Coal Operators' Conference

Faculty of Engineering and Information Sciences

2008

The Limitations of the Observational Method for Roof Support and Subsidence Management in High Production Longwalls

Ross W. Seedsman
University of Wollongong, seedsman@uow.edu.au

Publication Details

This conference paper was originally published as Seedsman, R, The Limitations of the Observational Method for Roof Support and Subsidence Management in High Production Longwalls in Aziz, N (ed), Coal 2008: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2008, 67-74.

THE LIMITATIONS OF THE OBSERVATIONAL METHOD AND MONITORING PROGRAMS FOR HIGH PRODUCTION LONGWALLS AND AN ALTERNATIVE FRAMEWORK

Ross Seedsman[1]

ABSTRACT: Monitoring is an essential component of the observational method but it is not a substitute for geotechnical design. Roof extensometry is used extensively for managing ground control. It provides an additional and essential level of control for the management of safety but it should not be relied on to provide the necessary warning of interruptions to longwall extraction. Longwall extraction does not have the flexibility to allow for the modifications that are an essential part of the observational method. A more conservative initial design for ground control is required. A logical framework for such design is presented.

INTRODUCTION

Like other branches of engineering, the design objectives in underground mining are structures that are safe, serviceable and affordable. The serviceability criterion applies to the underground roadways themselves as well as to the overall stability of the mine and in recent times to the surface. For mining, the affordability criterion differs substantially from civil engineering in that the economic wealth is produced during the works and not subsequently during the use of the infrastructure. Whilst this introduces some flexibility in terms of the precise location of the excavations during development, it does add requirements with respect to continuity of extraction. This need for regular planned production of coal is even greater for the new generations of longwalls that require coal flows in excess of 500 000 tonnes/month.

Rock and coal are complex materials. There is a large degree of uncertainty related to the ability to adequate characterise them in rationally designed engineering geology studies. Furthermore, their behaviour may be controlled by their high compressive strength or, perversely, their lack of tensile strength and very low strength shear strength along joints and bedding. The science of rock mechanics has evolved to study these materials, and finds application in both the civil and mining sectors. The practice of rock engineering deals with the uncertainties presented by the geology of rock and coal and requires a number of different strategies in the design and implementation process.

THE OBSERVATIONAL METHOD

The highly variable nature of rock and coal masses makes prediction of ground conditions at specific locations impossible. The observational method (Peck, 1969) recognises this. The observational method in ground engineering is "a continuous, managed and integrated process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction as appropriate." The objective of the observational method is to achieve greater overall economy without compromising safety. It also gives flexibility in the management of contracts. Because of this flexibility, it is often considered to be ideal for mining. In this definition it can be seen that monitoring is just one component.

Key components of the method are:

- It requires prior assessment of the range of likely ground conditions and excavation/support strategies so that the most probable can be chosen for construction
- The construction methodology must be demonstrably robust so that the flexibility is available
- The responses to monitoring are previously defined
- The responses can be implemented in a timely manner.

There are several problems in applying the observational method to longwall mining. Firstly there is no history or tradition in assessing a range of conditions, in fact the effort has been in determining the minimum support. The level of analyses that have been applied is poor and only applied to one presumed geological condition. While the flexibility to respond to monitoring may be present in development mining, it is not present in longwall production which, to sustain the necessary production rates, requires face retreats of 20 m – 30 m/day.

[1] *Honary Visiting Fellow - University Of Wollongong, Director- Seedsman Geotechnics Pty Ltd*

The observational method, and its component of monitoring is not a substitute for geotechnical design. In fact, it obliges a greater level of design effort than currently conducted so that the range of geological uncertainty can be anticipated and managed.

DESIGN IN ROCK MECHANICS AND THE STRATA MANAGEMENT PLAN

In the face of geological uncertainties, rock mechanics design protocols have evolved Bieniawski (1993). Figure 1 shows a design wheel where steps 3- 9 cover the technical aspects of excavation design (see later). Steps 10 onwards are well covered in the strata management plan process that is now part of coal mining in Australia. Most of the steps in Figure 1 can be found in recent mining regulations.

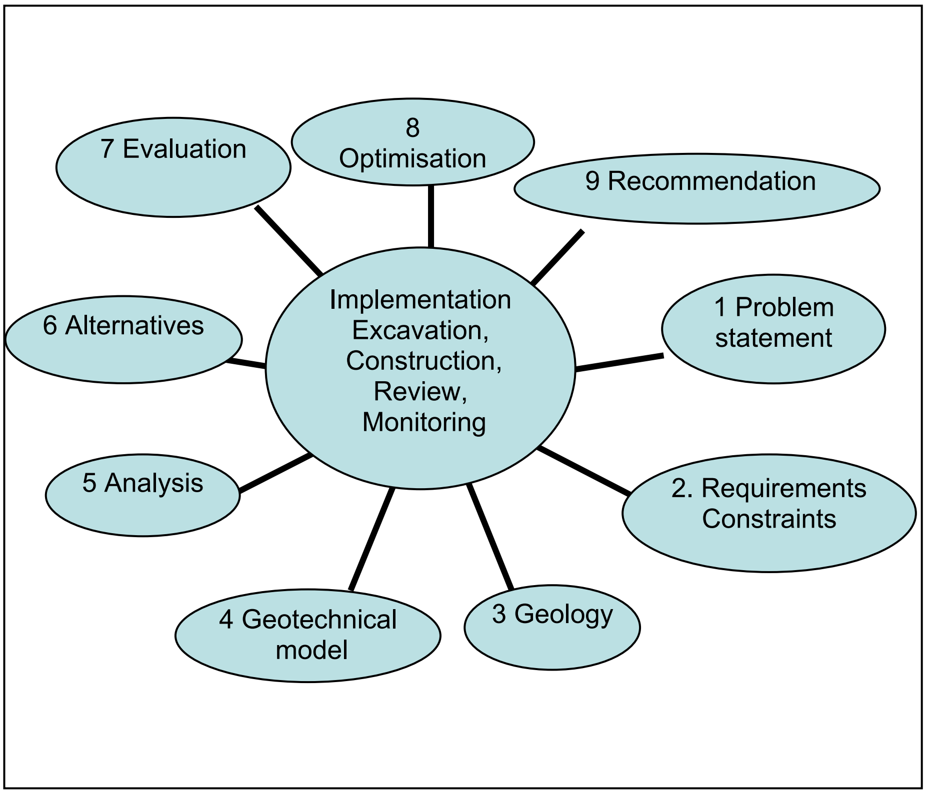

Figure 12 - A rock mechanics design methodology

Monitoring of roof movements is just one part of the whole design process. Monitoring has no value unless thresholds are set. Over the last two decades, thresholds for roof movement in roadways have been proposed and empirically validated. The monitoring results, combined with higher levels of knowledge at the face supervisory level and intrinsically safer method of work have improved workplace safety. In some cases monitoring does not give adequate time to allow a response and in other cases if poorly interpreted can lead to massive oversupport.

Currently site strata management teams (SMT) tend to operate in isolation of the overall excavation design process and there is insufficient feed-back to allow improved design. Figure 2 presents a way in which the strata management at the site can be better implemented into the longwall planning process by creating feedback links to the overall longwall process.

MONITORING

Monitoring assists in managing a safe work place. In the absence of detailed consideration of a range of geological conditions, there is a possibility that the interpretation of thresholds is inappropriate, leading to too many false positives, or even false negatives. In addition to magnitudes of movement, movement rates are being used to guide management decisions regarding secondary support. The longwall acceleration position is defined as when the roof movement in a maingate first exceeds 10mm/week (Thomas and Wagner, 2006). Plots of longwall acceleration positions against depth show a distribution that is remarkably well bounded by the Peng and Chiang (1984) relationship for vertical stress abutments.

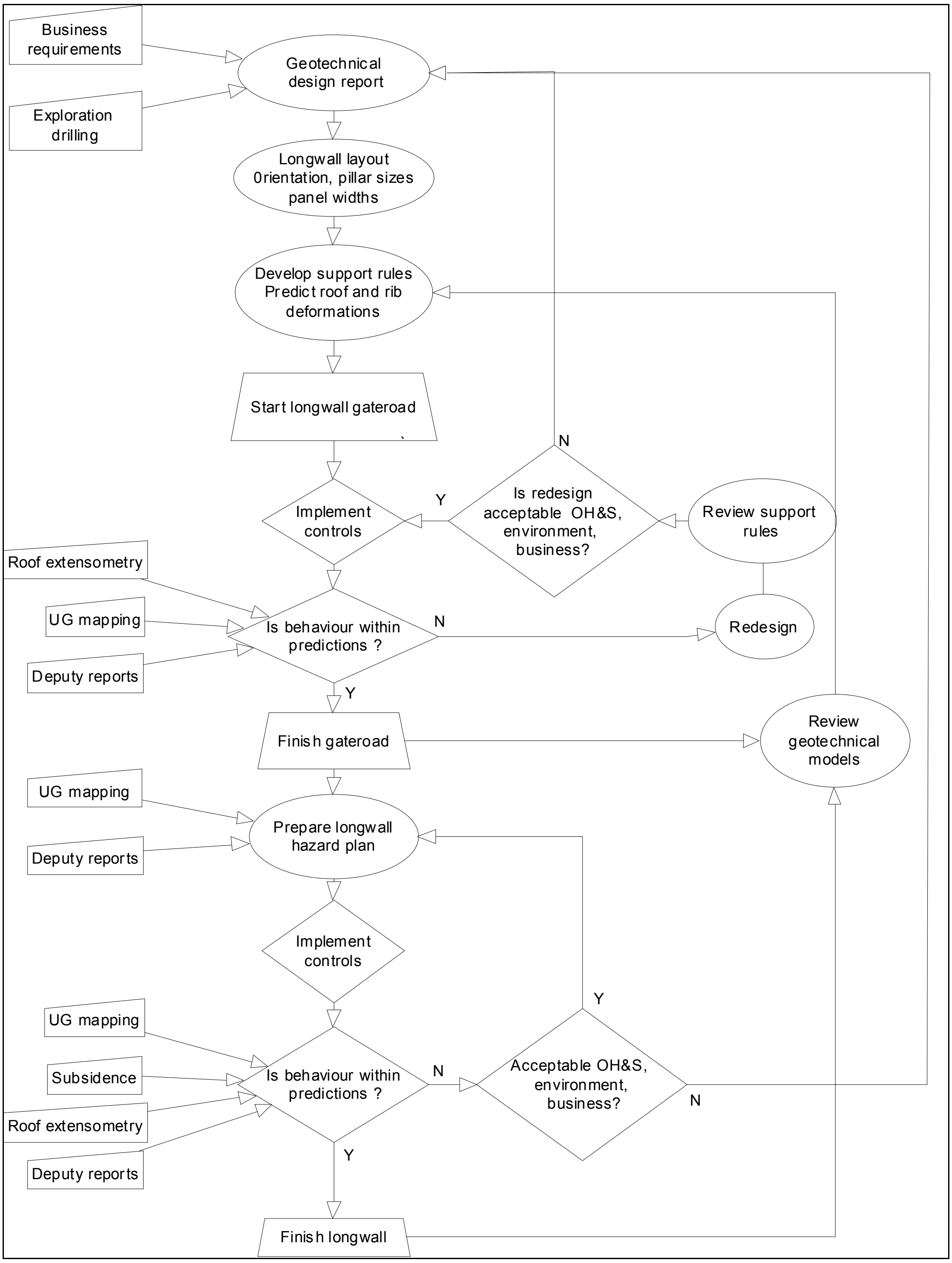

Figure 2 - A model for the integration of geological and geotechnical programs into longwall design, planning, and operations (diamonds – SMT, ovals – geotechnical designer)

The presumption is that movements continue to accelerate at a manageable rate once this 10mm/m threshold is exceeded and that there is still time to install secondary support. While accelerating movements are typically of a roof exposed to increasing deviatoric stress (as the rock fails and the supports yield), rapidly accelerating and stick-slip movements can develop in a low stress environment. Consideration of Figure 3 indicates that stick slip movements may also produce movements in excess of 10mm/week and cannot be resolved unless monitoring is conducted at closely spaced intervals. A better understanding of roof deformation mechanism could lead to more appropriate responses.

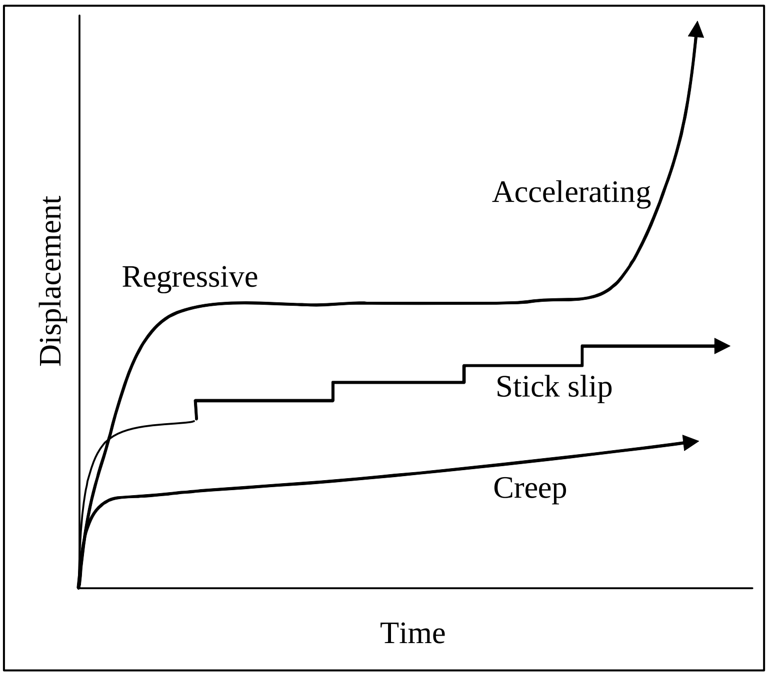

Figure 3 - Different patterns of roof movement

GEOTECHNICAL ANALYSES

The essential difference in design in rock mechanics lies in steps 4 and 5. There is a need to reduce the complex geology to something tractable and then to deduce likely behaviour. Rock mechanics design requires both inductive and deductive reasoning, together with heuristics and engineering judgement. The predictins will not be perfect which is why steps 10 onwards (Figure 1) and SMTs exist.

The complexity in rock mechanics comes from the need to identify the presence and interaction of discontinuities. Figure 4 recognises five different approaches to the formulation of the geotechnical model and the subsequent analyses. All have strengths and weaknesses, and that is why the recommendation is always to use at least two.

The five approaches are:

- Precedent/practice – if there is confidence that the geology and stresses are the same, continued use of a successful support regime is a legitimate strategy.
- Rock mass classification – numerical values are assigned to parameters considered likely to influence behaviour, these are combined into a rating and this is used to access a database of behaviour.
- Continuum numerical codes – a rating system is used to reduce laboratory scale continuum properties to values for a large-scale mass that behaves as apparent continuum with reduced strength and deformation properties. Analyses can be done in programs such as FLAC or Phase2, with calibration to mine behaviour.
- "Limit equilibrium" – Based on observations of failure and collapse, failure geometries are proposed and an analysis conducted for an equilibrium of driving and restraining forces at the stability/failure limit. The mathematics involved is often relatively simple. Validation to previous mining outcomes is required.
- Blocky numerical codes – maintain the complex discontinuity geometry and analyse behaviour of blocks without presuming the failure mode using codes such as UDEC and 3DEC.

Precedent/practice and classification schemes work well in rock masses and circumstance for which they were originally developed, for example within one mine or a set of closely related mines. However, Brady and Brown (2004) caution…."Although the use of this approach is superficially attractive, it has a number of serious shortcomings and must be used only with extreme care. The classification scheme approach does not always fully evaluate important aspects of the problem, so that if blindly applied without any supporting analysis of the mechanics of the problem, it can lead to disastrous results."

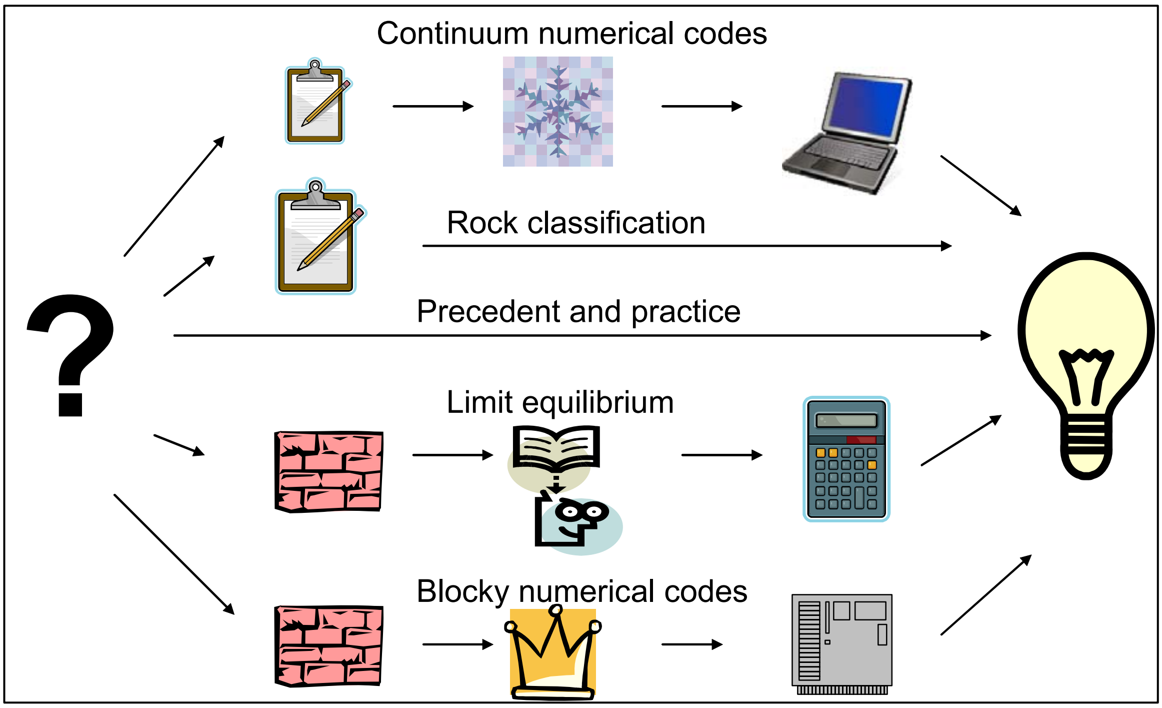

Figure 4 - Cartoon showing 5 different approaches to design in rock mechanics

Continuum numerical codes are readily available and have been used extensively in the last decade. They should be used with care at roadway scale as roof behaviour may be dominated by one or two discontinuities. Continuum codes are excellent for determining the stresses around excavations, the problem is the input of failure parameters, in particular the common assumption that the tensile strength of a rock mass is about 1/10 of the compressive strength and not the conventionally accepted assumption that the tensile strength is zero (due to presence of discontinuities). Blocky numerical codes are still computationally intensive and most likely suited only for academic research.

The limit equilibrium method is not well developed. In recent years it has often been considered as unnecessary in the coal sector in the face of sophisticated numerical codes. The author is currently developing an approach for underground coal. Coal mine geometry is much simpler than the typical metal mine or tunnel. The roof of development roadways consists predominantly of rectangular prisms with axes of the openings and the principal stresses being coplanar with the discontinuities - joints and bedding (Figure 5). This simple geometry allows the application of the logical framework of Brady and Brown (2004) which was initially proposed for one or two discontinuities and that they now note is applicable for moderately jointed rock masses.

Failure and subsequent gravity collapse modes for a assemblage of rectangular prisms (Figure 5) include:

- Compressive failure of the rock substance if the lateral stress is compressive and the deviatoric stresses in the roof exceeds the compressive strength
- Gravity fall of joint blocks if the lateral stress is tensile
- Delamination/buckling along bedding partings under self weight and imposed compressive lateral stress
- Shear along non-vertical joints such that the roof is unstable for all applied stress conditions.

For the longwall application, there is a need to recognise that the roof can undergo a range of stress conditions from development to being left in the tailgate behind the retreat face (Seedsman, 2001). There is also a need to recognise that the stress regime in stone is different from the regime in coal (Seedsman, 2004).

For stone, observations and measurements indicate that high deviatoric stresses in the face/maingate corner may cause compressive/shear failure. In some cases, when very low rock strengths are present, deviatoric stresses may also be high enough in the initial development. Stress conditions in tailgate are more controversial. Seedsman (2001) argues that roof stresses may be tensile due to adjacent goaf and yielding chain pillars; Colwell and Frith (2006) argue that the stresses must be compressive. The only measurements of tailgate stresses are in a coal roof at Ulan (Shen et al, 2006) and these suggest stress reductions. Seedsman (2004) argues that for coal the roof stress on development are very low, suggesting greater stability at the maingate corner and major concerns in the tailgate.

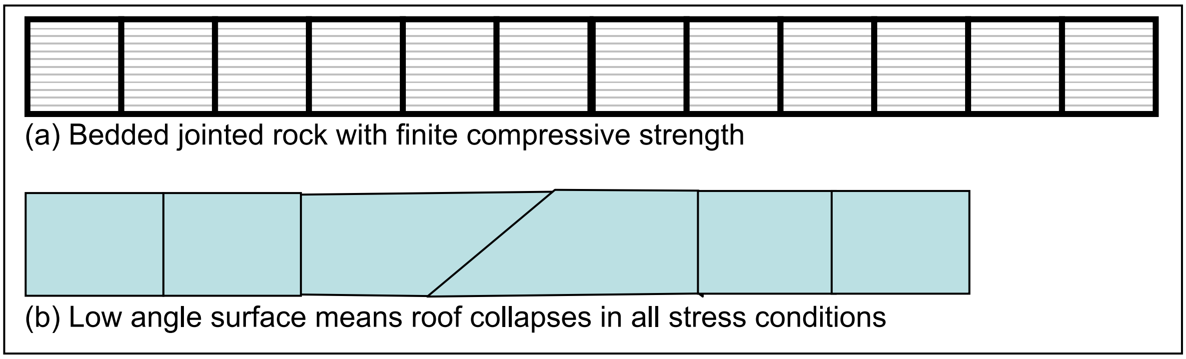

Figure 5 - Collapse modes for coal mine roof

The logical framework (Figure 6) starts with a test for the presence of angled surfaces which provide an intrinsically unstable geometry for all stress assumptions. The next test is for compressive failure which can be readily implemented by comparing the rock strength (either laboratory or sonic derived) with the vertical stress estimated from depth of cover. This vertical stress is a proxy to the deviatoric stress that is acting in a stone roof. From field observations, there is a possibility of the onset of compressive/shear failure concern if this ratio (referred to the roof strength index) is less than 3.5. The next check is for the possibly onset of tensile roof stresses. If the roof stress remain compressive, the support design proceeds based on the hazard of the presence of closely spaced bedding partings.

It is essential to recognise that designs in rock mechanics are predictions on which to base subsequent decisions and the formulation of risk management strategies. In the context of soils engineering, Lambe (1973) discussed how designs/predictions are limited by both the method used and the data available and that a balance is required (Figure 8) to maximise the accuracy of the prediction. It is considered that this observation certainly applies to rock engineering in 2008 (Figure 7).

CONCLUSIONS

Observation and monitoring are essential component to any engineering venture to demonstrate performance. But monitoring is not sufficient to assure performance. Acceptable performance comes from integrating monitoring into a geotechnical design process that recognizes the limitation of the observational method for retreating longwalls. The difficulty to adequately characterize the inputs necessary for analysis is not an excuse for failing to commit to improve the economic performance and reliability of the longwall method.

ACKNOWLEDGEMENTS

This paper is part of the ACARP funded project CL4029: "Anticipation of geotechnical hazards and planning the response –a tool box of techniques for roadway driveage" being conducted by the University of Wollongong and Seedsman Geotechnics Pty Ltd.

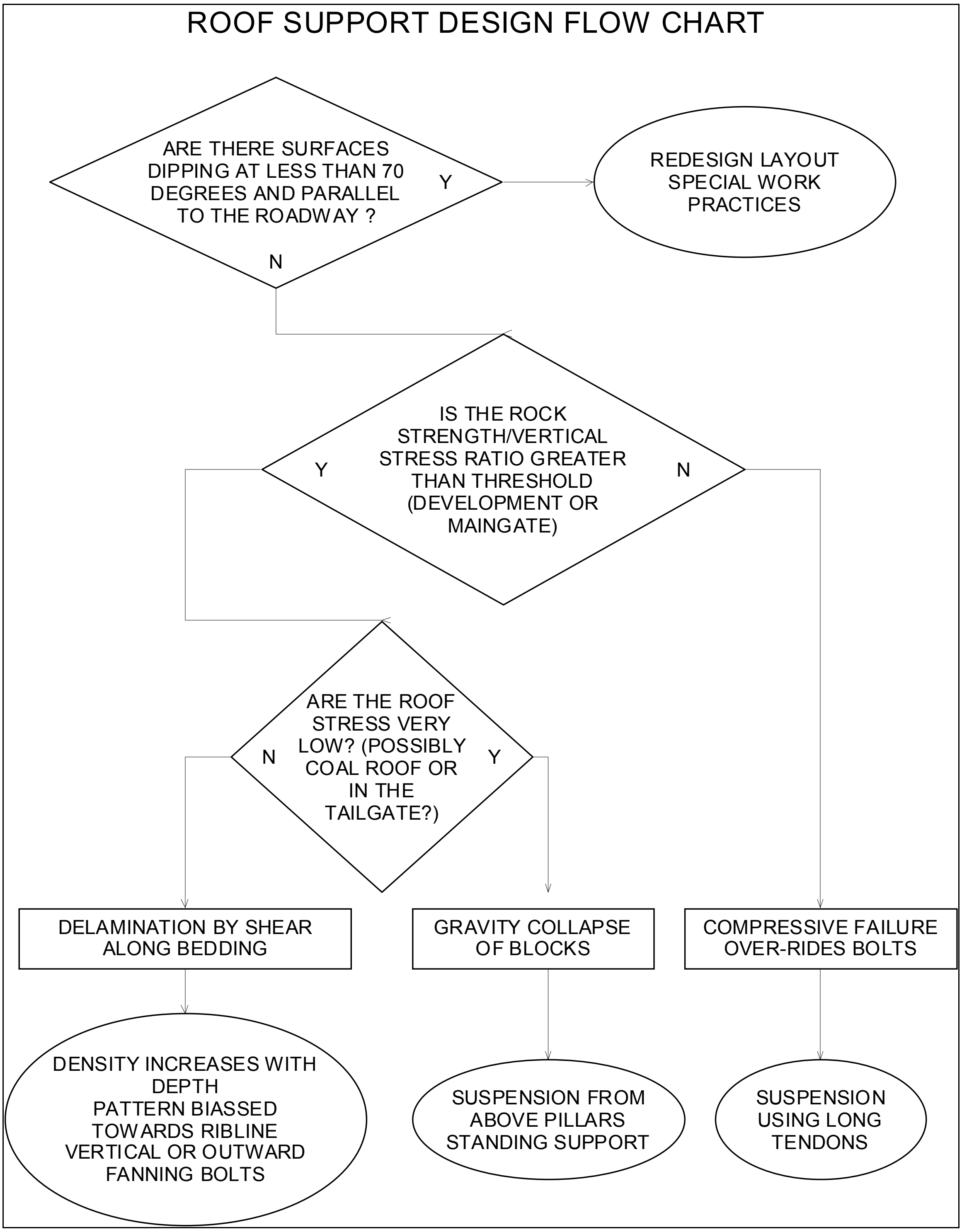

Figure 6 - Logical framework for coal mine excavation design

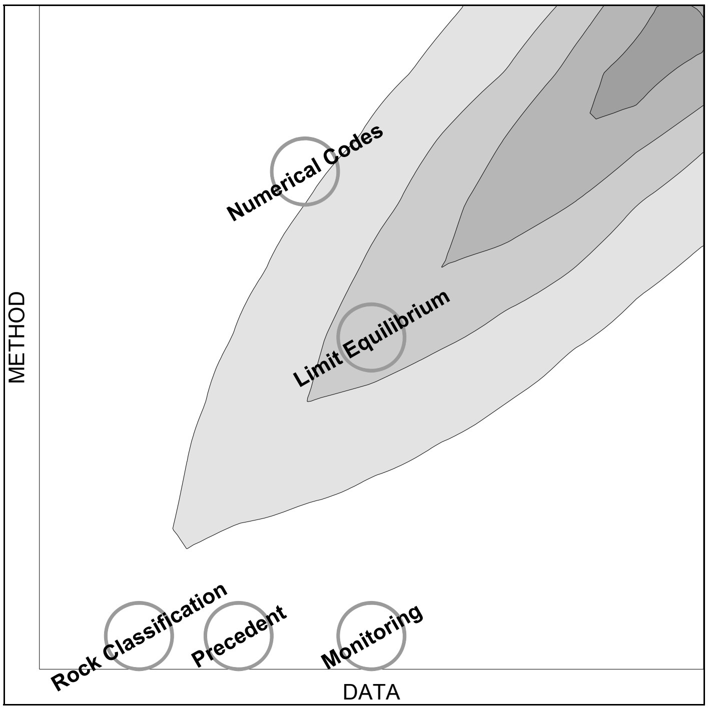

Figure 7 - Design can be limited by the method or the data

REFERENCES

Bieniawski, Z.T. 1993. Design methodology for rock engineering: principles and practice. Comprehensive Rock Engineering (eds J.A. Hudson, E.T. Brown, C.Fairhurst, and E. Hoek), 2,:779-793. Pergomon: Oxford.

Brady, B.H.G. and Brown, E.T. 2004. Rock Mechanics for underground mining Kluwer Academic Publishers, Dordrecht. 3rd Edition.

Colwell, M. and Frith, R. 2006, Why uniaxial compressive strength and Young's Modulus are commonly poor indicators of roadway roof stability – except in the tailgate. COAL2006, 7th Underground Coal Operators Conference. pp 28-43

Lambe, T.W. 1973. Predictions in soil engineering. Geotechnique, (23)2: 149-202.

Peck, R.B. 1969. Advantages and limitations of the observational method in applied soil mechanics. Geotechnique (19)2,:171-187.

Peng, S.S. and Chiang, H.S. 1984. Longwall mining. Wiley, 708p.

Seedsman, R W. 2004. Failure modes and support of coal roofs. In Ground Support in Mining and Underground Construction. Villaescusa and Potvin (eds), Balkema, pp 367 - 373.

Seedsman, R.W. 2001. The stress and failure paths followed by coal mine roofs during longwall extraction and implications to tailgate support. In 20th International Conference on Ground Control in Mining. Morgantown.

Shen, B., Guo, H., King, A. and Wood, M. 2006. An integrated real-time roof monitoring system for underground coal mines. COAL2006, 7th Underground Coal Operators Conference. pp 64-76.

Thomas and Wagner 2006 Maingate roof support design and management during longwall retreat in the Australian coal industry In 25th International Conference on Ground Control in Mining. Morgantown. pp 191-196