M PROPS (PTY) LTD

Risk Assessment of the Heavy Duty Camlok Prop

SRK Consulting
Engineers and Scientists

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Reviewed by:

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Risk Assessment of the Heavy Duty Camlok Prop

1 Introduction

The Heavy Duty Camlok Prop Risk Assessment as carried out by M Props Risk Assessment Team, has been reviewed by Mr G.C. More O'Ferrall, a Principal Mining Engineer: Geotechnical, working with SRK Consulting. The methodology followed in compiling the Risk Assessment was reviewed, but no attempt was made to verify the values associated with the various aspects related to the prop life-cycle. This risk assessment followed an approach previously undertaken by SRK Consulting (report ref: 366264)

The objective of the risk assessment is to logically describe the use of the Heavy Duty Camlok Prop in a systematic method in order to identify the hazards and their associated probability of occurrence so that the level of risk can be assigned to the hazards. By adopting this approach, it is hoped that reading of the document would not be onerous on the reader and the major hazards and their associated risks be clearly highlighted in the text with the full risk assessment as backup in the appendices. For this purpose the fault-event tree risk assessment method was selected as the most appropriate for this purpose. A brief description of the method can be found in Appendix A.

Cape Town	+27 (0) 21 409 2400
Durban	+27 (0) 31 312 1355
East London	+27 (0) 43 748 6292
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Johannesburg	+27 (0) 11 441 1111
Pietermaritzburg	+27 (0) 33 345 6311
Port Elizabeth	+27 (0) 41 581 1911
Pretoria	+27 (0) 12 361 9821
Rustenburg	+27 (0) 14 594 1280

2 Table 1: Risk Assessment Team Members

Name	Designation	Experience
Mr Ed Groves	Director M Props	33 Years Research and Development & Sales.
Mr Colin May	Sales Manager M Props	28 Years Research and Development & Sales
Mr John von Ruben	Techncial Represenative Training M Props	21 Years Mining 9 Years Training
Mr Mike Strong	Techncial Represenative Training M Props	4 Years Mining 9Years Training

3 Quality Assurance

The consistency of the performance of the Heavy Duty Camlok Prop supplied to the mine is maintained through a quality assurance program implemented during manufacture by M Props and the high quality of materials supplied to the manufacturer by their accredited suppliers.

4 Risk Assessment Process

This risk assessment was based on a risk assessment carried out previously by SRK Consulting on the Camlok prop. A workshop was held in which the risks to workers during the twelve stages of the life cycle of a typical Heavy Duty Camlok Prop were assessed. A probability of occurrence for each root cause was assigned by the risk assessment team on a subjective and judgemental basis. A probability of occurrence for each fault was calculated using the fault tree method. This probability of occurrence was used as the base to determine the probability of mining personnel being injured or fatally injured whilst using the Heavy Duty Camlok Prop. Finally a risk profile was compiled for the Heavy Duty Camlok Prop benchmarked against the life time probability of being fatally injured in a public place or on public transport (Cole, 1993).

4.1 Figure 1:

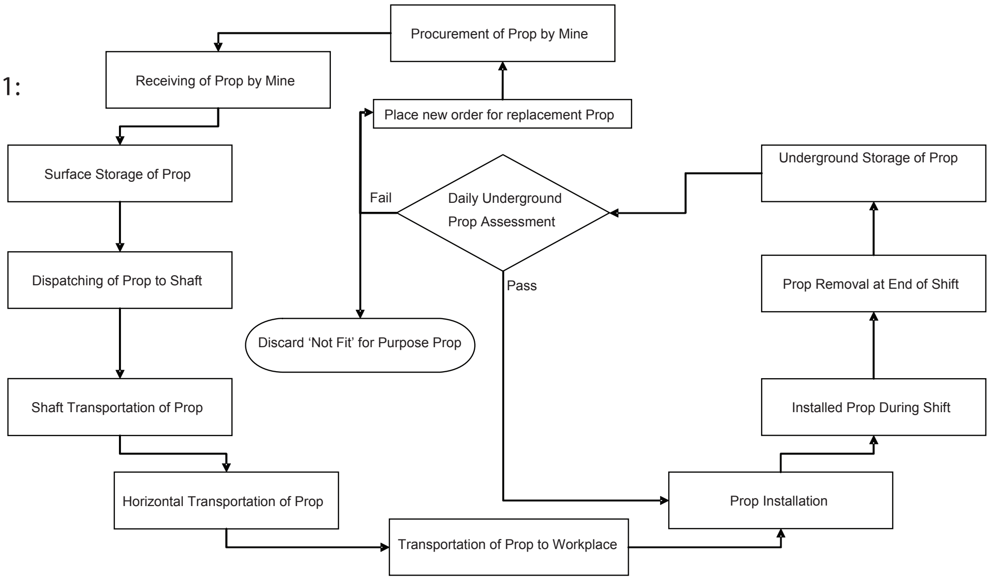


Figure 1: Life Cycle of the Heavy Duty Camlok Prop

The hazards associated with each stage of the life cycle of the Heavy Duty Camlok Prop were discussed and documented by the team during the workshops. Conclusions from these discussions are described for each stage of the life cycle, where the main risks associated with the use of the Heavy Duty Camlok Prop are highlighted. The full risk assessment can be found in Appendix B.

4.2 Heavy Duty Camlok Prop Life Cycle

The life cycle of a Heavy Duty Camlok Prop starts when an order is received from a mine by M Props for delivery and ends when the prop is declared not fit for purpose due to excessive 'wear and tear' and/or corrosion of the prop and removed from the work place (Figure 1).

4.4.2.1 Procurement Procedure

The hazards with the highest probability of occurrence associated with procurement of the Heavy Duty Camlok Prop by the mine purchasing department is identified to be the following:

Incorrect length of Heavy Duty Camlok Prop ordered for the current panel stoping width or excavation size with regards to development ends or large excavations is considered "Low" ~ (1.00 x 10^{-04}).

The overall probability of occurrence of a threat of injury to mining personnel through the use of the Heavy Duty Camlok Prop due to poor procurement procedures is considered "Low" ~ (3.31 x 10^{-04}).

However, the mine should ensure that the type of temporary support prop ordered is appropriate for the general loading conditions experienced on the mine, through a detailed Rock Engineering design and underground assessment.

4.4.2.2 Receiving by Mine

The hazards associated with this cycle of the prop's life were seen as mainly being the off-loading of the prop at the stores from the delivery vehicle. The hazards identified are related to:

Lack of off-loading equipment is considered "Low" ~ (5.00 x 10^{-04}) with the likelihood of hand and foot injuries to mine personnel due to falling or the dropping of props while off-loading;

- The probability of injuries occurring while **handling long props** is also considered to be **"Low" ~ (1.00 x 10^{-04})**;
- **Late time of delivery** increases the probability of occurrence of a failure where labour may have already left for the day, leaving insufficient personnel to assist with the off-loading of the delivery vehicle. The probability of occurrence is considered **"Low" ~ (1.01 x 10^{-04}).**

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor receiving practice by the mine is considered **"Low" ~ (7.07 x $10^{-04)}$**.

However, the mine should ensure that sufficient labour and off-loading equipment is available in the receiving yard to safely off-load and transport the props to the storage yard. The availability of Personnel Protective Equipment (PPE) and training in correct handling of props will reduce the risk of injury to mine personnel.

4.4.2.3 Surface Storage

The team identified the main hazard associated with storage of the Heavy Duty Camlok Prop at the mine's storage facility as **weathering of props,** if stored out in the open. Weathering of props can cause the following:

- **Sun damage to props** can lead to peeling off of the identification label which contains information on the type of prop. Without this label the user may be unable to identify the correct type of prop to be used. The probability of occurrence is considered **"Extremely Low" ~ (1.00 x 10^{-06})**;
- **Storage in mud / water** which may lead to premature corrosion of the prop is considered **"Extremely Low" ~ (2.00 x 10^{-06})**.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor surface storage by the mine is considered **"Low" ~ (2.09 x 10^{-04})**.

However, the mine should ensure that the Heavy Duty Camlok Props and accessories are stored under cover and are not exposed to sun and rain. A procedure should be implemented which ensures correct stock rotation.

4.4.2.4 Dispatching to the Shaft

The team agreed that the hazards associated with dispatching of the props to the shaft by the mine stores are similar to those identified during receiving by the mine. Although time of delivery is not an issue as the stores operate during set times and the hazards associated with rushing of loading may not exist.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor dispatching procedures by the mine is considered **"Low" ~ (7.07 x 10^{-04})**.

4.4.2.5 Shaft Transport

This stage of the prop's life cycle includes the transportation of the props in vertical and/or inclined shafts. The hazards identified by the team are:

- **Poor packing and stacking of props in material cars** could lead to prop handling injuries while unpacking is "**Medium" ~ (2.05 x 10^{-03})**;
- **Poor slinging practice of long props** also poses the hazard of material falling down the shaft or catching on shaft steel work while in transit. Although the probability of occurrence is considered "E**xtremely Low" ~ (2.00 x 10^{-06})**, the consequences could be disastrous;
- **Lack of shaft time availability** was also highlighted as a potential problem as this would delay the arrival of the props at the designated workplace and lack of support units in the workplace increases the risk of injury to mine personnel or lost production. The probability of occurrence is considered **"Very Low**" ~ **(2.00 x 10^{-05}).**

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor shaft transport procedures by the mine is considered **"Medium" ~ (2.07 x 10^{-03})**.

The mine should ensure that appropriate procedures are in place regarding the packing and transportation of props, with emphasis on long props and slinging if required.

4.4.2.6 Horizontal Transport

This section of the risk assessment workshop focused on the hazards associated with the transportation of props in material cars in mine haulages to the work place. The team identified the two main hazards as being:

- **Poor packing of material cars** which may lead to props falling off material cars or protruding from the material car and able to strike mine personnel while being transported is considered to be **"Medium**" ~ **(2.05 x 10^{-03})**;
- **Poor handling of long props** which may lead to protruding or falling of loose props from the material car is considered to be **"Medium**" ~ **(2.00 x 10^{-03})**.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Props due to poor horizontal transport procedures by the mine is considered "**Medium" ~ (4.24 x 10^{-03})**.

The mine should ensure that correctly sized material cars are available and correct packing and transport procedures are in place to ensure that this task is performed safely.

4.4.2.7 Transport in the Workplace

The team agreed that this was one of the important cycles of the prop's life, as the props are transported manually by mine personnel or attached to monorope winches for transportation into the place of work. The main hazards identified and the associated values are:

- Injury while **transporting the props to the workplace** is identified as having a **"Medium" ~ (7.25 x 10^{-03})** probability of occurrence with the following two categories:
    - Injury to mine personnel whilst the prop is being **transported by the monorope winch system** is considered to be **"Medium" ~ (1.23 x 10^{-03});**
    - Injury to mine personnel whilst **manually transporting** the prop to the workplace is considered to be **"Medium" ~ (6.03 x 10^{-03})**.
- Poor **underground storage** in the timber bay **may** result in injury due to tripping and falling or falling props due to poor stacking is considered to be **"Medium" ~ (4.40 x 10^{-03})**;
- When transporting props in tunnel developments, **inclined excavations** are identified as having a slightly higher probability of occurrence **(3.92 x 10^{-03})** than transporting in **horizontal excavations (1.72 x 10^{-03})**. This is due to the higher probability of injury caused by slipping and falling due to **poor footwall conditions** in inclined excavations.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor transportation to the workplace is considered **"High" ~ (1.72 x 10^{-02})**.

The mine should ensure that adequate procedures are in place for transportation of the Heavy Duty Camlok Prop to the workplace via a monorope winch system. [If the props are to be manually transported to the workplace, the mine is to ensure that the travel distance is not excessive, is adequately ventilated, and there is sufficient clearance in which to travel.]

4.4.2.8 Installation

The installation of the prop in the workplace has the highest probability of incident occurrence of all the stages of the Heavy Duty Camlok Prop life cycle. This stage is sub-divided into the following hazards:

- **Poor "making safe"** which can result in a fall of ground accident due to disturbing a weak hangingwall whilst installing the prop is considered **"Low" ~ (3.58 x 10^{-04})**;

- **Poor footwall conditions** may cause the user to slip and fall while installing the prop as well as providing an unstable footing for the installed prop, which will reduce the prop's performance capabilities is considered **"High" ~ (1.99 x 10^{-02})**;
- **Poor permanent support installation** as a result of the permanent support not being installed to mine standard or already having worked beyond its capabilities, the installation of the Heavy Duty Camlok Prop becomes more hazardous and is considered **"High" ~ (1.00 x 10^{-02})**;
- **Failure to examine prop condition and spanner availability** may result in unsafe work conditions by increasing the probability of fall of ground occurrences as the prop will not perform to the specified level or may not be installed due to being completely inoperable. The probability of occurrence is considered **"High" ~ (1.99 x 10^{-02})**;
- **Poor positioning of the prop** will result in insufficient support resistance being applied to the hangingwall or incorrect prop orientation which will increase the risk of removing the prop safely is considered **"Very High" ~ (1.80 x 10^{-01})**;
- **Failure to extend the inner tube and locate setting pin correctly** will result in poor performance of the prop due to an insufficient preload and the prop being easily dislodged is considered **"High" ~ (3.95 x 10^{-02})**;
- **Failure to pre-load the cam mechanism correctly** will result in an insufficient preload on the prop, allowing it to easily dislodge is considered **"High" ~ (2.41 x 10^{-02})**.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop during installation in the workplace is considered **"Very High" ~ (2.71 x 10^{-01})**.

The mine should ensure that all mine personnel required to use the Heavy Duty Camlok Prop are trained correctly according to the lesson plan provided by M-Props.

4.4.2.9 Installed Prop

This stage of the Heavy Duty Camlok Prop covers the period when the prop is installed and acting as temporary support in the workplace. The major hazards with the highest probability of occurrence are identified as:

- **Falls of ground** which may occur due to poor ground conditions or when the prop is dislodged as a result of block rotation of loose hangingwall, structural failure of the prop due to excessive loading, or lateral loading caused by a fall of ground. The probability of occurrence for this is considered **"High" ~ (3.55 x 10^{-02})**;

- **Inappropriate support design** which may result in prop failure due to inappropriate prop type or insufficient load bearing capacity of the prop is considered **"High" ~ (1.12 x 10^{-02})**. This hazard also includes lateral loading due to the installation of safety nets which may result in props being dislodged during a fall of ground;
- **Illegal removal** of an installed prop which normally occurs when the prop is deemed to be in the way, normally by the rockdrill operator, is considered **"Very Low" ~ (6.52 x 10^{-05})**. This illegal removal of a prop **increases the probability of falls of ground** due to the **increased support span or extra loading on the remaining props**;
- **Installed prop used for purpose other than support** may lead to falls of ground due to the prop being dislodged. Example: Rigging on an installed prop for cleaning purposes. The probability of occurrence is considered to be **"Medium" ~ (1.14 x 10^{-03})**.

The overall probability of injuries occurring to mining personnel through the correct use of the Heavy Duty Camlok Prop during the shift is considered to be **"Medium" ~ (4.75 x 10^{-02})**.

The mine should ensure that all stope and development mine personnel are trained in the correct use of the Heavy Duty Camlok Prop. The mine is to ensure that appropriate support design is in place and that the Heavy Duty Camlok Prop is used for the purpose that it is intended. If safety nets are to be implemented by the mine as a safety initiative, the mine must ensure that the lateral load capacity of the prop can comply with the maximum load bearing capacity of the safety net.

4.4.2.10 Prop Removal

The risk assessment process showed that prop removal is ranked third after prop installation and the installed prop during the shift. The major hazards identified for this cycle with values are as follow:

- **Falls of ground** which may occur during the release of the Heavy Duty Camlok Prop, where the probability of injury to mine personnel is significantly increased if the prop is **not released remotely** or the **incorrect spanner release sling length** is used. The probability of occurrence is considered **"Medium" ~ (1.42 x 10^{-03})**;
- Injury due to **prop falling on a person** is considered **"High" ~ (1.10 x 10^{-02})**;
- **Strain** injuries to person when releasing the prop or due to heat exhaustion are considered to be **"Low" ~ (3.03 x 10^{-04})**.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop while removing the prop after the shift is considered to be **"High" ~ (1.27 x 10^{-02})**.

The mine should ensure that all mine personnel required to use the Heavy Duty Camlok Prop are trained correctly according to the lesson plan provided by M-Props.

4.4.2.11 Underground Storage

The main hazard associated with underground storage of the Heavy Duty Camlok Prop is incorrect storage conditions leading to damage which may cause premature failure of the prop and its accessories. The potential types of damage which can lead to poor prop performance are:

- The probability of **blast damage** to the prop if stored in close proximity to the face area is considered to be **"Medium" ~ (1.00 x 10^{-03})**;
- The probability of **prop corrosion** when stored in wet muddy conditions, which may lead to defective cam operation and premature corrosion of the prop is considered to be **"Low" ~ (2.00 x 10^{-04})**;
- **Poor storage practice** may lead to injury to mine personnel through tripping and falling or falling props if the props are stored haphazardly. The probability of occurrence is considered to be **"Medium" ~ (1.20 x 10^{-03})**;
- **Scraper damage to the prop** may occur if the prop is stored in the path of the scraper or in contact with scraper ropes. The probability of occurrence is considered to be **"Medium" ~ (1.00 x 10^{-03})**;
- **Release spanner failure** due to poor storage may lead to props not being released resulting in props being left installed and suffering severe damage as a result of blasting, increasing the risk of ore contamination and jeopardizing the availability of props for support during the following shift is considered **"Medium" ~ (1.00 x 10^{-03})**.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor underground storage is considered **"Medium" ~ (6.38 x 10^{-03})**.

The mine should ensure that correct underground storage procedures are in place.

4.4.2.12 Daily Underground Prop Assessment

This is an important aspect of the Heavy Duty Camlok Prop's life cycle, as the performance of the prop depends on its condition and level of corrosion. The assessment should be done on a daily basis before prop installation to guard against the following:

- **Poor assessment of the physical condition** of the **prop** and **corrosion washer indicator** is considered **"Medium" ~ (2.60 x 10^{-03})**;
- **Poor assessment of the physical condition** of the **release spanner** is considered **"Medium" ~ (2.30 x 10^{-03})**.

The overall probability of injuries occurring to mining personnel through the use of the Heavy Duty Camlok Prop due to poor prop performance as a result of poor daily underground prop assessment is considered to be **"Medium" ~ (4.89 x 10^{-03})**.

The mine should ensure that a checklist is included in the daily assessment of the Heavy Duty Camlok Prop. Section 12 of the risk assessment in Appendix B lists the critical checks for the prop and should be incorporated into the daily checklist.

4.4.2.13 Removal of 'not fit for purpose' Props

This is the final stage of the prop's life cycle, when the daily prop assessment indicates that the prop is no longer fit for purpose. The prop should be removed from the workplace and transported to surface to be discarded. **Refurbishment of 'not fit for purpose' Heavy Duty Camlok Props by the mine or a contractor is only to be undertaken with the approval and or involvement of M-Props.**

5 Risk Profile

The probability of occurrence of the top fault, the threat to mine personnel while using the Heavy Duty Camlok Prop is calculated for each identified stage of the life cycle. From this, the probability of a mine employee being injured or fatally injured can be calculated taking into account their exposure time and the potential severity of the hazard (Figure 2).

From this risk profile, it is clear that the risk of injury to mine personnel increases as the prop progresses through its life cycle towards the workplace and decreases after the prop has been removed from the workplace and stored for the next shift.

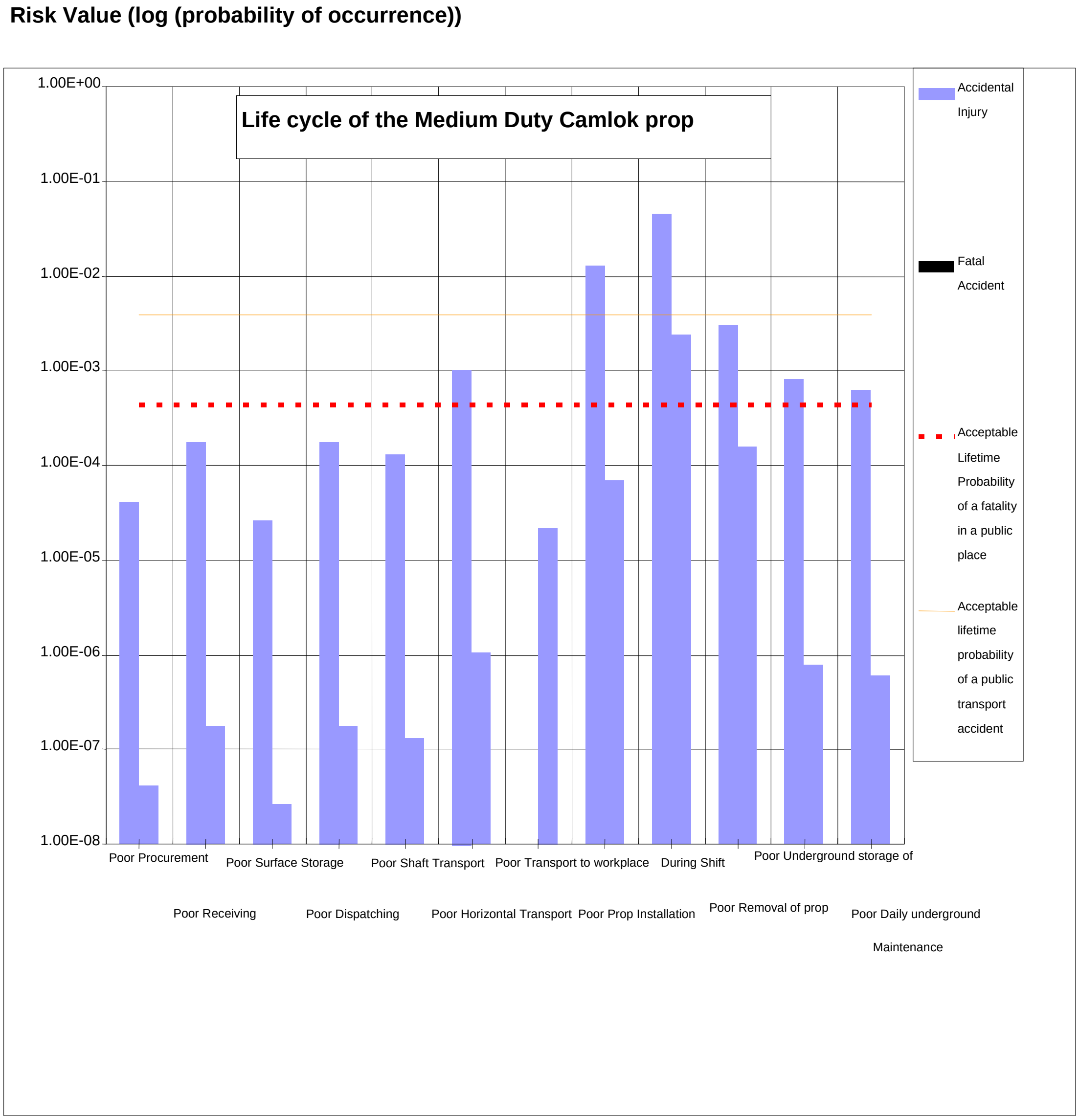


Figure 2: Risk profile of the Heavy Duty Camlok Prop

Figure 2 shows a significant increase in the risk profile as the Heavy Duty Camlok Prop enters the workplace. The indicated benchmarks are the acceptable lifetime probability of total loss in a public place and while using public transport (Cole, 1993). The probability of a fatal injury to mine personnel while using a Heavy Duty Camlok Prop remains within acceptable limits, except for the installation, during the shift and removal of the prop. However, a mine employee trained in the correct use of the Heavy Duty Camlok Prop should be aware of the hazards and risks associated with his/her daily tasks underground, making them more vigilant and thus reducing the risk to themselves when compared to a general member of the public with a low awareness and little ability to reduce the risk of being fatally injured in a public place or on public transport.

6 Conclusions

The threat of injury to mine personnel through the use of the Heavy Duty Camlok Prop was assessed during the study with the typical life cycle of the prop described and documented in thirteen definable stages.

The probabilities of injuries occurring during each stage of the Heavy Duty Camlok Prop's life cycle are determined, providing an overall probability of occurrence for the top risk, threat of injury to mine personnel through the use of a Heavy Duty Camlok Prop.

A risk profile is compiled for the life cycle, where the threat of injury to mine personnel is determined by calculating the probability of injuries or fatal injuries occurring to mine personnel, taking into account the exposure of mine personnel to the hazards and the severity of the hazard. These probabilities are benchmarked against acceptable lifetime probabilities of being fatally injured in a public place or on public transport (Cole, 1993).

The risk profile for the Heavy Duty Camlok Prop shows that the risk value for all the identified stages of the life cycle are within acceptable limits, except for the stages involving the installation of the prop i.e. the installation of the prop during the shift and removal of the prop after the shift.

The mine should ensure that strategies are in place to reduce or eliminate the risks associated with the identified hazards associated with the use of the Heavy Duty Camlok Prop.

G.C. More O'Ferrall

Principal Mining Engineer: Geotechnical

Appendix A

General Description of the Risks Assessment Method

GENERAL DESCRIPTION OF THE FAULT-EVENT TREE ANALYSIS TECHNIQUE

TABLE OF CONTENTS

7 GLOSSARY OF TERMS AND DEFINITIONS

Event, consequence	Potentially damaging consequences. It denotes the effects of the causative hazards, for example, injury to people or damage to machines and equipment.
Event tree analysis	An analysis that describes the possible range and sequence of the outcomes which may arise from an initiating event or top fault. The probability of occurrence of events is determined by considering the probability of occurrence of the top fault together with the relative weighting for the associated potentially adverse events.
Exposure	How often and for how long employees are exposed to a hazard.
Fatality accident rate (FAR)	The risk of death per 100 million hours of exposure to a dangerous activity. This is approximately the same as the probable number of fatalities from 1000 people involved in the activity for the whole of their working lives, each about 100 000 hours (50 years x 250 days/year x 8 hours/day).
Fault	Is a more general term than failure and can include the proper operation of an item at an inopportune time as well as the failure of an item to operate properly.
Fault Tree Analysis (FTA)	Is a technique, either qualitative or quantitative, by which sets of circumstances, which would need to co-exist, and can contribute to a specified undesired event (called the top event) are deductively identified, organised in a logical manner, and represented pictorially.
Gates	Show the relationships of faults needed for the occurrence of a higher fault. The higher fault is the output of the gate and the lower faults are the inputs to the gate. OR gates are used to show that the output fault occurs only if one or more of the input faults occur. AND gates are used to show that the output fault occurs only if all the input faults occur.

Harm	Injury or loss
Hazard, cause, fault, threat	Something that has the potential to cause harm; e.g. Fall of ground from the hangingwall.
Lifetime probability of occurrence	The probable unit number of times to which any person would be exposed to a detrimental event during his/her whole life. It is directly related to the fatality accident rate, FAR. Expressed as a percentage, the lifetime probability of occurrence of an event is therefore equal to FAR x 100/1000 = 0,1 x FAR.
Primary faults	The primary categories in which the hazards to safety and health are considered e.g. threat of fall of ground due to bord collapse or threat of fall of ground due to pillar failure.
Probability of occurrence	The likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes. It is expressed as a number between 0 and 1, with 0 indicating an impossible outcome and 1 indicating an outcome is certain.
Risk	Is the product of the probability of occurrence of a hazard and the consequence of the hazard (severity of the damage of an event).
Risk analysis	A systematic use of available information to determine how often specific events may occur and the magnitude of their likely consequences (often interchangeably used for ‘risk assessment’).
Risk assessment	The decision making process whereby a level of risk is compared against criteria and risks are prioritised for action.
Risk management	The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring risk.

Secondary faults	The component hazards that can be identified in each of the primary categories of hazards/faults e.g. with regard to the threat of a fall of ground due to bord collapse would be fall of ground originating from the hangingwall and fall of ground originating from the sidewall.
Tertiary faults	The component hazards that can be identified in each of the secondary categories of hazards/faults e.g. with regard to fall of ground from the hangingwall would be fall of ground from the hangingwall in the face area, fall of ground from the hangingwall in the back area, or fall of ground from the hangingwall at intersections.

8 1 INTRODUCTION

The failure of any system, e.g. a fall of ground in an underground excavation, is seldom the result of a single **cause** or **fault**. Failure usually results after a combination of faults occur in such a way that the factor of safety of the system falls to below unity. A disciplined and systematic approach is therefore required to determine the correct logic that controls the failure of the system and to analyse the potential consequences of failure. One such approach, the **Fault-Event Tree Analysis**, is discussed here.

9 2 CAUSE/FAULT TREE ANALYSIS

Fault Tree Analysis (FTA) is a quantitative or qualitative technique by which conditions and factors that can contribute to a specified undesired incident (called the **top fault**) are deductively identified, organised in a logical manner, and presented pictorially. It can also be defined as a deductive failure analysis which focuses on one particular undesired fault and which provides a method for determining causes of the fault.

FTA affords a disciplined approach that is highly systematic, but at the same time sufficiently flexible to allow analysis of a variety of factors. The application of the top-down approach focuses attention on those effects of failure that are directly related to the top fault. FTA is especially useful for analysing systems with many interfaces and interactions. The pictorial representation leads to an easy understanding of the system behaviour and the factors included, but as trees are often large, processing of fault trees may require computer systems.

Starting with the top fault, the possible causes or failure modes (**primary faults**) on the next lower system level are identified. Following the step-by-step identification or undesirable system operation to successively lower levels, **secondary faults, tertiary faults**, etc. are identified.

In order to determine the correct logic that controls the failure of the system, the faults are not initially given probabilities of occurrence. In this form the “tree” is referred to as a “**cause tree**”. Once the cause tree is considered to correctly reflect the combinations of faults necessary to result in failure, probabilities are either calculated or assigned to the faults. In this form, the “tree” is referred to as a “**fault tree**”.

Thus, a fault tree represents a quantitative or qualitative evaluation of the probabilities of various faults leading to the calculation of the **top faults,** which result in failure of the system. The objective of the fault tree is to identify and model the various system conditions that can result in the top fault (e.g. threat of FOG in East Block due to bord collapse).

10 3 PROBABILITY EVALUATION IN FAULT TREE

The fault tree is a complex of entities known as **gates** which serve to permit or inhibit the passage of fault logic up the tree. The gates show the relationships of faults needed for the occurrence of a higher fault. **AND** gates and **OR** gates denote the type of relationship of the input events required for the output event.

- AND gates are used where faults are statistically dependent. If it is necessary for *n* secondary faults to occur in order for a primary fault to result, then the probability of occurrence, *p*, is represented by:

  p[primary fault] = p[secondary fault 1] x p[secondary fault 2] x ………….x p[secondary fault n]

- OR gates are used where faults are statistically independent. If a primary fault can result as a consequence of the occurrence of any *n* secondary faults, then the probability of occurrence is determined from the calculation as follows:

  p[primary fault] = 1 - (1 – p[secondary fault 1]) x (1 – p[secondary fault 2]) ……. (1 – p[secondary fault n])

11 4 EVENT TREE ANALYSIS

The potential damaging consequences of a top fault is known as **events** and the systematic display of the events is referred to as an **event tree**. The probability of occurrence of a top fault together with relative weighting for the associated potentially adverse events, enable their likely occurrence to be determined. The product of the probability of occurrence and severity of the damage of an event is defined as the **risk**.

The systematic nature of the fault event tree enables the sensitivities of the potentially adverse consequences to any of the causative hazards to be evaluated. This enables the most threatening causative hazards to be identified and eliminatory measures to be defined.

12 5 ALLOCATION OF PROBABILITIES OF OCCURRENCE

Three measures are available for measuring reliability in engineering design, viz:

- the factor of safety;
- the reliability index, and;
- the probability of failure.

The factor of safety is a clearly understood and a numerically sensitive measure. It is, however, not a consistent measure and is not determined in terms of consistent processes. The reliability index is a consistent measure and is based on consistent processes for determining operational values. Its meaning is, however, not clearly understood. It is also not numerically sensitive, especially not with regard to higher orders of reliability.

The probability of failure is a consistent and numerically sensitive measure and is based on consistent processes for the determination of operational values. The numerical sensitivity of the probability of failure, however, detracts from the clarity of its meaning.

The probabilities of various kinds of losses of life, property, etc. vary exponentially over many orders of magnitude between very large and very small values. The meaning of such a measure is often difficult to understand.

The difficulties that designers have in selecting acceptable thresholds for probability of failure can be resolved by using the norms and guidelines for selecting acceptable probabilities of failure for design, presented in a paper entitled: "Review of norms for probability of failure and risk in engineering design", (Kirsten, 1994). Acceptable probabilities of failure are discussed further in Section 6.

The acceptable lifetime probabilities of total loss of life described in this paper by Kirsten are summarised in Table 1 below. Also included in the table are the corresponding probabilities assigned to hazards associated with the installation of rockbolts.

Table 2 Acceptable lifetime probabilities of total loss of life and corresponding probabilities assigned to hazards.

Degree of risk / Probability of occurrence	**Acceptable lifetime probabilities** (after Cole, 1993)
Very Risky / Certain (C)	$7x10^{0}$
Risky / Very high (VH)	$7x10^{-01}$
Some risk / High (H)	$7x10^{-02}$
Slight chance / Medium (M)	$7x10^{-03}$
Unlikely / Low (L)	$7x10^{-04}$
Very unlikely / Very low (VL)	$7x10^{-05}$
Practically impossible / Extremely low (EL)	$7x10^{-06}$
Practically zero (PZ)	$7x10^{-07}$

In certain cases, probabilities of occurrence could also be determined more accurately by assigning probability density functions to primary faults. This is particularly important in geotechnical engineering designs where input parameters, especially those that are affected by geology, are often not known accurately and the influence of their variability should be accounted for. However, probabilistic analyses of multiple variables require sophisticated numerical techniques that are beyond the scope of this project.

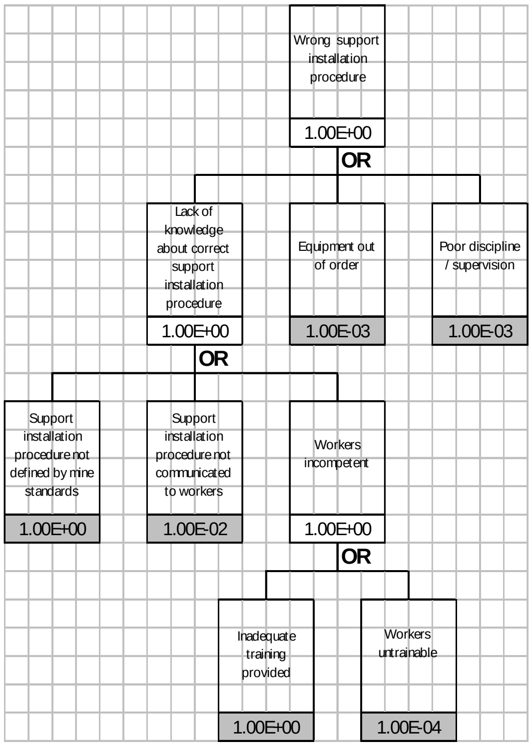
A simplified approach is to assign probabilities based on engineering judgement and past experience with this type of work. Probabilities assigned to certain levels of risk as described in Table 1 could be used as a guideline. The final result will then show if a more accurate assessment of the probability of occurrence would be necessary. It is likely that the detailed assessment will only be required for key sensitive areas which will be revealed by sensitivity analysis.

It is important to note that probabilities of occurrence may not have unique or discrete values. It is possible for a probability of a particular fault (or event) to change in sympathy with another probability that it is coupled with. This is best illustrated by means of an example:

> *Take the example of a "wrong support installation procedure" being used in an underground excavation. The probability of a wrong support installation procedure being used depends upon the probability that:*
>
> - *the knowledge about the correct support installation procedure is lacking, or;*
> - *the equipment being used for support installations is out of order, or;*
> - *the discipline and supervision are poor.*
>
> *The probability that the knowledge about the correct support installation procedure is lacking in turn depends on the probability that:*
>
> - *the support installation procedure is not defined by the mine's standards, or;*
> - *the support installation procedure is not communicated to the workers, or;*
> - *the workers are incompetent.*
>
> *The probability that the workers are incompetent depends on the probability that:*
>
> - *inadequate training is provided, or;*
> - *the workers are untrainable.*

The probability of a wrong support installation procedure being used could be different for different parts or sections of the mine. For example, the equipment being used for support installation in one section could be more reliable than the equipment being used in another section.

The probability of a wrong support installation procedure being used can be represented as follows:



13 6 ACCEPTABLE PROBABILITY OF FAILURE

The use of probability of failure is a means of incorporating acceptable and tolerable levels of risk into engineering designs. As mentioned before, risk is the product of the probability of failure and the consequence of an unwanted event, in this case, falls of ground.

The acceptability of probabilities of failure for particular design applications can be evaluated in terms of the magnitudes and distributions of actual frequencies of total losses of life, property and money. For example, the lifetime frequencies of fatalities due to unstable ground in gold and coal mines in South Africa in 1993 amounted to approximately 7,9% and 2,8% respectively (Kirsten, 1994). (These correspond with fatality rates/1000 at work of 0,76 and 0,37 respectively.)

According to Cole (1993), an acceptable lifetime probability of loss of life in respect of voluntary employment in underground mines would be 0,7%. This would bring about a 10 fold reduction in the number of fatalities in metalliferous mines and a 4 fold reduction in the number of fatalities in coal mines.

The lifetime frequency of a detrimental event represents the probable unit number of times to which any person would be exposed to it during his/her whole life. It is directly related to the fatality accident rate, FAR, defined by Hambly and Hambly (1994) as the risk of death per 100 million hours of exposure to a dangerous activity. This is approximately the same as the probable number of fatalities from 1000 people involved in the activity for the whole of their working lives, each about 100 000 hours (50 years x 250 days/year x 8 hours/day). Expressed as a percentage, the lifetime probability of occurrence of an event is therefore equal to FAR x 100/1000 = 0,1 x FAR. This measure enables losses from different occupations to be compared on a common basis. It also enables exposures to losses for part of a day to be compared to full time exposures.

When the consequences of failure are serious, a reduced probability of failure needs to be adopted in order to achieve an acceptable level of risk, e.g., when mining a panel of pillars, the normal acceptable level of risk in terms of probability of failure is 3 in 1000 (Galvin et al, 1998). However, this probability of failure would be unacceptable for a more serious consequence of failure, such as flooding of the workings. In this case, a probability of failure of at least 1 in 100 000 may be chosen as representative of the tolerable level of risk, considering the seriousness of the consequences.

Other recommendations for acceptable probabilities of failure found in the literature can be summarised as follows:

- According to Galvin et al (1998), a probability of coal pillar failure of 3 in 1000 relates to a FOS of 1,59, and a probability of failure of 1 in 100 relates to a FOS of 1,48. This correlation is based on data from the Australian coalfields.
- According to the back-analysis carried out by Salamon and Wagner (1984), the rate of coal pillar failure in South Africa had been 0,003, which compared with the predicted probability of pillar failure of 0,003 for a FOS of 1,6.

- D'Andrea and Sangrey (1982) have shown that probabilities of slope failure of 0,1; 0,01 and 0,001 correspond with factors of safety ranging from 1,25 to 1,93; 1,43 to 3,13 and 1,58 to 4,49 respectively.
- According to Cole (1993), an acceptable life-time probability of loss of life in respect of voluntary employment in underground mines would be 0,7% or 0,007.

Kirsten (1994) suggests that acceptable levels for probabilities of failure for which designs may be prepared should be significantly smaller than the actual probabilities of failure observed for similar situations. This is required to account for the following aspects.

1) Natural aversion to involuntary total loss

   Slovic (1987) found that the acceptability of risk is related to the benefits of the activity and the voluntary or involuntary nature thereof. Public aversion to risk is also related to the number of people involved. The design engineer should take note of these aspects when selecting a value for the probability of failure for a particular case.

2) Variations in perceptions

   Slovic (1987) found that risk means different things to different people, depending on their background. Selecting a value for probability of failure should take cognisance of the variations in the perceptions of risk, but need not cater unduly for misconceptions on the part of the public.

3) Non-representativeness of actual comparative probabilities of failure

   The design engineer should take note of the scatter of various acceptable probabilities of failure.

4) Variations in parameter values and biases in calculation procedures

   Design engineers should be aware of the effects of variations in parameter values on the reliability of the probability of failure that may be determined.

5) Deficiencies in design data

   Ground conditions are known to carry potentially high risks and uncertainty. According to Sowers (1993) a study of 500 geotechnical failures revealed that 88% of the failures

> were produced by human shortcomings and that 75% of the failures originated in the design process. Whyte and Tonks (1993) submit that these problems are directly and largely attributable to deficiencies in the site investigations undertaken for design purposes.

Acceptable probabilities of failure cannot be prescribed. Each mine should therefore decide on a value for probability of rockfall accidents that would be acceptable to the mine. In the mean time, SRK suggests that a value of 0,003 or 0,3% be used as an acceptable probability of a rock fall incident occurring. The lifetime probability of total loss of life should therefore be a few orders of magnitude smaller that the acceptable levels suggested by Cole (1993). This corresponds with Kirsten's (1994) suggestion that acceptable levels for probabilities of failure for which designs may be prepared should be significantly smaller than the actual probabilities of failure observed for similar situations.

14 7 REFERENCES

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Appendix B

Detailed Risk Assessment

1. Procurement Procedure

2. Receiving by Mine

3. Surface Storage

4. Dispatching to the Shaft

5. Shaft Transport

6. Horizontal Transport

7. Transport to the Workplace

8. Installation

9. Installed Prop

10. Prop Removal

11. Underground Storage

12. Daily Underground Prop Assessment

ACKNOWLEDGEMENT OF RECEIPT
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