Short Description of Rock Mechanics Textbook

The planned rock mechanics textbook is a synthesis of 22 classic texts on rock mechanics, solid mechanics, the author's 15 years' experience in rock mechanics in the gold mining industry, and 10 years as a professor at the University of Pretoria (1984-2009). Throughout this period, the author noted that all the introductory texts on stress and strain were incomplete in one way or another, and that this, together with the watered-down introductions to stress and strain currently accepted in the mining rock mechanics fraternity, forms a barrier to the rest of rock mechanics.

This incompleteness in the classic texts was not the result of the omission of important material by any of the authors of these texts, but the result of the *assumed level of learning of the reader*. Readers with an advanced tertiary engineering background would understand the work whilst almost all others would struggle. Most texts, for example Biot (1965), Fung (1965), Jaeger and Cook (1979) and Brady and Brown (2006) all require, in differing proportions, a grounding in solid statics and dynamics, prior knowledge of the calculus, including partial differential equations, linear algebra, and tensor calculus, when introducing fundamental concepts such as stress and strain. A sampling of the texts consulted by the author appears below.

Such high-level introductions to stress and strain can never be informative to the uninitiated, and this is part of the reason why so many flounder in the rock mechanics certificate examinations. In order to make the theory accessible to all, these more complete dissertations on stress and strain were stripped of much of their content, and re-introduced in simplified form in a book edited by Budavari (1983). In this book, (which is not wrong in any of its essentials) the theory of stress and strain are reduced to the notion that stress is a vector, defined by force divided by area, whilst strain is a ratio of change in length of a body through deformation with respect to some original length. These notions while not essentially wrong, are so reduced with respect to the reality that no candidate can actually develop from them a proper understanding of what the quantities of stress and strain actually are, unless they are prepared to make the leap from this text and grapple with more advanced (and complete) texts on the subject. Furthermore, stresses and strains are then treated as scalar quantities in two dimensions, whereas a three-dimensional view is essential for any proper understanding of rockmass behaviour in a mine. Therefore, in the opinion of the author, the practice of rock mechanics has stagnated within a reduced two-dimensional view of what is very much at least a three-dimensional problem, for the last thirty to forty years.

In response to this observation, the author spent the last ten years developing more accessible texts on the fundamentals in rock mechanics, which were presented as lectures on rock mechanics to undergraduate mining engineering and geology students at the University of Pretoria. The litmus test of these texts was that the geology students made equally good progress as the engineering students, even though they had lesser mathematical backgrounds. This encourages the author to believe that the newlydeveloped texts will be equally understandable to the uninitiated as the reduced texts such as that in Budavari (1983) were.

The price that the candidate has to pay is to develop a three-dimensional view of the forces, displacements, and hence stresses and strains that develop within rockmasses in mines, and to *understand* exactly what they are. The advantage is that the candidate will build a far clearer and deeper understanding of what is actually happening in a rockmass, and therefore will be far better equipped to understand the output of numerical models, which are at least three-dimensional (static), and sometimes four-dimensional (dynamic). Candidates with this background will therefore be able to make the right interpretations of the model outputs, and ultimately, to draw the correct conclusions, which are direct inputs into subsequent decision-making. This will result in the advancement of the practice of rock engineering in the future, with the concomitant improvement in rock-related safety in mines, both shallow, and deep.

The university lecture notes are currently undergoing further revision and expansion for the book. These revisions are aimed at simplifying the introduction of stress and strain further, but without removing any of the completeness and detail that is necessary for a full understanding of the theory. This short presentation provides a few glimpses of the new text which is in the process of being compiled now. The author hopes to have the manuscript 50% complete by the end of May 2010, and to have completed the manuscript by the end of 2010. It will then be sent for review by prominent practitioners in the field of rock mechanics before it is published in 2011. The SAIMM have agreed in principle to publish the book, and the author will bear some or all of the costs of publishing, because it is extremely unlikely that this more advanced text will gain financial support from the mining industry.

This book is not intended to supplant the learning material for the rock mechanics certificate that will be written for the MQA in the short- to medium-term. However, in accordance with the ninth ECSA exit level outcome: *Independent Learning Ability*, the learning texts for the rock mechanics certificate should provide a basis for life-long learning, and should therefore include a dissertation on the fundamental theory of this nature, otherwise the transition to more advanced texts will be too difficult. Providing uninitiated candidates with watered-down concepts of the fundamentals of rock mechanics - as has been done in the past - will not only fail to do this, but will constitute a barrier to further learning by the candidate, and therefore lead to a permanent barrier to real progress in the engineering science of rock mechanics, as it is practised in the mines in South Africa.

Examples of revised text

a) Proposed title and contents of new text

Theoretical Rock Mechanics for Hard Rock Mining

by

M.F. Handley

Contents

The Finite Element Method
The Finite Difference Method
Hybrid Numerical Methods
Elementary Numerical Solutions

Dynamic Rock Behaviour

Instability in Rock Masses
Elementary Models of Two Seismic Sources
Wave Transmission in Rock
Wave-induced Failure in Rock
An Elementary Method of Seismic Source Location

Rock Mechanics Studies of Mining Layouts

Case Studies of Gold and Platinum Mines

Problems and Solutions

1000 Problems
200 Solutions

b) Page from *Chapter 2: Stress*

The first memoir by Poisson on the same subject was presented before the *Paris Academy* in April, 1828. This work arrived at the same results but by different assumptions, Love (1927, p.10). Cauchy's work contained the correct equations of elasticity as well as currently accepted notions of stress and strain. It appeared in the 1828 volume of *Exercices de mathématique*, and entitled *Sur le équations qui experiment les conditions d'équilibre ou les lois de mouvement intérieur d'un corps solide* (Love, 1927, p.8). Cauchy's and Poisson's work represents a considerable intellectual achievement. The concept of stress in solid mechanics led to the definition of tensors, named after the French word *tenseur*, that which exerts tension or stress (Kay, 1988, p.29). Reviewing the general history of the development of the mathematical theory of elasticity, one can conclude that it was largely a French achievement (see Timoshenko, 1953, and Love, 1927).

Background concepts behind the stress tensor

Before describing the standard *continuum* derivation of the stress tensor as it has come to be accepted in continuum mechanics (see below for a definition of the continuum), the author presents a very simple macroscopic illustration of the notion of stress, which shows its tensorial character. Consider a steel rod of uniform composition and constant cross-section area a subjected to a tensile force along its length. The details of how the tensile force is applied to the rod are not important because of a principle first enounciated by Saint-Venant, that the stress will be uniform across its cross-section some distance away from the point of application of the force (Saint-Venant's Principle, see Love 1927, pp. 131-132, or Timoshenko 1953, p. 139-140).

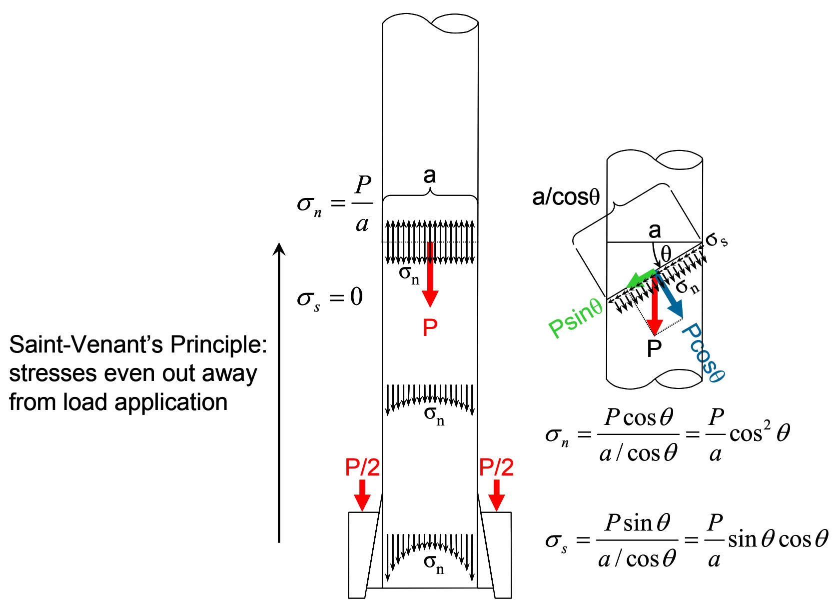

Figure 2.1: Stress components on a plane normal to, and inclined to the axis of a steel rod

c) Page from *Chapter 2: Strain:*

Equation 2.66 is often given in textbooks as a notional definition of strain, but this is incorrect, because in the one-dimensional case there can only exist one component of strain, which is a scalar division as shown. A proper definition of strain will follow later.

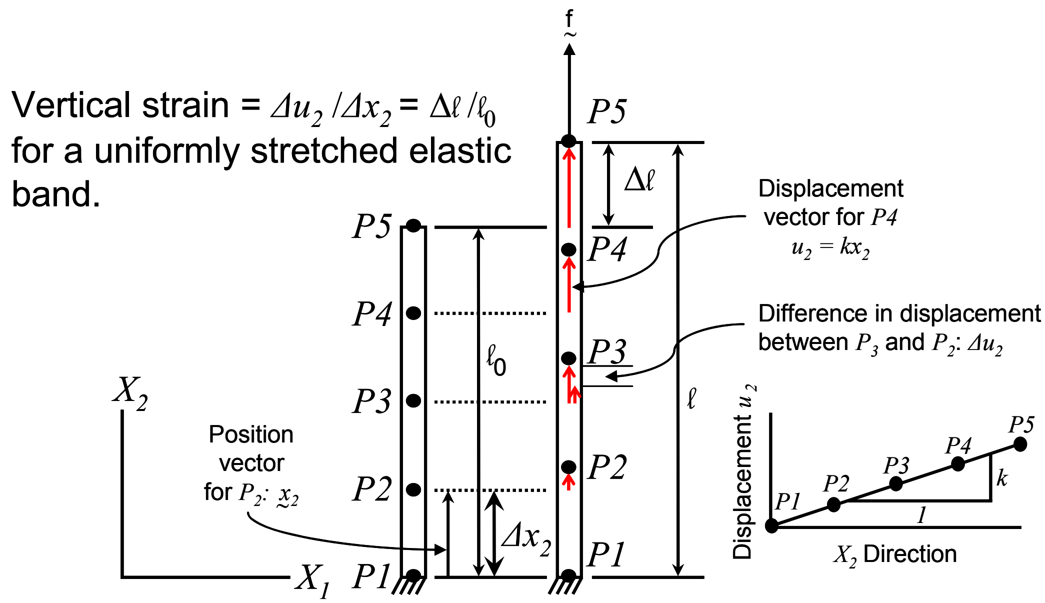

Figure 2.14: Notion of Strain Using the Elastic Band Model

Strain is dimensionless, since it is a ratio of lengths. The amount of extensile deformation depends on the position of the point under consideration in the elastic band, increasing from zero when X_2 is zero, to $\Delta\ell$ when X_2 is ℓ_0 (see Figure 2.14). The positions of five particles in the elastic material, labelled P_1 to P_5, are also shown. The further up the elastic band one chooses a particle, the larger the displacement it experiences when the elastic band is stretched, beginning with zero at the fixed base of the band and ending with $\Delta\ell$ at the top of the elastic band. The magnitudes of the displacements are indicated by the lengths of the vertical arrows below each of the five particles in the stretched elastic band. The displacements increase in the positive X_2 direction, hence the displacement gradient is positive in the positive X_2 direction.

There are two vectors involved here, namely a distance $\Delta \underset{\sim}{x}_2$ between any two points on the band, and a change in the displacement vector $\Delta \underset{\sim}{u}_2$ between the same two points on the band, both labelled in Figure 2.14. The strain tensor is a combination of these two vectors. The intuitive definition of strain is given as the ratio of the two magnitudes of these vectors, since actual vector division is undefined; a way around this will be shown later. The plot of displacement versus position assumes that the deformation in the elastic band is uniform along its length, so that the displacement of points along its

d) Page From *Chapter 5: Crustal Stress*

vertical joint. Stress differences can be very significant over small distances in a rock mass, and this illustrates why adjacent stress measurements would need to be averaged to obtain a plausible overall picture.

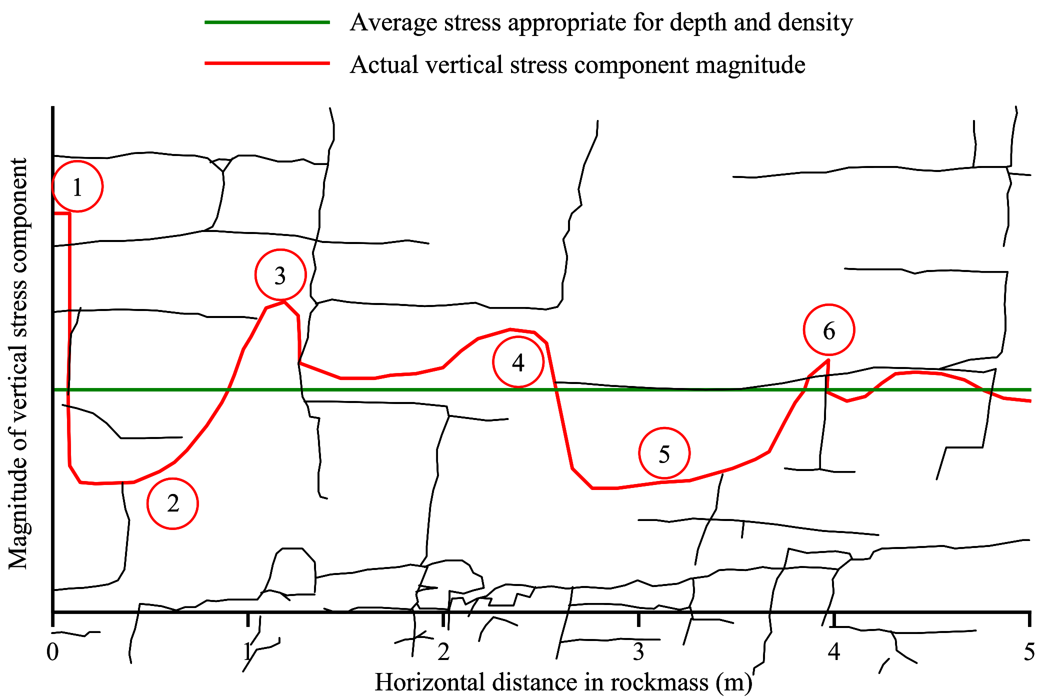

Figure 4.2: Effects of some common features in a rock mass on the vertical stress component

Rock mass equilibrium therefore dictates that the average vertical stress is restricted to being proportional to depth and rock density. Even in these conditions, vertical stresses are still able to have a spread of values around the average value, because of inhomogeneities and structures in the rock, as shown schematically in Figure 4.2. Rock mass equilibrium places no such restrictions on horizontal stresses, which can take on a far wider range of values than their vertical counterparts. The only restriction placed on horizontal stresses are the maximum and minimum values they may assume in relation to the vertical stresses, as dictated by the strength of the rock mass. Therefore horizontal stresses do not have to be related to depth in the way that vertical stresses are. Shear stress components also have greater freedom of variation than vertical stress, with their limitation being the shear strength of intact rock or discontinuities in the rock mass.

Since there is such a wide variation of possible conditions and therefore stress states, all the stress components have to be measured as there are no acceptably accurate crustal stress models from which to deduce them. The variation of the stress state in rock masses as well as the difficulty and expense required to obtain good stress data are major causes for the paucity

e) *References* (Note that these references are still incomplete)

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