

2008

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Recommended Citation

R. Frith and M. Colwell, Geotechnical Design at a Mine Site Level - We Have No Choice, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2008 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February 2019
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GEOTECHNICAL DESIGN AT A MINE SITE LEVEL – WE HAVE NO CHOICE

Russell Frith¹ and Mark Colwell²

INTRODUCTION

It is not that long ago that strata control was the domain of the Under Manager. When the authors joined the Australian Underground Coal Industry in the late 1980's, few if any mines or mining companies employed qualified geotechnical engineers and the determination of roof support rules and coal pillar design for example were done largely within mine management. One only has to look at the list of participants at the various UNSW pillar design and geomechanics courses in the early to mid-1990's to substantiate the above statement.

Geotechnical engineering in the coal industry was seen in a research and consulting role at that time, with specialist geotechnical engineers being employed by the likes of ACIRL and CSIRO and used by mine sites to advise on the causes of roof control problems and unplanned events after they had occurred. It was out of this environment that the consulting firm Strata Control Technology was formed.

By the mid-1990's, the formalised Strata Management Plan was beginning to evolve, it being focussed on the use of roof monitoring and mapping combined with the traditional observations of miners in order to improve the reactive ability of mine sites to changing strata conditions. The consulting firm Strata Engineering was at the forefront of developments in this area and still regularly publish today on the use of strata monitoring data for decision-making purposes (Thomas 2006). The current situation is that most mines now employ a person in the defined role of the geotechnical engineer, as formalised strata management is now firmly entrenched as one of the core requirements of underground coal mining in both NSW and QLD.

However despite the substantial improvements in strata management practices at coal mines in the last two decades, major strata control losses are still sustained by longwall mines on an occasional basis with consequent large business losses (especially given the high coal prices and longwall production levels compared to 20 years ago). No amount of roof monitoring data, borescope observations, hazard mapping or local mining experience was presumably able to either predict or prevent these losses being sustained. A critical element of the strata control process must at times be missing, which is the subject of this paper, namely effective geotechnical design, particularly as it relates to the role of the mine site geotechnical engineer.

In considering the role and importance of geotechnical engineering design in coal mining, several basic questions will be addressed:

- (i) What are the basic elements of engineering design?
- (ii) What does the legislation require in this area?
- (iii) Does it offer benefit to operating mine sites and the industry in general?
- (iv) Why is the mine site geotechnical engineer so important to the future of the coal industry?
- (v) Where is the industry up to and what are the potential areas for further development?

In answering these questions, the authors will address the title of their paper "*Geotechnical Design at a Mine Site Level – We Have No Choice*" and provide a general response to the question posed by Ross Seedsman and his co-authors several years ago in the paper entitled "*Chain Pillar Design – Can We?*" (Seedsman et al 2005), which discussed the design limitations and various required outcomes for chain pillars at that time.

WHAT IS ENGINEERING DESIGN?

Geotechnical engineering is an engineering discipline and therefore the general requirements of engineering design logically apply. Some of those required elements are listed as follows:

- It is undertaken by suitably qualified and competent engineers (this will be discussed in more detail later in the paper).
- It utilises engineering parameters (e.g. strength of steel, modulus of concrete, applied loads/stresses etc.) that can either be measured or estimated prior to construction.
- It converts engineered based input parameters into a design output that is linked to some form of risk-based measure (e.g. Factor of Safety, probability of failure etc.).

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- The design is implemented or constructed usually under the direct supervision of the designer or team of designers.
- The design methodology is transparent in its content, is numbers based and is amenable to independent review and audit.

What is not engineering design (as it does not meet the above requirements) are strata control practices that unfortunately still find use in the coal industry and are based on such considerations as:

"the roof looks to be in good condition/has only moved 3 mm prior to longwall retreat, therefore secondary support needs for extraction are minimal"

"we'll do what we have done before because it has worked in the past"

In fairness to the industry, without the availability of well founded geotechnical design methods that are focussed on coal mine strata control, mining personnel have had little option but to revert to site-specific observational "design", i.e. essentially rely on previous local experience and in many situations this has proven to be effective. However such methods tend to be unreliable when the geotechnical conditions change but go unnoticed. Only when strata control difficulties become visibly apparent (often during longwall retreat) do such changes in conditions become evident, by which time significant business losses are usually sustained even if effective remedial measures are put in place prior to a major fall of ground.

There is also at least one well demonstrated characteristic of mining geomechanics that limits the effectiveness of the observational design approach, that being the step-change in behaviour/condition.

A good example of step-changes in roadway roof behaviour is found in data published by Gale et al (1992) whereby the roof softens in a series of discrete steps that are driven by ever-increasing roof displacement – see Figure 1. Roof behaviour is clearly not gradational (i.e. roof stability is not lost incrementally with increasing roof displacement) and a roof environment that is visibly stable at say 2 mm of movement may in fact be similarly stable at 10 mm but highly unstable at 20 mm with several metres of associated roof softening. The potential for such step-wise reductions in roof stability are a major obstacle to the reliability of observational type geotechnical design as demonstrably, the visible conditions or magnitude of the measured roof displacement prior to secondary extraction will not always provide a reliable basis predicting any associated roof stability changes.

It is noted that in addition to roadway roof behaviour there are similar step-wise changes in such subject areas as mining subsidence, coal rib stability and overburden weighting.

The contention of the authors is that the only way that the industry can improve its ability to predict strata stability prior to mining (whether development or secondary extraction) and prescribe effective control measures is through the routine use of credible geotechnical design that conforms to all of the basic requirements for engineering design listed previously.

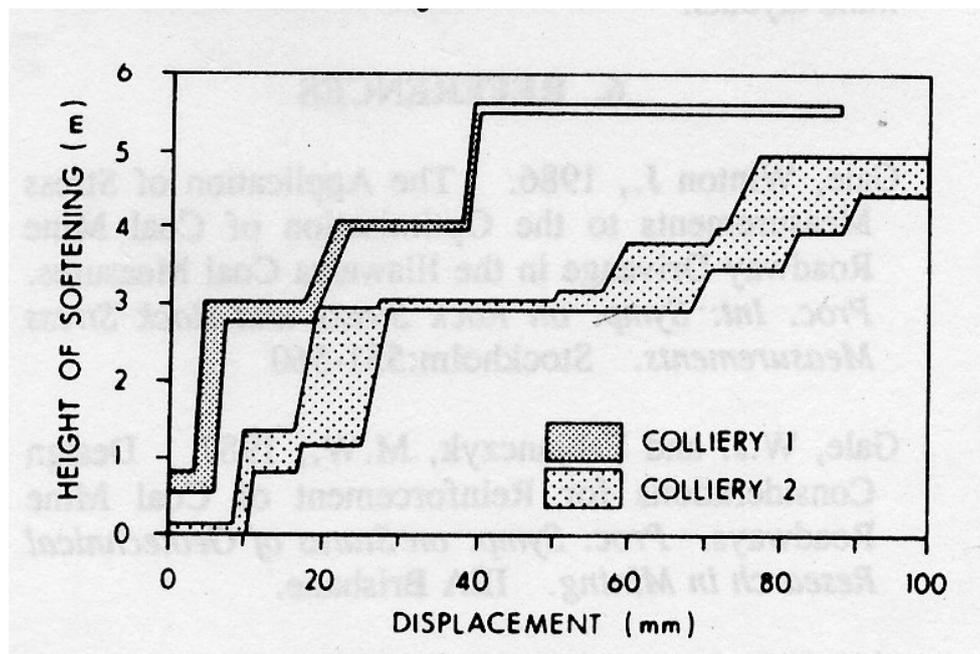


Figure 1 - Roof softening progression with displacement (Gale et al 1992)

Whilst on the subject of geotechnical design, one other subject area is commented upon. It is realistic to suggest that there is a point of view held by a significant segment of the rock mechanics fraternity that numerical modelling provides a researcher/consultant with a tool to undertake *real engineering* whereas empirical techniques offer only "simplistic formulae" (Tarrant, 2005). It would be naïve for any researcher, whose objective is to provide an underground coal mining industry with a widely accepted empirical geomechanics model, to be unaware of this point of view.

The first point to make is that empirical methods of design are absolutely not "trial and error" as was suggested by Tarrant (Tarrant 2005) in attempting to justify his adoption of a numerical modelling design approach to tailgate strata support in preference to existing empirical methods.

The authors would also like to note that probably the greatest scientist who ever lived (Sir Isaac Newton) made liberal use of empirical methods (that being the use of observations and data in developing sound reasoning) in his research work that ultimately led to his theory of universal gravitation as contained in what is generally accepted to be the greatest science book ever written, his *Principia* of 1687 (Bardi 2006). Furthermore those exact same principles were used by NASA nearly 300 years later in arguably man's greatest achievement, namely the moon landings of the late 1960's and early 1970's.

If the use of empirical methods were good enough for Newton in trying to develop an understanding of the universe and NASA in sending man to the moon, they are certainly good enough for the geotechnical engineering fraternity in trying to establish the fundamental laws of strata mechanics in coal mines.

The authors have in the past and will continue into the future to combine empirical observations and data with sound analytical methods and reasoning in attempting to further our understanding of the response of the geotechnical environment to mining and provide improved methods of analysis and design. To the best of the authors knowledge, this is the only approach that has been able to provide mine site geotechnical engineers with the transparent and useable design and assessment tools that they so desperately need. The current availability of such tools will be discussed in more detail later on.

WHAT DOES THE LEGISLATION REQUIRE?

Whilst the relevant legislation in NSW and QLD is worded differently, the intent in relation to strata control practices are essentially the same, as follows:

- (i) investigate those factors that influence strata stability
- (ii) estimate the likely geological/geotechnical conditions to be encountered
- (iii) estimate strata stability in the conditions likely to be encountered
- (iv) prescribe support measures to ensure strata stability

The QLD Regulations even go so far as to use the phrases "strata support methods shall be designed" and "records of numerical calculations used..." Clearly the intent is for a pro-active and engineering based geotechnical design process.

Another legal requirement that all practicing geotechnical engineers should be aware of is AS3905:12 (1999) entitled "Guide to AS9001:1994 for architectural engineering and design practices". Whilst this standard is not directly quoted in mining legislation, one of the defences under Queensland Mining Law for example, is that due consideration has been given to relevant standards and guidelines. Clearly this is one such standard and the industry would possibly benefit by being aware of and adopting its general principles, which are not onerous and would almost certainly contribute to improved practice.

Basically the relevant legislation requires that credible geotechnical design is undertaken on a pro-active basis. Given this, the paper will now examine some of the other associated benefits to both operating mines and the industry in general.

BENEFITS TO OPERATING MINES AND THE INDUSTRY IN GENERAL

In addition to the benefit of compliance with the requirements of relevant mining law and the defence position that it provides, there are other tangible benefits of ensuring that credible engineering based design is undertaken for all geotechnical matters.

As an example, few of us would travel on commercial airliners if we suspected for one second that Boeing and Airbus Industries simply took their best guess, built planes that looked about right and then relied on a management plan should problems eventuate during operations. Whilst detailed and rigorous engineering design is no guarantee of success in any field of engineering, the likelihood of problems occurring must surely be significantly reduced in line with its use.

When the consequences of inadequate strata control are considered (safety, financial and reputation), the case for and resources required to undertake credible engineering design for strata control practices are easy to justify. It is simply not good business to take undue risks in the area of strata control and the quotation at the bottom of all of Dan Payne's e-mails holds true:

"Nature cannot be tricked or cheated. She will give up to you the object of your struggles only after you have paid her price" (Napoleon Hill)

In this case, her "price" is the use of fit for purpose ground support/pillar dimensions etc. and the most reliable method of achieving this is surely through the use of credible and effective geotechnical design.

The other obvious benefit to operating mines of credible geotechnical design being undertaken by their own personnel are the professional developments that on-flow. There is nothing that focuses the mind of an engineer more than having to specify and fully document a geotechnical outcome in a transparent and auditable manner and then take responsibility for it by signing off the relevant documentation. This is the basis of real "engineering" as compared to the "geotechnician" type work undertaken in the on-going implementation of the strata management process (e.g. extensometry data collection and processing, borescoping, mapping etc.).

There is little doubt the coal industry will benefit hugely as more of its geotechnical personnel become proficient in the various areas of geotechnical design and apply them on an on-going basis at operating mine sites. It is also noted that this has the added advantage of having the designer fully involved with the construction process (listed earlier as a requirement of engineering design in general terms) which is rarely the case when the designer is a third party consultant.

WHY IS THE MINE SITE GEOTECHNICAL ENGINEER SO IMPORTANT TO THE FUTURE OF THE COAL INDUSTRY?

Some may argue and indeed have argued that there is no requirement for the mine site based geotechnical engineer to be able to undertake geotechnical design. His or her role is apparently to collect and collate the geotechnical data, run the strata management plan, manage secondary support contracts and simply draft support plans as they are required. It has even been suggested that geotechnical design is essentially beyond the mine site geotechnical engineer's ability and that it should be solely the domain of those experienced persons who have come through a research and consulting background. The authors strongly disagree with this view and furthermore consider such a view would have long term detrimental effects.

If one examines the age and experience/background of senior geotechnical consultants working within the coal industry as well as the establishment of the various geotechnical consulting groups, some worrying trends emerge. Most senior geotechnical consultants are ex-ACIRL and it is now over 10 years since the geotechnical group within ACIRL essentially ceased operating. Most of the underground coal geotechnical consulting businesses were formed during the 1990's. To the authors' knowledge only one geotechnical business has been formed this current decade by any person(s) working in the Australian underground coal industry but not already actively operating as a geotechnical consultant.

However the most disturbing issue relates to an ageing group of senior geotechnical consultants/researchers within Australia; unfortunately most are on the wrong side of 50 and as best as the authors' can ascertain very few (if any) less than 40. During a period of unprecedented growth in Australian underground coal mining that is predicted to continue for many years yet (albeit with cycles), the reality is that within the next 10 years many of the senior industry geotechnical personnel are likely to be retired or at the very least significantly reducing their geotechnical activities.

Clearly this is all indicative of an unsustainable situation and more to the point, an underground coal geotechnical knowledge "void" is potentially looming unless the industry recognises this and puts some succession planning in place.

The real problem is that the geotechnical training grounds are now gone or nowhere near as vibrant as they once were. The mining group at ACIRL is no longer in existence and large research establishments such as the Chamber of Mines in South Africa, the USBM (now NIOSH) and Bretby in the UK are either closed down or only a shadow of their former selves. Similarly the number of strata control Ph.D's being awarded annually is at a very low level.

Whilst the authors are not suggesting that having a Ph.D is a requirement for a minesite strata control engineer, there is little doubt that one gains immeasurable benefit from spending three to six years studying an aspect of coal mine geotechnical engineering in the greatest detail and attempting to advance the associated level of knowledge and engineering. As well as then passing on that geotechnical knowledge and research "know-how" to others (i.e. mentoring).

With the traditional training grounds effectively gone and current strata control consulting companies being in huge demand and therefore doing much less geotechnical research than they used to, the question has to be asked as to what is the way forward?

WHERE IS THE INDUSTRY UP TO AND SUGGESTIONS FOR THE FUTURE?

Without doubt the industry has made significant advances in the area of professional development for strata control personnel, but clearly more needs to be done. Many of the mining companies have offered great support for the Strata

Control Graduate Diploma offered by the UNSW and to-date more than 25 industry personnel have either completed the course or are in the process of completing it next year. This if nothing else is a clear indication that the role of the strata control engineer based at a mine site is becoming a specialist function (which it should be) requiring specific knowledge and training. The industry sees benefit in providing their personnel with appropriate qualifications and the individuals involved are prepared to opt for a career in this area.

However gaining a Graduate Diploma in Strata Control, a Masters in Rock Mechanics or even a Ph.D is not the end of the process. Competence in any discipline is a combination of skill and knowledge. A large parcel of knowledge can be gained in a classroom environment and tested under exam conditions. However as per the route to becoming a professional engineer or mine manager, a tertiary qualification is only a minimum requirement and the start of the process, not the end point. The competence requirement that is necessary to complement the knowledge component is that of skill, which is only borne of experience in the field. It is this aspect that now needs to be the focus of the industry so that mine site based strata control personnel become "engineers" in every sense of the word.

To achieve this, the following minimum requirements are suggested by the authors:

- (i) Training and Support – mentoring/supervision in their role by suitably qualified and experienced personnel. Mentoring is a well recognised vital aspect of personal and professional development and needs to be intrinsic to our industry.
- (ii) Design tools and Methods – in the same way that a ventilation officer would be unable to function effectively in their role without the availability of Ventsim for example, so a geotechnical engineer cannot function without fit for purpose design tools. A number are already available such as:
 - UNSW pillar design method(s) – now available in Windows based software format as the "FOS Calculator" from Colwell Geotechnical Services
 - ALTS 2006
 - ADRS (Colwell 2004)
 - NIOSH produced publications and assessment software
 - ACARP project final reports that contain at least guidelines in a number of subject areas from research work (e.g. Frith and McKavanagh 2000, Hill 2006).

Clearly not every strata control design problem is currently covered by freely available design and assessment methods, but this situation is improving over time, in particular due to the efforts of the current Colwell Geotechnical Services industry project, whereby an analytical model for roadway roof stability is being combined with a large industry database of roadway roof stability experiences in an attempt to provide empirical/analytical design methodologies and software for mine roadways in longwall mining.

Even if a given mine site or mining company wishes to utilise third party providers for geotechnical design services, the need for mine site based geotechnical design capability still remains, as there is still the basis by which such consulting advice is either accepted or rejected by the mine site. It is well established that there is a fundamental need for decision-makers on engineering matters to evaluate third party consulting advice before implementation and make an informed decision as to whether to accept or reject it. Such a decision must be made on a credible basis, the undertaking of independent geotechnical design/evaluation by mine site personnel being an effective method of doing so.

The need for site based geotechnical assessment and design ability still remains and therefore, providing a full suite of design tools and associated professional development support should be one of, if not the top priority for the geotechnical fraternity within the Australian Coal Industry.

SUMMARY

The paper has attempted to provide a thought provoking discussion on the future importance of the mine site geotechnical engineer to the Australian underground coal industry and why it is vital that those persons have the skills and tools to be able to undertake credible geotechnical design as part of their job functions. That is not to say

that none do so at the current time, but the intensive use of third party geotechnical consultants indicates that their primary function is in the on-going implementation of the strata management plan.

The reasons as to why geotechnical design needs to be undertaken routinely at a mine site level are many and varied, but include:

- compliance with mining law
- prudent management of business risks
- the continuing professional development of mine site strata control personnel
- the "aging" geotechnical population within the industry and the non-availability of the traditional training grounds for such personnel
- the large amount of geotechnical design that needs to be undertaken often in a short timeframe, making it impractical for third party consultants to provide a comprehensive turn-key type design service.

The paper is not intended to be critical of the industry; in fact it fully recognises the significant advances that have been made in the past twenty years. Its main point is that the focus of strata control design practices within the industry must inevitably change from the current crop of consulting providers to mine site based engineers and that the industry will benefit significantly as a result. Whilst the industry has already made significant progress along that track, there is still much to do in order for the mine site based person to transit from the geotechnician to geotechnical engineering role, this being best achieved through the establishment of geotechnical design capability at the mine site level.

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