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It is Better to be Approximately Right than Precisely Wrong: Why Simple Models Work in Mining Geomechanics

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ABSTRACT: The paper argues that, due to challenges such as large uncertainty and presence of ill-posed problems, simple models are well suited to mining geomechanics. It builds its case by defining what models are, outlining the usefulness of simple models, and explaining how they can be developed. The paper explains that models are necessarily incomplete representations of real world behaviour. The strategy it advocates for constructing a simple model requires a bottom up approach – starting with the simplest possible model, and growing it to capture the essential features of phenomena of interest. The paper calls for engineers to always view models for what they really are: tools of the trade, not unlike the physical tools of the sculptor, for example.

1. INTRODUCTION

In science and engineering, accuracy is the degree to which a measurement or calculated quantity matches its "true" value. Precision is a closely related, but different concept. It is the degree to which repeated measurements or calculations produce same or similar results. It is possible, for example, for a calculation to produce inaccurate but precise answers. This would occur if the answers are consistently close to each other, but are in reality far from being correct.

The first part of the paper's title, "It is better to be approximately right than precisely wrong," is a quote that has been variously attributed to Milton Keynes and Warren Buffet. In modelling, it means that although it may be possible to calculate something very precisely, the result may be meaningless if the underlying model, however elaborate, is incorrect. The result may be precisely wrong! In this case, you would be better off with an approximate answer from a simpler model that better represents the real situation.

We will argue in this paper that the quote succinctly describes the case of mining geomechanics. We believe that computer models are fundamentally essential to geomechanics. The paper seeks to emphasize exactly what models are, what they can be used for and how they can serve our purposes.

The paper will describe three broad challenges in mining geomechanics that make it imperative to prefer simple, approximate models over more complicated, precise ones. These include ill-posed questions and the ubiquitous presence of large uncertainty in mining.

The paper will discuss why simple models are well suited to answering mining geomechanics questions, and why complicated must be avoided at the start of the modelling process. It will outline what constitutes simple models, why they must be used solely as tools, and describe a simple strategy for developing such models.

As part of the effort to justify use of simple models, the paper will examine lessons we can learn from a very common pest, the cockroach, which has survived for many millennia using seemingly simple models of the environment. Parallels will be drawn between an ancient parable on a super-accurate map and the application of numerical modelling to the problems of mine geomechanics.

One of the key issues emphasized in the paper is the role of models as tools, not unlike the hammer and chisel of the sculptor. Engineers have to employ modelling such as Michelangelo used sculpting tools to express his vision of the masterpiece "David."

The paper will illustrate some of the principles advocated through an example in which simple models were used to develop a solution to an ore extraction problem.

2. WHAT IS A MODEL?

We will start off with the description of what a model is. As in science, knowledge and understanding of phenomena in engineering are often embodied in the form of models. As a result, the creation and modification of models is integral to engineering. Engineers use models to predict and control behaviour, and to develop technologies in order to satisfy the demands of society.

What then is a model? A model can be defined as a representation of a system that allows us to investigate the behaviour and attributes of the system, and sometimes, to predict outcomes of the system, under different conditions. The representation is usually

1. A physical model such as an architect's model of a building, or
2. An abstraction such as a set of equations or a computer program.

In this paper, by model we mean abstractions in the form of computer software.

2.1. Incompleteness of a model

By necessity, models are incomplete representations of the real world [1, 2]. If a model were to include every aspect of the real world, it would no longer be a model. This is illustrated by the one-paragraph story titled "*On Exactitude in Science*," narrated by the Spanish writer Jorge Borges [3]. In this story, the cartographers of a fictional empire attained such perfection that they created a map "whose size was that of the Empire, and which coincided point for point with it." Of course this map was so impractical – it took greater effort to use this map than to actually move around the empire – that following generations abandoned it to the "sun and winters."

To create a model, we always make some assumptions about the phenomenon we are representing, and the relationships between the different factors that explain the real world behaviour. We strive to include factors that affect behaviour and exclude those we deem are not essential. As a result of our assumptions and exclusion of factors, our models are always only approximations, and their results are always estimates. It is good practice therefore for us to develop a feel for how far off these estimates are or can be [4]. We should never take modelling results for granted, but always ask probing questions.

2.2. What can we accomplish with models?

Models allow us to attain many useful ends. These include:

1. Development of understanding
2. Proper formulation of questions
3. Reasonable approximation of behaviour and provision of meaningful predictions
4. Aid to design of solutions and decision making

It will be discussed later that ill-posed questions constitute a big challenge in mining geomechanics. A most powerful use of modelling tools is the proper formulation of questions. It has been said that a problem well stated is a problem half solved [5]. Models permit us to perform "what if" analysis, which are experiments with different inputs, assumptions and conditions. Answers to these questions can often lead to the correct diagnosis of problems of key behaviours.

Through the insights they yield, models also help us to reduce uncertainty. Successful modelling does not have to eliminate uncertainty. By merely reducing uncertainty, especially when its costs are much less than the costs of the problem, modelling is often worthwhile. In some cases, models can be explicitly used to assess the likelihood of events and to help formulate plans for coping with such events.

2.3. Models are tools

"Tool" refers to any device used to perform or facilitate work. Just as a hand tool might be used to fix a physical object, computer models can be used to accomplish a task. They are tools of engineering just as hammers and chisels are tools for sculptors. They are tools in the sense that they allow us to explore problems in exhaustive detail without having to do the lengthy and involved calculations; the computer and software do all the drudge work, which enables us to analyze and design.

Through vision, and skillful use of the hammer and chisel, Michelangelo created the masterpiece known as "David." Likewise our models do not in themselves solve problems. We use them to answer questions.

3. CHALLENGES OF MINE GEOMECHANICS

Engineering can be defined as the process of providing solutions to the problems of clients as efficiently as they can, based on the resources (budget, manpower, time, data, etc.) available to them. The third part of this definition is about challenges. Although these challenges may not be unique to mine geomechanics, they feature strongly in this field. We will examine three of the most important categories of challenges to effective mining geomechanics.

3.1. Large uncertainty

Mining is carried out in the geological environment, which offers one certainty: uncertainty. For our purposes, uncertainty [5] is defined as the

- Lack of complete certainty, the fact that the "*true*" state or outcome is unknown

- Existence of more than one possibility, or
- Chance of being wrong.

It gives rise directly to risk – the situation in which some of the possibilities involve loss, catastrophe or other undesirable outcomes [5].

In the geological environment, the likelihood of encountering unanticipated conditions is almost always high. The complex behaviour of geologic materials and the distribution of their properties in space do not also lend themselves easily to investigation or measurement. Consequently, rock mechanics modelling has been characterized as belonging to the data-limited categories [6] of Holling's classification of modelling problems [7].

As has been argued by others [6], we believe that it is dangerous to apply the methods of exactitude to mining geomechanics problems. Unfortunately, however, the elegance of elaborate models has so fascinated many an engineer that answers have been sought which fit models, rather than conform to reality in an uncertain world.

3.2. Ill-posed problems

Geomechanics problems in mining often come to us as questions, ill-posed [6] by clients who know they have difficulties, but which they cannot always articulate. Ill-posed problems often have one or more the following characteristics (adapted from [8]):

1. Under-specification or the absence of crucial information that somehow has to be determined
2. Unconnected pieces of information that require understanding in order to determine what is important and what has to be ignored
3. Inconsistent, conflicting or contradictory information as a result of which solutions cannot be envisaged, even in principle
4. Uncertainty as to what solution method or approach that has to be applied
5. Ambiguity or the possibility of different answers, depending on what assumptions are used, and/or
6. Intractable answers that exist in principle, but which we have no reasonable ways of determining.

The first battle in many mining geomechanics situations therefore is to understand what the problem is. After doing this, we are better placed to provide adequate answers. John Tukey, the renowned statistician, once wrote [9]: "Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made more precise."

3.3. Limited resources – personnel, budget, time

It is not uncommon for mining geomechanics engineers to work with limited resources – small budgets, tight deadlines and insufficient manpower. These constraints can be quite severe. Let us take the situation of a rock mechanics engineer in a mine as an example. He/she has several tasks to fulfill each work day in different parts of the operation. This can leave very little time for reflective thinking or strategic problem-solving.

Personnel, well trained in the use of modelling tools and equally well grounded in practical geomechanics, are scarce. In many firms and companies today, the senior engineers who very well understand the practical geotechnical issues that need to be resolved are often not that comfortable with numerical modelling tools. Even when they are, they have only limited time to work with them. As a result they rely on junior engineers for modelling expertise. Often however, the junior engineers, although comfortable with software, have not as yet acquired sufficient understanding of real-world geotechnical problems, and generally require clearly defined questions.

This leads to a situation in which those building the models, may not be sufficiently aware of the weaknesses or assumptions in their models, while those who make the decisions, may not fully understand what the models are doing or how they work (similar to situation in financial risk modelling described in [10]). We will argue later on that the best way to rectify this situation is to make modelling tools as simple-to-use as possible. This affords senior engineers time and opportunity to also "play" with models and more fully utilize their experience on problem-solving and design.

3.4. The opportunities of constraints

It is easy to view the challenges to mine geomechanics modelling as negatives. However, they can be looked at positively, as opportunities to innovate; given fewer resources we are forced to make better decisions [11]. The only question is, "What modelling tools are best for addressing mining geomechanics problems under our constraints?" We propose an answer next.

4. SIMPLE MODELS AS USEFUL TOOLS FOR MINING GEOMECHANICS

We have determined that models are powerful tools for engineers in the quest to determine the best possible solutions to problems, under finite (limited) resources. There are costs (time, effort and money) associated with modelling itself. If we are to be successful, we have to keep those costs low.

Let us briefly revisit the parable "*On Exactitude in Science*" for an important lesson on modelling. The cartographers' "point for point" map, although perfectly accurate, was absolutely impractical. The effort and resources required to create and read that map far exceeded any utility it offered. The parable teaches that in the practical world, simple and easy-to-use tools can be much more useful than very elaborate ones, which although more accurate, may be too costly or impractical to build or use.

In modelling, simplicity is also referred to sometimes as parsimony. The principles of parsimony require that we take great care to develop computational algorithms and models that use the smallest possible number of parameters in order to explain behaviour [1]. They encourage us to avoid unnecessary complexity and pursue the most straightforward approaches.

Simplicity applies not only to the concepts (essence of phenomena) captured by models, but also to how straightforward it is to use modelling tools. Easy-to-use tools free engineers from drudgery, enabling them to dedicate brainpower to skeptical probing of what can go wrong. We will explore this issue further in a later section.

4.1. Reasons for simplicity

As we have discussed large uncertainties exist in mining geomechanics. As well, questions are commonly ill-posed and must be solved under the tight constraints of time, budget and human resources. Under these conditions precise answers are not the most useful. Often, understanding of behaviour and interactions between various factors must take precedence.

Given the above-described challenges, it is better to leave out some details of a problem, or imperfectly cover those details (keep models simple) than to try and cover every conceivable aspect but to create an overly complex model. Models that yield "good enough" answers and help us to make decisions suffice [1].

Uncertainty is dealt with through parametric and scenario analysis – the assessment of possible ranges of behaviours through variation of input properties and consideration of different conditions – or statistical methods. These approaches all require development of alternative models, accompanied by multiple computations.

Simple models facilitate the use of such techniques. Through the diversity of assumptions and scenarios that we can consider, simple models can help us to develop designs that are robust to unexpected or unusual conditions.

The lack of exact numbers should not be equated to knowing nothing [5]. The information they give reduces uncertainty in our understanding and helps us improve the quality of the decisions we have to make. As we have discussed, we can use such models to better define ill-posed problems, and test our knowledge and assumptions.

There are many other reasons for adhering to the principle of simplicity in the development of mining geomechanics models. Every parameter or input included in a model introduces a source of uncertainty, since we have to assign it a value. Therefore keeping parameters to a minimum reduces uncertainty in the solution process.

Simple models and modelling tools are also much easier to understand and explain. They make it easier to think through problems. When we start out with simple models and use increments in our understanding to direct further modelling, we are able to identify "unnecessary" details that have insignificant effects on the model system.

Although it can be argued that simple models are flawed (but we should remember so is every other model no matter how complicated), they should be judged by how much they explain compared to how many input parameters they require. Viewed this way, their strengths over more sophisticated approaches quickly become evident. They are generally easy to use and manage, and much quicker to compute. As a result they are oftentimes of great merit due to the time savings they afford.

4.2. What is a simple model?

Our preceding discussions indicate that the greater the number of simplifying assumptions made about the real world phenomenon we are studying, the simpler the resulting model. We have concluded therefore that the ultimate goal of modelling is to create parsimonious models – models that have great range of explanation using the simplest possible concepts and smallest possible number of inputs.

This brings us to a more formal definition of what constitutes a simple model. It is the simplest description of a complex phenomenon that still captures those features we are interested in. It is the model for which any additional gain in explanatory power through inclusion of more assumptions or parameters is no longer warranted by the increase in complexity.

The art of modelling then reduces to finding the simplest models that do outrageously good jobs at describing complex phenomena [10]. It aims to say much with little [1].

4.3. A simple strategy for building simple models

The definition of what constitute simple models alludes to a strategy for building them. The process starts with careful reflection on the problem we are trying to solve. This exercise helps us to be clear about our purpose.

We then proceed to build models from the bottom up. We begin with radical simplifications. If investigation shows that the phenomenon of interest cannot appear at this level of simplicity, we add to this model as parsimoniously as possible.

The manner in which we enlarge our model is guided by the understanding we gain from study of the influence of each added assumption (concept) or variable. If we determine an addition to be irrelevant to our particular task we eliminate it.

This process strengthens our fundamental understanding of the phenomenon we are studying. The care and detail we exercise in constructing our simple model compels us to avoid hand waving (the failure to rigorously address central issues or the glossing over of important details). It forces us to strive to fill gaps in our understanding.

When a model is built from the bottom up, it is deemed to have met its goals the moment it passes the test, “Is it fit for its purpose?”

4.4. The trouble with “complexity” and “precision”

When we start with a model that is too complex, we can quickly reach the point where understanding is replaced by “blind faith.” A model that starts off complex – has many inputs, assumptions and aspects – actually obscures understanding. When too many details are included before the behaviour of the model is appreciated, interactions among its components will not be clearly apparent. Such a model becomes little more than a “black box” which mysteriously converts input values to numbers or charts. As a result, its outcomes are not readily interpreted and are difficult to subject to commonsense tests. Rather than clarify the model confuses.

Obsessive focus on modelling detail often coincides with fascination with precision. Under the considerable uncertainties and other constraints of mining geomechanics, obsession with details we cannot get right, and precision we have no hope of attaining, hinder our ability to make decisions. Although the ranges of values from simple models may seem less sharp, they offer the advantage of keeping us honest and humble about what we are doing [10] – estimating. They help us ward off the “hubris of spurious precision [10]”.

4.5. Lessons from nature

Studies of living organisms can indicate to us optimal strategies for handling large uncertainties and unexpected changes in conditions. The length of time a species has survived is a good measure of how it has adapted under such conditions [12, 13].

The common cockroach is an example of an organism that has survived for many, many millennia because of its strategy for dealing with unanticipated environmental changes [12, 13]. Scientists have determined that it uses very simple or “coarse” rules (models) for deciding what actions to take in response to environmental changes. Given a wide set of possible inputs about the environment, the cockroach ignores most of these details and focuses on a select few.

At first glance, it appears that such an approach is not optimal in the least. However, research has shown that although suboptimal for any one environment, “coarse” rules are far more efficient over a wide range of different environments. This is especially true when some of the changes in these environments are unforeseeable. Coarse rules are much more likely to anticipate risks and bring about necessary adjustments.

The cockroach’s use of simple models seems to tell us that precision and focus on the known comes at the cost of reduced ability to address the unknown. When we spend less time focusing on detailed investigation, we can spend more time thinking and reacting to unknown conditions.

5. A NOTE ON EASE-OF-USE

From the example above, biology seems to indicate that we must run our simple models with different inputs and assumptions in order to cope well with our uncertainties and constraints. This requires that models be developed, and changed or manipulated with relative ease. They must be easier and less expensive to manage than the real world.

User-friendly, intuitive software interfaces make this possible. Given the challenges of mine geomechanics modelling, it can be argued that user-friendly interfaces can have far greater impact on the work of engineers than sophistication in underlying model concepts.

The design of a user interface must consider the productivity of users [14]. It must ensure a short, gentle sloping learning curve. Practitioners are keenly aware that people’s time costs more than computers and software. The real cost of a modelling tool, therefore, is not so much purchase price as the user effort it demands.

Intuitive, graphical ways of displaying results are also important since they help engineers make sense of model results. Visual representation of data is satisfying to most people, because it helps them to make sense of model results in instinctive ways.

6. EXAMPLE OF GOLDEN GIANT MINE

The Golden Giant Mine is a gold operation in the Hemlo camp in Northern Ontario, Canada. The orebody at the mine consists of a main and a lower zone. The main orebody, which is tabular, has a strike length of 500 m, an average thickness of approximately 20 m, and dips at angles between 60^o and 70^o [15, 16, 17]. The lower zone is 30 to 80 meters below the main zone. The gold-bearing ore is located along the contact of a metasedimentary rock formation with felsic metavolcanic rocks.

6.1. Description of problem

Near the main shaft was a pillar that was open above and mined out below. It contained 660,000 tonnes of high grade ore. The original mine plan was to mine all ore at depth, abandon the shaft below a certain level, and extract the shaft pillar as the final mining block. Analyses indicated, however, that a significant portion of this high grade ore would be lost unless the shaft pillar was mined at the same time as the deep ore.

At the same time, for more than a decade, this pillar had been a source of concern, particularly due to its proximity to the main production shaft. Preliminary modelling had indicated that the pillar, and nearby infrastructure, were under significant stresses as a result of mining throughout the Hemlo camp [18]. There were also indications that the stress levels were increasing and would adversely impact the shaft stability.

The task therefore was to design an extraction sequence for the shaft pillar that would not jeopardize the shaft's integrity. It was evident that the solution would have to reduce the stress concentrations around the shaft.

6.2. Constraints and information from prior experience

There were a number of challenges that constrained the numerical modelling tool(s) that could be used on the project. The overall extents of the mine (stopes, infrastructure and other excavations) were large, and laid out in complex, three-dimensional fashion. Due to the tabular orebody, the stopes were flat-shaped. The infrastructure excavations on the other hand were more regularly shaped.

As well, information or data on stress levels and rock mass properties (especially post-failure parameters) were very scant. (Evidence of high stress damage in parts of the mine existed though.) Lastly, a solution to the problem had to be found in short time.

From prior experience with elastic three-dimensional models of the mine, engineers knew that model zones with stresses exceeding 98 MPa corresponded well with zones of observed stress damage.

6.3. Simple elastic modelling and the determination of mining strategy

A displacement discontinuity-based boundary element program [19], which readily accommodated the different shapes of excavation, was selected as the analysis tool. It could handle the large extents of the mine and the complex, three-dimensional layout. It also offered the ease of model building and computational speeds for developing a solution within the required time. On the other hand however, it required representation of the three primary rock mass types – orebody, metasedimentary and metavolcanic rocks – with only one set of elastic properties.

Despite the simplified assumptions of homogeneous material and elastic behaviour, the numerical modelling tool showed three-dimensional stress flow patterns and stress concentrations that matched observations at the mine [17]. It helped engineers understand the influence excavation layout had on stress concentrations within the mine. Each single model run took about two – three hours to compute, compared with the 20 or more hours it took with a more detailed (multi-material) boundary element program.

Numerical studies with the simplified model helped establish that the excavation of a destress slot could reduce existing stresses near the main shaft, and control stresses induced during mining of the shaft pillar; the slot pushed high stresses away from the main shaft into non-orebearing rock mass zones. The tool allowed engineers to experiment with several alternative slot geometries (location, dimensions, and excavation sequencing) and extraction sequences for the shaft pillar and deeper lying ore.

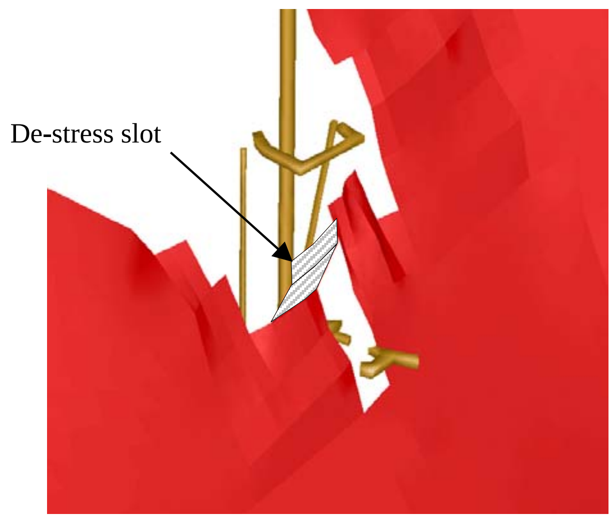

Figure 1. Three-dimensional view of destress slot geometry and location

Figure 1 provides a three-dimensional view of the final slot geometry and location. (On the figure, the tabular shaded zones represent excavated stopes.) The slot was to be 55 m wide by 58 m high, and parallel to the main orebody, with a dip of 60^{o} towards the shaft.

Displacements from the numerical modelling indicated that the destress slot would experience closure on the order of one meter. This signified that the slot thickness had to exceed a meter [17]. If this condition was not met, the walls would make contact and significantly reduce the efficiency of the slot.

This also led to study of the properties (primarily the Young's modulus or stiffness) of the material for backfilling the slot (there was no way a slot of that size could be left open). For this investigation, a finite element program was used; it could accommodate the multiple material properties integral to the study. Although this program performed only two-dimensional analysis, that was sufficient for this stage of design. The modelling outcomes showed that the material used to backfill the slot had to have very low stiffness – far less than one fiftieth the stiffness of the host rock.

6.4. Real-world performance of destress slot

Excavation of the destress slot, according to the sequence developed from the numerical modelling exercise, began in early 2002 and ended in summer 2003 [15]. The slot was backfilled with a soft paste. Measurement of its performance, which was attained through comprehensive instrumentation, has shown that it met its goals.

7. CONCLUDING REMARKS

In this paper, we have argued that, in the face of large uncertainties, ill-posed questions, and limited resources, simple, easy-to-use, modelling tools are most practical for mining geomechanics. They facilitate the modelling process.

We have also shown that the strategy of building up models from the bottom up tends to restrict the creation of complicated, and potentially meaningless, models. We are not advocating simplistic, trivial design and analysis. What we are saying is that mining geomechanics is best served with the use of the simplest models that fulfill our purposes.

We will end with an analogy from the world of biology – the growth of a tree sapling [11]. Given enough water and sunshine a sapling will grow. However, with careful pruning – removal of low-hanging branches – in early the early stages of development, the sapling will not merely grow but flourish; it will grow faster and become taller and stronger. This is because the pruned sapling will not waste precious resources on growth that does not serve its ultimate purpose.

The same is true of modelling. When we carefully prune or models and keep them simple, they will help us thrive in solving mine geomechanics questions.

If this paper gives pause for thought any time we have to solve mining geomechanics problems, it will have fulfilled its purpose.

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