National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

Canada

University of Alberta

Development of hydraulically-powered hand-held scaler device for underground mining

by

Zdenko Felbinger ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirement for the degree of Masters of Science

in

Mining Engineering

Department of Mining, Metallurgical and Petroleum Engineering

Edmonton, Alberta

Spring 1996

National Library
of Canada

Bibliothèque nationale
du Canada

Acquisitions and
Bibliographic Services Branch

Direction des acquisitions et
des services bibliographiques

395 Wellington Street
Ottawa, Ontario
K1A 0N4

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file   Votre référence

Our file   Notre référence

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-612-10705-1

Canada

University of Alberta

Library Release Form

Name of Author: Zdenko Felbinger

Title of Thesis: Development of hydraulically-powered hand-held scaler device for underground mining

Degree: Masters of Science

Year this Degree Granted: 1996

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly, or scientific research purposes only.

The author reserves all other rights in association with the copyright in the thesis, and except as hereinbefore provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Mr. Z. Felbinger
#102 - 407 Saddleback Rd.
Edmonton, AB
T6J 4M6

February 7, 1996

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance a thesis entitled *Development of hydraulically-powered hand-held scaler device for underground mining* submitted by Zdenko Felbinger in partial fulfillment of the requirements for the degree of Masters of Science in Mining Engineering.

Prof. I. Muirhead

Dr. J. Szymanski (Supervisor)

Dr. N. O. Egiebor

Dr. S. Planeta

Dr. D. Budney

Date 30. 01. 1996

ABSTRACT

Scaling is defined as the process of clearing and removing fractured and unstable rock from the walls of a development or stope in an underground mine. In an underground mine loose rocks must be removed to ensure the physical safety of the workers. Manual scaling is considered to be one of the most stressful, labour intensive, and dangerous activities in mining. Hence, the search for mechanical methods to replace this manual activity has become essential, especially in the age where all other mining processes are becoming more technologically advanced.

The author has developed and tested the hydraulically powered hand held scaler for dislodging and removing loose rock. The designed device can be mounted on and powered from the existing mining equipment.

The laboratory and field testing identified the following performance characteristics:

- The impact energy of the scaling device as a function of the thrust force.
- The vibration and noise level produced by the scaler during scaling operation.
- Scaling cycle components and utilization of the device during field testing.

TABLE OF CONTENTS

PAGE

Abstract

Table of Contents

List of Tables

List of Figures

CHAPTER ONE INTRODUCTION AND RESEARCH OBJECTIVES

1.1 Background 1

1.2 The research objectives 2

CHAPTER TWO SCALING OPERATIONS IN UNDERGROUND MINING

2.1 Scaling and scaling factor 3

2.1.1 Components of the scaling process 8

2.2 Scaling practices in underground mining 15

2.3 Scaling tools used in underground mining 17

2.3.1 Directions in development of the portable mechanized scaler 19

CHAPTER THREE EVOLUTION IN MINING EQUIPMENT

3.1 Pneumatically versus hydraulically powered equipment 27

3.2 Development in hydraulically powered hammers 31

CHAPTER FOUR DESIGN OF HYDRAULICALLY POWERED HAND HELD SCALER

4.1 Scope of the project 36

4.2 Methodology 36

4.3 The concept development and the design work 37

  4.3.1 The hydraulic hammer 38

  4.3.2 The final assembly of the prototype of the hydraulically powered hand held scaler 41

  4.3.3 The designed mechanisms for impact energy transition from the hammer to the scaling moil through the aluminum connecting rod 42

  4.3.4 The designed scaling tool(moil) 42

    4.3.4 - 1 The shape of scaling tool(moil) 42

    4.3.4. - 2 Scaling moil's dimensions 44

CHAPTER FIVE LABORATORY AND FIELD TESTING OF HYDRAULICALLY POWERED HAND HELD SCALER

5.1 Impact energy and impact power measurement 53

  5.1.1 Calibration procedure and impact energy measurement 53

  5.1.2 Impact power measurement 60

  5.1.3 Calculations and results 60

5.2 Field testing of the prototype scaler 64

  5.2.1 Experimental site and equipment 64

  5.2.2 Field tests results 64

5.3 The measurement and assessment of the operator's exposure to hand transmitted vibration during the scaler's operation 73

5.3.1 Introduction 73
5.3.2 Vibration measurement protocol 75
5.3.3 Testing program 76
5.3.4 Data analysis 76
5.3.5 Discussion of the results 77
5.4 Measurement of sound emission from the hydraulically powered hand held scaler 81
5.4.1 Introduction 81
5.4.2 Method of noise testing and the results 82

CHAPTER SIX CONCLUSIONS

6.0 Conclusions 86

REFERENCES 88

APPENDICES

APPENDIX A Stoping details in underground hard rock mining 91
APPENDIX B Scaling moil calculations 105

GLOSSARY 109

LIST OF TABLES

TABLE		PAGE
Table 2 - 1	Summary of conventional scaling bar characteristics	17
Table 2 - 2	The results of the INCO's hammers tested	22
Table 2 - 3	Pneumatic hammers used in development of the Laval scaler	25
Table 2 - 4	Technical specifications of the prototype Laval scaler	24
Table 3 - 1	Comparison of published hydraulic hammer performance statistics	35
Table 4 - 1	Technical specification data of the hydraulic hammers considered	40
Table 4 - 2	Technical specifications of the protype scaling bar	41
Table 5 - 1	Calibration data	57
Table 5 - 2	Power calculation data	61
Table 5 - 3	Breakdown of the scaling cycle elements for the operators (hydraulic scaler)	66
Table 5 - 4	Exposure time before finger blanching appears	77
Table 5 - 5	Results of the sound pressure level measurements	84
Table 5 - 6	Occupational Exposure Limits, Alberta Regulation 314/81	85

LIST OF FIGURES

FIGURE		PAGE
Fig. 2 - 1	Distribution of fatal accidents in the mines of members of Quebec Mining Association	5
Fig. 2 - 2	Distribution of activities in progress during accidents caused by ground fall	6
Fig. 2 - 3	Scaling factor for shrinkage or cut-and-fill stoping as a function of the stope width	9
Fig. 2 - 4	Scaling factor for room and pillar mining as a function of the stope height	10
Fig. 2 - 5	Scaling factor as a function of the width of development opening	11
Fig. 2 - 6	Breakdown of scaling activities using conventional scaling bar	13
Fig. 2 - 7	Time devoted to scaling by miners	14
Fig. 2 - 8	View of the conventional scaling bars	18
Fig. 2 - 9	View of the INCO custom designed pneumatic hammer and scaling bar	23
Fig. 2 - 10	Scaler developed by U. S. Bureau of Mines	23
Fig. 2 - 11	View of the Laval University prototype scaling bar	24
Fig. 2 - 12	Breakdown of scaling cycle time components for the Laval scaler	26
Fig. 3 - 1	The trend in application of different drive types in underground drilling equipment	30
Fig. 3 - 2	Tool point velocity measurement device	33

LIST OF FIGURES (Continued)

FIGURE		PAGE
Fig. 4 - 1	View of the Stanley tampers TA-57 and TA-55	39
Fig. 4 - 2	Assembled prototype hydraulic scaling bar	45
Fig. 4 - 3	Assembled connecting rod	46
Fig. 4 - 4	Extension to TA-55	47
Fig. 4 - 5	Connecting rod assembly parts	48
Fig. 4 - 6	Lower rod shank + shank	49
Fig. 4 - 7	View of the assembled mechanism for impact transfer to the scaling moil	50
Fig. 4 - 8	Moil	51
Fig. 4 - 9	View of the assembled moil	52
Fig. 5 - 1	Calibration curve	58
Fig. 5 - 2	Calibration setup	59
Fig. 5 - 3	Weight adding assembly	62
Fig. 5 - 4	Thrust force vs. Power	63
Fig. 5 - 5	Breakdown of the scaling cycle elements for the operator #1 John(hydraulic scaler)	67
Fig. 5 - 6	Breakdown of the scaling cycle elements for the operator #2 Steve(hydraulic scaler)	68
Fig. 5 - 7	Breakdown of the scaling cycle elements for the operator #3 Henry(hydraulic scaler)	69
Fig. 5 - 8	Breakdown of the scaling cycle elements for the operator #4 Zeny(hydraulic scaler)	70

LIST OF FIGURES (Continued)

FIGURE **PAGE**

Fig. 5 - 9 Breakdown of the average scaling cycle elements for the four operators(hydraulic scaler) 71

Fig. 5 - 10 Comparative breakdown of scaling cycle components for a U of A, conventional and Laval scalers: a) scaling b) detection c) res 72

Fig. 5 - 11 Mounting of vibration sensor 78

Fig. 5 - 12 One third octave band spectrum for the direction of percussion axis of the hydraulic scaler 79

Fig. 5 - 13 One third octave band spectrum comparison for the three types of scalers 80

Fig. 5 - 14 Location of the sound pressure sensor according to EPA portable compressor noise emission standard 84

CHAPTER ONE

INTRODUCTION AND RESEARCH OBJECTIVES

1.1 BACKGROUND

The predominant underground hard rock mining method today is the same that is being used for centuries. It consists of all cycle operations and is called "drill - blast - muck" mining.

The conventional "drill-blast-muck" mining cycle components can be summarized as:

Step	**Operation**
Drilling	Drill series of blastholes
Explosive loading	Load explosives charge
Blasting	Blast the rock or ore
Scaling	Detect and remove loose material
Supporting	Secure the back
Mucking	Haul away ore for processing

The cycle starts with drilling the pattern of blast holes, then loading the required amount of explosive, initiating the blast, scaling which involves detecting and prying the loose rock using a steel bar, supporting the scaled walls with a special bolts, wire mesh or timber, and finally mucking the broken ore or rock for further processing. The most hazardous step in this cycle is manual scaling using the conventional steel bar.

Recent developments in the use of ammonium blasting agents, rock drilling equipment, mechanized raise boring, and the introduction of load-haul-dump(LHD) equipment has helped mines to maintain a competitive edge in the face of increased labour costs. In this dramatic contrast between the old and new technologies for drilling, blasting and mucking, the manual scaling bar, the most hazardous activity, needs to be elevated to the same level of technology being applied to drilling and mucking. At the same time it would improve the safety, efficiency and reliability of the mining operation.

1.2 THE RESEARCH OBJECTIVES

The purpose of this study was to develop and test an hydraulically powered hand held scaler for dislodging and removing loose rock. This device could be mounted on and powered from the existing mining equipment (LHDs, scissor lifts, etc.), and should satisfy the following objectives:

- Be able to detect loose rock
- Reduce the amount of energy required during the manual insertion of the scaling bar into the cracks
- Generate the pry forces necessary to detach the loose rocks from the surrounding ground
- Have a weight comparable to the present hand held scaling bar.

CHAPTER TWO

SCALING OPERATIONS IN UNDERGROUND MINING

2.1 SCALING AND SCALING FACTOR

Over the last two decades, major changes in mining have been brought about through mechanization. The next step in the evolution of mining technology is being achieved through the automation of mining equipment to ensure better operation and utilization. This evolution will lead to new mining methods, important changes in the working conditions of the miners, and encourage the development of new machinery.

However, manual scaling, although an inherently risky operation, is still the predominant method of scaling prior to installation of the rock support (Appendix A). This manual method of detecting and dislodging loose rock with a hand held steel scaling bar has not significantly changed in over a hundred years.

In underground excavations, the potential for ground falls is always present. Unstable ground is the result of the inherent geological structure compounded by blasting and another mining activities.

Rock fall incidents as monitored by the Mining Health and Safety Branch of the Ontario Ministry of Labour show that 44% of ground falls under fifty tonnes occur in the range of less than ten tonnes. This statistic is based on the investigation into ground fall incidents that occurred between 1986 and 1989.

Rock fall incidents, as monitored by the Committee for Investigation of Incidents in the province of Quebec (1991), shows that 50 % of all underground accidents are attributable to falls of ground from inadequate scaling [1]. It can be seen from the data in Fig. 2 - 1 and Fig. 2 - 2 that during 1989 and 1990, 66 % of all lost time incidents occurred when either a scaling bar, jackleg, or stoper were in use.

A study in the United States [2] revealed that between 1978 and 1983, about 85% of all lost time accidents were attributed to accidents involving the use of jacklegs 44%, or scaling bar 41%. The results are similar to the statistics presented in Fig. 2 - 2.

From the previous discussion it is clear that the scaling operation has a significant effect on the mine safety performance. Sound mine design and operation requires that emphasis be given to the potential health and safety aspects of planned systems, procedures, and equipment. Such planning provides direct economic as well as safety benefits. Lost time, decreased productivity, increased compensation costs, and absenteeism are tangible costs inherent in mine safety considerations.

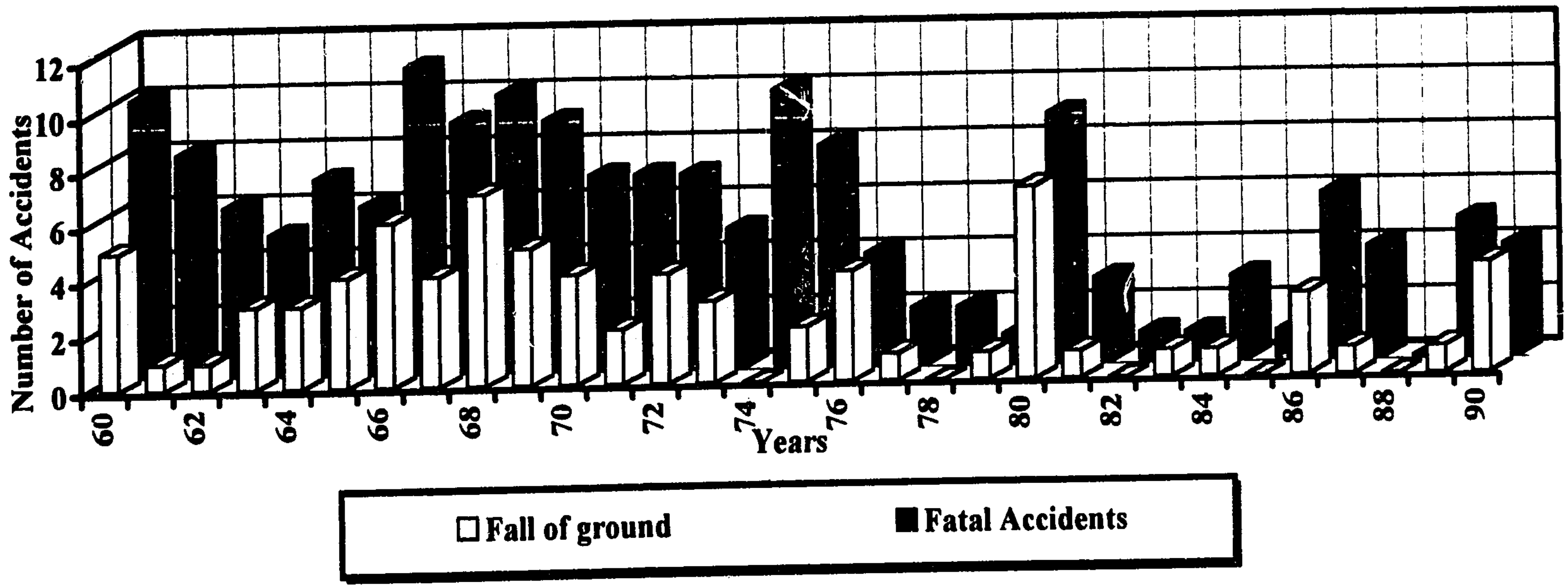


Fig. 2 - 1 Distribution of fatal accidents and ground falls in the mines members of Quebec Mining Association

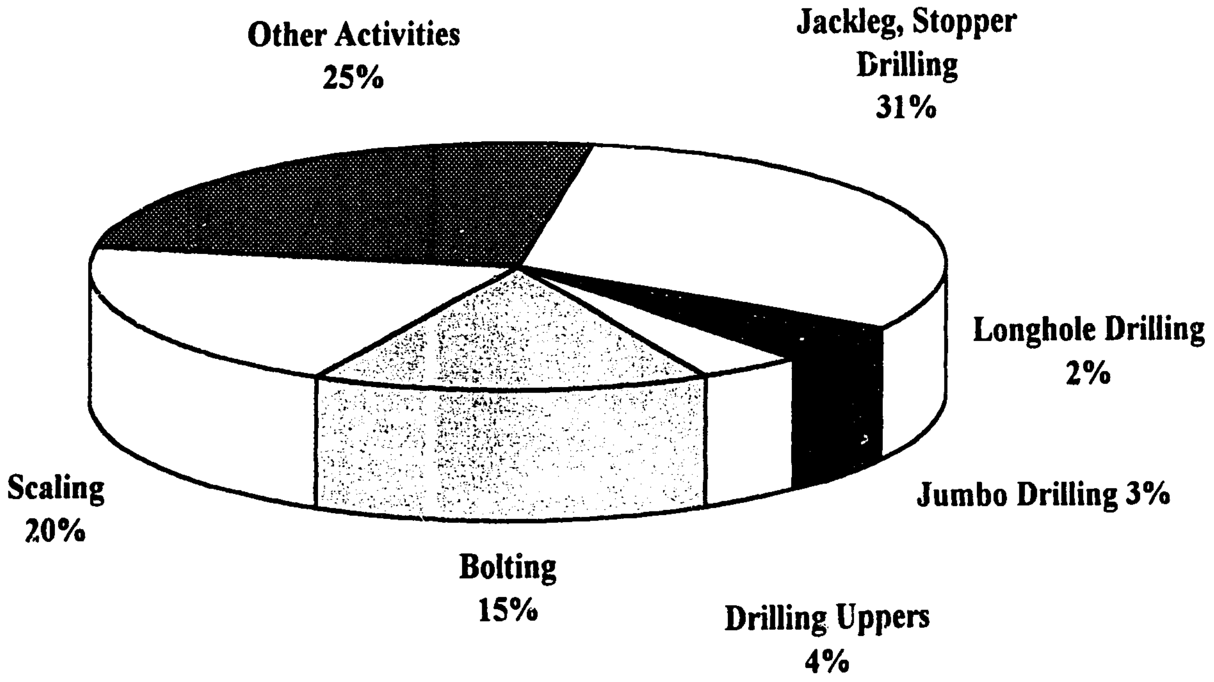


Fig. 2 - 2 Distribution of activities in progress during accidents caused by ground fall in 1991

In order to consider the effect of scaling in the process of mining the concept of scaling factor has been proposed [1]. It would allow comparison between different mining methods to take place. Fig. 2 - 3 and Fig. 2 - 4 show the scaling factor as a function of the stope dimensions for a shrinkage and room-and-pillar mining.

The scaling factor is defined as the ratio of the area scaled to the tonnage of ore mined. This corresponds to the scaling area necessary to extract one tonne of ore.

$$\mathbf{SF} = \frac{\mathbf{SS}}{\mathbf{T}}$$

where SF = scaling factor, $\frac{m^2}{t}$

SS = scaling surface, m^2

T = tonnes of ore mined, t

Analysis of the critical cost factors for mine development in underground mines shows that the time required for development has the major bearing on the cost of the projects. It is well documented that the scaling activity is the significant component of the development. In most cases the development openings are located outside the ore-waste contact zone, in the waste rock. For this reason it is proposed in this study to introduce the distinct scaling factor for the development openings defined as scaled area per meter of advance. The above relationship for the development may be expressed by the following equation:

$$\mathbf{SF_d} = \frac{\mathbf{SS_d}}{\mathbf{m_a}}$$

where SS_d = scaling area of development, m^2

m_a = one meter of advance, m

The calculation of the scaling area should exclude one meter (3 ft) above the floor on both sides of the drift for the reason that does not require scaling even under the worst of ground conditions. Coupled with the time studies for different ground conditions, the use of scaling factor should enable mining engineers to find out reasons for costly development delays and improve the safety within an existing mine. In the case of planning the development of a new mine, it will improve the required precision in cycle time calculations and scheduling the capital outlays, therefore, increasing the overall economic performance of the mining operation. The most common sizes of development drifts and respective scaling factors are shown in Fig. 2 - 5.

Analysis of Fig. 2 - 3 and Fig. 2 - 4 reveals that selective mining methods, such as shrinkage stoping and cut - and - fill stoping, require the largest amount of scaling. For a narrow stope size of 1.5 m in width, this factor is 0.74 m^2/t. For example, a small, narrow vein mining using the shrinkage or cut - and - fill stoping, with production rate of 1000 t/day requires of 740 m^2/day to be scaled.

Based on the statistics obtained from the 1995 " Mining Sourcebook" [6] and the total base metal production in 1994 of 175,103 t/day, the required scaled area (excluding development openings) is in the order of 16,000 m^2/day. These figures reiterate the importance, and significance of manual scaling in the underground hard rock mining operations.

2.1.1 COMPONENTS OF SCALING PROCESS

Manual scaling, still the predominant technique in mines today, is one of the most stressful, labor intensive and dangerous operation in mining. Scaling, using a conventional scaling bar, consists of three activities:

Detection of loose ground. Based on experience by tapping the ground, the miner is able to detect by ear, areas where there is loose ground

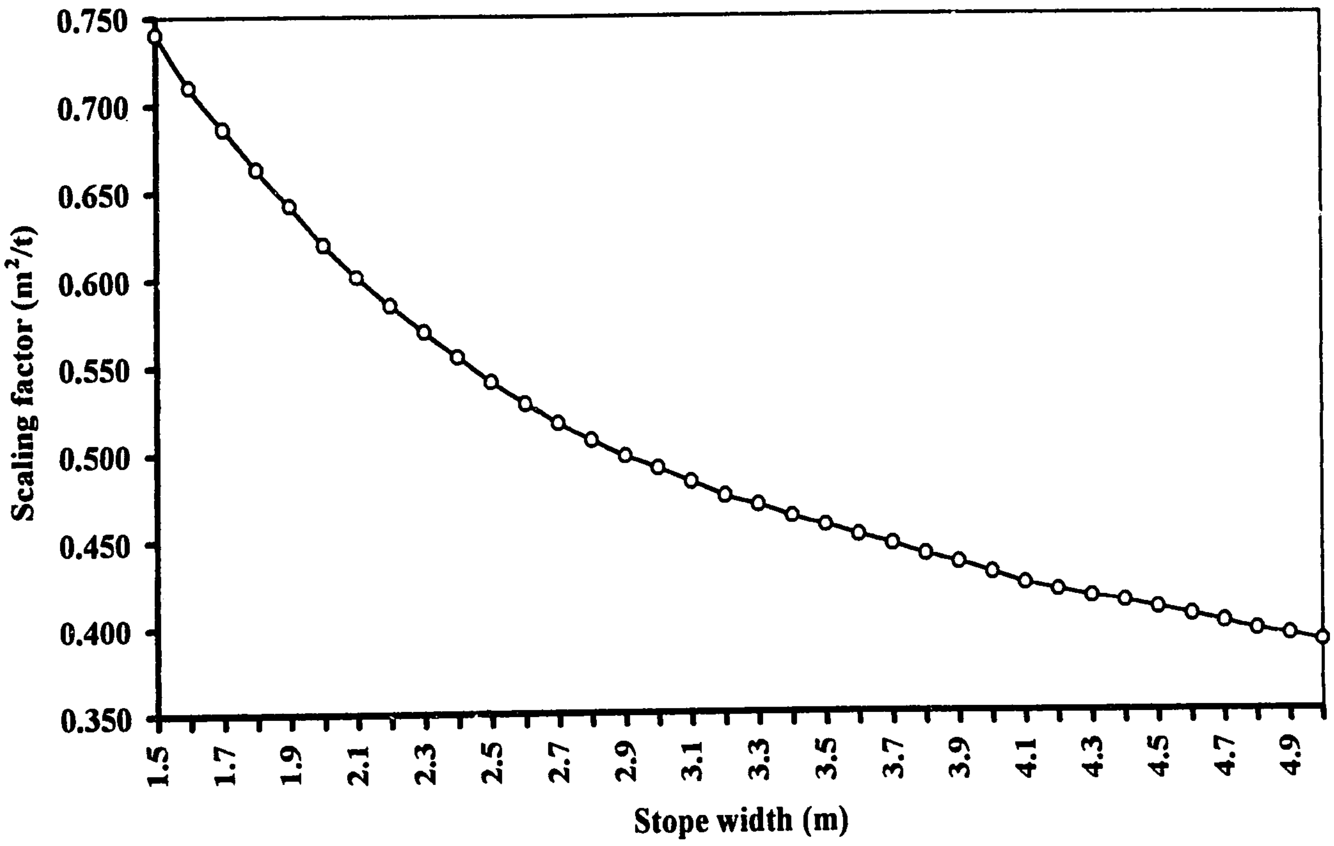


Fig. 2 - 3 Scaling factor for shrinkage or cut-and-fill stoping as a function of the stope width

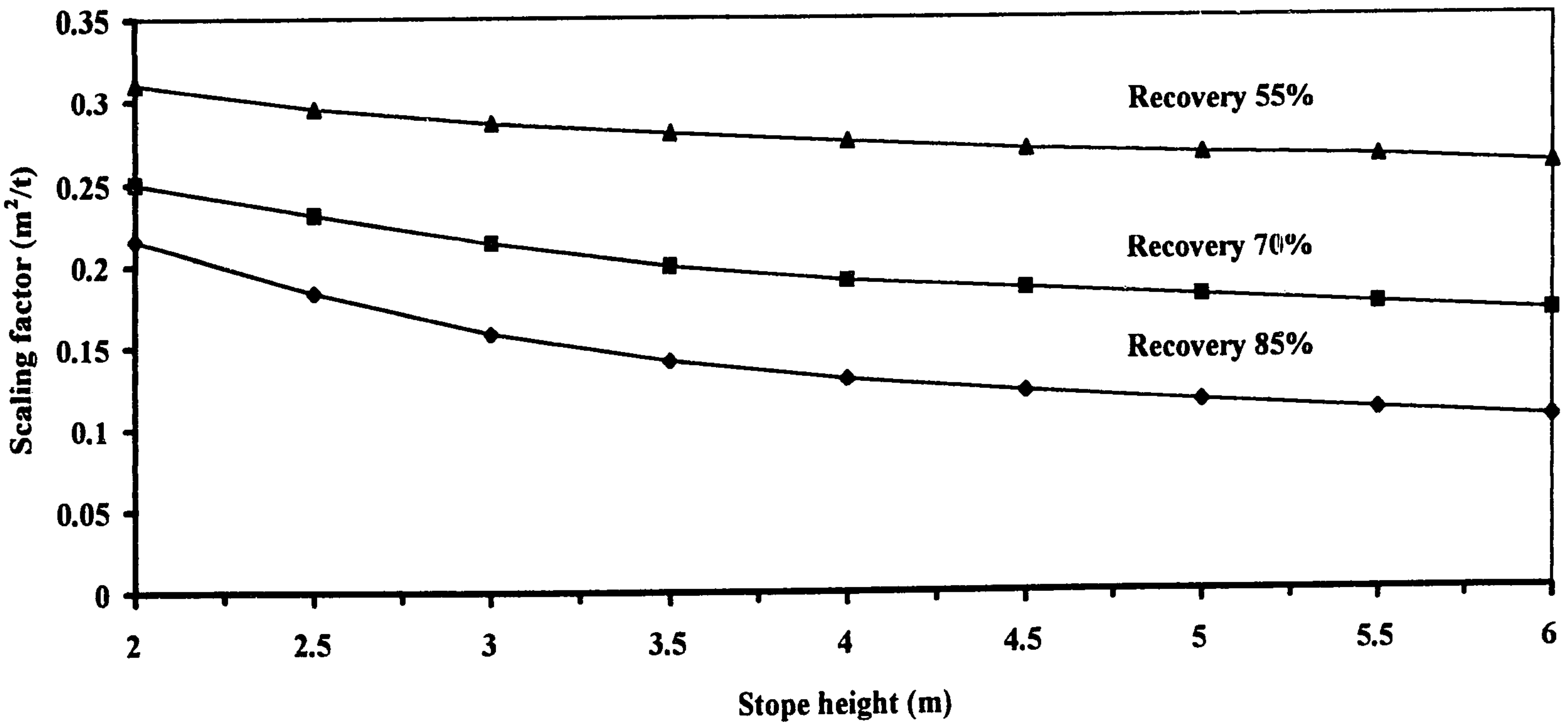


Fig. 2 - 4 Scaling factor for room-and-pillar mining as a function of the stope height

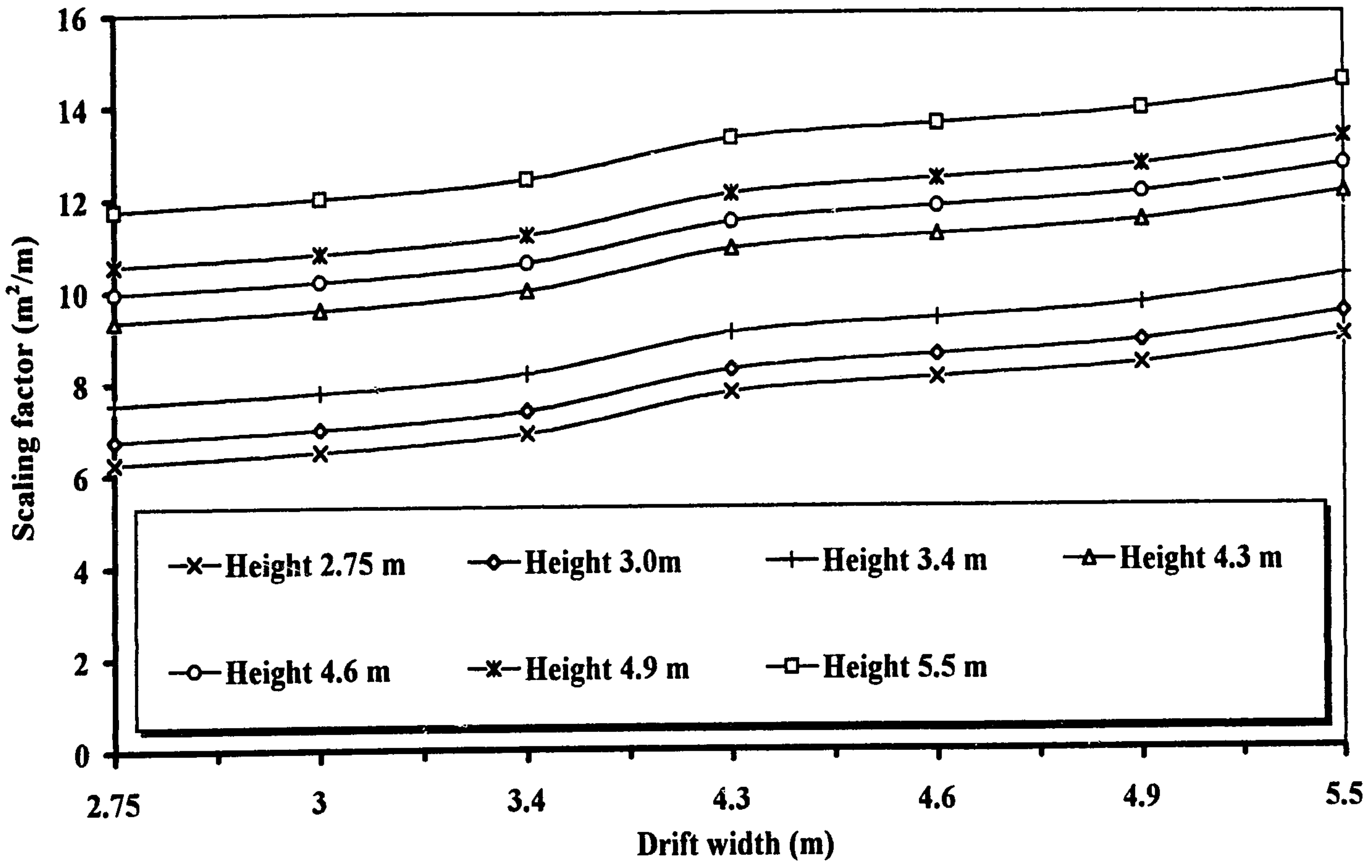


Fig. 2 - 5 Scaling factor as a function of the width of the development opening

- Penetration of the bar. Using the scaling bar, miner exerts pressure to penetrate one of the ends of the bar into the opening present or to produce an opening

- Use of the bar as prying lever. After inserting the end of the bar in the fissure the miner uses the bar as lever to pry the loose rock (usually referred as loose) onto the ground

From an ergonomic standpoint, scaling is very demanding on miners. This is because it takes considerable percussion and traction effort to use the scaling bar, sometimes in very difficult positions [3]. In the case of very small openings, the end of the bar often does not remove the loose rock entirely, forcing the miner to strike again, trying to insert the bar into the fissure.

A study of the manual scaling process in the Mouska Mine [1] revealed that the loose rock detection component represents 20% to 30% of scaling time, while penetration and prying account for 70% to 80% of the physical effort required for scaling, subsequently reducing the overall endurance of miners. This indirectly decreases miners concentration, and as result the actual time devoted to scaling -penetration and prying- decreases as the task progresses, demonstrating how arduous scaling really is (Fig. 2 - 6).

Out of seven miners performing scaling work, for as long as each was physically able, only one (Fig. 2 - 7) was able to work for more than eight minutes by devoting only 32% of his time to actual scaling (penetration and prying) at the end of this period. The graph in Fig. 2 - 6 also indicates that pause time increases rapidly as scaling work progresses, from 5% at the beginning to 26% at the end of the eight minutes. The increasingly longer pause time is a reliable indicator of the stressfulness of scaling.

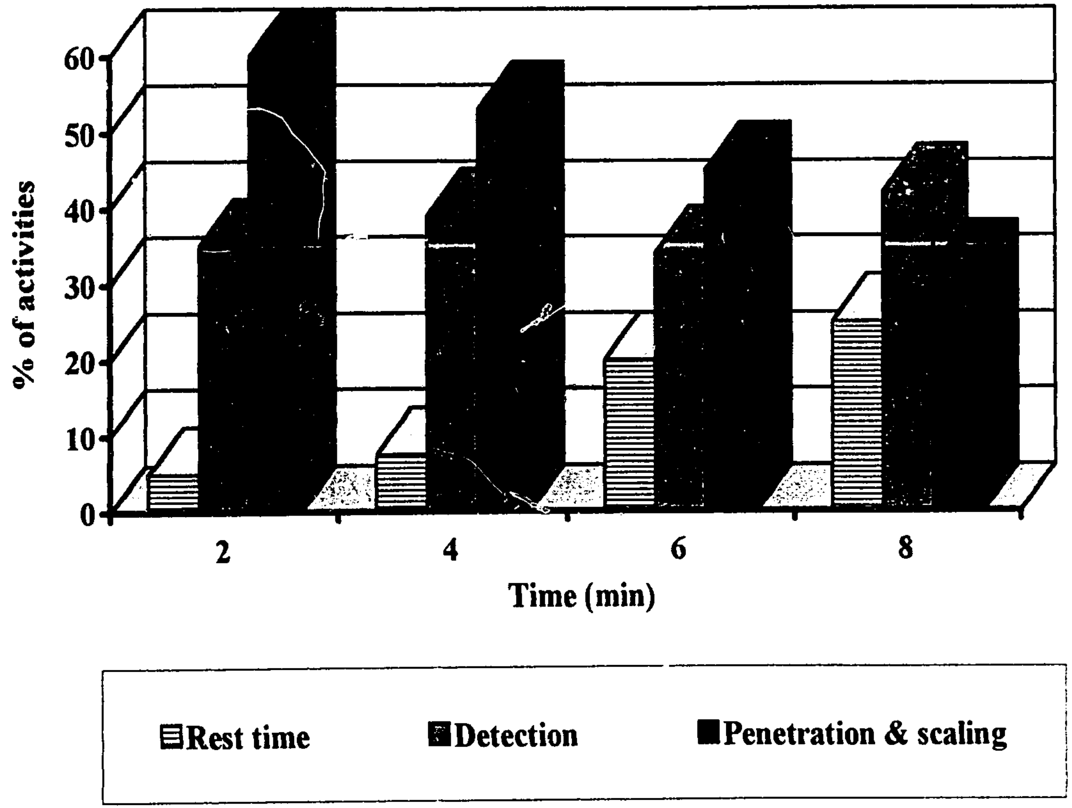


Fig. 2 - 6 Breakdown of scaling activities using conventional scaling bar

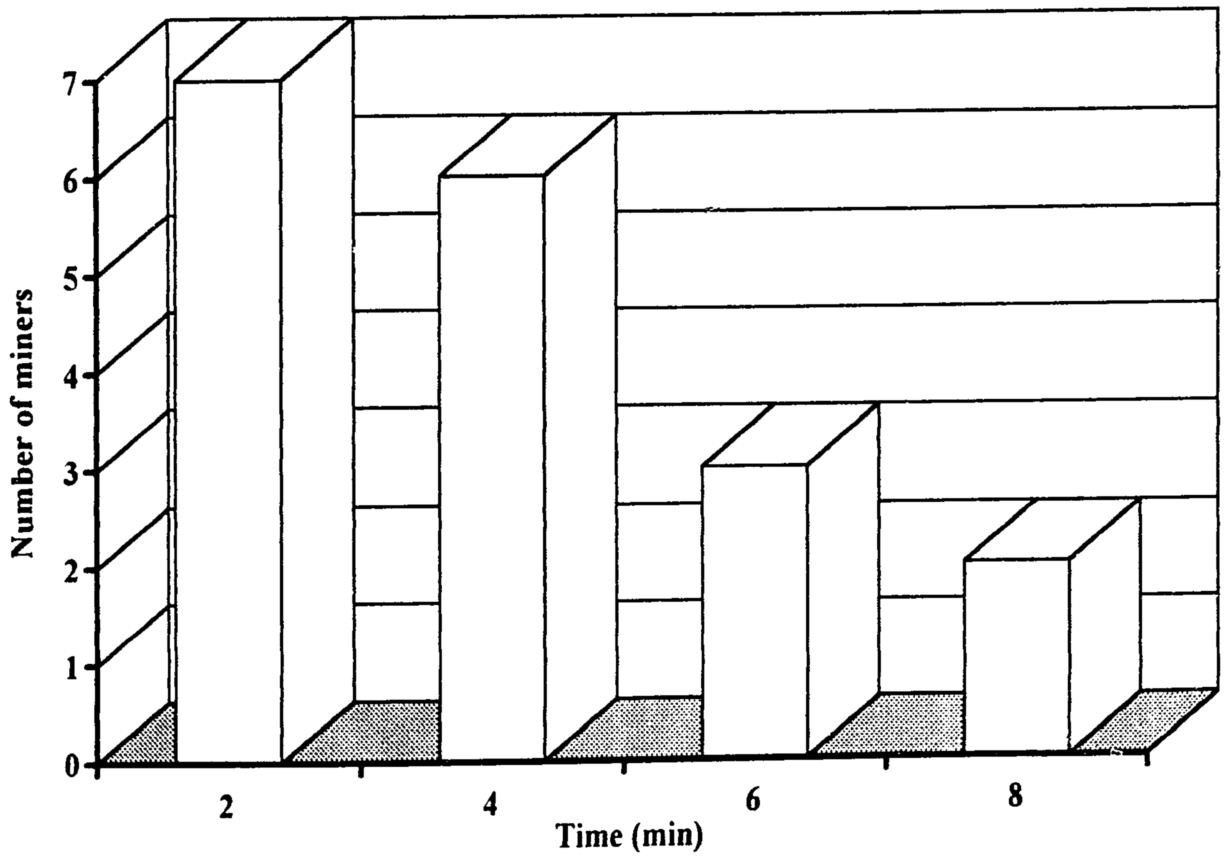


Fig. 2 - 7 Time devoted to scaling by miners

2.2 SCALING PRACTICES IN UNDERGROUND MINING

Different mines adopt different scaling practices to suit their own conditions. In general these will be governed by:

- Size and geometrical shape of the orebody
- Geological and geomechanical characteristics of the orebody, which in turn determine the mining method and size of the stope and development
- Type of equipment used and the degree of mechanization at the particular site

Scaling practices also vary upon the type of excavations and its applications. Variations in scaling practices can be classified according to the type of underground excavation as follows:

- Shafts. Scaling is done off the muckpile after the blast or off the Galloway stage if one is used. In the both cases scaling is done manually
- Drifts, ramps and drawpoints. In this type of excavations, if height is in excess of 5m, scaling is done manually off the muckpile, scissor lifts, and utility tractors
- Conventionally driven raise, serving as orepass, wastepass, or manways. After every blast the staging has to be rebuilt, and used as a platform for the scaling and drilling. This method is being replaced by Alimack raise climbers where staging is part of the equipment, but scaling is done manually in both techniques
- Stopes. Mining methods that depend heavily on the scaling efficiency in the stope area itself are shrinkage stoping and cut and fill stoping. Miners are directly exposed to loose rock in the stope for the duration of the whole shift. Mines using these methods usually produce under 3000 t/day, in the narrow

vein type orebodies, characteristic for the precious metals mines. Whether these are conventional or mechanized methods makes no difference, their dependence upon scaling remains the same for the same stope area (Fig. 2 - 3). Scaling is done manually using conventional scaling bars. Larger and wider deposits are mined at rates above 3000 t/day using the mining methods where there is no access into the stope area except for the drawpoints and drill rooms considered part of the development, and described under drifts, ramps and drawpoints

Scaling is just as important in the stope as it is in the development stage. However, there is one noticable difference. In the stope, the situation is more difficult, because all the work is being done in the immediate vicinity of the footwall and hangingwall contacts where rock mass deformations are the most pronounced. It is for this reason that shrinkage and especially cut and fill mining methods are used.

Development on the other hand, is always done in the host rock, twenty or more meters away from hangingwall and footwall contacts, where better ground conditions prevail except in extreme cases. The amount of scaling to be done in development can be significantly reduced by:

1. Proper choice of the blasthole diameter
2. Proper lookout angle of the perimeter holes
3. Matching the explosives to the rock blasted
4. Choosing the right initiation delays and sequence
5. Placing the cut holes with regard to the rock jointing

In development headings it is not uncommon under fair conditions to spend at most half an hour on scaling prior to commencement of rock bolting.

2.3 SCALING TOOLS USED IN UNDERGROUND MINING

Until today the tool used to do scaling in the mines has not changed in shape, nor has the amount of human physical effort required. The main tool remains the manual scaling bar (Appendix A). There are currently several different types of scaling bars available on the market (Table 2 - 1), each used according to the specific needs, depending on the ground conditions and the heights of excavations, and personal preferences of the miners. The 7/8" steel octagonal crossection bars are very heavy, and their use is limited to the worst of ground conditions occurring naturally or caused by improper blasting practices. Aluminum and fiberglass scaling bars are classed as disposable, since after being damaged no straightening out is possible. Table 2 - 1 is representative of standard scaling bar production stock presently available to the mining industry. Fig. 2 - 8 shows the conventional scaling bars used for the manual scaling.

Table 2 - 1 Summary of conventional scaling bar characteristics

Length (ft) m	**Steel hexagonal crossection (3/4") 19.05mm** (lb) kg	**Steel octagonal crossection (7/8") 22.23mm** (lb) kg	**Aluminum square crossection (1"x1") 25.40x25.40mm** (lb) kg	**Fiberglass round crossection (1 1/2") 38.10mm** (lb) kg
(4) 1.22	(7) 3.18	(9) 4.08	(4.3) 1.95	(7.5) 3.40
(5) 1.52	(8) 3.63	(11) 4.99	-	-
(6) 1.83	(10) 4.54	(13) 5.90	(5.3) 2.40	(9.5) 4.31
(7) 2.13	(11.5) 5.22	(15) 6.80	-	-
(8) 2.44	(13) 5.90	(17) 7.71	(6.3) 2.86	(10.5) 4.76
(10) 3.05	-	-	(7.3) 3.31	(11.5) 5.22
(12) 3.66	-	-	(8.3) 3.76	-
(14) 4.27	-	-	(9.3) 4.22	-
(16) 4.88	-	-	(10.3) 4.67	-

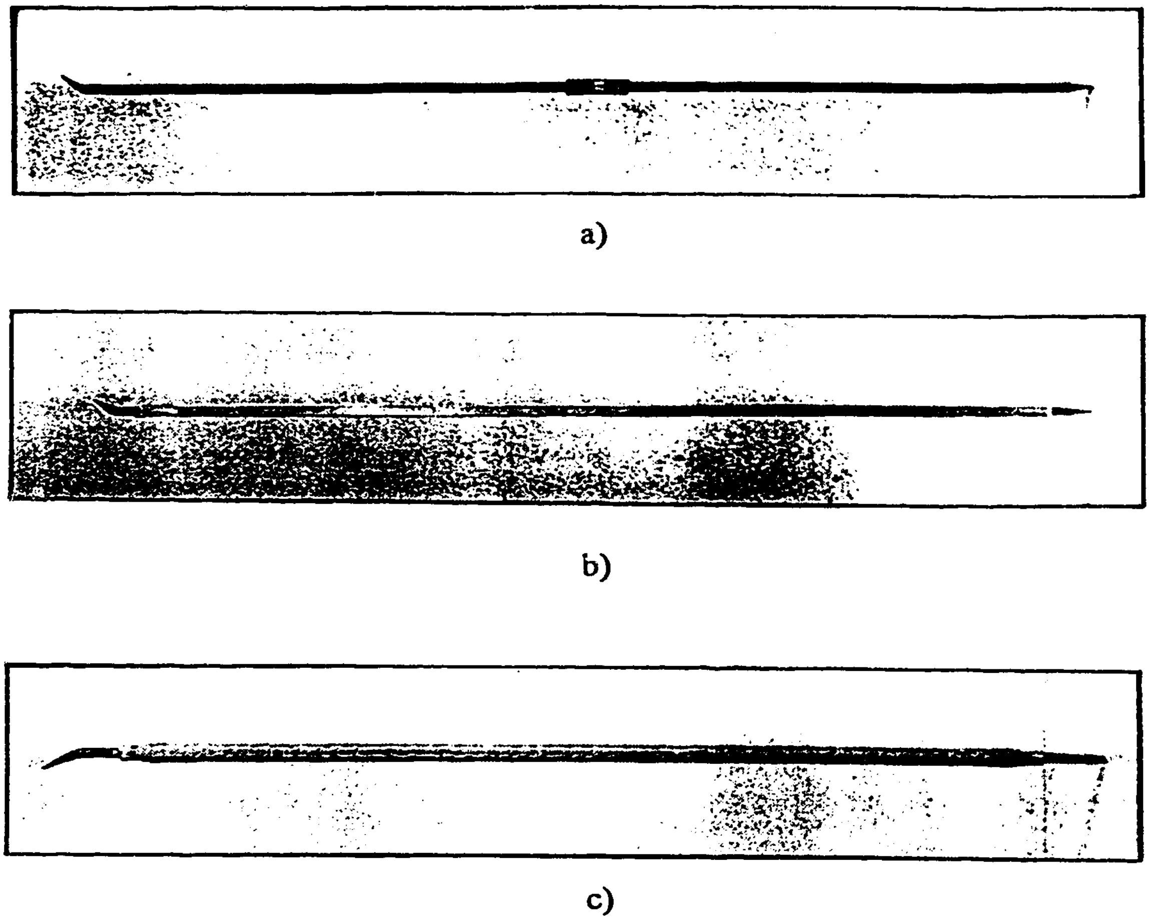


Fig. 2 - 8 Views of the conventional scaling bars, a) (3/4") 19.05 mm hexagonal steel, b) (1"x1") 25.40x25.40 mm aluminum c) (1 1/2") 38.10 mm fiberglass

In mines using room and pillar mining methods with productions rates over 5000 t/day, large size excavations allow use of boom mounted hydraulically powered impactors or ripping lips for scaling. The first applications were recorded in the early seventies in the coal mines in the United States. In general, impact ripping is used for the harder rock types, siliceous shales, and sandstones that are encountered in sedimentary carboniferous formations.

The use of boom mounted hydraulic hammers for the purpose of scaling in hard rock is limited to the tunneling operations involved in road and railroad transportation, and hydropower producing facilities. The size of openings in these operations is in the range of 20 m^2 to 125 m^2, which is very seldom used in the hard rock mining operations. Only the few permanent excavations used during the life of a mine fall into this size category. These are special purpose excavations, and the expense for the purchase of the mobile boom mounted hydraulic hammers-scalers is not justified.

2.3.1 DIRECTIONS IN DEVELOPMENT OF THE PORTABLE MECHANIZED SCALER

Scaling is a dangerous and time consuming operation that reduces mine production. No specific numbers on the cost benefits of mechanical scaling are available at present, but there is a little doubt that, under many circumstances, they can be substantial, since time saved in scaling can be utilized for production. As stated earlier more efficient scaling procedures also reduce accidents and increase the safety in the mines.

A limited number of research projects were initiated during the past twenty years aiming to develop and manufacture a portable mechanized scaling device.

Between 1975 and the present day, this area has received increased effort. This is due to scaling equipment having highly cyclical application, and portable mechanical tools having the following important advantages:

- Moving from level to level in the mine or bringing it to the surface is easy, either via ramps or shafts. During the moves no assembling or dismantling is required

- When in the particular drift or stope no specially built maintenance and storage facility need to be excavated

A project conducted by INCO Ltd. Manitoba Division, consisted of developing a hand held pneumatic scaling tool to be used in the development headings and vertical crater retreat stopes topsill areas [4]. The types of pneumatic hammers used and the results of testing are presented in the Table 2 - 2. General observations from underground testing indicated the following :

- For the miners working side by side, one with a pneumatic scaler and the other with a manual scaling bar, it takes less time to scale a given area with the pneumatic scaler
- The larger impact action of the pneumatic scaler is needed to eliminate the penetration action involved in the use of manual scaling bar
- A pneumatic scaling bar facilitates the widening of cracks in loose ground with less physical effort
- To achieve higher impact forces, a larger diameter piston and a shorter stroke are required, which in turn increases the cylinder wall thickness, and therefore, the weight of the tool
- A custom designed hammer (Fig. 2 - 9) with a larger diameter piston, the inclusion of surge chamber to prevent flutter, and the use of a floating disc type valve instead of the sliding valve arrangement increased the impact force significantly
- The significant amount of contaminants in the mine air lines caused stoppages in hammer operation

- The limited prying force of the moil caused the stalling of the hammer while penetrating a crack
- The hammer attached to the end of an aluminum tube (Fig. 2 - 9) required too large a bearing force to be handled by the miners

Due to the above mentioned disadvantages no further research work was conducted.

The project conducted by the U. S. Bureau of Mines, Spokane Division [5] also concentrated on developing a pneumatic scaling tool where impact on the moil was generated by an air powered piston in an aluminum tube 2.8 m long (Fig. 2 - 10). Tests were disappointing because the striking frequency was erratic and inadequate. Further development of the tool was abandoned.

The project done by the Vein Deposit Development Group, Department of Mining and Metallurgy at Laval University [1] focused on the development of the manual scaling tool, and the ergonomic aspect of the scaling process. Based on a study of the scaling process done at the mine site employing shrinkage stoping, the following objectives were set forth for the design of a pneumatic scaling bar design:

- Ability to detect loose ground
- Reduce the physical effort required for penetration
- Generate the leverage to dislodge loose ground
- Weigh the same as the conventional scaling bar

Several studies were carried out on different moil design [1] backed by testing in the mines. The pneumatic hammers tested are listed in Table 2 - 3. The work produced the prototype pneumatic scaling bar with the air driven handle (Fig. 2 - 11). Technical specifications of the product are shown in Table 2 - 4.

Table 2 - 2 The results of the INCO's hammers tested

Hammer Manufacturer	Total weight (lb) kg	Total length (ft) m	Piston stroke (in) mm	Bore (in) mm	Effectiveness	Reason
Model 2B Allen Fyfe Equipment Ltd.	(10.14) 4.6	(5.97) 1.82	(1.38) 35	(0.87) 22	Limited	Impact too low
Model 3B Allen Fyfe Eqyipment Ltd.	(14.11) 6.4	(8.86) 2.70	(1.50) 38	(1.06) 27	Limited	Impact too low
Model 182 L (3.97lb) 1.8 kg Ingersoll Rand	(7.05) 3.2	-	-	-	Not satisfactory	Impact too low
Custom designed model Energy 27 J, 1400-1800 blow/min State Industries + INCO	(9.92) 4.5	-	-	-	Acceptable impact and weight	-

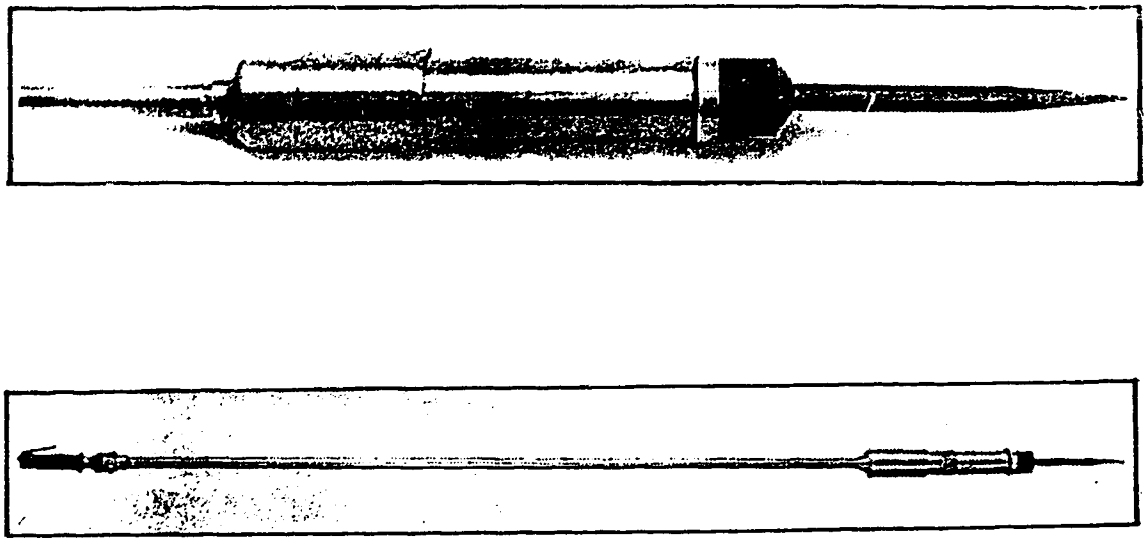


Fig. 2 - 9 View of the INCO-Custom designed pneumatic hammer and scaling bar

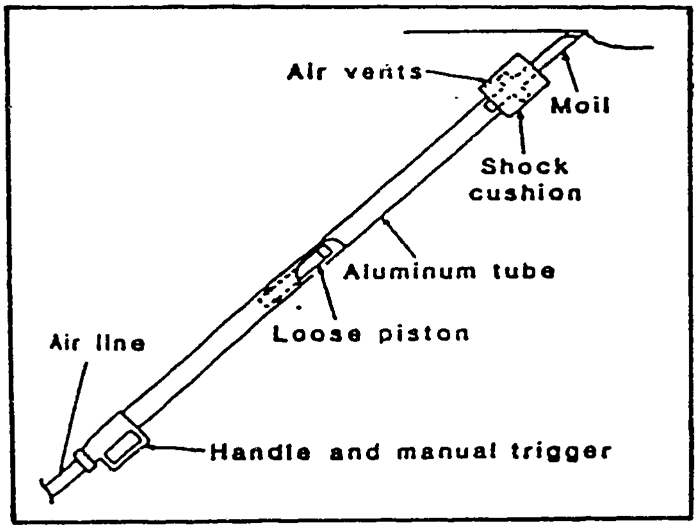


Fig. 2 - 10 Scaler developed by U. S. Bureau of Mines

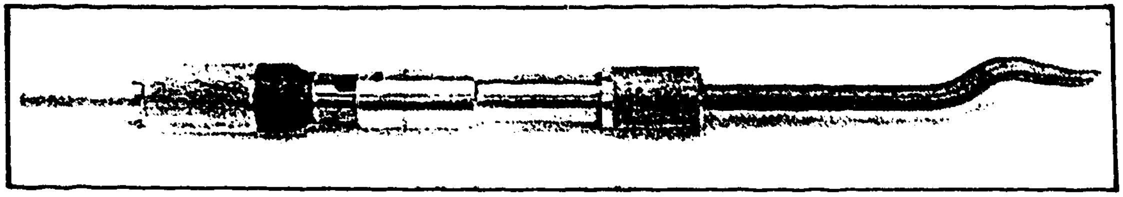


Fig. 2 - 11 View of theLaval University prototype scaling bar

In order to assess the potential of the pneumatic scaling bar in terms of workload, mechanical qualities and degree of acceptance among miners, tests were carried out in three mines in Abitibi region of Quebec, with the participation of the miners. Six working periods lasting eight minutes each, two per miner in each of the mines, were recorded on the video tape.

Table 2 - 4 Technical specifications of the prototype Laval scaler [1]

Air leg	Retracted (5.25 ft) 1.60 m Extended (7.38 ft) 2.25 m
Weight without moil	(8.60 lb) 3.9 kg
Weight with moil	(10.58 lb) 4.8 kg
Nominal compressed air pressure	(89.92 psi) 0.62 MPa
Piston stroke	(2.01 in) 51mm
Piston diameter	(0.79 in) 20 mm
Piston frequency	3 000 blows/min
Air flow	(74.79 Gal/min) 340 l/min
Average impact force @(99.21lb) 45kg bearing pressure on the tool	(6018.62 lb) 2 730 kg
Moil shape	Maximize impact and leverage using the axial power of the pneumatic hammer

Table 2 - 3 Pneumatic hammers used in development of the Laval scaler

Hammer Manufacturer	Weight Handle + hammer		Weight Hammer		Piston stroke		Piston diameter		Blow frequency	Air consumption	
	(lb)	kg	(lb)	kg	(in)	mm	(in)	mm	Blows/min	(ft^3/min)	m^3/min
UPT NC-0 Wesco production tools imports Ltd.	(5.25)	2.38	(2.16)	0.98	(2.00)	50.80	(0.787)	19.99	3000	12	0.34
MCF-5 Montabert	(9.81)	4.45	(6.22)	2.82	(2 13/32)	61.12	(1 1/8)	28.58	2620	14	0.40
UPT NC-4 Wesco production tools imports Ltd.	(15.22)	6.90	(7.75)	3.52	(4.00)	101.60	(1 1/8)	28.58	1700	23	0.65

In order to evaluate the performance of the pneumatically driven scaler, the scaling cycle time component were measured during the eight minute periods. The results were compared to the results obtained previously by using two conventional scaling bars, a rectangular aluminum bar (7.87 ft) 2.4 m long weighting (6.61 lb) 3.0 kg, and an hexagonal steel bar (5.91 ft) 1.8 m long weighting (14.33 lb) 4.5 kg. Fig. 2 - 12 presents the average percent of scaling activities in each of the four consecutive two minutes periods. The results of testing revealed following:

- The work strategy employed by miners using the pneumatic scaling bar was superior to that of miners using conventional bars
- The tool eliminates time required for the penetration action
- Rest time is almost non existent
- Results revealed a substantial drop in physical effort requirement
- For the similar area scaled the tool requires less energy from miners

Because of the relatively low impact power output, the application of the Laval scaler is limited at present time.

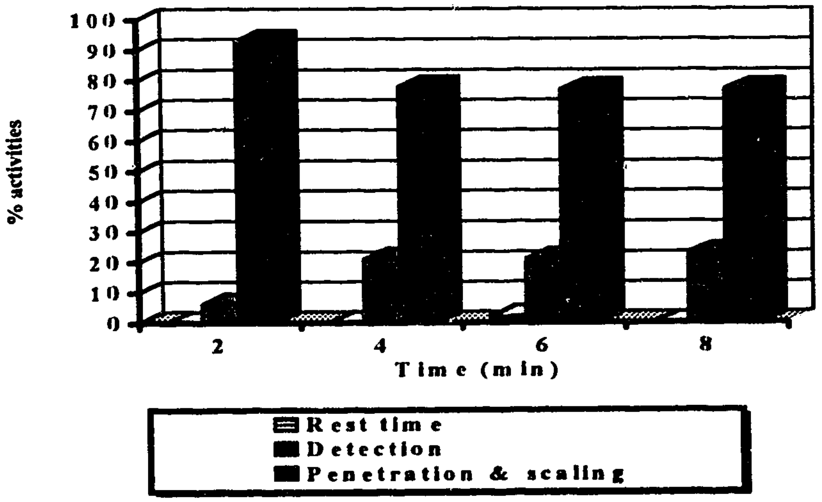


Fig. 2 - 12 Breakdown of scaling cycle time components for the Laval scaler

CHAPTER THREE

EVOLUTION IN MINING EQUIPMENT

3.1 PNEUMATICALLY VERSUS HYDRAULICALLY POWERED EQUIPMENT

The drilling rig is the most important equipment in underground mining. It is for this reason that drills went through several revolutionary design stages through the last couple of decades. This also made the major impact on the other equipment used in the mining industry.

After decades of undisputed superiority, pneumatics is being challenged by hydraulics. Fig. 3 - 1 shows the trend in application of different drive types in underground drills. The dramatic increase in the cost of energy has been reflected in rock drilling by the development of hydraulically powered percussion drills. The second most important factor that affected drilling equipment are environmental legislations. The two most important considerations in the case of underground drills are noise and dust control.

Today, two groups of factors, technological/economical and ergonomical, affect the choice between pneumatic and hydraulic rock drills. The parameters of each individual job such as the basic nature of the operation, its scope, time frame, geographical location, geology, and manpower availability, will keep the boundaries between the two technologies somewhat vague for some years.

Rather than debating whether hydraulic rock drills will replace air powered drills, it is of more interest to consider the effects of using hydraulic drills as an integrated part of a modern system for rock excavation. A simple example is that in tunnel driving where a single source of energy could power drill rigs, loaders, pumps etc. In an all hydraulic eqipment system, diesel or air powered equipment gives way to electrical mucking equipment. In mining, one power source system is especially advantageous. It is simpler and less costly to extend the electric power cable in the mine, or replace the power cable in the shaft, than to increase the size of the compressor plant, or replace the main air line in the shaft. This especially is the case if the compressor plant is at, or near full, capacity and the pressure loss in the lines is already large. Since hydraulic drills do not require air power, mines experience considerable savings by not having to extend or enlarge mine air capabilities. The 50 to 100 percent higher rate of penetration of hydraulic drills can be exploited in different ways: either to cut down time required for drilling the round by having the equivalent number of hydraulic drills, or to cut down the number of drills but still complete the round in the same time span. Local conditions would be decisive. A reduced number of drills offers such advantages as more compact drill rigs, fewer booms and fewer miners to pay. For example, a two boom hydraulic rig can replace a three boom pneumatic rig. Decisions in favor of hydraulic drilling make a high demand on the rational organization of all other aspects of the operation, it also calls for a rational mine layout, with an advanced ramp system, in order to eliminate assembly and disassembly of the rigs required when moving from level to level using the shaft. All these elements are required to achieve the maximum degree of utilization in order to offset the high capital investment.

Compressed air will always play the role in mining, for instance, in shotcreting, loading explosives, small diameter drilling etc. Portable, electrically powered compressors will, however, satisfy these requirements, eliminating the need for large compressor stations and costly mine air line network installations in the shaft and throughout the mine.

Possibly dominating the issue of hydraulics versus pneumatics are environmental considerations - the importance attached in each individual case to sound levels, visibility at the drilling site, quality of breathing air, manual labour versus mechanization. Experience to date suggests that such questions will be of even more importance in the future, and the answers to them will find one expression in stricter environmental legislation. Modern pneumatic drills can meet most of the present requirements, but the technical difficulties involved in satisfying more stringent standards are much greater in the case of pneumatics. As an example, more effective silencing entails greater machine volume and mass.

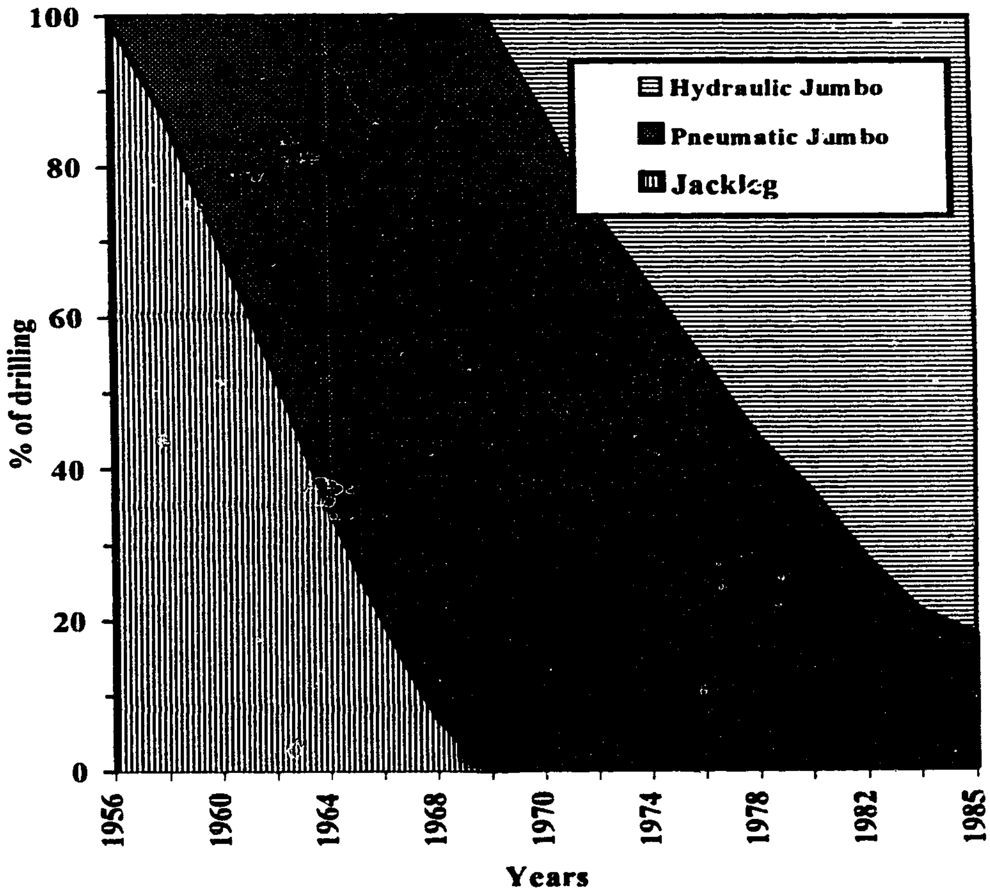
The majority of the development headings in Canadian mines today are driven using hydraulic jumbos with two booms or one boom sometimes called minijumbo (Appendix A). In the range of drillhole size (3.5") 88.90 mm to (6.5") 165.10 mm most of the pneumatic rotary drilling rigs had been replaced by hydraulic rigs. These hydraulic rigs utilize hydraulic power for driving the rotary head, and compressed air to power the "In The Hole" hammer. A portable compressor is used for supplying the drill with compressed air. The mines with the established compressed air network underground use the compressors to boost the mine air from (90 - 120 psi) 0.62 - 0.83 MPa up to (350 psi) 2.4 MPa. Narrow orebodies dictate the use of drillholes in the range of (1.25" - 3.5") 31.75 - 88.90 mm in diameter for which purpose there is a wide range of hydraulically powered drilling rigs that do not require any compressed air.

Mining methods, dictated by the geology, strike length and width of an orebody, will naturally play an important role in the decision between pneumatics and hydraulics. For smaller scale mines, where an investment in high efficiency, capital intensive drilling equipment is difficult to justify, compressed air will continue to hold its own. The nature of the service back-up required for hydraulic drilling equipment also speaks in favor of pneumatics at the smaller mine site, in the remote geographical locations.

Hydraulic drills have efficiencies 3.0 to 3.5 times that of comparable pneumatic drills [8], providing a considerable savings in cost per unit length of hole drilled. This fact makes it imperative that no "bottlenecks" occur in other aspects of the mining operation, if overall economy is to be maintained. Indirectly this puts the pressure on developing more productive mucking equipment, which has gone through dramatic improvements already, and scaling.

Regulations concerning the working environment may make hydraulic drills the only alternative in certain cases, even if a purely technical study would argue in favor of pneumatic rock drills. For the time being most manufacturers carry a full line of both types of equipment, in order to be able to offer the technical and economical equipment for each specific mining project.

Fig. 3 - 1 The trend in application of different drive types in underground drilling equipment [7]



3.2 DEVELOPMENT IN HYDRAULICALLY POWERED HAMMERS

High energy breaking is an alternative to using explosive in underground secondary breaking operations. It is also a means of upgrading conventional hand held breakers, manual sledge hammer breaking in use till early 1970s, and conventional scaling bar operations still in use today. Major areas of application are in secondary breaking over grizzlies and at the drawpoints, the parts of the mining system that became the " bottleneck " of operations after the introduction of hydraulic and advanced pneumatic drills followed by the rubber tired LHD mucking equipment. There is considerable interest in high energy impact breakers for use in primary ore breaking, but all such applications remain experimental.

A high energy impact hammer is a boom mounted pneumatically or hydraulically powered breaker. It basically consists of a piston that oscillates in a housing and impacts the end of tool or moil thrusting it against the rock. The force applied to the rock primarily depends upon the impact energy of the piston - the higher the impact or blow energy the greater the force, thus, the greater the rock breakage. Among drill and breaker designers, a common expression for blow energy is " force of blow".

Hand held breakers are limited to blow energies of about 140 J (100 ftlb), [9] because the operator is unable to handle heavier machines efficiently or to absorb the recoil energy resulting from higher blow energies. These restrictions do not apply to boom mounted breakers; machines with blow energies in the order of 4000 J (3000 ftlb) and higher are commercially available for underground use [10].

The blow rate of boom mounted impact breakers is not as important as it is for the rock drills, because the breaker must be moved over the work surface between the blows. The blow rates are governed by the power supply, the typical range being between 550 and 1100 blows per minute. As general rule, lighter, lower blow energy machines have higher blow frequency rates than heavier machines, therefore, lower efficiency.

Restrictions are placed on the blow energy by machine weight and size, and by the strength of the boom. Typically boom mounted impact hammers have a blow energy (J, ftlb)to mass (kg, lb) ratio of about 1.5, with lower values for the lighter machines, and higher values for heavier machines. In addition to supporting the hammer weight, the boom also has to absorb the recoil energy of the blow, which can be in the order of 1400 J (1000 ftlb) for the larger hammers operating in horizontal position.

High energy hydraulic hammers were introduced for rock and concrete breaking in construction work during 1960s [11]. These early units were used more in construction work than in mining industry. There were no formal energy ratings. The weight of the unit and the size of the striking bar or moil were evaluated against the price quoted for the unit. Performance was evaluated based on the thickness of the concrete and strength when it was available. Nominal ratings in Joules (foot-pounds) of energy were developed in the late 1960s and early 1970s. The ratings were based on engineering design factors of estimated energy stored and horsepower input along with an estimated efficiency. There was no effective measure of the strength of materials being broken nor of piston energy or of energy output at the striking bar tool point.

The piston velocity limitations were defined by Joy Manufacturing's Galt Advance Center in Ontario [12], which was devoted to impact hammer development, as high as 10 m/sec (33 ft/sec). Steel on steel impacts must be limited to impact velocities of about 10 m/sec (33 ft/sec) due to the high impact stresses generated. Higher velocities require higher strength steel at costs that are not practical for these wearing parts. Therefore, increasing the blow energy can be achieved only by increasing the piston size. At the development center, several testing techniques were developed. A drop tower test provided measurable results.

This was followed by accurate electronic measurement of the tool point velocity (Fig.3 - 2). From this information and using the striking bar or moil mass, blow energy was calculated using the familiar equation $E = 0.5\ Mv^2$.

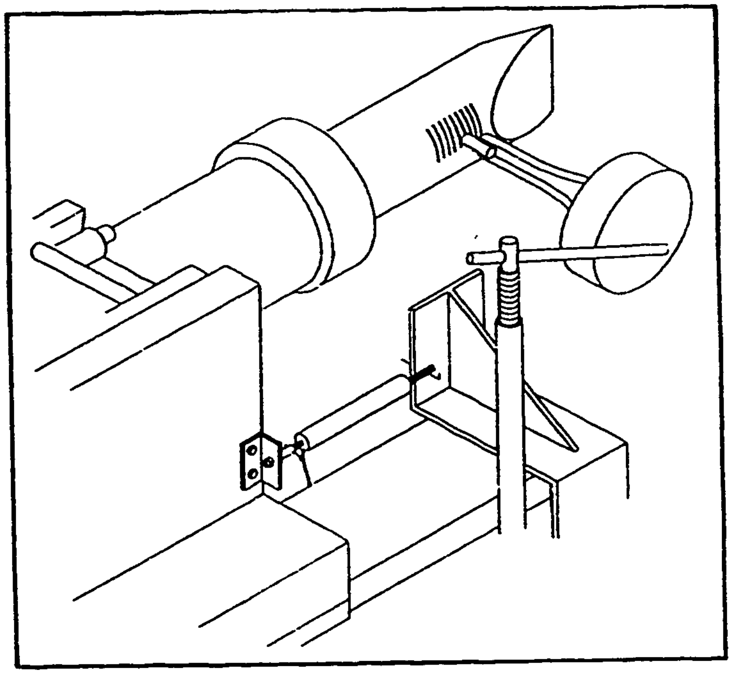


Fig. 3 - 2 Tool point velocity measurement device

The exception to the piston velocity limit is the Joy Hefti hydraulic hammer. This operates a piston at about 40 m/sec (133 ft/sec) without the risk of breaking the piston or striking bar. This is possible because the piston energy is transmitted to the striking bar through an hydraulic fluid between them, serving as a cushion. Usually it is referred to as the " fluid tappet " principle. The use of this system allows the use of light pistons, in case of Hefti hammers 42 kg (92 lb), reducing the overall machine weight. The recoil energy, which must be absorbed by the boom for a given blow energy, is directly proportional to the piston to machine mass ratio. Operating with light pistons provides an additional benefit in reducing the boom size. The Table 3 - 1 shows the published current operating data for various manufacturers of high energy hydraulic hammer units.

Both pneumatic and hydraulic hammers are available commercially. Although hydraulic hammers are a relatively recent development, they already outnumber the pneumatic machines in use. This is primarily due to the several distinct advantages they have over pneumatic machines:

- Hydraulic hammers improve the underground working environment by not producing an air borne oil mist. Having no air exhaust, they are significantly less noisy
- Because the operating pressure with hydraulics is much higher than with compressed air and because oil is relatively incompressible, hydraulic hammers and power packs tend to be lighter and less bulky. These advantages especially come to light in confined working areas and where the mobility of unit is required
- As general rule, hydraulic hammers are more efficient

Almost all mobile boom mounted hammers used today in underground mines are hydraulically powered, while pneumatic hammers are restricted to stationary units such as those over grizzlies, primarily due to availability of mine air throughout the mine.

Table 3 - 1 Comparison of published hydraulic hammer performance statistics

Manufacturer	Model	Energy Class		Blow Frequency	Operating Pressure		Flow		Operating Weight		Hammer Power		Weight to Energy Ratio
		ftlb	kJ	Blows/min	psi	kPa	Gal/min	l/min	lb	kg	hp	kw	
Teledyne	TB-425x	1100	1.49	1100	2300	15.86	21.0	79.49	1155	523.90	37	27.60	1.05
Indeco	MES-1200	1200	1.62	950	1500	10.34	24.0	90.85	1320	598.74	35	26.11	1.10
Okada	305	1250	1.69	900	1990	8.20	21.1	79.87	850	385.55	34	25.37	0.68
Tramac	BHR-450	1350	1.83	665	1100	7.58	34.0	128.70	1400	635.03	27	20.14	1.04
Jacty	JB-10S	1400	1.89	800	2500	17.24	18.0	68.14	1140	517.09	34	25.37	0.81
Hanix	HHB-10	1500	2.03	850	2100	14.48	21.2	80.25	1070	485.34	36	26.86	0.76
Allied	740	1500	2.03	750	2400	16.55	29.0	109.77	1500	680.39	34	25.37	1.00
Balder	B110	1500	2.03	560	2030	14.00	26.0	98.42	2090	948.01	25	18.65	1.39
Rammer	S52	1500	2.03	560	2030	14.00	26.0	98.40	2090	948.01	25	18.65	1.39
FMI	HD-6D	1500	2.03	560	2000	13.79	60.0	227.12	1665	755.23	25	18.65	1.11
Esco	ES40	1500	2.03	750	3000	20.68	55.0	208.19	1100	498.95	34	25.37	0.73
NPK	H-7X	1500	2.03	550	2100	14.48	37.0	140.06	1880	852.75	25	18.65	1.25
Stanley	MB1550	1500	2.03	550	1900	13.10	35.0	132.49	1678	761.13	25	18.65	1.12
Ch Pneu	CP-600H	1590	2.15	720	2175	15.00	27.7	104.85	1389	630.04	35	26.11	0.87

CHAPTER FOUR

DESIGN OF HYDRAULICALLY POWERED HAND HELD SCALER

4.1 SCOPE OF THE PROJECT

The scope of the project was to develop and test a hydraulically powered hand held scaler for dislodging and removing loose rock. The proposed device could be mounted on and powered from existing mining equipment (scooptram, scissor lift etc.). This concept will allow a single source of energy to power drill rigs, LHDs, scalers etc.

As proposed, the focus of the project was on the design as seen from the perspective of the mine operators in regard to improved safety, efficiency and reliability for the most hazardous mining activity - manual scaling.

4.2 METHODOLOGY

The mechanization of the manual scaling operation has attracted a limited amount of interest in the past ten years. Only Inco Ltd., the U. S. Bureau of Mines, and the Mining Department of Laval University showed interest in mechanization of the manual scaling operation [1, 4, 5].

Currently available mobile scalers using impactors in 350 - 700 J class are in the price range of $250,000, and it is difficult to justify employing such a unit in each individual workplace, unless it is a large production complex. Furthermore, the development height or back as well as stope heights are limited. Boom mounted impactor/scalers require the working areas with a high back, usually over 5 meters.

Based on the above survey, and the innovations and trends in the development of the underground mining equipment over the past few years, as discussed in chapter 3, it was decided that the mechanized hand held scaling device should meet the following objectives:

- Be able to detect loose rock
- maximize impact and leverage using axial power produced by the hydraulic hammer
- reduce the amount of energy expended during the manual insertion of the scaling bar into the rock cracks
- generate the prying force necessary to detach the loose rocks from the overlying ground
- have the weight comparable to the presently used hand held scaling bar
- the device could be used with mineral oil or fire resistant fluids

4.3 THE CONCEPT DEVELOPMENT AND THE DESIGN WORK

In order to address the mechanical and ergonomic requirements it has been decided that the anticipated device should incorporate the following features:

- impact energy should be generated by the hydraulically actuated hammer with the output energy level between 500 and 900 J
- the weight of scaling device should not exceed 20 kg
- the weight distribution should not cause excessive fatigue of the miner
- the shape of the scaling tool (moil) should generate leverage to dislodge loose rocks

- the hand transmitted vibration level should meet the ISO 5349 standard
- the noise level should meet the Occupational Health and Safety Act, Noise Regulation, Alberta Regulation 314/81 to 439/81

4.3.1. THE HYDRAULIC HAMMER

In order to reduce the cost of the project only hydraulically powered hand held, commercially available devices were of interest. The design of a hydraulic hammer suitable for this project has not been considered in this work. Prior to the final selection of a suitable hammer, a detailed survey of the various manufacturers of the mining equipment was conducted.

The primary factors involved in hammer selection were:

- hammer weight - the light, easily handled tool reduces operator fatigue
- blow frequency - the faster tool runs under load, the quicker the scaling job gets done
- power - the greater the power the better stabilization of speed
- "feel" - the operator must be able to use the scaler comfortably
- size - it must be such that it can reach the back of the opening readily
- relative efficiency - the output efficiency comparable to that of the presently used scaling tools and methods of doing a scaling job

Only two manufacturers were identified as having a suitable product with the required hydraulic hammer characteristics, namely Allied Inc., and Stanley Hydraulic Tools. The technical specification data of these devices is listed in Table 4 - 1.

After a thorough analysis, only two devices were of interest: the Stanley hydraulic tampers TA 55 and TA 57 models. Based on the identified selection factors the tamper model TA 55 was chosen as a source of the impact power for the hand held scaler. Fig.4 - 1 is the view of the two considered hydraulic tools.

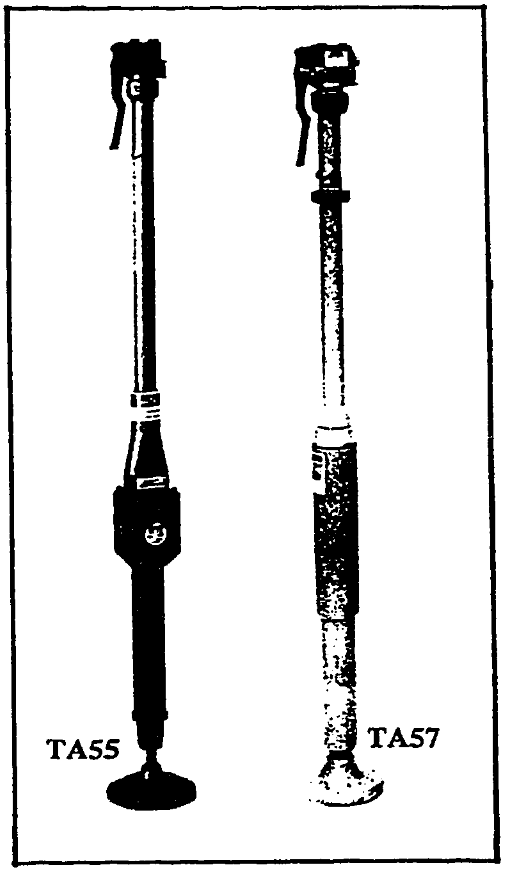


Fig. 4 - 1 View of the Stanley tampers TA 57 and TA 55
(TA 55 was chosen as power source for the prototype)

Table 4 - 1 Technical specification data of the hydraulic hammers considered

Manufacturer	Model	Piston Stroke		Blow Frequency	Operating Pressure		Flow		Operating Weight		Length		Width		Max. Ret.pres	
		in	mm	Blows/min	psi	kPa	gpm	l/min	lb	kg	in	mm	in	mm	psi	kPa
Allied	AH-30	-		2500	1000	6895	4.75	18	27	12.5	-		-		145	700
					1300	8963	5.25	20								
Stanley	TA-55	1	25.4	2300	1000	6895	7	26	23	10.5	49	1240	4	102	-	
	Tamper				2000	13790	9	34			55	1400				
Stanley	TA-57	2.5	63.5	750	1000	6895	7	26	39	17.7	48	1220	3	76	-	
	Tamper				2000	13790	9	34			54	1370				
Stanley	CH-18	-		-	1500	10342	7	26	24	11.0	20	510	3	76	-	
	Chipping hammer				2000	13790	9	34								
Stanley	BR-37	-		-	1500	10342	7	26	37	17.0	22.5	570	14		-	
	Breaker				2000	13790	9	34						360		

4.3.2 THE FINAL ASSEMBLY OF THE PROTOTYPE OF THE HYDRAULICALLY POWERED HAND HELD SCALER

Figure 4 - 2 depicts the assembled prototype of the hydraulically powered hand held scaler and its essential features. The hydraulic fluid from the power pack (1), causes the piston in the hammer (3) to reciprocate and to strike the shank (4) of the lower end of the connecting rod (5) in repetitive manner. Energy is imparted to the loose rock through the moil (6). The technical specification data of the prototype is shown in Table 4 - 2.

Table 4 - 2 Technical specifications of the prototype scaling bar

Weight without extension tool	12.93 kg (28.5 lb)
Weight with extension tool	17.92 kg (39.5 lb)
Total length	2.73 m (8.95 ft)
Moil length	0.38 m (1.27 ft)
Nominal oil pressure	13.8 MPa (2000 psi)
Piston stroke	1 in (25.4 mm)
Blow frequency	2,300 blows/min
Oil flow	30.3 l/min (8 gpm)
Output power @ 10.31 Mpa(1,500 psi) and 3,154 l/min.(3.3 gpm)	134 W (0.18 hp)

4.3.3 THE DESIGNED MECHANISMS FOR IMPACT ENERGY TRANSITION FROM THE HAMMER TO THE SCALING MOIL THROUGH THE ALUMINUM CONNECTING ROD

In the designed scaling device, piston energy is transmitted to the loose rock by the connecting rod and scaling moil. Unfortunately, not all of the energy from the piston is transmitted into the rock. A part of it travels back up the scaler's connecting rod. This has a negative effect on the service life of the integral shank, scaler's connecting rod, and prying tool. It also increases the amount of vibration transferred from the source(scaler) to various physiological structures within the hand and arm of the miner.

Figure 4 - 3 shows the detail drawing of the designed mechanism that allow the impact energy to be transferred from the piston (5) of the hydraulic hammer to the scaler's aluminum connecting rod (8). The chuck bushing (2) of the adapter sleeve (1) (Fig.4 - 4) and the collar on lower shank (3) fix the impact surface (7) in relation to the piston (5). The retaining spring (6) permits easy release of the connecting rod (8) and fixes it during the operation of the scaler.

Figure 4 - 5 shows the detail drawing of the scaling tool(moil) attached to the upper part of the connecting rod. The fitting sleeve (9) fixes the surface of the scaling tool (moil) 10 (Fig.4 - 8) according to the drawing. Fig. 4 - 7 is the view of the assembled mechanism for the impact transfer to the scaling moil.

4.3.4 THE DESIGNED SCALING TOOL (MOIL)

4.3.4.1 THE SHAPE OF THE SCALING TOOL (MOIL)

In order to magnify the effect of the axial impact force generated by the scaler's hydraulic hammer, it was decided that the scaling moil will have a shape of the two stage wedge. Wedges are simple machines used to raise large stone blocks and other heavy loads. These loads may be raised by applying to the wedge a force usually considerably smaller than the weight of the load. The object of the design was to shape the scaling tool in such a way that a final prying torque would be achieved in two stages. The effect of the impact force would be maximized by having the magnitude of each stage wedge angle reasonable small and equal to 11^0 during the scaling process (the resultant of the friction force and the normal force will almost be perpendicular to the rock beam).

In order to evaluate the magnitude of the bending stress generated by the first stage of the moil's angle of 11°, the cantilever beam of loose rock hanging from the back of the excavation was considered. The value of the impact force generated by the hydraulic hammer and exerted by the wedge during scaling was calculated for the average moil advance rate of 0.016 m/s and impact power output of 90 W (Table 5.1 - 2), and its magnitude is equal to 5.6 kN. It was assumed that the value of the coefficient of static friction between the steel moil and the rock mass was 0.30.

Base on the research work done by the HDRK Mining Research Limited [13] it was assumed that the average mass of the detached loose rock was 454 kg, the average thickness of the loose rock slab was 0.3 m, the average detached loose rock area was 0.6 m^2, and the rock density was 2,522 kg/m^3.

Inspection of the beam reveals that for the assumed loading conditions and the moil geometry all fibers along the upper surface will experience the tensile stress of 2.5 MPa in this first stage of scaling. Taking into consideration the rock physical properties, it is evident that most of the rocks will fail under such tensile stress conditions. This finding justified the selected magnitude of the first stage moil wedge angle of 11 degrees. Figure 4 - 8 shows the final drawing of the adopted shape of the moil prototype.

4.3.4.2 SCALING MOIL'S DIMENSIONS

The 4340 steel, heat treated, was used for manufacturing of the designed prototype of the scaling moil. This steel combines deep hardenability with high ductility, toughness and strength. It has high fatigue and creep resistance [14]. It is often used where severe service conditions exist and where high strength in cross section is required.

The scaling moil shown in Fig. 4 - 8 has a maximum value of the cross-section of 0.018 m in diameter. This cross-section dimension of the moil, proved to be superior and there were no failures of the moil during the field testing of the scaler. The view of the assembled moil is shown is Fig. 4 - 9, and the pertinent calculations in the Appendix B.

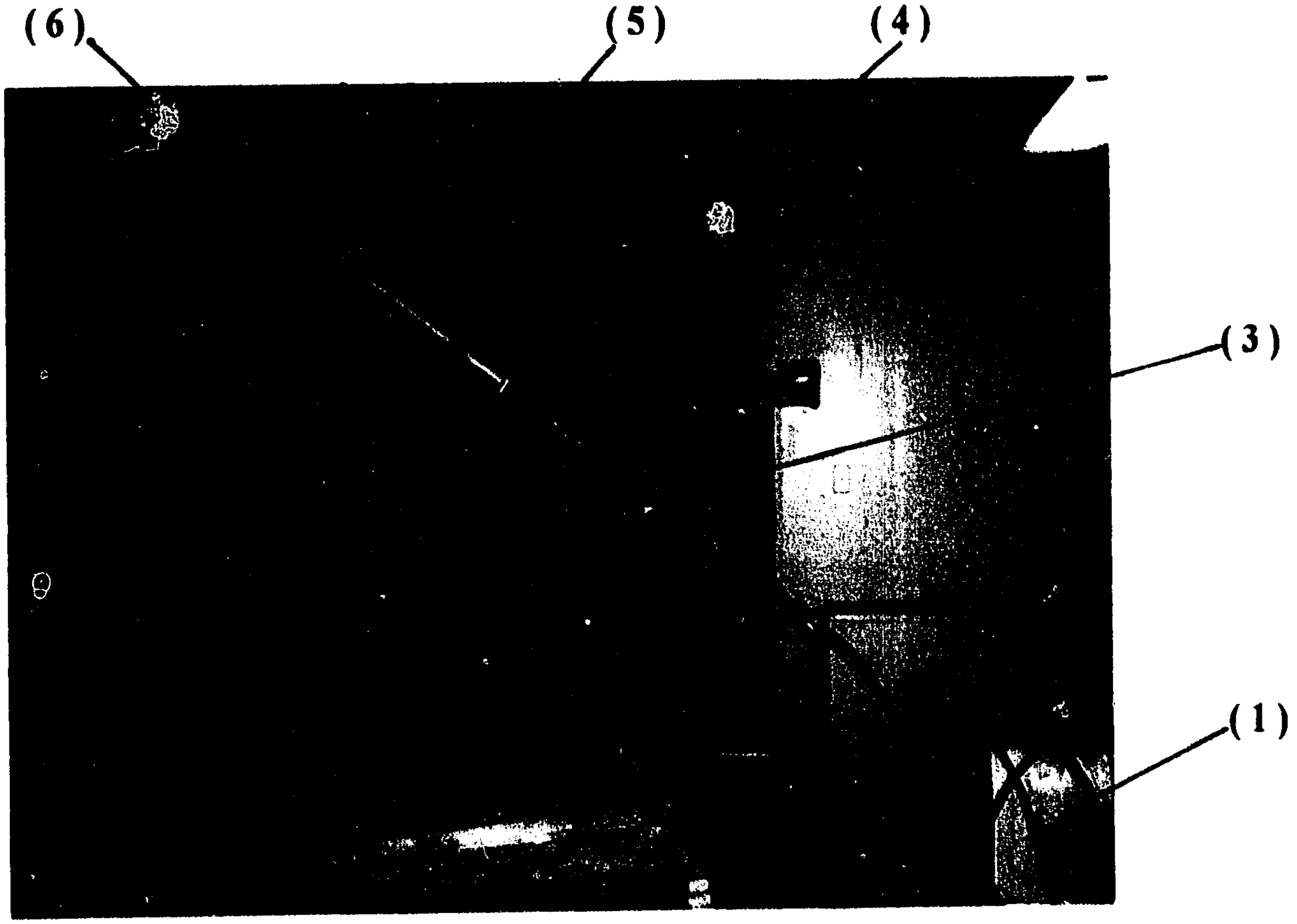
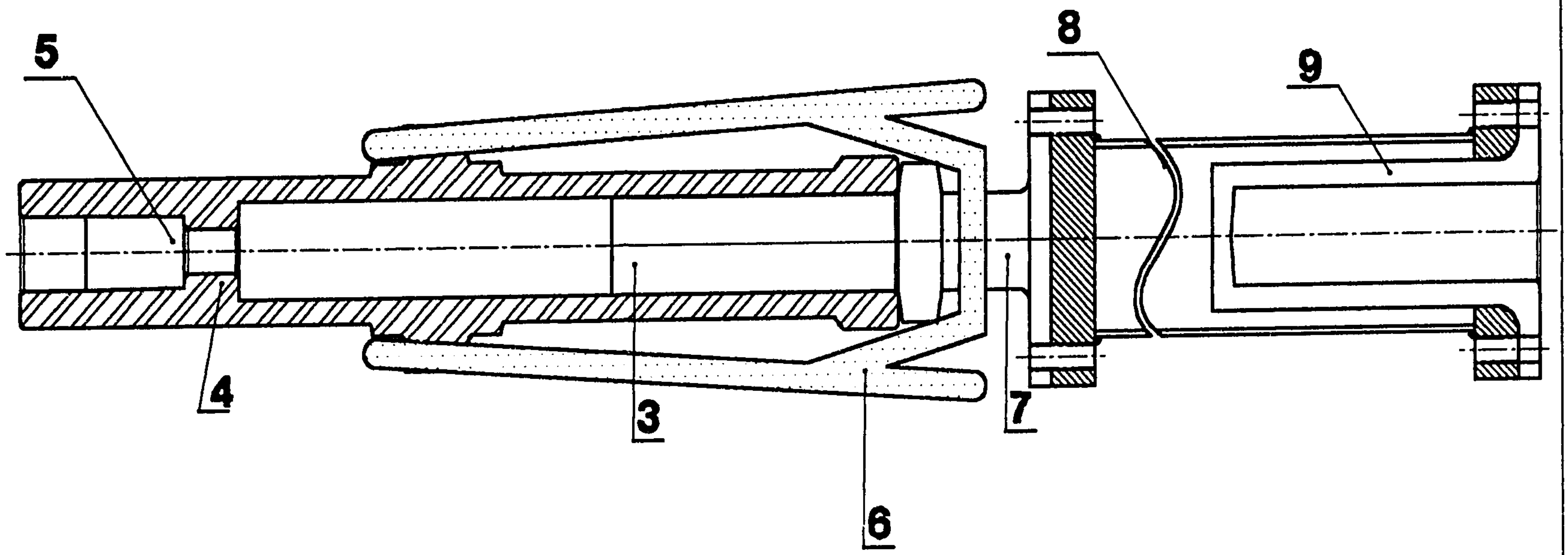


Fig.4 - 2 Assembled prototype hydraulic scaling bar



PART LIST

SUBJECT: ASSEMBLED CONNECTING ROD

DRAWN BY: Z.F.
CHECKED BY: Z.F.
APPROVED: Z.F.

SCALE: 1:20
DATE: June 30/95

Fig. 4 — 3

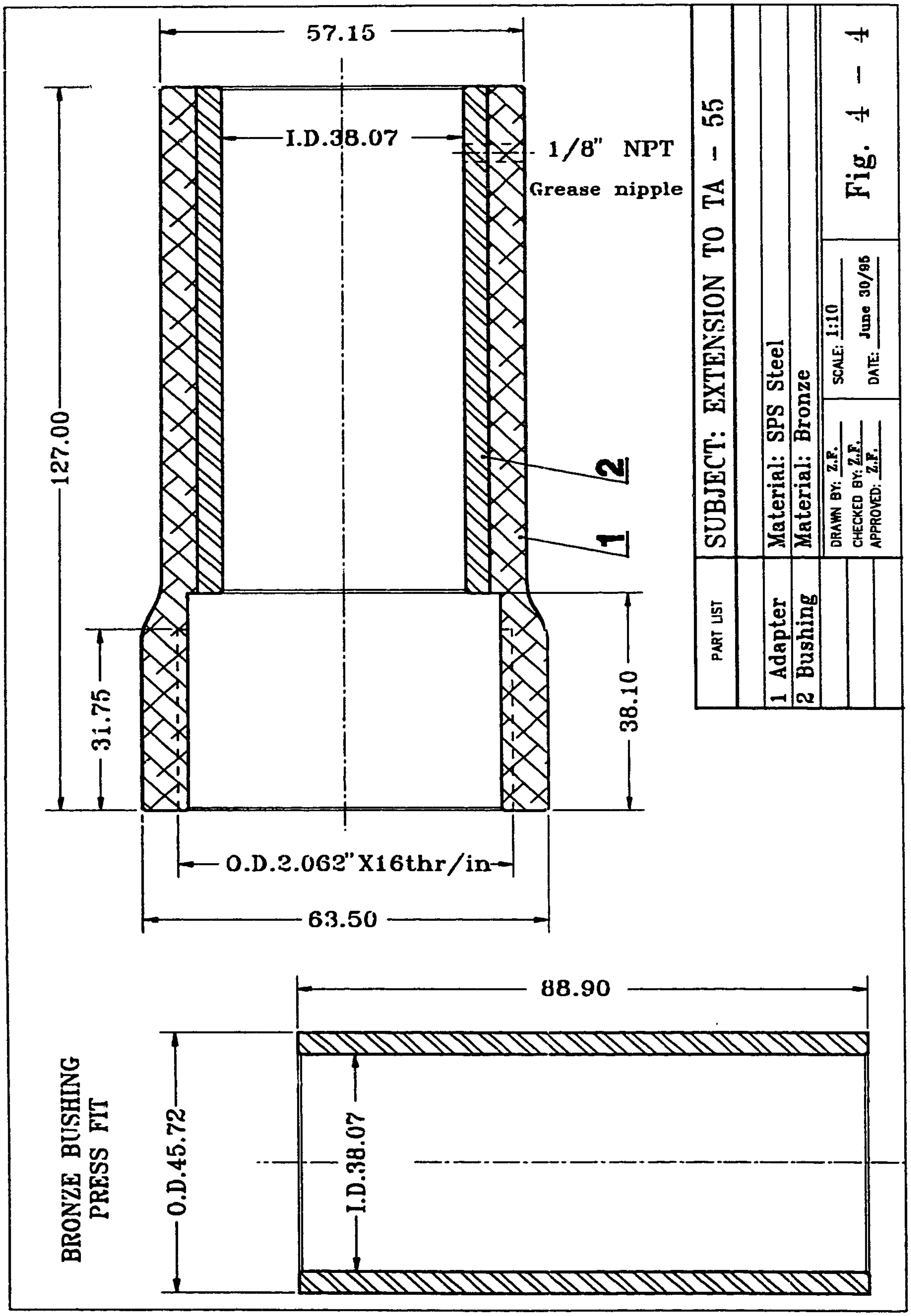
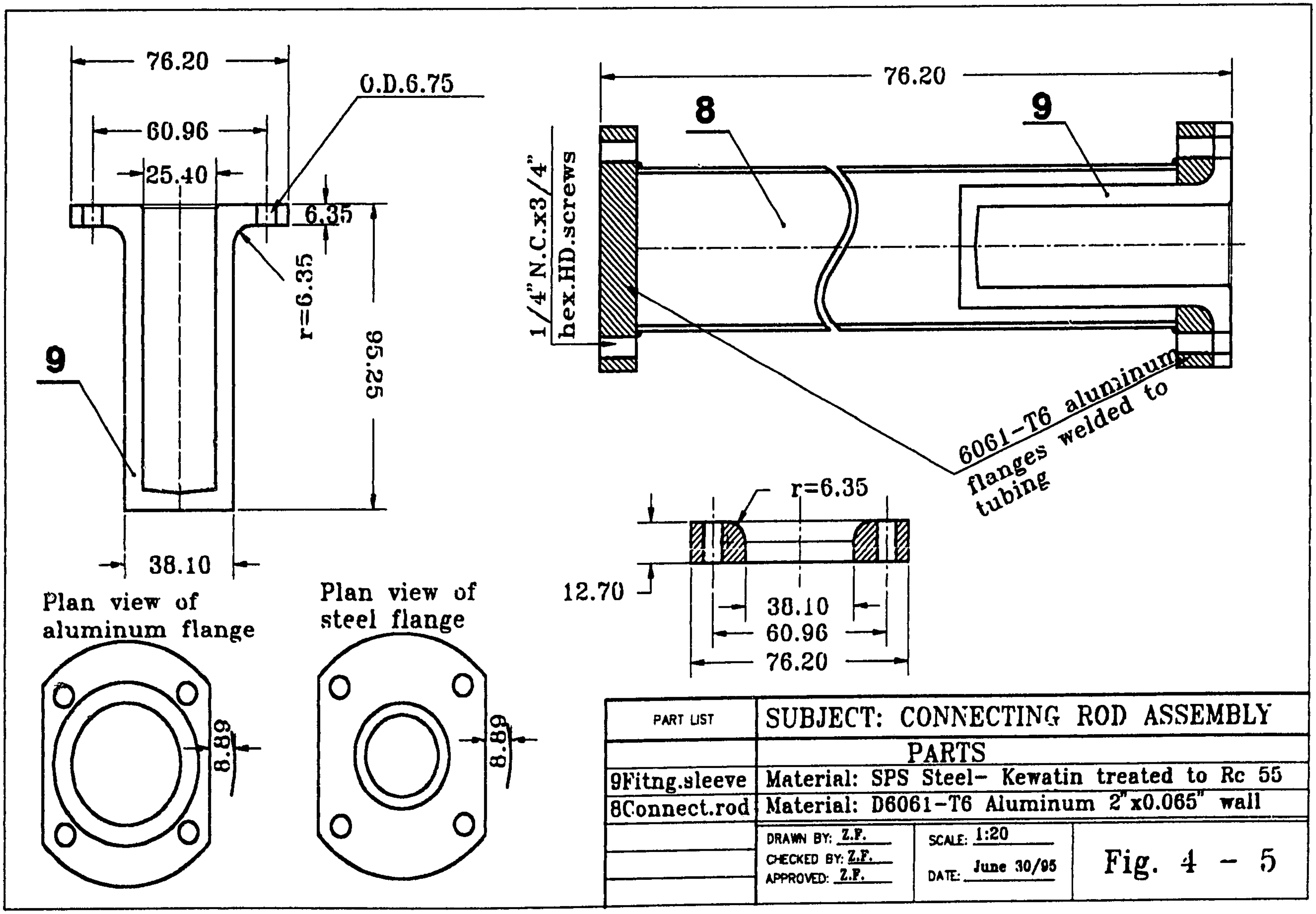

57.15
I.D.38.07
1/8" NPT
Grease nipple
127.00
31.75
38.10
1
2
O.D.2.062"X16thr/in
63.50
88.90
BRONZE BUSHING
PRESS FIT
O.D.45.72
I.D.38.07
PART LIST
1 Adapter
2 Bushing
SUBJECT: EXTENSION TO TA - 55
Material: SPS Steel
Material: Bronze
DRAWN BY: Z.F.
CHECKED BY: Z.F.
APPROVED: Z.F.
SCALE: 1:10
DATE: June 30/95

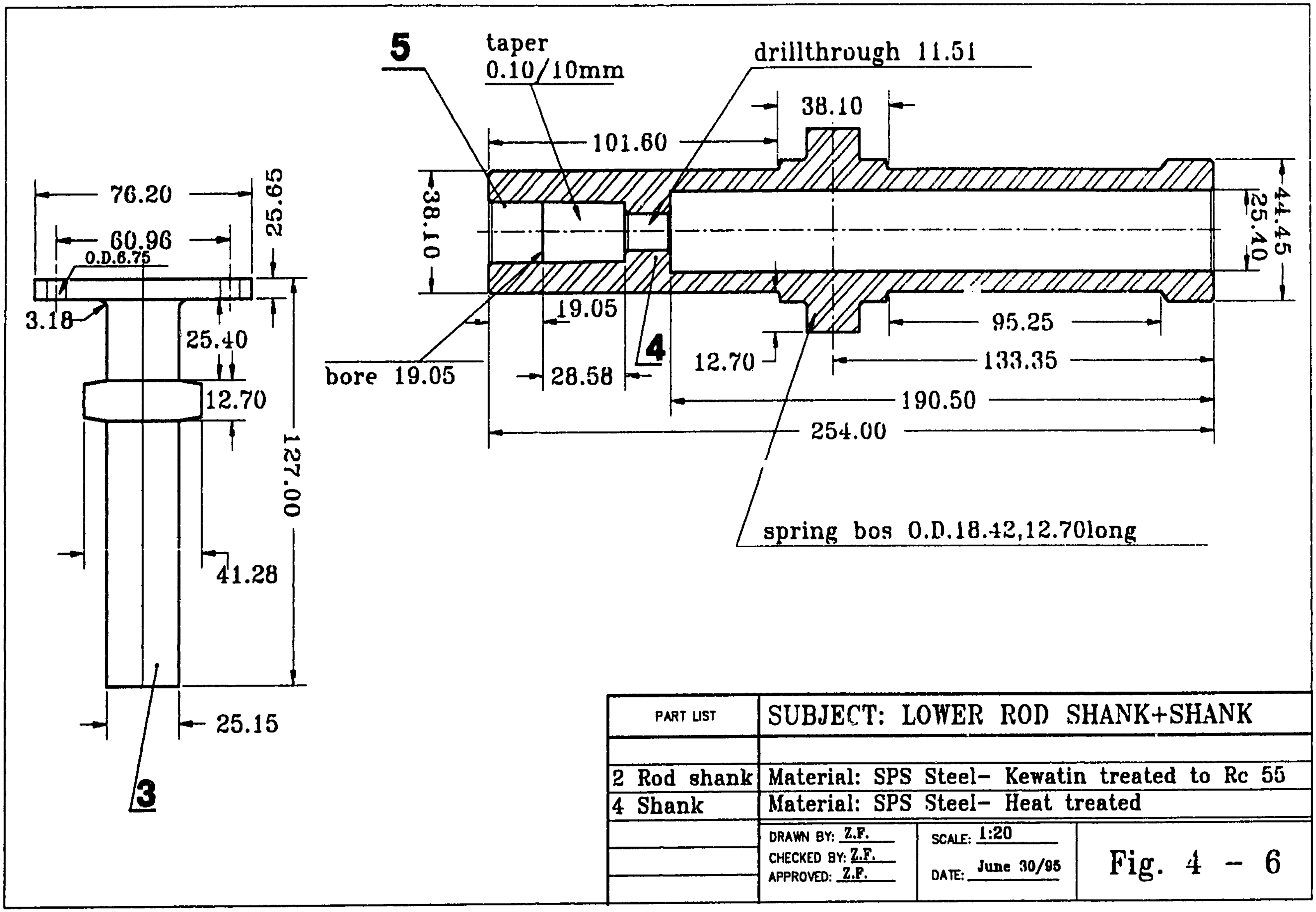
Fig. 4 - 4



PART LIST	SUBJECT: CONNECTING ROD ASSEMBLY
	PARTS
9Fitng.sleeve	Material: SPS Steel- Kewatin treated to Rc 55
8Connect.rod	Material: D6061-T6 Aluminum 2"x0.065" wall

DRAWN BY: Z.F.
CHECKED BY: Z.F.
APPROVED: Z.F.
SCALE: 1:20
DATE: June 30/95

Fig. 4 - 5



PART LIST	SUBJECT: LOWER ROD SHANK+SHANK		
2 Rod shank	Material: SPS Steel- Kewatin treated to Rc 55		
4 Shank	Material: SPS Steel- Heat treated		
	DRAWN BY: Z.F. CHECKED BY: Z.F. APPROVED: Z.F.	SCALE: 1:20 DATE: June 30/95	Fig. 4 - 6

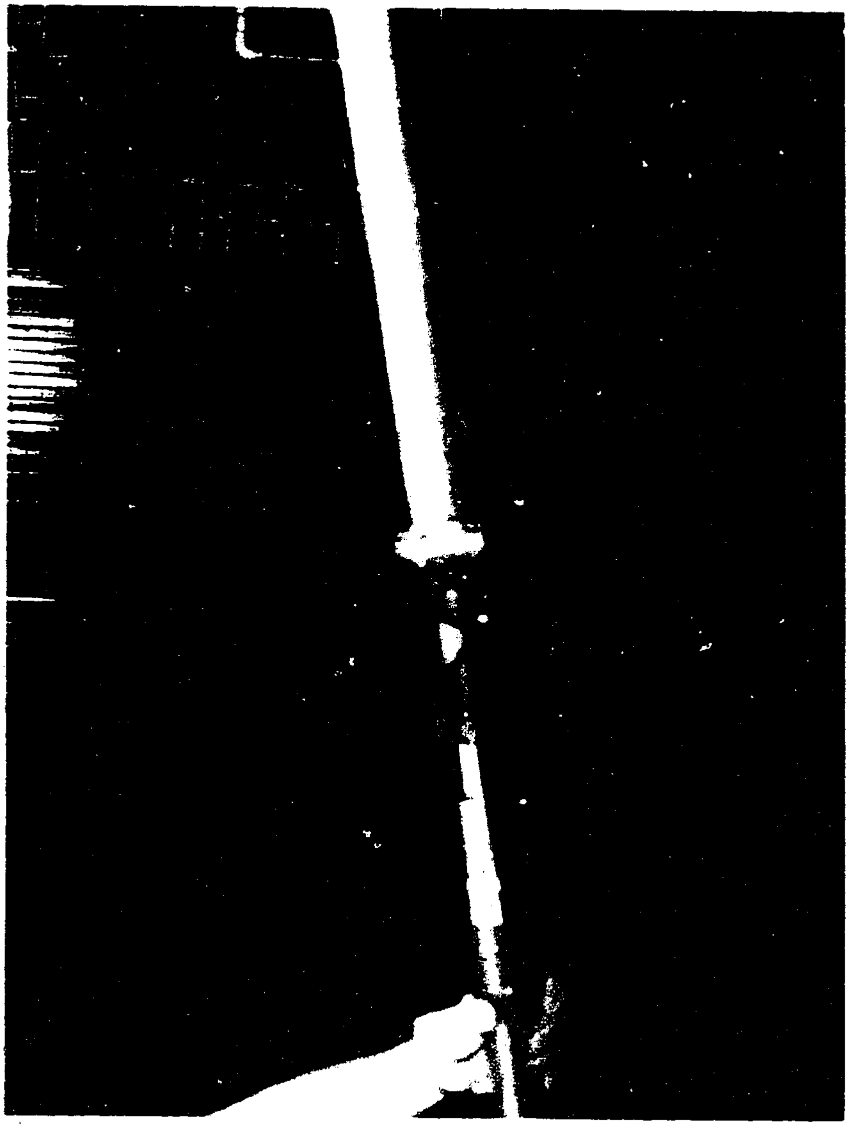
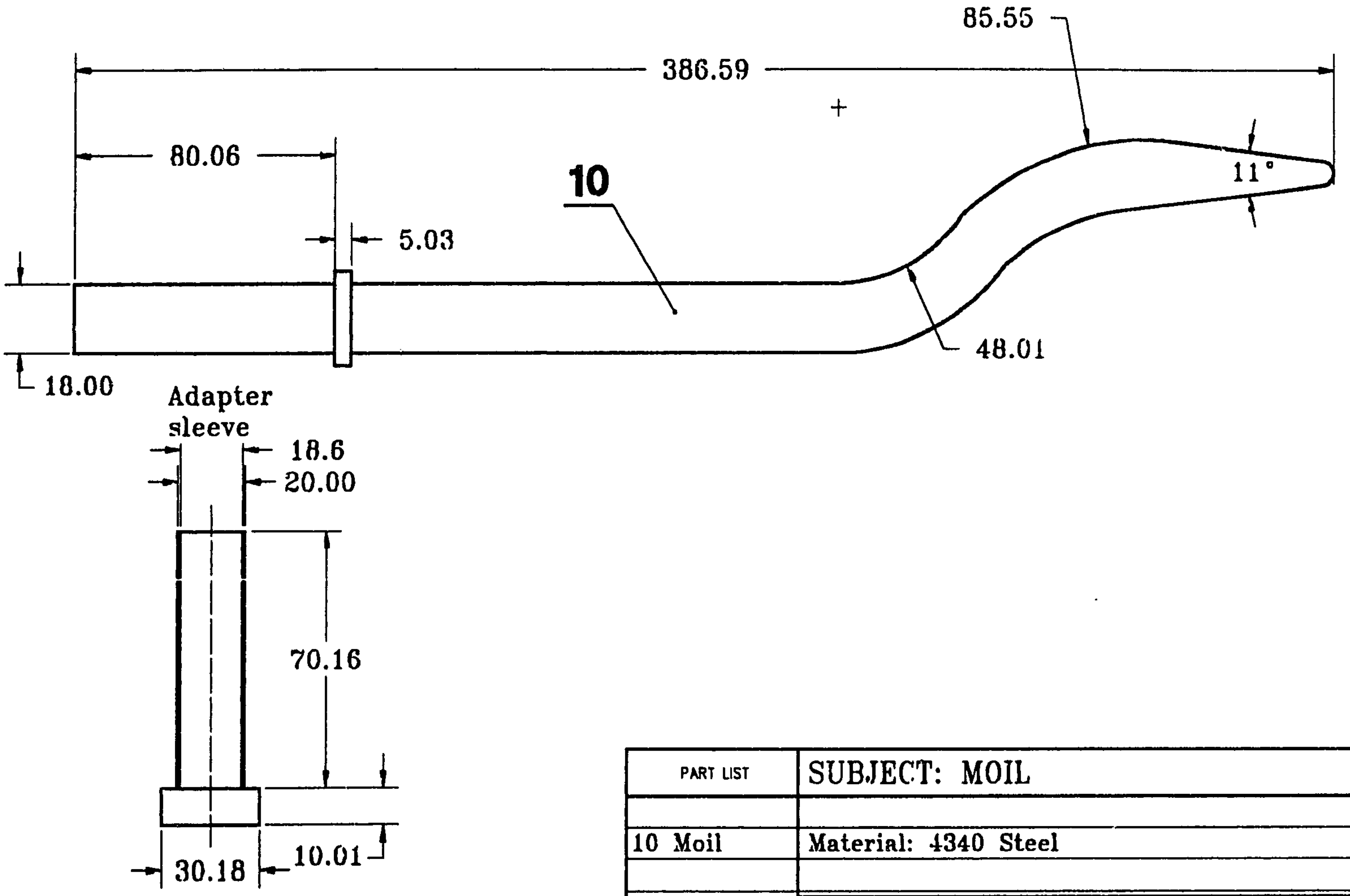


Fig. 4 - 7 View of the assembled mechanism for impact transfer to the scaling moil



PART LIST	SUBJECT: MOIL		
10 Moil	Material: 4340 Steel		
	DRAWN BY: Z.F. CHECKED BY: Z.F. APPROVED: Z.F.	SCALE: 1 : 20 DATE: June 30/95	Fig. 4 – 8

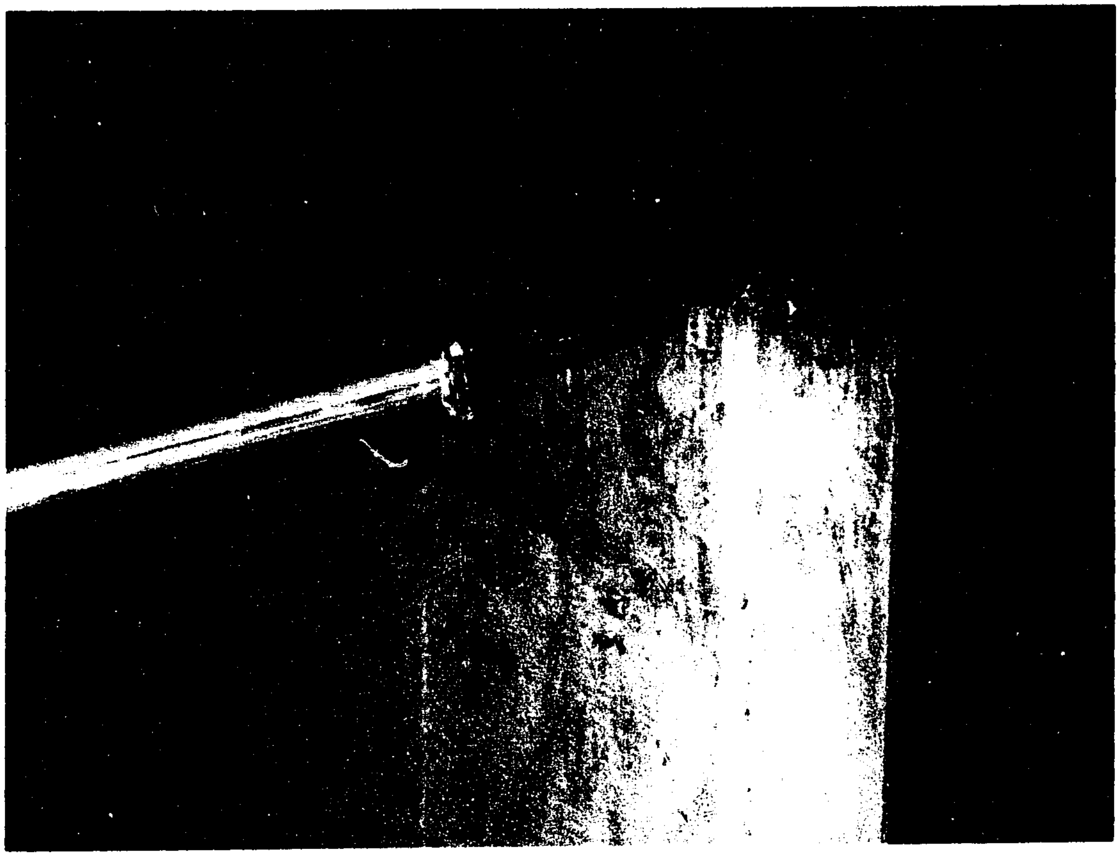


Fig. 4 - 9 View of the assembled moil

CHAPTER FIVE

LABORATORY AND FIELD TESTING OF HYDRAULICALLY POWERED HAND HELD SCALER

5.1 IMPACT ENERGY AND IMPACT POWER MEASUREMENT

In order to properly design the components of a hydraulically powered scaling device it was necessary to define the relationship between the thrust applied to the hammer by the miner and the power output at the tip of the scaling tool. It was also desirable to know whether a maximum power output from the scaler is within the required range at a particular thrust exerted during scaling activity. The results of this experiment confirmed the expected power output magnitudes required to perform effective and reliable scaling operation.

5.1.1 CALIBRATION PROCEDURE AND IMPACT ENERGY MEASUREMENT

In order to generate required magnitude of bending stress in the cantilever beam of loss rock during the prying process, it was desired that the magnitude of the impact force delivered by the hydraulic hammer to the moil of the scalier was in the neighborhood of 6 kN (see Chapter Four and Appendix B). To achieve this magnitude of impact force the required power output of the hydraulic hammer should be in the range of 90 to 160 W, which is equivalent to impact energy level of 500 to 900 J. It was also important to know whether this power output can be materialized if the typical thrust exerted by the miner to the scaler was in the range of 200 to 500 N during scaling activity.

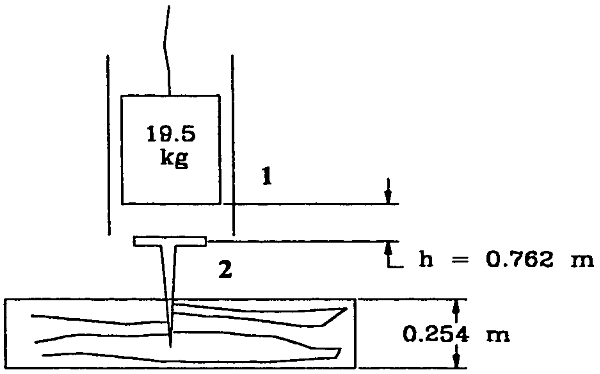
The calibration curve for this range of impact energies was obtained by dropping a 19.5 kg block from various heights onto top of a steel spike of mass

0.1 kg and length of 0.3 m which was driven into an eight inch by ten inch (25.4 cm) timber.

In order to use the entire height of the timber (25.4 cm) for the impact energy level of 100 to 1000 J during the calibration procedure it was desired to determine how far the nail will be driven into the wood by a single blow of the 19.5 kg block as a result of a 0.762 m initial free fall. It was assumed that the initial resistance to spike penetration is 163 N and the impact is perfectly plastic [23].

Solution. The impact between the falling block and the nail must be treated separately; therefore the solution is decided into three phases.

Phase I - Conservation of Energy: Block drops - 0.762 m.



The total mechanical energy of the block is:

T + V = constant

where, T = kinetic energy of the block, J

V = potential energy of the block, J

Applying the principle of conservation of energy between position 1 and 2, we write

$$0 + m_H\ g\ 0.762 = 0.5\ m_H\ V_H^2$$

where,

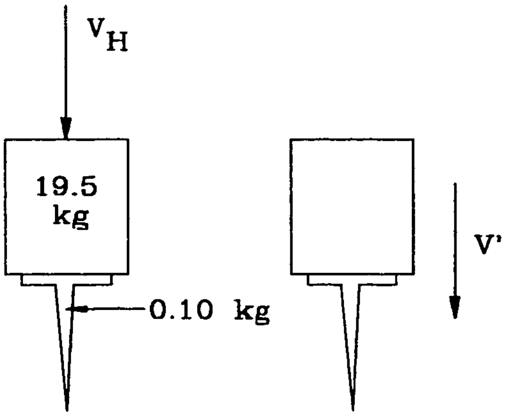
m_H = mass of the steel block, kg

V_H = block velocity after it has moved to position 2 , m/s

$V_H^2 = 2 \quad 9.81 \quad 0.762 \ = 14.95$

$V_H = 3.87$ **m/s**

Phase II Impact: Conservation of Momentum. Since the impact is perfectly plastic, e = 0; the block and nail move together after the impact.



Applying conservation of momentum equation, we write

$m_H \ V_H \ + m_N \ V_N \ = (m_H + \ m_N)\ V'$

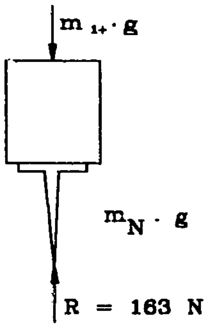
where,

m_N = mass of the nail, kg

$19.5 \quad 3.87 \quad + 0 \quad = 19.6\ V'$

$V' = \ 19.5/19.6 \quad 3.87 = 3.85$ **m/s**

Phase III Conservation of Energy. Block and nail move against wood resistance.



Work and energy for block and nail. We write

$$T_1 + U_{1-2} = T_2$$

where,

U_{1-2} = work of the block weight force between point 1 and 2

$$0.5\,(m_H + m_N)\,V'^2 + [\,(m_H + m_N)\,g - R\,]\,x = 0$$

$$0.5(19.6)(3.85)^2 + [19.6\,(9.81) - 163]\,x = 0$$

$$x = 145.26/3002.52 = 0.048 \text{ mm}$$

Considering the magnitude of this initial penetration distance and the fact that the resistance of wood to penetration will increase after each consecutive increment of energy delivered by the falling block, it is evident that the thickness of the timber is more then sufficient to obtain the calibration curve in the full range of energies considered.

The calibration data obtained is shown in Table 5- 1 and the calibration curve is plotted in Fig 5 -1. The view of calibration stand is shown in Fig. 5 - 2. The calibration curve shows the relationship between the impact energy of the falling block and cumulative penetration of the steel nail into the timber. The calibration data was also fitted to a least-square fit line. The best fit equation of the strait line is:

$$E = 6.8\,x - 156.2$$

where,

E = impact energy, J

x = depth of penetration of the nail, mm

The coefficient of correlation of 99.1% for that straight line indicate high linear association between impact energy and depth of penetration of the nail.

Table 5 - 1 Calibration data

Weight kg	Height m	Force applied N	Cumulative energy J	Incremental penetration mm	Cumulative penetration mm
19.504	0.762	191.269	145.747	46.038	46.038
19.504	0.816	191.269	301.823	22.225	68.263
19.504	0.991	191.269	491.37	33.337	101.600
19.504	1.557	191.269	789.175	28.525	130.175
19.504	1.321	191.269	1,041.842	39.688	169.863
19.504	1.575	191.269	1,343.091	57.15	227.013

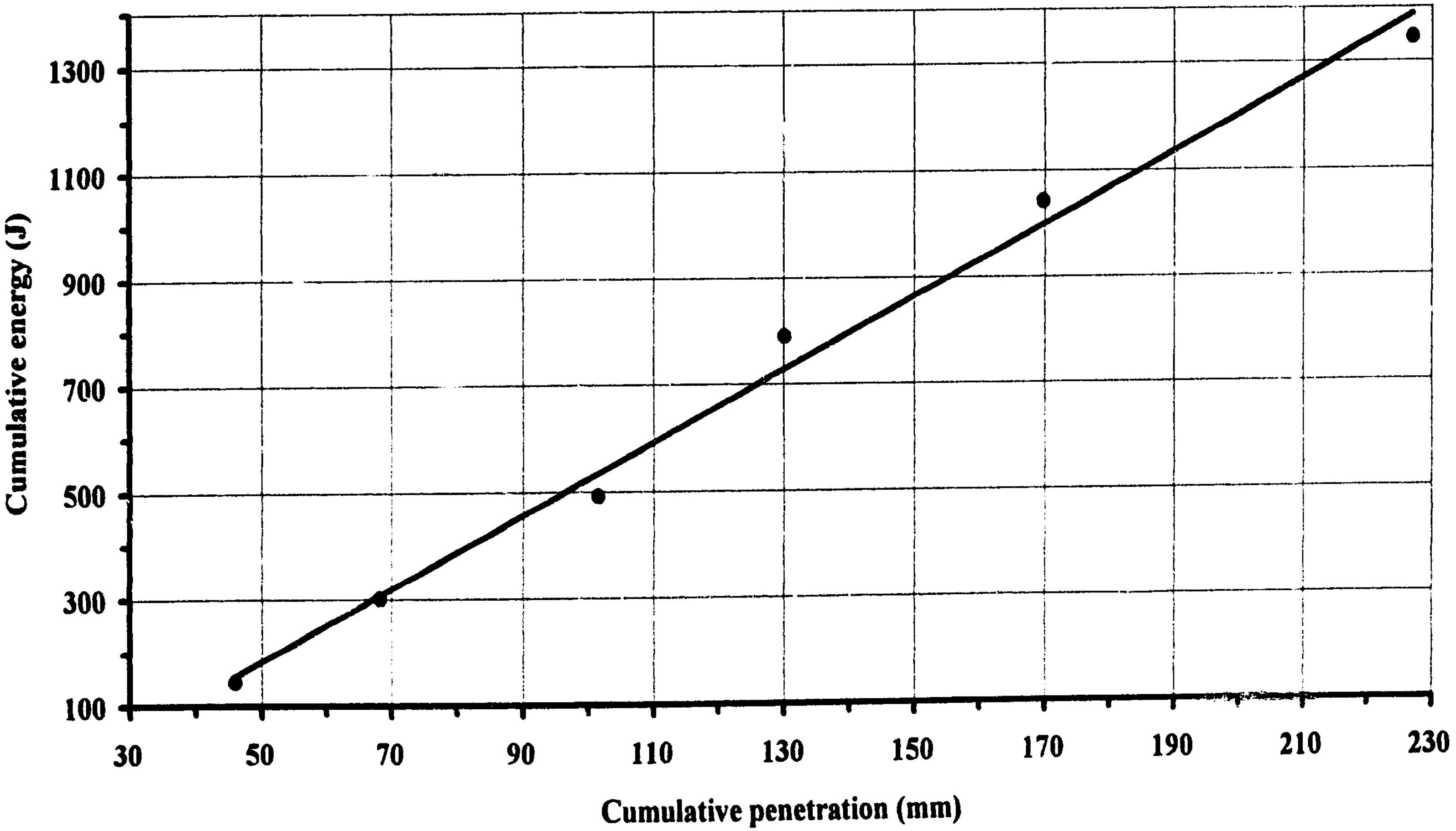


Fig. 5 - 1 Calibration curve of output cumulative energy vs. cumulative penetration of the nail

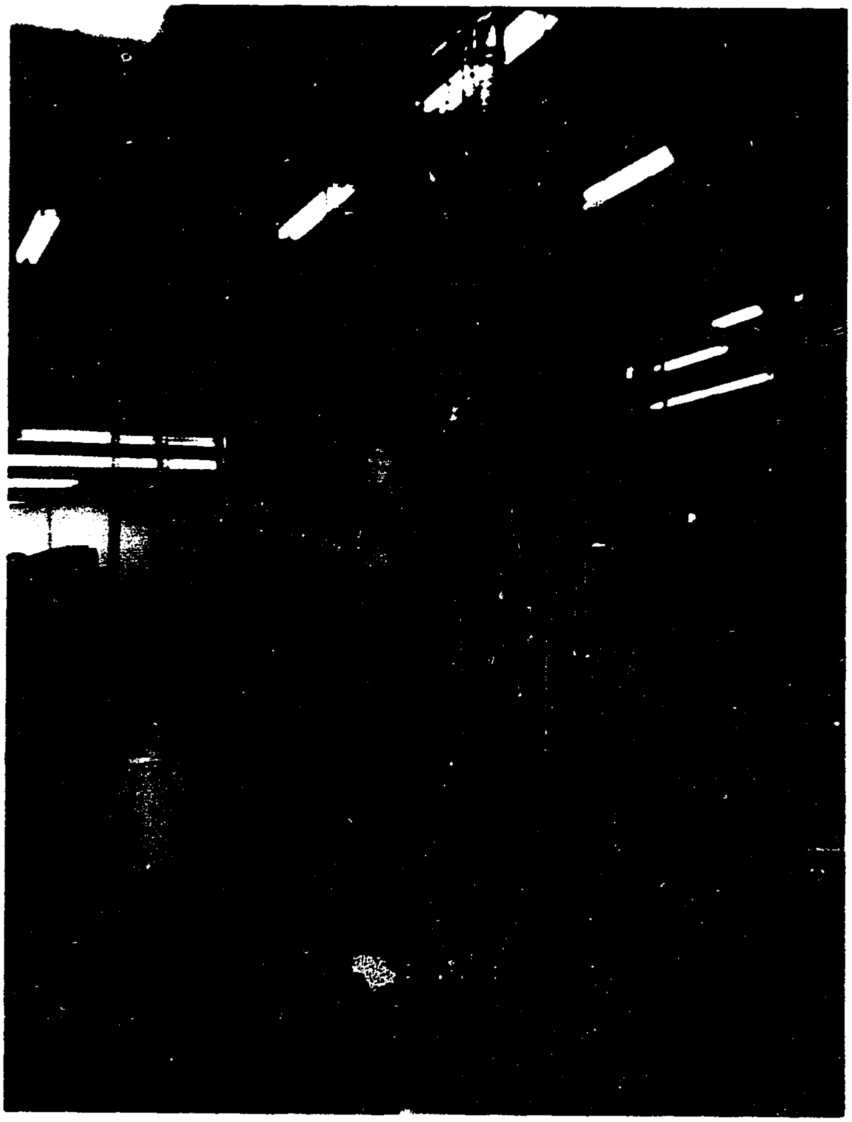


Fig. 5 - 2 View of the impact energy arrangement

5.1.2 IMPACT POWER MEASUREMENT

This experiment used a hydraulically driven hammer adapted from the Stanley TA 55 tamper. The constant fluid pressure of 10.3 MPa (1,500 psi) and constant flow rate of 12.5 l/min (3.3 gpm) were supplied by a gasoline powered engine coupled to a hydraulic pump. The hammer had been modified by having a bowl placed around the shaft. Into the bowl, weights were added simulating variation in thrust force. The hammer was loaded with ballast in increments of 9.07 kg (20 lb). The hydraulic impactor was held by several volunteers as it drove a 30.48 cm (12 in) long construction nail into an eight inch by ten inch timber. At each weight increment the rate of displacement was determined by measuring the time and the penetration depth of the nail. Fig. 5 - 3 shows the experiment arrangement.

5.1.3 CALCULATIONS AND RESULTS

The power required to drive the nail is:

$$P = \frac{E}{t},$$

where E = cumulative impact energy, J

t = time to drive nail certain length, sec

P = impact power output, W

The energy to drive the nail a certain distance was obtained from a calibration curve that plots cumulative impact energy versus cumulative penetration (Fig. 5 - 1). The hammer's output power exerted at each particular thrust was then calculated and plotted versus the load on the hammer. This relationship is shown in Fig. 5 - 4 and the calculations are detailed in Table 5 - 2.

Table 5 - 2 Power calculation data

Case No.	Load N	Distance mm	Time s	Energy J	Power W
1	213.51	155	5.4	897.8	166
2	309.15	150	6.8	863.8	127
3	404.79	63	2.4	272.2	113
4	493.75	98	5.7	510.2	90
5	589.39	80	5.2	387.8	75

The data was also fitted to a least-squares best-fit line, with the eqation:

$$\mathbf{P = 0.24\ F + 212.6}$$

where P = power output of the hydraulic hammer, W

F = applied thrust force, N

The coefficient of correlation of the line is 96.7 %.

The calculated power output equation shows a strong linear relationship between thrust and power output (coefficient of correlation of 96.7%). The trend of the best fit line in Fig. 5 - 4 is consistent with the theory of operation behind the hammer. As additional thrust was applied to the hammer, the power output at the tool decreased. The results obtained in this experiment indicate that the selected hydraulic hammer will perform satisfactory during the normal scaling operation.

As can be seen from Fig. 5 - 4, the power output is in the range between 95 W to 165 W, for the range of typical thrust forces of 200 N to 500 N, expected to be exerted by the miner during a normal scaling activity.

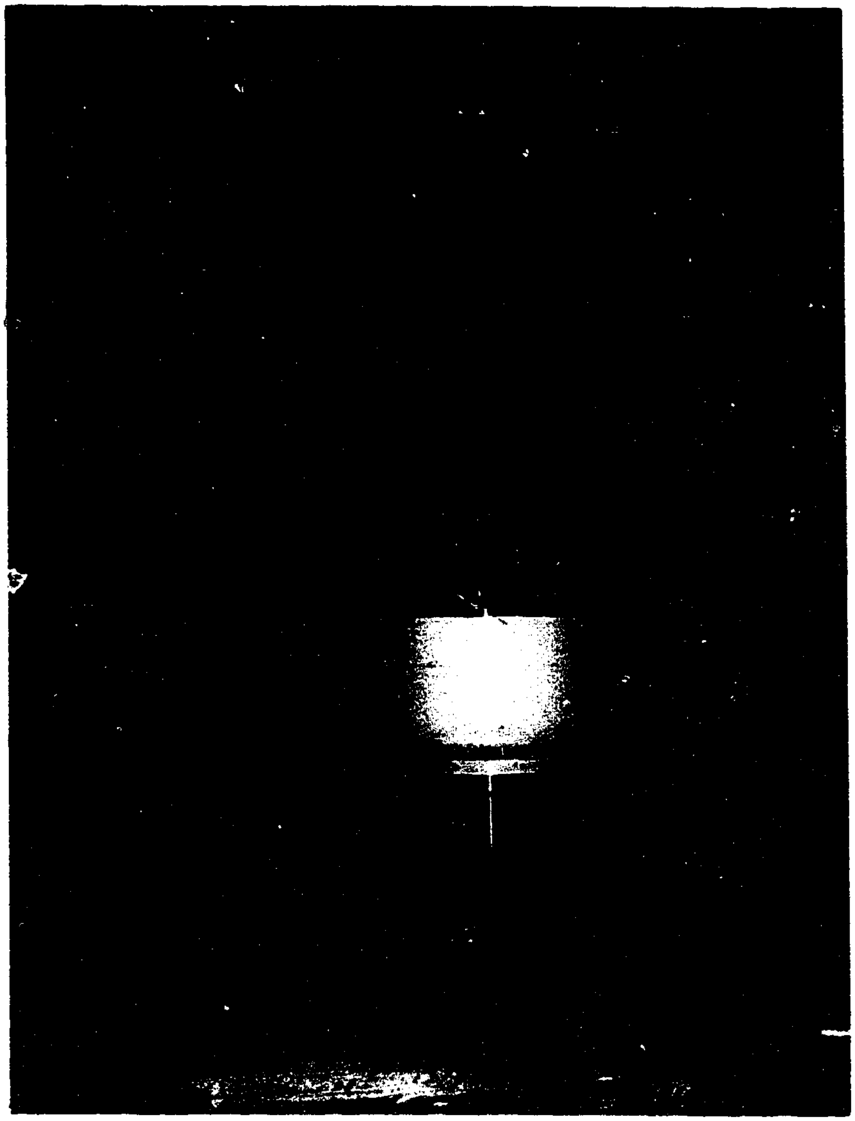


Fig. 5 - 3 View of the weight adding assembly

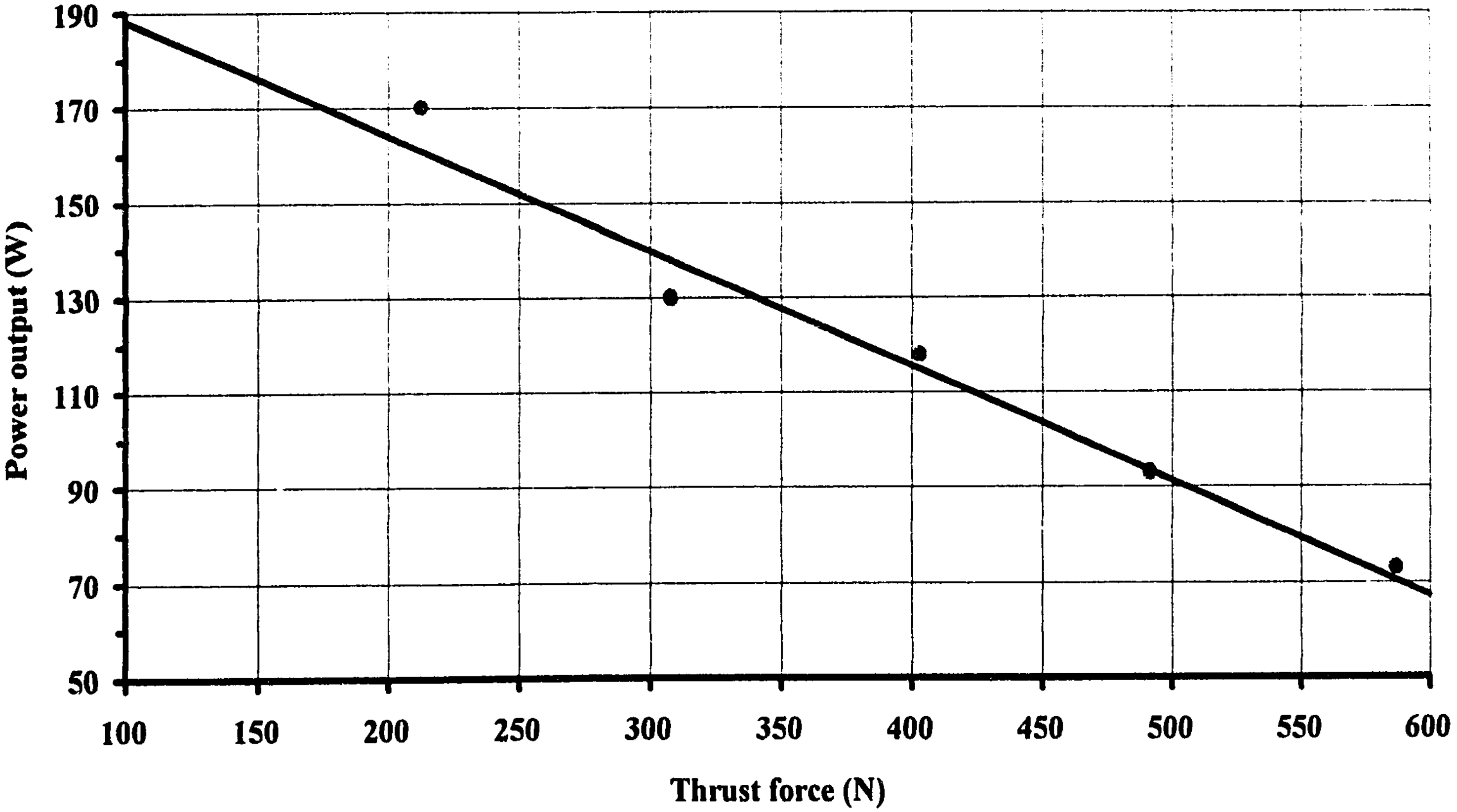


Fig. 5 - 4 Thrust force vs. power output

5.2 FIELD TESTING OF THE PROTOTYPE SCALER

5.2.1 EXPERIMENTAL SITE AND EQUIPMENT

In order to evaluate the actual performance of the assembled scaling device the field tests were carried out in the month of November, 1995. Because of stringent underground safety regulations it was decided to test the prototype at an abandoned quarry. However, the results of this study were not affected by this choice. To operate the hydraulic prototype a gasoline powerpac unit was rented. This unit was capable of delivering hydraulic fluid at constant operating pressure of 1,500 psi (10.31) MPa, and a constant flow rate of 3.3 gpm (12.5 l/min).

5.2.2 FIELD TEST RESULTS

To determine the components of the scaling cycle (using the developed prototype), the scaling operation was broken down into three major activities namely:

- detection of loose ground
- scaling - comprising of penetration and prying action of the moil tip
- pause - rest time during which the operator is not performing any scaling activity

The time to perform each individual element of a scaling cycle was measured using a stopwatch and the frequency of its occurrence was evaluated during a predetermined period of time. Four sets of these three activities were measured for each operator, each set being 2 minutes in total. The time for each activity was expressed as a percentage of the 2 minute set. Table 5 - 3 shows the results of the field tests expressed as percentages of the 2 minute scaling cycle.

The Figures 5 - 5 through 5 - 8 are plots of the field data, comparing the performance of each operator that tested the hand held scaler. It can be seen that on average detection component represents 10% of the cycle time, while penetration and prying account for more then 80% of the total scaling period. It is interesting to note that as scaling time progresses the detection element remains almost the same, in the neighborhood of 10% (Fig. 5 - 9). This time entirely depends upon the amount of a loose rock at the face or drift back posing the danger to people and equipment, which in turn depends upon geological characteristics of a formation and blasting practices preceding the scaling.

In order to compare the performance of the developed hydraulic scaler with the conventional hand held scaling bar and the pneumatic scaler developed by Laval University [1], the comparative plots have been prepared (Fig. 5 - 10 a, b, c). These plots show that the hydraulic prototype results are similar to findings by Laval University, which prove that assembled design is at least equally feasible to that of Laval University. The conclusion should be that the designed prototype of the hydraulically powered hand held scaler is worth pursuing further.

Table 5 - 3 Breakdown of the scaling cycle elements for the operators (hydraulic scaler)

Elapsed scaling time (min)	Type of scaling activity	Operator #1 John Cycle time component (sec)	Operator #2 Steve Cycle time component (sec)	Operator #3 Henry Cycle time component (sec)	Operator #4 Zeny Cycle time component (sec)	Average Cycle time (sec)
2	**Detection**	12.5	10	9	8.5	10
	Scaling	80	85	85	85.5	83.875
	Rest	7.5	5	6	6	6.125
4	**Detection**	13.5	14	11.5	10	12.25
	Scaling	79	79	80.5	82.5	80.25
	Rest	7.5	7	8	7.5	7.5
6	**Detection**	11.5	10.5	10.5	10	10.625
	Scaling	76	78.5	77	78.5	77.5
	Rest	12.5	11	12.5	11.5	11.875
8	**Detection**	11	9.5	10.5	9	10
	Scaling	74	76.5	75	78.5	76
	Rest	15	14	14.5	12.5	14

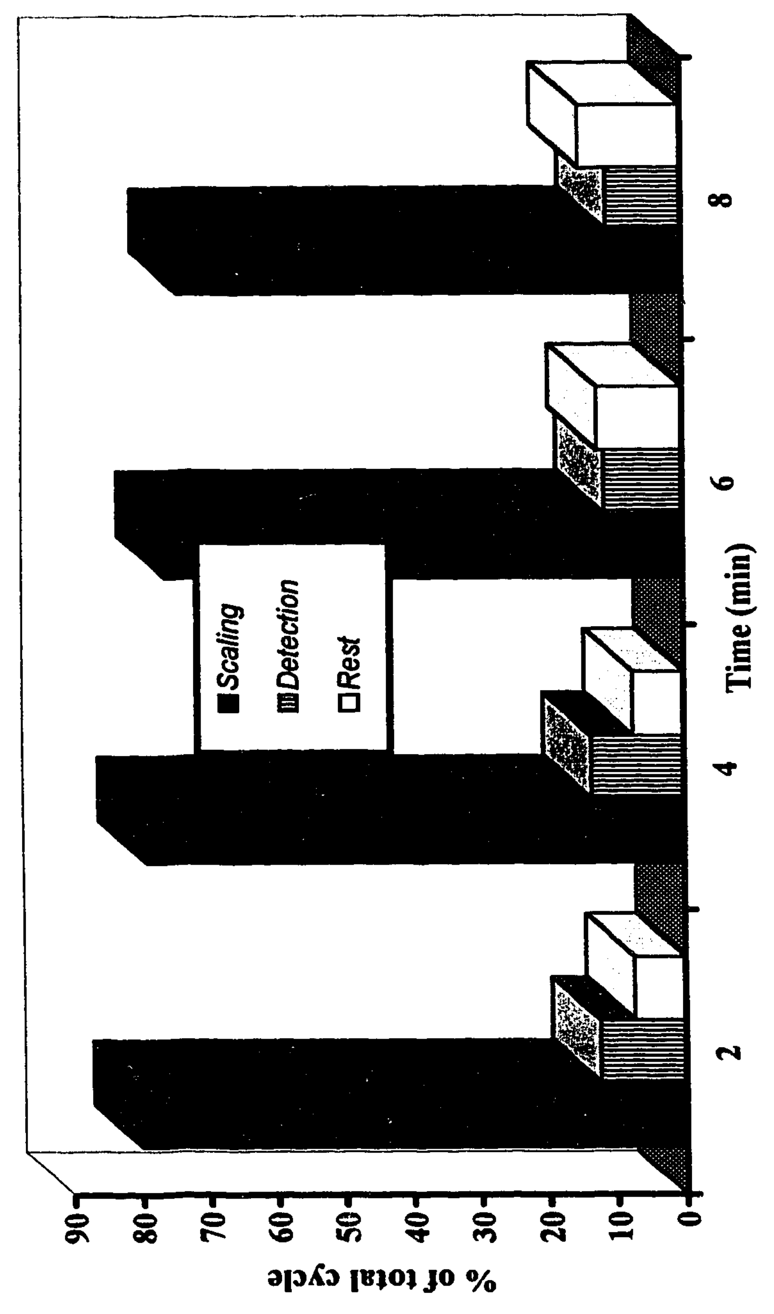


Fig. 5 - 5 Breakdown of the scaling cycle elements for the operator #1 John (hydraulic scaler)

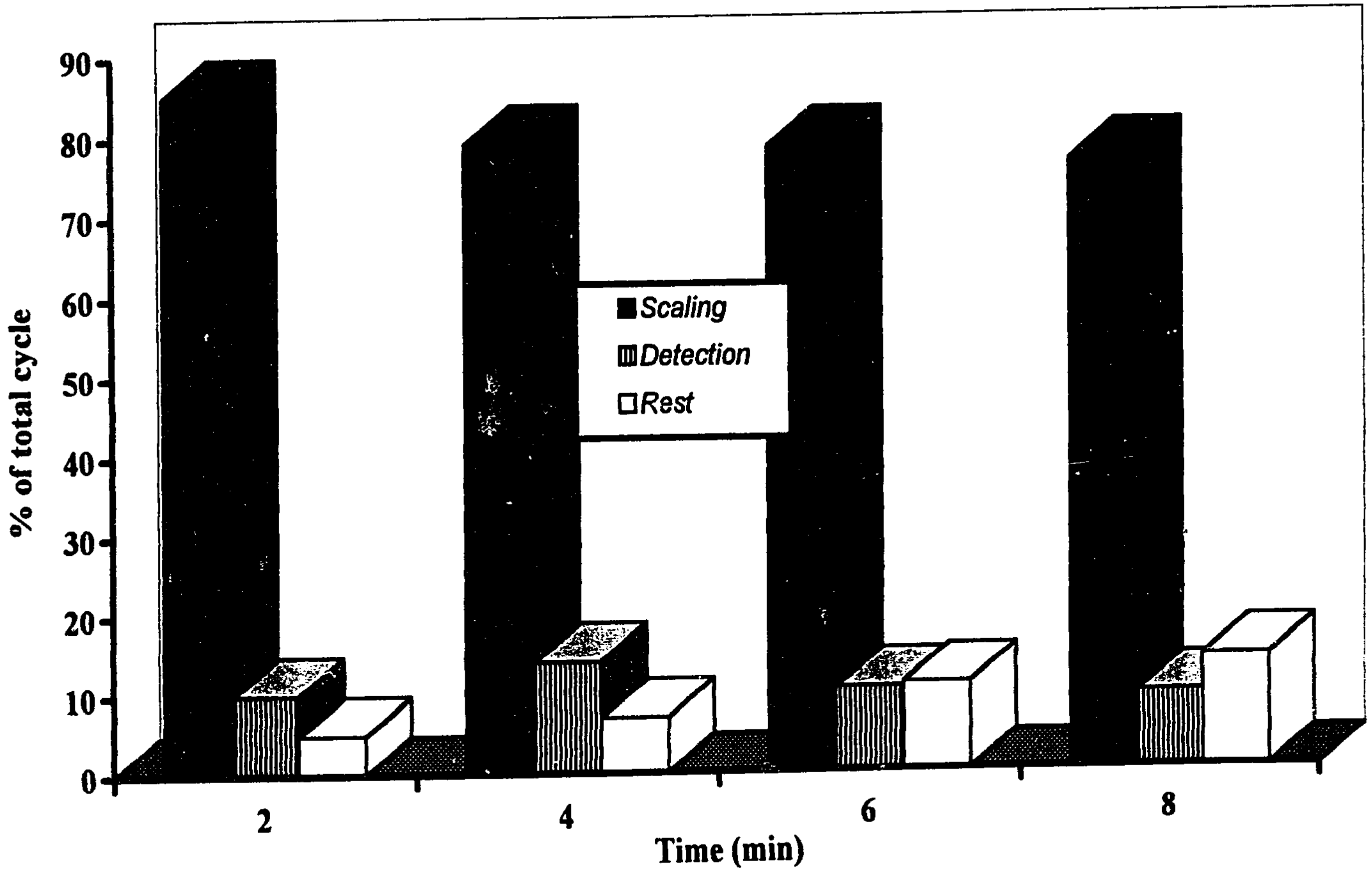


Fig. 5 - 6 Breakdown of the scaling cycle elements for the operator #2 Steve (hydraulic scaler)

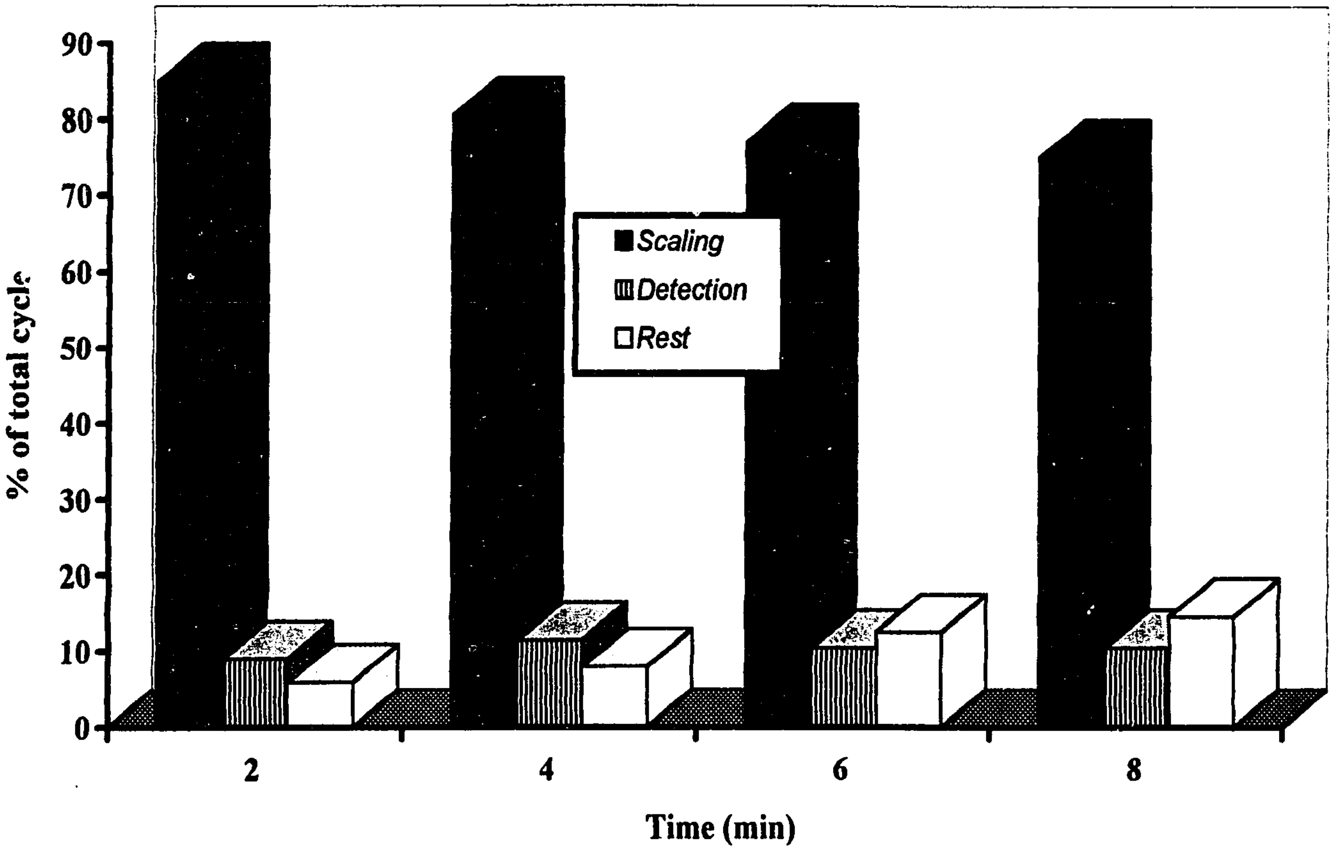


Fig. 5 - 7 Breakdown of the scaling cycle elements for the operator #3 Henry (hydraulic scaler)

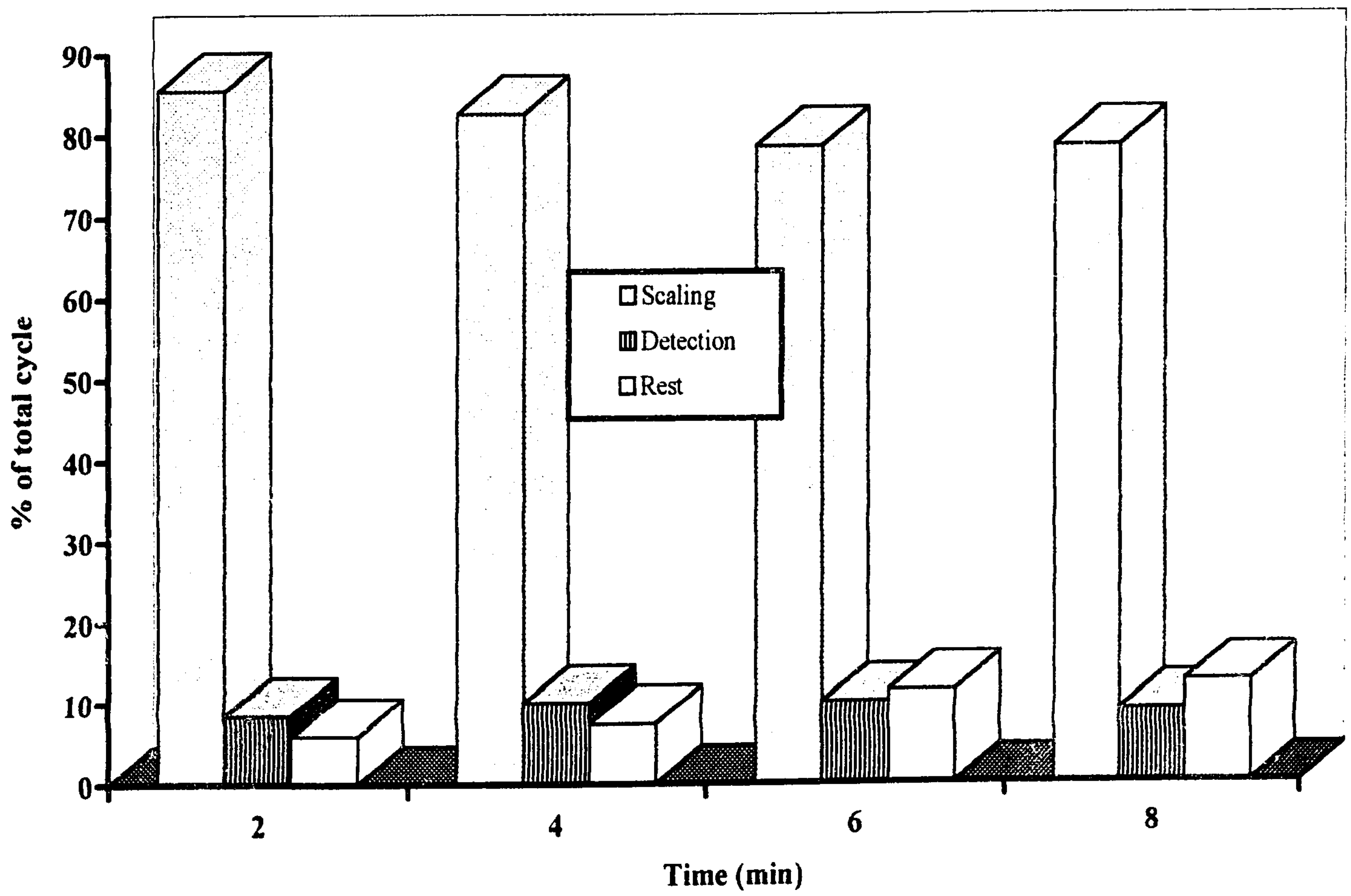


Fig. 5 - 8 Breakdown of the scaling cycle elements for the operator #4 Zeny (hydraulic scaler)

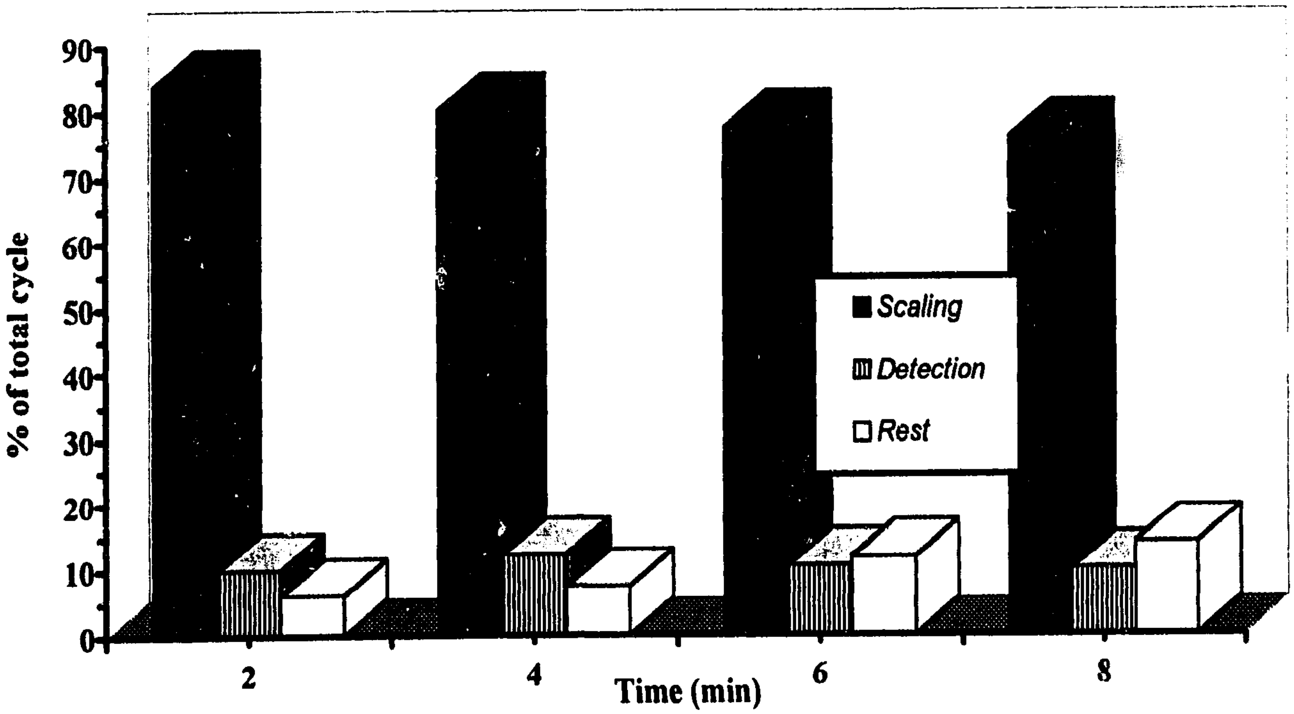


Fig. 5 - 9 Breakdown of the average scaling cycle elements for the four operators (hydraulic scaler)

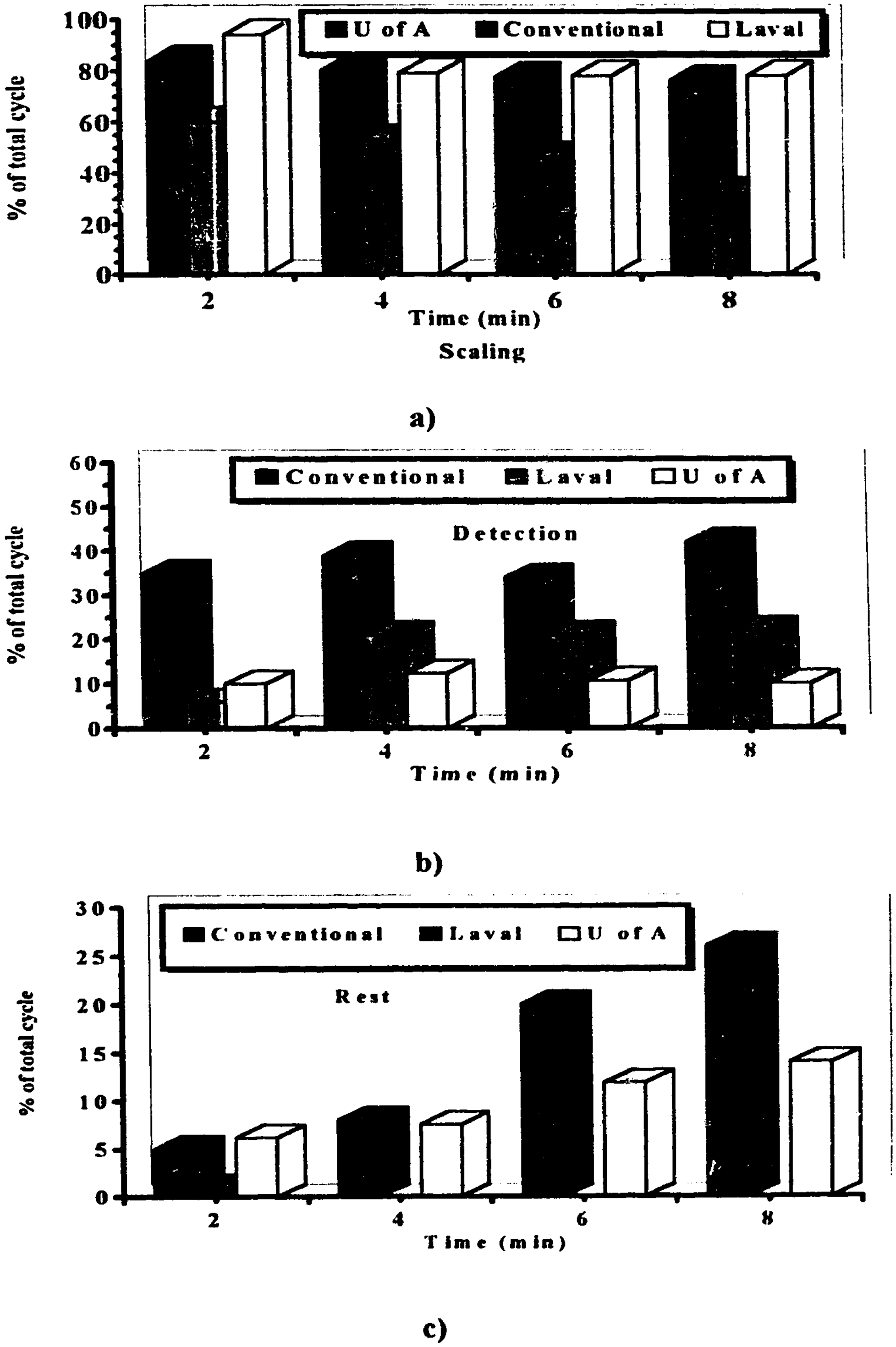


Fig. 5-10 Comparative brekdown of scaling cycle components for a U of A, conventional, and Laval scalers: a) scaling b) detection c) rest

5.3 THE MEASUREMENT AND ASSESSMENT OF THE OPERATOR'S EXPOSURE TO HAND TRANSMITTED VIBRATION DURING SCALER'S OPERATION

5.3.1 INTRODUCTION

It has been recognized that operators of vibration producing hand held tools such as the rock drill, impactor type scaler and chipping hammer, often suffer from tingling members and blanching of their fingers [15, 16, 18]. Depending on the type and place of work, vibration can enter one arm or both arms simultaneously, and may be transmitted through the hand and arm to the shoulder. The vibration of body parts and perceived vibration are frequently the source of discomfort and possibly reduced proficiency. Continued, habitual use of many vibrating tools has been found to be connected with various patterns of diseases affecting the blood vessels, nerves, bones and joints, muscles or connective tissues of the hand and forearm [1].

The vibration exposures required to cause these disorders are not known exactly, either with respect to vibration intensity and frequency spectrum, or with respect to daily and cumulative exposure duration.

The severity of the biological effects of hand transmitted vibration in working conditions is influenced by the following:

- the frequency spectrum of vibration
- the magnitude of vibration
- the duration of exposure per working day

- the temporary exposure pattern and working method, that is the length and frequency of work and the rest spells; whether the tool is laid aside or held idling during breaks, etc.
- the cumulative exposure to date
- the magnitude and the direction of forces applied by the operator through his hands to the tool or the work piece
- the posture of the hand, arm and body position during exposure (angles of wrist, elbow and shoulder joints)
- the type and the condition of vibrating machinery, hand tool or work piece
- the area and the location of the parts of the hands which are exposed to vibration

The severity of biological effects of hand transmitted vibration in working conditions may be influenced by:

- the direction of the vibration transmitted to the hand
- the method of working and the operator's skill
- any predisposing factors in the individual's health

The following factors may specifically affect the circulation changes caused by hand-arm vibration:

- climatic conditions
- diseases which affect the circulation

- agents affecting the peripheral circulation, such as smoking, certain medicines or chemicals in the working environment
- noise

5.3.2 VIBRATION MEASUREMENT PROTOCOL

It was decided that the measurement protocol to be used in evaluating the performance of the hydraulically powered hand held scaler should be based on the International Standard **ISO 5349 - 1986 (E) [18]**. Such an approach ensures that generally accepted measuring techniques are employed, and that the results obtained will be directly comparable with results obtained by other researchers who use the same standard. The protocol used is summarized as follows:

- **Direction of vibration:** The magnitude of vibration was reported in the direction of the percussion axis of the hydraulic scaler. The studies conducted by the University of Laval revealed that the vibration level in this direction reaches the highest magnitude [1, 15].
- **Magnitude of vibration**: The quantity used to describe the magnitude of vibration was (RMS) Root Mean Square acceleration. The acceleration value was expressed either in m/s^2 or in (dB). In the latter case, $\mathbf{L_h = 20 \log (a/a_0)}$, where, $\mathbf{L_h}$ is the acceleration level of the scaler in dB, $\mathbf{a}$ is the RMS acceleration in m/s^2, and $\mathbf{a_0}$ is the reference acceleration of 1 µm/s^2.
- **Frequency range**: The frequency range of the measuring and analysis system used was 6.3 Hz to 1,250 Hz. Due to the high peak acceleration associated with percussive tools, the accelerometer used had a resonant frequency above 25 kHz and a cross-axis sensitivity at least 20 dB below the sensitivity in the axis to be measured.

- **Mounting of vibration transducer**: Measurements were made in only one coordinate direction (the direction of percussion axis). A magnet and the ducting tape was used to enable the accelerometer type 4375 to be mounted in the appropriate direction. Figure 5 - 11 shows the mounting of the transducer in the direction of percussion axis of the scaler.

- **Quantities measured**: The International Standard ISO 5349 suggests that the acceleration can be reported either as a frequency - weighted value or analyzed in 1/3 -octave bands, However, the latter approach was used in this study, since the 1/3 - octave data is far more useful because its provides a clear record of the frequency content of the measured acceleration.

5.3.3 TESTING PROGRAM

The actual test data was obtained at the abandoned quarry near Jasper National Park. The basic test approach was to perform a series of scaling activities under essentially identical conditions. The hydraulic pressure and flow rate was maintained constant at 10.3 MPa and (1,500 psi) and 12.5 l/min (3.3 gpm). During the scalers's operation every effort was made to systematically employ a grip pressure and static thrust force representative of typical manual scaling activity. The scaler operator was bare - handed during testing. All data was tape recorded for later laboratory analysis. For each test condition, about 30 seconds of acceleration data was recorded.

5.3.4 DATA ANALYSIS

The data analysis consisted of determining overall vibration levels and 1/3 - octave frequency spectra. The overall vibration level for each test condition was obtained using a Bruel & Kjaer model 2511 vibration analyzer. In order to prevent the accelerometer from detecting high frequency vibration a B&K UA 0559 mechanical filter was installed. The data was digitized using a digital signal processing software package in order to obtain graphical output.

To complete the data analysis, 1/3 - octave frequency spectra were obtained. This analysis was limited to the second test series data since it was believed that this data fairly represented the performance of the hydraulic scaler. The analysis system consisted of a Bruel & Kjare model 2511 and was interfaced with the data acquisition system. Typical results of this analysis are presented in Figure 5 - 12 for the direction of percussion axis of the scaler.

5.3.5 DISCUSSION OF THE RESULTS

In order to compare performance of the tested hydraulic scaler with the conventional hand held scaler and the pneumatically powered scaler, the comparative plots of the 1/3-octave spectra have been prepared. Figure 5-13 shows that hydraulic prototype spectra differ somewhat in detail for each scaler type [illegible] results are clear significant reduction in acceleration level **occurs only below [illegible] Hz.**

Table 5 - 4 is a summary of rate of acceleration **a** $_{(h,w)}$ on the basis of the percussion axis, which is the dominant axis during scaling. The results revealed that the latency period with the hydraulic scaling bar is more than three times longer than for the work with an conventional aluminum or steel bars for a population of 50 %.

Table 5 - 4 Exposure time before finger blanching appears (ISO 5349)

Scaler	**a** $_{(h,w)eq\,4}$ **[m s^{-2}]**	**Latency period**	
		10th percentile	**50th percentile**
Conv. Aluminum	11.5	2.4	6.8
Conv. Steel	8.5	3.4	8.2
Pneumatic Laval	3.3	9.8	25
Hydraulic	2.0	12.0	>25

The exposure time is calculated based on one hour of scaling daily, using the equation $(a_{h,w})_{eq(4)} = \left(\frac{T}{T}\right)^{\frac{1}{2}} \times a_{h,w}$, where:

$(a_{h,w})_{eq(4)}$ is the energy equivalent acceleration for period of 4 hours

$(a_{h,w})_{(T)}$ is the instantaneus value of the weighted acceleration (measured value)

T_4 = 4 hours (the length of daily exposure on the basis of the dose-effect relationship in accordance with the stanard)

T is the length of actual daily exposure (T= one hour of scaling)

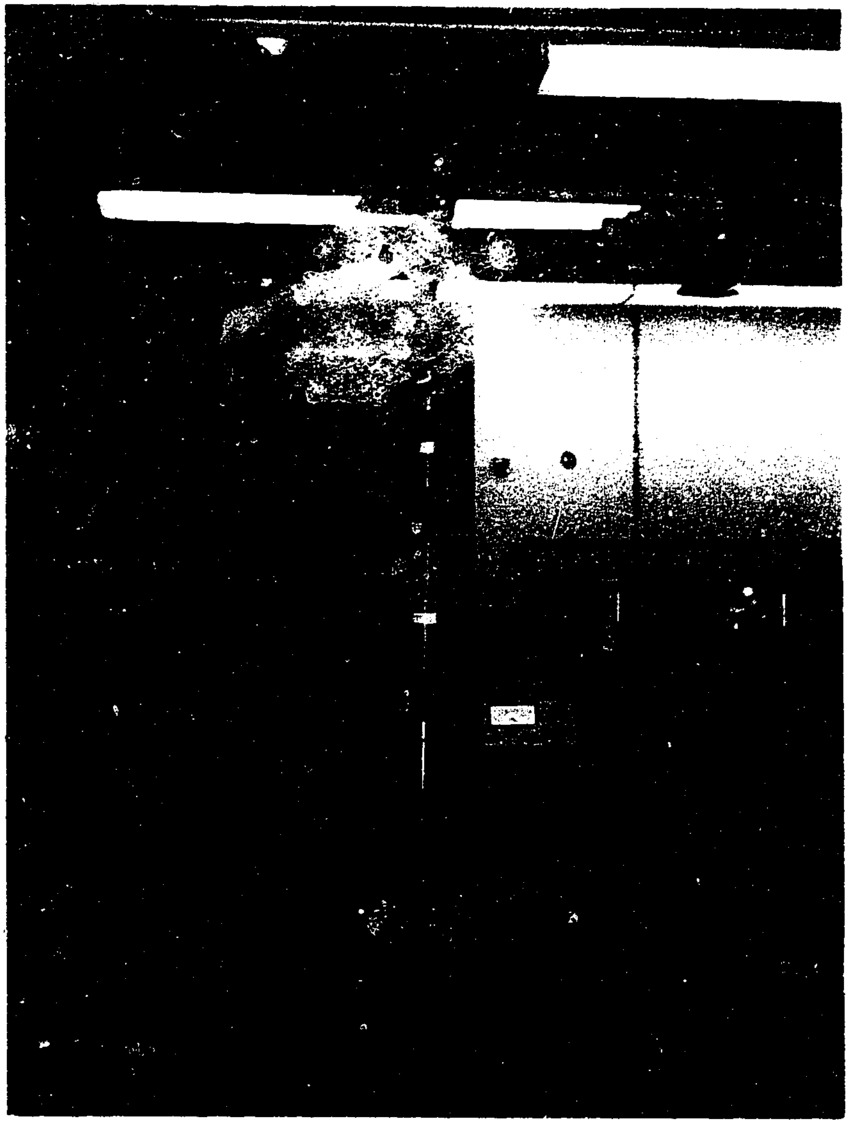


Fig.5-11 Mounting of vibration sensor

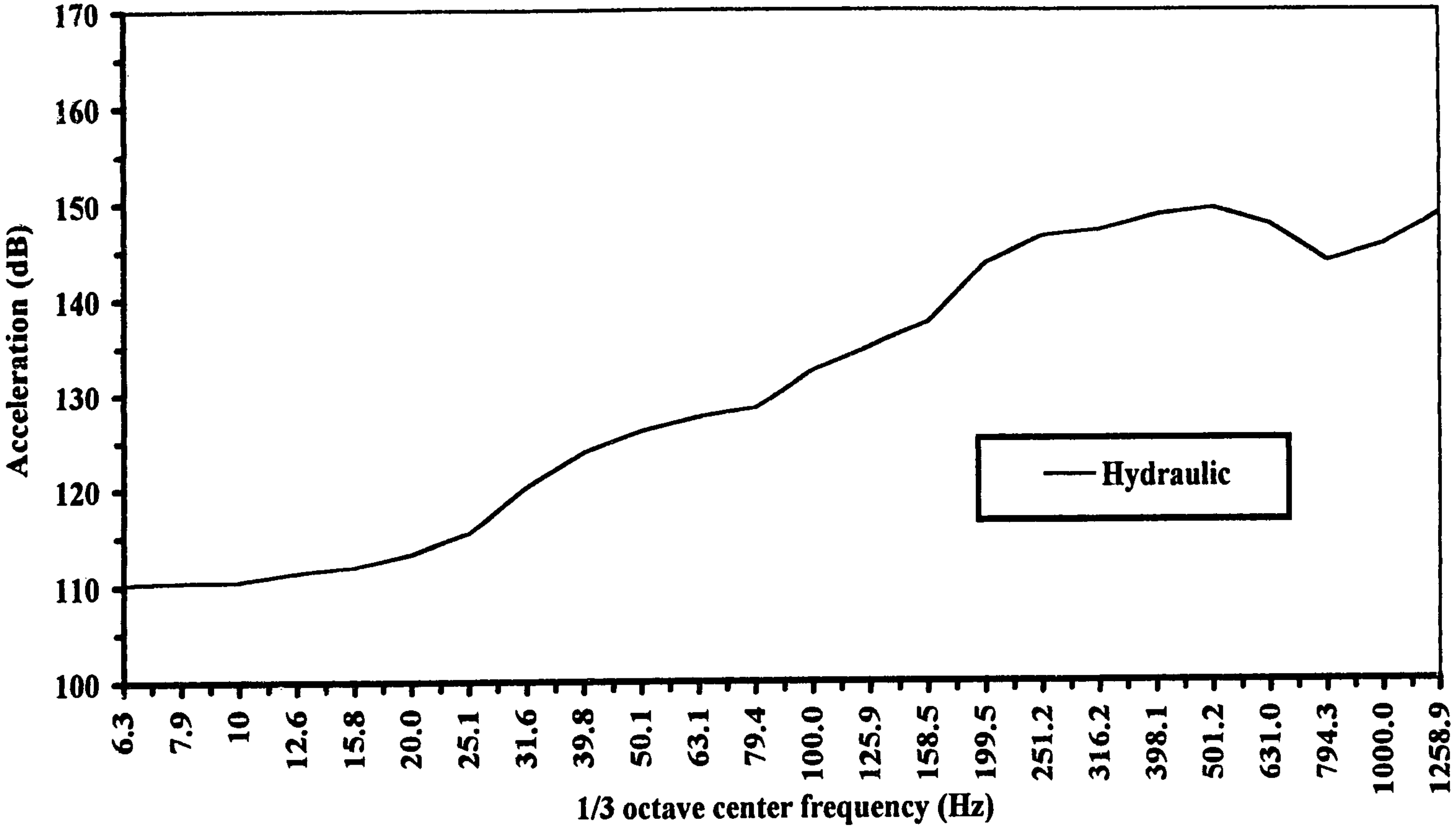


Fig. 5 - 12 One third octave band spectrum for the direction of percussion axis of the hydraulic scaler

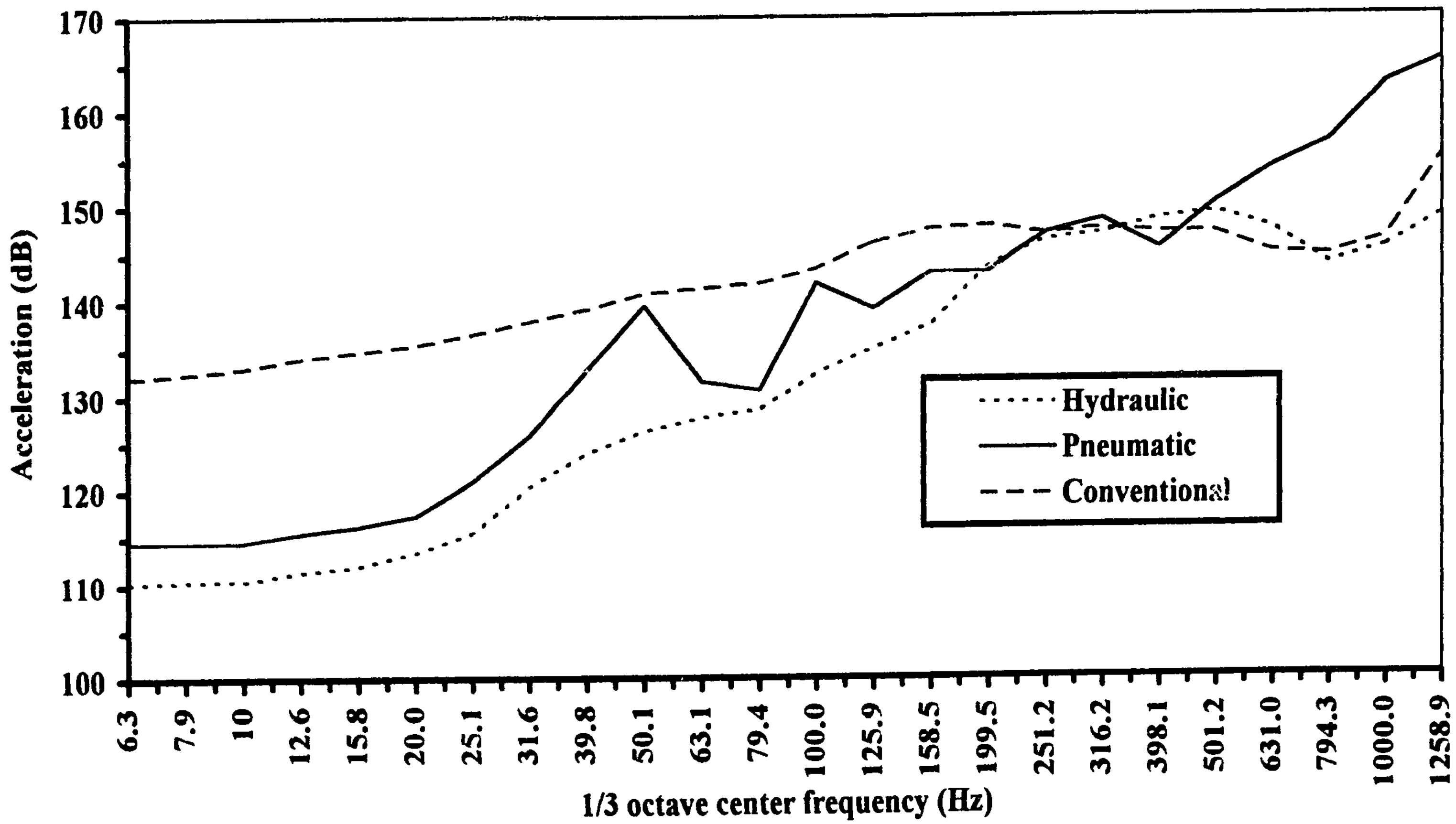


Fig. 5 - 13 One third octave band spectrum comparison for the three types of scalers

5.4 MEASUREMENT OF SOUND EMISSION FROM THE HYDRAULICALLY POWERED HAND HELD SCALER

5.4.1 INTRODUCTION

A secondary effect of operating equipment is the generation of sound. When the sound reaches an uncomfortable level, it is called noise.

Sound arises from the tools and equipment from different sources, and each source has its own sound level. The total noise thus consists of a large number of sound levels, and the designer tries to suppress them all.

The equipment noise can be very complex consisting of many sinusoidal components, described in terms of amplitude and frequency. Amplitude determines loudness of the sound, and frequency its pitch measured in cycles per second(Hz). A sound can consists of a single frequency or it can be composed of a number of frequencies. The environmental legislation as well as natural concern for the well being of the people requires that manufacturers pay particular attention to noise control.

The mining environment is filled with extensive distracting and/or damaging noise. Noise is any sound with an A band weighting sound pressure level greater than or equal to 80 dB(A). In underground mines the noise waves travel through the air and rebound off the drift walls, resulting in a lot of reflected noise. By regulations, mining companies are obligated to provide the lowest practical level of noise, specifically, noise should not exceed 85 dB(A) for an eight hour exposure time [21].

5.4.2 METHOD OF NOISE TESTING AND THE RESULTS

The instrumentation used to conduct the noise surveys included sound level meter and a sound analyzer. The sound level meter by itself reads an overall air pressure disturbance - the net result of air vibrations at many wave lengths. It consists of a microphone, an amplifier and a reading or recording instrument which registers the sound level in decibels(dB). The amplifier has three filters to accommodate it to the frequency sensibility of the ear 20 to 20,000 Hz range. The registered values are designated dB(A) dB(B) or dB(C) [8, 19].

Instructions on how to carry out the measurements are part of the international codes and national test codes. In the absence of testing codes in the Mining Act, the Occupational Health and Safety Act is usually followed.

In the province of Alberta, Noise Regulation in Alberta Regulation 314/81 [21] no testing procedure is outlined. The regulation specifies the type of sound level meter and the occupational exposure limits in the industrial environment.

The noise testing performed on the prototype scaler included sound pressure level measurement in spherical free field. It was decided that the measurement protocol to be used in evaluating the sound pressure level should be based on the U.S. Environmental Protection Agency (EPA) (1978) procedure for portable air compressor noise emission standard [20]. The standard procedures were used to convert sound pressure level to the sound power level. Such an approach ensures that generally accepted measuring techniques are employed.

The average sound pressure level is calculated according to the following formula (there are five measurement positions, four at 7 metres from the geometric center of the scaler and one, 7 metres above the scaler):

$$\mathbf{SPL = 10 \log 1/5 \left(\sum 10^{L_i/10}\right)}$$

where

SPL = the average A-weighted sound presure level in decibels (dB)
L_i = the A-weighted sound pressure level at i_{th} position

Figure 5 - 14 shows the general instrument array for tests performed in accordance with recommended EPA testing procedure. The EPA has opted to use the A weighted sound pressure level with dB(A) as the descriptor of noise for environmental impact considerations, referred to in the Alberta Regulation 314/81 as the A weighted network. The sound power level SWL was calculated using the measured data at five points on the sphere according to the standard equation:

$$\mathbf{SWL = SPL + 10 \log 4 \pi r^2}$$

where

SWL = Sound Power Level (dB)

r = measurement location -radius of 7 m from the geometric center of the scaler

During the testing the power pack was eliminated as an additional source of noise by placing it outside of the testing room.

The sound level meter used was the General Radio 1565-B, Type 2 ANSI, SI.4 1971 & R123 1961, also conforming to CSA Standard Z107.1-1973. The results of the measurements are shown in Table 5 - 5, and measured using the A weighted network and reference pressure of 20 micropascals.

Table 5 - 6 shows the occupational exposure limits as per Alberta Regulation 314/81. For the measured mean sound pressure level in theTable 5 - 5 of 85 dB(A), the maximum permitted exposure duration for the tested hydraulic scaling bar is 4 to 8 hours per day. Under operating conditions in a mine this time is not expected to surpass two hours per day.

Table 5 - 5 Results of the sound pressure level measurements

Test No.	Position (1)	Position (2)	Position (3)	Position (4)	Position (5)	SPL 5 Point dB(A)	SWL dB(A)
1	88	86	84	83	83	85.3	113.2
2	87	87	84	83	83	85.2	113.1

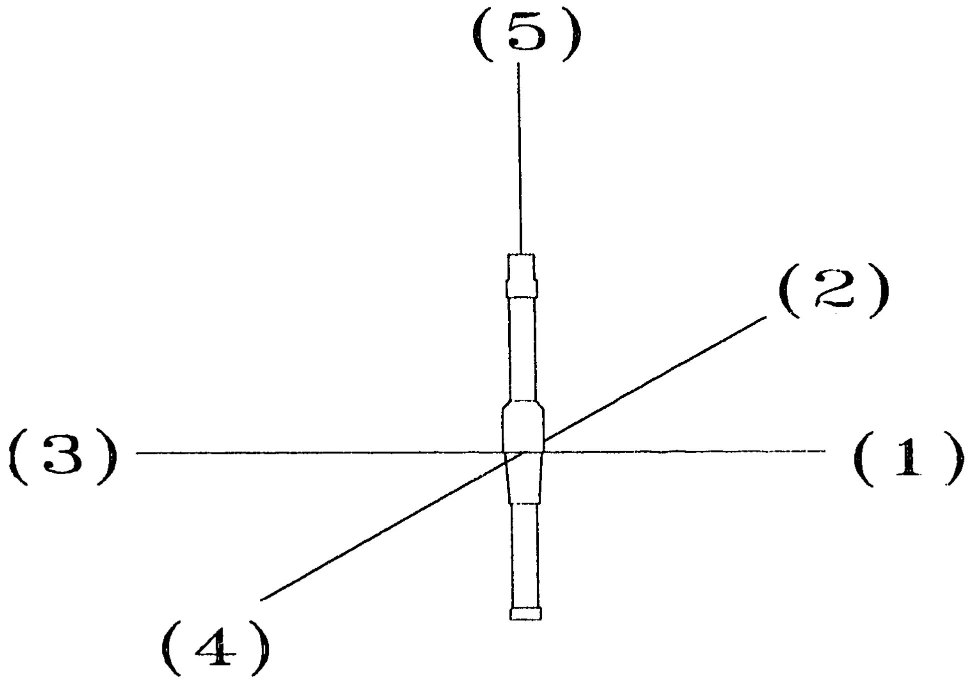


Fig. 5 - 14 Location of the sound pressure sensor according to the EPA portable compressor noise emission standard

Table 5 - 6 Occupational Exposure Limits, Alberta Regulation 314/81[18]

Sound Level (dBA)	Maximum Permitted Duration (hours/day)
80	16
85	8
90	4
95	2
100	1
105	1/2
110	1/4
115	1/8
greater than 115	0

CHAPTER SIX

6.0 CONCLUSIONS

The following conclusions may be drawn from this study:

1. The major factors affecting the ability of the developed hydraulically powered hand held scaler are:

    a) the impact energy of the hydraulic hammer

    b) the total weight of the scaler

    c) the shape of the scaling moil

    This study gave indication of the significance of all the factors above. Based on this study the final decision can be made regarding development and manufacturing of the efficient and reliable hand held scaling tool.

2. It has been demonstrated in the laboratory and in the field that the developed prototype of the hydraulically driven hand held scaler is a feasible alternative to presently used conventional or pneumatic scaling bars in underground hard rock mining.

3. The field tests of the developed prototype scaler revealed that:

    a) the physical stress involved during scaling operation is significantly reduced

    b) the enormous effort required for penetration is virtually eliminated

    c) over a similar scaling area, the hydraulic scaler requires less energy

d) the subjective evaluation by the testing team members, confirms that the physical effort required is significantly reduced

4. The results obtained from the sound emission testing shown that, when overall decibel level is considered, the performance of the prototype of the hydraulically powered scaler is satisfactory, and the maximum permitted exposure duration (based on the Alberta Regulations) would be in the range of 4 to 8 hours per day.

5. Based on the guidelines provided by ISO 5349, the vibration exposure resulting from the use of the prototype of the hydraulically powered scaler was significantly reduced below about 400 Hz. Above this frequency level, the tested hydraulic scaler shows similarity in 1/3 - octave spectra with the conventional hand held scaler and the pneumatically powered scaler.

6. The uniqueness of the design of the prototype scaler's power source (hydraulic) will allow this device to be powered from the existing underground mining equipment.

7. Based on the previous experience, the first stage angle of 11^0 of the scaling moil has been adapted during the initial design. In order to optimise the shape and stress distribution in the moil during the scaling, it is recommended that further research be conducted before manufacturing the final version of the scaler.

REFERENCES

[1] Planeta, S.,(1995), *Progress in scaling in underground mines*, Mining Engineering, February 1995, pp 183-188.

[2] Marras, W., Lavender, J. P.,(1988), *Risks of hand tool injury in US underground mining from 1978 through 1993, Part II: Metal - nonmetal mining*, Journal of Safety Research, Vol. 19, No. 3, pp. 115 - 124, fall.

[3] Marras, W. S., Lavender, S. A.,(1991), *Effects of method of use, tool design, and roof height on trunk muscle activities during underground scaling bar use*, Ergonomics, Vol. 34, No. 2, pp. 221 - 232, February.

[4] Ludwig, G.,(1988), *Scaling and hang-up removal*, Task I of the Canada/Manitoba Mineral Development Agreement, INCO Ltd..

[5] Goris, J. M., Conway, J. P.,(1987), *Grouted flexible tensors and scaling investigations*, 13th Mining Congress Exposition, Sweden.

[6] *Mining Source Book, 1995*, Canadian Mining Journal.

[7] Broman F., Johansson K. A., (1987), *Improving Mining Operation by Electrification*, 13th Mining Congress, Stockholm, Sweden.

[8] *Atlas Copco Manual*, Third Edition, Sweden 1978.

[9] Hustrulid, W. A.,(1982), editor, *Underground Mining Methods Handbook*, SME of AIME.

[10] Grantmyre, I., and Hawkes, I.,(1975), *High Energy Impact Rock Breaking*, Canadian Mining and Metallurgical Bulletin, July, p. 8.

[11] Bauer, E. E.,(1994), *High - energy hydraulic hammer ratings, Mining Engineering*, July 1994, pp. 656 - 658.

[12] *Joy Corporate Report, Project 974*, January 1980, 177 pp.

[13] Fisher N. J., Pettigrew P. J., Smith P. J., Rod B. H., (1991), *Development of Rock Sample Characterization and Surveying Techniques*, Research Company, Atomic Energy of Canada Limited.

[14] Le Grand Rupert, Senior Aassociate Editor, *The New American Machinist's Handbook*, Published by McGraw-Hill Book Company.

[15] Knight, G.,(1990), *Vibration Exposure Studies on Jack-Leg Drilling at Opemiska Mine*, Report 90-35. Canadian Centre for Mineral and Energy Technology, Ottawa.

[16] De Souza, E. M., and Moore, T. N.,(1991), *Quantitative vibration evaluation of modified rock drill handles*, Mining Engineering, Vol. 43, No. 3, March 1991, pp. 319 - 324.

[17] De Souza, E. M., and Moore, T. N.,(1991), *Discussion, Quantitative vibration evaluation of modified rock drill handles*, Mining Engineering, September 1991, pp. 1170.

[18] International Standard ISO 5349 - 1986(E), *Mechanical Vibration Guidelines for the Measurement and Assessment of Human Exposure to Hand - Transmitted Vibration.*

[19] Gibbs Charles, W.,(1971), editor, *Compressed Air and Gas Data*, Ingersoll - Rand Company, Second Edition.

[20] Gray Larry, (1977), *Portable air compressors, how do you measure their sound emissions?*, Compressed Air Magazine, May.

[21] Occupational Health and Safety Act, Noise Regulation, Alberta Regulation 314/81 with amendments up to and including Alberta Regulation 439/81., Published by Queen's Printer for Alberta.

[22] Pettigrew, M. J., et al.,(1989), *Development of an automated tool for detection and quantitative assessment of loose rock in hard rock mines,* AECL project report, May.

[23] Staley W.W., (1949) *Mine Plant Design,* McGraw-Hill Book Company.

[24] Hanson, D. R.,(1985), *Rock stability analysis using acoustic spectroscopy,* USBM Report RI 8950.

[25] Leighton Fred, (1983), *Growth and Development of Microseismics Applied to Ground Control and Mine Safety,* Mining Engineering, August 1983, pp. 1157 - 1162.

APPENDIX A

STOPING DETAILS IN UNDERGROUND HARD ROCK MINING

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Agnico Eagle,Laronde	Transverse open stope	1 Tamrock Solo H1006RA 1 Tamrock Data Solo H1006RA Cubex 5200	4" 6.5'x6.5'	ANFO 1.5 lb/ton	By hand from lift	3.5 & 6 cu.yd some with remote control	Normet cassette Tractors
Algoma McLeod	Blasthole open	2 Boart BC12 carriers I-R S36 drills 1 I-R CMM DHD (for slot)	2.25" 6' burden 4.25" 10'x10'	ANFO 0.3 lb/ton ANFO 0.3 lb/ton	By hand	JC JS500	GM 3/4 t pick-up GM 3t trucks
American Barrick Halt-McDermott	Longhole (4") Longhole (21/8")	2 Cubex IHD 2 Boart longhole wagons	4" 8'x8' 2 1/8" 3.5'x8'	ANFO Minerite II	By hand By hand	El or diesel LHD Copco LM56 slusher	Locos or LHDs Locos or LHDs
Aur Resources Dumont	Dev't Waste fill	Jacklegs	1 1/4"		By hand from lift	JC JS220	4.5 t locos
Aur Resources Ferderber	Hyd. Cut & fill	Jacklegs	1 1/4"		By hand from lift	LM56 3 drum el. slushers	Fiat tractor
Aur Resources Norlartic	Shrinkage Longhole	Jackleg 1 GD airtrack Contract	1 1/4" 2"	ANFO ANFO	By hand By hand	Slusher & chute, ST2	Fiat tractor
Bethehem Goldstream	Short hole Longhole	2 Tamrock longhole 2 Tamrock 2-boom jumbos	2.25" 1.2m x1.2m 1.75" 0.76 mx.90m	ANFO 1.8 lb/ft Watergel 0.55 lb/ft	By hand By hand	JC JS400 JC JS400	Toyota landcruiser

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Brunswick Mining & Smelting	Mech.Cut & Fill Open stope	8 CMS IHD 2 I-R IHD	41mm 1.2mx1.8m 127mm 3mx4m 3.3mx4.3m	ANFO 0.5kg/t ANFO 0.5kg/t Slurry 0.7kg/t Emuls. 0.7kg/t	By hand from muckpile or lift	8 cu.yd LHD Cat 966 loaders 30 t trucks	Eaton carriers
Cambior Beliveau	Blasthole	1 CMS longhole	6.5" 3.2mx3.2m	ANFO 0.8 kg/t	By hand	ST 3.5 ST 5	
Cambior Chimo	Longhole Longhole	2 McLean IHD 2 BBC120	4.5" 8'x8' 2 1/8" 4'x4'	Anfo 0.61kg/t Anfo 0.41 kg/t	By hand	EST3.5 ST7B	Bombardier tractor
Cambior Mouska	Shrinkage	Stoper & Jackleg	1 1/4"	Anfo	By hand	Cavo 320 slusher	
Cambior Pierre Beaushemin	Open shrinkage Shrinkage	Atlas Copco BBC120 Secan 250 jacklegs	5cm 3.2 m	Gelatins & amonium nitrate	By hand By hand	30 HP air slusher Copco LM56	none none
Canadian Salt Co. Pugwash	Room&pillar	2 Joy SD8 2 boom jumbo	1 3/4" 4'x5.5'	Amex	Gradal G660 C By hand,P&H crane	Cat 980 C	Mercedes 1117/48 Ford F250
Cape Breeton Dev't. Lingan	Longwall retreat	Anderson AM500 elec.hydrl. shearer				Dowty Meco cutter&stag eloader	
Cape Breton Dev't. Phalen	Longwall retreat	AM500 shearer				Dowty cutt. stg.loader	

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Cape Breton Dev't Prince	Longwall retreat	Eickhoff EDW250-2L2W shearer 740 HP				H&B Panline face conv.	
Cluff Mining	Mech.undercut &fill	Jacklegs	28mm	Lomex 0.85 kg/t	By hand	CT500HE Elec. LHD	Mine Karts
Cominco Polaris	Sublev. longhole	2 GD airtracks 2 Tamrock Solo	76 mm 1.8mx2.0m	1.0 lb/t	By hand from lift mech.scaler	ST8A ST8B	Dux scissor lift Dux crane truck
Cominco Snip	Slush.Cut & fill Mech.Cut & fill	Secan S250 jackleg Tamrock Minimatic 1boom jumbo	1 3/8" 3'x3' 1 3/4" 4'x4'	Amex,Geldyne Xactex 1.4kg/m^3	By hand	Elc.10HP 3 drum slush. JCI400M JCI250M	none Hiab truck Toyota 4WD
Cominco Sulivan	Slush.Slot&shell Mech.Slot&shell Longhole open	4 Copco 120 bar & arm 8 Copco 99 bar & arm 6 GD Airtrack 1 I-R IHD 1 I-R IHD	2-2 1/2" 2-2 1/2" 2-2 1/2" 4" 6" 4" 2-2 1/2" 2 1/2" 2 1/2" 2 1/2"	ANFO 0.45-0.5 lb/t	By hand	Slushers & LHD	6 TD TMP FWD 19 Toyota BJ75 9 Getman A64 (lube crane & platform) 1 JC Ensign 300 Hiab 1 TD TMP FWD
Curragh Faro	Mech.Cut & fill	Tamrock Jumbos, 1of each 1 boom, 2 boom, 3 boom 1 Tamrock rock bolter 2 Jacklegs, 2 stoper	2 1/4" 30'x30'	ANFO, Cilgel Xactex	By hand from lift	3 ST8 1 JCJS220 3 JC JDT426	2 Kubota tractors 1 Hiab truck

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Deak Resources Kerr	Longhole	Boart buggy	2 1/4" 4'x5'	ANFO	By hand	JC JS100	
	Shrinkage	Stoper	1 1/4" 1'6"x1'6"	ANFO	By hand	Chute	
Dickenson White	Cut & fill	Secan S250 stopers & jacklegs Tamrock H107L jumbo Eimco Secoma Quasar	1 1/4" 2'6"x2'6" 1 1/2" 0.75mx 0.75m	Amex	By hand By hand	2-drum slushers Cavo 310 JC JS100 JC JS220	
Echo Bay Lupin	Centre zone sublevel open	Tamrock Data Solo	3 1/2" 2mx2m	ANFO 0.5 kg/t	By hand	JCI 600M ST6C	Toyota,landcruis Mine Cat tractors
	West zone sublevel open	Tamrock H506 Micro Solo	2" 0.75mx 0.75m	ANFO 0.85 kg/t	By hand	JCI 600M ST6C	
Falconbridge Gold Hoyle Pond	Cut & fill	Secan stopers	Various 2'x2'	ANFO 1.6 lb/t	By hand	Slushers LHD 1.5 cu.yd	Ford tractors Mine Cart
Falconbridge Craig	Ramp access Cut & fill	1Copco 2-boom jumbo 1GD 2-boom jumbo	1 3/4" 3'6"x3'6"	Nilite.Tredyne 2.4 lb/t	By hand from scissor truck	JCI 600 Toro 500	Toyota, Getman scissor truck
Falconbridge Fraser	Blasthole	Mission IHD Data Solo	6.5" 10'x 10'.4.5" 8'x8'.	ANFO 0.9 lb/t	By hand	5,6,&8 cu.yd LHD 5,&8 cu.yd	Scissor lift trucks
	Cut & fill	GD Mark III jumbo	1.75"	ANFO 0.86lb/t	Getman scaler	LHD	Toyota Landcruisers
Falconbridge Kidd Creek No.1	Blasthole	3 I-R CMM II 3 Mission 1 Cubex IHD	140 mm 15mx12m 114 mm 12'x9'	Variable	By hand from hydraulic scaler	ST8 Toro 400D	Ford tractors Kubota tractors Toyota Landcruisers

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Falconbridge Kidd Creek No.2	Blasthole	3 I-R CMM II 3 Mission 1 Cubex IHD	140 mm 5mx4m 114 mm 4mx3m	Variable	By hand from hydraulic scaler	ST3.5 ST5 Toro 400D	Ford tractors Kubota tractors Toyota Landcruisers
Falconbridge Kidd Creek No.3	Blasthole	Contractor	89 mm		By hand		Kubota tractors
Falconbridge Lockerby	Bulk VCR	2I-R IHD 1 Atlas Copco IHD 1 Atlas Copco Simba	6.5" 7'x10' 3" 6'x5'	Water Gel Packaged slurry		JC 5&6 cu.yd LHD	JC PC carrier Ford tractor JC scissor lifts Miller Mine carts
Falconbridge Onaping	Mech. Cut & fill	1 Copco 2-boom jumbo	1.5" 2'6"x2'6"	Amex 1.0 lb/t	Tamrock scaler or by hand from scissor lift	ST2 ST3.5	Marcotte scissor trucks, Miller Mine Cart
Falconbridge Strathcona	Mech. Cut & fill postpillar	Long Toms	1.25"	1.0 lb/t	By hand	LHD 4&5	
	Mech. Cut & fill narw.vein	1-boom el.hyd.jumbo	1.5"	1.0 lb/t	By hand	LHD 1& 2.5 cu.yd.	
	Blasthole	IHD & blasthole drills	6.5"	0.75 lb/t	By hand	LHD 4&5	
Heath Steele Mines B Zone	Blasthole open	2I-R CMM2 DHD 1Boart BC12	64 mm 1.5mx2.1m 130 mm 3.35mx 4.3m	Nilite, Tovex& emulsions 0.80 kg/t	By hand	ST6B JC JS500	Marcotte flat deck Marcotte scissor lift
Heath Steele Stratmat	Blasthole open	1Boart BC12 1Atlas Copco 812	64 mm 1.5mx2.4m 89 mm 2.4mx2.4m	Nilite, Tovex& emulsions 0.80 kg/t	By hand	ST6B	GM pickup truck Marcotte scissor lift

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Hemlo Gold Golden Giant	Blasthole	2 Tamrock Data Solo Boart under contract	64&89 mm 1.5mx1.8m 1.8mx2.4m	ANFO & Magnafrac	By hand from scissor lift	ST8	Hiab
Hudson Bay Callinan	Mech.Cut & fill Open stoping	3 Copco 3-boom jumbos 1Copco el.hyd.longhole drill H254	1.75" 3'x3' 2" 6'x6'	ANFO ANFO & Iremite	By hand By hand	Toro 400D Toro 400D	Toyota Landcruiser Casette carrier
Hudson Bay Namew Lake	Blasthole drift & fill open from raises	Tamrock ring drillBBC120 Boart wagon	2.5" 3'x3' 2" 4'x4' 2" 4'x4'	1.5 lb/t	By hand from sleigh	ST5H	Getnan scissor truck
Hudson Bay Ruttan	Blasthole hyd.fill	4Cubex 6200	4.5" 8' burden 12' spacing	Nilite. Lonite Tovan L	By hand from lift	JC JS800 Toro D500 ST8	JC JUT
Hudson Bay Stall Lake	Mech.Cut & fill	JC MJM20B 2-boom jumbo	1 3/8" 3'x2'6"	ANFO	By hand	JC JS220 ST3.5	Miller Mine Carts
Hudson Bay Trout Lake	Cut & fill Blasthole retreat	3 Tamrock 2-boom jumbos JC 2-boom jumbo 2 Simba 254	1.75" 3'x3' 3" 8'x6'	ANFO Iremite 0.75 lb/t ANFO Powermite & Iresplit 0.68 lb/t	By hand from muckpile	Toro 35D Toro 40D Elphinstone 9 cu.yd Toro 8 cu.yd	Toyota 1t Eimco utility Normet Getman
Inco Birchtree	Blasthole	CMS CD360 IHD GD Boart wagon	4.5" 8'x10' 2.5" 6'x8'	ANFO Lomex	By hand	ST2 JC JS350 JC JS500 JCI 400	

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Inco Copper Cliff North	Vertical retreat & blasthole	CMS CD90 IHD	6.5” 10’x10’ 8” 12’x12’	Canamex 550 1.3 lb/t	By hand	ST8	Hydr.second.drill Cat D4 dozer Bobcat
Inco Copper Cliff South	Vertical retreat & blasthole	CMS Go60 CMS CD90 CMS CD360 CIR IHD	6.5” 10’x10’ 8’ 15’x15’		By hand	ST8E	Jeep Cat 1206 grader
	Crown pillar	Data Solo Boart hyd.IHD	6’x6’		By hand	ST8 JC JS500	
Inco Crean Hill	Bulk VCR	CMS CD90 IHD	6.5” 10’x10’ 8.5” 15’x15’	Watergel 1.3 lb/t	By hand from scissor lift	EST8A	Bobcat Kubota
Inco Creighton No.3	Blasthole VCR	Simba	6.5” 10’x10’	ANFO 0.8 lb/t	By hand	Eimco 918	Hydr.second.drill Cat D4 dozer Boom truck
	Apex recovery	CMS CD90 CMS CD360	6.5” 10’x10’	ANFO 0.8 lb/t	By hand	ST8	
Inco Creighton No.9	Vert. retreat	CMS CD90 CMS CD360	6.5” 10’x10’	Anfo, Watergel 0.8-1.2 lb/t	By hand	JC JS500E ST6C	Dies.&el.scissor lifts
Inco Frood	Sublevel caving	GD 2-boom jumbo	2.5” 3.0” 3’6”x5’	ANFO 0.8-1.2 lb/t	By hand	ST8	Diesel scissor lifts
	VRM	Inco Go60 IHD CIR IHD	6.5” 10’x10’	Watergel 0.8-1.2 lb/t	By hand	JC JS500	Toyota 4WD Hyd.secndry.drill

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Inco Levack	Cut & fill VRM Uppers retreat	Airleg Inco Go60 IHD,CIR IHD Joy IHD GD fan drill Boart drills	1.25" 2'x2' 6.5" 10'x10' 2 1/8" 3'x3'	ANFO Watergel ANFO	By hand By hand By hand	3hp slusher ST2 CL contin. Mucker ST5 remote	Diesel scissor lift Kubota backhoes
Inco Little Stobie	Sublevel caving Blasthole	Elec-hyd u-hole drill CMS CD360 IHD	3.5" 5'x6' 6.5" 10'x10'	ANFO 0.8-1.2 lb/t	By hand By hand	JC JS500 JCI 600	Hyd. Drill, JUT Teledyne scissor lift Getman lube truck
Inco Lower Coleman	All methods	2-boom elec jumbos	1.75" 31"x31"	ANFO	Byhand from scissor lift	ST8 EST8B	Toyot 4WD Mechanics truck
Inco McCreedy West	VRM	Atlas Copco	6.5" 10'x10'	Watergel T600 0.2-1.2 lb/t	By hand	ST8	Russel bus JC JDT426
Inco Stobe	Sublevel caving VRM Blasthole	Tamrock Data Solo CMS CD90 IHD CMS CD90 IHD CMS CD360 IHD	4.5" 7'x8' 6.5" 10'x10' 6.5" 10'x10'	ANFO Watergel 1.3 lb/t Emulsions 1.5 lb/t	By hand By hand By hand	ST8	Hyd secn drill Diesel scissor lift Toyota 4WD Bulk Anfoloader Emulsion loader
Inco Thompson	Vertical block	CMS CD360 Mission	4.5" 7'x7' 6.5" 10'x10'	ANFO Lomex Aquamex	By hand	ST2 JC JS350 JC JS500 JCI 400	Ford tractor Toyota mancarrier
LAB Chrysotile Bell	Block caving	2Teledine 1-boom jumbos	1.25" secd drilling only	Tovex 0.07 lb/t	By hand from ground	Eimco 913	MF tractors Ford tractors

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Lac Minerals Doyon	Shrinkage	Jackleg	1.25" 1.6mx1.7m	ANFO Powmx 0.3 kg/t	By hand	JC JS350	White Fiat John Deere tractors
	Longhole	2 Atlas Copco BBC120	2.5" 1.5mx1.5m	ANFO 0.65 kg/t	By hand	JC JS600	
	Transverse	3 Cubex 1 Data Solo	4.5" 2.4mx2.4m	ANFO 0.5 kg/t	By hand		
Meston Resources Joe Mann	Longhole	BBC120	2 1/8" 4'x3'	0.91 kg/t	Cablebolted	Eimco 22 Eimco 21	Fiat cars Loco & mine Fiat cars
	Shrinkage	Jackleg & Stopers	1.25" 2'x2'	0.91 kg/t	By hand		
Mines Selbaie	Blasthole	2 I-R CMM1 1 I-R CMM2 2 Boart carriers S86 drill 1 Atlas Copco longhole	6.5" 3.3mx3.3m 2" 1.2mx1.2m	ANFO Canamex 150 slurry 0.7kg/t	By hand from scissor lift	ST5A Scissor lift	Fiat tractor White tractor JC JS200 JUT 45
Mines Sigma	Longhole	BBC120	1 5/8" 3'6"x4'	ANFO magnafrac 1.1 lb/t	By hand	Air slushers Cavo 310	
	All other method	Secan 250	1.25" 2'x3'				
Minnova Ansil	Blasthole	2 IHD 1 TRW Mission 1 CMS CD360 IHD	114 mm	ANFO Tovan 1.7 kg/t	By hand from scissor lift	JC JS600	White tractor
Minnova Winston Lake	Modified Avoca	1 Boart 1 1-boom elec-hyd jumbo	2.25"	0.2 kg/t	By hand from scissor lift	3 EJC 6 cu.yd LHD	5 Ford tractors
Nanisivik Mines	Room and pillar	3 JC MJM21 2 GD Airtrack	1.75" 1mx1m	ANFO 0.45 kg/t	By hand from scissor lift	3 EJC 6 cu.yd LHD	1 JCANFO truck 1 JC high lift

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Nerco Con	Mech cut & fill	JC MJM20B jumbo	1.75" 2'x3'	ANFO	By hand	1.5 & 2 cu.yd LHD	Dux scissor truck
	Conv cut & fill	Secan jackleg	1.25" 2'x2'	ANFO	By hand	Joy 20&40 hp slushers	White traktors
	Shrinkage	Secan jackleg	1.25" 2'x2'	ANFO	By hand	2&2.2 cu.yd LHD	
	Longhole	Boart carriers	2" & 2.5" 4'x4'	ANFO	By hand	2& 3.5 cu.yd LHD	
Niobec	Open stoping	Copco ROC 301 -06 HD I-R CMM2 IHD	6.5" 13'x16'	ANFO,Tovan 0.68 lb/t		LHD	Ford traktors Kubota traktors
Noranda Minerals Gaspe	Mechanized open	2 CMS 360B	4.5" 10'x10'	ANFO,slurries		2 ST8B 9 cu.yd	Toyota 4WD
Noranda Minerals Geco	Blasthole & Alimak	3",4",6"&8" DHD BBC 120 BBE 57 Bar & arm 3 wheel carriers Crawlers	3" 4.5" 6.5" 8.5"	ANFO Watergel 0.6 lb/t	By hand	125 hp slushers Var elec & diesel LHD JCI 413 truck	Flatbed Carriers Miller Anfo Karts
Noranda Minerals Isle-Dieu	Blasthole	2 MEM837 IHD 4 Atlas Copco carriers	4.5" 10'x12' 2.5" 4'x5'	Tovan extra ANFO 0.8 lb/t	By hand from lift truck	ST5	Traktor Scissor lift

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Placer Dome Cambell	Cut & fill Longhole	Secan jacklegs & stopers Boart Stopemaster Sican drills on Boart buggies	1.25" 3'x3' 2 1/8" 4'x5'	ANFO 1.1 lb/t Magnafrac & Powermex 0.75 lb/t		Slushers Cavo 310 0.5,1&2cu. yd LHD	
Placer Dome Dome	Mech cut & fill Longhole	Joy 2-boom stope wagon with Secan 250 stopers Copco 1&2-boom elec hyd jumbos	1.25" 4'x4' 1.5"&2" 4'x8'	ANFO ANFO & Magnafrac	By hand By hand	Cavo 310 France 1.5cu.yd LHD	Loader
Placer Dome Dona Lake	Blasthole	CMS CD360 IHD	6.5"	0.45 kg/t	By hand	JC JS500	
Potacan Mining	Room & pillar	1 3-boom jambo 3 Boart 3-boom jumbos 5 Alpine AM1000 2 Merrietta 1012A	1 7/8"	ANFO	By hand	ST8 NMS-12t shuttle car	Getman trucks Toyota man cerriers Kubota traktors Ford traktors
Rio Algom Stanleigh	Romm & pillar	7 JC elec-hyd 2-boom jumbos	41 mm 4'x4'	Amex 2.2 lb/t	By hand	ST6C JC JS350	ANFO loaders Ford traktors
Royal Oak Pamour	Blasthole	CMS CD360 CMS CD90	6.5" 10'x10' 8'x13' staggered	ANFO 1.0 lb/t	By hand	JC JS600 ST8	Ford traktors
St. Andrew Stock	Cut & fill Longhole	Jacklegs & stopers PR123	1.25" 18"x24" 2 1/8"		By hand	LHDs LHDs	Case tractor

Appendix A Stoping details in underground hard rock mining

Company Mine	Method	Drilling equipment	Hole diameter Drill pattern	Explosives Powder factor lb/ton	Scaling method & equipment	Mucking equipment	Service equipment
Teck Corona David Bell	Longhole	2 Tamrock Solo 606RA	7 mm 1.7mx1.7m	Emulsion 1.1 kg/t	Byhand from scissor lift	JC JS600	Getman scissor deck
TVX Gold Casa Berardi East	Bulk	Copco 1-boom jumbo 1032	2.5” 1.8mx1.6m	0.6 kg/t	By hand from platform	JC JS600	Toyota Landcruis
	Cut & fill	Copco 1-boom jumbo 1032	1.75”	0.6 kg/t		JC JS600	Toyota Landcruis
TVX Gold Casa Berardi Quest	Bulk	Boart	2.5” 1.8mx1.6m	0.6 kg/t	By hand from lift	JCI 600	Toyota Landcruis
	VRM	CMS CD360	6.5” 3mx3m	0.6 kg/t	By hand from lift	JCI 600	Toyota Landcruis
	Cut & fill	1Copco 1-boom jumbo1032	1.75”		By hand from platform	JCI 350	Toyota Landcruis
Westroc Industries	Room & pillar	2 Joy CD71A 1-boom jumbo	1.75” slash	ANFO 2 lb/t	By hand	LHD	1 Mine Cart
Williams Operating Corporation	Blasthole open	9 Cuex IHD 2 Atlas Copco EH tophammer	4.5” 3.5”	Amex 0.7 kg/t	By hand from lift	JC JS 600	White traktors John-Deere traktors

APPENDIX B

SCALING MOIL CALCULATIONS

Consider a beam of loose rock hanging from the back of the excavation opening shown in Fig. B-1. The loose rock is to be pried down by forcing the wedge of the scaling moil between the loose and solid back of the opening.

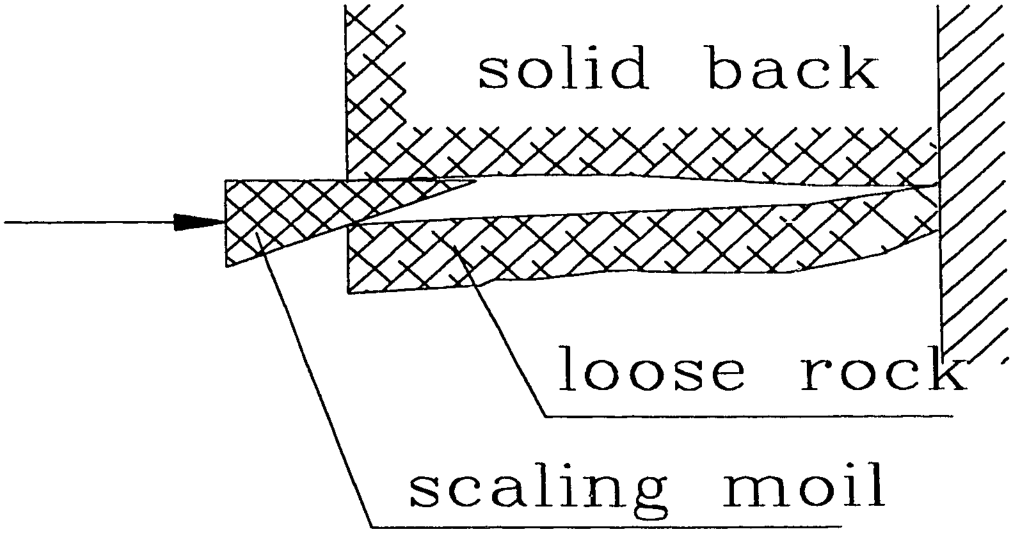


Fig. B-1 Schematic representation of the lose rock prying process

The problem was to determine the magnitude of bending stress in the cantilever beam of rock generated by the prying action of the moil wedge (for details see Chapter 4).

Determination of the moil wedge reaction

In order to define the rock beam external loading condition it was necessary to determine the magnitude of the moil wedge reaction **R** exerted by the action of the impact force **P.** The summary of the data considered is listed below:

The magnitude of the impact force P = 5.6 kN

The assumed moil wedge angle $\alpha = 11^0$

The coefficient of static friction between the steel moil and the rock surface T = 0.30

The free body diagram of the moil wedge is shown in Fig B-2 with the corresponding force triangle.

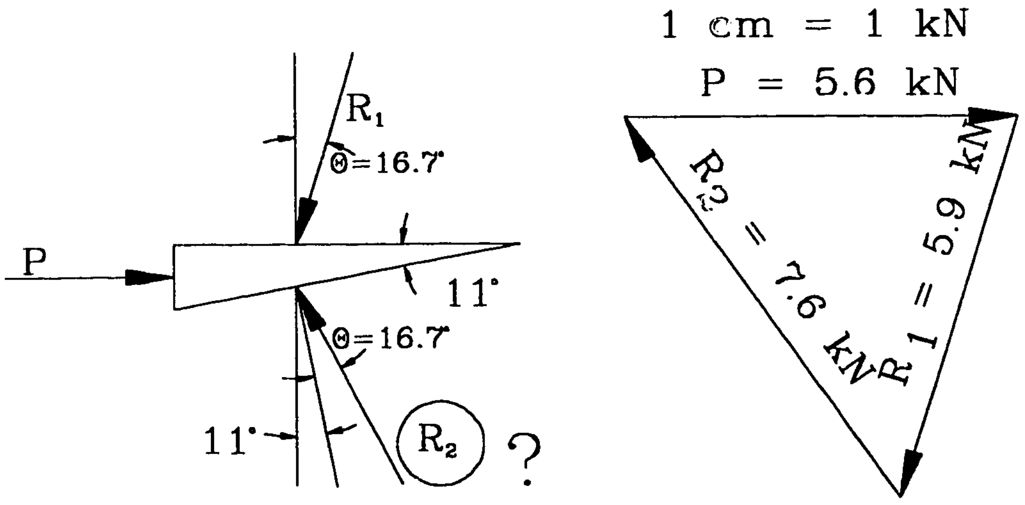


Fig B-2 Free body diagram and force triangle for moil wedge

The value of the force exerted by the wedge of the moil R_2 = 7.6 kN is found graphically from the force triangle drawn to scale.

Determination of the bending stress in the rock beam

a) The rock beam's bending moment

For the cantilever beam of loose rock subjected to the uniformly distributed load 'w ' 14.84 kN/m and the vertical component of the moil prying force R_{2v} = 6.7 kN as shown in Fig. B-3 below. The chosen axis of the beam is x-axis of a coordinate system with origin at the right end of the beam.

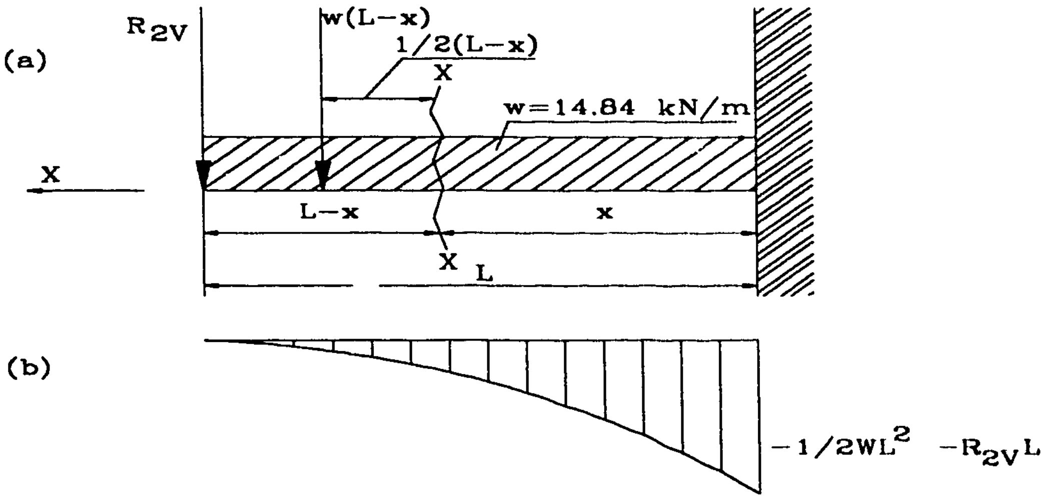


Fig. B-3 The loose rock loaded beam with accompanying bending moment diagram

The equation for the bending moment at any point along the length of the rock beam can be written:

$$\mathbf{M_{b\,x\text{-}x} = -0.5\ w\ (L - x)^2 - R_{2v}\ (L\text{-}x)}$$

The minus sign is necessary because downward loads indicate negative bending moments. By this equation the bending moment is zero at the left end of the beam (point A) and $\mathbf{-\ 0.5\ w\ L^2 -\ R_{2v}\ L}$
at the clamped end when x = 0 (point B). The variation of bending moment is parabolic along the beam and may be plotted as in Fig B-3 (b) above.

The maximum moment at the clamped end of the loose rock is

$$\mathbf{M_{b\,x\text{-}x} = -0.5\ w\ (L - x)^2 - R_{2v}\ (L\text{-}x) = -0.5\ \ 14.84\ \ 0.86^{\,2}\ - 6.7\ 0.86 = -\ 11.09\ kN\text{-}m}$$

b) Normal stress in the beam

For any beam having a longitudinal plane of symmetry and subject to a bending moment M_b at a certain cross-section, the normal stress 's' acting on a longitudinal fiber at a distance y from neutral axis of the beam is given by:

$$\mathbf{s = M_b\, y / I}$$

where, I denotes the moment of inertia of the cross-section area about the neutral axis.

For a rectangular cross - section of the rock beam (see discussion in Chapter 4),

$$\mathbf{I = 1/12\ bh^3 = 1/12\ (0.7)\ (0.3)^3 = 1.58 \times 10^{-3}\ m^4}$$

Thus, under the concentrated load of the prying force and uniform distributed load the bending stress at any fiber a distance 'y' from the neutral axis of the beam is

$$\mathbf{s = M_b\, y / I = 11.09\ 0.15 /\ 1.58 \times 10^{-3} = 2.4\ MPa}$$

The maximum bending stress in tension occurs along the upper surface of the rock beam, since these fibers elongate slightly and at this surface y = 0.15 m and s = 2.4 MPa.

GLOSSARY

Breaking: To cause to part or divide by force; to break a large rock into a smaller pieces

Development: Process of excavating an access to a orebody so that ore can be mined and ore transported to the surface for processing; it refers to a shaft, level,drift, raise, drawpoint, ramp, orepass, wastepass, etc.

Drawpoint: Loading point beneath a stope, utilizing gravity to move bulk material downword and into a conveyance, by shute or loading machine like scooptram; also boxhole

Drift: Primary or secondary horizontal or near horizontal opening; oriented parallel to strike of a pitching deposit

Footwall: Wall rock under the deposit

Galloway stage: Platform being raised and lowered in a shaft sinking operation for a purpose of bringing in and out people and materials

Grizzly: Coarse screening or scalping device that prevents oversized bulk material from entering a material transfare system; constructed of rails, bars, beams, etc.

Hanging wall: Wall rock above deposit

Jackleg: Hand-held rock drill, mounted on a pneumatic cylinder which supports the weight of the machine and pushes it forward in horizontal or uphole direction

Jumbo: Mobile, two or more boom mounted rock drills

LHD: Short for a load-haul-dump; low profile rubber tired equipment, capable of loading, hauling, and dumping ore or waste rock; constitutes concept of "trackless" mining

Loose: Short for loose rock, fall of which causes accidents in a mine

Moil: A tool sometimes used by miners instead of a pick, and worked like a crowbar in making accurate cuttings

Muckpile: Pile of rock broken by blasting and ready to be mucked and hauled away

Round: Blasted length of a drift, predetermined by type of rock drill and a drill rod length

Scooptram: Low profile front end loader for underground mining; same as LHD; term first introduced by the Wagner Equipment Co.

Shotcreting: Applying a shotcrete (spray-applied concrete) to the walls of an excavation, as a means of ground support in order to prevent the ground falls

Shrinkage: The technique of shrink stoping; involves vertical or subvertical advance of mining in a stope, with the broken ore used as both a working platform and temporary support for the stope walls

Stope: Large exploitation opening, usually inclined or vertical, but may also be horizontal