CHAPTER 2

REVIEW OF PUBLISHED DESIGN METHODOLOGIES AND CURRENT PRACTICES IN THE MINING INDUSTRY

2.1 INTRODUCTION

Single stope support element performance is described by a number of authors where the support practices are described and often referred to as stope support design. A number of papers simply reflect the current state, type and spacing of stope support (titled as a stope support design), while no engineering design methodology is given or described in these papers.

Jager (1986) gives in his paper a review of stope support developments of the previous decade. Waldeck (1986) describes the different types of permanent stope support used but does not give any indication of stope support design methodology or design considerations during the selection of permanent stope support.

In his summary of stope support practices Coggan (1986) states that the main philosophy behind stope support design is to maintain the integrity of the immediate hangingwall and prevent key stone fall-out by maintaining the horizontal clamping forces. This is achieved by utilising the frictional forces in the fractured rock. Requirements of support elements have also been identified and described by him as: "Ideally support should have sufficient initial stiffness to prevent bed separation in the immediate hangingwall and yields in a controlled manner as a result of the irresistible elastic closure. Timely and efficient installation is pre-requisites for effective local support in the face area." No indication as to how this is to be achieved is described in this paper.

During the discussion of the stope support practices at E.R.P.M. by Spengler (1986), Free State by Davies (1986), Evander by Steyn (1986), Springs by Steyn (1986) and of Randfontein Estates Gold Mine by Spearing (1986), the selection for stope support types of the different mining districts are given. No mention is made of engineering design approaches that were adopted for the design of the specific stope supports that are listed.

Research has been done and these are all well documented where the performance of a support element type has been researched. For instance, Roberts (1991) discusses the ability of yielding timber props to absorb energy during a rockburst and investigates the capability to withstand a range of dynamic loading. It was found that the stope closure prior to a rockburst strongly influences the behaviour of the support system during a rockburst. Roberts also suggested that a strain hardening support system such as packs or backfill be considered for rockburst conditions. This recommendation is confirmed by the research described in this thesis.

Roberts and Brummer (1988) first documented the support requirements for stope support in rockburst conditions. A value of 200 kN/m² was published as the support resistance required under rockburst conditions. They made the assumption that 3.0 m of hangingwall will be separated from the hangingwall during a rockburst. The need for integration of hydraulic props with stope support is emphasised. This became one of the stope support criteria widely used in the gold mining industry for rockburst conditions.

The methodology that is described in the thesis has an approach towards seismicity where both the energy criteria as well as the strata- versus support stiffness during dynamic loading are evaluated.

2.2 STOPE SUPPORT AND ROCKMASS INTERACTION

Roberts (1986) identified the need in the late 1980's to address the interaction between the support element and the rockmass. He pointed out that the interaction of support and the rockmass may be described by two aspects, namely the interaction of the individual support units with the immediate fractured hangingwall, and secondly the interaction of the support system with the large volume of inelastic rock around the stope. From this work it became increasingly apparent that the function of support in the working area is to maintain the integrity of the first few metres of hangingwall strata and not to prevent bedding plane separation, as opposed to comments made earlier by Coggan (1986). Roberts (1986) also showed that stope support need not to support the full thickness of the hangingwall up to the limit at which bedding separation occurs. Conclusions at the time revealed that support systems with only moderate support resistance are adequate and that more attention should be given to the areal support ability of support units.

The methods to be adopted when designing and evaluating stope support are described in: "A handbook on rock engineering practice for tabular hard rock mines" edited by Ryder and Jager (1999). Factors governing the design of support systems are described. The publication does not prescribe a design methodology in terms of the design parameters such as quality of the rockmass to be supported, rockmass deformation, support reaction or rockmass-support interaction, but refers to the design rationale as published by Roberts et al (1995) the GAP032 SIMRAC report in principle. It refers to support design methodologies for both rockfall and rockburst conditions, taking the relevant parameters such as closure rate, beam thickness and energy absorption capacity into consideration.

Izakson (1981) is one of the few authors who listed the importance of support stiffness in the design of underground workings, and realised that deformation of support results in the generation of force(s) in a support element. Displacement and forces from structures (a square plate) were analysed for different loading conditions, but the research stopped short by not investigating typical support elements and its yieldability for various mining configurations. No evidence that this research was developed any further, could be found.

A number of design methodologies have been developed recently to address the issue of stope support design. The main objective is to develop a user-friendly support design model that can be used by rock engineering practitioners as a tool for the design of stope support as summarised in Chapter 1.

The following is a summary of the more important recent work done in South Africa with regard to stope support design. An unbiased and balanced critique of the work is attempted with the objective to evaluate the methodology taking into consideration fundamental laws of physics and good engineering practice.

2.2.1 Stope and gully support

(a) SIMRAC Project GAP032: *Stope and gully support*

A stope support design program commonly used in the gold and platinum mining industry today is the one developed by the CSIR Division of Mining Technology as a SIMRAC Project GAP032 by Roberts et al (1995) that addresses stope and gully support design. The initial project had two objectives namely to develop a rationale for the design of stope support systems and to develop a support resistance criteria for the support of stope gullies under both static and dynamic loading conditions. The criteria listed in the research refer to a study of the Vaal Reef, Ventersdorp Contact Reef and Carbon Leader reef.

The support resistance of a support system is defined as the force applied by the support unit per tributary square metre of hangingwall, and is presented in kN/m^2. It therefore depends on the force-deformation characteristic of the support element, the rate of closure and spacing of support elements. The program is developed in a way that deformation of a support element is determined from a given rate of closure at a specific distance back from the stope face, given an installed distance from the stope face. The load generated (kN) by the support element is determined and the support resistance (kN/m^2) calculated from the spacing of the support elements. This value is compared to the criteria required for that area.

Design criteria

The criterion from which the required support resistance is calculated, is based on the thickness of the immediate hangingwall that collapsed with stope support that might or might not have been in place. The required support resistance criterion is determined from fall out heights derived from a reef specific rockfall fatal database containing a large number of cases. The required support resistance criterion is then determined from the fallout height representing 95% cumulative fallout thickness based on all these cases in the database. Databases from which this information is extracted are based on statistics where in some cases supports were installed and failed, and in other cases no support was installed at all.

The determination of the ability of a support system to absorb energy with the objective of reducing rockburst damage is realised in the research as not a simple one since it depends on a number of variables. One of these variables is identified as the ability of the support system to yield during rapid deformation and so absorb energy.

As in the case with the support resistance calculation, is it necessary to have a good estimate of the stope closure rate that would occur prior to and during dynamic closure. Other variables that also influence the ability of a stope support system to absorb energy are the spacing of the support elements, the velocity of dynamic stope closure and the distance in which the hangingwall must be brought to rest.

The area underneath the load-deformation curve represents the energy absorption *ability* of the support element and is expressed in kilojoules (kJ). As deformation takes place, the amount of energy that the support system can absorb will decrease. The amount of normal stope closure that occurs prior to any potential dynamic closure increases from the stope face towards the back area. This means that the ability of the support system to absorb energy during dynamic closure reduces from the face towards the back area.

The required energy absorption criterion in kilojoules per square metre (kJ/m^2) is determined from the ejection thicknesses derived from a rockburst fatal database containing a large number of cases. The required energy absorption criterion is then determined from the ejection thickness representing 95% cumulative fallout thickness based on all the cases in the database.

Support spacing

During the design process the spacing of the support elements can be changed and the support types varied. The program addresses both temporary- and permanent stope support types. The effect of those changes can be viewed and the performance of the various options compared to the criteria set for both falls of ground and rockburst conditions.

Criticism

- Even though the final project report shows that several numerical rockmass models were used during the research process, this does not form part of the final design process published. It is stated in the final project report that results of the studies are purely qualitative and values used should not be applied in practice without first collecting sufficient data from underground to calibrate the model.

- The support design analysis is modelled in two dimensions only and the mining geometry in the third dimension is not taken into account. Systematic regional support such as pillars cannot be taken into consideration with this methodology. The hangingwall is assumed to be a solid beam with linear stope closure towards the back area. This approach can be used to determine the support reaction of a given support element in comparison to another. It can therefore be viewed as a support evaluation rather than a design approach, when considering the main two parameters used in the analysis namely support resistance (kN/m^2) and energy absorption criteria (kJ/m^2).

- Support resistance generated by a support element changes as deformation of the support takes place. It is the opinion of the author of the thesis that this may not reflect the true *capacity* of a support element. It may therefore correct to suggest that the design analysis only shows a snapshot in time for the parameters quoted. A support element well capable in having the potential to meet the support requirements as deformation takes place might not meet the support requirements shortly after installation according to this analysis. A typical example of such a unit would be a solid matpack.

- Another criticism of this approach is the fact that the support resistance generated by the stope face is ignored. The design methodology does not take into account the stope resistance offered by the stope face. It is suggested that the support offered by the stope face, as is the case with regional pillars, be taken into consideration when analysing stope support.

- A gully ledge is damaged by the stress exerted onto the ledge by the gully support. The stress exerted onto the ledges by a support element is a function of both the force generated by the support unit and its footwall/hangingwall contact area. It is suggested that the criterion for gully support is expressed in stress rather than force or load, as is possible with the methodology published in this thesis.

- For the analysis of a support system during dynamic loading, the energy absorption capacity of the support element is analysed. The support stiffness and stress exerted onto the hangingwall during dynamic loading of the hangingwall is neither calculated nor taken into consideration. In practice this means that even a very stiff and strong support that is well capable to absorb energy and meet the design requirements, may cause damage to the hangingwall during dynamic loading according to Pretorius (1995). This is as a consequence of the magnitude of the stress exerted onto the hangingwall. The opposite is also true; that is that a softer support element with less energy absorption capacity but with a positive load-deformation curve may not meet the design criteria. The pack will not exert an excessively high stress onto the hangingwall during dynamic loading that causes punching failure to the hangingwall.

(b) Key block analysis using J-Block

This support analysis approach is based on the block theory as described by Goodman and Shi (1983). Esterhuizen (1996) has applied this theory into a software design programme. The program is designed to analyse the generation of three-dimensional blocks by the intersection of joint sets, bedding planes and other geological discontinuities. Although discontinuities have to be planar, dip and dip direction can be simulated as having a normal distribution around an average. The spacing of the joints can be defined as varying between a specified minimum and maximum value, while the user specifies the average joint spacing. Joint lengths are specified in a similar manner. This allows for a more natural and accurate representation of the input data.

The analysis assumes a planar hangingwall and determines blocks by combining joints with varying dip and dip directions according to specified input parameters. The blocks that are generated this way vary as the joint orientations are also assumed to be subject to variation. A typical analysis therefore requires the generation of multiple blocks in order to be of statistical relevance. Removable blocks* are determined from the blocks that are generated this way. (*Removable blocks can be defined as those that can be dislodged from the hangingwall.)

The way that removable blocks can be prevented from being removed is by providing support that is presented by point forces at specified points. In the analysis it is assumed that these forces are sufficient to prevent fall-out of blocks. Support failure is thus ignored and only blocks that could fall out between support elements are recorded.

No face stresses are assumed to be present, and no frictional resistance taken into consideration, with only gravity acting on the blocks. The three-dimensional geometry will control the ultimate behaviour of the hangingwall relative to the type and spacing of support.

This approach allows for a realistic comparative analysis between different support elements for varying mining layouts. Results are generated relatively quickly as there is no need for time-consuming stress/deformation calculations, and output is well presented and easy to understand. Input parameters are crucial, but are limited to joint and fracture orientations and spacing.

Even with its shortcomings, this programme provides the rock engineer with a practical tool to analyse local conditions, which is a major step in the engineering design of stope support. The program does not take cognisance of the support reaction and magnitude of forces generated during the deformation of support.

(c) Review and application of stope support design criteria: Daehnke A., van Zyl M. and Roberts M.K.C. (2001).

Stope support has over the years evolved into a comparatively complex discipline involving the quantification of various rockmass and support parameters. This paper reviews some of the fundamental rockmass and support design criteria that form the basis of an improved support design methodology. The proposed support design methodology that needs to be followed is summarised in the form of a flowchart indicating the principal design steps that need to be implemented when designing stope support for any given geotechnical area.

The design process is systematically done for both quasi-static and dynamic conditions in 9 sections and illustrated at the end of the paper with a support design example in order to illustrate the procedure.

The stope design methodology that is reviewed in the paper consists of the following sections:
Section 1: This section addresses the *critical rockmass parameters* and describes the height of the potential rock falls and stope closure rates for both quasi-static and dynamic conditions. It also addresses the compressive hangingwall stresses, discontinuity spacing, and orientation and interface properties. Each of these is well illustrated and properly defined.

Section 2: This section addresses the *critical support performance parameters* such as the effect of the support length and its effect on the potential for buckling failure of support. It gives a detailed summary of all previous work done on the buckling of a Profile Prop type of elongate, timber packs, hydraulic props and mechanical props. The effect that the closure rate has on the performance of timber elongates, timber packs and cementitious packs is also shown. The support performance variability of support and the areal coverage of support systems are all described in this section. Examples of recent developments by the CSIR Division of Mining Technology are shown in the paper.

Section 3: This section deals with the *testing programme to evaluate support performance* and proposes a test procedure to provide a systematic approach to the performance of elongates. The test procedure entails various laboratory and underground compression tests of the support units with emphasis on repeated tests using units of the same type. This is done to investigate the performance variability and to obtain a statistical distribution of the load-deformation performance curves.

Section 4: *Stope support design based on the tributary area theory* is described in this section of the paper. It describes the tributary area requirements for both rockfall and rockburst conditions as well as tributary area requirements that are related to stope closure. This section of the paper contributes much to the general understanding of the tributary area concept that is very often simply accepted as the product of the centre-to-centre dip- and strike spacing of underground support elements.

Section 5: This section reviews the a formulation by Daehnke et al (1999) *quantifying stable hangingwall spans between support units* and assessing the influence of rock discontinuities on stable hangingwall spans. Hangingwall span stability is assessed by considering two failure mechanisms namely (i) beam buckling, and (ii) shear/rotational failure due to slip at the abutments. A very useful buckling stability envelope of a discontinuous hangingwall beam showing the relationship between beam thickness and maximum stable spans between supports is part of this section. This section of the paper concludes with the remark that the stability of a keyblock delineated by extension and shear fractures is dependent on buckling, shear and/or rotational failure mechanisms. When investigating the stability of the keyblocks the possibility of each of the three failure mechanisms need to be considered. If the keyblock is unstable in any of the three failure modes, the unsupported span between adjacent support units needs to be decreased until neither buckling, shear nor rotational failure can occur.

Section 6: The *zone of support influence* is quantified in this section and forms a substantial part of the paper. The zone of support influence for a homogeneous hangingwall beam i.e. a continuous beam not discretized by any discontinuities is given and the model expanded to an unclamped hangingwall beam fragmented by discontinuities, and further expanded to a clamped hangingwall beam fragmented by discontinuities. The effect that shear fractures have on the zone of support influence is also shown in this section of the report. The zone of *support* influence for intermediate- and deep-level mines and the zone of influence of the *stope face* in intermediate-, deep-level- and shallow mines are quantified. This section is concluded with the quantification of the zone of influence of backfill.

Section 7: A *unified engineering approach to quantify stable hangingwall spans with face parallel fractures* is proposed in this section of the paper. It is intended as a design tool of practical value that will enable the rock engineer to make initial designs of appropriate support spacing by using a few comparatively simple graphs. In this section the zones of influence is combined with keyblock stability while the support spacing requirements for both rockfall- and rockburst conditions of hangingwalls with face-parallel fractures is determined.

Section 8: The *support spacing requirements for blocky conditions* is described in this section of the paper and addresses both rockfall- and rockburst conditions. This section summarises a second approach to support spacing requirements which is particularly applicable for blocky hangingwall conditions, whereas the previous section of the paper is only applicable if the hangingwall stability is controlled by sliding and rotating of keyblocks, or by beam buckling.

Section 9: The last section of this paper describes the *choice of the appropriate support spacing based on the tributary area and the maximum stable spans.* It gives the support spacing for both a face-parallel fractured- and blocky hangingwall.

Criticism

- This paper is gives a very detailed summary of the most up-to-date design methodology for stope support design in the South African Mining industry to date, where most of the critical issues that are related to stope support design are included.
- Section 2 describes the influence of the length of a support element on its load bearing capacity, and gives general rules for the slenderness ratio of elongates, timber packs, hydraulic props and mechanical props. No general rule is published for cementitious packs like a Durapak that forms quite a substantial part of current stope support, particularly in some of the higher risk areas of the South African gold mining industry.

- Even though the paper gives a detailed design methodology it does not show the mode of failure that can be expected of the support element(s). The report stated if the prop is compressed for a distance exceeding its yielding range, rapid and unpredictable failure due to buckling or punching can occur. The work described in this thesis is an attempt to determine whether the support unit will fail in a stable- or unstable fashion once a certain amount of deformation is reached.

2.2.2 SIMRAC Project GAP 330: *Stope face support systems*

Research done by the CSIR Division of Mining Technology as part of SIMRAC research report on Stope face support systems, Project GAP330 (1998), evaluates stope face support systems. The study focuses on relating the geotechnical area properties to existing support types used and the occurrence of fatalities. During the research, support performance and implementation as well as rockmass behaviour were addressed.

During the study geotechnical areas are delineated on the basis of different rockmass behaviour. The use and performance of existing support systems were also evaluated, and a detailed analysis done on rock-related accidents. A study on the interaction between the rockmass and support concludes that local support did not affect the (inelastic) closure in a longwall stope according to Herrmann (1987). It was not possible to investigate the support interaction as unrealistically thick layers had to be represented due to numerical constraints. The slenderness of the beams had to be limited in order to obtain reliable results. This is a universal problem and affects all traditional numerical models. This problem needs to be addressed by mining industry.

The study also indicated that many local rockmass instabilities are the result of the inability of the rockmass to bridge the span between the individual support units. The report also suggests that the main support units should not have to be designed to provide local stability. Such stability needs to be ensured either by the rockmass itself or by a combination of that rockmass and some form of appropriate and effective reinforcement. The study suggests that additional work be conducted to quantify the effect of arbitrary oriented discontinuities of geological origin on support spacing. Particularly in the case of steep dipping fractures stresses transmitted across discontinuities could stabilise the hangingwall, leading to wider permissible spans. Further work could re-address the influence of the modified hangingwall stress distribution due to loading by the stope face, support units and backfill. The work described in the thesis takes into consideration the presence of the stope face as well as regional support such as pillars and backfill.

The research into the application of keyblock methods in the design of a support system for deep gold mines has shown that:

- Most keyblocks will be held in position by horizontal clamping stresses in the hangingwall under quasi-static conditions. It is only when shallow dipping discontinuities exist or when clamping stresses are lost through falls of ground, that keyblock stability becomes a concern. Under dynamic loading conditions the additional load may dislodge keyblocks that were previously stable.
- Slab shaped keyblocks are very stable even if clamping stresses are low. Wedge shaped keyblocks are most likely to fail and their occurrence and stability may be evaluated using keyblock techniques. The ratio of slabs to wedges in a stope hangingwall may be an indication of its stability.
- While the dominant stress fracture in a stope hangingwall is steeply dipping, shallow dipping fractures occur and are likely to result in keyblock type failures. Geological structures are often flat dipping and may define unstable keyblocks.
- Keyblock analysis techniques are suitable for the analysis of the effect of stress fractures and geological structures on the stability of a stope hangingwall. The analysis provides a realistic block size distribution, and can therefore assist in optimising support design for local geotechnical conditions.

The investigation into the keyblock method has shown that keyblock analysis techniques are able to provide insight into the interaction between support units and the fractured hangingwall. The method may therefore be used to account for site specific geological and stress fracturing conditions in support design.

2.3 STATUTORY REQUIREMENTS

The importance of stope support design in the mining industry is reflected in the Guidelines for the Codes of Practice to Combat Rock Fall and Rock Burst Accidents in Tabular Metalliferous Mines (2002) as well as the Mine Health and Safety Act published in 1996. The Guideline for the Compilation of a Mandatory Code of Practice to Combat Rock Fall and Rock Burst Accidents in Tabular Metalliferous Mines is issued in terms of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996). Section 9(3) requires that a

Code of Practice shall be drawn up in accordance with guidelines issued by the Chief Inspector. Failure by the employer to prepare and implement a Code of Practice in compliance with the Guideline is a breach of the Mines Health and Safety Act.

The objective of the Guideline is to enable the employer at every mine to compile a Code of Practice, which, if properly implemented and complied with, would reduce the number of rock fall and rock burst accidents at the mine since the majority of the accidents occurring at the mines are as a result of rock falls, are either seismically or gravitationally induced. The Guideline is a generic document and is not intended to address the rock related accident problems encountered on a particular mine. The guidelines pertaining to the design, geometry and support requirements are not rigid and prescriptive due to the complexity and variability of conditions at the mines. An approach was adopted which allows for the local expertise, experience and knowledge of the mines to be effectively utilised.

Section 11 of the Mine Health and Safety Act stipulates that the manager must assess and respond to risks. Stope support design can be classed as one of the elements that have an influence in managing some of these risks. The work described in this thesis is an attempt to contribute towards achieving this objective.

2.4 CONCLUSION

During the years of mining in the South African gold and platinum industries, valuable work has been done with regard to stope support and numbers of papers have been published in this respect. A study of literature has shown that very little work has been done with regard to the rockmass-support interaction for stope support. Papers describe either the reaction of the support medium or the behaviour of the rockmass and not much about the interaction of the two. The research should be viewed as complementary to the existing stope support design methodologies developed by researchers and engineers in the South African mining industry over many years. It describes the interaction of the hangingwall beam and stope support in order to determine whether the stope support will fail in a stable- or unstable manner. This is done by comparisons of (a) the rockmass and support stiffness at a given deformation, and (b) the energy for a given deformation interval. It differs from the conventional methodologies in that it does not take into consideration the fallout thickness of the immediate hangingwall.

A rigorous engineering approach is defined as one where the interaction between the support medium and that of the excavation it is intended to support is evaluated and described systematically in terms of the laws of physics. The research published in the thesis conforms to a rigorous but simple engineering approach and is described in terms of and conforms to the laws of physics.

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