CHAPTER 8
CONCLUSION FROM THE STUDY

8.1. INTRODUCTION

The objective of the study described in the thesis is to evaluate stope support by means of a rockmass stiffness approach. In a similar fashion as where the supply of a product is compared to the demand in business economics, the capacity of stope support is compared to the demand placed on it by the rockmass. It is achieved by quantifying the capacity of stope support and then to compare this to the rockmass demand.

Three models were developed for the purpose of the study. The first model describes and quantifies the support capacity while the second one describes rockmass behaviour though the rockmass stiffness approach. These two models were successfully combined and the capacity compared to the demand in the third part of the study when applied to two case studies. The case studies represent both an unstable failure as well as a stable failure of the stope support.

In the past different researchers referred to the concept of rockmass or strata stiffness, but no magnitudes were attached to the rockmass stiffness. The statement made by Ozbay and Roberts (1988) that the rockmass stiffness will decrease, that is that the rockmass will react softer as the mining span increases is confirmed by this study.

8.2 STOPE SUPPORT CAPACITY

Stope support behaviour is expressed in the thesis by a polynomial function and is a novel approach that has never been done for these particular applications. The constants for the polynomial functions are given for the support described in the thesis as well as other popular support types used in the mining industry at the time of the study.

The mathematical representation of support performance made it possible that the equations can be manipulated and adjusted to compensate for the aspects that influence support performance. It proves to be an effective way to quantify the capacity of stope support as the in-situ performance of a particular support can be calculated and compared to the laboratory test result of the same unit. All the relevant aspects that influence the support performance were successfully described into a mathematical format and integrated into a single equation that represents the capacity of a support element.

This exercise was successfully repeated for timber packs, lightweight cementitious packs as well as the timber elongates used in the mining industry at the time of the study. The aspects that influence support behaviour and that are successfully incorporated into an 'all inclusive" mathematical representation of support capacity is the following:

- Type of support;
- Rate of deformation from quasi-static (mm/day) to dynamic loading of support (m/s);
- Height of unit installed as opposed to the height of the unit tested (m);
- Pre-stressing of the unit during installation (kN); and
- Support spacing of support (m).

From the above the in-situ performance of supports was determined and the buckling failure calculated in the case of timber elongates. The following is calculated as output from the mathematical representation of the support capacity model:

- Load generated by the support element (kN);
- Height factor (H_f) that quantifies the influence that the difference in the height of the support installed versus the test height;
- The buckling failure factor (B_f) that is applicable to timber elongates;
- The stiffness (both positive and negative) of the support element (kN/mm);
- Energy generated by a support element for a given deformation interval (kJ);
- Support resistance generated by the support taking into consideration the dip and strike spacing of supports (kN/m^2);

The approach makes it possible that various conditions and influences on the support behaviour cannot only be quantified, but also described for the different deformation intervals to coincide with the mining during that particular mining interval.

8.3 ROCKMASS DEMAND

The rockmass demand is described during the second phase of the study. The objective with the study was to develop a way in which the support capacity and the rockmass demand can be represented on a common graph. The rockmass demand and the support capacity can be compared directly this way.

The rockmass demand is represented by the rockmass stiffness and is represented on a common force-deformation graph with that of the supports. This methodology is a novel one and has proven to a successful way to evaluate stope support.

Both the force and deformation components are required to establish the rockmass stiffness. The attributed area technique where an area gets allocated to a measuring station for successive mining steps was developed during the study. This novel approach has also proven to be successful and makes it possible that the mining layout and the presence of regional support be incorporated in the study.

All aspects that influence rockmass stiffness are taken into consideration and are the following:

- Mine layout that is related to the mining span;
- Presence and location of regional support;
- Beam thickness of the immediate hangingwall;
- Rockmass density; and
- The position of the point investigated relative to the solid abutments and regional support.

The study confirms the statements made by Ozbay and Roberts (1988) that the rockmass stiffness is related to the mining span. This is best illustrated when the rockmass stiffness is plotted for consecutive mining steps where the slope of the line representing the rockmass behaviour flattens with every mining step, or as the mining span increases.

The influence of regional support is also illustrated in the study where the rockmass stiffness decreases to a certain magnitude as mining progresses. With the stope closure that is limited by the regional support at that point will the rockmass reach a certain stiffness after which is remains unchanged as mining progresses.

8.4 COMBINED MODELS

This methodology gives the design engineer the opportunity to evaluate a combination of different support types that support the area attributed to a measuring station for any given mining stage. Here the capacity of a support system as a whole can be compared to the demand of the rockmass. It gives the engineer the opportunity to take into consideration the various aspects that influence rockmass behaviour and the characteristics that are unique to a specific support type(s).

Two illustrative case studies are described in Chapter 7. These case studies illustrate the applicability of the models that are proposed in the thesis, and confirm that it can be applied to assess permanent stope support.

The methodology also proves that it is possible to evaluate stope support even when a combination of different supports is used as permanent stope support. The latter is achieved by adding the capacities of the stope support as deformation takes place and compare that to the rockmass stiffness for the same mining steps.

In the first case study a total collapse of the excavation took place. This condition is simulated and reproduced by the study and shows that unstable failure of the support has taken place after the fourth stage of mining. The underground observations were confirmed by the outcome of the evaluation of support and rockmass interaction. The energy released by the rockmass, that is rockmass demand, exceeded the capacity of the stope support after the fourth stage of mining. The absolute value of the rockmass stiffness was also less than the absolute value of the load-deformation curve of the stope support for the same mining interval.

Underground observations were again confirmed during the second case study. Here the Pencil Props failed some distance of approximately 39 m from the stope face. In this case the absolute value of the rockmass stiffness was less than the magnitude of the negative load-deformation curve of the Pencil Props, while the Matpacks have a positive load-deformation behaviour throughout the deformation process. In the latter case the total energy generated by the rockmass never exceeded the capacity of the permanent stope support. This is referred to as stable failure of the stope support where part of the permanent support failed whilst the excavation remained open and stable.

The principle of comparing rockmass demand to the capacity of stope support can be done by comparing both stiffness and the energy released by the rockmass to that absorbed by the stope support for a given deformation interval or mining stage.

The author believes that research done and presented in this thesis can reproduce and quantify some aspects of the behaviour of stope support observed and measured underground, and that is a useful tool for stope support evaluation and analysis. It is believed that this work will contribute towards a better understanding, analysis and design of stope support in the discipline of rock engineering.

There is a concentration of the underground workforce in a stope. The stope represents a relatively small area where the workforce spends at least five hours per shift. An understanding and quantification of the rockmass-support interaction in turn has the potential to contribute towards a more stable and safe stoping environment in the mining industry.

8.5 FUTURE WORK

The study confirms the publication by Salamon and Oravecz (1976) that the surrounding strata behave as a progressively softer loading machine as the width of the mining panel is increased. The statement made by Ozbay and Roberts (1988) that the rockmass stiffness decreases as the mining span increases is also confirmed.

It was assumed in this study that the rockmass stiffness is linear for every mining interval as shown in Chapters 5 and 6. The system stiffness may in fact react in a non-linear fashion when considering the history of a particular point in an excavation through different stages of mining as demonstrated in Figure 6.7 of Chapter 6. It is suggested that further research be done in determining the linearity of the rockmass stiffness.

It is important that the rockmass stiffness approach be tested and expanded to intermediate and deep-level mines. It is likely that a fractured and blocky hangingwall will react in a *softer* fashion and may reach a condition of zero rockmass stiffness with dead-weight fall-outs. More research is required to confirm this statement. The study should therefore be repeated for a stratified and fractured rockmass such as the Carbon Leader-, Leader- and Vaal reefs where these stopes have a large inelastic component of closure. The large inelastic component of closure is due to local mechanisms in the immediate hangingwall such as sliding bedding planes that are induced by face fracturing. With the large magnitude of deformation and the potential narrower hangingwall beam may this well result in a softer rockmass behaviour that needs to be quantified.

It is recommended that the potential for buckling failure of all the new generation elongate type of support be quantified. This will also address one of the concerns expressed by Daehnke et al. (2001).

Further research is also needed to determine the upper height to width ratio limit to which cementitious packs can be installed underground. It is generally accepted in industry that this type of support is less likely to fail by buckling due to its homogeneous composition and proper contact between consecutive layers, and support is therefore often installed to a height to width ratio that is not necessarily confirmed by research.

REFERENCES

Daehnke A. & Roberts M.K.C. (2001). *Review and application of stope support design criteria*, The Journal of the South African Institute of Mining and Metallurgy, Johannesburg, May/June 2001.

Kotzé T.J. (1991). Internal rock engineering report for Beatrix Gold Mine, Gengold, South Africa.

Ozbay M.U. & Roberts M.K.C. (1988). *Yield pillars in stope support* – Proceedings of the first Regional Conference in Africa, South African National Group on Rock Mechanics, Swaziland, 1988.

CHAPTER 9

GLOSSARRY OF TERMS AND CONCEPTS

9.1 DESIGN AREAS FOR STOPE SUPPORT

The condition of the rock around stopes depends largely on the type of rock in which the gold bearing reef occurs, the geological structures and the depth at which mining takes place. In South African gold mines most stoping takes place in rock strata comprising strong brittle quartzite, separated by thin layers of poorly argillaceous material. Other common rock types that may form the country rock enclosing gold-bearing reefs are well-bedded shales and massive lavas.

The underground production environment includes all working places in areas where the workforce is involved with some activity related to the production of ore. These excavations all have different active working life spans depending on the functions of the excavations. This as well as the dimensions and orientation of the excavation relative to strata will impact on the support design in terms of the type and density of the support units.

The content of this research is restricted to the higher risk area namely the stope as the majority of the workforce is concentrated in this confined area.

9.1.1 Face area

The face area is defined as the area on the stope face for a distance of approximately six meters back towards the mined out area. This is the area where pre-entry examination, installation of temporary support, marking-off of drill holes as well as drilling and cleaning operations take place.

Temporary support along the stope face in this area normally consists of an elongate type of support. Permanent support is installed as follow-on support behind the temporary support and consists of elongates, packs, backfill and/or a combination of these. Tendon or internal hangingwall support often complements temporary and permanent support.

9.1.2 Working area

The working area is defined as the face area to a distance of about twelve meters back to the so-called sweeping line. It includes all access- and travelling ways as well as dip- and strike gullies.

Gully support normally consists of tendon or internal support with packs on the gully ledges.

9.1.3 Back area

The back area of a stope is described as the area behind the sweeping line to a distance varying from approximately twenty to thirty meters towards the mined out area. No work that is related to the production of ore is normally performed in this area.

9.1.4 Remote back area

The remote back area can be classed as the area from the back area towards the original central raise of the stope.

9.2 SUPPORT TYPES AND AREAS IN WHICH USED

9.2.1 General

Temporary support is support that will be removed. Temporary support is installed on the stope face during pre-entry examination of the stope face. It normally consists of an elongated type of support that can be manufactured from either timber or steel. In some instances these units are pre-stressed during installation to actively exert a force onto the hangingwall. The pre-stressing of temporary support can be done hydraulically, pneumatically or mechanically. Temporary support is mostly released remotely before the blasting operation if it is not a blast-on type.

Permanent support is support that once installed is not removed. Permanent support is installed on the stope face as follow-on support behind the temporary support. It is normally installed on fixed dip and strike spacing. As suggested by its classification this support is installed for its permanency and may only be removed in accordance with legally prescribed procedures. Permanent support consists mostly of packs, elongates or a combination thereof. It can be pre-stressed in a similar way as the temporary support.

Stiff support can be classed as support with a high initial stiffness where little deformation is required for the support to generate a high resisting force. A stick is a typical example of a stiff support type.

Soft support on the other hand has a relatively low modulus and more deformation is required for the support element to generate a high resisting force. A matpack is a typical example of such an element.

Active support exerts a load onto the excavation walls during installation. This is achieved by a loading mechanism of some kind. The support does not require any deformation of the excavation to take place for it to generate a resisting force. Even in those early days of mining on the Witwatersrand, the miners were aware of the need for the pre-stressing of stope support. One of the developments to achieve this need in those days was the so-called "Q-block." The Q-block consisted of two pieces of round timber, 15-20 cm in diameter and 30 cm in length, which were drawn together by a bolt with washers and nuts. By tightening the nuts, head or footblocks placed above and below can be wedged tightly against the rock surfaces. According to Jeppe (1946) Q-blocks could be installed easily and quickly and proved to be very successful in narrow stopes. A typical example of a modern day active type of support is a hydraulic prop.

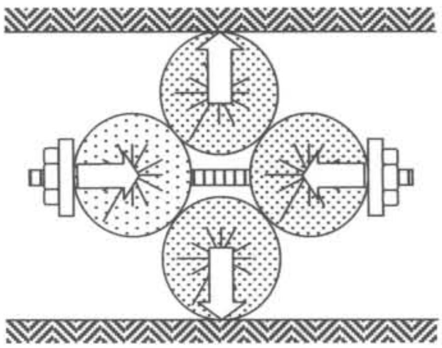

Figure 9.1 – Mechanism of the Q-block described by Jeppe (1946)

Passive support does not exert a load onto the excavation walls during installation and requires deformation of the excavation to take place for it to generate a resisting force.

A typical example of such a type of support is a minepole that is not pre-loaded during installation.

Face support relates to the support installed on the stope face and may consist of elongates, pack support or a combination thereof.

Regional support refers to the support required to stabilise the working area and excludes packs and elongate types of support. Regional support can be rock left in-situ during the mining process or backfill to support local hangingwall. The aim of regional support is to stabilise the macro-working environment.

Tendon support or internal support refers to support installed into the walls of the underground excavation with the objective of reinforcing the rockmass skin surrounding the excavation. Tendon type of support can be used in conjunction with elongate and pack types of support, meshing and lacing.

Stable failure of support refers to the condition where the stope supports fail, while the mine opening remains open and stable. This type of failure of the supports does not have any detrimental effect on the production cycle.

Unstable failure of the supports refers to a condition where the supports fail in such a way that the excavation collapses and that the production cycle cannot continue. Extreme measures are normally required to open the excavation or alternative measures are implemented to re-establish the excavation.

9.2.2 Elongates

Elongate support can be defined as support where the diameter of the unit is small in relation to the height or length of the element. Props and sticks fall in this category. Elongate support is normally a stiff type of support and has varying yieldability depending on the type and design of the support unit. Elongates are used as temporary and/or permanent stope support and is mainly manufactured from timber or steel.

Props refer to an elongated type of stope support. Limitations of ordinary timber sticks were realised early on in the history of the South African mining industry. According to Jeppe (1946), the timber support elements used in those early years were varied. The most common element was the timber prop that was used for local support.

The development of the Pipe-stick in the early 70's heralded a revolution in permanent elongate support practices. This was followed by a wide variety of columnar timber support units that were devised to give improved post-failure yielding properties. These props are generally machined timber poles with either one or both ends modified by tapering or grooving to allow it to yield in a controlled fashion.

A number of different types of elongates have been developed over the last decade and a half with the objective of producing a type of prop with the maximum yielding while maintaining a constant yield load. Several types of materials are used in this process of which steel and timber form the main components. Props are used as a permanent type of stope support.

A stick in the context of stope support refers to timber poles installed as support. It has a low yieldability and is a stiff type of support. According to Jeppe an attempt to overcome the lack of yieldability in a stick was achieved by sharpening one end of the stick to induce yield at a lower load. Jeppe also reported favourably on a compressible pipe support filled with sand.

Minepoles with no engineered yield performance are used in stopes either as permanent support in shallow and/or wide reef stopes where stope closure is limited or as temporary stope face support.

9.2.3 Timber packs

The use of timber as a medium for stope support dates back to 1886, and it is remarkable to reflect that a century later, timber still constitutes the major component of stope support in the gold and platinum mining industry. According to Jeppe (1946) Hildick Smith on Nourse Mines first introduced matpacks in April 1928. The matpack is still used on quite a number of South African gold and platinum mines today.

The use of timber for back area support is a common practice in the South African mining industry although the types of pack in use vary considerably depending on the mining depth, stope width and hangingwall condition. Timber packs are normally a soft support but can be designed and constructed into a stiff type of support by changing the orientation of the timber fibres within the composition of the pack. The incorporation of stiffer elements such as concrete bricks can influence the load-bearing characteristic of a timber pack quite significantly when compared to the conventional matpack.

End-grain type of support refers to a pack where components of the pack are constructed with the timber fibres oriented in the direction of the applied force, i.e. with the fibres oriented vertically in the pack. The end-grain component of the pack produces a stiffer behaviour of the pack.

9.2.4 Cementitious packs

Cementitious packs have been introduced in the mining industry as a substitute for timber packs. Lightweight concrete packs have mainly been developed over the last decade and a half when requirements for support performance have been specified more accurately.

Cementitious packs consist of either pre-cast blocks or can be constructed underground on-site by grout pumped into a pack construction or containment of some kind. These packs can either be square or circular, stiff or soft, depending on the design and construction of the pack matrix. Concrete packs are used as permanent stope support and are often used for specialised applications such as shaft pillar extraction and as gully support.

9.2.5 Reef pillars

Reef pillars can be described as ore left in-situ during the mining process with the aim to support the local hangingwall, or to provide stability to the mine or portion thereof [28]. In shallow mines where convergence rates are low and where the hangingwall stratigraphy is such that bed separation to a height of several metres can occur, may conventional support be unable to prevent stope collapse. This is due to the mass of the hangingwall exceeding the strength of the support elements. To overcome this problem, support systems comprising systematically spaced reef pillars, together with intervening rows of yielding stope support such as timber elongates are used.

The reef pillars are designed so that they are able to crush or yield in a controlled manner in order to ensure the stability of the excavation.

Over the past 30 years strike- and dip stabilising pillars have been used on a number of deep level gold mines as a means of regional support. To date the implementation of stabilising pillars has been based on the understanding that through limiting elastic convergence, will this reduce the elastic deformation in the stope and therefore influence the seismicity in the working area.

REFERENCES

Jeppe C.B. (1946). *Gold mining on the Witwatersrand* pp. 815-829, Transvaal Chamber of Mines.