1 are in incremental order according to the chapter in which they occur. These changes have been classified according to whether they are entirely new sections, additions to existing sections or corrections. Each entry comprises the section number and heading where it occurs within the guidebook as well as a brief description of the enhancement. In the case of select new sections the descriptions have been omitted as all new subsection headings are listed in the table making it evident as to the content of the new text.

To date no modifications have been made to Volume II as this work forms part of the project GAP625.

2.2 Milestone Delivery

The progress achieved on this project was far greater than originally anticipated and consequently completion has been achieved six months ahead of the scheduled completion date. Copies of the updated pages have been distributed to the relevant parties.

Table 2-1. Summary of new sections, additions to existing sections and corrections made to Volume I of *Numerical Modelling of Mine Workings*

Chapter	New Sections	Additions to Existing Sections	Corrections
Chapter 1 **Overview of Numerical Modelling**	**1.3 Occam's Razor** Box on William of Ockham		
Chapter 2 **Solid Mechanics**	**2.7.7 Volumetric Strain** Concept and formula for volumetric strain are given in addition to the deviatoric and non-deviatoric strain matrices **2.10 Friction** The section on friction is divided into the following subsections: **2.10.1 Amonton's Laws** **2.10.2 Coulomb Friction** **2.10.3 Internal Friction** Box on the Adhesion Theory of Friction **2.12 Elastic Convergence** Calculation of convergence assuming an elastic rock mass.	**2.4.1 Linear Elasticity, Young's Modulus and Hooke's Law** Description of the three most common ways of defining Young's modulus. **2.7.9 Special Cases** This section and its subsections have been rearranged. **2.7.9.3 Pure shear** Improved explanation for the Mohr circle diagram. **2.7.9.4 Simple shear** Improved diagram to illustrate concept of simple shear. **2.11.2 Induced and Resultant Stresses** Inclusion of a Mohr circle diagram to illustrate the concept of induced stress.	**2.7.9.4 Simple shear** The incorrect Mohr circle diagram has been removed.
Chapter 3 **Modelling Criteria**	**3.2.1 Mohr-Coulomb Failure Criterion** Box on Otto Mohr ***Estimation of extent of plastic zone*** Method of estimating the extent of the plastic zone surrounding a circular excavation based on the Coulomb failure criterion.	**3.2 Rock Strength and Failure Criteria** and **3.3.3 Excess Shear Stress Criterion** The symbols relating to the coefficient and angle of friction, cohesion and tensile cutoff have been modified to be consistent with the new section on friction (Section 2.10).	

	3.3.1.3 Tributary area theory Approximation of average pillar stress using tributary area theory and an explanation as to why this technique is only valid for pillars at shallow depths.	**3.2.1.1 Mohr circle diagram** Comment on the use of the Mohr circle diagram for the representation of strain. **3.2.1.2 Calculation of the Mohr-Coulomb failure envelope** Section now includes the calculation of the Mohr-Coulomb failure envelope in terms of the principal stresses and UCS of a material.	
Chapter 4 **Material Models**	**4.3 Non-Linear Elastic Reef or Seam Models** Box describing the difference between monotonic and non-monotonic curves. **4.5 Strength of Discontinuous Rock Masses** This discussion has been subdivided as follows: **4.5.1 Influence of a Plane of Weakness on Rock Strength** **4.5.2 Strength of Rock Masses with Multiple Discontinuities**	**4.3.2 Piece-Wise Linear Models** Graphical explanation of stable and unstable loading conditions. **4.3.3.1 Hyperbolic model** Computational implementation of the hyperbolic material model. **4.3.3.2 Quadratic Model** Improved explanation of the implementation of the formulae used to describe a quadratic material. **4.4.1 Mohr-Coulomb Model** Symbols modified to be consistent with the new section on friction (Section 2.10). **4.6 Use of Rock Mass Ratings** A number of additional sentences have been included to clarify the limitations of rock mass ratings.	**4.3.3.2 Quadratic model** Figure describing the quadratic backfill material model has been corrected.
Chapter 5 **Solution Methods**		**5.2 Analytical Methods** and **5.3 Computational Methods** Use of the words slot, crack and slit have been clarified.	

Chapter6 **Numerical Modelling Programs**		**6.1 Introduction** New code included in the tables. **6.2 Commonly used Programs** New table describing the differences between the three commonly used boundary element codes. **6.3 Other Commercial Programs** New code included in the table.	
Chapter 7 **BESOL/MINAP_97**	**7.3.5 Circular Slot** Verification of the code using a comparison between the results computed by the program with those obtained using the Kirsch equations.		
Chapter 8 **MINSIM-W**			**8.3.5.2 Quadratic Backfill** A typing error in Figure 8-12(b) has been corrected.

3 Internet Web Site

Enabling Output 2: Continued maintenance of the web site to include information regarding new software releases and other pertinent SIMRAC information. New data files and software utilities will be added on a continual basis. A database of key references will be maintained. Important new links to other sites of interest will be added.

Milestone Date: 03/2000
Actual Date: 09/1999

3.1 Web Site Development

When work commenced on updating the Internet web site it was discovered that the original layout of the site was not conducive to easy maintenance. In response to this problem a decision was taken to completely redesign the web site. At the same time a further decision was made to switch from the Microsoft Windows operating platform to Red Hat Linux 6.0 with a 2.2.5 kernel and to use Apache 1.3.6 from Apache Software Foundation as the web server. A subcontractor with expertise in web site construction was employed to setup the server and implement the new design. The site was constructed entirely using HTML with some CGI (Common Gateway Interface) content.

The current web site now has a more logical structure that will facilitate easy updates in future. The structure of the web site is summarised in Figure 3-1. Furthermore, it is comprehensively cross-referenced allowing for easy navigation.

Some measures have been taken to ensure security of the site such that persons accessing it cannot directly view the directory content even if they know the directory structure.

Chapters 1 and 6 of Volume I of the guidebook and all freeware can be downloaded by any visitor to the site, however, downloads of all other chapters are password protected. When a visitor wishes to download any of these other chapters, upon receipt of payment of R 200-00 for SIMRAC contributors and R 300-00 for non-SIMRAC contributors, he/she will be issued a password allowing the user unlimited access to all documents. The issuing of passwords and maintenance of the password database will be done by Miningtek. Downloads of both freeware and the guidebook are in zip file format. Furthermore, the guidebook downloads are in Adobe Acrobat Portable Document Format, or PDF, to prevent most individuals editing the document.

The web site is now fully functional providing a facility for the interaction between rock mechanics engineers in the industry and numerical modelling experts at facilities such as CSIR Miningtek and Itasca Africa. The web site resides within the CSIR domain at the following address http://simrac.csir.co.za.

3.2 Milestone Delivery

The progress achieved on this project was far greater than originally anticipated and consequently completion has been achieved six months ahead of the scheduled completion date.
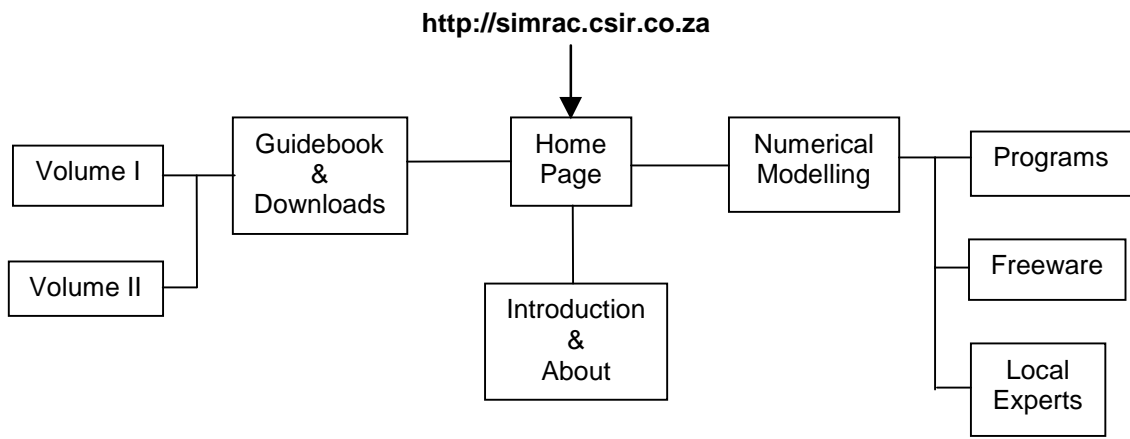
Figure 3-1. Summary of the structure of the web site to be found at http://simrac.csir.co.za.

4 Conclusion

Internal and industry feedback subsequent to the release of the guidebook in April 1999 identified a number of typing errors and some short coming actual explanations of numerical modelling techniques. Two significant errors were identified by the authors. All of these inaccuracies have been corrected.

A correct and more complete edition of the guidebook, *Numerical Modelling of Mine Workings*, is now available for use by rock mechanics engineers in the South African gold and platinum mining industries.

An Internet web site providing a facility for the interaction between rock mechanics engineers in the industry and numerical modelling experts is now readily accessible. The web site contains information regarding currently available numerical modelling codes and the contents of the guidebook. This web sit can be found at http://simrac.csir.co.za.