OPTIMISING ROADHEADER PERFORMANCE BASED ON LABORATORY AND FIELD WORK.

by

MICHAEL JOHN GOLLICK, CEng, MIMinE.

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APPENDICES

OPTIMISING ROADHEADER PERFORMANCE BASED ON LABORATORY AND FIELD WORK.

SYNOPSIS

This thesis covers in detail a study of the excavation of rock salt by roadheader, the factors affecting performance and finally a specification with operational results of a new production machine to suit the South African Coal Mining Industry.

Dosco Overseas Engineering Ltd., the author's employer, is introduced. Reference is made to how, over the years, performance prediction has radically changed from a mere approximation to a position where an accurate value with a performance guarantee is a necessity.

Reference is made to the Universities of Newcastle-upon-Tyne, Nottingham and Leeds who have been the main suppliers of rock testing facilities. The University of Newcastle-upon-Tyne has had further responsibilities for a specific test programme, funded by Dosco, to establish a Performance Prediction Methodology.

A general introduction to the trial site at Domtar Salt, located in Canada, is given, along with the current mining methods and the particular aspects requiring consideration if machine mining were to be adopted. A detailed study over a twelve month period covering three main topics; fines production, performance rates, and cutter pick suitability is described. Results are discussed at length and valuable conclusions are drawn.

Extrapolation of the results to predict the performance of a larger machine suitable to Domtar's high production requirements is shown.

The ability to relate this study to other applications and, in particular, the aspect of pick penetration and its effect on machine design is discussed. A prediction curve suitable for South African coal is shown, along with the necessary calculations to enable a high production rate and the corresponding effect on machine design. Specification features, such as boom force, cutter head design and cutter motor power, are considered at length.

The implications for the machine manufacturer for even larger, more powerful machines is shown.

An early correlation of findings is established by comparison to field results from a smaller single boom, Dosco roadheader.

The study concludes that current or new machine design can be favourably influenced to reflect varying market requirements and that accurate prediction of machine performance is possible.

A later, overall study of the TB2500 shows achieved production rates and comments in particular, on machine mining rate and available mining time.

Recommendations having particular reference to the equipment suppliers involvement in the sales procedure are given.

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1. REVIEW OF ROCK CUTTING PREDICTION PERFORMANCE

1.1 INTRODUCTION

In order to provide this particular Roadheader study, it has been necessary to initially undertake a comprehensive literature search and review relevant information accordingly.

Such information is available from a number of sources, but in particular, published papers, data bases and text books. These have proved most useful in understanding the general principles of machine design, identifying some important milestones in development and ultimately arriving at the techniques which are used in current day performance prediction.

The collated information has, in itself, made a considerable library and will in its own right become a future company reference document.

The quantity of information on such a subject is considerable and it is necessary to add structure to the review in order to emphasise major topic areas and help clarify discussion. The main topics are as follows and it is appreciated that they can and do overlap: -

* Rock testing

* Performance / Prediction

* Cutting Head design

While reviewing it has been interesting to note the type of information available relating to case studies. There are many recorded projects, mainly by the end user, which indicate initial expected performance from a certain class of machine and indeed how this has varied from that actually achieved. In general, deficiencies in one or a combination of factors such as the mining system, ground conditions, equipment reliability, are cited as the cause.

On the other hand there appear to be few instances where machines have been specifically tailored to suit a particular production requirement, and whether or not the actual specification was justified.

A likely explanation is that the roadheader manufacture is greatly influenced by such things as competition and economies of scale and as such designs to make equipment suitable to a broad, not specific, range of application. Ultimately this versatility enhances its attractiveness and normally results in development costs being recovered over a number of sales.

By comparison, producing specific variants in the Tunnel Boring Machine (TBM') industry is common practice. These however, are designed for specific jobs and as such require the price to reflect the accumulated on costs.

1.2 ROCK TESTING

For many years all rock testing at Dosco has been undertaken by Universities and in particular those of Newcastle and Nottingham. There are long standing arrangements with the main contacts, Dr R.J.Fowell and Dr S.Smith who control such work and who's expertise is widely recognised. In 1991 and as a result of the closure of Newcastle's Mining Engineering Faculty a proportion of the work was transferred to the University of Leeds but still remains under the supervision of Dr R.J.Fowell.

Since the introduction of roadheaders there has been the need to assess the intended application and test the rock to give common parameters by which it and future applications could be judged. Simple relationships relating to production rate have been produced by most machine manufacturers and these have been modified over time to reflect new and larger machine developments.

The early use of compressive strength was found to be generally suitable for this purpose and could be derived from either the NCB Cone Indentor (CI) or by removing suitable specimen cores in the correct orientation and height to diameter ratio and crushing between steel platens.

A full description of the Uniaxial Compressive Strength (UCS) test is given in Rock Characterisation Testing and Monitoring (ISRM suggested methods) by E.T.Brown [1].

A second parameter the Cerchar Abrasivity Index (CAI) which indicates wear characteristics and is of particular use for cutting tool assessment was also found to be of considerable merit. The test described in Valantin [2] and Suana [3] consists of pulling a sharp conical steel stylus with a 90 degree tip, 10 mm across the rock specimen under a constant load of 70 N. The abrasivity of the rock is determined by measuring the resultant wear flat of the stylus (expressed in 0.1 mm's) by using a travelling microscope which is attached to a dial micrometer.

Atkinson et al [4] proposed a classification of abrasive rocks based upon the Cerchar Index. Table 1.1

TABLE 1.1

CLASSIFICATION OF ABRASIVE ROCKS [4]

Classification	Cerchar Index	Rock Type
Extremely Abrasive	>4.5	Hornblende Gneiss,Pennant Grit
Highly Abrasive	4.25 - 4.5	Amphibolite, granite
Abrasive	4.0 - 4.25	Granite, Darley Dale Sandstone
Moderately Abrasive	3.5 - 4.0	Sandstone Siltstone
Medium Abrasivity	2.5 - 3.0	Californian Granite, Dolerite
Low Abrasivity	1.2 - 2.5	Portland Sandstone
Very Low Abrasivity	< 1.2	Limestone

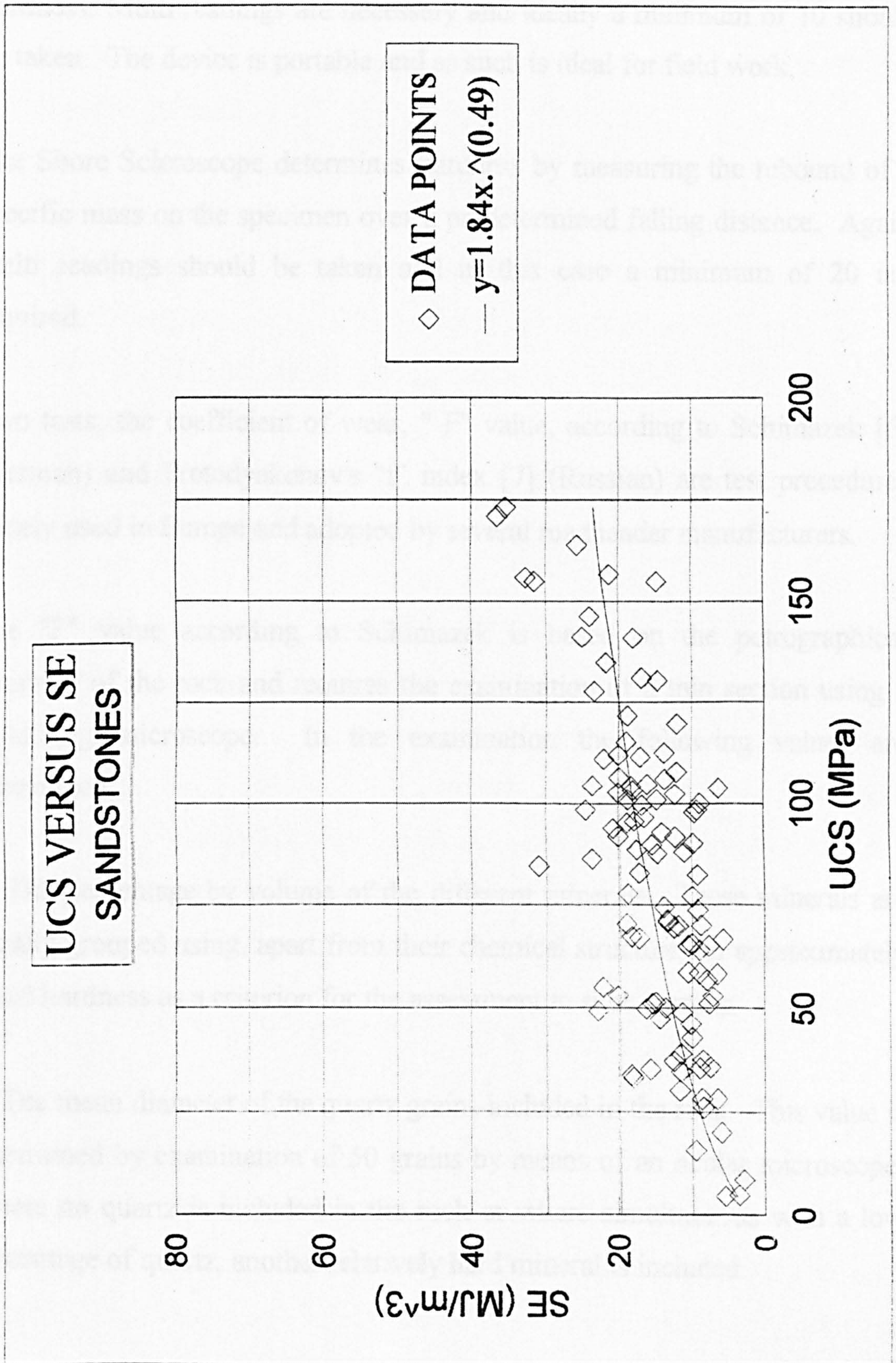
A Standardised Cutting Test, complementing both UCS and CAI and giving a much greater understanding of the necessary forces required to both penetrate and cut the rock was adopted later. The test which is fully described, McFeat - Smith and R.J.Fowell [5] involves cutting the rock to specified parameters and primarily results in Specific Energy (SE) and tool wear values. The SE value is a good indicator of suitable machine application and the tool wear value compliments the CAI.

Testing produces large quantities of data which must be filed in such way as to allow quick and easy access. The adoption of a computer data-base for such a process is ideal as it not only allows the rapid retrieval of such data but facilitates data interrogation. A typical example is shown in Appendix 1 where details of many sandstone samples have been collated and ordered, firstly by UCS and then by SE value. A corresponding graph of UCS against SE is shown in Fig 1.1. Although there is a considerable spread of data a mean line is indicated and a relationship is apparent. This type of relationship could be used to estimate SE values in instances where the sample is too small to complete the Standardised Cutting Test.

The importance of other testing techniques, such as the Schmidt Hammer - rebound hardness and the Shore Scleroscope is recognised. These tests along with others are again described in Brown [1], and although not normally company specified are encountered on occasions and therefore require a general understanding.

FIG 1.1

UCS VERSUS SE (SANDSTONE'S)



The Schmidt Hammer determines the rebound hardness and consists of a loaded plunger which is depressed by pushing against the specimen. The height of the rebound is measured on a scale and is a measure of the hardness. Multi readings are necessary and ideally a minimum of 10 should be taken. The device is portable and as such is ideal for field work.

The Shore Scleroscope determines hardness by measuring the rebound of a specific mass on the specimen over a predetermined falling distance. Again multi readings should be taken and in this case a minimum of 20 are required.

Two tests, the coefficient of wear, " F" value, according to Schimazek [6] (German) and Protodyakonov's "f" index [7] (Russian) are test procedures widely used in Europe and adopted by several roadheader manufacturers.

The "F" value according to Schimazek is based on the petrographical structure of the rock and requires the examination of a thin section using a polarising microscope. In the examination the following values are determined;

1) The percentage by volume of the different minerals. These minerals are usually grouped using, apart from their chemical structure, an approximately equal hardness as a criterion for the assessment to such a group.

2) The mean diameter of the quartz grains included in the rock. This value is determined by examination of 50 grains by means of an ocular microscope. Where no quartz is included in the rock or where simultaneous with a low percentage of quartz, another relatively hard mineral is included.

3) In addition to the aforementioned values, the following parameters are examined and described in terms of quality. Bond of grain using the Brazilian test (tensile strength), homogeneity and secondary factors such as solidification which could influence the machinability of a rock. On the basis of these values, the coefficient of wear "F" is calculated according to the following formula :

$$F = V * d * T / 100$$

where V = percentage (in volume) of hard minerals related to quartz.

d = Mean diameter of the contained quartz grain (mm).

T = Tensile strength according to Brazilian test (MPa).

The coefficient of wear of a rock varies between 0 (ash free coal) and 80 (coarse grained granite).

The "f" index according to Protodiakonoff is based on a five samples test of approx 50 g, consisting of particles between 20 and 25 mm and subject to 3 or 5 impacts from a 2.4 kg weight over 60 cm. The samples are then screened at 0.5 mm; and the particles which are smaller than 0.5 mm are collected in a cylindrical receptacle with a cross-section of 4.15 cm^2. Protodiakonoff's "f" index is equal to K/L, L being the height in mm of the fine products contained in the volumeter. The constant K is equal to 62 or 103 depending on whether the sample was subject to either 3 or 5 impacts.

To compliment test results and procedures there ideally needs to be an appropriate description and classification of the rock. It is not sufficient to merely name the rock type but to investigate further with regard to such things as grain size, weathering and fracture state, as all may have an influence. The Code of practice for Site Investigations [8] gives clear and precise information relating to such factors.

Other useful publications are Stones and Minerals by W.Schuman [9] and Rocks and Minerals by C.Pellant [10].

Specifying the type of testing necessary to determine meaningful cutting data is now well established. It is however also necessary to be familiar with other associated test procedures which although sometimes more applicable to roadway support, can still offer guidance.

Rock Mass Rating (RMR) is such an example and is a system developed during 1972-3 and modified over the years as more case histories became available and to conform to international standards and procedures. Bieniawski [11] and [12]. The system involves rating the rock mass against five main parameters.

The classification is presented in Table 1.2 [13] and shows the scores grouped into five ranges of values. These values indicate very good rock through to very poor rock with expected, unsupported stand up times. It can be clearly seen that very good rock while having excellent support characteristics will be difficult to excavate by roadheader and vice versa for very poor rock.

The real significance of this type of classification is as additional site specific information and hence its likely additional effect on projections based purely from laboratory results.

TABLE 1.2
ROCK MASS RATING SYSTEM [13]

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Ranges of Values						
1	Strength of intact rock material	Point-load strength index (MPa)	> 10	4 – 10	2 – 4	1 – 2	For this low range, uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	> 250	100 – 250	50 – 100	25 – 50	5 – 25	1 – 5	< 1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90 – 100	75 – 90	50 – 75	25 – 50	< 25		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 – 2 m	200 – 600 mm	60 – 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered wall	Slickensided surfaces or Gouge < 5 mm thick or Separation 1 – 5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (L/min)	None	< 10	10 – 25	25 – 125	> 125		
			or	or	or	or	or		
		Ratio (Joint water pressure / Major principal stress)	0	< 0.1	0.1 – 0.2	0.2 – 0.5	> 0.5		
			or	or	or	or	or		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

Strike and Dip Orientations of Discontinuities		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
Ratings	Tunnels and mines	0	−2	−5	−10	−12
	Foundations	0	−2	−7	−10	−25
	Slopes	0	−5	−25	−50	−60

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 20
Class no.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK MASS CLASSES

Class no.	I	II	III	IV	V
Average stand-up time	20 yr for 15-m span	1 yr for 10-m span	1 wk for 5-m span	10 h for 2.5-m span	30 min for 1-m span
Cohesion of the rock mass (kPa)	> 400	300 – 400	200 – 300	100 – 200	< 100
Friction angle of the rock mass (deg)	> 45	35 – 45	25 – 35	15 – 25	< 15

Rock Quality Designation (RQD) is another procedure that helps determine roadheader suitability. Introduced by Deere [14] in 1967 it is a simple and practical method of describing the quality of rock core recovered from boreholes. The RQD number indicates the percentage of solid core recovered in lengths greater than 100 mm. Again, this site specific information is most helpful when combined with laboratory test results.

During the early eighties Dosco entered into a specific R & D contract with the University of Newcastle. The basis of the contract involved the construction of a large cutting rig with the purpose of determining a methodology for prediction of machine performance in a variety of rock types. Specification for such a model included the use of the Standardised Cutting Test in order to make use of the many test results already on file. Following completion of the contract the rig was further adapted for high pressure water jet trials prior to its final decommission in 1990.

At this point and prior to continuing on this particular aspect it is worthwhile reviewing the achievements of other test rigs.

During the late fifties a patent was taken out by C.V.Peake for a ripping machine utilising the cutter pick principle. The machine, initially designed for use in soft shales was subsequently developed by the then Central Engineering Establishment of the National Coal Board. In order to provide information to improve its cutting ability a large test rig, Barker [15], was manufactured to investigate the cutting effects of picks, in particular, chisel and point attack types. The rig was extremely large, some 7.0 m long, 3.0 m wide and standing 3.5 m high and operated by rotating large rock blocks around a stationary cutter. The rig was fully instrumented. Considerable testing to measure the effects of pick type, spacing, rotational speed and depth of cut were undertaken. The main conclusions from the work and which still hold good today are;

* Cutting efficiency increases with depth of cut.

* For a given depth of cut the cutting efficiency increases as the spacing between adjacent cuts is increased to a optimum value.

* Increasing the depth or spacing increases the amount of rock cut and also its coarseness.

* Cutting forces increase up to a point where relief is no longer gained from preceding cuts.

Following on the work at the National Coal Board Mines Research Establishment, Roxborough [16], developed equipment and progressed research into rock cutting for tunnelling machines. At this particular time Roxborough was Lecturer in Mining Engineering at the University of Newcastle.

The research was undertaken covering major aspects i.e. both single and multiple tool rock cutting experiments, metallurgical considerations in tool design and methods of assessing the cuttability of rock.

A small test rig was developed for single tool cutting from a modified 10 kW, 660 mm shaping machine which allowed cutting forces of 50 kN and variable cutting speeds between 150 mm/s and 660 mm/s. By measuring the total work done in any cutting test and dividing the value by the volume of rock cut, then the energy consumption of the process is fully described.

This is referred to as the specific energy E and is normally reported in MJ/m^3.

Thus $E = f.d/v$

where f = mean cutting force on tool.

d = distance or length of cut.

v = volume of rock produced.

This test forms the basis of the Standard Cutting Test used today and has been described and adopted by Roxborough and numerous other authors in various later publications. Some good examples are;

* Roxborough [17], 1973, The mechanical cutting characteristics of the Lower Chalk.

* Roxborough [18], 1973 Cutting rock with picks.

* Roxborough and Phillips [19], Experimental studies on the excavation of rock using picks.

Although single tool cutting tests of the type described are useful, they do not in many ways model the actual process of cutting. In application, an array tools interact to create the cutting process and the efficiency of this depends on many issues such as machine specification, head design and rock characteristics. In an effort to further reflect the true cutting process, Roxborough devised a method for recording field data based on bored holes in a rock face. These holes housed an instrumented cutting tool which could be withdrawn while producing an inner grove. Complementing the derived SE values, the abrasivity of the rock which is reflected in the weight loss of the cutting tool could also be computed. The procedure, although it had considerable merit, suffered from the smallness of scale in respect of the real situation and was not pursued.

The basic Roxborough test was used by McFeat - Smith and Fowell [20] but adapted to make four equally spaced cuts about a 76 mm diameter core. The cuts are made at a depth of 5 mm with a standardised geometry and composition tungsten carbide chisel - shaped tool mounted on an instrumented cutting rig. The strain gauge output from the dynamometer is recorded as analogue U.V. traces which are analysed together with other recorded information such as weight of debris and length of cut to provide the following cutting parameters;

* Cutting and normal mean peak force components acting on the cutting tool.

* Specific Energy defined as the work done to excavate unit volume of rock.

* Cutting wear defined as the weight loss experienced by the tungsten carbide tip during the four experimental cuts.

* Coarseness Index. This gives a comparative measure of the size and distribution of the debris produced.

The test has been used by McFeat - Smith and Fowell for various works, [21][22][23].

This test is today accepted as the industry standard and is used extensively by machine manufacturers, contractors and consultants. At present only one rig is in operation, located at the University of Leeds and is under the control of Dr R.J.Fowell.

Other researchers involved in a variety of rock cutting work have developed test apparatus and procedures for such investigations.

Nishimatsu [24] studied the process of rock cutting using a test rig facility. Rectangular blocks of rock (sandy tuff and cement mortar), some 20 by 300 by 100 mm in size were cut with a wide blade, variable rake angle tool at depths ranging between 2 and 16 mm and at a speeds of 86 mm/s. Relationships between depth of cut and cutting force for the various tool rake angles were produced.

The Transport and Road Research Laboratory (TRRL) developed a pilot - scale boring machine with a 1m diameter cutting head for rock cutting research, Hignett and Howard [25]. The machine had 3 main uses: (i) the testing of a small number of full size rock cutting tools, (ii) the study of 1/4 to 1/8 scaled model of large arrays of cutting tools and (iii) the development and proving of instrumentation. The experiments which were conducted using reconstituted chalk blocks enabled the prediction of optimum pick shape, spacing, and depth of cut relationships etc. The information gathered under laboratory conditions was ultimately transferred and evaluated on a full size TBM.

Further work conducted by TRRL in developing a large linear rock cutting rig is reported by Snowdon, Temporal and Higget [26]. The rig was designed to allow the full scale testing of various types of disc cutter in a variety of rocks with average UCS up to 200 MPa. Relationships between spacing / penetration ratio and SE are shown in the report.

A report by Hustrulid [27] Associate Professor, Colorado School Of Mines describes in detail investigative work carried out to predict tunnel boreability in respect of TBM's. The work, amongst other things, attempted to predict likely performance based on cutting test results obtained from a small linear cutting rig. The aspect of SE featured strongly and in some cases a correlation between laboratory and field, low penetration cuts was observed. This was not to be unexpected based on the limited benefit gained from shallow cutting however, comparisons with deeper field cuts did not follow a similar trend. The rock cutting rig was used again by Dollinger and Ozdemir [28] in a study of disc cutters in soft rock, in co-operation with the Robbins Company.

Speight and Fowell [29] describe the construction of a test rig built to satisfy the aims of Dosco/Newcastle University R & D project. The rig, as previously mentioned, was considerable in size and incorporated a light duty cutting boom and support pedestal powered by a 37 kW thyristor controlled electric motor. The rock sample to be tested was cast in a 20 tonne capacity, reinforced steel box and represents a mock face some 3 m wide by 2 m high. The boom, contained by a substantial steel structure, is able to operate in a similar mode to a production unit although sumping is afforded by pulling the sample towards the boom with hydraulic rams. The rig is fully instrumented and monitors cutting and arcing forces, power consumption, depth of cut, etc. The information, which also incorporates results from the Standardised Cutting Test, was used to determine a performance prediction model for Dosco Roadheaders.

Finally, further work by Fowell, Anderson and Waggot [30] incorporating special computer aided design (CAD) cutting heads in conjunction with high pressure water were used to investigate and predict cutting vibration and force levels. It was found that the use of high pressure water jets significantly reduces the vibration levels measured on the cutting boom.

This test rig is now back with Dosco following the closure of the Department of Mining at Newcastle University.

1.3 PERFORMANCE / PREDICTION

Light duty roadheaders were first introduced in the late 1950's for roadway development in European coal mines. The success of these machines has led to its adoption by many mining organisations as the primary tool for rock breaking. Over the years the product has been extensively developed to reflect both its intended duty and the customer needs and in particular the ability to operate in harder conditions. Today applications can be extremely diverse with machines gainfully employed across a wide spectrum of mining activities involving various types of rock.

The development of such machines has resulted in a much improved level of specification as the need to operate in stronger rock with increased production and reliability has occurred. In general roadheaders have grown in size in relation to duty and this has resulted in equipment ranging from light duty units at less than 35 tonnes to those classed as heavy or super heavy and in excess of 80 tonnes. Tables 1.3,1.4 and 1.5 based on a comprehensive study by Neil et al [31] and various manufactures sales literature, [32][33][34][35][36][37] lists many of the roadheaders which are currently available today with general specification and related range classification.

Site assessments are necessary to determine the information relevant to machine suitability. Production potential can then be gauged using this and certain established performance criteria. Such criteria, while extremely useful as a sales aid, also enable the machine limitations to be established and thus offer the supplier some degree of safeguard from a contractual viewpoint.

TABLE 1.3

ROADHEADER SPECIFICATIONS [32][33][34]

	Class	Cutter Power (kW)	Total Power (kW)	Weight (t)	Cutting Reach (m)	Cutting Height (m)	Sump Force (kN)	Cutting Force (kN)	Arcing Force (kN)	Lifting Force (kN)
DOSCO										
MK2B (RH)	M	82	194	43	7.1	5.0	259	84	79	94
MD1100	L	82	135	32	5.8	4.2	170	50	76	51
SL120	L	82	164	33	4.3	4.3	170	50	76	51
LH1300	M	142	310	50	6.0	4.1	280	135	128	106
MK3	H	142	250	90	7.1	5.1	400	180	160	160
TB2000	M	240	426	76	7.6	3.2	460	146	320	320
TB2500	H	500	605	120	7.9	5.5	668		380	254
TB3000	H	500	800	125	9.0	6.0	700	300	314	260
WESTPHALIA										
WAV130	M	160	290	48	5.4	4.3	260			
WAV178	M	200	337	73	8.3	7.2	360			
WAV250	M	250	380	60	7.6	5.1	480			
WAV300	H	300	470	90	7.9	5.4	330			
ANDERSON										
RH22	L	112	187	35	6.0	5.3	250	102	60	60
RH25	L	82	157	25	5.6	4.3		45		
RH14	M	112	224	66	6.4	6.0	170	150	85	85
RH90	H	215	300	90	6.0	5.0		140		

TABLE 1.4

ROADHEADER SPECIFICATIONS [35][36]

	Class	Cutter Power (kW)	Total Power (kW)	Weight (t)	Cutting Reach (m)	Cutting Height (m)	Sump Force (kN)	Cutting Force (kN)	Arcing Force (kN)	Lifting Force (kN)
EICKHOFF										
ET100	L	110	190	28	6.1	4.7	180	60		
ET200	M	200	350	60	7.6	5.5	320	72		
ET300	H	250	430	98	9.4	7.4	540	140		
ET400	H	300	490	110	10.3	7.3	660	120		

PAURAT										
T1.10	M	140	225	44	5.5	4.4	180	67	65	65
T1.20	M	170	263	43	5.1	4.1	160	54	95	90
T2.10	M	150	353	70	4.7	4.1	250	230	100	100
T2.11	H	150	422	83	7.0	6.9	250	230	100	100
T2.50	H	135	390	87	8.0	5.3	400	250	120	120
T3.10	H	350	520	115	7.6	6.0	600	610	160	180
T3.20	H	300	460	120	8.9	7.7	800	234	120	120
T3.30	H	300	486	83	8.3	7.0	560	290	120	120
T4.10	M	400	507	69	5.2	4.1	350	120	210	200
T4.20	M	400	544	72	6.5	4.1	350	152	210	200

TABLE 1.5

ROADHEADER SPECIFICATIONS [37]

	Class	Cutter Power (kW)	Total Power (kW)	Weight (t)	Cutting Reach (m)	Cutting Height (m)	Sump Force (kN)	Cutting Force (kN)	Arcing Force (kN)	Lifting Force (kN)
VOEST ALPINE										
AM65	L	132	217	32	6.3	4.1	130	50		
AM75	M	160	290	52	7.0	5.2	140	70	51	160
AMT70	M	175	440	62	9.5	7.5	200			
AM85	M	270	504	72	8.0	5.2	160	80		
AM100	H	250	450	84	7.7	6.6	130	100		
AM105	H	300	445	90	9.0	5.8				
AM30	L	45	75	15	4.8	3.4	100	20		

The use of Uniaxial Compressive strength (UCS) in conjunction with machine cutting rate is one such method and was adopted by most manufacturers during the early years of machine development. Typical graphs for two equipment manufactures Voest Alpine [38] and Eickhoff [39] are show in Figs 1.2 and 1.3. These types of performance relationships are still used today, although they will have been modified over time to reflect experience, machine modification and the introduction of new models.

FIG 1.2

VOEST ALPINE CUTTING RATES [38]

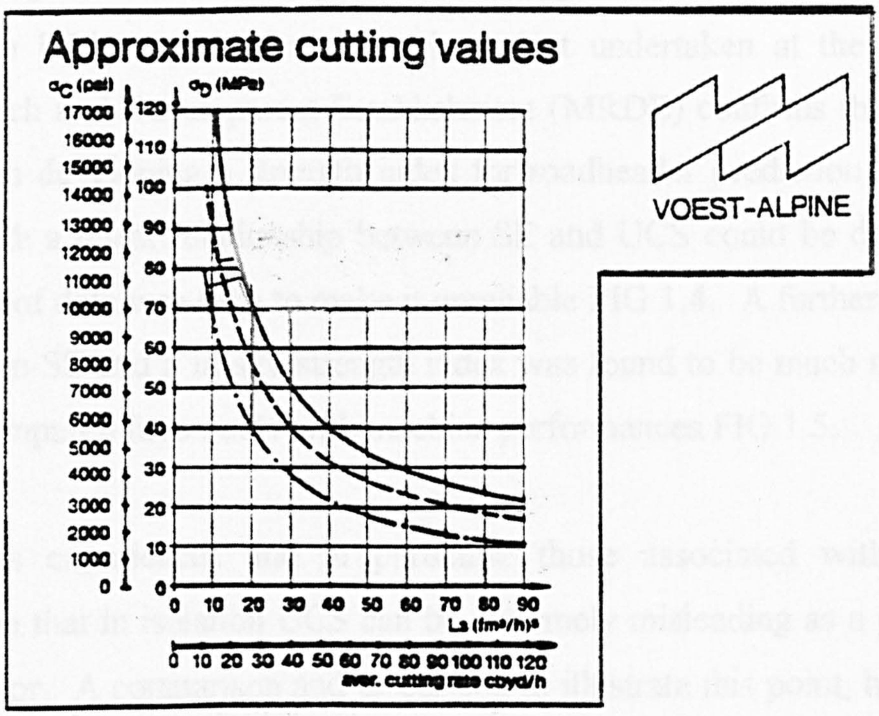
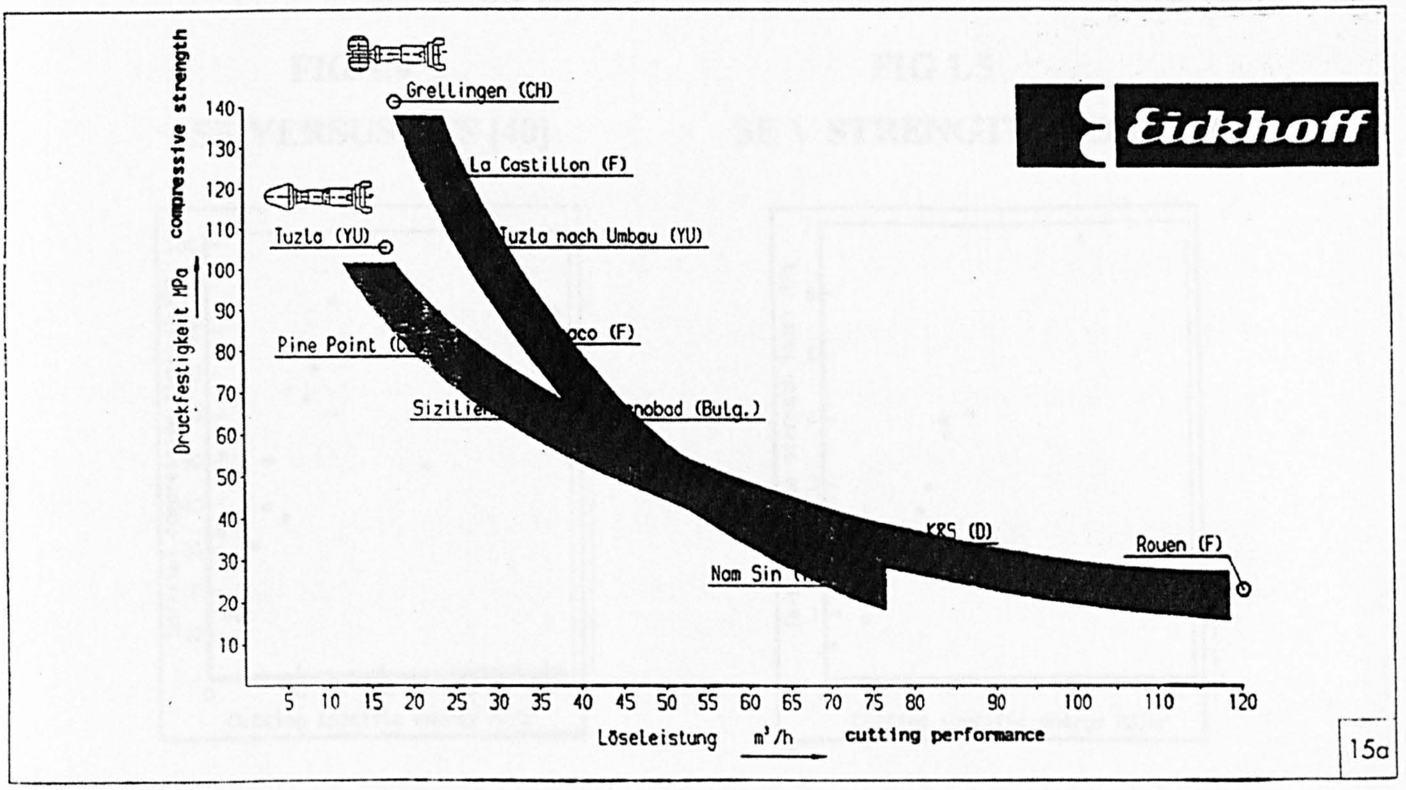


FIG 1.3

EICKHOFF CUTTING RATES [39]



One of the limiting aspects of using UCS and CI, certainly when considering an actual situation is the poor indication of likely energy requirements necessary for both cutting and achieving a specified production level. Aleman [40] as part of a research project undertaken at the UK Mining Research and Development Establishment (MRDE) confirms this view. His work in developing a strength index for roadheader prediction showed that although a linear relationship between SE and UCS could be developed the spread of data was such to make it unreliable FIG 1.4. A further relationship between SE and a In-situ strength index was found to be much more precise and compared favourably with machine performances FIG 1.5.

Dosco's experiences and in particular those associated with evaporites confirm that in isolation UCS can be extremely misleading as a performance predictor. A comparison and discussion to illustrate this point, based on two similar strength materials, (coal and salt) but with different SE values is made later in section 2.3.

FIG 1.4

SE VERSUS UCS [40]

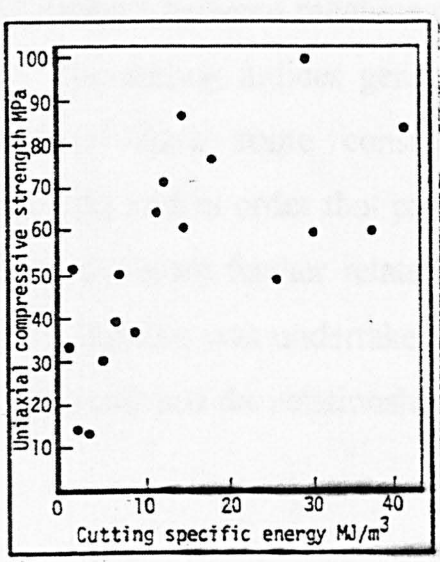
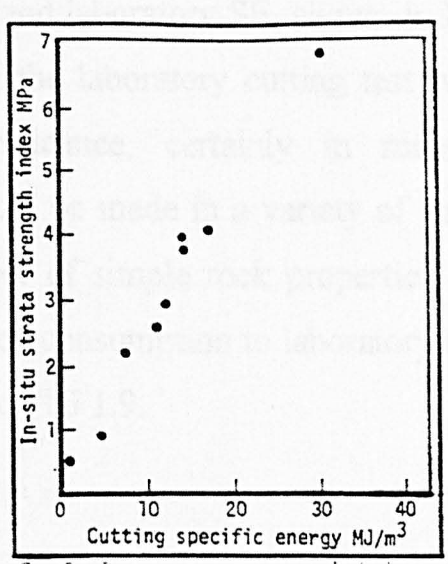


FIG 1.5

SE V STRENGTH INDEX [40]



The use of laboratory SE as a means of indicating an appropriate method of excavation, related machine classification and associated production rate is well documented.

McFeat-Smith [41] conducted a series of cutting tests in mudstones at a variety of directions to the planes of laminations. FIG 1.6 shows diagrammatically the values obtained, which can be related to the four principal directions of pick attack employed by roadheaders. From these it can be seen that there are significant differences in SE values illustrating that the direction of pick attack has an important influence on rock cuttability. It is of particular importance to observe the much greater yield content of cuts 3 and 4 and obviously try to reproduce this effect in the field situation. FIG 1.7 illustrates typical roadheader undercutting, traversing and overcutting modes and how assistance to the cutting action can be made depending on the direction of boom travel. Results from field studies confirmed that large reductions, up to 60% in SE were possible.

McFeat-Smith and Fowell [42] conducted a study on the selection and application of roadheaders. Considerable field testing and monitoring of medium and heavy duty roadheaders was undertaken which resulted in relationships between machine cutting rate and laboratory SE, shown in FIG 1.8. The cutting indices generated during the laboratory cutting test were found to have some considerable significance, certainly in massive conditions and in order that predictions could be made in a variety of strata the indices were further related to a number of simple rock properties. A similar exercise was undertaken to relate pick consumption to laboratory tool cutting wear and the relationship is shown in FIG 1.9.

FIG 1.6

RELATIONSHIP, CUT DIRECTION AND ROCK CUTTING PARAMETERS [41]

Cut number	Specific energy MJ/m^3	Mean cutting force kN	Yield kg/m
1.	10.73	1.04	0.26
2.	10.15	1.02	0.27
3.	5.70	0.89	0.43
4.	4.64	0.73	0.43

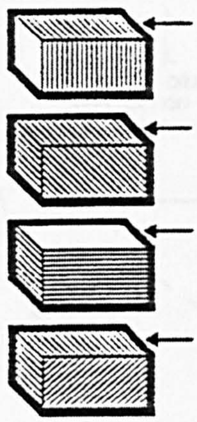


FIG 1.7

ROADHEADER CUTTING MODES [41]

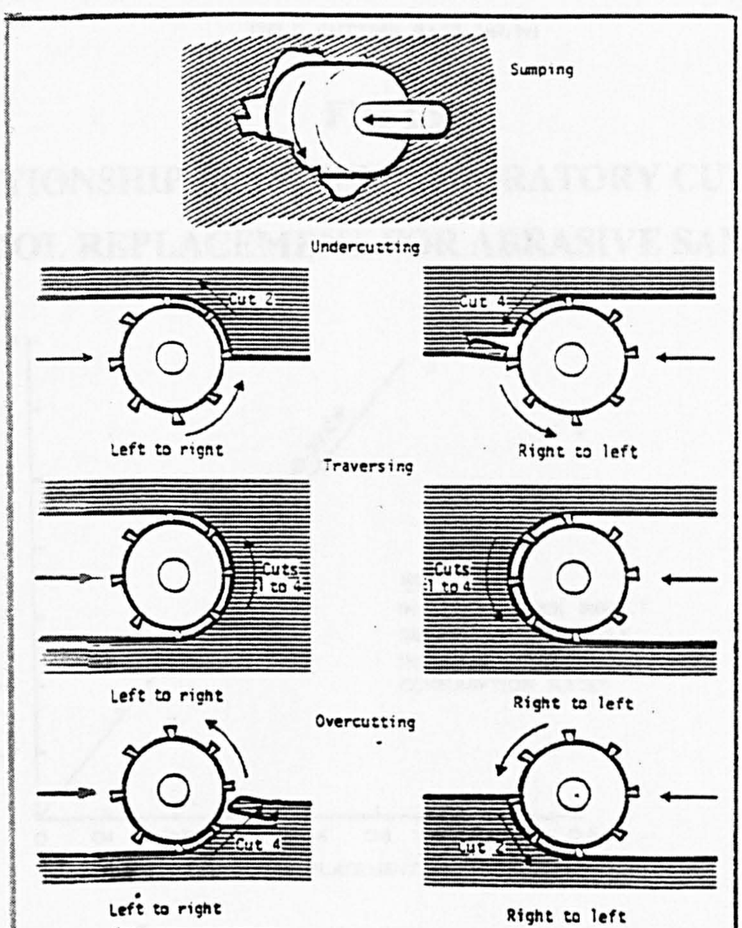


FIG 1.8

PREDICTION OF CUTTING RATE FROM LABORATORY SPECIFIC ENERGY FOR MASSIVE CONDITIONS [42]

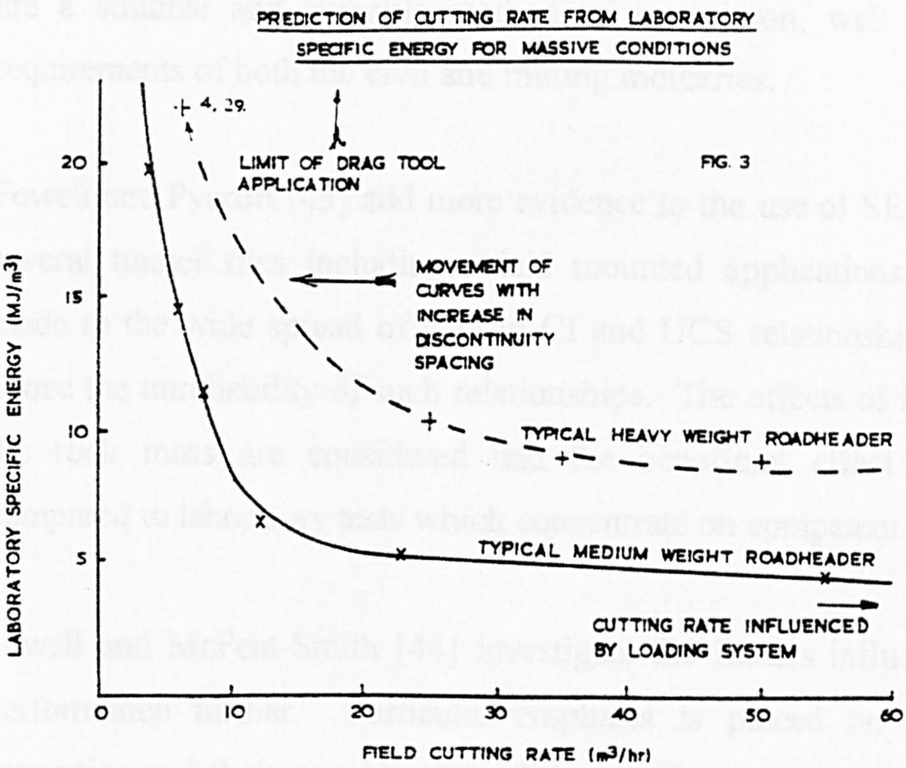
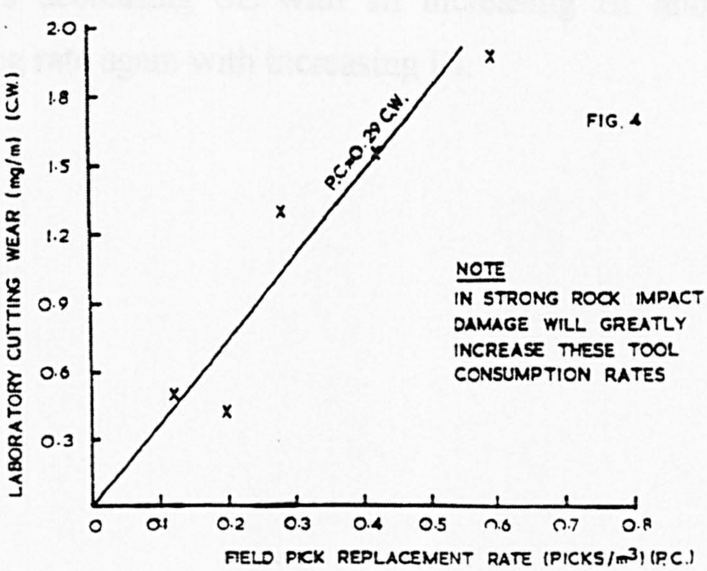


FIG 1.9

RELATIONSHIP BETWEEN LABORATORY CUTTING WEAR AND TOOL REPLACEMENT FOR ABRASIVE SANDSTONE'S [42]



A number of other factors which influence machine performance, notably ground conditions, tunnel profile, gradient, the occurrence of occasional hard strata bands etc, are also discussed. The report concludes that roadheaders are a suitable and versatile method of excavation, well matched to the requirements of both the civil and mining industries.

Fowell and Pycroft [43] add more evidence to the use of SE from studies of several tunnel sites including shield mounted applications. Reference is made to the wide spread of data in CI and UCS relationships with SE and hence the unreliability of such relationships. The effects of fracture state on the rock mass are considered and the beneficial effect is clear when compared to laboratory tests which concentrate on competent rock only.

Fowell and McFeat-Smith [44] investigate the factors influencing machine performance further. Particular emphasis is placed on the rock mass properties and their considerable effect. A Break Index (BI) for assessing rock fractures is used and defined as the average number of weakness planes intersecting horizontal and vertical scan lines per metre for each strata bed. The benefits of excavating rock containing fractures is clear. FIG 1.10 shows decreasing SE with an increasing BI and 1.11 shows increasing cutting rate again with increasing BI.

FIG 1.10

INFLUENCE OF BREAK INDEX ON SPECIFIC ENERGY IN MUDSTONE [44]

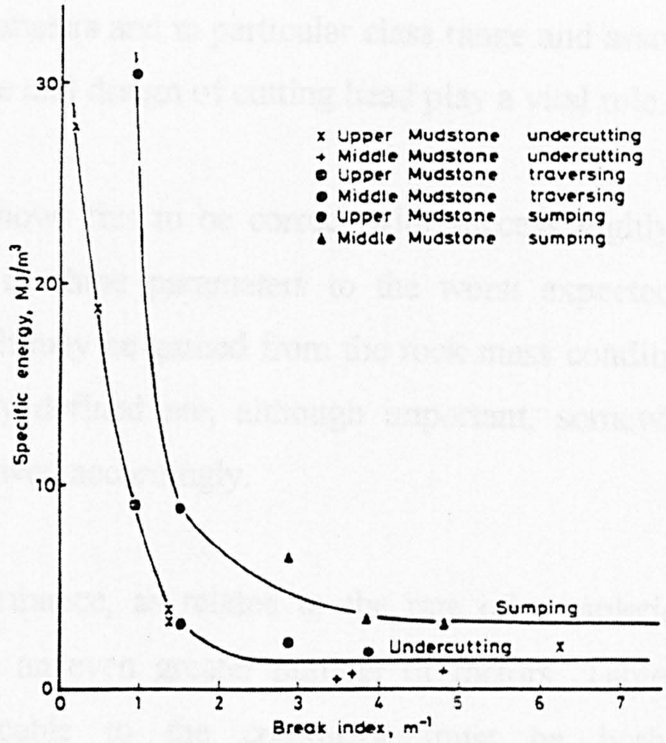
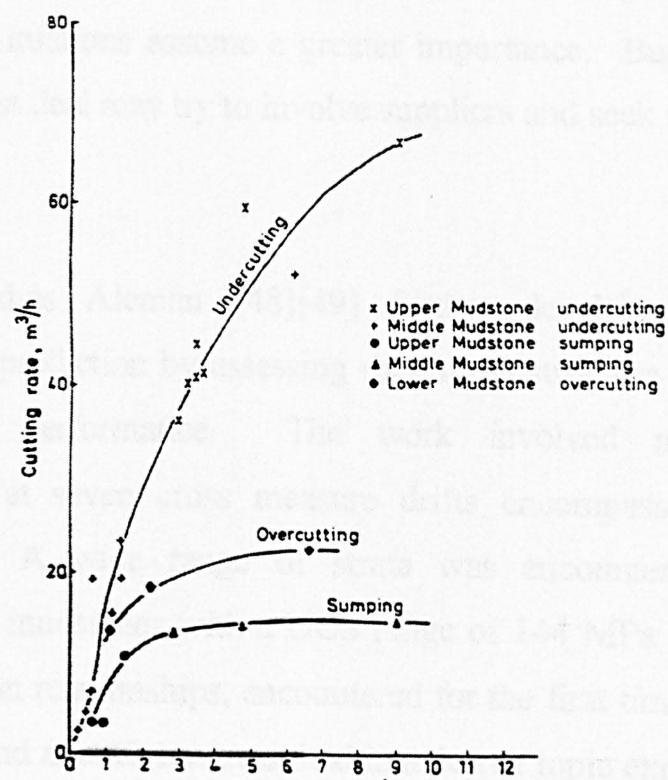


FIG 1.11

INFLUENCE OF BREAK INDEX ON CUTTING RATE IN MUDSTONE [44]



Studies by Fowell and Johnson [45][46] and Fowell, Johnson and Speight [47] on machine performance assessment, recognise the importance of factors other than those associated with rock mass characteristics. The machine parameters and in particular class range and associated specification including type and design of cutting head play a vital role.

Experience shows this to be correct with success highly dependent on the matching of machine parameters to the worst expected conditions. The benefits which may be gained from the rock mass condition unless they can be specifically defined are, although important, somewhat secondary and have to be viewed accordingly.

Overall performance, as related to the rate of completion of a project is influenced by an even greater number of factors, Table 1.6 [45]. These factors applicable to the contractor must be both recognised and accommodated when either deciding or confirming a project completion date. Again, from experience, although these factors are normally deemed outside the influence of the equipment manufacturer they can in highly competitive situations assume a greater importance. Buyers in an effort to secure the best deal may try to involve suppliers and seek unrealistic forms of guarantee.

In later studies Aleman [48][49] further developed the process of performance prediction by assessing rock mass structure and the measuring of machine performance. The work involved monitoring cutting performance at seven cross measure drifts encompassing four types of roadheader. A wide range of strata was encountered, varying from sandstones to mudstones with a UCS range of 144 MPa to 16 MPa. Force and penetration relationships, encountered for the first time are significant to future work and as such have resulted in a deeper topic explanation.

TABLE 1.6 FACTORS INFLUENCING MACHINE PERFORMANCE AND UTILISATION [45]

Table 1 Factors influencing machine performance

MAIN FACTOR	VARIABLES		
ROCK PARAMETERS	INTACT PROPERTIES	CUTTABILITY	
		CUTTING WEAR	ABRASIVITY; IMPACT RESISTANCE; THERMAL PROPERTIES
		DURABILITY	SLURRY MAKE
	MASS PROPERTIES	DISCONTINUITIES	VOLUMETRIC INTENSITY; ORIENTATION; SHEAR STRENGTH
		MIXED FACE CONDITIONS	
		DEGREE OF VARIATION IN STRATA (along line of tunnel)	
	ENVIRONMENT	WATER	FROM WITHIN ROCK MASS; FROM DUST SUPPRESSION
		TUNNEL GEOMETRY	SIZE; SHAPE; GRADIENT
		IN-SITU STRESSES	
MACHINE PARAMETERS	CUTTING HEAD	NO. OF TOOLS	
		TOOL TYPE	RADIAL/FORWARD ATTACK; TIP GEOMETRY; CARBIDE GRADE IN TIP
		LACING PATTERN	
	WEIGHT	SLEWING + LIFTING FORCES	
		HEAD SPEED	
		HEAD POWER	
		RIGIDITY OF MACHINE CONSTRUCTION	
	OPERATIONAL CHARACTER	PROFILING	
		GUIDANCE	

Table 2 Factors influencing machine utilisation

MAIN FACTOR	VARIABLES	
DOWNTIME	PLANNED	MAINTENANCE; SPARES AVAILABILITY
	UNPLANNED	STAFF AVAILABILITY; SPARES AVAILABILITY; CONDITIONS IN THE TUNNEL
SUPPORT	TYPE AND AMOUNT REQUIRED	
	ERECTION SYSTEM	
	DEGREE OF MECHANISATION	
	ANCILLARY OPERATIONS	GROUTING; LAGGING BOARDS
DEBRIS DISPOSAL	AT THE FACE	CLEANING UP; GENERAL MUCKING; SECONDARY BREAKAGE
	BEHIND THE FACE	CONVEYORS; MINE CARS; WATER PRESENCE
ANCILLARIES	VENTILATION	
	DUST EXTRACTION	WATER/PUMPING EQUIPMENT; AIR DUCTS FOR EXTRACTION
	EXTENSIONS	TRACK; POWER CABLES; TELEPHONE; CONVEYOR
LABOUR	AVAILABILITY	
	EXPERIENCE/SKILL	
	TRANSPORT TO FACE	DISTANCE/TIME; METHOD
ORGANISATION	MANAGEMENT	BONUS SCHEMES; COMMUNICATION
	SHIFT TIMES	TOTAL PAYABLE TIME; PRODUCTION TIME
FINAL USE	ENGINEERING TOLERANCES	GRADE; ALIGNMENT
INTER-GRATION	IS TUNNELLING THE ONLY ON-SITE ACTIVITY, OR IS IT COMPETING FOR RESOURCES WITH OTHER OPERATIONS (i.e. MINING)?	
water	A PROBLEM OF DISPOSAL AND DRAINAGE.	

Following measurements in various strata types it became apparent that the limiting condition on cutting rate was the amount of thrust available to the cutting head. When cutting softer strata the power consumption was found to increase relative to that of harder strata, this due to increased penetration in the softer ground. The findings agreed with Hurt et al [50] which concludes that power absorbed is a function of the penetration achieved by each pick. This in turn is dependent on the arcing thrust which is available from the machine and the rock type. Therefore, arcing force is the true limitation on the cutting performance of a roadheader and generally not the power available from the cutting head. It thus follows that when measuring cutting performance a relationship combining head penetration and thrust exerted is required.

To examine the relationship between thrust and penetration Aleman plotted thrust/cutting head unit area (kN/m^2) against penetration/head rev (cm) for all strata conditions but grouping results in to four strength zones, FIG'S 1.12, 1.13. This showed that as the ground became more difficult to cut there was a decrease in penetration for a given value of thrust. For each of the zones a linear relationship of the form $P=nT+c$ was defined where P was equal to penetration/rev and T equal to thrust/area of head in cut and n and c are constants depending on ground type.

FIG 1.12 [49]
UNGROUPED

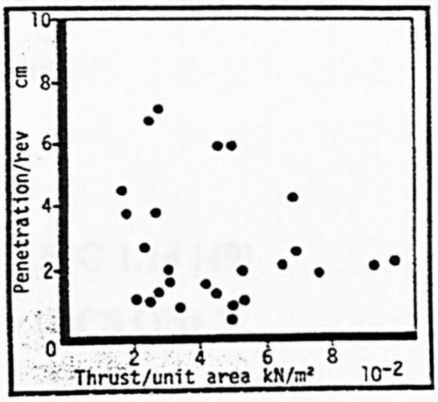
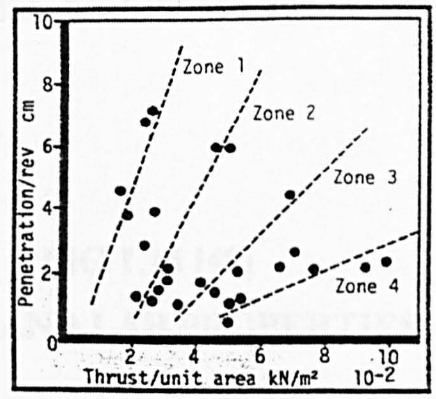


FIG 1.13 [49]
GROUPED



Subsequent prediction of machine performance therefore relies on identifying with the appropriate zone relationship, equating thrust/cutting head unit area to arrive at penetration/rev and adjusting for head rpm and minutes/hour to give a production rate in m^3/hr.

Aleman's research showed that when determining performance both the intact strength and in-situ characteristics of the rock were required. While intact properties could be assessed in the laboratory a different approach to assess the in-situ characteristics such as joints and bedding planes was necessary. Recognising the importance of fractures and the considerable work by Deere on discontinuity spacing (RQD), Aleman decided to record joints and fractures, including microfractures revealed by a penetrant dye and establish an index that would account for fracture density. The index known as the "A" value varied from 0 to 300 with the competence of rock increasing for a decrease in A.

The results of strata assessment in terms of both compressive and tensile strength, RQD and A values were regressed against machine cutting performance, FIG'S 1.14, 1.15. The most significant fit of curve (correlation coefficient 0.9 and a standard deviation of 0.39) related not to UCS but to a combination of all the factors, confirming the importance of in-situ characteristics. By further classifying the strata into either homogeneous, part or totally fractured the accuracy of the prediction could be further improved.

FIG 1.14 [49]

UCS ONLY

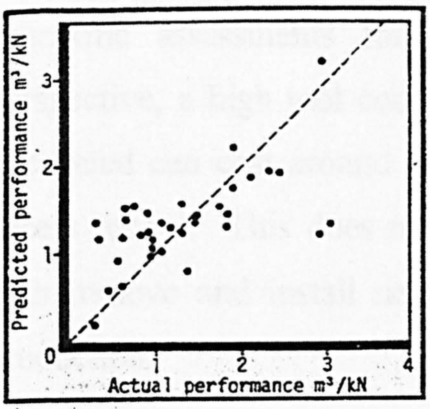
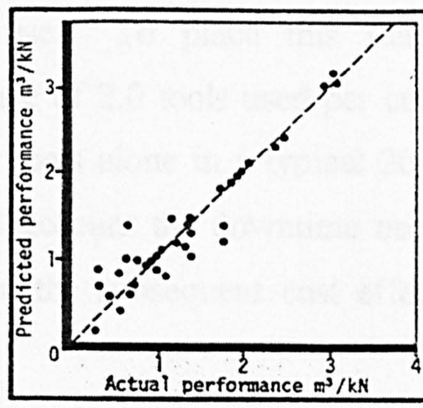


FIG 1.15 [49]

UCS AND LAB PROPERTIES



* The main conclusions of Aleman's work are;

* A relationship exists between thrust applied to the cutting head and the penetration of the ground cut

* Rock mass characteristics can be quantified from borehole cores with the aid of penetrant dye to measure microfractures.

* UCS is not a representative measure of strata type and gives a poor indication of expected machine cutting performance.

There are many studies with several already cited concerning machine performance in relation to rock mass characteristics. In particular, the effects of rock strength, required cutting energy and inherent fractures are well documented. Machine specification is yet another important factor with the larger, more powerful units both producing more and having higher operating limits. Such limits are normally expressed as a function of rock strength but with little or no reference to rock type and hence the likely tool consumption. In practice this aspect cannot be ignored as high tool wear rates can have a deleterious effect on production, upsetting predetermined economic assessments for machine use. To place this statement in perspective, a high tool consumption rate of 2.0 tools used per cubic metre excavated can cost around £400/m for tools alone in a typical 20 m^2 mine access tunnel. This does not take into account the downtime necessary to both remove and install new tools and the subsequent cost effect of lost production.

Research studies by Larson and Basse [51] and Altinoluk [52] have identified the major wear mechanisms affecting cutting tools. These mechanisms namely Abrasion, Impact, Thermal and Vibration, are considered to be the main causes of tool failure and as such are explained in greater detail below.

Abrasion A similar process to micro - machining and a function of the distance travelled by the tool in contact with the rock.

Impact Micro - spalling and gross brittle failure. The latter is attributed to high tensile stresses caused by the deformation of the surrounding steel shank or by partially reflected stress waves at the insert - braze interface.

Thermal / Vibration Thermal fatigue produces deep cracks into the tungsten carbide structure. The cracking process is aided by the constant cycle of heating and cooling. Rae [53] indicated that temperatures in excess of 1250^{0}C were experienced when running tungsten carbide against sandstone wheels. Mai [54] demonstrated a critical temperature above which significant strength is lost instantaneously on quenching. Osburn [55] highlighted that above 400°C the hardness of tungsten carbide drops dramatically and becomes softer than the quartz in the rock at ambient temperature.

A study by Johnson and Fowell [56] identified and evaluated the various factors which govern tool wear and suggested how tool consumption might be assessed for roadheaders. Field observations at various roadheader sites showed abrasive wear to dominate in most applications. Quartz rich rocks gave higher tool wear rates due to both increased abrasivity and thermal fatigue. Laviers [57] demonstrated a 2 to 3 fold increase in tool life even in abrasive sandstone by diverting the heat away from the tool tip. Where the rock has a hard surface (i.e. hard cemented siltstones, limestone's and fine grained igneous/metamorphic rocks) impact wear becomes a major consideration. In more plastic rocks (gypsum and rock salt) wear can also be high. This is due to the high tool temperatures caused by the rock movement around the tool and maintaining considerable contact during the cutting process.

A number of factors were identified as affecting tool consumption with compressive strength on its own proving to be an inadequate predictor. Although trends were apparent the data scatter was excessive and was found to give poor assessments outside of narrow lithological bands. A summary table to show the factors requiring consideration when assessing tool consumption was produced and these are;

* Intact rock material properties.
* The rock mass properties
* The roadheader specification.
* Cutting Tool types.
* Operational characteristics.
* Environmental conditions.

With regard to assessment of tool consumption (TC) some success was gained from the use of an abrasivity coefficient (AB) based on the weighting of the CAI for each rock type within a given face. However, using this relationship, TC = 0.25 AB - 0.07 consistently gave a large over assessment of actual achieved tool consumption. The discrepancy was thought to be due to a number of factors but in particular the lack of real data from a site e.g. rock mass quality, long averaged abrasivity values and variations in tool carbide and head design.

Another aspect investigated was that of increased machine specification and in particular the effects of greater arcing (rock penetration) force and improved machine stability. Deeper rock penetration gives rise to an increase in product relieved per unit length of contact and improved stability in turn leads to greater rigidity and hence less vibrational damage caused by unequal loading of the tools. Both these aspects were found to improve tool consumption. Company experience of these aspects confirm this to be true with further improvements possible if shield mounted booms replace the equivalent track mounted unit.

Studies by Fowell and Gillani [58] and Speight and Fowell [59], to assess the influence of operational parameters on roadheader productivity give further guidance with particular regard to the effects cutting tool wear. While these concur with those of Johnson and Fowell [56], of further interest are the particular effects concerning the machine operating parameters.

These parameters and in particular the effect of cutting speed on machine forces, specific energy and rate of energy input also, the effect of mode of cut on efficiency and pick forces were investigated using a full scale laboratory approach and research rig previously described in section 1.2 page 15. The conclusions from the work are significant and as such are listed below, indeed they had considerable influence on problems experienced during the trial of the LH 1300H roadheader in Canada.

* Abrasive wear, micro chipping, thermal wear and impact damage all contribute to reduce tool life.

* Efficient head design and high quality of head and pick manufacture are essential for rapid excavation in hard ground.

* Reducing pick speed increases pick life in difficult cutting conditions.

* Head forces were shown to be unaffected by speed and high tool consumption rates at high speeds are attributed to thermal destruction of the tungsten carbide.

* To reduce tool consumption, shallow, inefficient depths of cut must be avoided. The higher arcing and lifting forces available on the new range of machines will significantly improve the tool penetration attainable, contributing to increased cutting efficiency.

* High pressure water jet assisted roadheaders currently on trial show promise in removing heat from tool/rock interface, prolonging tool life as well as reducing the cutting duty required of the mechanical tools.

The application of water in the coal mining industry for tool cooling and as an aid to both excavation and dust suppression is common place. In certain applications however, and due to a variety of reasons this may not always be tolerated. Water, for example, has a degragating effect on salt and as such was strictly prohibited on the LH1300H Domtar trial.

High pressure water jet assisted cutting (HPWJAC) a development to assist convential tools in rock and coal cutting recieved much attention in the early eighties and although not strictly relevant to the main trial study still has some overall significance and as such requires a comment.

HPWJAC is the application of water through the cutting head to emerge as a fine jet a short distance infront of the cutting tool and impinge on the rock face. In general there are benefits to be gained from this process such as improved cutting and reduced dust makes but also some disadvantages such as extra equipment cost and work place (floor) incompatibility.

An early study by Hood [60] investigated the effects of water jet cutting as part of the development of a rock cutting machine for use in narrow stopes in gold mines. Results showed that by directing a water jet immediately ahead of the drag tool while cutting strong rock reduced the magnitude of the forces acting on the tool by a factor of 2. It was also discovered that the point of impingement of the water jet relative to the tool would dramatically effect the forces. Finally the effect of the water jet was shown to be restricted to a zone directly ahead of the leading edge of the cutting tool.

Plumpton and Tomlin [61] produced a report for MRDE detailing the development of water jet assisted roadheaders. The first results of the field trials which were based using an adapted Dosco MK2A roadheader were published in the Colliery Guardian 1984 [62]. A summary of the results can be shown as follows;

* At high pressures (66 MPa) a cutting improvement with a reduction in machine vibration was apparent. The amount of airborne dust was reduced and incendive sparking appeared to disappear. There was also a reduction in tool usage and lower cutting head temperatures were noted.

* At low pressures (13 to 66 MPa) the cutting improvements were less although the other factors were still apparent.

Several major papers were presented at the 8th International Symposium on jet cutting technology in 1986. Morris and McAndrew [63] from work carried out in the laboratory attempted to quantify the success of HPWJAC by comparing the wear rate of the tool to the rate of increase in normal force over a set cut distance. They concluded that;

* Pick life is influenced by the cutting speed more than water pressure.

* Most benefits are gained at moderate pressures, with a law of diminishing returns as pressure increases.

* Water jet assistance in rock cutting was probably effective due to the cooling of the rock/carbide interface.

* The amount of assistance to cutting is a function of both cutting speed and the rock type.

A report by Fowell, Ip and Johnson [64] studied the effects of water jet cutting on cut depth, cutting speed and rock properties. They reported that the water jet did not initiate fractures in the rock but assisted the cutting process by washing debris away from the tool. They also illustrated that HPWJAC is not energy efficient in terms of specific energy requirements with any savings in cutting energy being absorbed by the high pressure pumping requirements.

An interesting report by Barham and Tomlin [65] explains the development of phasing systems where high pressure water is delivered to the tools which are in rock contact only, thus reducing both water and power consumption. Such systems have subsequently been developed by equipment manufactures and operate in two ways. One via a valve which opens when the pick is in contact with the rock and the other which has proven more reliable is a phased valve system where valves open and close alternatively with each 90 degrees of rotation.

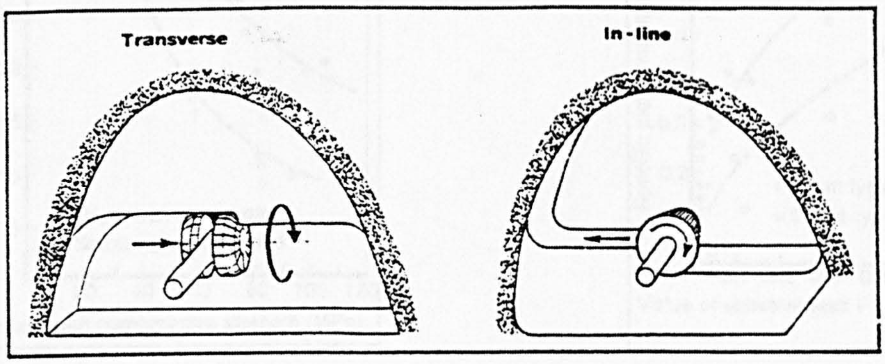
Other studies relating to machine trials and reviews of current practice have been produced by Hurt,Morris and Mullins [66],McAndrew, Morris and Hurt [67], Fowell and Ip [68], Barham and Buchanan [69]. Works on equipment developments, such as the design of water jet phasing systems by Parrot [70] have also been published.

In conclusion it can be stated that there is a significant reduction in respirable dust when utilising water jets at pressures of 20 MPa. Above 20 there is little benefit on further dust reduction although tool wear, reduced frictional hazard and cutting improvements continue up to 70 MPa. Above this point any further benefits are minimal.

Since the early days of roadheader technology, two different types of cutter head have been used - drum (transverse) and spiral (in-line). The identification ( ) relates to the direction of head rotation in relation to the cutter boom axis FIG 1.16, with individual manufacturers claiming various advantages for each head type. In more recent years, some manufacturers have adapted their machines to allow applications with both types of cutter heads, thus meeting the demand from a broader range of customer and in many ways accepting the philosophy of the alternate head style.

FIG 1.16 [71]

TRANSVERSE AND IN-LINE CUTTING ACTIONS



A report by Gearing [72] which compares the two head types goes some way in providing a rational overview of this emotive subject. Of interest is the explanation of machine stability and in particular how the drum design benefits from a vertical as opposed to a horizontal cutting action also, the aspect of higher cutting head inertia resulting from a greater head mass (two halves) and rotational speed and its beneficial effect on stronger, brittle rock. The report goes on to compare the performances of two similar specification roadheaders, one equipped with a spiral head the other with a drum both operating under similar mining conditions. Two aspects, production rate and pick consumption FIG's 1.17 1.18 show that while the drum head is more productive, it is much worse from a tool usage view. Useful comments on the general operating aspects highlight the effectiveness of the drum cutting action for debris loading but also cite the disadvantage of increased dust make, poor roof profiling characteristics and difficulty when excavating a non-uniform face.

FIG 1.17 [72]

CUTTING PERFORMANCE

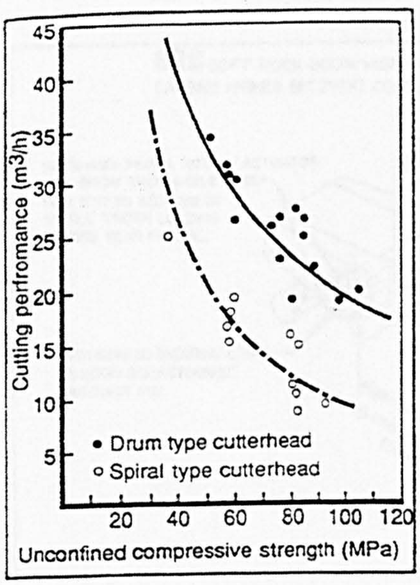
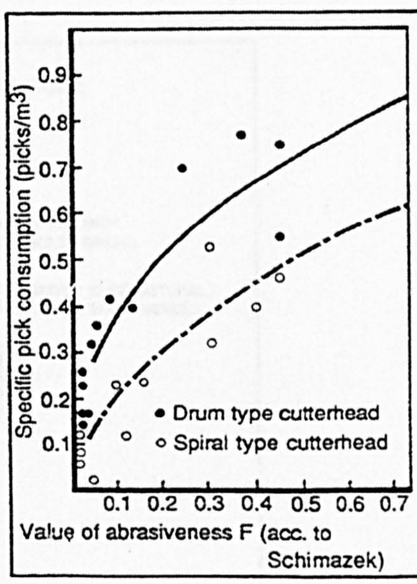


FIG 1.18 [72]

TOOL CONSUMPTION

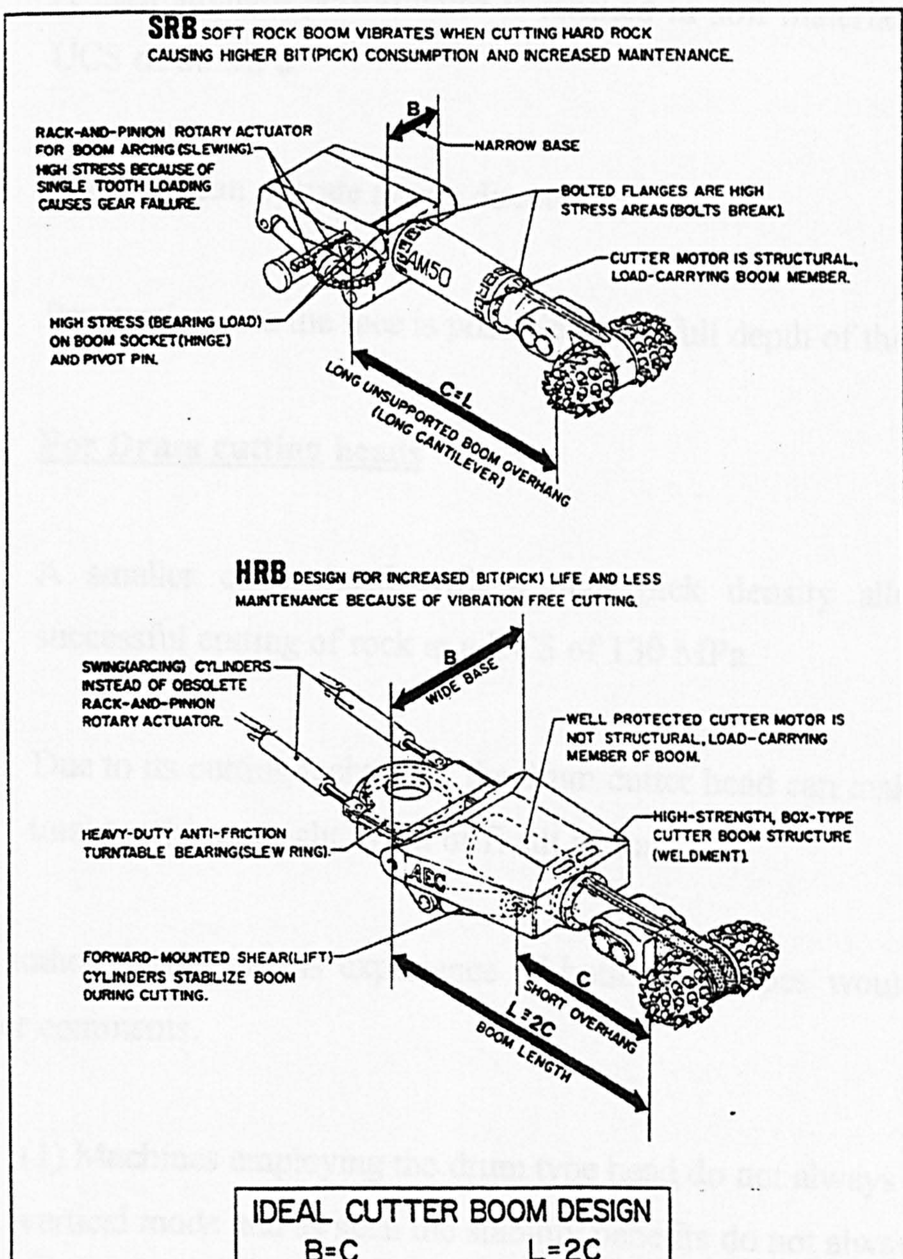


Kogelmann [73] [74] confirms many of the points discussed in the previous paragraph and expands the aspect of debris loading with a possible 80% of all cuttings thrown directly on to the gathering head via the drum cutting action. No figures are given for spiral heads although attention is drawn to the detrimental effect of debris thrown to the roadway edge by this cutting action.

The limit for economical excavation of rock with roadheaders is given at some 120 MPa although rock up to 150 MPa is also possible using the larger more powerful cutting units. There are surprisingly no rock mass qualifications to this statement other than that of abrasivity, which must not be too high. The aspect of cutter boom development in relation to machines and their ability to excavate harder rocks is discussed. New machines now incorporate limited cantilever designs with forward mounted lift cylinders giving rise to increased stability and reduced vibration from the effects of cutting. The layout of such boom designs are shown in FIG 1.19.

FIG 1.19 [73]

COMPARISON OF OLD AND NEW BOOM DESIGNS.



A report by Schneider [71] also compares the advantages of either head design and concludes the following;

For Spiral cutting heads

* A large, long spiral affords excellent loadability of the cut material.

* The smaller and narrow cutter head is suited to selective cutting.

* A high strength performance is reached in soft materials at around a UCS of 60 MPa.

* The head can operate in any direction.

* Penetration into the face is possible to the full depth of the head.

For Drum cutting heads

* A smaller cutter head with a high pick density allows for the successful cutting of rock at a UCS of 130 MPa.

* Due to its cutting technique, the drum cutter head can make use of the total machine weight to cut difficult strata.

The author, based on his experience of both head types would add three further comments.

(1) Machines employing the drum type head do not always cut in a vertical mode and as such the stability benefits do not always apply.

(2) The use of high pick density as a method of extracting hard rock has the disadvantage of requiring a higher energy input which results from a lower pick penetration.

(3) Unless the limitation in cutting ability is a result of insufficient motor power then the author would strongly disagree with the 60 MPa UCS limit given for the spiral type head.

A report by Boldt [75] discusses the production methods associated with bulk mineral deposits in particular salt and gypsum and comments on how the roadheader is gaining popularity at the expense of the Continuous Miner. The main reasons appear due to a change in circumstances as mining extends to less favourable deposits requiring equipment with a higher degree of flexibility.

Reference is made to Mines de Potasse d'Alsace (MDPA) which produce potash from mines in Alsace in the north east of France. The workings which were originally flat and uniform are now experiencing variable seam inclinations which affect both the shape of roadway and the proportions of rock which encroach the excavated profile. Performance from long standing equipment such as Jeffrey Heliminers has dropped significantly. Resultant discussions between MDPA and a roadheader manufacturer (Paurat), has led to collaboration on boom type machines specifically for these conditions.

The E195 at 46 t and with 170 kW of cutter power proved highly successful giving an average output of 2.1 tpm and an advance rate of around 400 m per month, with some eight units purchased. Results from a larger machine the E295 at 68 t and with 400 kW of cutter power gave output levels of 4.3 tpm and increased advances to between 600 and 800 m per month. Both machines have spiral type cutting heads which rotate at 50 rpm. The machine manufacturer hopes to achieve further sales of equipment, in particular to the Canadian Gypsum mining industry.

Case studies of the type just described have considerable benefit to those contemplating a similar machine application. It is unfortunate, but understandable, that detailed information relating to the cutting head design was not in this instance released. The relevance of this statement will become apparent following Section 3, which describes the lengthy development process for a cutting head suitable to the Domtar Salt application.

The final part of this section concerns the research undertaken by the Department of Mining Engineering of the University of Newcastle-upon-Tyne on behalf of Dosco Overseas Engineering Limited. The main aims of the research were to define the fundamental parameters controlling performance and hence improve the methods of machine design and selection. The work formed the basis of two Ph.D. studies and was undertaken by Speight [76] and Waggott [77].

The approach considered necessary by the Mining Department was one which would best reflect the actual machine conditions and methods of excavation. It would also be necessary to avoid both faults inherent in small scale modelling and problems associated with the monitoring of field machines. Operating under controlled conditions, such as those available in a full scale laboratory environment provided the best option.

Speight can be attributed with the initial design, build and testing of a linear cutting rig which would provide the facilities for evaluating machine cutting parameters in concrete and various rock types. The rig which in concept operates in a similar manner to a roadheader has been briefly described on page 15.

Following the completion of the rig commissioning, trials were carried out which included around 100 individual experiments utilising a selected mass concrete as the cutting sample. The final period of research was taken up in data interpretation and presentation.

The experimental programme produced significant conclusions and those considered to have particular relevance are listed below;

* The machine boom force is fundamental to performance and productivity.

* Higher productivity may be achieved by cutting in a vertical mode if the rate of movement can be made flow rather than pressure dependent.

* It is the boom force rather than the cutting power which decides the performance of the machine.

* By normalising relationships to be independent of head size, machine type etc, it should be possible to empirically develop performance curves for particular head lacing patterns from which rational preselection of machines for proposed applications can be carried out.

This final aspect showing how future machine selection could result from a new process which related specification to rock type was well received and indeed encouraged Dosco to continue to support the research.

Waggott in his work, extended the research and established similar cutting parameters to those of Speight [76], but in sandstone and limestone. Such parameters which are listed below have fundamental cutting importance and when developed in a specific relationship show how predicted performance can be achieved.

* Advance/Rev (cm) - Defined as the distance travelled in the direction of boom movement for each revolution of the head. In this respect it is similar to the depth of cut in linear cutting.

* Swept Area (m^2) - Defined as the cross-sectional area of the head in contact with the rock normal to the direction of travel.

* Spacing to Depth Ratio - Defined by the equation $S_L n/Ad$, where:
  S_L = line spacing of cutting head
  n = number of starts
  Ad = advance/rev
  and was originally considered so comparisons could be made with linear research.

* Specific Energy - As previously defined.

* Other aspects such as traversing force and cutting torque as related to a roadheader are fairly obvious and as such do not require detailed definition.

FIGS 1.20 and 1.21 are important examples of two such derived relationships and show the influence of force and torque, when related to swept area, on the rate of penetration. The regressed curves are in the form $Y = AX^B$.

These type of curves enable the penetration rate for a particular cutting head design to be determined.

FIG 1.20 [77]

ADVANCE/REV VERSUS FORCE/SWEPT AREA

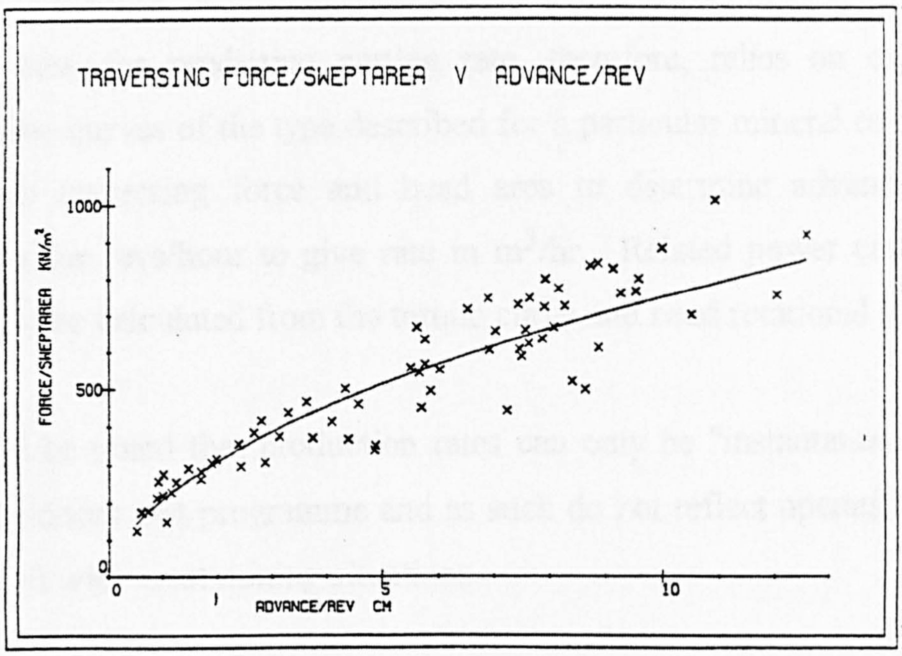
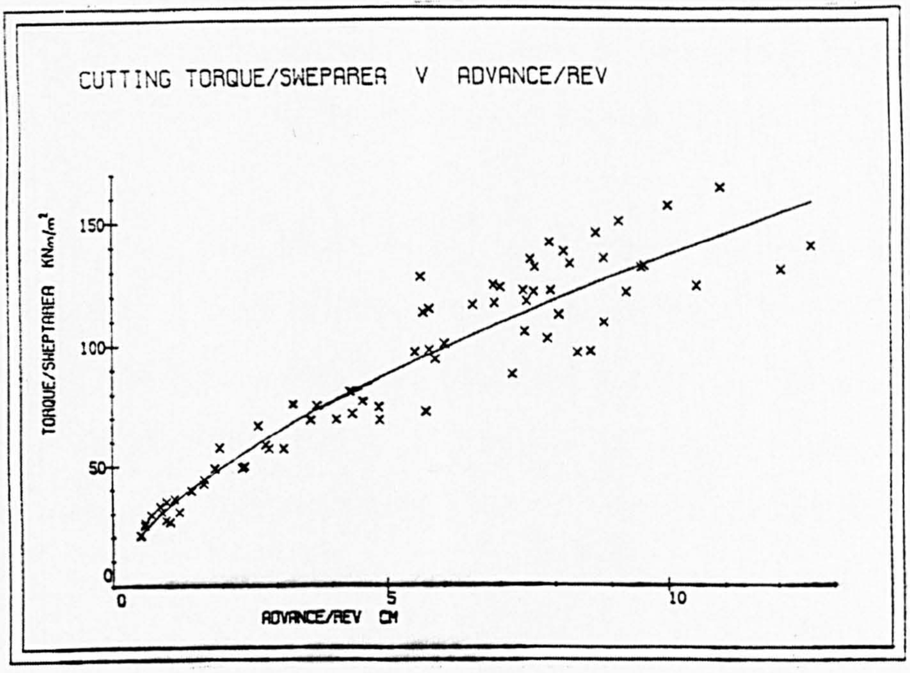


FIG 1.21 [77]

ADVANCE/REV VERSUS TORQUE/SWEPT AREA



Similar relationships established for a number of rock types gave similar shaped curves but with different A an B values. Waggott concluded that the A value increased with rock penetration force, as per the Standardised Cutting Test, and the B value was greatly influenced by any blunting effect of the tool.

The process for predicting cutting rate, therefore, relies on establishing penetration curves of the type described for a particular mineral or rock type, using the traversing force and head area to determine advance/rev and adjusting for revs/hour to give rate in m^3/hr. Related power consumption can easily be calculated from the torque curve and head rotational speed.

It should be noted that production rates can only be "instantaneous", based on a laboratory test programme and as such do not reflect operational delays associated with most mining situations.

1.4 CUTTING HEAD DESIGN

The necessary forces for excavation in the form of machine thrust and cutter motor torque are developed by the roadheader and these are focused at the cutting head. The head which can be described as a revolving cone shaped structure fastened at the end of a boom is the device which provides the cutting interface. Excavation involves an initial penetration of the head (called the sump), followed by lateral sweeps with the boom to remove the bulk of the rock. The final process is trimming to the required profile and loading of any remaining debris.

There are a wide variety of cutting head designs available to suit a range of mining conditions, machine specifications and cutting actions. The design of such heads encompass an array of cutting tools which radiate from the nose backwards usually in a scrolled pattern over the whole head. The cutting tools are normally arranged in such away, (called the lacing), to present an interactive cutting action as the head rotates about its axis. Ideally, such designs should reflect both machine specification and intended duty and in operation give rise to adequate penetration of the tools, an efficient cutting and debris clearing action and be capable of absorbing the high stress fluctuations associated with the rigours of the cutting cycle.

Experience shows that head design has a major influence on machine performance and in particular the cutting rate. It therefore follows that the correct head configuration for a particular application is vital and as such its importance can not be overstressed. Many might argue that this is the most significant aspect of any machine package, if it is to be successful.

Some of the first research into the aspects critical for good head design were carried out by Morris [78] at the MRDE. The work was primarily concerned with shearer drums and resulted in a computer package which could be used to produce optimum designs with related graphical printouts, highlighting such aspects as fluctuations in drum force loadings.

Hurt and McAndrew [79] and Hurt, Morris and McAndrew [80], in later research undertaken at both the MRDE and an underground site, investigated similar aspects, but in particular with regard to roadheader cutting heads. The work involved testing various cutting head designs, operating under similar conditions and comparing such aspects as tool line-space to penetration relationship, start or sequence number, cutting speed and depth of sump. The development of computer programmes to assist in the design of cutting heads was also a part of the research. Such programmes enabled the individual tool forces of a particular head design to be determined and from these the efficiency of the cutting action could be gauged. Computer printouts showed the angular position of cutting tools and related interaction of the cutting process and how for example the nose area is compromised by the lack of space to fit tool holders. The research produced several conclusions and these are summarised below;

* Cutting tools should have comparable duty.

* Cutting tools should not cut successively in the same grove.

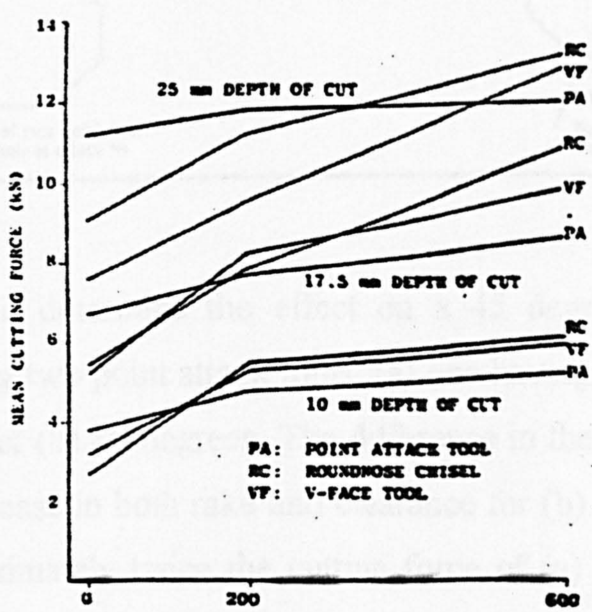
* For hard rock, cut spacings as low as 40 mm may be used, but for maximum output in softer rock 70 mm is better.

* The tools should take maximum depths of cut during traversing of at least 5 mm and preferably 10 mm or more. If necessary, the depth of sump should be reduced to allow this.

Studies by Hurt and Evans [81], Hurt [82] and Hurt and McAndrew [83], concentrate on the effects of tool type and attack orientation (presentation to the rock), during the cutting process. Tests in a moderate strength, but abrasive sandstone to compare point attack, round-nose and vee-faced wedge tools showed that while point attack tools initially require the highest cutting force , when blunt, the exact opposite applies FIG 1.22. Thus in abrasive conditions the point attack tools will give best service however, where conditions are such that the tools can be maintained in good condition conventional wedge tools will be superior.

FIG 1.22 [81]

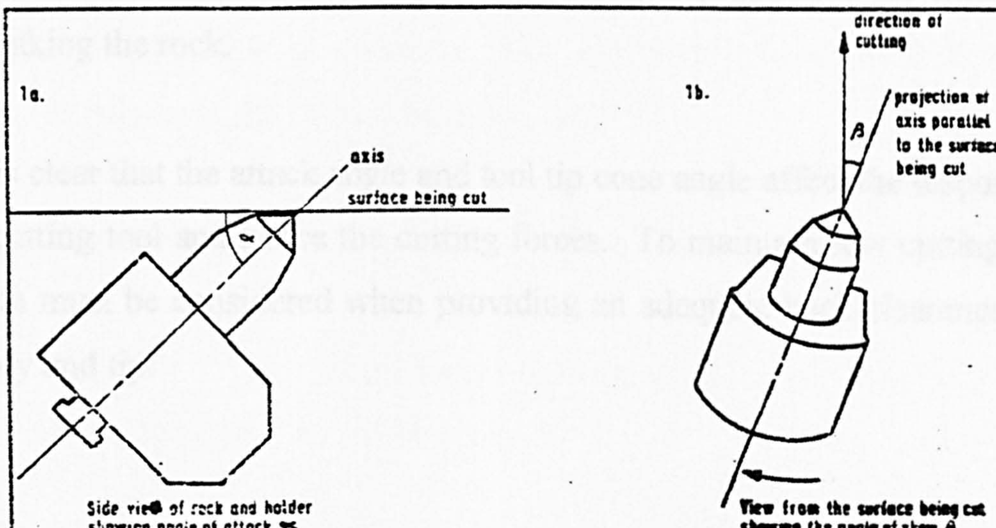
BLUNTING EFFECT ON MEAN CUTTING FORCE (THREE TOOL TYPES)



Hurt's work [82], considered the presentation of the tool when divided into its two fundamental components of angle of attack and skew. The angle of attack can be defined as the minimum angle between the tool axis and the surface being cut and appears to vary depending on manufacturer between 40 to 55 degrees. The angle of skew is the angle between direction of cutting and the axis of the tool when viewed normally to the surface being cut. It gives the head a sumping capability and is sometimes claimed to cause the tools to rotate and self sharpen. FIG 1.23 illustrates.

FIG 1.23 [82]

THE PRESENTATION ANGLES OF A POINT ATTACK TOOL



Investigations to determine the effect on a 45 degree attack angle were carried out using two point attack tools, (a) one having a tip cone angle of 76 degrees the other (b) 80 degrees. The difference in the cone angles results in a 2 degree decrease in both rake and clearance for (b). It was found that (b) required approximately twice the cutting force of (a) at any given depth of cut. Part of the body on (b) did project beyond its cutting path and this resulted in tool body contact giving rise to the high force requirement. After more cutting part of the projecting body of (b) had worn away and this resulted in a drop in cutting force but not to the level of (a).

A series of individual tests using tool (a) only, were recorded whilst varying attack angle from 40 to 60 degrees in 5 degree increments. The results showed that angle of attack had an important effect on tool forces with about 50 degrees corresponding to a back-clearance of 12 degrees giving the lowest cutting forces. Hurt concluded that at low angles of back clearance considerable rubbing occurs and tool forces increase but at values above about 10 degrees this contact is minimised. The forces then rise slowly with increasing angle of attack because the consequent reduction in rake angle means that the point of the tip is less favourably disposed for entering and breaking the rock.

It is clear that the attack angle and tool tip cone angle affect the disposition of a cutting tool and hence the cutting forces. To maintain low cutting forces, both must be considered when providing an adequate back-clearance to tool body and tip.

A series of tests were conducted at varying skew angles, the tool being angled towards the unrelieved side of the cut at settings varying from 0 to 30 degrees in 5 degree increments. The cutting force results were less conclusive than previous work, although there was some indication of a minimum force requirement at an angle of 15 degrees.

Rotation of the tool in its holder during cutting is sometimes observed although its occurrence seems to depend mainly on the type of ground being cut and the level of clearance between the tool and its holder. No rotation was observed when cutting Darley Dale or Grindleford sandstone as fine particles filled the gap between the holder and the tool. Some rotation was however observed when cutting non-abrasive Middleton limestone and there was a tendency for holders to become less seized.

A summary of Hurt's conclusions are as follows;

* For efficient cutting the tool tip has to be large enough to clear a path for the tool body.

* A minimum back clearance of 12 degrees was also necessary for efficient cutting.

* The provision of adequate back clearance also eliminated frictional sparking of the point attack tool used.

* The skew angle did not have any great effect on efficiency.

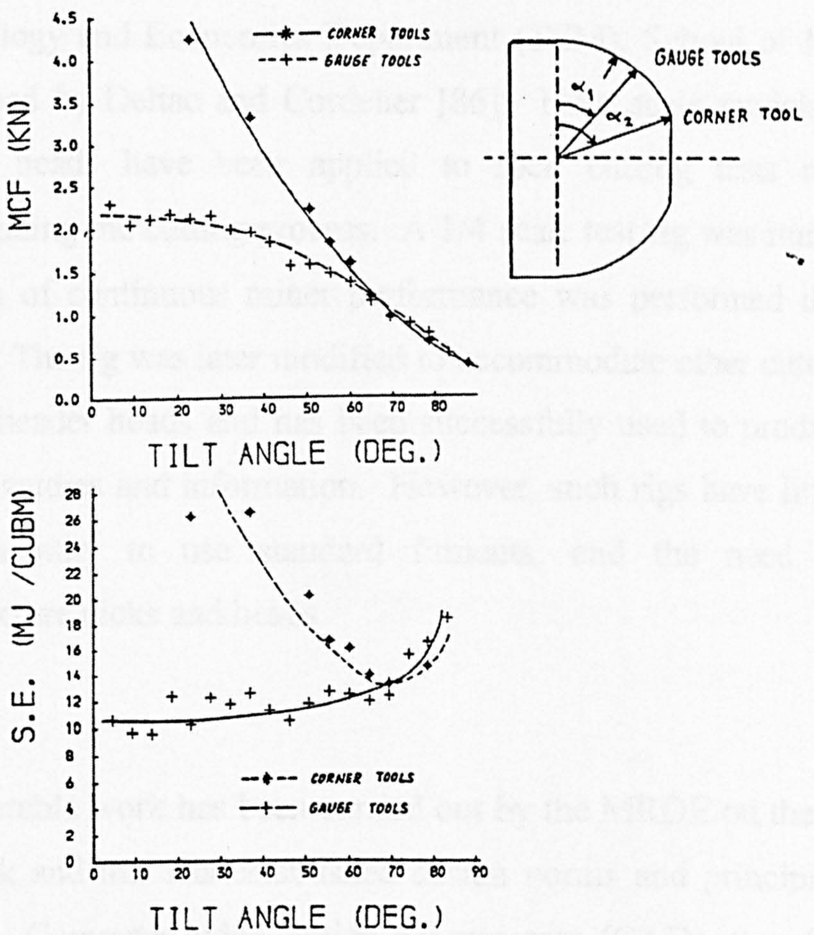
* Rotation of point attack tools does not result in "self sharpening" but is a symmetrical form of blunting.

Two interesting studies by Hekimoglu and Fowell [84][85], investigate the positioning of tools on the cutting head. The nose section of the head in particular poses problems for the designer as it has to provide a sumping capability and also allow a smooth transition between the sumping and arcing tools on the cylindrical portion of the head. This requires the tools to be tilted to the perpendicular to the head axis.

A series of laboratory tests simulating the cutting action of a roadheader but with various lacings and tilt angles were undertook with the effects gauged against cutting force and specific energy FIG 1.24 [84]. In both cases, force and energy requirements reduced as tilt angles increased with an optimum being achieved around 65 degrees. Further testing involved the production of several cutting heads using the modified tilt angles with actual roadheader performance monitored at several underground sites in Turkey.

FIG 1.24

TILT ANGLE CUTTING RESULTS



The main conclusions can be summarised as follows;

* The cutting head nose design should be based on the hardest material expected and requires special attention.

* The avoidance of head design with harmful induced vibrations has to be undertaken to prevent major machine component failures. In this context tilt angles of 65 to 70 degrees offer the lowest specific energy and relative freedom from vibration problems.

* There was found to be a great difference in cutting rate, tool consumption and cutting head life for nominally similar designs.

The use of reduced scale testing equipment has gained backing at the Mining Technology and Economics Department (TEM), School of Mines, Paris, as developed by Deliac and Cordelier [86]. Here scale models of actual pick cutting heads have been applied to rock cutting tests as a means of investigating the cutting process. A 1/4 scale test rig was manufactured, and analysis of continuous miner performance was performed during the early 1980's. The rig was later modified to accommodate other cutting heads, such as roadheader heads and has been successfully used to produce preliminary cutting studies and information. However, such rigs have limitations due to their inability to use standard fitments, and the need to specifically manufacture picks and heads.

Considerable work has been carried out by the MRDE on the cutting of coal and rock and this has established design norms and principles for efficient cutting. Computer-aided design programmes (CAD), to reflect such work have subsequently been developed and are available to cutting head manufacturers. The programmes are user friendly, but do require the user to be a specialist in head design in order to fully understand the screen displays. In order to illustrate how a CAD programme works, head design is considered against three important aspects fundamental to efficient cutting MRDE [87].

Manufacturing Feasibility. The cutting head boss is defined on the screen with the pick line spacings, number of starts/spirals and number of picks/line required. The computer then positions the pickboxes so they do not interfere. Gaps can be left for welding and water sprays and individual pickboxes can be moved or deleted. Screen displays show head changes and the system allows the head to be rotated on the screen and hence viewed from any position FIG 1.25 [87].

Pick Loading. Pick loading is assessed by use of the breakout pattern. This is a diagrammatic display of the area of rock that each pick is required to cut by virtue of its position on the head. Screen displays are dynamic so that the cutting process can be seen in slow motion. When complete, the cutting pattern can be viewed and should show, that areas removed by the picks are sensibly equal with no pick overloaded or under utilised FIG 1.26 [87]. Any corrections can easily be made by moving individual boxes to optimise design.

FIG 1.25 [87]

PICK POSITIONS LOOKING ALONG BOOM AXIS

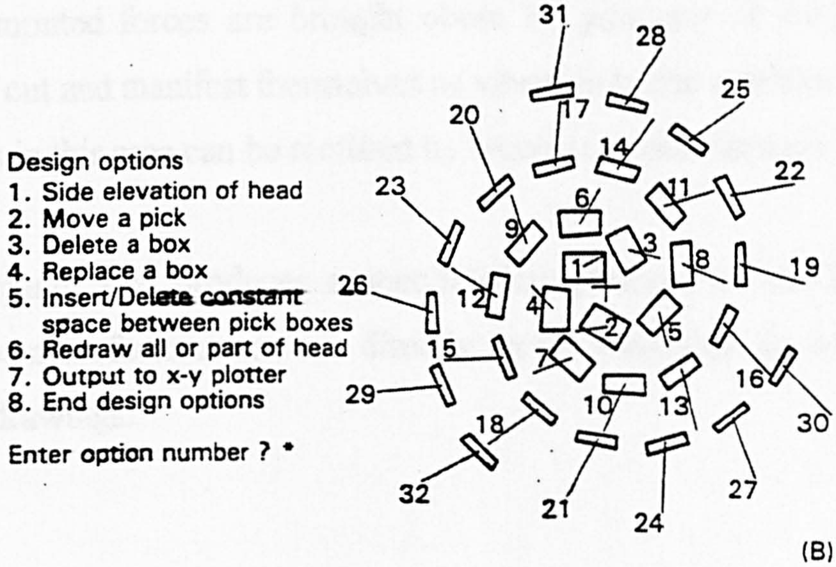
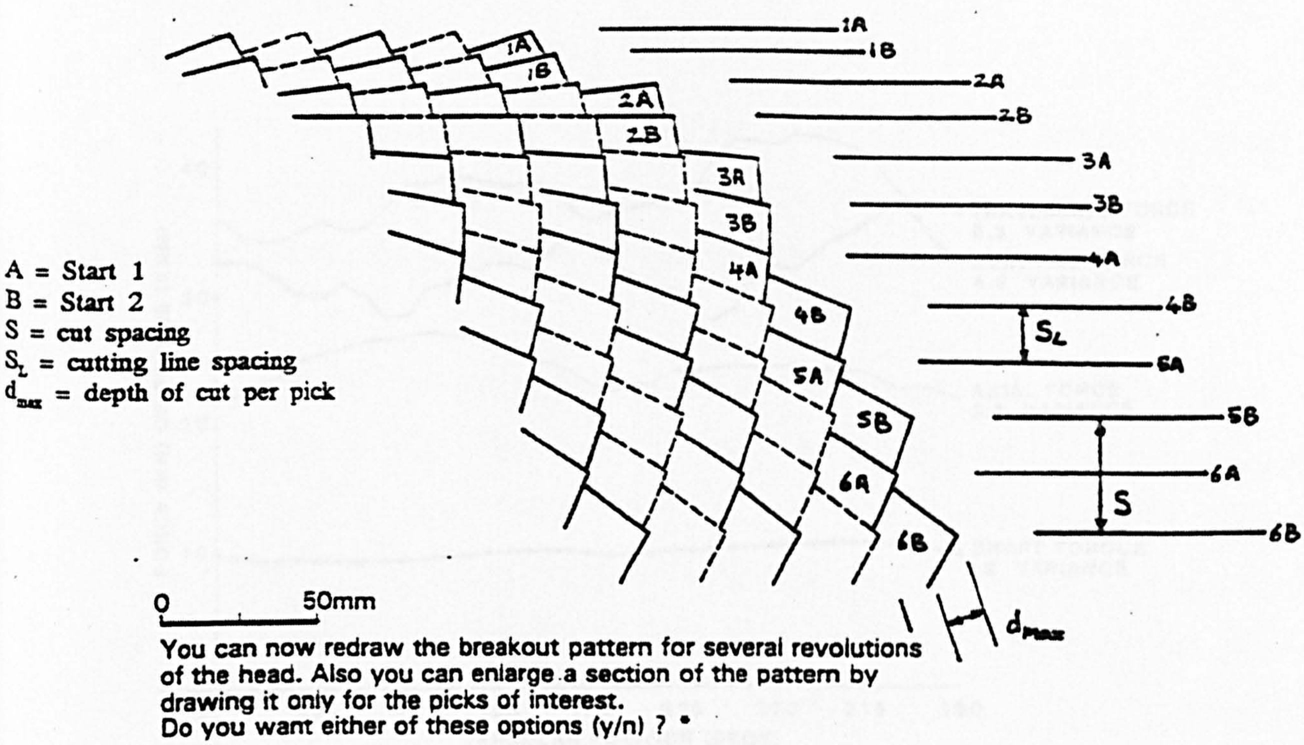


FIG 1.26 [87]

BREAKOUT PATTERN FOR CAD HEAD

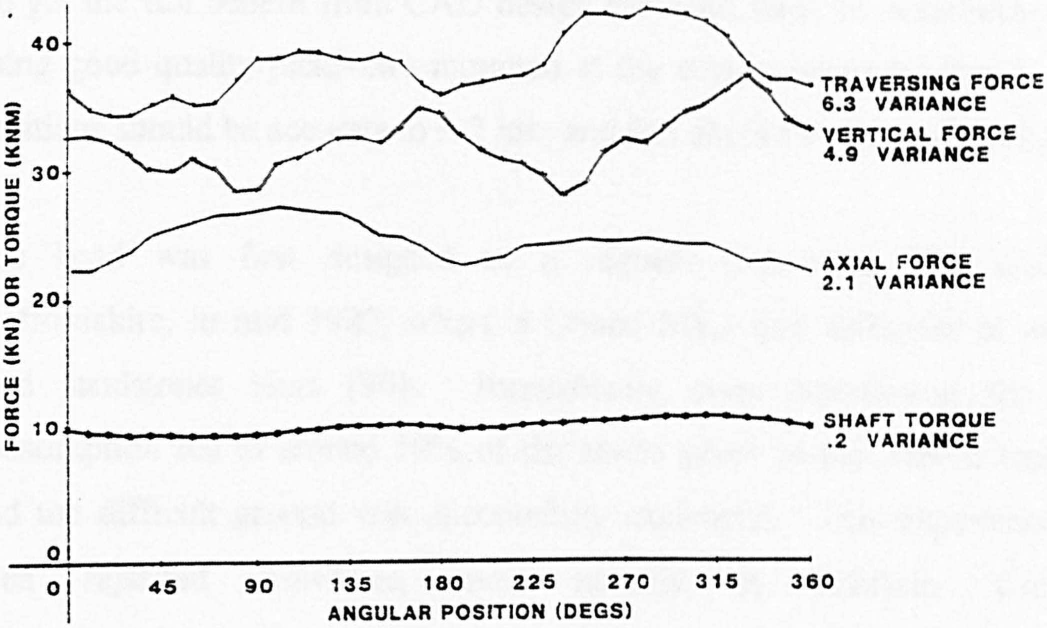


<u>Vibration Analysis</u>. The probability of excessive vibration is checked by computing the forces produced by the head as it cuts through one revolution. Screen displays show relationships between motor torque and the components of force transmitted to the boom FIG 1.27 [87]. Fluctuations in these computed forces are brought about by grouping of the picks in the sector of cut and manifest themselves as vibration to the machine. Again, any problems in this area can be rectified by recourse to the displays.

The computer also produces a specification print-out of the lacing design which the manufacturer can use directly on his workshop jig without further need of drawings.

FIG 1.27 [87]

FORCE BALANCE DIAGRAM FOR WELL DESIGNED HEAD



The benefits to be obtained by careful design of cutting heads with the aid of CAD have been demonstrated in several studies. Hurt [88] and Hurt and Morris [89] produce a comparisons with a standard head as fitted to many Dosco MK3 roadheaders and a CAD unit produced under the control of MRDE. The cutting head has two pick starts/spirals with one pick in each cutting line. Research has indicated the value in maintaining a narrow pick line spacing of about 20 mm in the critical corner cutting regions where the maximum pick duty occurs. At the same time the line spacing near the back of the head increases to 30 mm, to give a total of 44 cutting tools about 20% less than is usual on the Dosco MK3. An excellent breakout pattern was achieved with no picks either overloaded or under utilised. The variation in forces induced by the cutting head can be minimised and the "wrap" of the spirals can be adjusted and the resulting vibration level calculated. The CAD head, despite having fewer tools, had significantly lower vibration levels than previous heads.

To get the full benefit from CAD design the head must be accurately made using good quality pickboxes mounted at the correct angle of attack. Pick positions should be accurate to ± 2 mm and this should be carefully checked.

The head was first designed to a request from Lea Hall Colliery, Staffordshire, in mid 1982, where a Dosco MK3 had difficulty in cutting hard sandstones Hurt [90]. Immediately upon installation the pick consumption fell to around 10% of the levels given to the head it replaced and the difficult ground was successfully excavated. This experience has been repeated elsewhere, most notably at Thoresby Colliery, Nottinghamshire. Here detailed records show a CAD head reduced pick consumption from 16 to 3 picks/m advance in similar conditions. Engineers in charge of all installations where CAD heads were used commented favourably on a smoother cutting action and less machine vibration. Finally, comment is made on how CAD heads together with the best possible standards of manufacture can substantially improve the performance of roadheaders and so reduce the cost of roadway drivage.

Hurt, McAndrew and Morris [91], discuss cutting vibration, its effect on roadheaders and how head design has a major role to play. Results of roadheader cutting vibration using an instrumented cutting rig show large low frequency components, typically less than 20 Hz dominate the vibration spectrum. These frequency peaks correspond to multiples of cutting head rotational frequency and are generated by variation in pick loading as the head rotates, in other words, by poor cutting head design.

The effects of cutting vibration on roadheader reliability are well known; loosening of bolts and fasteners is a major problem, which can lead in turn to component wear and damage through misalignment. The failure of welds and structural members has been attributed to vibration induced fatigue, and the effects of vibration on bearings and rotary seals has been cited as the cause of early failures of gearboxes and electric motors. The importance of machine vibration as an inhibiting factor in the application of roadheaders in hard rock has also, not gone unnoticed.

One approach to the problem has been to relate cutting force fluctuations to the design of the cutting head and so reduce vibration levels by appropriate design - Hurt [87]. As a result of this work a theoretical vibration level calculation technique was developed as part of a CAD package for roadheader cutting heads. The objective of this work was to take the research a stage further, by measuring roadheader cutting vibration under controlled conditions and determine the effect of major variables such as head design, pick type, pick condition and rate of cutting.

The practical implications of the work emphasised the importance of correct cutting head design to minimise machine vibration levels and confirmed that the existing computer model gives an adequate assessment of vibration levels. The results also show that the use of point attack or worn radial tools increases the vertical force fluctuations; i.e. the cutting head becomes difficult to hold in position as the boom is slewed, and although point attack picks give longer life in hard rocks, they may exact a penalty in the form of reduced machine reliability. Some of the worst cases of excessive vibration leading to machine damage were as a result of inaccurate head manufacture, and in a few cases picks were found to be as much as 20 mm out of alignment. Although isolated missing picks have only a minor effect on the cutting head balance a single pick cutting 20 mm deeper than its neighbour is potentially disastrous. In order to operate satisfactorily as designed, the manufacturing tolerances allowed on pick positions should be no more than $\pm$ 2 mm and pick angles should be correct to $\pm$ 2 degrees.

The main conclusions can be summarised as follows;

* The cutting action of a roadheader generates force fluctuations which are predominantly of low frequency and are mainly composed of discrete low frequency peaks corresponding to multiples of cutting head rotational frequency.

* Cutting head design, pick type and condition, exert a major influence on the vibrational mode and level.

* The computer model for calculating force fluctuations was found to accurately predict the effect of cutting head design on the vibration mode and level. The model is capable of further development to include the effect of pick type and condition.

The computer packages developed by the MRDE for British Coal are still the current reference system for the design of roadheader cutting heads, although this system has been upgraded for use on IBM PC type micro computers. Various machine and cutting head manufacturers also use such design packages. As already stressed the manufacture of cutting heads must be carefully controlled with tolerances maintained, otherwise the detailed design processes will have minimal effect.

2. INTRODUCTION TO RESEARCH PROJECT AT DOMTAR SALT

2.1 DOSCO OVERSEAS ENGINEERING LTD.

Dosco Overseas Engineering Ltd. specialises in the design and manufacture of mining and tunnelling equipment. The product range mainly consists of excavating machines, more commonly known as "roadheaders", whose application is diverse in mining and civil engineering, and in a variety of mineral and rock types.

Equipment takes the form of tracked, self contained cutter units which are electro hydraulically powered and capable of excavating a face or a bench. Cut debris is loaded by a gathering head and is fed through the machine by a chain conveyor, where it is discharged at the rear on to a suitable conveying system. The machine can be equipped with a variety of accessories, such as arch setting brackets and roof bolting drills, and these can be designed to suit specific applications.

Evolution of the range has progressed over many years with particular applications, be it mining or civil, giving rise to a varied machine development programme. In latter years, considerable emphasis has been placed on specific machine parameters to suit individual sites and requirements.

Historically, the main thrust of Dosco business has been UK based, with machines supplied ranging up to 90 t and 400 kW installed power. Much of the equipment has centred on the coal mining industry, although civil tunnelling gained importance and benefited from proven componentry specifically re-worked to suit circular applications.

2.2 APPROACH TO PERFORMANCE PREDICTION

Prediction of machine performance, i.e. whether it could tackle a particular rock type, and at what rate, was a normal sales requirement, and therefore basic relationships between an easily identified parameter, in this case rock strength, and cutting rate were established using field data and laboratory unconfined compressive strength (UCS). The resulting prediction curves were of a general nature and only suitable as a guide in sedimentary conditions. Typical curves for a light, medium and heavy duty machine are shown in Fig. 2.1.

Further testing procedures to complement UCS, primarily to determine cutting energy requirements and abrasivity levels were undertaken, with general relationship between specific energy (SE) and cuttability established. See Table 2.1 [1].

While this provided a significant step forward, it did not allow for full performance prediction.

During the 1980's and with the decline of the home based market, Dosco sought to expand its business through export sales, in particular targeting coal mining and civil tunnelling, as well as forays into unknown territories, such as evaporite deposits.

FIG. 2.1

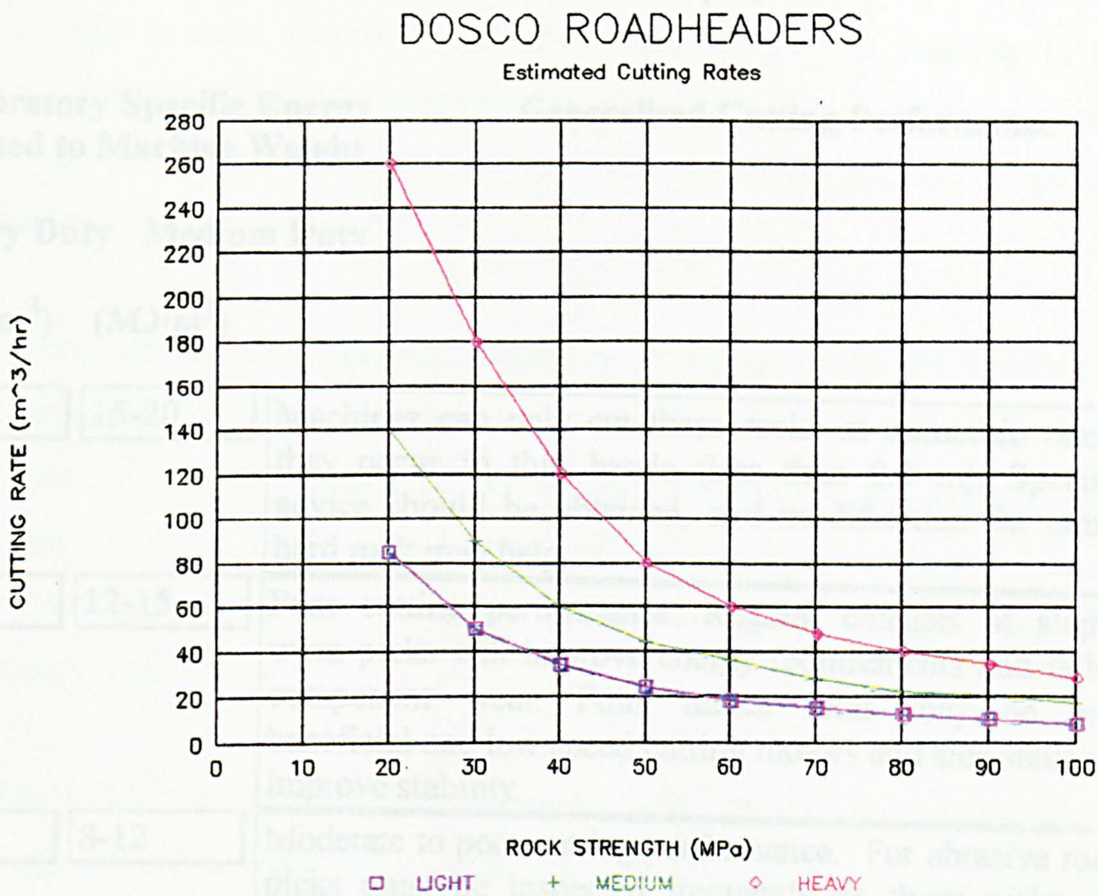

DOSCO ROADHEADERS
Estimated Cutting Rates
CUTTING RATE (m^3/hr)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
ROCK STRENGTH (MPa)
LIGHT
MEDIUM
HEAVY

TABLE 2.1
MACHINE PERFORMANCE RELATED TO LABORATORY SPECIFIC ENERGY [92]

Laboratory Specific Energy Related to Machine Weight: Heavy Duty (MJ/m^3)	Laboratory Specific Energy Related to Machine Weight: Medium Duty (MJ/m^3)	Generalised Cutting Performance
25-32	15-20	Machines can only cut these rocks at economic rates if they occur in thin bands (less than 0.3 m). Specialist advice should be obtained, and modification for cutting hard rock may help.
20-25	12-15	Poor cutting performance. Regular changes of slightly worn picks will improve energy requirements and reduce component wear. Point attack tools may be more beneficial and low speed cutting motors and side stells will improve stability.
17-20	8-12	Moderate to poor cutting performance. For abrasive rocks picks must be inspected frequently as sharp picks will improve performance.
8-17	5-8	Moderate to good cutting performance with low wear of machine components. Picks must be changed regularly when excavating abrasive rocks.
Under 8	Under 5	Machines well suited to these rocks. High advance rates. Mudstones in lower end of category may be ripped rather than cut and very high cutting rates can be achieved.

As a consequence of operating internationally and with the constant exposure to competitive manufacturers, it became obvious that it would be necessary to offer realistic machine production rates, and to be prepared in many instances to guarantee performance; something not normally undertaken. With this in mind, the need to establish improved machine performance criteria became paramount.

Accepting the challenge, and following discussions with the University of Newcastle-upon-Tyne, a contract to establish a laboratory prediction model suitable to Dosco Roadheaders was placed. The basis of the contract was the construction of a full size test cutting rig and exhaustive testing in a number of homogeneous rocks, followed by in-depth reporting of the results with conclusions.

By 1988, the contract was complete, with Dosco in possession of a methodology suitable for establishing machine performance, a prediction model and a considerable file of laboratory reference data [76], [77].

During 1988, an enquiry for a machine application in salt was received. Although previous investigative work in this type of material had been undertaken, it was felt that this site could provide further valuable data with which to correlate with Laboratory results.

Early in 1989, Dosco agreed a contract to supply a medium duty roadheader, the LH1300H, on trial to Domtar Salt Ltd. in Canada, and the author was committed to oversee and progress the trials to a satisfactory conclusion.

By way of further information, the author has spent some 29 years in the mining industry, the last nineteen years employed by Dosco, with Project

Control, Site Investigation, Machine Performance Prediction and Operational Research forming the basis of his duties.

2.3 PROJECT DESCRIPTION

Domtar Salt is located in Eastern Canada, about 100 km west of Toronto, with the actual mine site situated in the town of Goderich, on the shores of Lake Huron. Plate 2.1 shows general location.

The mine, as its name suggests, produces rock salt from a large underground deposit, some 500 m below ground, and it has vast reserves extending out under the lake.

Current mining practice involves the extraction of high volumes of salt, 2-3 mt p.a. from a cyclic drill and blast, room and pillar type operation. Rooms are large, up to 20 m wide, and similar in height, and are advanced some 2-3 m per blast. Loading operations follow blasting, using large capacity Load-Haul-Dump trucks (LHD's), with a lengthy, but vital, scaling operation to finish the cycle.

PLATE 2.1

Scaling is a major problem at Domtar. It can be dangerous due to the roof height, and is time-consuming in operation. This can ultimately give rise to expensive compensation claims from workers involved in the task. This particular aspect of the mining system, when coupled with new legislation proposals to increase employer liability, obviously gives rise for concern and needed to be addressed.

Changes to the current mining system were evaluated, resulting in discussions with several roadheader manufacturers, whose machines, it was hoped, could be developed to produce salt at an acceptable rate, while negating the need to scale.

The success of any machine required the following aspects to be duly considered:-

* **Production rates suitable to the Domtar operation.**
* **Minimum fines production.**
* **Low operating costs, in particular pick consumption.**
* **Manufacturer's ability to extrapolate results against a larger production machine.**

Against these parameters, manufacturers were given the opportunity to propose a suitable test bed machine and to negotiate trial terms covering a period of six to nine months, with a possible extension to twelve months. Complementing this, Domtar undertook to provide a suitable site and to supply all the necessary manpower and back-up services.

Dosco recognised the importance of such a trial from the benefit of operational data but, more significantly, from the influence a committed and informed manufacturer might have on future machine sales. It therefore proposed a medium duty roadheader with high installed power, which was considered generally suitable with regard to cutting and penetrating forces, but likely requiring some head and cutter pick development.

The roadheader proposed was a re-furbished LH1300H, a low height, medium duty unit, utilising an axial cutting action, i.e. rotation around the central axis of the machine. In an effort to offer some flexibility on standard two-stage rotational head speed, a second, higher-powered boom option was included. Table 2.2 gives the general machine specification and Plate 2.2 shows the machine at base prior to despatch.

An unusual feature of the machine was a requirement to fit a closed loop cooling system, since normal water discharge via the cutting elements was not acceptable, due to the degrading effect on the salt. This aspect was fully appreciated, with an air blast radiator being sourced locally and fitted at the mine site. Plate 2.3 shows the machine underground with the cooling system in use.

Prior to serious contractual discussions, Dosco obtained several salt samples for testing, and surveyed the intended site. No major problems were identified, other than a thin band of dolomitic limestone, some 150 mm thick and close to roof line. Plate 2.4 shows its extent and face position.

TABLE 2.2

LH1300H GENERAL SPECIFICATION

Overall length	10205 mm
Overall height	1583 mm
Overall width	3530 mm
Machine weight	52 tonnes
Maximum cutting height	4336 mm
Maximum cutting width	6263 mm
Maximum sumping force	357 kN
Maximum lifting force	106 kN
Maximum arcing force	130 kN
Cutter motor size @ 60 Hz	170/270 kW
Cutting head speeds @ 60Hz	33/60 and 63 rpm
Machine conveyor	Centre strand electric
Speed of conveyor	2 m/s
Conveyor motor @ 60Hz	67 kW
Conveyor throat	400 by 711 mm
Gathering method	2 * spinners
Gathering spinner speed	49 rpm
Track speeds	0.0045 and 0.187 m/s
Track drive motors	Hydraulic
Track length contact	3146 mm
Track centres	2254 mm
Track pad width	550 mm
Track ground contact pressure	0.147 MN/m^2
Maximum tracking effort	357 kN
Power pack motor @ 60 Hz	134 kW
Number of pumps	1

PLATE 2.2

LH. 1300H PRIOR TO DESPATCH TO SITE

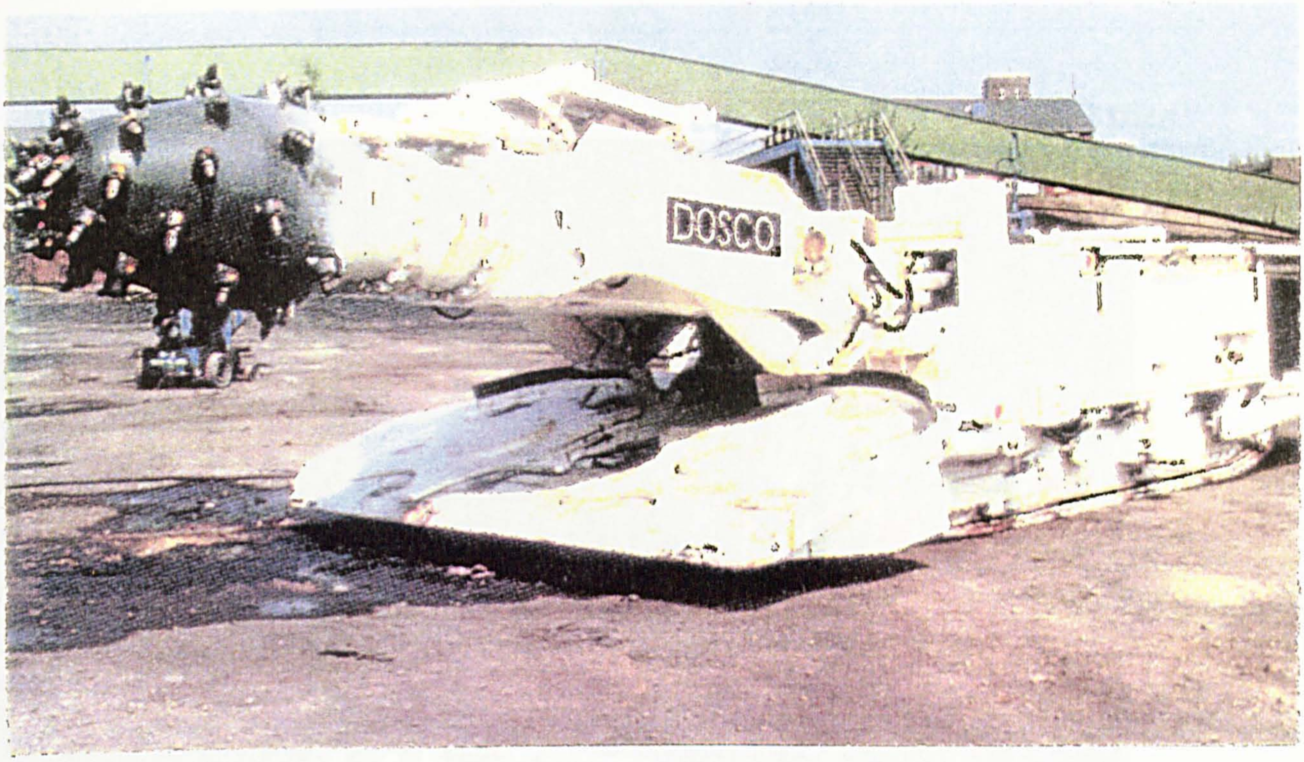


PLATE 2.3

LH. 1300H SHOWING COOLING SYSTEM

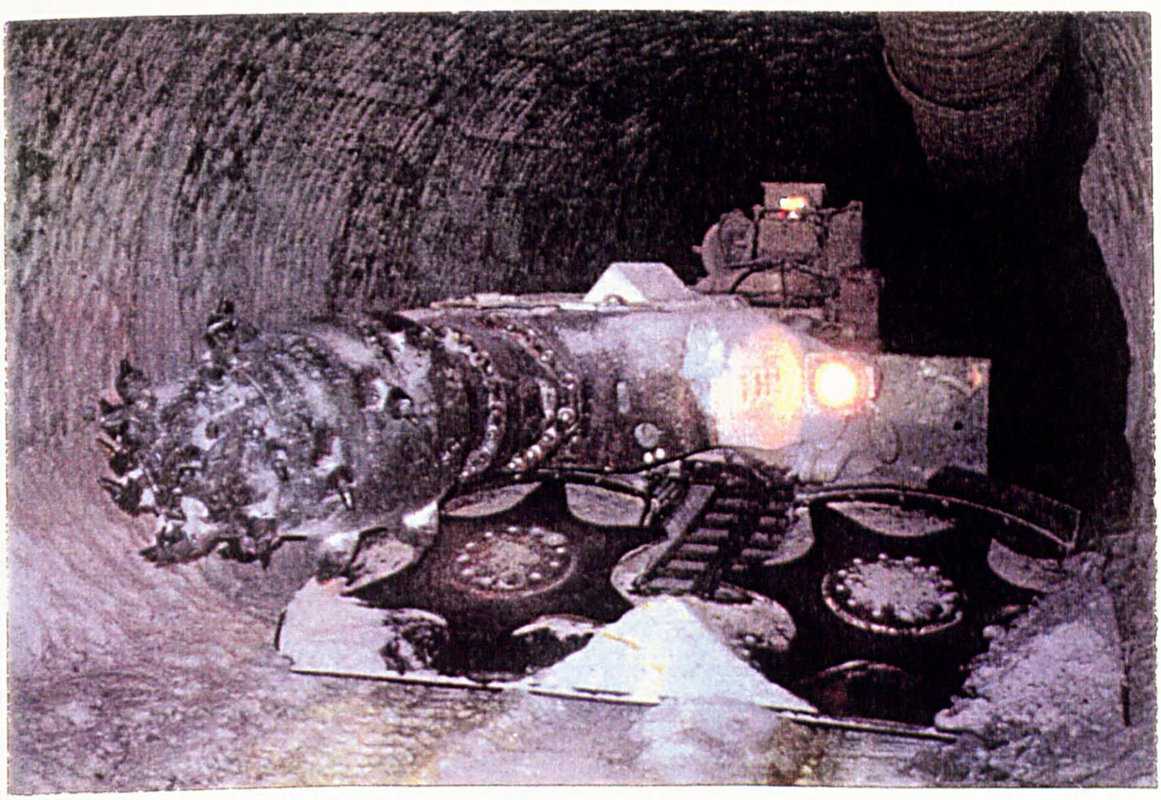


PLATE 2.4

POSITION AND EXTENT OF HARD DOLOMITIC LIMESTONE BAND

Reducing the machine cutting height was proposed. However, this was not possible due to the planned mining horizon, and therefore was accepted as a necessary part of the trial.

Salt samples were analysed in the UK, and complete results, including UCS and SE values, are shown in Table 2.3.

At this stage a comparison between salt and coal is made, as these two minerals are good examples of where variations in machine performance can occur.

As an example of how misleading UCS can be, test comparisons between salt and coal are shown in Table 2.4. While both have similar UCS values, field experience in salt gives lower production rates, with a much greater use of cutter power. Laboratory cutting tests confirm this view, with much higher SE values being recorded for salt. Obviously, as performance is a function of cutter motor energy, then SE appears more suited to performance assessment in this case. This aspect clearly shows the need for full laboratory assessment to identify both UCS and SE levels.

A description of cutting tests, as undertaken by the University of Leeds, is included for reference as Appendix 2.

TABLE 2.3

TEST ANALYSIS OF SALT

Unconfined compressive strength (MPa)	28.70
Cerchar abrasivity index	Nil
Density (t/m^3)	2.14
Mean cutting force (kN)	1.40
Peak cutting force (kN)	3.01
Mean normal force (kN)	0.46
Peak normal force (kN)	0.85
Specific energy (MJ/m^3)	10.52
Tool cutting wear (mm/m)	Nil
Note:	
Unconfined compressive strength of limestone (MPa)	72.70

TABLE 2.4

COMPARISON BETWEEN SALT AND COAL TEST RESULTS

	Salt	**Coal**
Unconfined compressive strength (MPa)	**28.70**	**27.20**
Cerchar abrasivity index	Nil	Nil
Density (t/m^3)	2.14	1.40
Mean cutting force (kN)	1.40	0.31
Peak cutting force (kN)	3.01	1.02
Mean normal force (kN)	0.46	0.19
Peak normal force (kN)	0.85	0.58
Specific energy (MJ/m^3)	**10.52**	**4.72**
Tool cutting wear (mm/m)	Nil	Nil

2.4 DOMTAR TRIAL OBJECTIVES

The trial was to extend to a maximum of twelve months' duration and involve Dosco and Domtar as main parties. It would also involve a cutter pick manufacturer, as and when required.

Four main aspects to be considered in the trial were:-

* **To produce mineral with a fines content of less than -12 mesh (Tyler) at below 10%. Table 2.5 shows the range of mesh sizes with metric equivalents.**

* **A production rate of 200 tph.**

* **A pick consumption of 1 per 150 tonne.**

* **Extrapolation of results to the largest roadheader currently available in the Dosco range.**

The trial was to culminate in separate reports from both main parties, and all information would be bound by a secrecy agreement.

Finally, there would be no obligation on the part of Domtar Salt to purchase equipment following a successful trial.

TABLE 2.5

TYLER MESH VALUES

Imperial (inches)		Metric (mm)
3.00		76.20
2.00		50.80
1.50		38.00
1.05		26.67
0.74		18.85
0.50		12.70
0.38		9.52
6 mesh		3.35
12 mesh		1.52
28 mesh		0.53
60 mesh		0.25

3. DEVELOPMENT OF THE CUTTING HEAD DESIGN AT DOMTAR SALT MINE

3.1 INTRODUCTION

This section of the report concerns the development of the cutting head lacing pattern necessary to produce at a size fraction less than 12 mesh of below 10%.

A considerable file of information has resulted from over 370 individual cutting tests, and for the sake of clarity these have been condensed into readable groups in the data chart, attached as Appendix 3 to the main report.

The trial period can be split into three main sections covering the initial investigation, the development of the head, and finally a realistic proving of the preferred head design. The first stage concerns the standard head normally used in road heading applications, a 3-start, 1 pick/line arrangement, utilising 42 pick boxes at a nominal 30 mm line spacing. The second stage includes the opening up of the lacing on this head and the testing of a wide laced 2-start head, while the final stage is devoted to the testing of the finally derived 3-start, 1 pick/line arrangement, utilising 24 pick boxes on a line spacing varying from 65 mm at the nose section to 80 mm over the main body.

3.2 TESTING PROCEDURE

The machine worked a horizontal bench, normally excavating full width, nominally 5.5 m, and full height, nominally 4 m. The section included a 15 cm thick band of hard dolomitic limestone, some 1.2 m from the preferred roof line. Cut salt was gathered conventionally prior to being rear dumped into a large Load-Haul-Dump truck. Plate 3.1 shows a typical unit.

Testing involved a series of confined cuts, followed by under-cutting and over-cutting at a web height of around half head diameter, the cuts being carried out over a range of sump depths.

Confined cuts produce a slot in the face and do not gain benefit from a free cutting edge. Under and over-cutting exploit the slot, either above or below, and do benefit from the free edge.

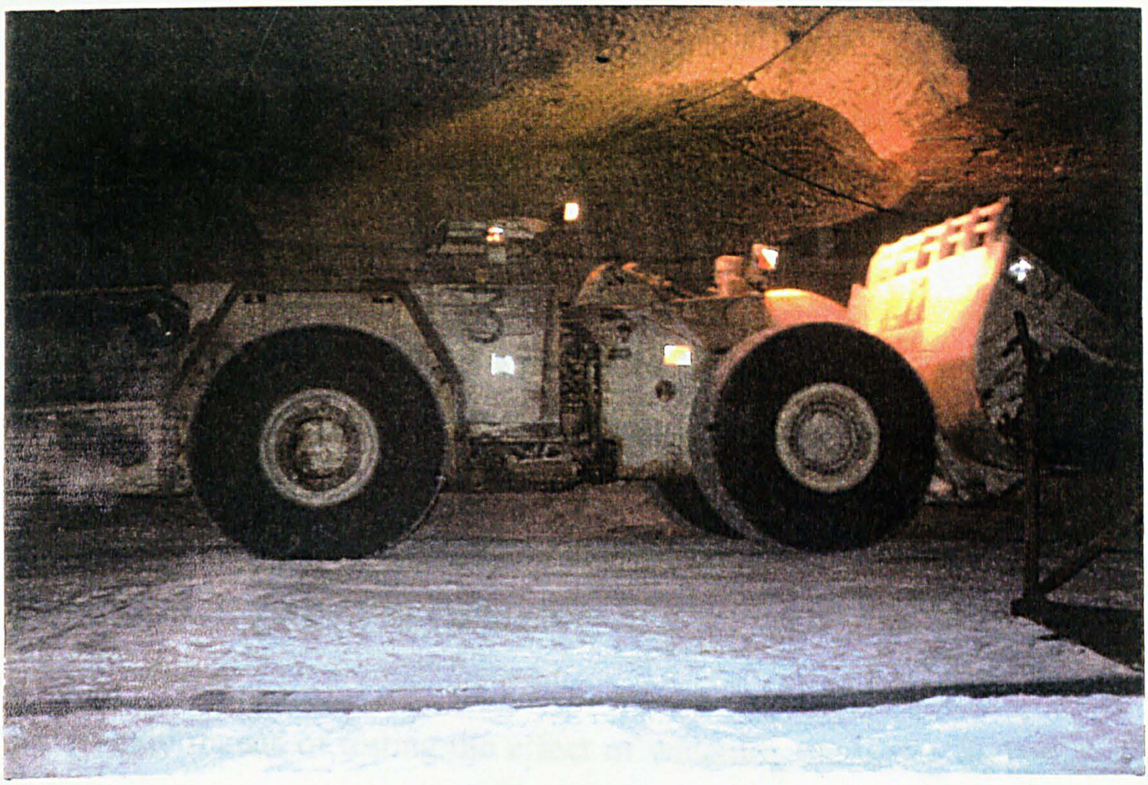
Following each cut, debris amounting to around 30 kg was collected for laboratory sizing analysis, the product being separated at Tyler mesh values of 3", 2", 1.5", 1.05", 0.742", 0.5", 0.375", 6 mesh, 12 mesh, 28 mesh and 60 mesh.

3.3 STAGE 1 - 42 BOX HEAD

During this stage, 127 individual cuts were tested with the boom cutting in a horizontal mode, and a further 43 cuts were tested with the boom cutting in a vertical mode. Head rotational speed was constant at 63 rpm, and pick gauge varied from 90 to 114 mm.

PLATE 3.1

LHD TRUCK



Sizing analysis for the two separate modes of cutting is shown in Figs. 3.1 and 3.2. Both results show an unacceptable fraction of material at -12 mesh, 21.9% for the horizontal cuts and 25.7% for the vertical cuts.

Detailed analysis of the results for the horizontal cuts show that variation in pick length over the range examined did not have any significant effect on the product size.

Cutting in the vertical mode appeared to be worse than in the horizontal mode, and produced unacceptable machine vibration. No further testing was carried out in this mode.

3.4 STAGE 2 - DEVELOPMENT

As a ready means of testing the effect of widening the lacing on the cutting head, picks were removed such that the effective lacing was widened from a nominal 30 mm to 60 mm, the head then carrying 23 picks.

The results of this action can be seen in Fig. 3.3, where there is a significant reduction in the -12 mesh fraction to 16.3%, and a significant increase in the larger size fractions. The target value of less than 10% at -12 mesh had not been reached.

FIG. 3.1

Sizing Analysis Cuts A–F, G–M, N–T

43 picks, 90,100,115mm reach, 63 rpm

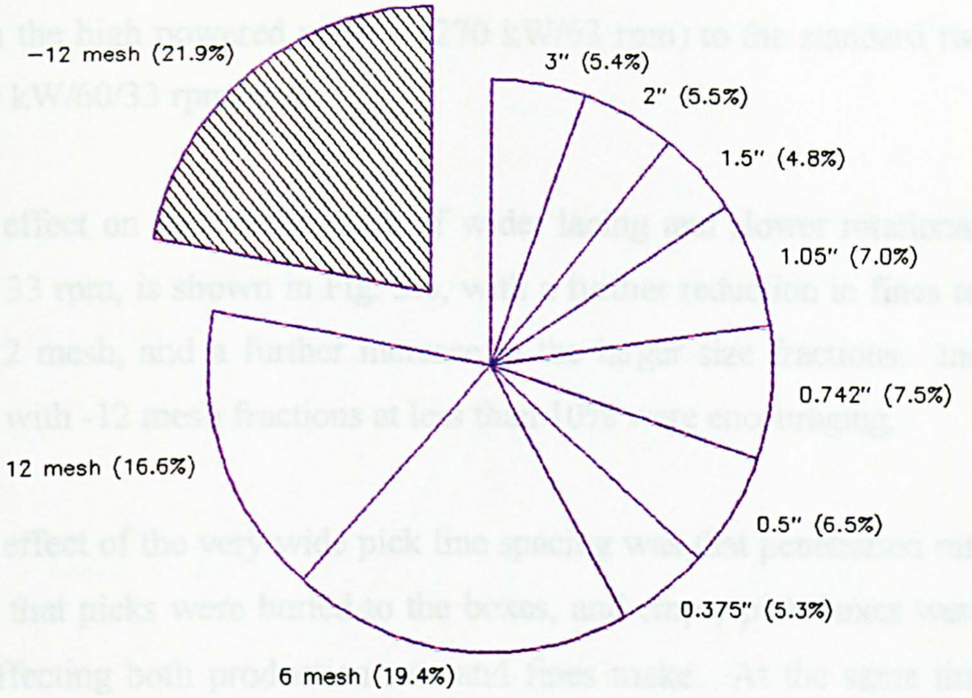
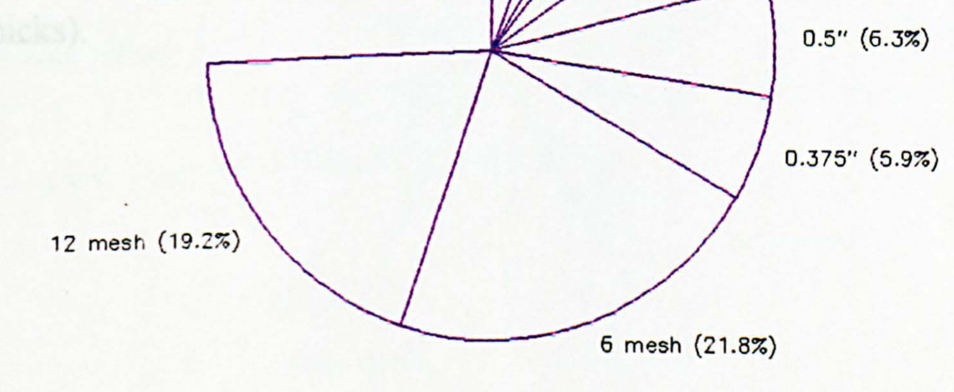


FIG. 3.2

Sizing Analysis Cuts U–X,Y–YY, Vertical

43 picks, 100,mm reach, 63 rpm



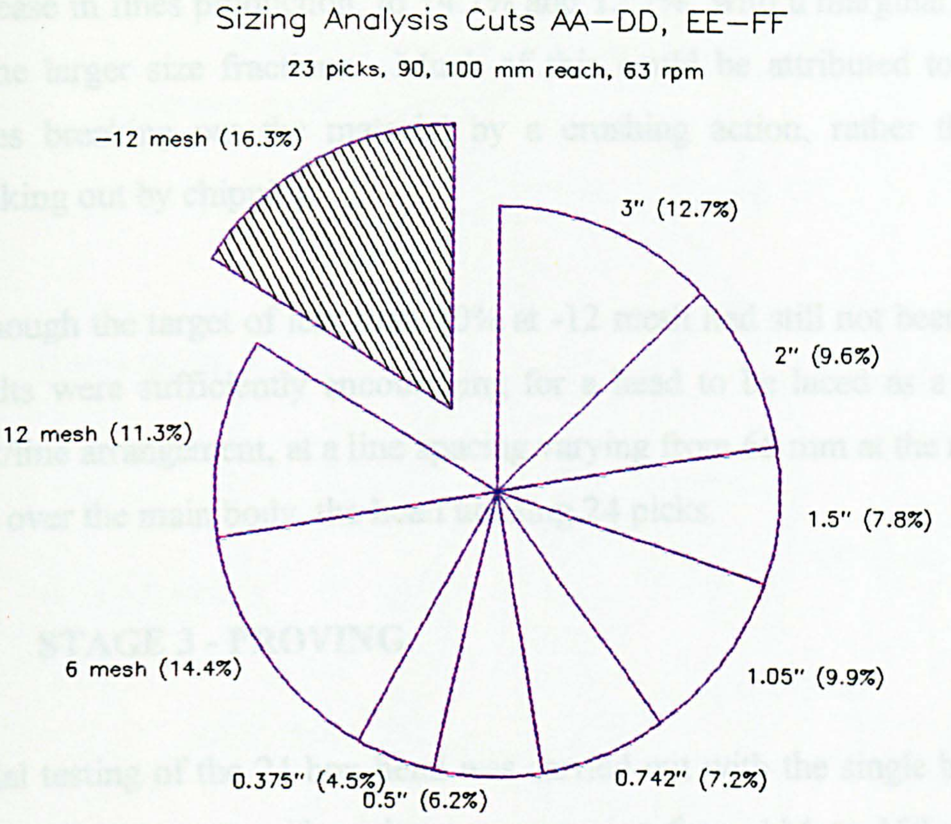
At this stage, two parameters were changed simultaneously, in that further picks were removed from the head, giving effectively a 120 mm line spacing with the head carrying twelve picks, and the boom assembly was changed from the high powered version (270 kW/63 rpm) to the standard two-speed (170 kW/60/33 rpm) unit.

The effect on the combination of wider lacing and slower rotational speed, now 33 rpm, is shown in Fig. 3.4, with a further reduction in fines to 11.4% at -12 mesh, and a further increase in the larger size fractions. Individual tests with -12 mesh fractions at less than 10% were encouraging.

One effect of the very wide pick line spacing was that penetration rates were such that picks were buried to the boxes, and empty pick boxes were felt to be affecting both production rate and fines make. At the same time, pick consumption was unacceptably high.

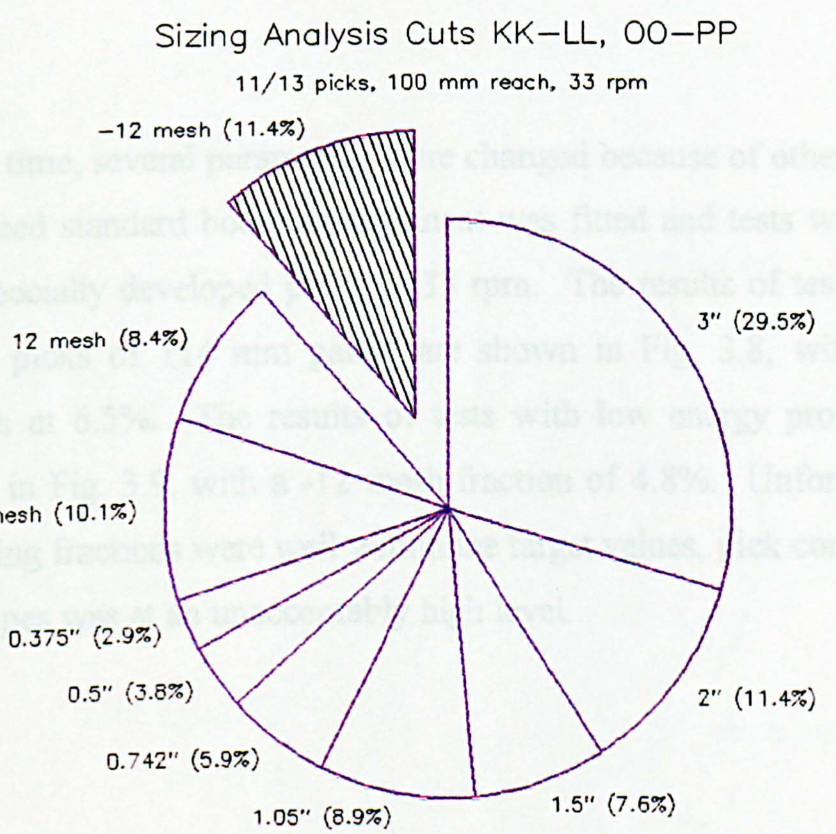
In an effort to improve performance, a head was laced up with a 2-start, 2 pick/line arrangement, at a nominal 130 mm line spacing, the head utilising 26 picks. Attempts to cut with this head were abortive, as the material could not be broken out effectively between pick lines, and severe coring resulted. As a temporary measure, plates were welded to the head at positions between boxes, which effectively reduced the lacing to a nominal 65 mm line spacing, and tests were carried out, both with 2 picks/line (26 picks) and 1 pick/line (13 picks).

FIG. 3.3



Sizing Analysis Cuts AA–DD, EE–FF
23 picks, 90, 100 mm reach, 63 rpm
–12 mesh (16.3%)
3" (12.7%)
2" (9.6%)
12 mesh (11.3%)
1.5" (7.8%)
6 mesh (14.4%)
1.05" (9.9%)
0.375" (4.5%)
0.5" (6.2%)
0.742" (7.2%)

FIG. 3.4



Sizing Analysis Cuts KK–LL, OO–PP
11/13 picks, 100 mm reach, 33 rpm
–12 mesh (11.4%)
12 mesh (8.4%)
3" (29.5%)
6 mesh (10.1%)
0.375" (2.9%)
0.5" (3.8%)
2" (11.4%)
0.742" (5.9%)
1.05" (8.9%)
1.5" (7.6%)

The results of these tests are shown in Figs. 3.5 and 3.6, showing a marginal increase in fines production, to 14.2% and 12.7%, with a marginal reduction in the larger size fractions. Much of this could be attributed to the steel plates breaking out the material by a crushing action, rather than picks breaking out by chipping.

Although the target of less than 10% at -12 mesh had still not been reached, results were sufficiently encouraging for a head to be laced as a 3-start, 1 pick/line arrangement, at a line spacing varying from 65 mm at the nose to 80 mm over the main body, the head utilising 24 picks.

3.5 STAGE 3 - PROVING

Initial testing of the 24 box head was carried out with the single high speed boom arrangement, with pick gauges varying from 114 to 150 mm. The results of 34 individual cuts are shown as Fig. 3.7, with a fines fraction at 12.6%.

At this time, several parameters were changed because of other reasons. The two-speed standard boom arrangement was fitted and tests were carried out with specially developed picks at 33 rpm. The results of tests with narrow profile picks of 114 mm gauge are shown in Fig. 3.8, with a -12 mesh fraction at 6.5%. The results of tests with low energy profiled picks are shown in Fig. 3.9, with a -12 mesh fraction of 4.8%. Unfortunately, while the sizing fractions were well within the target values, pick consumption with both types was at an unacceptably high level.

FIG. 3.5

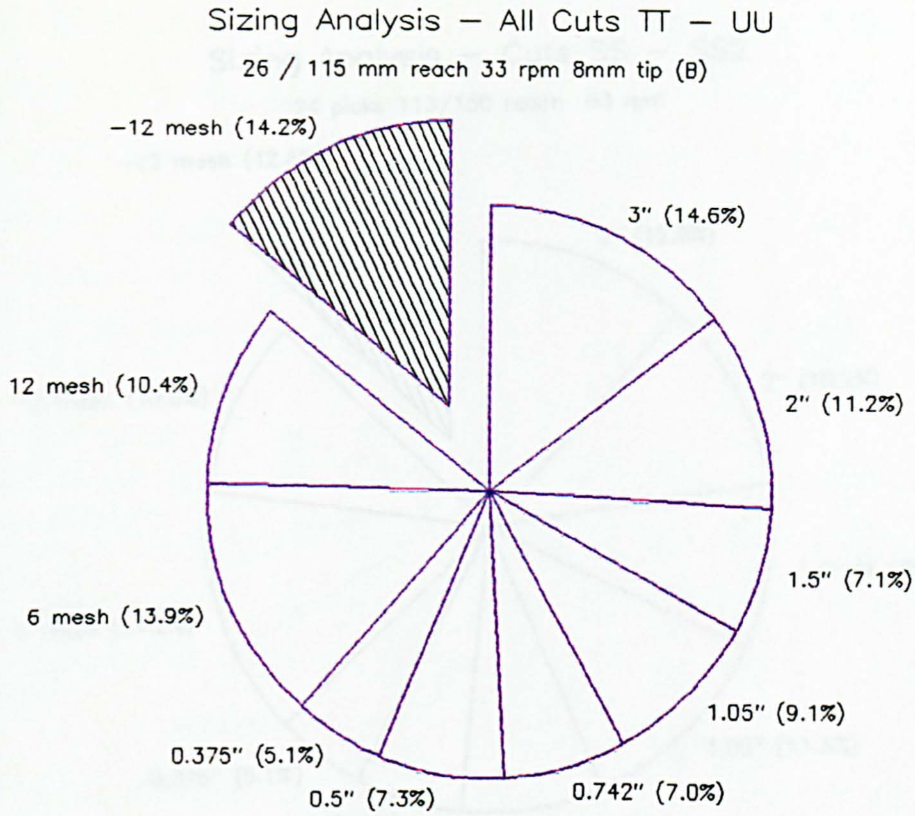

Sizing Analysis – All Cuts TT – UU
26 / 115 mm reach 33 rpm 8mm tip (B)
–12 mesh (14.2%)
3" (14.6%)
12 mesh (10.4%)
2" (11.2%)
1.5" (7.1%)
6 mesh (13.9%)
1.05" (9.1%)
0.375" (5.1%)
0.5" (7.3%)
0.742" (7.0%)

FIG. 3.6

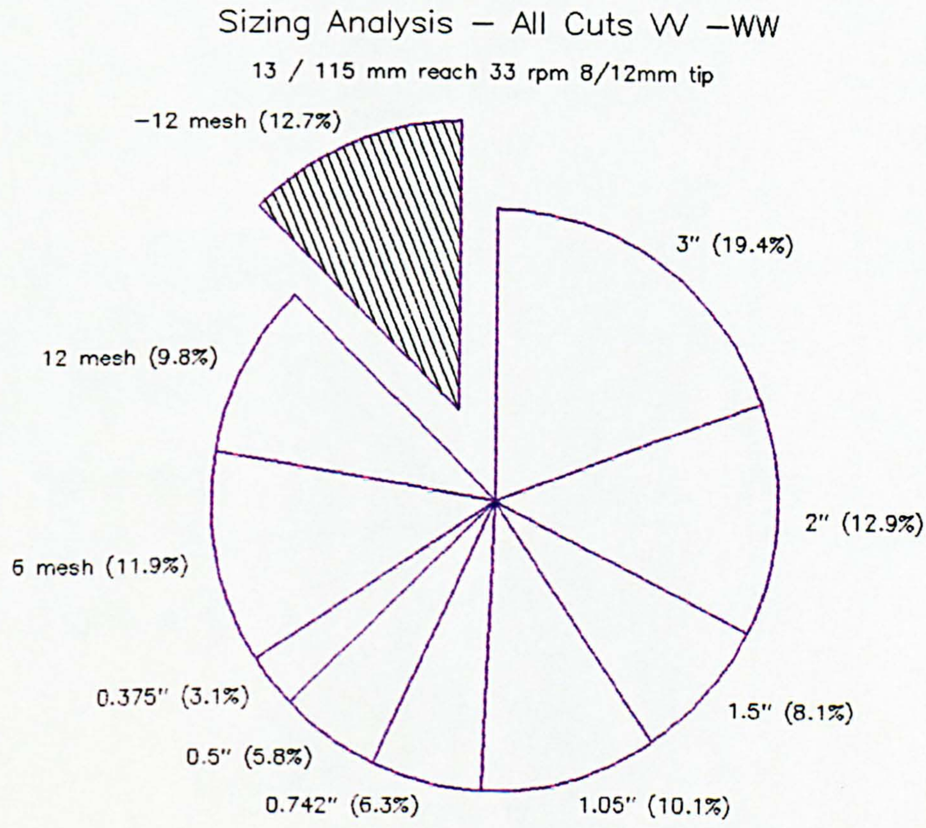

Sizing Analysis – All Cuts VV –WW
13 / 115 mm reach 33 rpm 8/12mm tip
–12 mesh (12.7%)
3" (19.4%)
12 mesh (9.8%)
2" (12.9%)
6 mesh (11.9%)
0.375" (3.1%)
1.5" (8.1%)
0.5" (5.8%)
0.742" (6.3%)
1.05" (10.1%)

FIG. 3.7

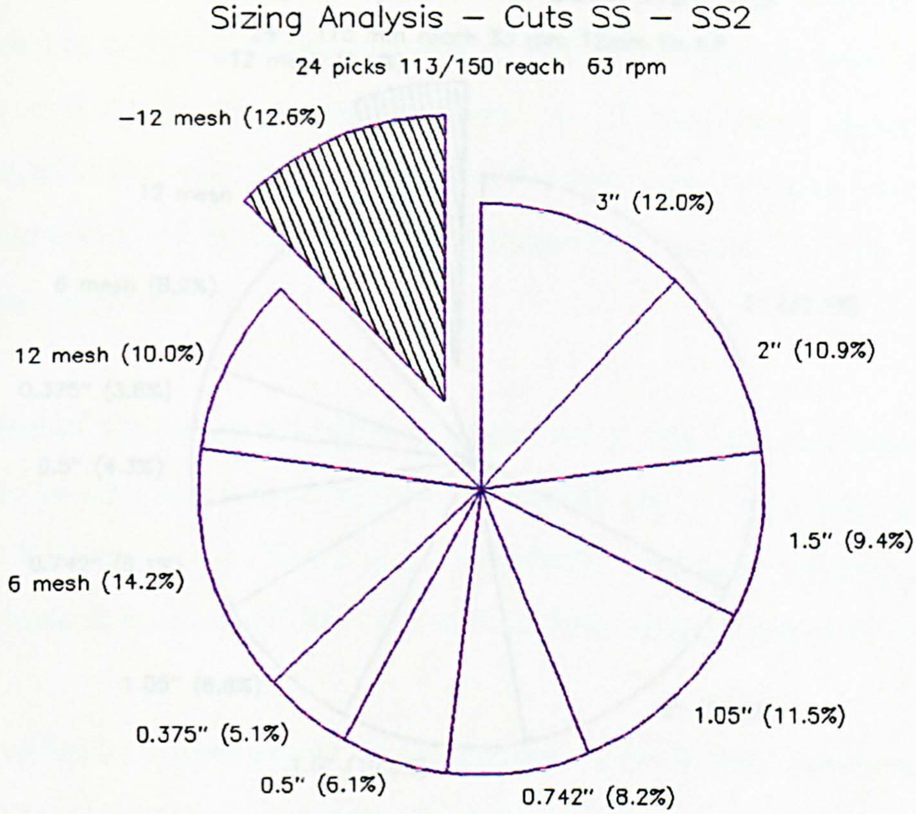

Sizing Analysis – Cuts SS – SS2
24 picks 113/150 reach 63 rpm
–12 mesh (12.6%)
3" (12.0%)
2" (10.9%)
12 mesh (10.0%)
1.5" (9.4%)
6 mesh (14.2%)
1.05" (11.5%)
0.375" (5.1%)
0.5" (6.1%)
0.742" (8.2%)

FIG. 3.8

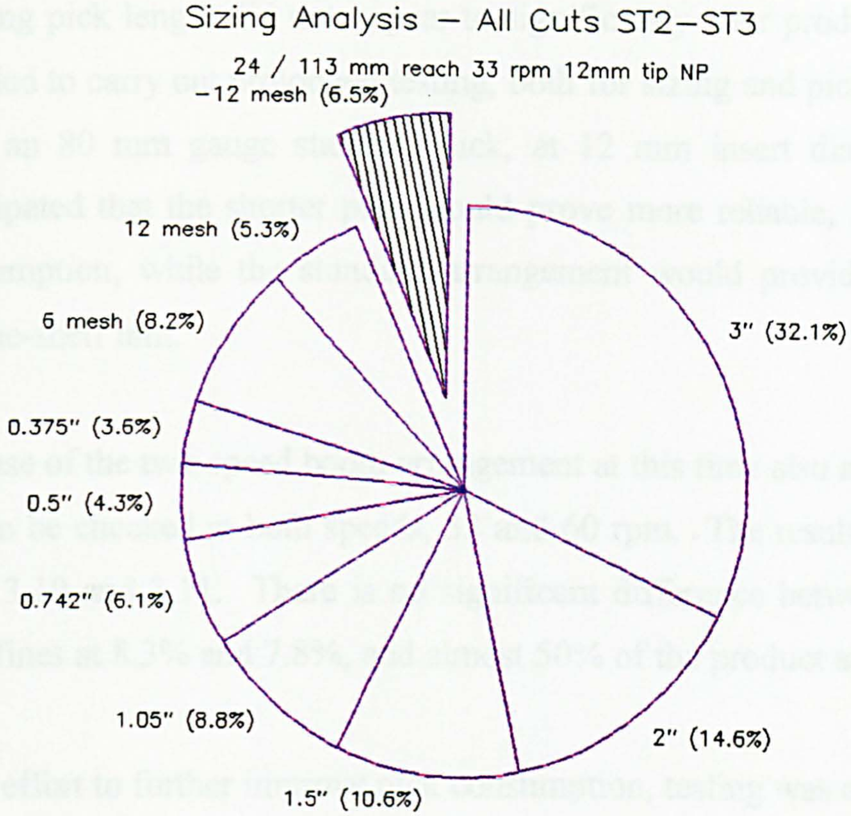
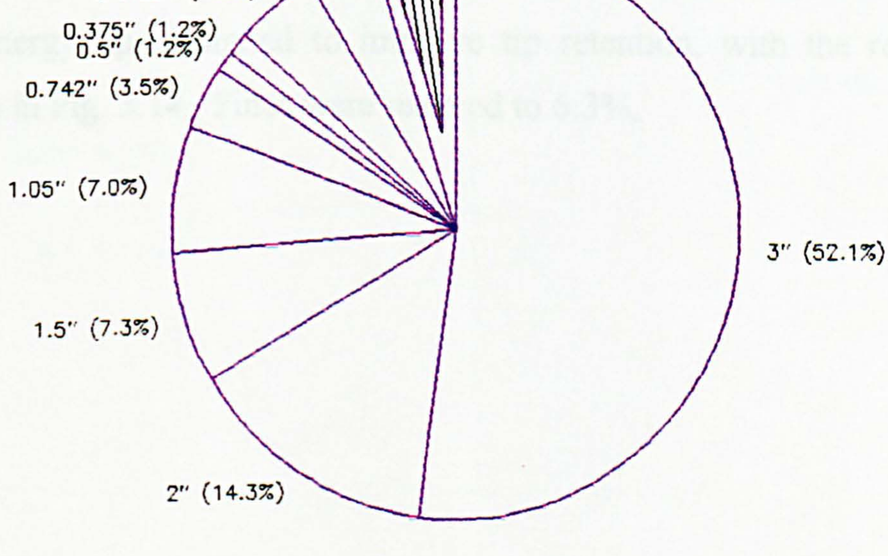

Sizing Analysis – All Cuts ST2–ST3
24 / 113 mm reach 33 rpm 12mm tip NP
–12 mesh (6.5%)
12 mesh (5.3%)
6 mesh (8.2%)
3" (32.1%)
0.375" (3.6%)
0.5" (4.3%)
0.742" (6.1%)
1.05" (8.8%)
2" (14.6%)
1.5" (10.6%)

FIG. 3.9


Sizing Analysis – All Cuts ST4–ST5
24 / 113 mm reach 33 rpm 12mm tip LE
–12 mesh (4.8%)
12 mesh (3.9%)
6 mesh (4.6%)
0.375" (1.2%)
0.5" (1.2%)
0.742" (3.5%)
1.05" (7.0%)
3" (52.1%)
1.5" (7.3%)
2" (14.3%)

Having regard to the range of pick penetrations achievable, and the fact varying pick length did not appear to significantly alter product size, it was decided to carry out prolonged testing, both for sizing and pick consumption, with an 80 mm gauge standard pick, at 12 mm insert diameter. It was anticipated that the shorter pick would prove more reliable, improving pick consumption, while the standard arrangement would provide the cheapest off-the-shelf unit.

The use of the two-speed boom arrangement at this time also allowed product size to be checked at both speeds, 33 and 60 rpm. The results are shown in Figs. 3.10 and 3.11. There is no significant difference between the results, with fines at 8.3% and 7.8%, and almost 50% of the product at over 2".

In an effort to further improve pick consumption, testing was carried out with the same parameters, but with the pick insert increased in size to 17 mm diameter. The results are shown in Figs. 3.12 and 3.13. Again, there is no significant difference between the results at different speeds, but fines production had increased to 11.9% and 12.2%, with a corresponding reduction in the larger size fractions.

A final series of tests was carried out using 80 mm gauge picks fitted with a low energy tip, designed to improve tip retention, with the results being shown in Fig. 3.14. Fines were reduced to 6.3%.

FIG. 3.10

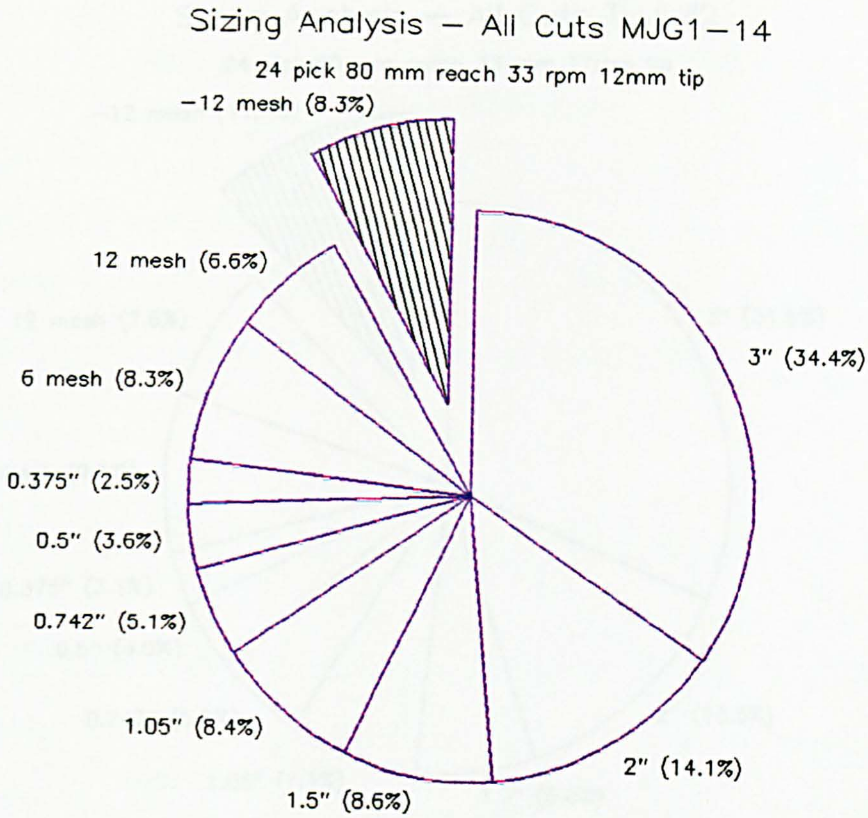


FIG. 3.11

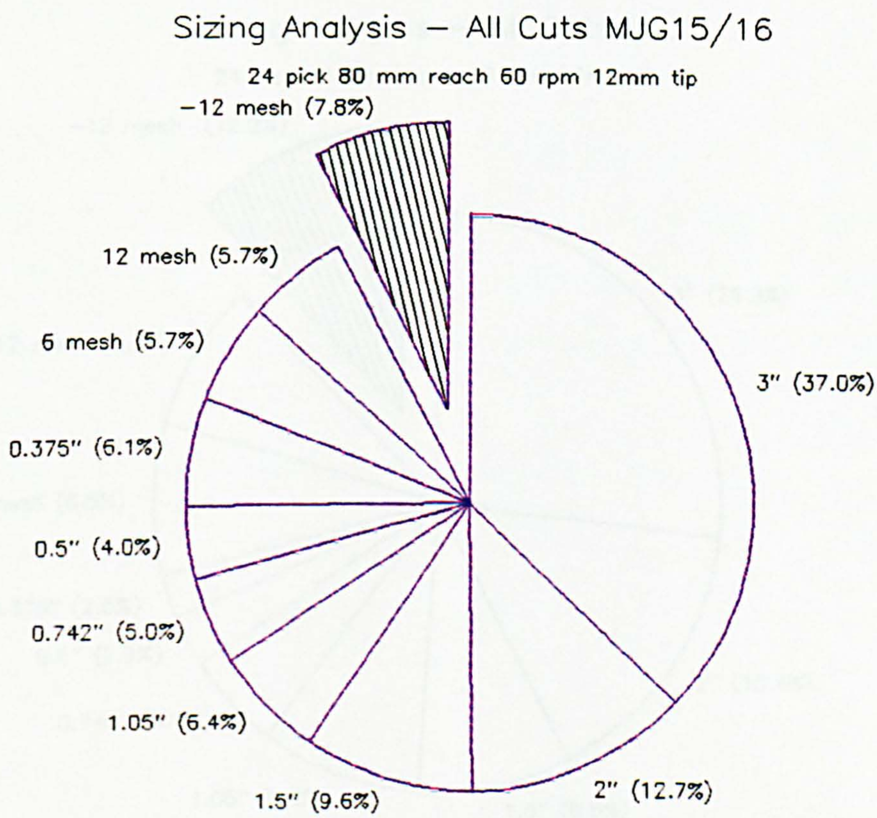


FIG. 3.12

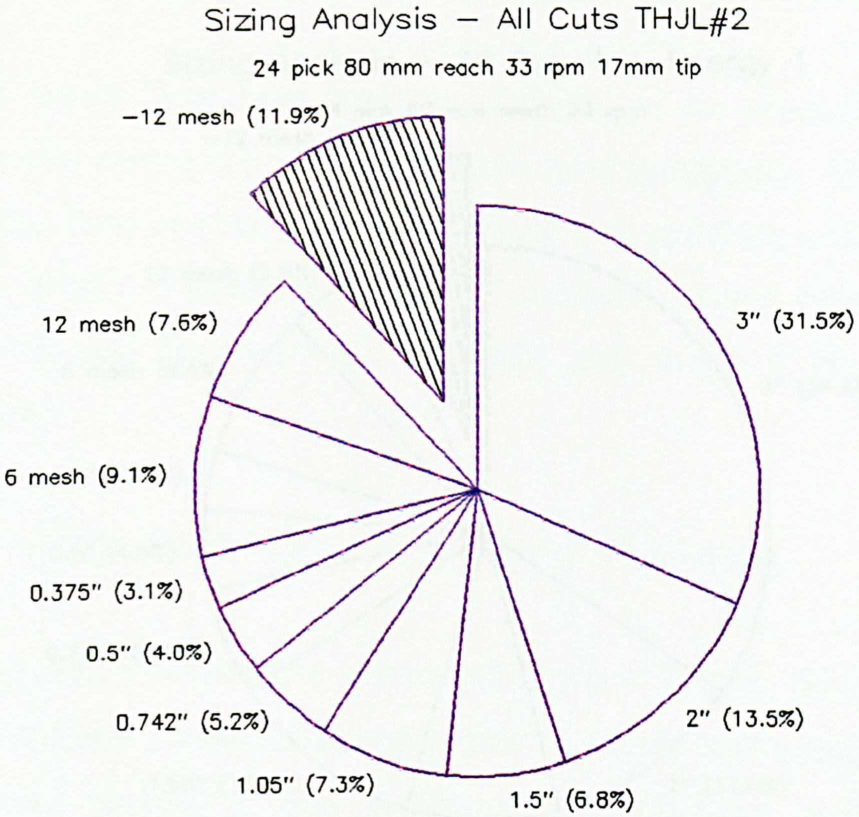


FIG. 3.13

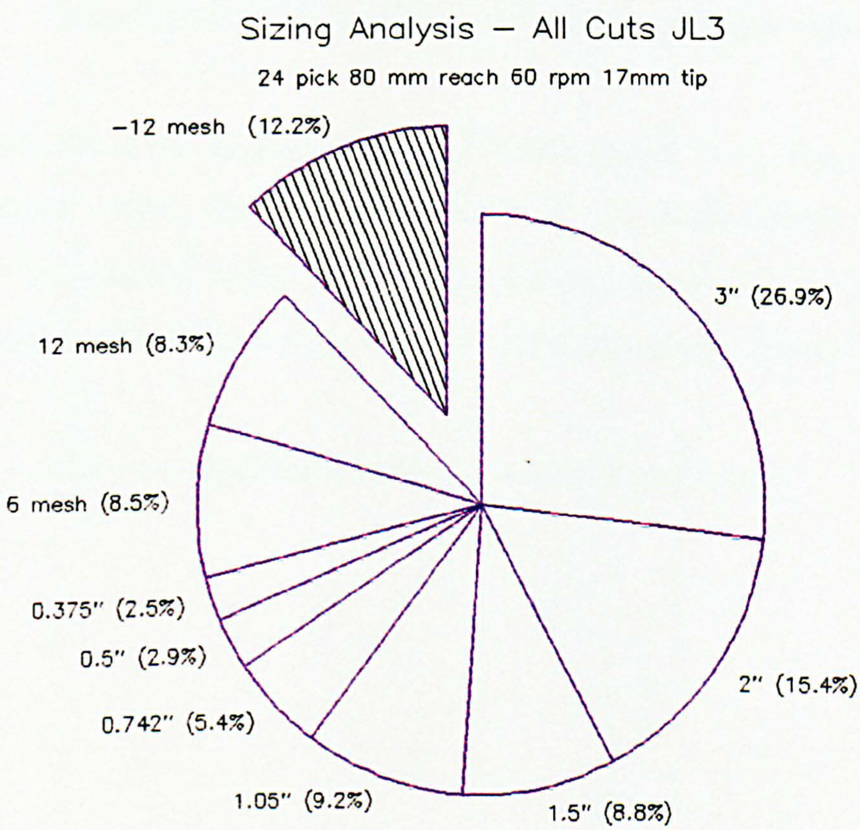
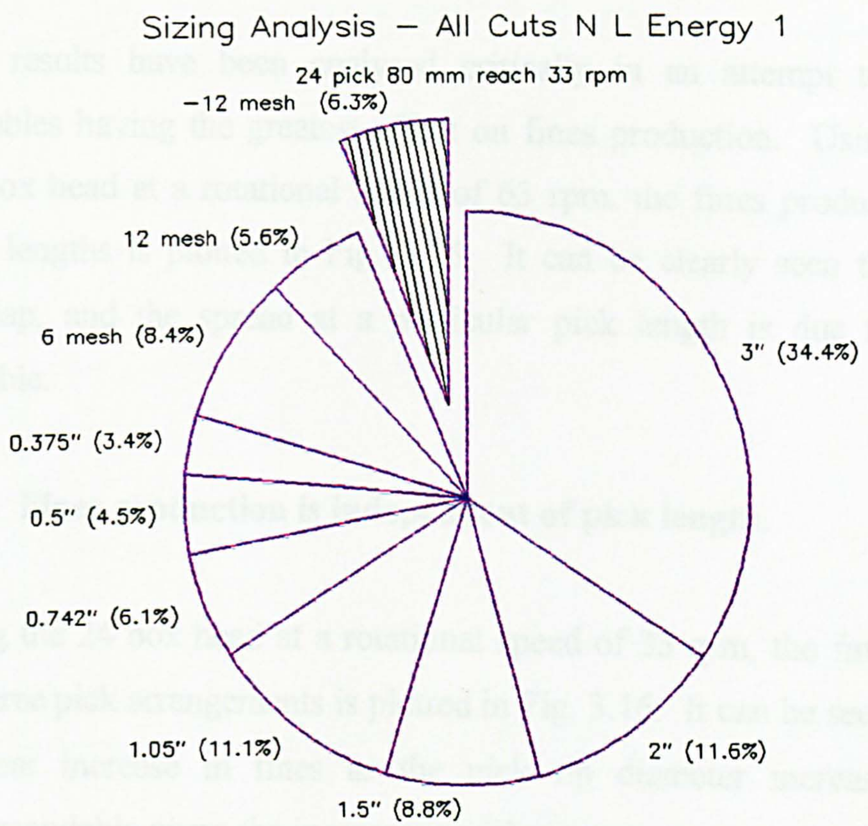


FIG. 3.14


Sizing Analysis – All Cuts N L Energy 1
24 pick 80 mm reach 33 rpm
−12 mesh (6.3%)
12 mesh (5.6%)
6 mesh (8.4%)
0.375" (3.4%)
0.5" (4.5%)
0.742" (6.1%)
1.05" (11.1%)
1.5" (8.8%)
2" (11.6%)
3" (34.4%)

3.6 DISCUSSION

The results have been analysed critically in an attempt to identify the variables having the greatest effect on fines production. Using the original 42 box head at a rotational speed of 63 rpm, the fines production for three pick lengths is plotted in Fig. 3.15. It can be clearly seen that the ranges overlap, and the spread at a particular pick length is due to some other variable.

* **Fines production is independent of pick length.**

Using the 24 box head at a rotational speed of 33 rpm, the fines production for three pick arrangements is plotted in Fig. 3.16. It can be seen that there is a linear increase in fines as the pick tip diameter increases. This is understandable given the increase in pick contact area.

* **Fines production is minimised with small pick tips.**

Using the 24 box head with an 80 mm gauge pick, fitted with a 17 mm diameter insert, the fines production at two head speeds and three sump depths is plotted in Fig. 3.17. It can be seen that head speed is not the major variable, and within testing limits does not appear to have any effect.

* **Fines production is independent of head speed.**

FIG. 3.15

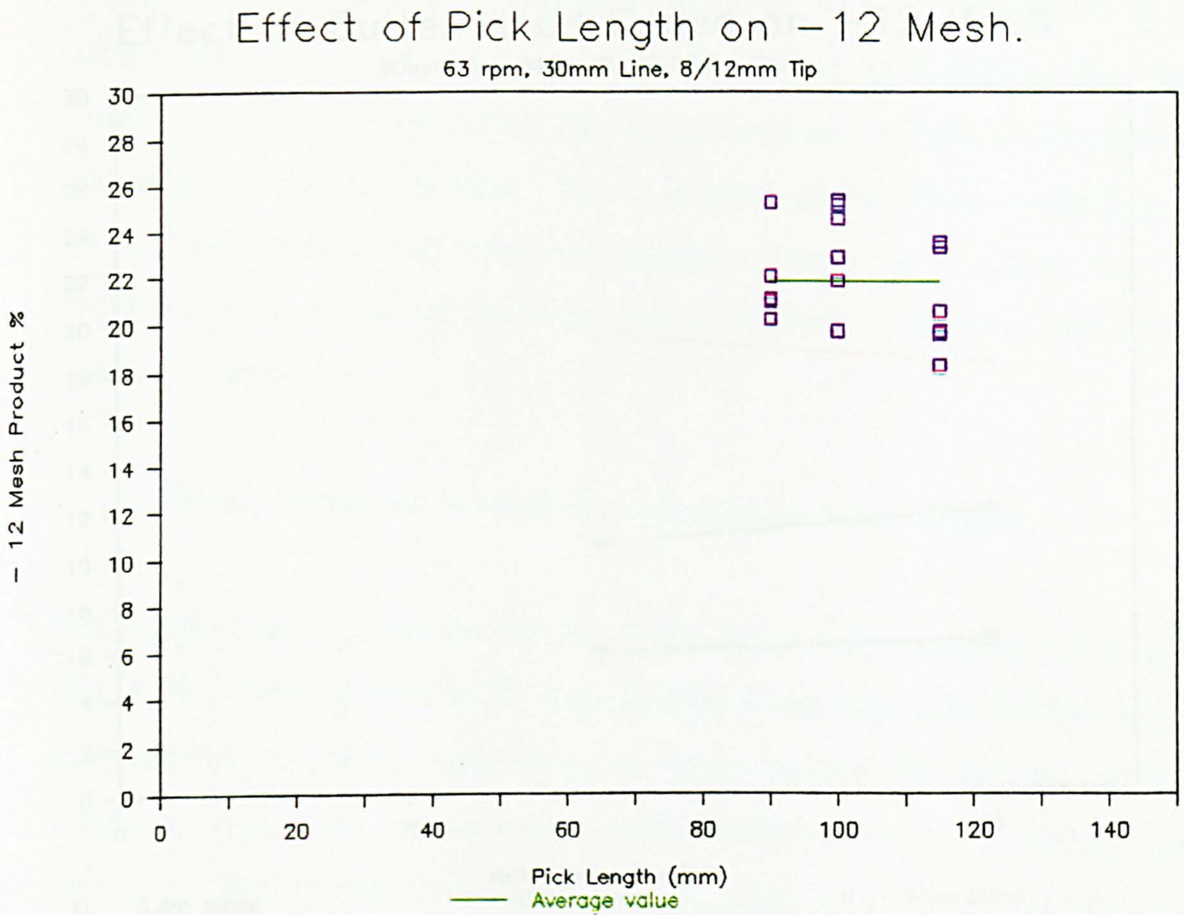


FIG. 3.16

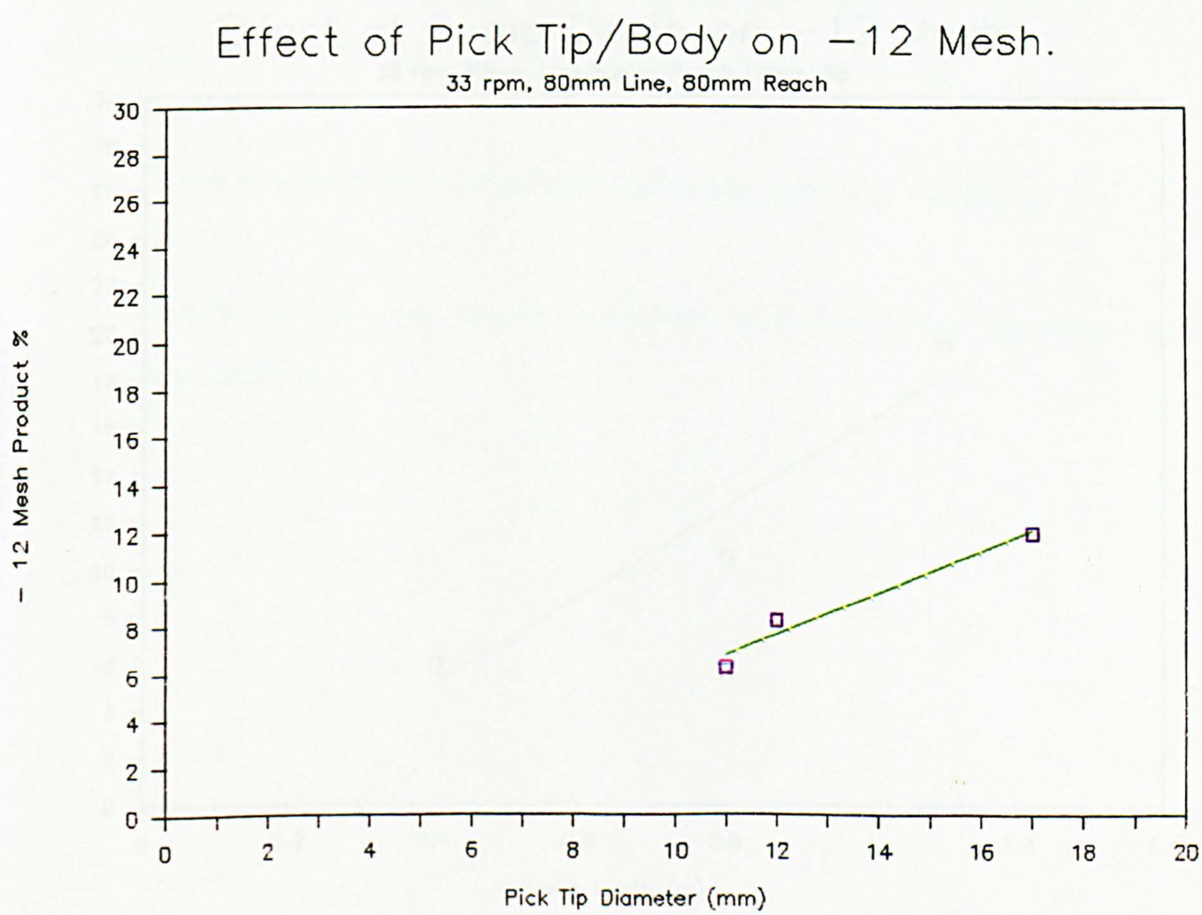


FIG. 3.17

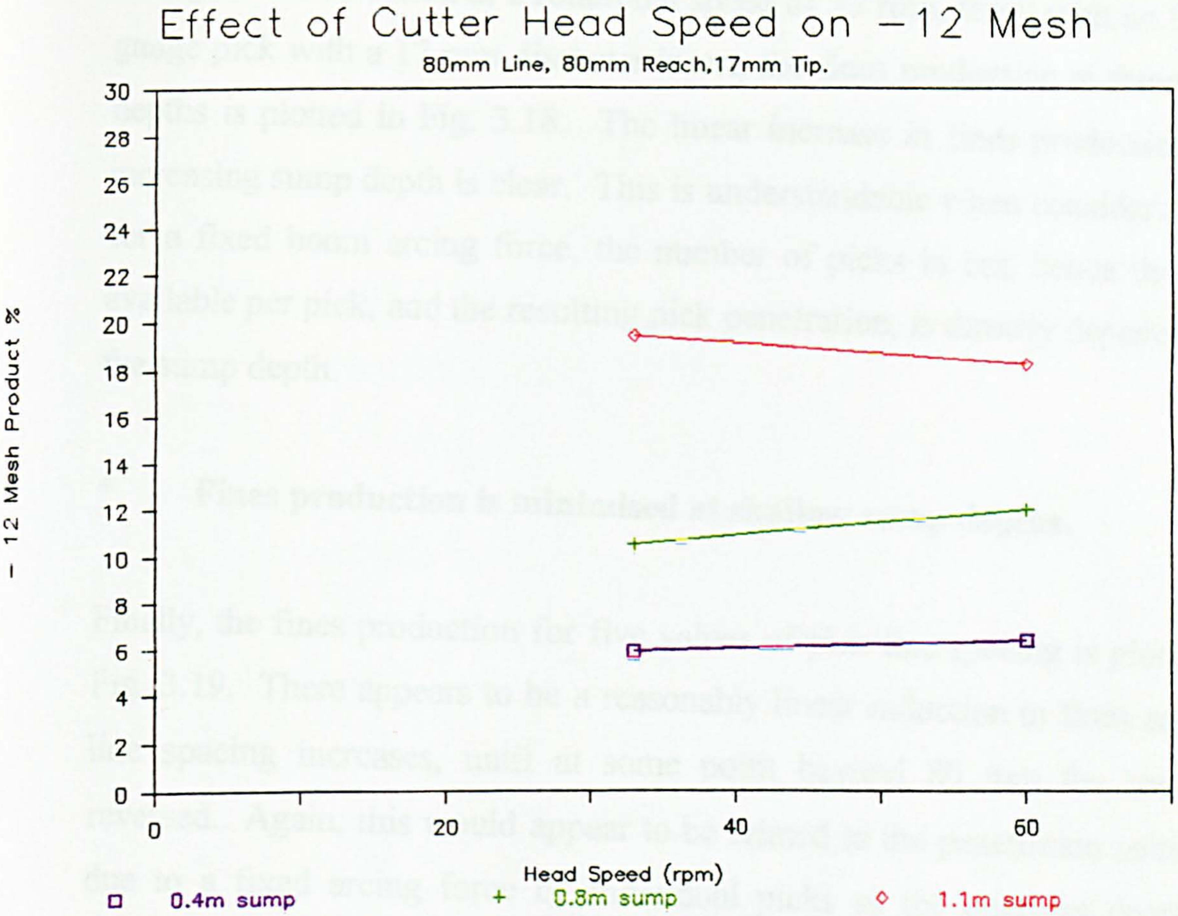
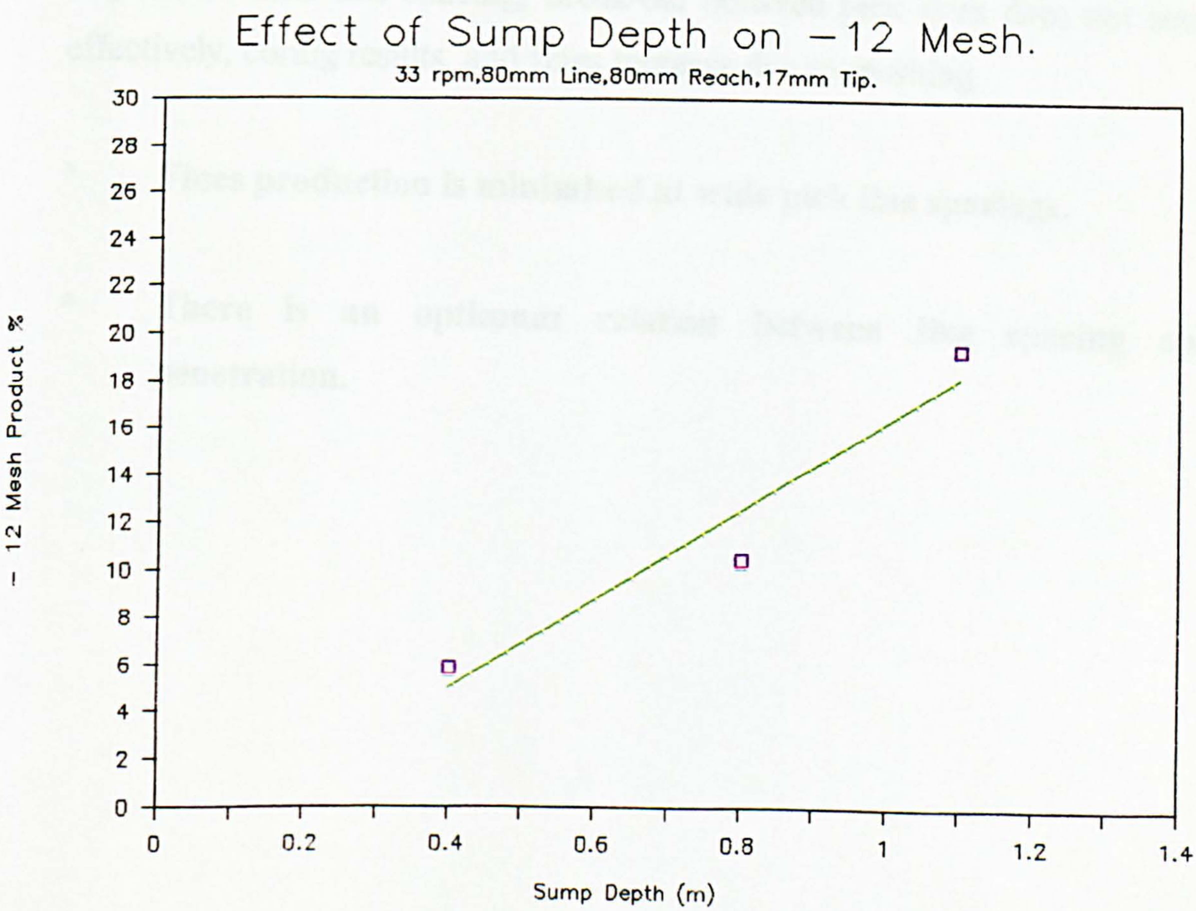


FIG. 3.18



Using the 24 box head at a rotational speed of 33 rpm, fitted with an 80 mm gauge pick with a 17 mm diameter insert, the fines production at three sump depths is plotted in Fig. 3.18. The linear increase in fines production with increasing sump depth is clear. This is understandable when considering that for a fixed boom arcing force, the number of picks in cut, hence the force available per pick, and the resulting pick penetration, is directly dependent on the sump depth.

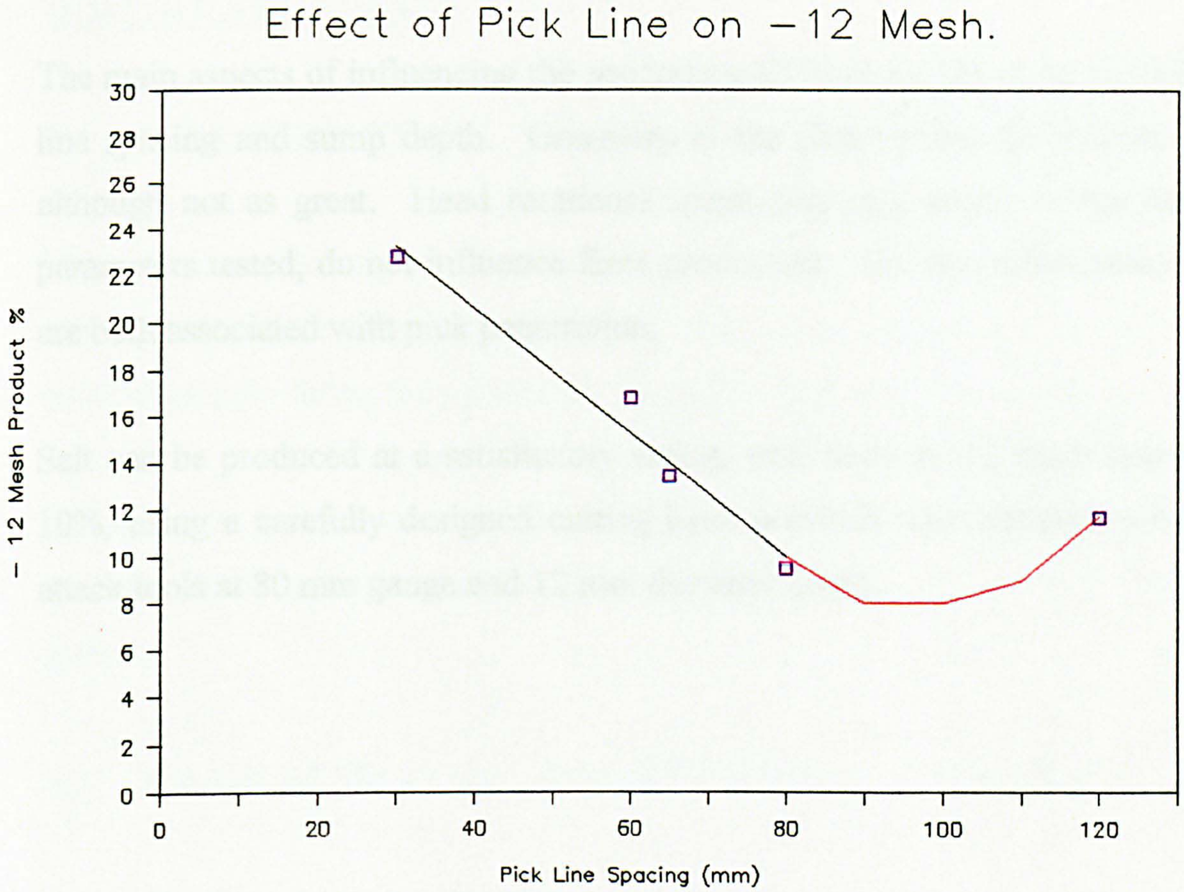
* **Fines production is minimised at shallow sump depths.**

Finally, the fines production for five values of pick line spacing is plotted in Fig. 3.19. There appears to be a reasonably linear reduction in fines as pick line spacing increases, until at some point beyond 80 mm the trend is reversed. Again, this would appear to be related to the penetration achieved due to a fixed arcing force by individual picks as the numbers decrease. Beyond an ideal line spacing, break-out between pick lines does not occur effectively, coring results, and fines increase due to crushing.

* **Fines production is minimised at wide pick line spacings.**

* **There is an optimum relation between line spacing and penetration.**

FIG. 3.19


Effect of Pick Line on -12 Mesh.
- 12 Mesh Product %
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
Pick Line Spacing (mm)

3.7 CONCLUSIONS

The main aspects of influencing the production of fines are shown to be pick line spacing and sump depth. Geometry of the pick tip has an influence, although not as great. Head rotational speed and pick length, within the parameters tested, do not influence fines production. The two major factors are both associated with pick penetration.

Salt can be produced at a satisfactory sizing, with fines at -12 mesh below 10%, using a carefully designed cutting head provided with standard point attack tools at 80 mm gauge and 12 mm diameter insert.

4. MACHINE CUTTING RATE EVALUATION AND PREDICTION AT DOMTAR SALT MINE

4.1 INTRODUCTION

This section of the report concerns the measurement of parameters which allow prediction of instantaneous cutting rates and measurement of machine production rate during the various phases in development of the cutting head.

As with the previous section, the trial period is split into three phases, covering initial testing, development and final proving of the preferred head design.

4.2 MEASUREMENT OF INSTANTANEOUS CUTTING RATE

4.2.1 TESTING PROCEDURE

Individual horizontal cuts were timed with a hand-held stopwatch, in traversing, under-cutting and over-cutting modes, with a note being made of the indicated arcing pressure, and careful measurement made of the cut length, web height and sump depth. Plate 4.1 shows the author at site.

A considerable bank of data has been collected, covering 176 individual cuts. The raw data and calculated parameters are attached as Appendix 4.

PLATE 4.1

AUTHOR AT SITE

The important parameters calculated from the raw data are the swept area of the head in cut and the advance/head rev. of the boom across the face. The results are plotted in the form of curves of boom force/head swept area against advance/head rev. Previous research and field testing has shown good correlation between the parameters, which can be used for predicting machine performance.

Over-cutting is normally done near floor level, with the boom rotating in a pile of cut material, and this can reduce the true rate. While it is important to measure the effect of this, the over-cutting results have not been included in the data analysis.

4.2.2 STAGE 1 - 42 BOX HEAD

Testing was carried out with the 270 kW high powered boom arrangement, at a rotational speed of 63 rpm. The variable parameters were sump depth, nominally at 40, 80 and 110 cm, and pick gauge, at 90, 100 and 115 mm. The 115 mm gauge pick was fitted with an 8 mm diameter insert, against the 12 mm insert in the 90 and 100 mm gauge tools.

The results are plotted in Fig. 4.1, together with the mathematical form of the best fit line:-

* **Force (kN) swept area (m^3) = 80.5 * Advance (cm)/rev.$^{(0.79)}$**

FIG. 4.1

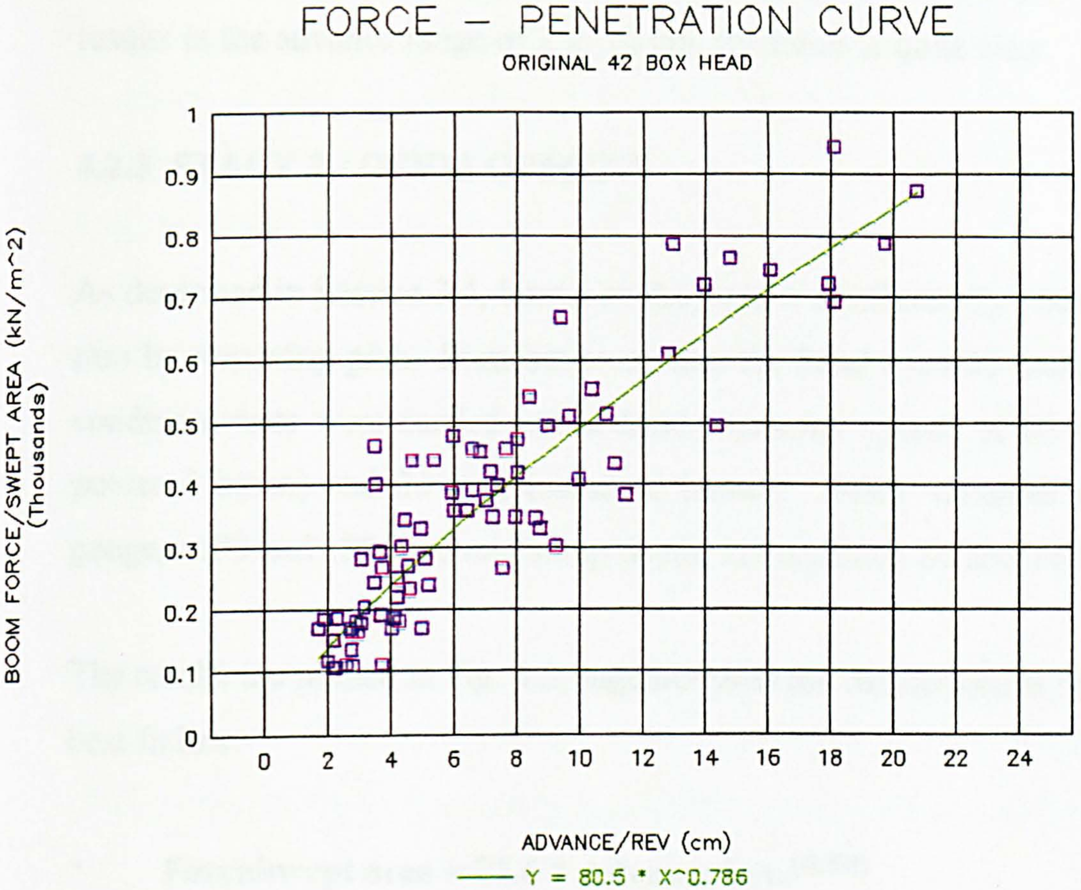
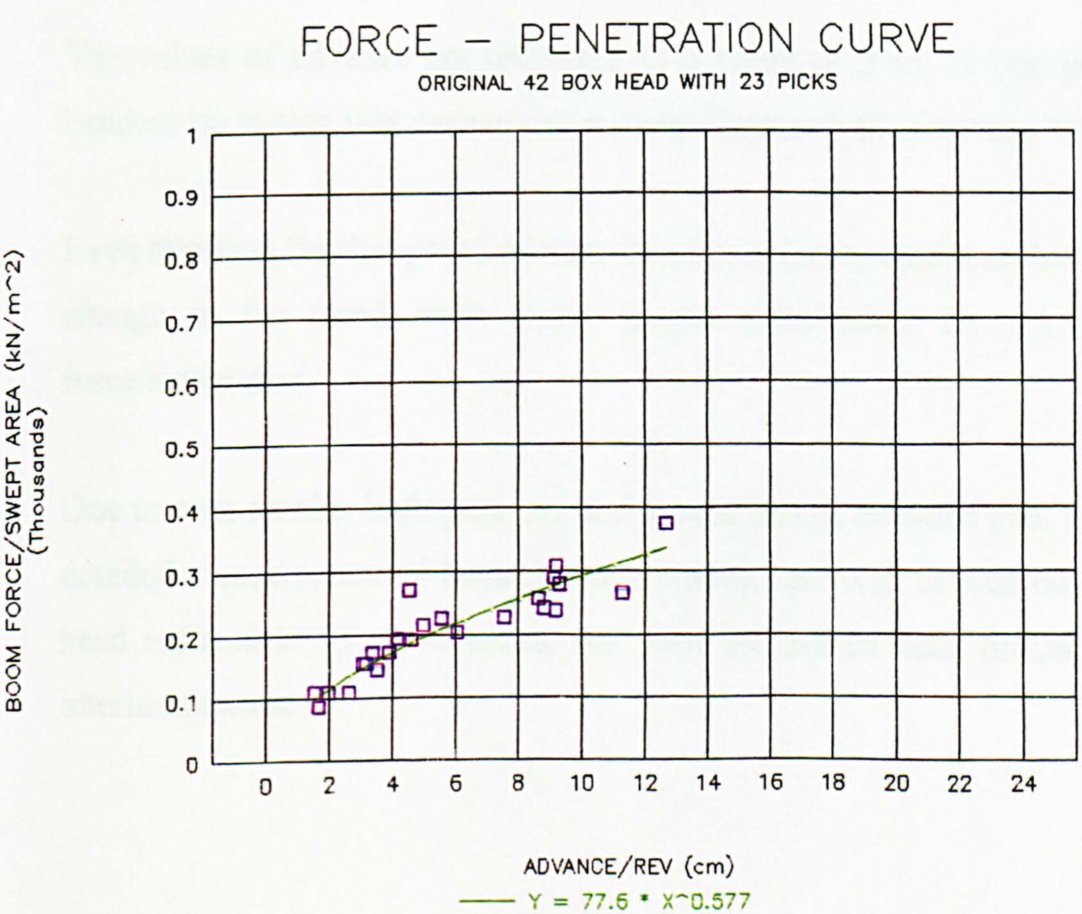

FORCE – PENETRATION CURVE
ORIGINAL 42 BOX HEAD
BOOM FORCE/SWEPT AREA (kN/m^2)
(Thousands)
ADVANCE/REV (cm)
Y = 80.5 * X^0.786

FIG. 4.2


FORCE – PENETRATION CURVE
ORIGINAL 42 BOX HEAD WITH 23 PICKS
BOOM FORCE/SWEPT AREA (kN/m^2)
(Thousands)
ADVANCE/REV (cm)
Y = 77.6 * X^0.577

Whilst there is a reasonably wide spread of data, with a pre-ponderance of results in the advance range of 2 to 10 cm, the trend is quite clear.

4.2.3 STAGE 2 - DEVELOPMENT

As described in Section 3.4, lacing on the head was effectively widened to 60 mm by removing picks from boxes so that the head used 23 picks. In this condition, tests were carried out at head rotational speeds of 63 rpm (high powered boom) and 33 rpm (standard boom). Other variables were pick gauge, at 90 and 100 mm, and sump depth, at nominally 80 and 110 cm.

The results are plotted in Fig. 4.2, together with the mathematical form of the best fit line:-

* **Force/swept area = 77.6 * Advance/rev.$^{(0.58)}$**

The values of advance are restricted to a range of 2 to 12 cm, principally because no testing was carried out at sump depths shallower than 75 cm.

Even allowing for the spread of data, it is immediately apparent that there is a change in the trend, with much greater penetration for any value of force/swept area.

Due to poor results, high pick use and severe coring between pick groves, no detailed measurement of instantaneous cutting rate was carried out with the head reduced to 11 to 13 picks, nor with the 2-start head produced as an interim measure.

4.2.4 STAGE 3 - PROVING

A series of cuts was monitored with the final 24 box head, at rotational speeds of 33 and 60 rpm, the other variables being pick gauge, at 80 and 100 mm, and sump depth, at 40, 50, and 70 cm.

The results are plotted in Fig. 4.3, together with the mathematical form of the best fit line:-

* **Force/swept area = 229 * Advance/rev.$^{(0.24)}$**

There is a wider spread of data than obtained with the former head, with fewer values at lower advance rates, and more values at higher advance rates. This is due, in part, to not testing the head at sump depths greater than 70 cm.

It is apparent that the curve follows a different form to that obtained with the original 42 box head, with greater penetration being achieved for any value of force/swept area.

FIG. 4.3

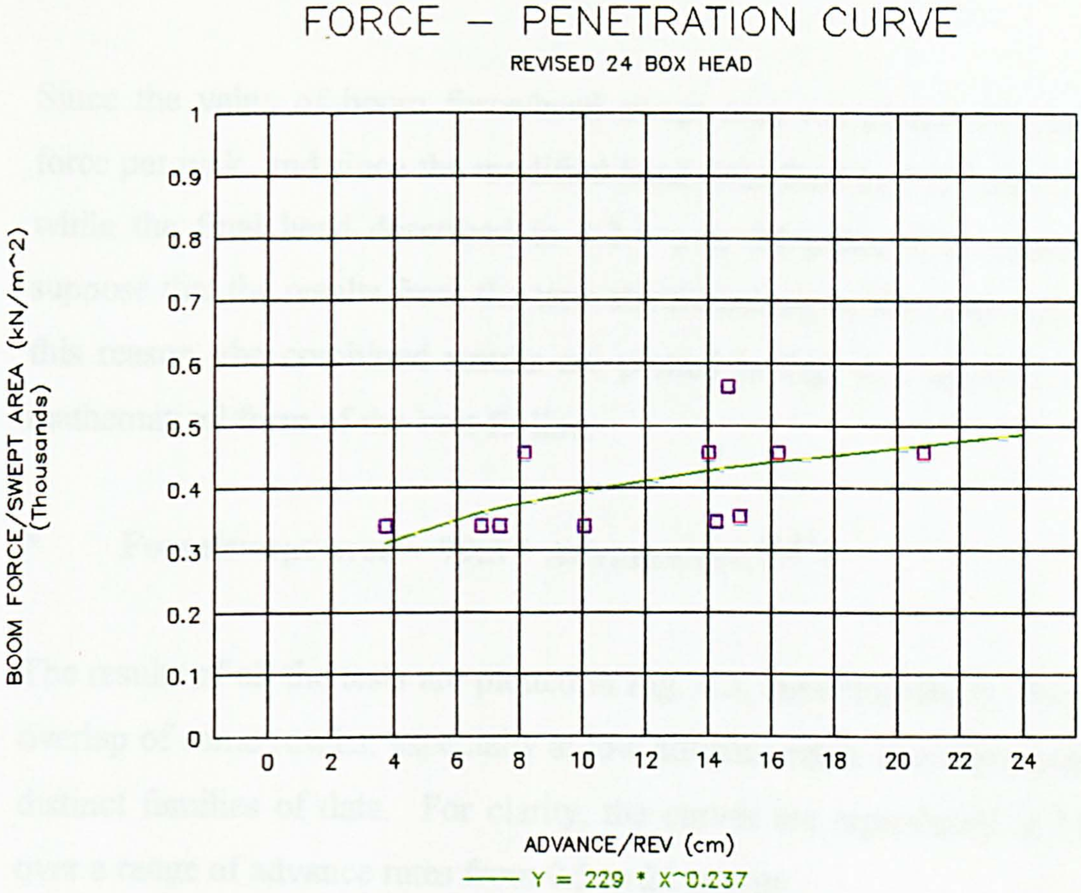
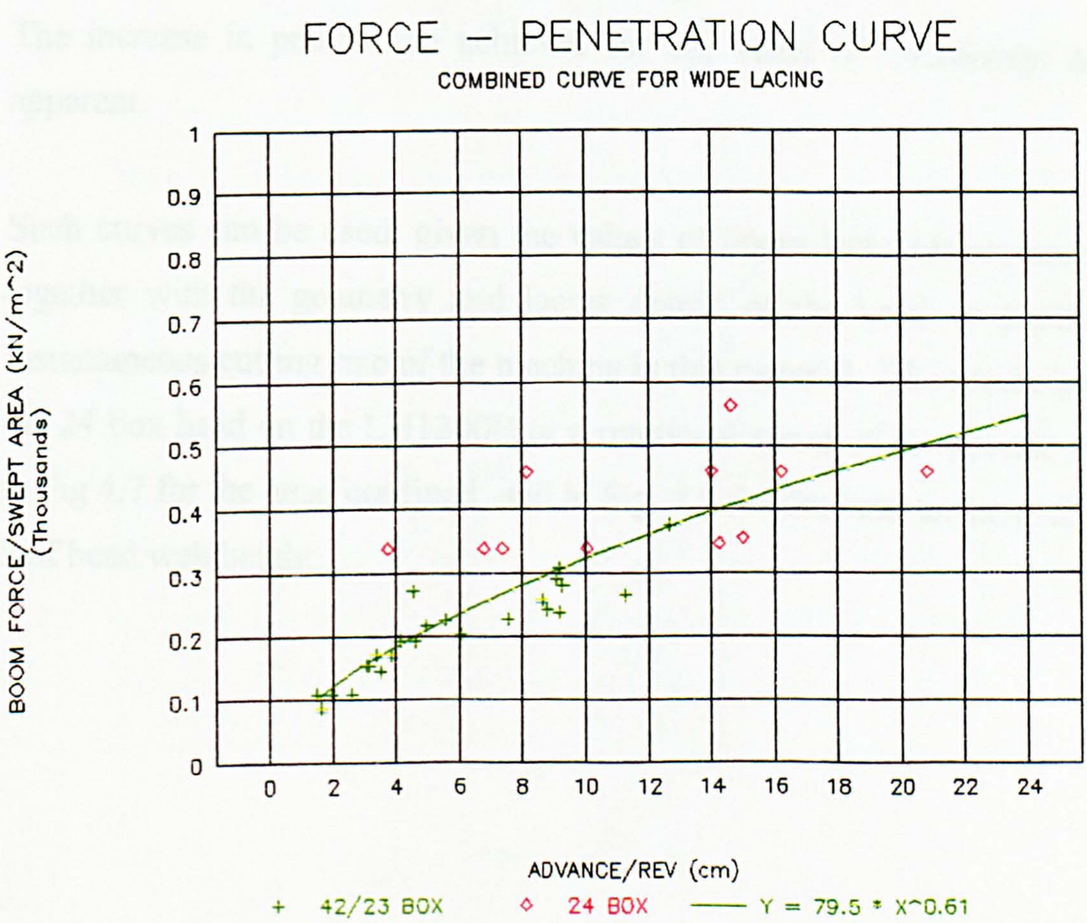

FORCE – PENETRATION CURVE
REVISED 24 BOX HEAD
BOOM FORCE/SWEPT AREA (kN/m^2)
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 2 4 6 8 10 12 14 16 18 20 22 24
ADVANCE/REV (cm)
Y = 229 * X^0.237

FIG. 4.4


FORCE – PENETRATION CURVE
COMBINED CURVE FOR WIDE LACING
BOOM FORCE/SWEPT AREA (kN/m^2)
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 2 4 6 8 10 12 14 16 18 20 22 24
ADVANCE/REV (cm)
+ 42/23 BOX
◇ 24 BOX
Y = 79.5 * X^0.61

4.2.5 DISCUSSION

Since the value of boom force/head swept area represents the penetrating force per pick, and since the modified head described in 3.2.3 uses 23 picks, while the final head described in 3.2.4 uses 24 picks, it is reasonable to suppose that the results from the tests should belong to the same family. For this reason, the combined results are plotted in Fig. 4.4, together with the mathematical form of the best fit line:-

* **Force/swept area = 79.5 * Advance/rev.$^{(0.61)}$**

The results of all the tests are plotted in Fig. 4.5, showing clearly, despite the overlap of some results, especially at low advance rates, that there exists two distinct families of data. For clarity, the curves are reproduced in Fig. 4.6 over a range of advance rates from 0.5 to 22 cm/rev.

The increase in penetration achieved for any value of force/swept area is apparent.

Such curves can be used, given the values of boom force for any machine, together with the geometry and lacing details of the head, to predict the instantaneous cutting rate of the machine in this material. The predictions for the 24 box head on the LH1300H at a rotational speed of 63 rpm are shown in Fig 4.7 for the head confined, and in Fig. 4.8 for the head under-cutting on half head web height.

FIG. 4.5

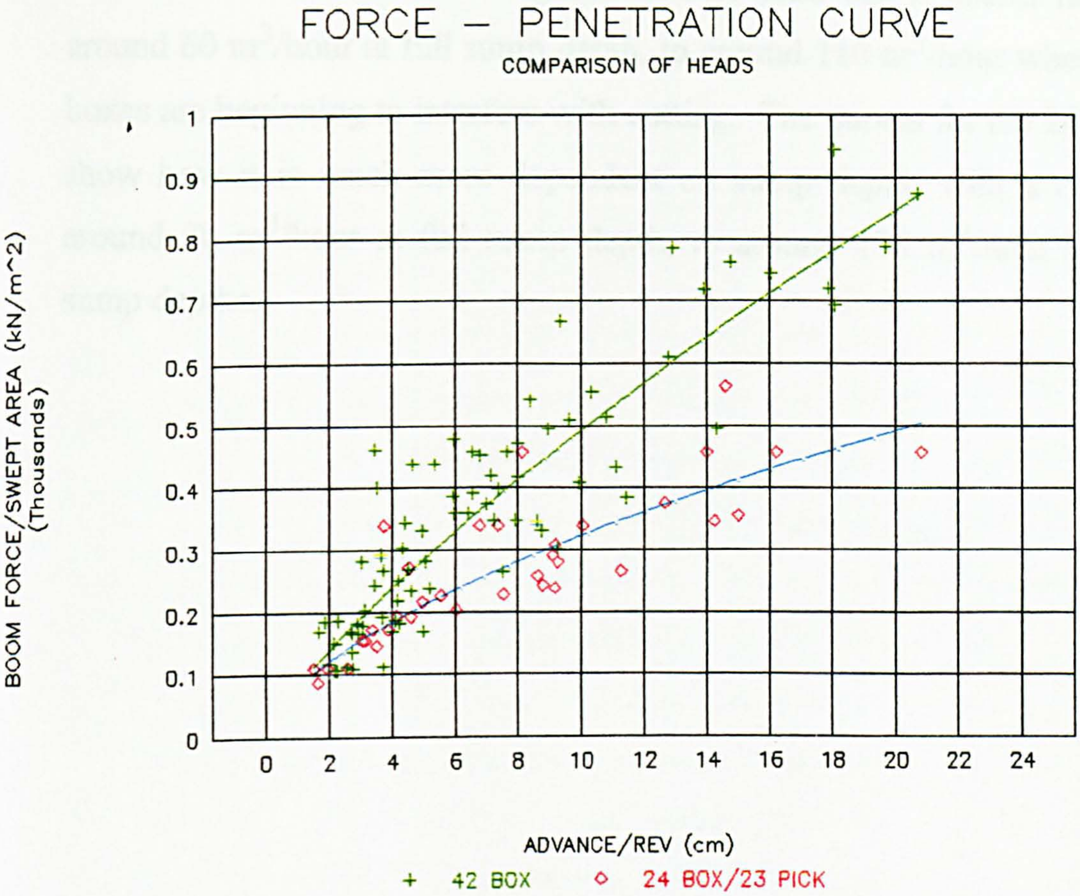
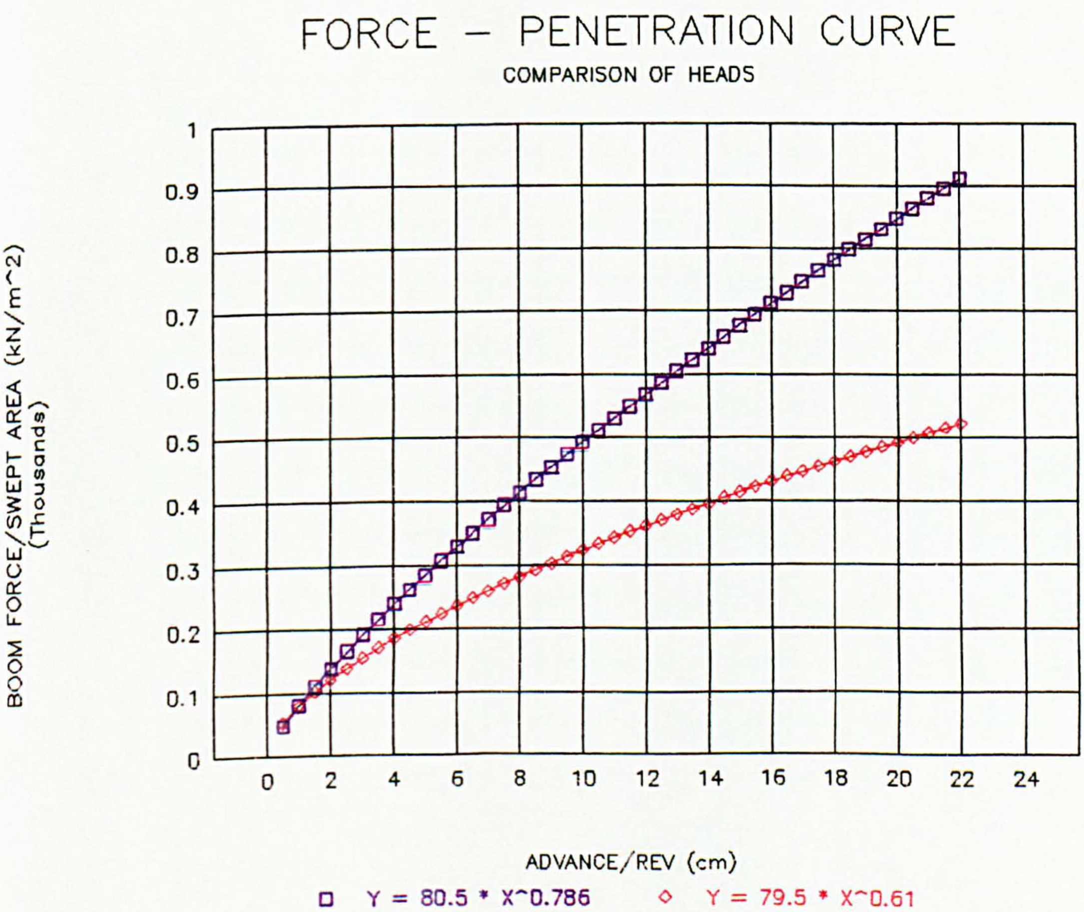

FORCE – PENETRATION CURVE
COMPARISON OF HEADS
BOOM FORCE/SWEPT AREA (kN/m^2)
(Thousands)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
14
16
18
20
22
24
ADVANCE/REV (cm)
42 BOX
24 BOX/23 PICK

FIG. 4.6


FORCE – PENETRATION CURVE
COMPARISON OF HEADS
BOOM FORCE/SWEPT AREA (kN/m^2)
(Thousands)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
14
16
18
20
22
24
ADVANCE/REV (cm)
Y = 80.5 * X^0.786
Y = 79.5 * X^0.61

The curves show that the original 42 box head has a useful range from around 60 m^3/hour at full sump depth, to around 110 m^3/hour when the pick boxes are beginning to interfere with cutting. The curves for the 24 box head show how it is much more dependent on sump depth, with a range from around 70 m^3/hour at full sump depth, to around 170 m^3/hour at shallow sump depths.

FIG. 4.7

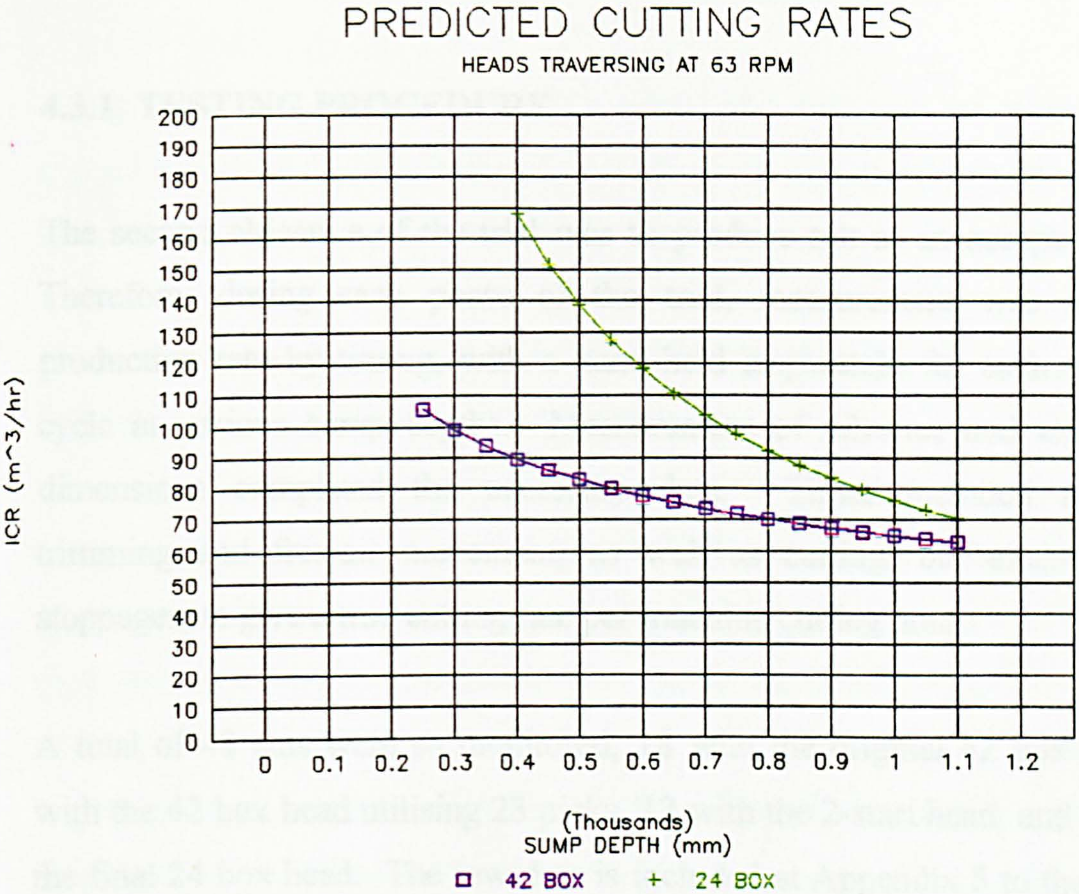
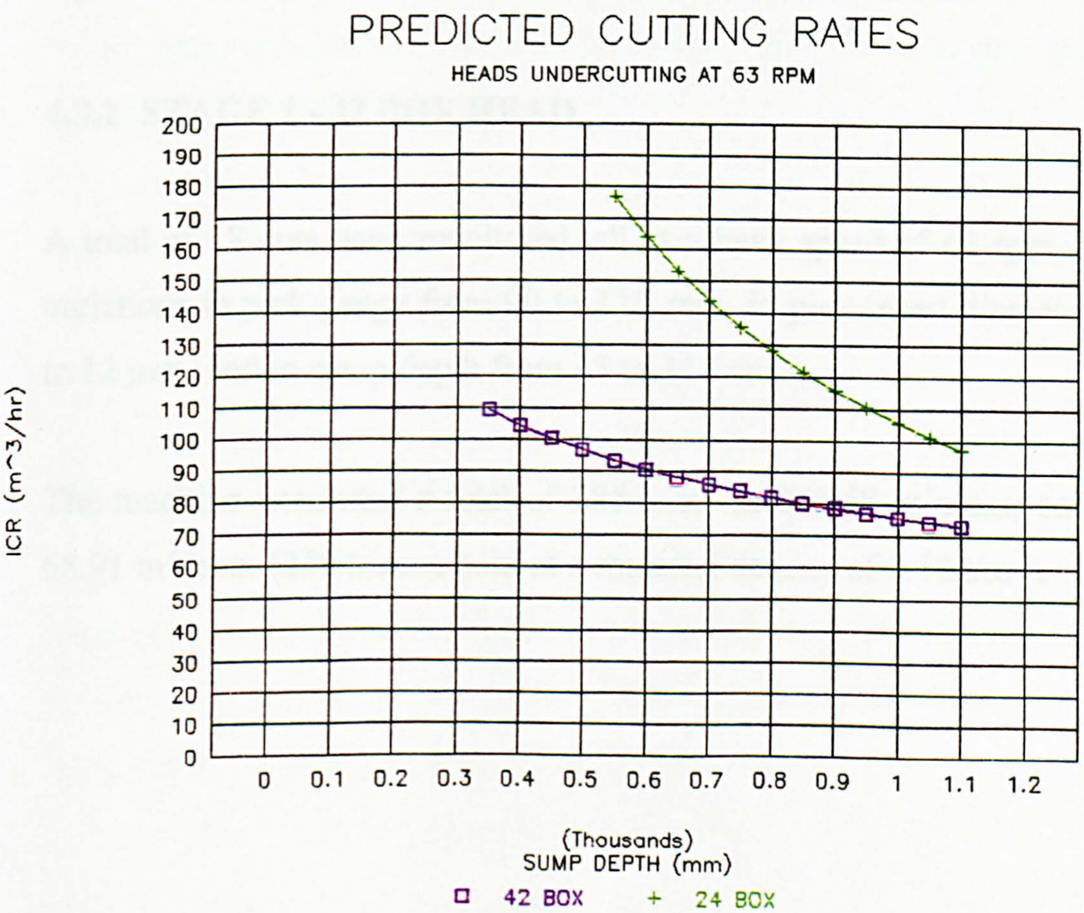

PREDICTED CUTTING RATES
HEADS TRAVERSING AT 63 RPM
ICR (m^3/hr)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2
(Thousands)
SUMP DEPTH (mm)
42 BOX
24 BOX

FIG. 4.8


PREDICTED CUTTING RATES
HEADS UNDERCUTTING AT 63 RPM
ICR (m^3/hr)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2
(Thousands)
SUMP DEPTH (mm)
42 BOX
24 BOX

4.3 MEASUREMENT OF PRODUCTION RATE

4.3.1 TESTING PROCEDURE

The second objective of the trial was to produce salt at an acceptable rate. Therefore, during each phase of the trial, measurement was made of production rate by timing, with a hand-held stopwatch, for each complete cycle at various sump depths. Measurement of advance and excavation dimensions completed the necessary data. Times included sumping, trimming and free-air movement, as well as cutting, but excluded any stoppages, to give a true cutting rate per machine cutting hour.

A total of 48 cuts were so monitored, 18 with the original 42 box head, 6 with the 42 box head utilising 23 picks, 12 with the 2-start head, and 12 with the final 24 box head. The raw data is included at Appendix 5 to the report, together with a note of the variables under each test condition.

4.3.2 STAGE 1 - 42 BOX HEAD

A total of 18 cuts were monitored, all at a head speed of 63 rpm, but with variations in pick gauge from 90 to 115 mm, in pick insert diameter from 8 to 12 mm, and in sump depth from 45 to 117 cm.

The machine excavated a total of 285.5 m^3 in 248.58 minutes, equating to 68.91 m^3/hour (150 tonnes/hour at a material density of 2.18 t/m^3).

4.3.3 STAGE 2 - DEVELOPMENT

Using the 42 box head with 23 picks, a total of 6 cuts were monitored, all at a head speed of 63 rpm, but with variations in pick gauge, at 90 and 110 mm, and in sump depth, from 78 to 117 cm.

The machine excavated a total of 92.67 m^3 in 43.46 minutes, equating to 127.95 m^3/hour (280 tonnes/hour).

Using the 2-start head, a total of 12 cuts were monitored, at head speeds of 33, 60 and 63 rpm, and with variations in pick gauge at 100 and 115 mm, in pick insert diameter at 8 and 12 mm, and sump depth from 85 to 107 cm.

At 33 rpm, the machine excavated 51.90 m^3 in 47.95 minutes, equating to 64.95 m^3/hour (142 tonnes/hour).

At 60 rpm, the machine excavated 11.64 m^3 in 6.47 minutes, equating to 108.00 m^3/hour (235 tonnes/hour).

At 63 rpm, the machine excavated 135.02 m^3 in 69.10 minutes, equating to 117.24 m^3/hour (256 tonnes/hour).

4.3.4 STAGE 3 - PROVING

Using the 24 box head developed, a total of 12 cuts were monitored, at head speeds of 33 and 60 rpm, with variations in pick gauge, at 80, 100 and 115 mm, and in sump depth, from 40 to 137 cm.

At 33 rpm, the machine excavated 163.92 m^3 in 136.00 minutes, equating to 72.32 m^3/hour (158 tonnes/hour).

At 60 rpm, the machine excavated 33.13 m^3 in 20.00 minutes, equating to 99.38 m^3/hour (228 tonnes/hour).

4.3.5 DISCUSSION

The opening of the lacing on the original head by removal of picks has a dramatic effect on production rate, an effect which is independent of head speed.

The 2-start head was tested at three head speeds, and the production rate is clearly linked to the head speed, showing a linear increase with increasing head speed. The effect is confirmed by the results of testing the final 24 box head at two head speeds.

The results for the 2-start head (line spacing around 65 mm), the 24 box head (line spacing between 65 and 80 mm), and the 42 box head with 23 picks (line spacing around 60 mm), appear to lie on a single line, showing a direct relation between production and head rotational speed.

* **Production rate is directly dependent on head rotational speed.**

That the results for the original 42 box head lie on a different line is confirmed by reference to a series of similar tests carried out with the same machine, fitted with the higher powered boom assembly and the same cutting head, at ICI's Winsford mine in the UK. Here, head rotational speed is 50 rpm due to the 50 Hz electrical supply. A series of 34 cuts were monitored in August 1988, in the same manner as at Domtar, and gave a mean production rate of 52.2 m^3/hour. The strength and cutting characteristics of the salt at both locations is almost identical. Table 4.1 gives the test results.

* **Production is maximised at wide head lacings.**

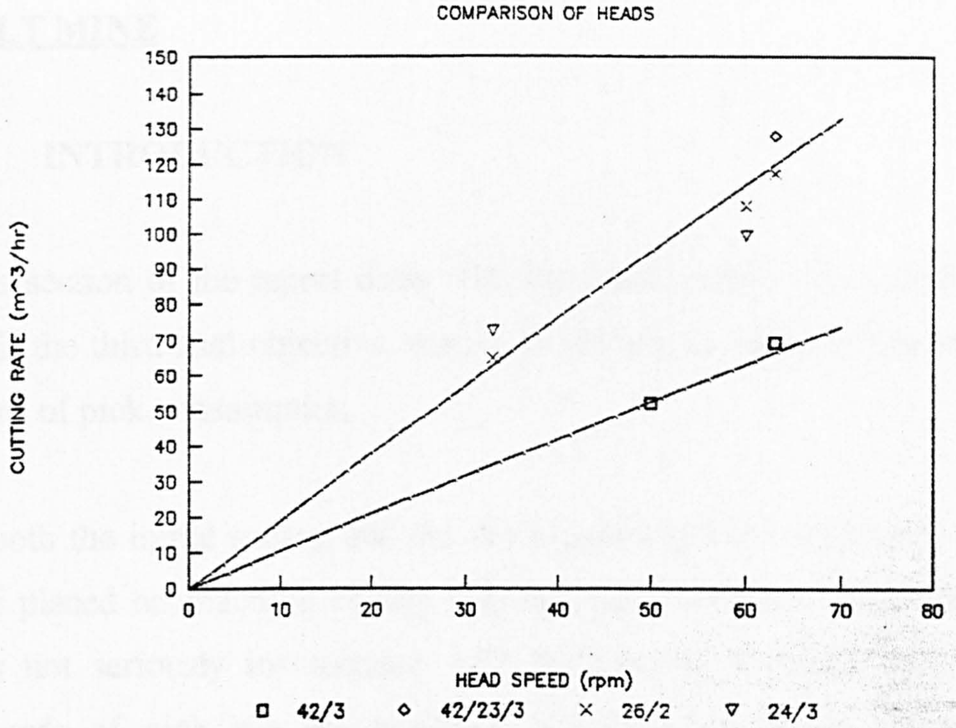
The results of all the tests are plotted in Fig. 4.9. This clearly shows the linear relation between production rate and head speed, and the increase (over 70%) in production rate achieved by opening up the head lacing.

TABLE 4.1

TEST ANALYSIS OF ICI, WINSFORD SALT

Unconfined compressive strength (MPa)	27.2
Cerchar abrasivity index	Nil
Density (t/m^3)	2.17
Mean cutting force (kN)	1.42
Peak cutting force (kN)	3.46
Mean normal force (kN)	0.17
Peak normal force (kN)	0.41
Specific energy (MJ/m^3)	10.67
Tool cutting wear (mm/m)	Nil

FIG 4.9



From Fig. 4.9, the machine cutting rate is around 120 m^3/hour at a head speed of 63 rpm with the latest head design. From the 12 monitored cuts, the average sump was 79 cm. From Fig. 4.8, the instantaneous cutting rate predicted for the head at this sump depth is 128 m^3/hour.

4.4 CONCLUSIONS

The main aspects influencing machine production rate are shown to be pick line spacing, head rotational speed and sump depth.

With the latest head design, salt can be produced at a rate of around 120 m^3/hour (260 tonnes/hour) at a rotational speed of 63 rpm.

Simple field measurement of arcing force, cut parameters and cut times can be used to predict machine cutting rate with a reasonable degree of accuracy.

5. CUTTER PICK EVALUATION AND OPTIMISATION AT DOMTAR SALT MINE

5.1 INTRODUCTION

This section of the report deals with the identification of a suitable pick to fulfil the third trial objective, that of producing salt at an acceptable cost in terms of pick consumption.

In both the initial testing and the development phases of the trial, emphasis was placed on machine cutting rate and fines fraction. Pick consumption was not seriously investigated until the final head design was available. Records of pick use are available, but they are neither exhaustive nor conclusive.

In general, the rate of pick consumption is dependent on the effects of frictional heat, which melts the braze holding the tungsten carbide insert and results in loss of the tip. As expected, abrasive wear is negligible. Due to the presence of the 15 cm thick dolomite layer near the top of the extracted section, some impact damage has been observed, and this accounts for the relatively high consumption. Plates 5.1 and 5.2 show typical failure.

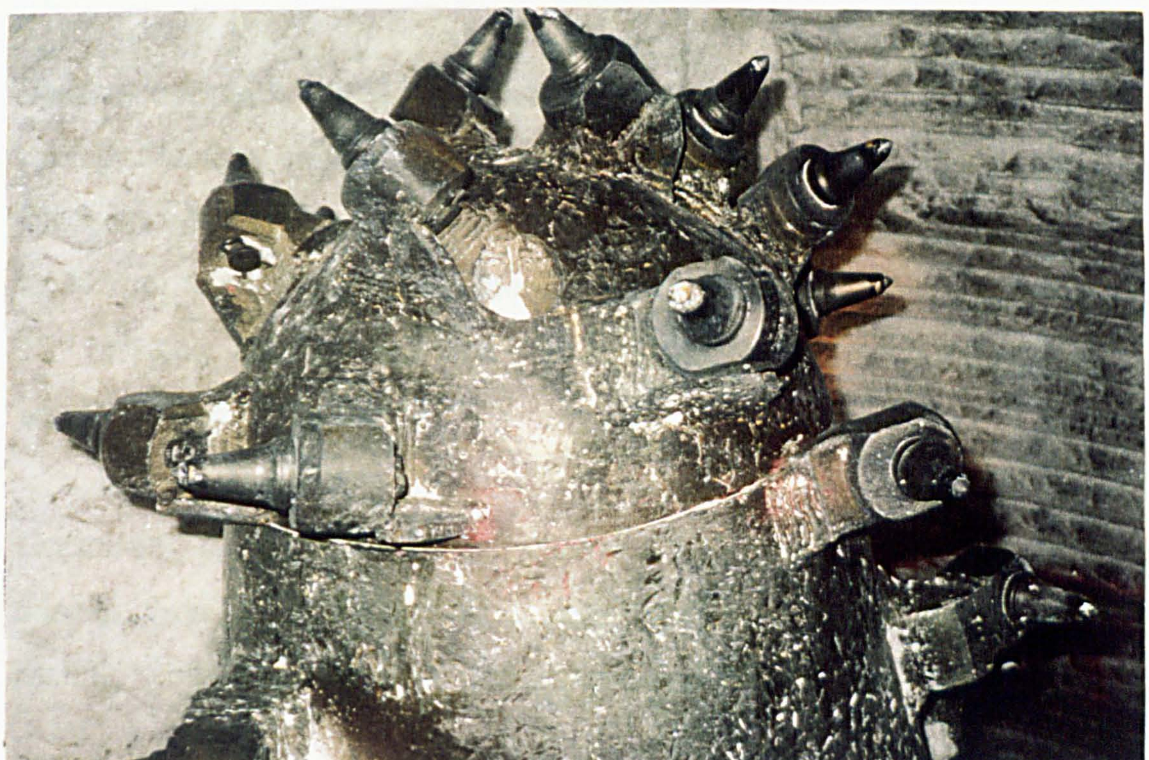
5.2 TESTING PROCEDURE

Having standardised on a pick gauge of 80 mm early in the final proving stage of the trial, all the reported tests are carried out with picks of this gauge.

PLATE 5.1

PICK TIP FAILURE

PLATE 5.2



Tests were undertaken to establish pick consumption in the total extracted section, and separately in the salt and in the dolomite, in an attempt to quantify the effect of the hard band.

Results are listed in Table 5.1. The table is divided into tests with standard point attack tools, and tests with a range of picks specially adapted for this application.

5.3 STANDARD PICKS

The geometry of the pick is shown at Fig. 5.1, the important details being the insert diameter at 12 mm and the insert length at 17 mm.

Tests at 33 rpm in the combined section indicate a pick use of 10 tools for an extracted volume of 352 m^3, 35 m^3/pick. At 60 rpm, 9 picks were used in extracting 343 m^3, 38 m^3/pick.

Tests at 60 rpm in salt only indicate a consumption of 146 m^3/pick, and at 33 rpm in dolomite only, a consumption of 10 m^3/pick. The effect of the hard dolomite band is clear. Cutting in salt at 60 rpm, then changing head speed to 33 rpm to cut through the dolomite band, gives an overall consumption of 195 m^3/pick, although this was only measured in 195 m^3 of extraction, not an exhaustive test.

Decreasing tip size from 12 mm diameter to 8 mm diameter increased pick consumption to 11 m^3/pick at a head speed of 33 rpm in the combined section, when a relatively short test, extracting 137 m^3, used 12 picks.

TABLE 5.1

Domtar Pick Test Results Final Head Design (Jan 1990 Onwards).

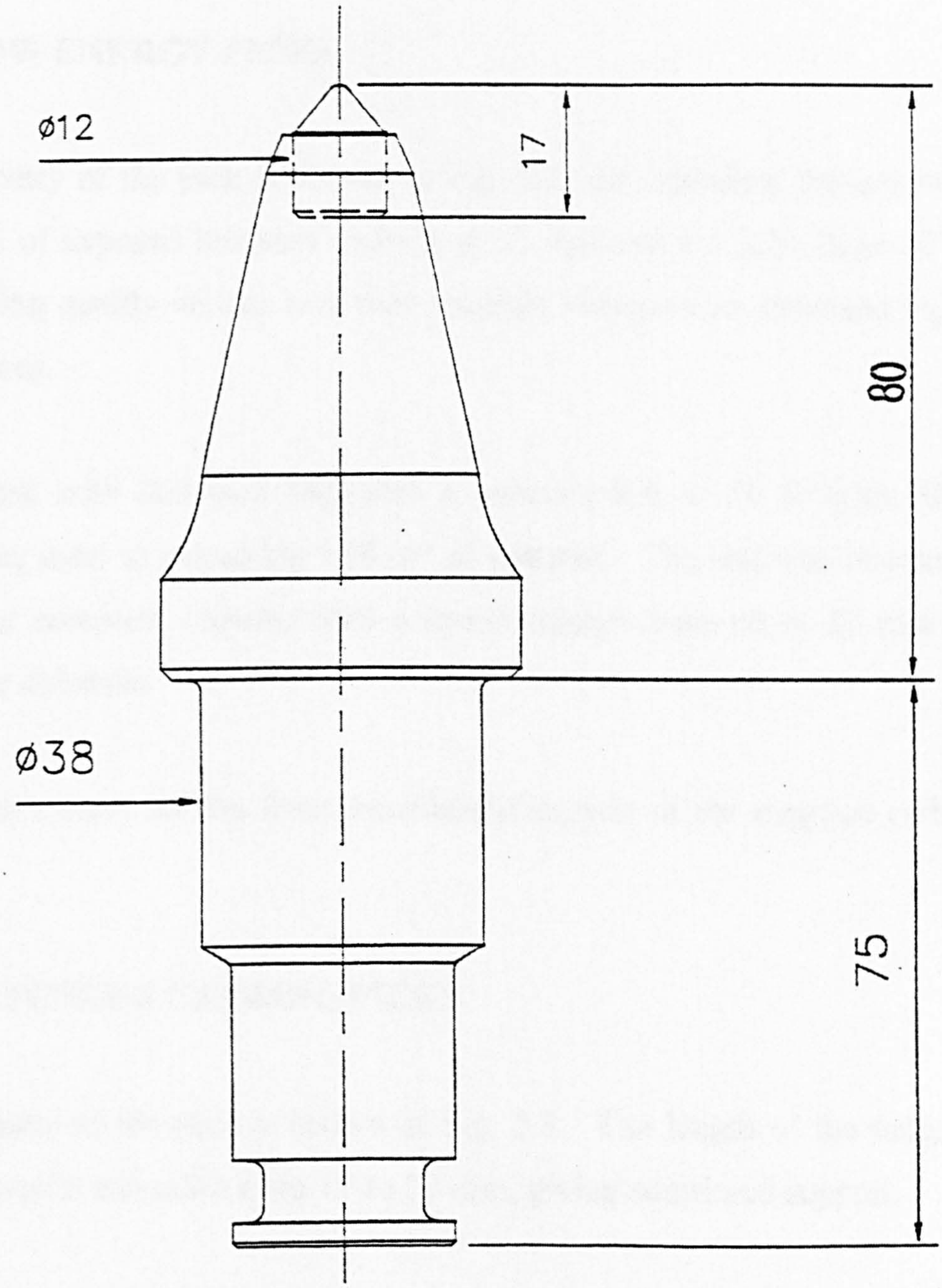
Pick Make	Pick Type	Reach (mm)	Tip (mm)	Material Mined	Head Speed (rpm)	Boom Type	Volume (m^3)	Tons (2000 lbs)	Picks Used	Pick Use (m^3)	Comments
Standard Picks											
Sandvik	PA	100	12	Salt/Dol	33	STD	21	51.00	5	1/4	Tip loss due to heat / impact
Sandvik	PA	80	12	Salt/Dol	33	STD	172	420.00	4	1/43	Tip loss due to heat / impact
Sandvik	PA	80	12	Salt	60	STD	586	1427.00	4	1/146	Tip loss due to heat
Sandvik	PA	80	12	Dol	33	STD	21	51.00	2	1/10	Tip loss due to heat / impact
Sandvik	PA	80	12	Salt/Dol	60	STD	343	835.00	9	1/38	Tip loss due to heat / impact
Sandvik	PA	80	8	Salt/Dol	33	STD	137	333.00	12	1/11	Tip loss due to heat / impact
Sandvik	PA	80	12	Salt/Dol	33/60	STD	195	476.00	1	1/195	Tip loss due to heat / impact
Sandvik	PA	80	12	Salt/Dol	33	STD	180	438.00	6	1/30	Tip loss due to heat / impact
Sandvik	PA	80	17	Salt/Dol	60	STD	144	350.00	0	1/144	Note caution on this rate
Special Picks											
Sandvik LE	PA	80	12	Salt/Dol	33/60	STD	169	412.00	3	1/56	Tip loss due to heat / impact
Sandvik DC	PA	80	12	Salt/Dol	33/60	STD	147	359.00	1	1/147	Tip loss due to heat / impact
Sandvik DCS	PA	80	12	Salt/Dol	33/60	STD	169	412.00	1	1/169	Tip loss due to heat / impact

Note - PA - Point Attack

LE - Low Energy
DC - Deeper Carbide
DCS - Deeper Carbide and Spray Coating

33/60 - Speed change for Dolomite

FIG. 5.1
STANDARD POINT ATTACK



Increasing tip size from 12 mm diameter to 17 mm diameter appears to decrease pick consumption. In a test extracting 144 m^3, no picks were used. However, as stated in Section 3 of this report, fines production increased when using this tool.

5.4 LOW ENERGY PICKS

The geometry of the pick is shown at Fig. 5.2, the important aspects being the length of exposed tungsten carbide at 17 mm and the slim shape of the tip. Brazing quality on this tool was specially designed to withstand higher temperatures.

A short test with this pick indicated a consumption of 56 m^3/pick, three picks being used in extracting 169 m^3 of material. The test was conducted cutting the complete section, with a speed change from 60 to 33 rpm for cutting the dolomite.

The tool obviously suffers from insufficient support of the tungsten carbide insert.

5.5 EXTENDED CARBIDE PICKS

The geometry of the pick is shown at Fig. 5.3. The length of the tungsten carbide insert is extended from 17 to 22 mm, giving additional support.

A short test indicated a consumption of 147 m^3/pick. The test was conducted cutting the complete section, with a speed change from 60 to 33 rpm for cutting the dolomite.

FIG. 5.2

LOW ENERGY (LE)

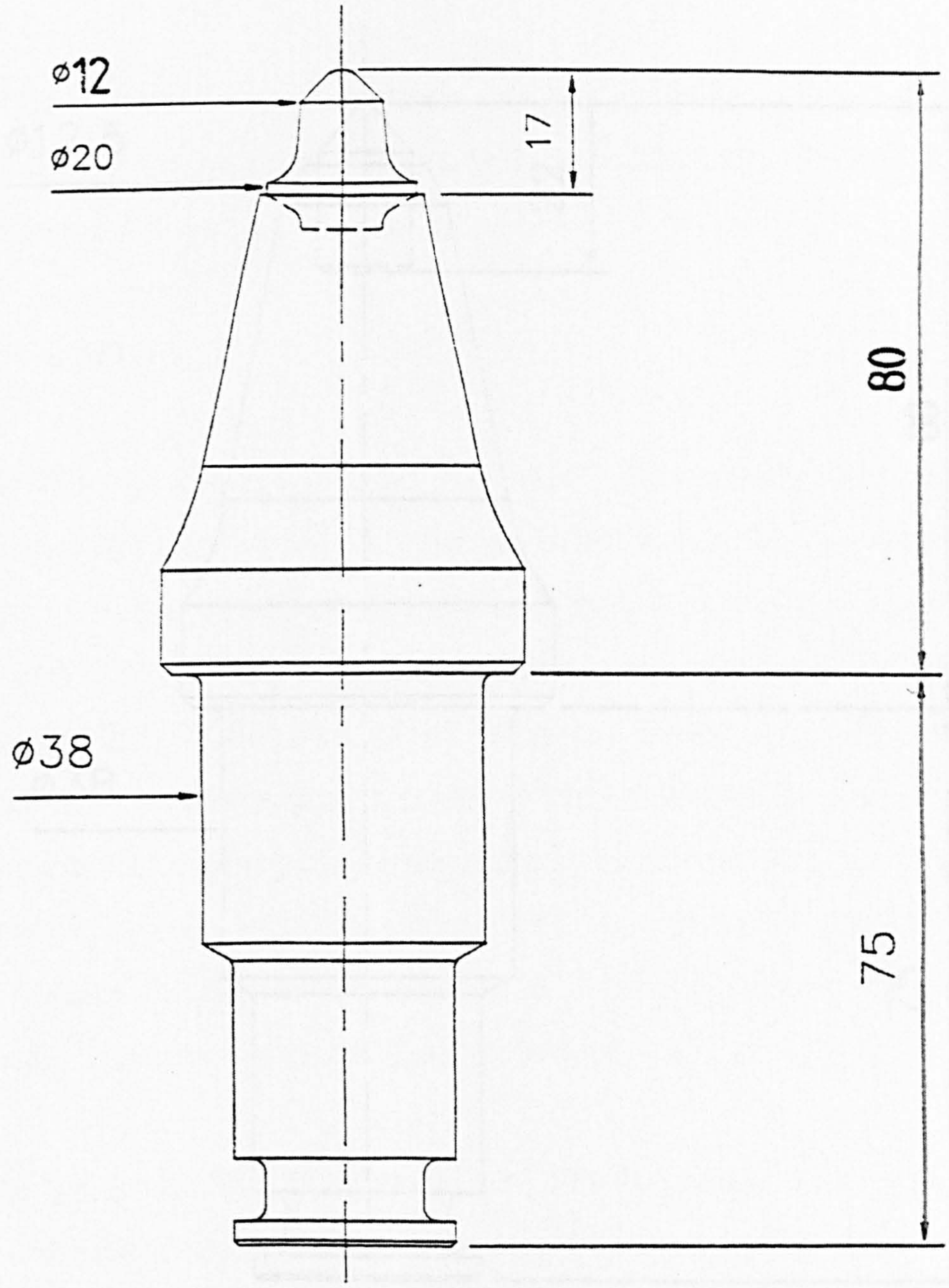
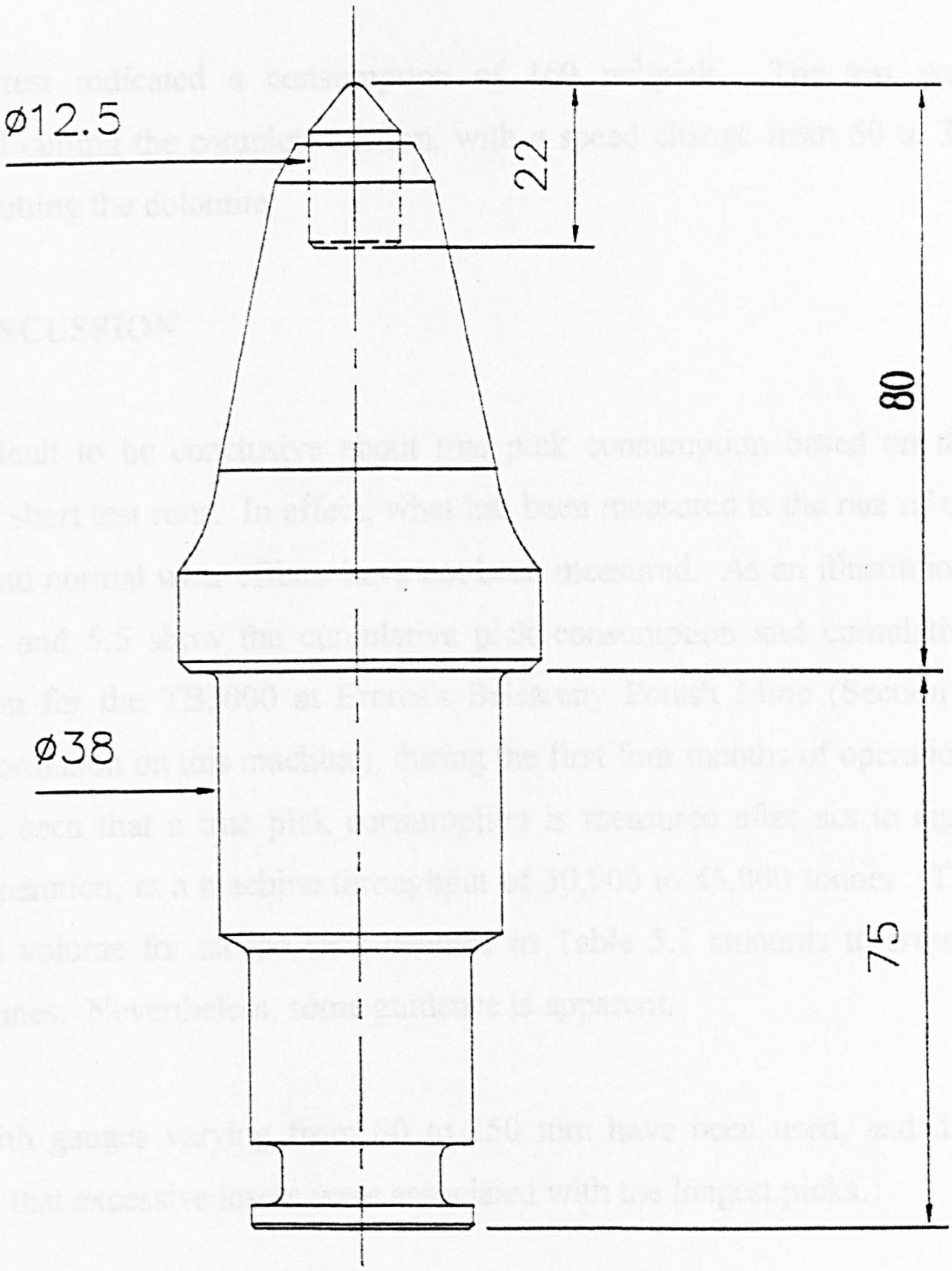


FIG 5.3

DEEPER CARBIDE (DC)



5.6 SPRAY COATED PICKS

The geometry of the pick is as Fig. 5.3, that is with the extended carbide insert. In addition, the tip is coated with a heat-resistant material.

A short test indicated a consumption of 169 m^3/pick. The test was conducted cutting the complete section, with a speed change from 60 to 33 rpm for cutting the dolomite.

5.7 DISCUSSION

It is difficult to be conclusive about true pick consumption based on the results of short test runs. In effect, what has been measured is the rate of tip failure, and normal wear effects have not been measured. As an illustration, Figs. 5.4 and 5.5 show the cumulative pick consumption and cumulative production for the TB3000 at Ercros's Balsareny Potash Mine (Section 7 gives information on this machine), during the first four months of operation. It can be seen that a true pick consumption is measured after six to eight weeks' operation, at a machine throughput of 30,000 to 45,000 tonnes. The extracted volume for all the tests detailed in Table 5.1 amounts to around 5,000 tonnes. Nevertheless, some guidance is apparent.

Picks with gauges varying from 80 to 150 mm have been used, and it is apparent that excessive losses were associated with the longest picks.

FIG. 5.4

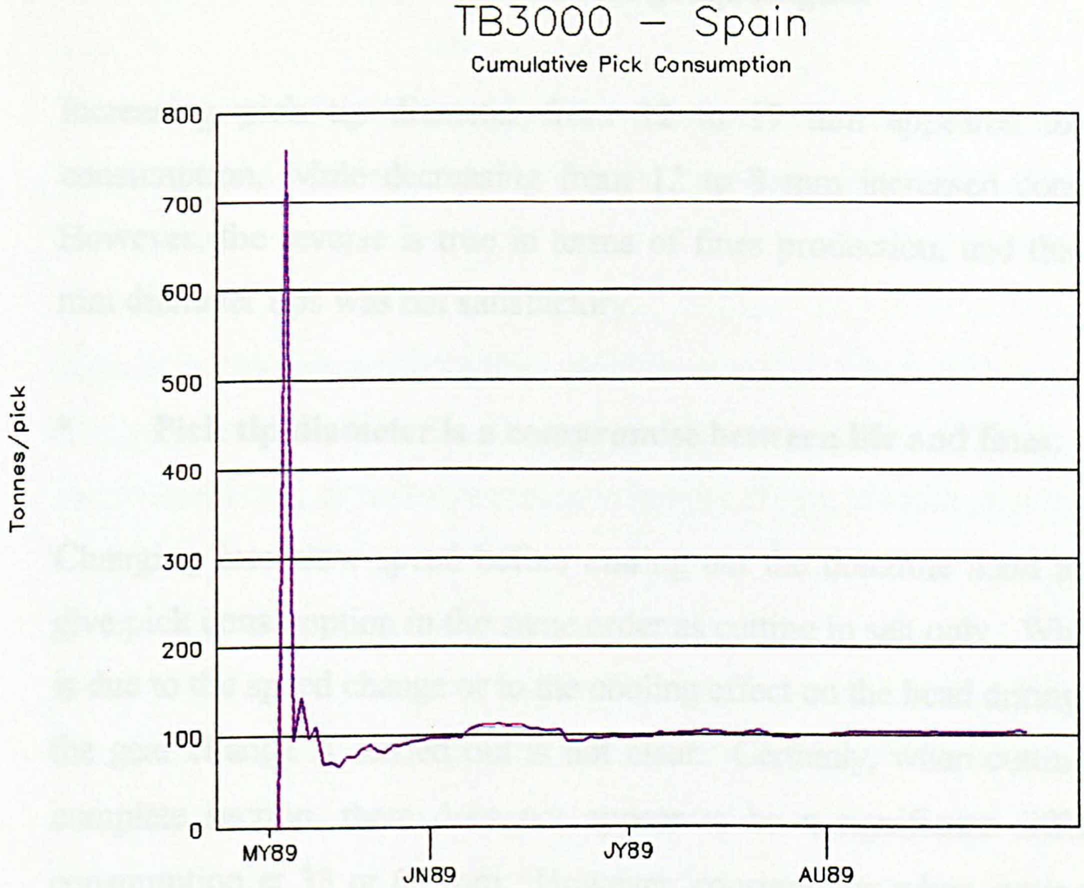
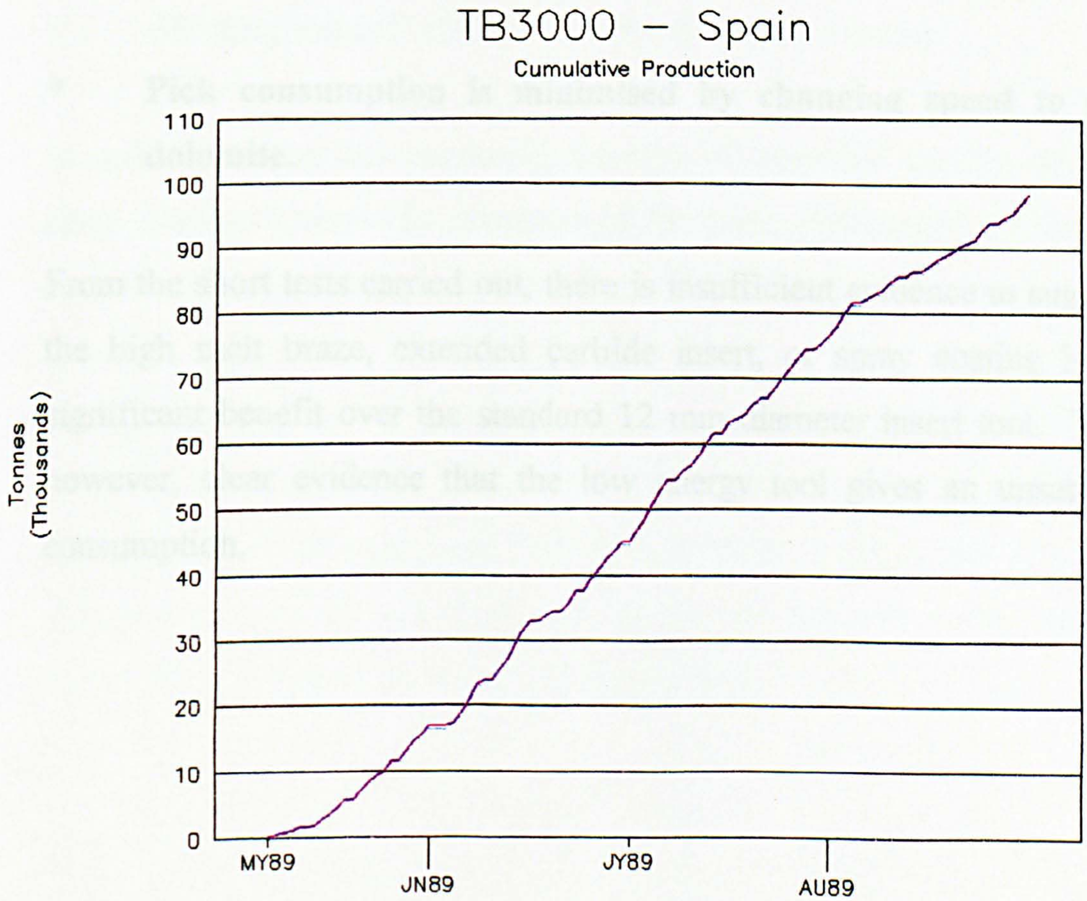

TB3000 – Spain
Cumulative Pick Consumption
Tonnes/pick
800
700
600
500
400
300
200
100
0
MY89
JN89
JY89
AU89

FIG. 5.5


TB3000 – Spain
Cumulative Production
Tonnes (Thousands)
110
100
90
80
70
60
50
40
30
20
10
0
MY89
JN89
JY89
AU89

* **Pick use is minimised at short gauge lengths.**

Increasing pick tip diameter from 12 to 17 mm appeared to improve consumption, while decreasing from 12 to 8 mm increased consumption. However, the reverse is true in terms of fines production, and that with 17 mm diameter tips was not satisfactory.

* **Pick tip diameter is a compromise between life and fines.**

Changing into slow speed before cutting out the dolomite band appears to give pick consumption in the same order as cutting in salt only. Whether this is due to the speed change or to the cooling effect on the head during the time the gear change is carried out is not clear. Certainly, when cutting out the complete section, there does not appear to be a significant difference in consumption at 33 or 60 rpm. However, consumption when cutting out the complete section is much worse than when stopping for a speed change.

* **Pick consumption is minimised by changing speed to cut the dolomite.**

From the short tests carried out, there is insufficient evidence to suggest that the high melt braze, extended carbide insert, or spray coating have any significant benefit over the standard 12 mm diameter insert tool. There is, however, clear evidence that the low energy tool gives an unsatisfactory consumption.

5.8 CONCLUSION

The main aspects influencing pick consumption are shown to be frictional heat, and shock loading when cutting the hard dolomite band. Abrasive wear has little influence.

Pick consumption when cutting in salt only, or when effecting a speed change to cut the dolomite, is around 300 tonnes/pick. When cutting the complete section, pick consumption is around 80 tonnes/pick, a ratio of 3.75.

Economic and mining considerations are therefore:-

* **Examine the consequences of moving the mined section well below the hard band, to leave it intact in the roof.**

* **Examine the extra pick cost against the loss of production time in effecting a speed change to cut out the hard band.**

In order to assess any economic benefits of extended carbide tips, and/or spray coating, it would be necessary to carry out a prolonged trial with each, with a machine throughput in the order of 30,000 tonnes.

6. CONCLUSIONS FROM DOMTAR TRIALS

6.1 PRODUCT SIZE

Careful development and tuning of the roadheader type cutting head resulted in a reduction in the fines fraction of the product from over 20% at -12 mesh to around 8%. The corresponding increase in the fraction at +1" was from around 23% to 65%.

6.2 PRODUCTION RATE

With the roadheader type cutting head at 63 rpm, initial production was at a rate of 150 tonnes/hour. The final head design at the same rotational speed produced at a rate of 260 tonnes/hour, without any other changes to the machine.

6.3 PICK CONSUMPTION

Many different tools were tested over short periods. The most consistent results were obtained with a standard point attack tool at 80 mm gauge, with a 12 mm diameter tip.

At high head speeds (60 to 63 rpm), pick consumption when cutting salt was up to 300 tonnes/pick. When cutting the complete section, including the dolomite band, consumption increased to around 80 tonnes/pick. When effecting a speed change to 33 rpm to cut the dolomite, pick consumption was of the same order as when cutting salt only.

Pick consumption could probably have been improved by further development and longer term testing of specially developed tools with higher melt point brazes and spray coating.

6.4 MOTOR POWER

The machine was not fitted with power transducers during the trial period, so no accurate assessment of power requirement was possible. The need for higher powers than normally associated with roadheaders can be seen from the fact that when fitted with the standard boom assembly at 142 kW, it was not possible to cut consistently at 60 rpm. There were no problems cutting at 63 rpm with the 270 kW high powered boom assembly.

6.5 ROADWAY CONDITIONS

Although not mentioned in the main body of the thesis, one of the reasons for looking at machine mining was to obviate the need for scaling of the roof. Roadways driven by the LH1300H are in excellent condition, and have remained stable.

7. SPECIFICATION FOR TB3000 MINING MACHINE

The TB3000, a 125 tonne twin boom machine, capable of a cutting width of 8.9 metres and a cutting height of 6 metres, is the ideal machine for high capacity mining of thick salt beds. Plate 7.1 gives a typical view.

All motors on the machine are air-cooled, and an air blast radiator is provided for cooling of the hydraulic oil. At present, the boom is a single speed arrangement at 63 rpm on a 60 Hz electrical supply, powered by a 300 kW, 4-pole motor. If it is necessary to extract the hard dolomite band in the section, there is an advantage in considering a dual pole motor to effect a speed change, either to 32 rpm (8-pole) or 21 rpm (12-pole).

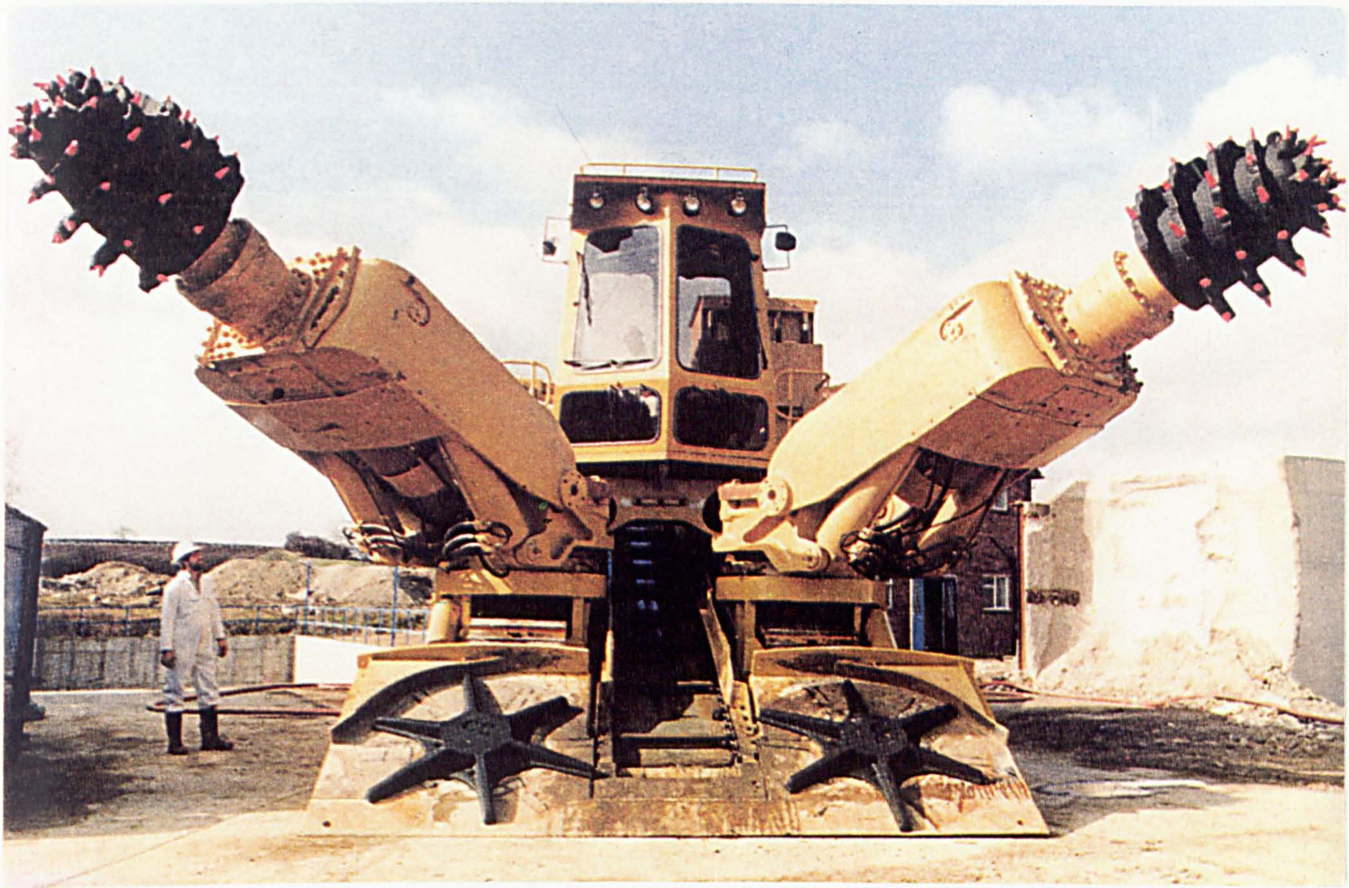
Because the mineral is extracted dry, the ventilation system provided needs to be of a high standard. There is an advantage in considering the mounting of a dust extraction system on the machine, to handle an air volume of around 6 m^3/sec.

Because the fines fraction and production rate are very much dependent on the cutting pattern and sump depth, there is an advantage in considering the use of automatic profiling of the cut section, removing much of the variation from the operator's control.

With the cutting head design based on the finally developed head from this trial, and with boom arcing force increased from 130 to 155 kN, it is predicted that at 80 cm sump depth, each boom will produce at a rate of 130 to 180 m^3/hour, giving the machine a production rate in the range 500 to 600 tonnes/hour.

PLATE 7.1

DOSCO TB.3000



Based on a 16 hour working day and an overall 40% utilisation, the machine has a potential of 3800 tonnes/day.

8. ADVANCED PERFORMANCE / PREDICTION METHODOLOGIES FOR ROADHEADERS

8.1 INTRODUCTION

This section of the thesis is probably the most interesting, certainly in the author's view, as it brings together the experiences gained from operational research, and seeks to show how these can influence roadheader design.

The prime intention of the work, first commissioned at the University of Newcastle-upon-Tyne, was to provide a means by which the expected performance of a roadheader could be readily assessed. Information contained in this thesis, as well as parallel studies in gypsum and potash, confirm this is possible, and with some degree of accuracy.

While the production rate of a machine with known specification can now be defined, it is also possible to determine the increases in specification required to give performance beyond this limit. This aspect, which was identified during the course of the work, is not confined to existing machines, and has major implications for new designs and potential markets. There is also a considerable benefit to the engineer and designer alike, as pre-determined machine parameters reduce the likelihood of an inadequate design.

The ability to relate production and specification is a major step forward, and offers significant advantages for the roadheader manufacturer.

The long term future for Dosco or any other roadheader manufacturer lies in the ability to supply a product which is suitable to the application, competitive in price, and ideally contains features which offer benefits over its competitors. Furthermore, any potential new market must be fully investigated, with particular attention given to the major players.

Entry into a new market, and certainly one which is already well served, is obviously difficult and requires a committed approach if the risks involved are to be minimised. While many aspects need to be considered, a fundamental issue is the machine's ability to produce. Current production levels acceptable to the industry must, at the very least, be matched, and ideally be bettered, if the product is to provide a substantial and quantifiable cost benefit, and hence an attractive option.

In 1991, Dosco were approached by Joy South Africa, a well established Continuous Miner manufacturer with specific interests in the South African Coal Mining Industry. Current business levels were under threat from Voest-Alpine, an Austrian roadheader manufacturer, who had successfully entered the market with the ability to excavate hard stone inclusions occurring in-seam, something the Joy units were unsuitable for. Plates 7.1 and 7.2 show typical Joy and Alpine mining machines.

Dosco were asked to consider the market and make proposals for suitable equipment, including a primary requirement to out-perform current best production levels by 25%.

PLATE 8.1

JOY CONTINUOUS MINER 12HM17

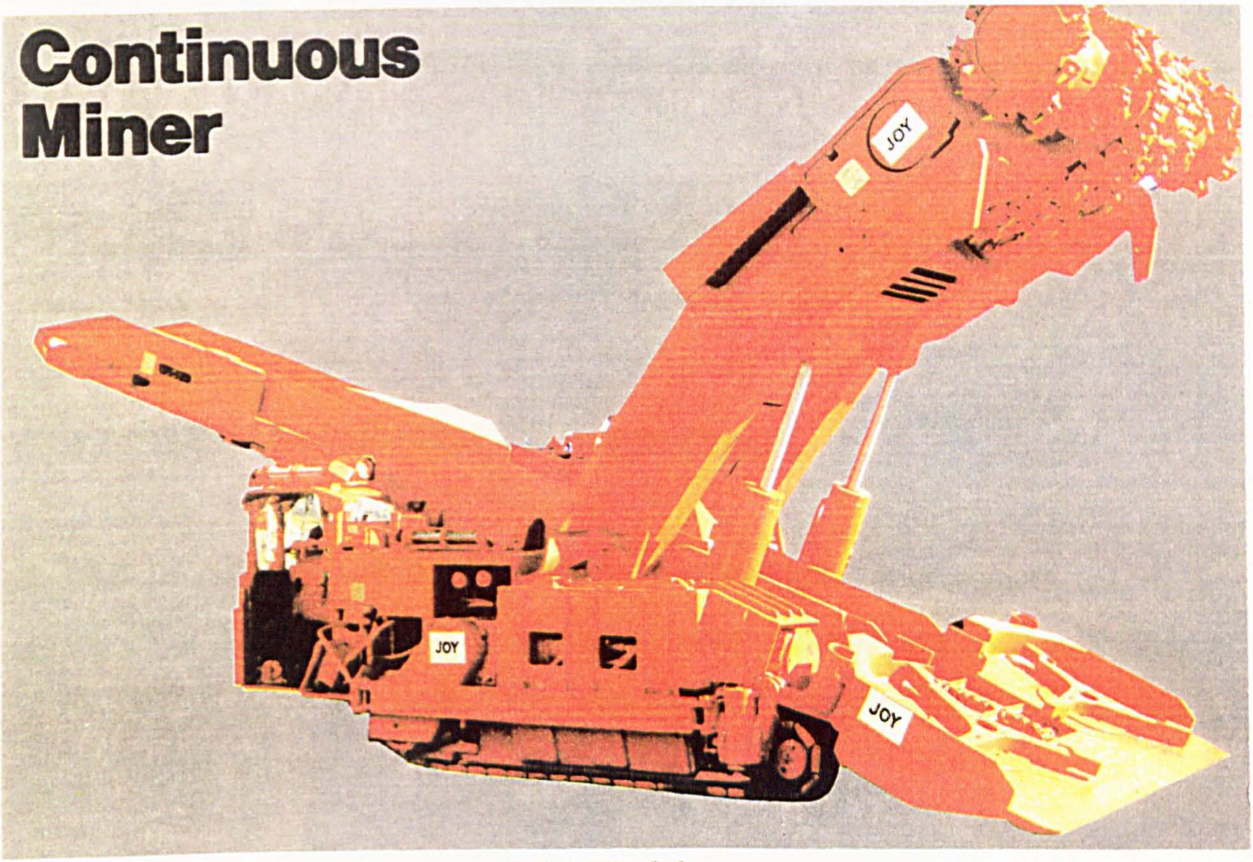
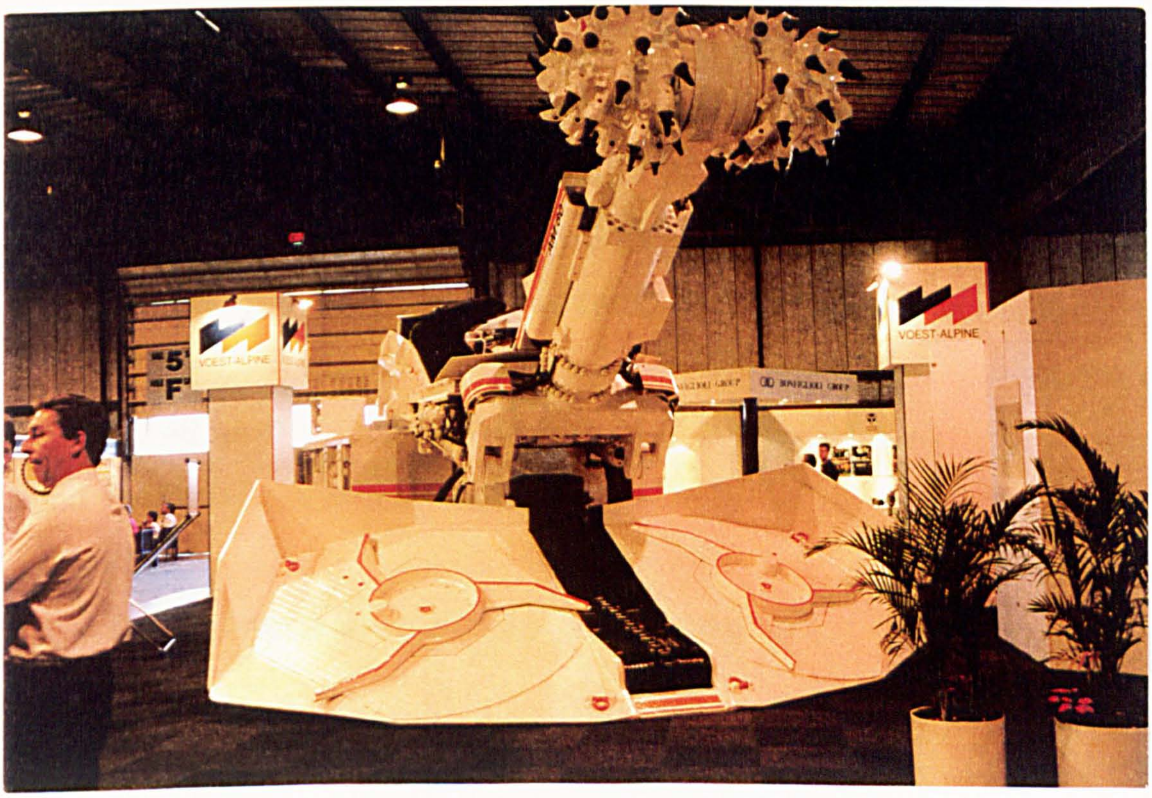


PLATE 8.2

VOEST-ALPINE AM85 ROADHEADER



Following an in-depth market study, a new specification for a machine, to be known as the TB2500, was determined, with an availability of late 1993 given as a practical completion date. Fig. 8.1 shows the new machine design.

Furthermore, an agreement by which Joy would act as Dosco's distributor was finalised.

8.2 TB2500 PERFORMANCE CRITERIA

Best monthly performance levels by Voest-Alpine roadheaders are up to 80,000 tonnes per month in a predominantly all-coal section, but including thin bands of strong rock. The rate required for the TB2500, including a 25% target improvement, is therefore clear.

* **Target monthly production is 100,000 tonnes.**

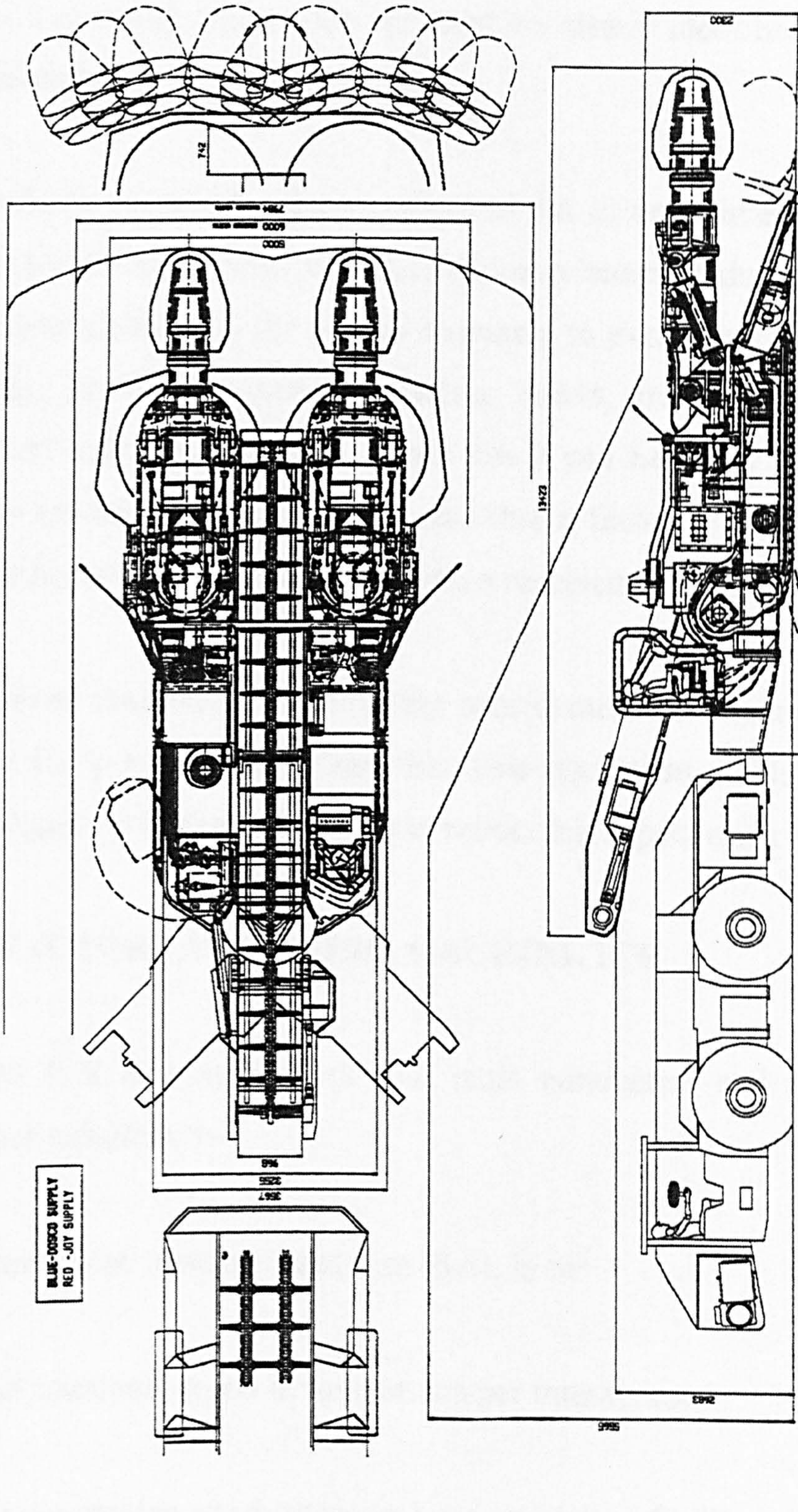
Shift analyses provided by Joy indicate that on average 3.4 hours are directly related to actual cutting operations, with the remaining time relating to loading, place changing and breakdowns. A normal production cycle is two shifts per day, and on average twenty days per month are worked. From this data, an hourly production rate or capability requirement can be determined:-

100,000 / 40 / 3.4 = 736 t/hour, or 736 / 1.37 = 540 m^3/hour.
Solid density of coal is 1.37 t/m^3.

* **Target hourly production is 736 t or 540 m^3.**

FIG. 8.1

TB.2500 DESIGN



8.2.1 CLARIFICATION OF THE TERM "PRODUCTION RATE"

There are many occasions where reference to machine instantaneous cutting rate (ICR) is confused with machine cutting and loading rate (CLR). This aspect is of major importance and must be clearly identified if problems are to be avoided.

ICR reflects the ability of a machine to cut in an uninterrupted mode, for example when traversing, and results in maximum production. CLR on the other hand includes all the factors necessary to excavate a face; for example, sumping, boom manoeuvring, loading debris, trimming, etc., and gives overall machine performance. From this it can be easily deduced that ICR will always be greater than CLR, and that a factor (F1), depending on the application, will be necessary to obtain a representative CLR to ICR ratio.

Twin boom machines require further consideration as experience shows that actual CLR performance is less than two equivalent single boom machine units. Again, a further factor (F2) to reflect this aspect must be applied.

8.3 FACTORS AFFECTING MACHINE ICR

Machine ICR is a function of four main parameters and results from the following calculation:-

(1) Cutting head contact/swept area (SA), in m^2.

(2) Head rotational speed in revolutions per minute, rpm.

(3) Pick penetration or advance per head revolution (A/R), in cm, determined by boom force (BF), in kN.

(4) Sufficient available motor power in kW.

ICR m^3/hr = SA * A/R / 100 * rpm * 60

It can be clearly seen that changing one or more of the above parameters will result in either an increase or decrease in machine ICR. It can also be seen that three are directly related to the machine specification and are therefore somewhat fixed, while the fourth, A/R, is subject to the strata encountered and is the likely major variable in any rock type.

8.3.1 CUTTING HEAD - GENERAL PARAMETERS

It is envisaged that for South African coal, a 3-start, spiral cutting head, having a large contact area of 1.22 m^2, will be used. The design of the head will be conical, a necessary feature to provide a flat roof and floor profile. During operation it is expected that a maximum sump depth of 1.1 metres is initially achieved, followed by a series of lateral boom sweeps to gain the required profile.

8.3.2 CUTTING HEAD ROTATIONAL SPEED

Conical-shaped cutting heads which vary in diameter will be affected by rotational speed, and pick tip speed will obviously increase towards the rear of the head where the diameter is greatest. Experience shows that, in general, low pick tip speeds are more suitable to hard abrasive strata, while easier conditions allow a higher speed. Based on the South African coal results and in conjunction with the required production and dust levels, a head rpm of 52 is selected as that most likely to give the optimum result. Average pick tip speed is 1.63 m/s.

8.3.3 PICK PENETRATION/ADVANCE PER HEAD REVOLUTION

Section 4 of this thesis described in detail the methodology used to establish penetration curves. These criteria, in conjunction with findings from other similar studies, enable a realistic assessment of South African coal.

A range of penetration curves for coal, salt, concrete and sandstone are shown in Fig. 8.2, with corresponding laboratory cutting test results shown in Table 8.1.

It can be seen that the constants of each curve appear to have a relationship with the cutting test results, in that the lower the value of the constant, the lower the normal force requirement.

FIG. 8.2

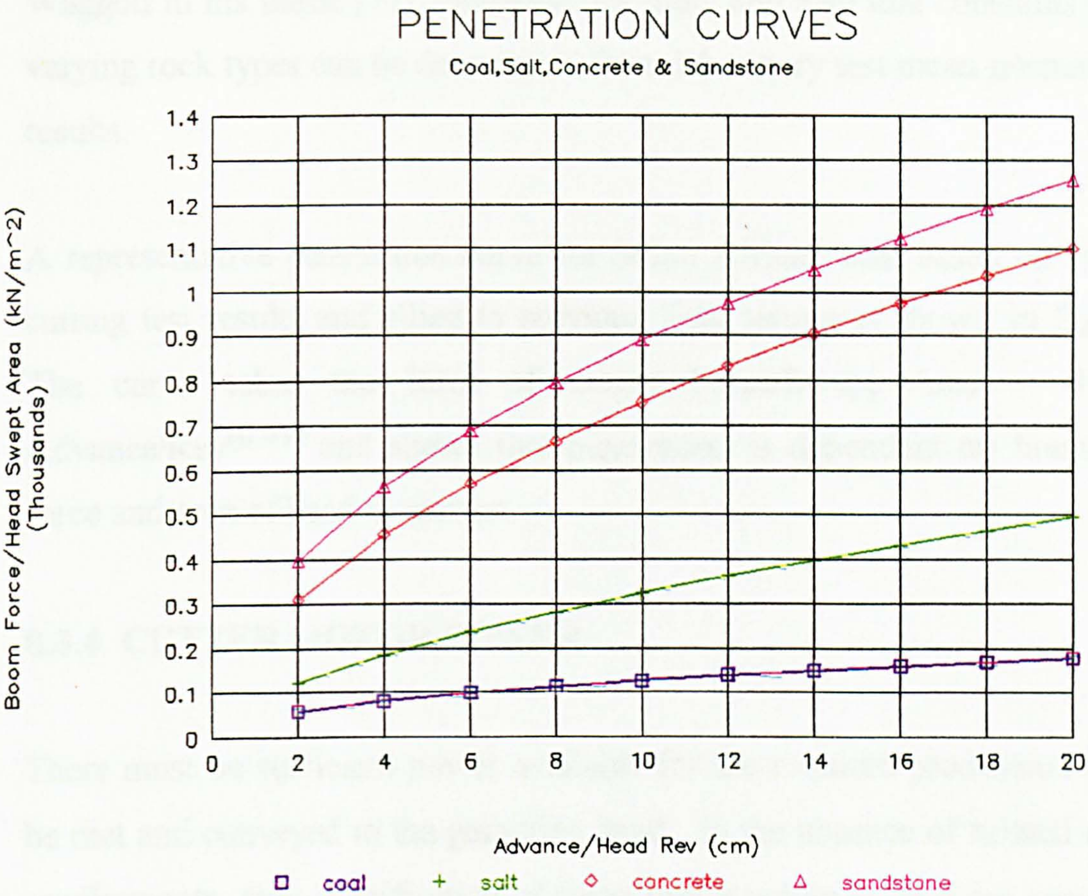


TABLE. 8.1

RELATIONSHIP BETWEEN PENETRATION CONSTANT AND MEAN NORMAL FORCE

Strata Type	Penetration Curve Value	Mean Laboratory Force (kN)
Coal	$BF/SA = 41.0 * A/R^{(0.49)}$	0.19
Salt	$BF/SA = 79.5 * A/R^{(0.61)}$	0.46
Concrete	$BF/SA = 212.0 * A/R^{(0.55)}$	0.92
Sandstone	$BF/SA = 281.0 * A/R^{(0.50)}$	1.10

Waggott in his thesis [77], confirms this view and also that constants to suit varying rock types can be determined from laboratory test mean normal force results.

A representative penetration curve for South African coal based on specific cutting test results and allied to previous field testing is shown in Fig. 8.3. The curve takes the form of Boom Force/Swept Area = 41.0 * Advance/Rev$^{(0.49)}$ and shows that penetration is dependent on boom slew force and area of head in contact.

8.3.4 CUTTER MOTOR POWER

There must be sufficient power available for the required production rate to be met and conveyed to the gathering head. In the absence of related energy requirements, over-specification of cutter motor power is far more acceptable than under.

8.4 PERFORMANCE CALCULATION

Pre-determined Information

Head contact/swept area: SA = 1.22 m^2

Head rpm = 52

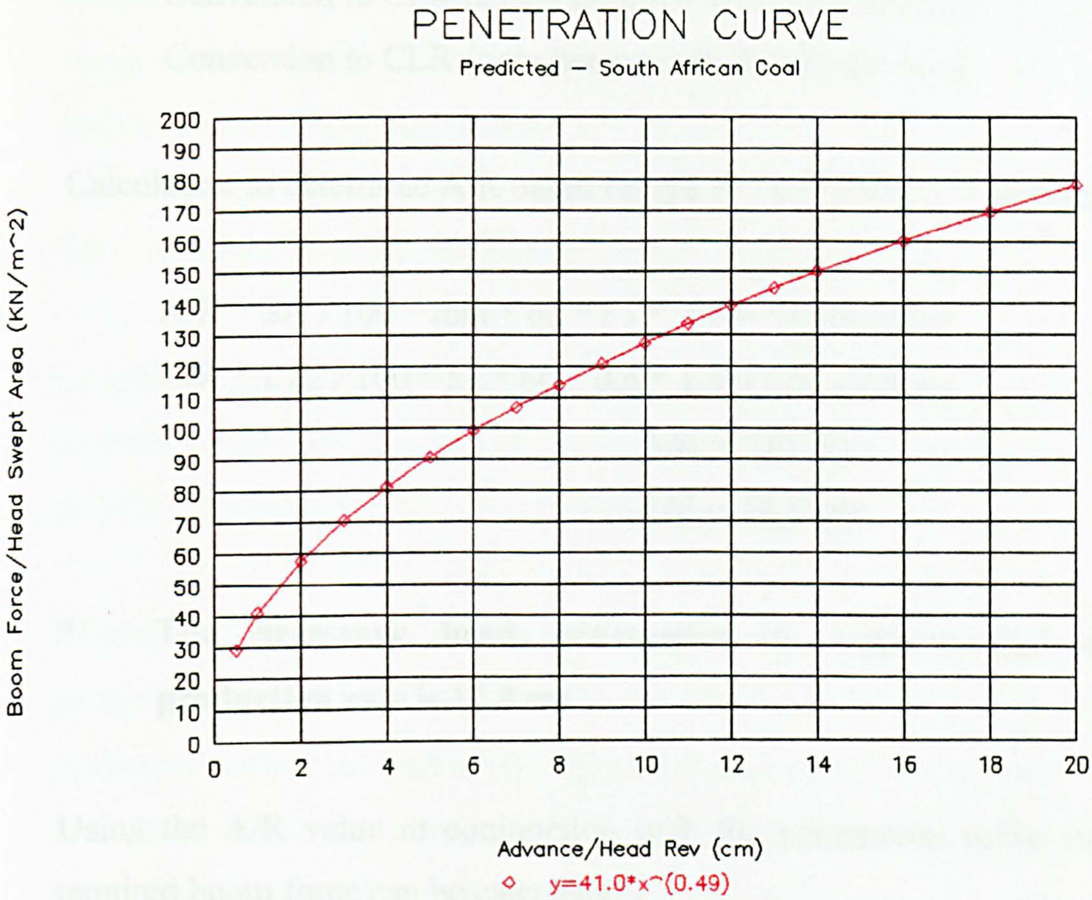
Penetration curve value: BF/SA = 41.0 * A/R$^{(0.49)}$

Factor values F1 and F2 based on field testing:-

F1 has a value of 0.6 and converts single boom ICR to CLR

F2 has a value of 1.6 and converts single boom CLR to twin boom CLR

FIG. 8.3


PENETRATION CURVE
Predicted – South African Coal
Boom Force/Head Swept Area (KN/m^2)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
Advance/Head Rev (cm)
y=41.0*x^(0.49)

Basic ICR formula = A/R * SA / 100 * rpm * 60 m^3/hour

Conversion to CLR (single boom) = ICR * F1 m^3/hour

Conversion to CLR (twin boom) = CLR * F2 m^3/hour

Calculation to determine A/R based on the 540 m^3/hour CLR requirement:-

A/R * SA / 100 * rpm * 60 * F1 * F1 = 540 m^3/hour

A/R * 1.22 / 100 * 52 * 60 * 0.6 * 1.6 = 540 m^3/hour

A/R = 540/36.5

A/R = 14.8 cm

* **The necessary head penetration to achieve the required production rate is 14.8 cm.**

Using the A/R value in conjunction with the penetration curve value, the required boom force can be calculated:-

$BF/SA = 41.0 * A/R^{(0.49)}$

$BF/1.22 = 41.0 * 14.8^{(0.49)}$

BF = 187 kN

* **The individual boom penetration force necessary to achieve the required production rate is 187 kN.**

This figure is significant in that it is some 40 kN or 30% greater than any boom force currently in the Dosco range. Without the information contained in this thesis, it is highly unlikely that boom forces would have progressed to such a level.

In an effort to show how boom force can be altered, depending on production requirements, Fig. 8.4 shows a plot of varying penetrations, which give a range of forces from 150 to 190 kN. The values of A/R and BF calculated above can be readily observed on this graph.

8.5 CUTTING HEAD - MAIN PARAMETERS

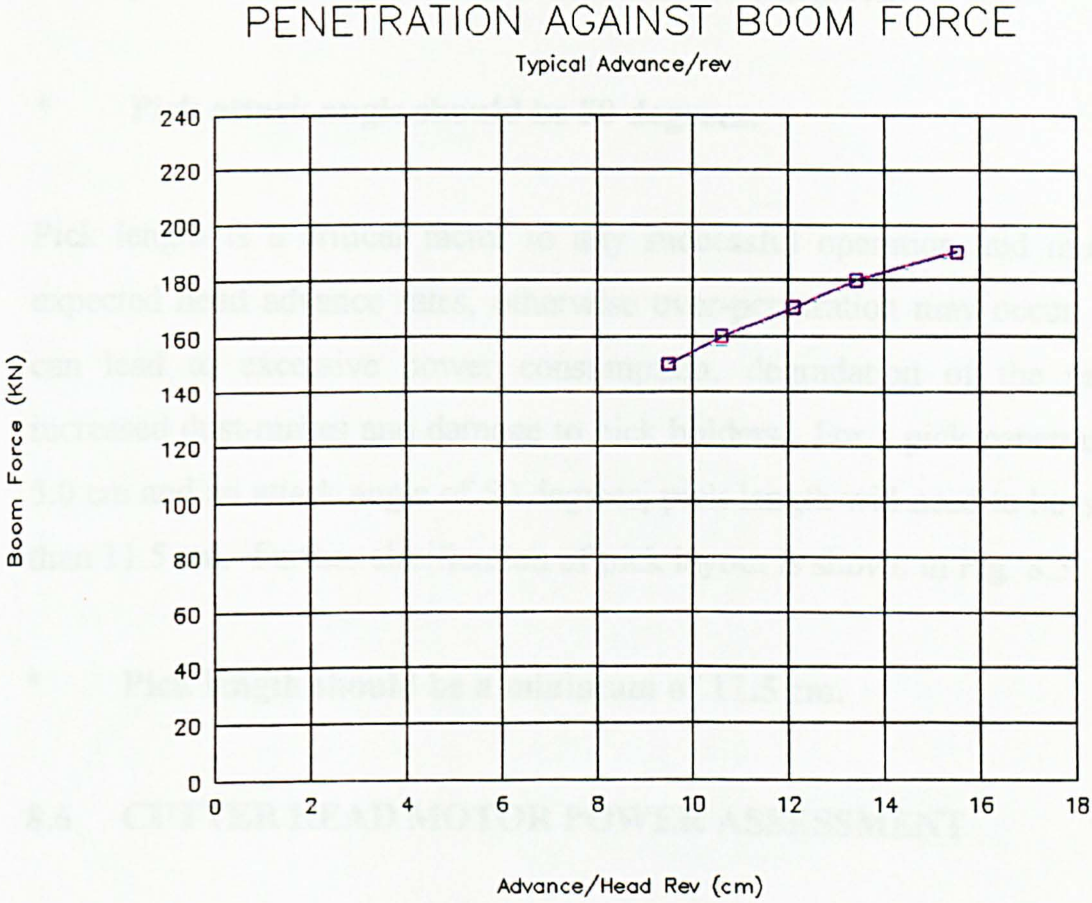
In order to maintain cutting efficiency and hence a low specific energy, it is important that cutting tools are presented to the working face at the best possible attack angle, with an appropriate line spacing.

Expected A/R is 14.8 cm, which equates to approximately 5.0 cm of penetration per pick per head revolution. The break-out pattern derived from laboratory cutting tests gives an angle from the vertical of near to 45 degrees, and from this a pick line spacing to penetration ration of 2:1 can be determined. It therefore follows that based on individual pick penetrations of 5.0 cm, pick line spacing needs to be around 10.0 cm to give optimum material break-out.

* **Pick line spacing should be 10.0 cm.**

Cutting picks used predominantly in South African coal mines are of point attack design, with typically a 75 degree tip cone angle. This aspect must be considered when deciding clearance and rake angles, as both have an effect on the pick attack angle, and hence the cutting efficiency.

FIG. 8.4


PENETRATION AGAINST BOOM FORCE
Typical Advance/rev
Boom Force (KN)
0
20
40
60
80
100
120
140
160
180
200
220
240
0
2
4
6
8
10
12
14
16
18
Advance/Head Rev (cm)

For this particular application, and assuming a positive rake requirement of 2.5 degrees, attack angle will need to be set at 50 degrees.

*   **Pick attack angle should be 50 degrees.**

Pick length is a critical factor to any successful operation and must suit expected head advance rates, otherwise over-penetration may occur, which can lead to excessive power consumption, degradation of the product, increased dust-makes and damage to pick holders. For a pick penetration of 5.0 cm and an attack angle of 50 degrees, pick length will need to be not less than 11.5 cm. Further clarification of pick layout is shown in Fig. 8.5.

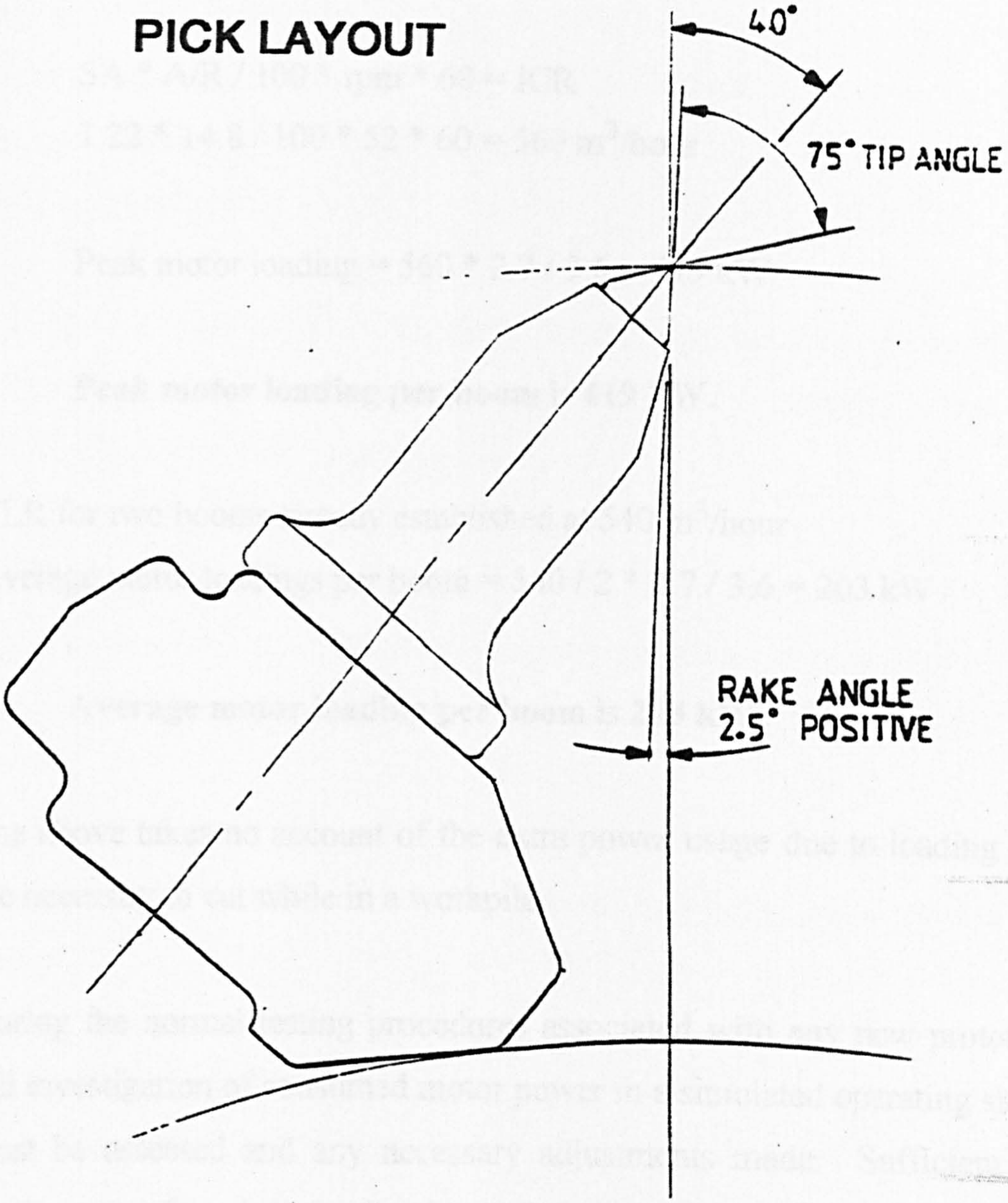
*   **Pick length should be a minimum of 11.5 cm.**

8.6 CUTTER HEAD MOTOR POWER ASSESSMENT

While no specific information is available on power requirements for South African coal, an exercise using Voest-Alpine experience has been undertaken to provide a general guide.

Voest-Alpine, AM85 roadheader results, give average specific energy values of 2.7 MJ/m^3, based on recorded performance and installed cutter motor power. No allowance has been made for under or over motor loadings, as no information is currently available. Using 2.7 MJ/m^3 as a basis, estimates for average and peak cutter motor loadings for the TB2500 can be made.

FIG. 8.5



The ICR rate of each boom, using the information contained in Section 7.4, can be readily determined and used to indicate peak and average motor loadings:-

SA * A/R / 100 * rpm * 60 = ICR
1.22 * 14.8 / 100 * 52 * 60 = 560 m^3/hour

Peak motor loading = 560 * 2.7 / 3.6 = 419 kW

* **Peak motor loading per boom is 419 kW.**

CLR for two booms already established at 540 m^3/hour
Average motor loadings per boom = 540 / 2 * 2.7 / 3.6 = 203 kW

* **Average motor loading per boom is 203 kW.**

The above takes no account of the extra power usage due to loading out, or the necessity to cut while in a workpile.

During the normal testing procedures associated with any new prototype, a full investigation of consumed motor power in a simulated operating situation must be assessed and any necessary adjustments made. Sufficient motor power, as referred to in Section 8.3, must be available as it forms the corner-stone of attaining high production levels.

8.7 NEWLY-ACQUIRED REFERENCE DATA

Since the inception of the TB2500, a LH1300H roadheader, similar to the one described in Section 2, has been placed on trial in a South African coal mine. Although its intended application was one of rock excavation, it has, due to changing circumstances, recently operated in an all-coal section, albeit for a short time only.

The cutting head, which is similarly laced to that specified in Section 8.5 of the thesis, has an SA of 1.03 m^2 at full head sump. Machine boom force is 130 kN and head rotational speed is 53 rpm.

Results from timed lateral cuts over a 6.0 metre distance with the head at maximum sump gives advance rates of approximately 11.3 cm per rev, equating to an individual pick penetration of some 3.8 cm.

Applying LH1300H BF and SA values to the pre-determined South African penetration curve gives a direct comparison between hypothetical and actual results.

$$BF/SA = 41.0 * A/R^{(0.49)}$$

$$130/1.03 = 41.0 * A/R^{(0.49)}$$

A/R = 10 cm and equates to a 3.3 cm pick penetration

Summarising, actual results show an advance rate of 11.3 cm and an individual pick penetration of 3.8 cm. Projections based on current test work give 10.0 and 3.3 cm respectively.

* **A correlation of some accuracy is apparent.**

8.8 CONCLUSIONS

Based on considerable test work, field references and the parameters outlined in Section 8, a production rate suitable to the South African market appears feasible.

* **Aspects critical to the success of the TB2500 are:-**

* **Boom Force - 187 kN**
* **Head Penetration - 14.8 cm**
* **Head Speed - 52 rpm**
* **Head Swept Area - 1.22 m^2**
* **Pick Line Spacing - 10.0 cm**
* **Pick Attack Angle - 50 degrees**
* **Pick Effective Length - 11.5 cm**
* **Motor Power - 250/300 kW (per boom)**

Confirmation of actual production rate via the machine test programme is vital.

8.9 FUTURE CONSIDERATIONS FOR INCREASED PERFORMANCE LEVELS

Although not specifically relevant to the TB2500 and its intended application, some consideration has been given to how essential machine parameters would need to change if higher CLR's were required to offset a threat from a competitor's new machine.

The designed CLR of the TB2500 is 540 m^3/hour, and therefore new rates from 600 to 1000 m^3/hour are considered. Table 8.2 shows the range of

CLR's, with the necessary increases in machine boom force and head swept area.

For calculation purposes, advance per rev. is kept constant at a maximum value of 15.0 cm to prevent over-penetration, with head speed maintained at 52 rpm. Factors 1 and 2 remain at 0.6 and 1.6 respectively.

Calculation based on a CLR of 600 m^3/hour:-

$$A/R * SA / 100 * rpm * 60 * F1 * F2 = 600 \text{ m}^3/\text{hour}$$
$$15 * SA / 100 * 52 * 60 * 0.6 * 1.6 = 600 \text{ m}^3/\text{hour}$$
$$SA = 600 / 449.28$$
$$\underline{SA = 1.33 \text{ m}^2}$$

Using the SA value in conjunction with the penetration curve value, the required boom force can be calculated:-

$$BF/SA = 41.0 * A/R^{(0.49)}$$
$$BF/1.33 = 41.0 * 15.0^{(0.49)}$$
$$\underline{BF = 205 \text{ kN}}$$

* **The necessary boom force and head swept area to achieve the required production rate are 205 kN and 1.33 m^2 respectively.**

Similarly, this calculation is used to determine parameters for CLR values up to 1000 m^3/hour, as shown in Table 8.2.

A similar exercise, but based on an established specific energy, as used in Section 8.6, is undertaken to determine power requirements. Table 8.3 gives expected peak and average motor loadings applicable to the CLR range.

This final aspect has considerable merit when viewed against the likely long-term requirements for improved machine performance. The engineer, when armed with the basic parameters of boom force, motor power and related performance, can make valued judgements against corresponding machine design. Such designs obviously impact on how a company views its future business, and whether or not certain markets can, or should be pursued.

Parametric analysis can be of particular use in this type of situation. Fig. 8.6 seeks to show how extrapolation to larger designs can be made.

8.10 GENERAL CONCLUSIONS

* A prediction curve suitable to South African coal and allied to a machine design has been derived from both laboratory and field investigative studies. Some confidence in the curve values and hence its effect can be taken from recent findings based on an LH1300H.

* Standard cutting test results now undertaken by Leeds University have a particular role when establishing penetration curve values for a given rock type.

* Performance prediction is subject to many factors, with machine specification and strata type playing major roles. Penetration curves, as described in this thesis, appear a fundamental necessity if the task is to be achieved with any degree of accuracy.

TABLE 8.2

INCREASED CLR RANGE WITH NECESSARY BF AND SA VALUES

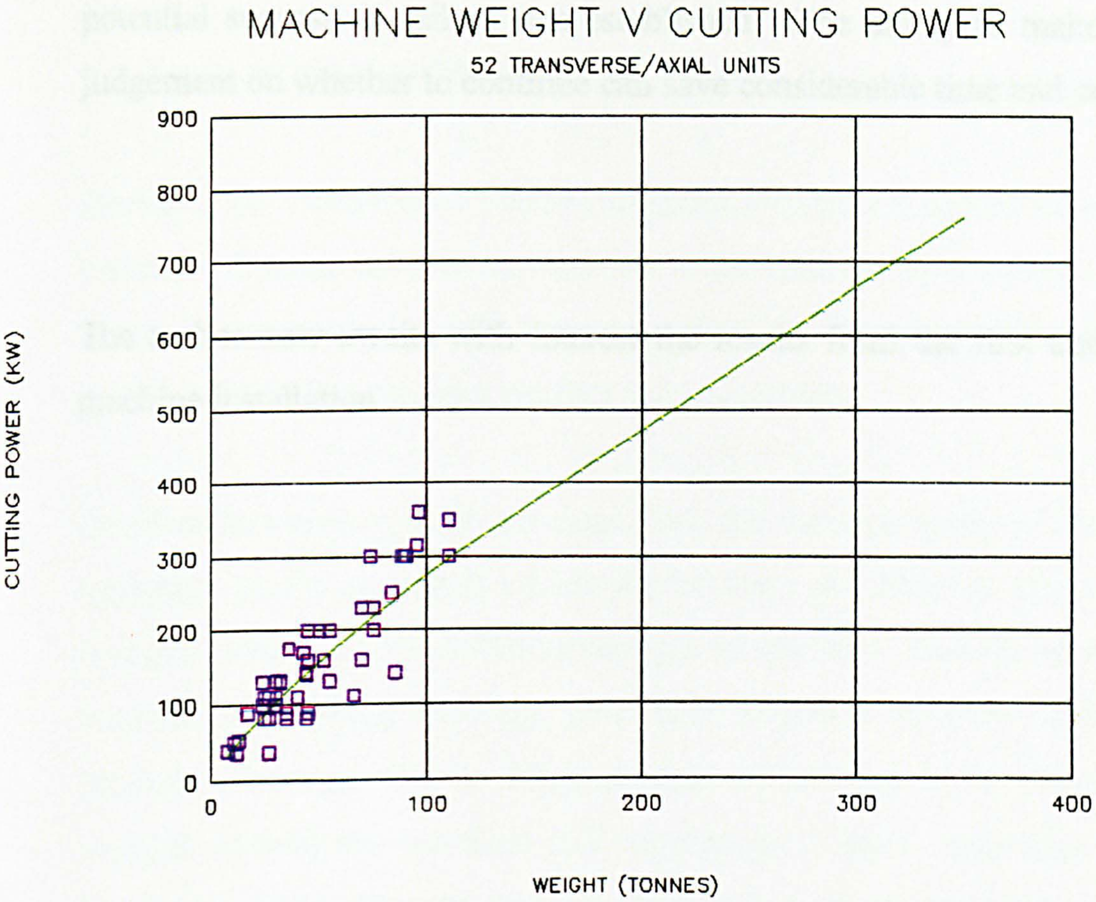
CLR	Boom Force	Head Area
(m^3/hour)	(kN)	(m^2)
600	205	1.33
650	222	1.44
700	239	1.55
750	257	1.67
800	274	1.78
850	291	1.89
900	308	2.00
950	325	2.11
1000	342	2.22

TABLE 8.3

INCREASED CLR RANGE SHOWING PEAK AND AVERAGE MOTOR LOADINGS

CLR	Peak Power per Boom	Average Power per Boom
(m^3/hour)	(kW)	(kW)
600	466	255
650	505	243
700	544	263
750	586	281
800	624	300
850	663	319
900	702	338
950	740	356
1000	780	375

FIG. 8.6


MACHINE WEIGHT V CUTTING POWER
52 TRANSVERSE/AXIAL UNITS
CUTTING POWER (KW)
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
WEIGHT (TONNES)

A wider issue is the evaluation of a particular machine enquiry with a potential success or failure rate established. The ability to make an early judgement on whether to continue can save considerable time and cost.

The author now awaits with interest the results from the first underground machine installation.

9. ROADHEADER CASE HISTORY IN SALT

9.1 INTRODUCTION

During early 1995 Dosco secured an order to supply a medium duty, single boom roadheader for a new, small salt mine application in Spain. Payment terms, in this particular case were to be monthly, for a fixed five year period and be subject to a machine performance guarantee.

Roadheaders have a high purchase cost and as such many of the smaller operators prefer an option of leasing or lease purchase as opposed to an outright sale. This can offer advantages in that new funding capital is not required and leasing costs can be directly financed from the profits in the product. There can also be disadvantages and in particular for the equipment supplier should the machine fail to perform. Such cases can result in equipment being returned with an obvious loss of revenue and extra costs incurred from idle, dirty plant.

9.2 SITE DETAIL

The mine is located in northern Spain about 150 Km north west of Barcelona. The deposit is extensive and "dome" shaped and is typical of other salt domes that occur in the area. Access to the mine is via a 150 m long surface drift, approx 4.7 m by 6.0 m wide and declined at 25%. Seam workings are normally level and roadways are of similar dimension to the decline. The salt has excellent support characteristics and there is no need for roadway supports. Production is a relatively simple process and utilises Volvo 15 t capacity trucks which haul to the surface dumping site about 1.5 km away. Working conditions are comfortable with an ambient temperature of some 18 degrees C.

9.3 PERFORMANCE GUARANTEE / EQUIPMENT

A production requirement of 80 t per operating hour with a minimum of 400 t produced within the five hour shift time was specified. Mineral clearance i.e. from machine rear discharge to surface dump remained the sole responsibility of the mine. This statement formed the basis of the production guarantee.

A machine of medium duty classification was considered necessary to achieve the required performance and a suitable unit weighing some 43 t and equipped with a heavy duty, axial cutter boom, powered by a 112 kW motor was proposed. Table 9.1 gives the general machine specification and Plate 9.1 shows a typical view of the MK2B roadheader. Again and similar to the LH1300H which worked at Domtar Salt, a closed loop cooling system and air blast radiator were necessary to negate the need for water discharge.

9.4 SALT ASSESSMENT

Analysis of the salt showed it to be similar to that tested from the Domtar project where basic parameters relating to pick penetration and power consumption had been established. Although, in this case, both UCS and SE values were less, it was felt that this would not be detrimental to production rates infact quite the reverse. The original projections from Domtar could be used with reasonable confidence.

A comparison of both test results are shown in Table 9.1.

TABLE 9.1

MK2B GENERAL SPECIFICATION

Overall length	9800 mm
Overall height	1960 mm
Overall width	3000 mm
Machine weight	43 tonnes
Maximum cutting height	4320 mm
Maximum cutting width	5760 mm
Maximum sumping force	259 kN
Maximum lifting force	59 kN
Maximum arcing force	76 kN
Cutter motor size @ 50 Hz	82/112 kW
Cutting head speeds @ 50 Hz	32/58 rpm
Machine conveyor	Centre strand
Speed of conveyor	0.97 m/s
Conveyor motor	Hydraulic
Conveyor throat	
Gathering method	2 * spinners
Gathering spinner speed	31 rpm
Track speeds	0.04 and 0.14 m/s
Track drive motors	Hydraulic
Track length contact	3470 mm
Track centres	1900 mm
Track pad width	457 mm
Track ground contact pressure	0.119 MN/m^2
Maximum tracking effort	259 kN
Power pack motor @ 50 Hz	112 kW
Number of pumps	2
Hydraulic system pressure	140 bar

PLATE 9.1

MK2B ROADHEADER

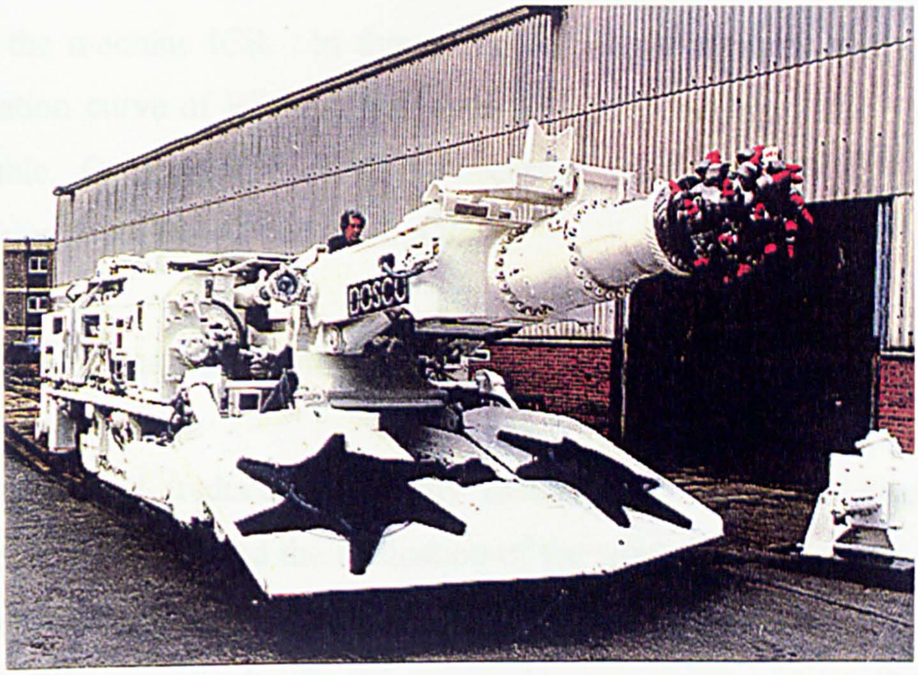


TABLE 9.2

COMPARISON BETWEEN SALT TEST RESULTS

Unconfined compressive strength (MPa)	28.7	25.5
Cerchar abrasivity index	Nil	Nil
Density (t/m^3)	2.14	2.14
Mean cutting force (kN)	1.40	0.97
Peak cutting Force (kN)	3.01	2.76
Mean normal force (kN)	0.46	0.47
Peak normal force (kN)	0.85	1.10
Specific Energy (MJ/m^3)	10.52	8.63
Tool cutting wear (mm/m)	Nil	Nil

9.5 PERFORMANCE ASSESSMENT

As already illustrated in Section 8, it is a relatively easy process to determine the amount of pick penetration, provided certain criteria are available and hence the machine ICR. In this particular case and using the appropriate penetration curve of BF/SA=79.5*A/R$^{(0.61)}$ a value of 12.9 cm should be attainable. Combining this with the necessary machine parameters results in a machine projected ICR of 90.4 m^3/hr.

* **Mk2B has a projected ICR of 90.4 m^3/hr or 193.5 tph**

ICR is affected (reduced) by many factors such as profile size, support requirement, backup and the dedication of the workers to name but a few. In determining CLR it is therefore necessary to consider such factors and down rate the ICR accordingly. In this particular case and based on other similar installations, CLR is assessed at 54.2 m^3/hr i.e. a factor of 0.6.

* **MK2B has a projected CLR of 54.2 m^3/hr or 116 tph**

* **MK2B at 116 tph is capable of achieving the required hourly production rate of 80 tph and has a safety factor of 45%.**

9.6 OPERATIONAL DETAIL

In order to gain acceptance, machine performance was monitored over several shifts and the results analysed as follows:

Based on 10 individual timings ICR ranged from 135 to 176 tph with an average value of 132 tph.

Based over 5 shifts CLR ranged from 60 to 67 tph with an average value of 64 tph.

It can be clearly seen that ICR achieved is considerably less than that projected, as is the corresponding CLR. It can also be seen that the CLR to ICR factor at 0.48 is much lower than the original estimate of 0.6.

The following points were considered to have a detrimental effect on production rates:-

* Production heading declined at 25%.
* An inefficient cutting to gathering head relationship due to a non-standard lengthened boom, necessary to achieve the cutting height.
* Reduced boom arcing force and hence lowered pick penetration, resulting from an electrical problem.

Following consideration of the above points, a second series of tests were undertaken where:-

* The machine now worked a level heading.
* The boom spacer was removed and the gathering head toe modified to maximise the loading efficiency.
* The electrical problem was resolved allowing the maximum use of machine arcing force and associated pick penetration.

Final monitoring showed ICR benefiting with values of up to 170 tph. Average rates increased to 163 tph with a corresponding increase in average CLR to 86 tph. The CLR to ICR factor also increased to 0.53.

Monitoring of the electrical system gave some interesting data.

Cutter power consumption at maximum ICR was 248 kW, some 221% of nominal motor rating. This corresponds to a SE of 8.5 MJ/m^3 at a A/R of 12.3 cm.

When rotating the cutting head through the work pile, no actual cutting, power consumption varied between 32 and 48 kW! The no-load running characteristics of the motor were 12 kW.

Only rarely did the average cutter power recording fall below the nominal rating of the motor.

No cutter motor overload trips were recorded.

9.7 RESULTS

There is good correlation between projected A/R at 12.9 cm, relating to an ICR of 193.5 tph and that recorded of 12.3 cm for a maximum ICR of 170 tph.

Average ICR and CLR values are 163 tph and 86 tph respectively. The ICR compares reasonably well with an expected 193.5 tph but the CLR is quite low when compared to 116 tph.

The CLR to ICR factor is 0.53 compared to an estimate of 0.6. Again reasonably close values, but having a noticeable affect, resulting in a much lower than expected CLR .

9.8 CONCLUSIONS

* It is clear from the results that poor machine performance can be initially attributable to a combination of factors as specified on page 164. CLR at 64 tph is considerably less than expected and fell well below the required performance guarantee.

* Following remedial action CLR improved to 86 tph. This figure is excess of that required to satisfy the performance guarantee and the machine was subsequently accepted.

* ICR is sufficiently close to the projected value obtained from the salt penetration curve to give further confidence in the use of such curves as previously described.

* Whilst the use of such penetration curves will be extremely beneficial, it is also of major importance to consider the effect of any shortfall in the projected CLR to ICR ratio. In this particular case it has considerably reduced expected performance rates.

* CLR, although above the target of 80 tph is disappointing. More data / case studies to assist in estimating CLR from ICR are required.

* Considerable power is consumed by the cutting head as it revolves through a salt work pile when loading. This aspect which until now was not fully appreciated requires further consideration and in particular with regard to a total cutter power requirement for all excavation operations.

10. TB2500 OPERATIONAL PERFORMANCE CASE HISTORY IN SOUTH AFRICAN COAL MINE

10.1 INTRODUCTION

This final section of the thesis concerns the application of the TB2500 in an underground, production environment at Bosjesspruit mine in South Africa.

It has not been possible to conduct a similar machine study to that described for the Domtar LH1300H application. However, extensive operational information in the form of shift reports have been made available by the mine and these in conjunction with certain specific recordings have enabled the machine production rate to be critically analysed.

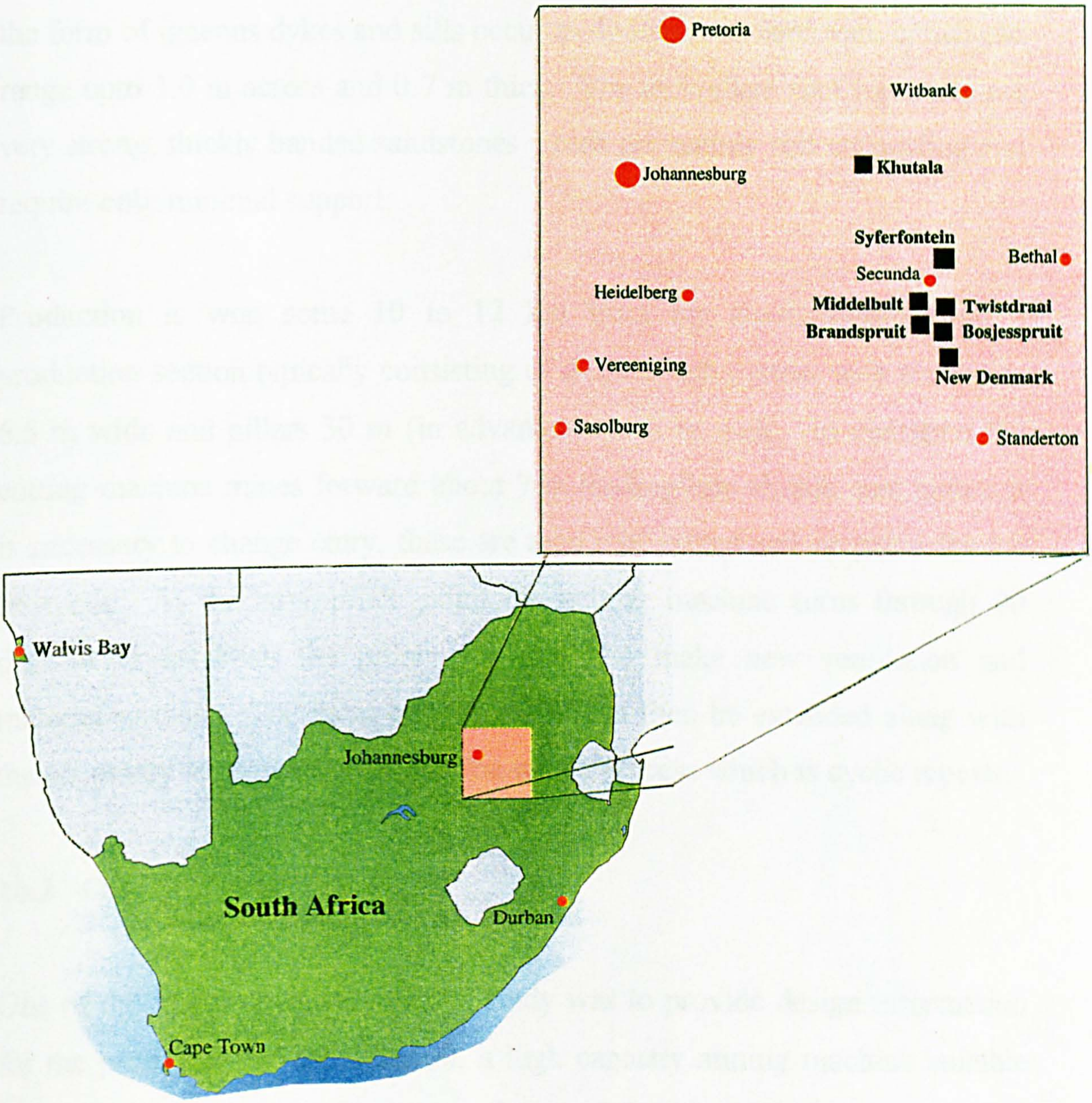
The shift reports contain many aspects which relate not only to the machine, but also to the mine and some of these are considered to be of a confidential nature. It has, therefore, been necessary to extract and use only "relevant" information and not include the basic reports as an appendices for viewing.

Bosjesspruit mine is part of the large Secunda mining complex which supplies coal to Sasol 2 and 3 which are treatment plants for the production of synthetic fuels and chemicals. There is a large demand for coal and in 1994 the complex which consists of four mines: Middelbult, Brandspruit, Bosjesspruit and Twistdraai plus the Syferfontein strip mine supplied in excess of 36 Mt of coal for conversion. The mines which are located 120 Km to the east of Johannesburg are shown in FIG 10.1.

Over the next few years the demand for South African coal will increase dramatically as both home and export markets grow. World Coal [93] in an article on the industry describes the production methods currently used and mines in the Secunda complex and in particular the importance of both continuous miners and roadheaders.

PLATE 10.1

LOCATION OF BOSJESSPRUIT MINE [93]



10.2 SITE DETAIL

Bosjesspruit mine works the No 4 lower seam at a depth of around 160 m which here varies in thickness from 2.7 to 3.0 m and occasionally increasing up to 3.5 m thick. The coal is quite hard having a UCS of 30 to 40 MPa and normally sits on a level competent floor. Throughout the seam intrusions in the form of igneous dykes and sills occur as do lenses of hard rock which can range upto 1.0 m across and 0.7 m thick. The immediate roof measures are very strong, thickly banded sandstones which are mainly self supporting and require only minimal support.

Production is won some 10 to 12 km from the shaft bottom from a production section typically consisting of a seven entry panel with roadways 6.5 m wide and pillars 30 m (in advance) by 18 m wide. In operation the cutting machine mines forward about 7 m loading into shuttle cars before it is necessary to change entry, these are then roof bolted and prepared for the next cut. At the appropriate point the cutting machine turns through 90 degrees to establish the pillar crosscuts and make new ventilation and material circuits. The main conveyor belt can then be extended along with the necessary support services and the whole process which is cyclic repeats.

10.3 OBJECTIVES

One of the major objectives of this study was to provide design information for the production of the TB2500, a high capacity mining machine suitable for the South African coal industry. Section 8.2, gives a machine potential of 100,000 t/month at a rate of 735 tph provided 3.4 hours of cutting time is made available each shift. Unfortunately, actual tonnage achieved is dependent on many factors, mining and otherwise, and most of these are outside the influence of the machine supplier.

PLATE 10.2

DOSCO TB2500 MACHINE

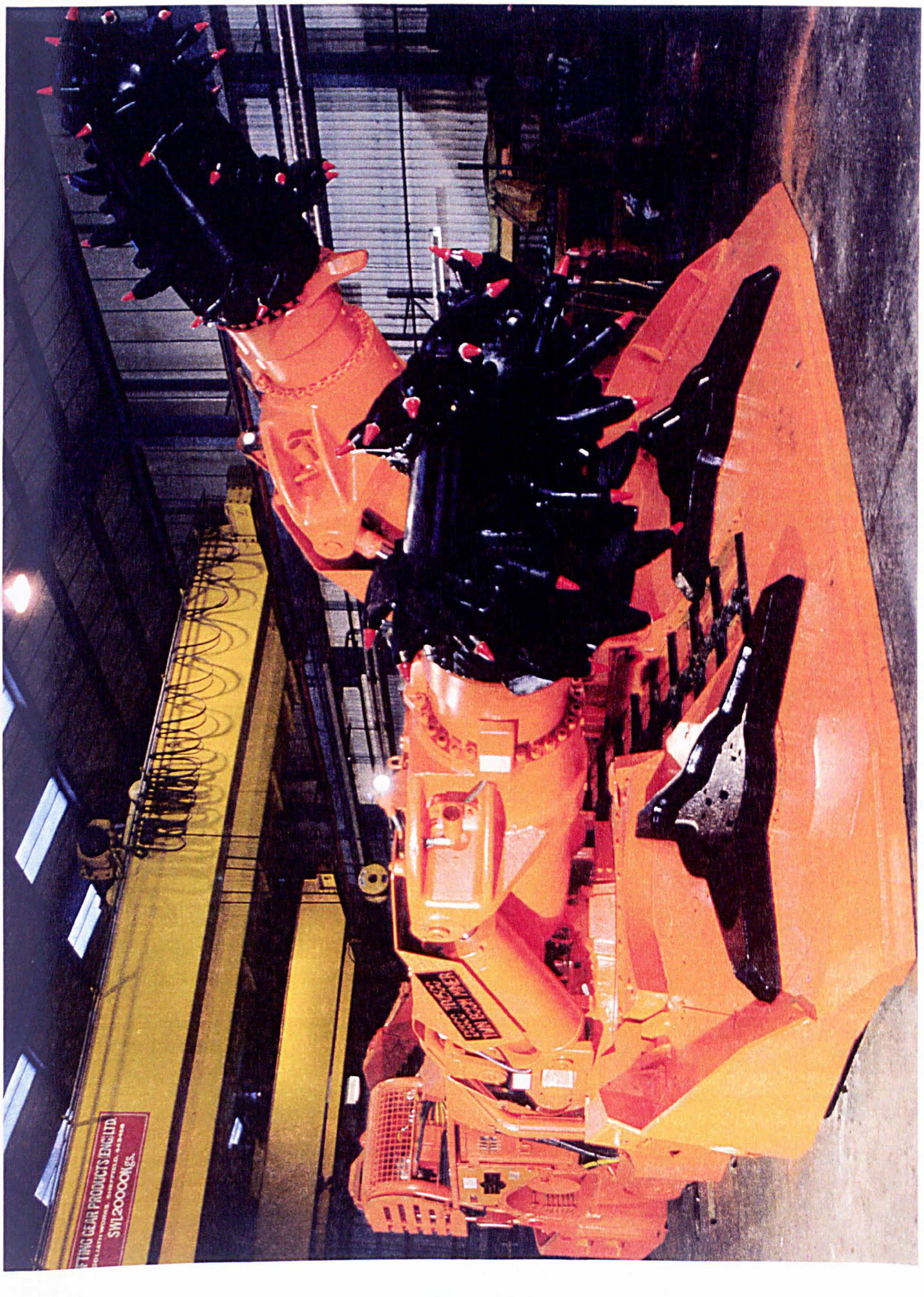


TABLE 10.1

TB2500 GENERAL SPECIFICATION

Overall length	13423 mm
Overall height	2200 mm
Overall width	5000 mm
Machine weight	120 tonnes
Maximum cutting height	5500 mm
Maximum cutting width	7984 mm
Maximum sumping force	668 kN
Maximum lifting force	127 kN
Maximum arcing force	190 kN
Cutter motor size @ 50 Hz	2*250 kW
Cutting head speed @ 50Hz	52 rpm
Machine conveyor	Centre strand electric
Speed of conveyor	2.4 m/s
Conveyor motor @ 50Hz	45 kW
Conveyor throat	unlimited
Gathering method	2 * spinners
Gathering spinner speed	30 rpm
Track speeds	0.06 and 0.30 m/s
Track drive motors	Electric
Track length contact	3556 mm
Track centres	2550 mm
Track pad width	559 mm
Track ground contact pressure	0.147 MN/m^2
Maximum tracking effort	668 kN
Power pack motor @ 50 Hz	60 kW
Number of pumps	2

For the purpose of this particular analysis, emphasis is placed on those aspects featuring strongly in design criteria, i.e. mine cutting time and machine cutting rate and how any variance has influenced production rates. Plate 10.1 shows an operational view of the TB2500 and Table 10.1 gives its general specification.

12 MONTH DELAY ANALYSIS

The initial installation and learning curve experiences, a three month period, although useful are not considered relevant to this operational study and as such have been ignored. Data covering a subsequent twelve month operating period is shown in Table 10.2 along with certain deductions applicable to both the mine and machine. The following comments are relevant:

* Monthly output has ranged up to a maximum of 47,068 t/month with an average rate of 36,214 t/month.

* Machine availability is an average of 88.2% and is slightly lower than the expected 90%. This reduction is not considered a critical factor, nor will it significantly affect production rates.

* Delays associated with the mine are high and initially manifest themselves as low mine availability - average 43.6%. They have a further deleterious effect on mine system availability giving an average of only 31.7%.

* The resulting average mining time of 152 mins/shift is disappointing and can only precipitate low tonnages. Greater tonnages rely primarily on a much higher proportion of mining time as indicated in section 8.2.

TABLE 10.2

BOSJESSPRUIT 12 MONTH DELAY ANALYSIS

TB2500 BOSSJESPRUIT SOUTH AFRICA

YEAR	MONTH	SHIFTS WORKED	MINUTES AVAILABLE (8 HRS/SHIFT)	OUTPUT TONNES	OUTPUT T/SHIFT	MACHINE DELAY MINUTES	MACHINE AVAILABLE %	MINE DELAY MINUTES
1994	JULY	43	20640	46420	1080	1051	94.9	14544
	AUGUST	48	23040	38313	798	6770	70.6	7265
	SEPTEMBE	46	22080	44711	972	3252	85.3	13782
	OCTOBER	46	22080	35085	763	1775	92.0	9717
	NOVEMBEF	48	23040	31121	648	2928	87.3	16859
	DECEMBEF	41	19680	29726	725	1890	90.4	13130
1995	JANUARY	45	21600	40432	898	1480	93.1	15292
	FEBRUARY	42	20160	47068	1121	1663	91.8	10578
	MARCH	44	21120	43644	992	1070	94.9	8188
	APRIL	21	10080	17470	832	1856	81.6	5582
	MAY	17	8160	14836	873	305	96.3	5818
	JUNE	42	20160	37666	897	2752	86.3	11307
	JULY	43	20640	44296	1030	3070	85.1	10411
	AVERAGE	**40**	**19422**	**36214**	**895**	**2297**	**88.2**	**10959**

YEAR	MONTH	MINE AVAILABLE %	TOTAL DELAY MINUTES	SYSTEM AVAILABLE %	MINING TIME MIN/MONTH	MINING TIME MIN/SHIFT	MINING RATE T/MIN
1994	JULY	29.5	15595	24.4	5045	117	9.2
	AUGUST	68.5	14036	39.1	9005	188	4.3
	SEPTEMBE	37.6	17034	22.9	5046	110	8.9
	OCTOBER	56.0	11492	48.0	10588	230	3.3
	NOVEMBEF	26.8	19787	14.1	3253	68	9.6
	DECEMBEF	33.3	15020	23.7	4660	114	6.4
1995	JANUARY	29.2	16772	22.4	4828	107	8.4
	FEBRUARY	47.5	12241	39.3	7919	189	5.9
	MARCH	61.2	9258	56.2	11862	270	3.7
	APRIL	44.6	7438	26.2	2642	126	6.6
	MAY	28.7	6123	25.0	2037	120	7.3
	JUNE	43.9	14059	30.3	6101	145	6.2
	JULY	49.6	13481	34.7	7159	166	6.2
	AVERAGE	**43.6**	**13257**	**31.7**	**6165**	**152**	**5.9**

* The machine mining rate also has a significant role to play in high tonnages. Ideally, both a high mining rate with time are necessary and again this is indicated in section 8.2.

* Section 8. of this thesis defines a machine design capable of producing 736 t/hr or some 12.2 t/min. The average recorded mining rate of 5.9 t/min gives obvious rise for concern as it appears to be less than half this value.

As a ready means of investigating this last aspect timed cuts were undertaken to measure the machines mining rate over several excavation cycles. The actual rate recorded confirmed the designed rate although at a slightly less value of 690 t/hr or 11.5 t/min.

In view of the continuing discrepancy in mining rates a further dedicated delay analysis to examine all aspects was undertaken. Of particular interest were shuttle car change out times which had previously not been recorded as an individual delay. Such delays if of any significance would obviously impact on available mining time and so reduce the actual mining rate.

10.5 SECOND DELAY ANALYSIS

During the trial period the machine worked 38 shifts, i.e. two per day each having a maximum duration of 560 mins usuable time. In total 39,000 tonnes of coal was produced at an average rate of 1027 t/shift. The best shift performance was considerably better at 1,980 tonnes. Further comments relevant to this study are listed below:

* Machine availability dropped to 81.3%. This significant reduction is due to a major component failure occurring for the first time.

* Actual shuttle car change out time is 76 mins or 13.5%. This delay aspect previously considered unimportant was unrecorded, as on occasions the machine would continue to mine and bunker coal on the loading apron.

* The shuttle cars have a capacity of 18 tonnes and some 57 loads are necessary to move an average shift production. This equates to around 1.3 mins loss per change out.

* Mine availability is 51.2% based on the original premise of not recording change out time and 37.7% otherwise.

* Mine system availability is 32.5% again based on the original premise or 19% and these equate per shift to 182 and 106 minutes of mining respectively.

* Based on the average 1,027 shift tonnage, mining rate is either 5.6 or 9.6 t/min.

It can be clearly seen that the two rates will have major significance for both the user and the supplier. The user rate which ignores shuttle car change out times are much lower at 5.6/5.9 t/min while the supplier rate which includes change out time is considerably higher at 9.6 t/min. This latter rate also compares reasonably well with the machine's designed rate of 12.2 t/min and the 11.5 t/min from site measurements.

10.6 CONCLUSIONS

* The true mining rate of the machine appears close to 10 t/min and this compares favourably with its designed rate of 12.2 t/min and 11.5 t/min from site measurements.

* Based on the results to date, further confidence can be placed in the use of penetration curves as a realistic means of determining production rates.

* The machine has an hourly production potential of around 600 tonnes, provided coal clearance is continuous.

* Monthly tonnages achieved so far are primarily a result of low mine availability and in turn a low mine system availability and not low mining rate.

* Machine availability is marginally lower than expected. Although its effect on production is minimal, it is still necessary to match or better the reliability of other similar mining products.

* Shuttle car change out time must be identified and correctly assigned if discrepancies in machine mining rate are to be avoided.

11. CONCLUSIONS/RECOMMENDATIONS SUMMARY

The cutting trials undertaken at Domtar Salt resulted in a much improved understanding of how to efficiently excavate salt. Although initial results were disappointing, careful development of the cutting head design proved successful and this resulted in trial parameters within specified guidelines being met. The following points have particular relevance

Conclusions

* Careful development and tuning of the roadheader type cutting head resulted in a reduction in the fines fraction of the product from over 20% at -12 mesh to around 8%. The corresponding increase in the fraction at +1" was from around 23% to 65%.

* With the roadheader type cutting head at 63 rpm, initial production was at a rate of 150 tonnes/hour. The final head design at the same rotational speed produced at a rate of 260 tonnes/hour, without any other changes to the machine.

* Many different tools were tested over short periods. The most consistent results were obtained with a standard point attack tool at 80 mm gauge, with a 12 mm diameter tip.

* At high head speeds (60 to 63 rpm), pick consumption when cutting salt was up to 300 tonnes/pick. When cutting the complete section, including the dolomite band, consumption increased to around 80 tonnes/pick. When effecting a speed change to 33 rpm to cut the dolomite, pick consumption was of the same order as when cutting salt only.

* Pick consumption could probably have been improved by further development and longer term testing of specially developed tools with higher melt point brazes and spray coating.

* The machine was not fitted with power transducers during the trial period, so no accurate assessment of power requirement was possible. The need for higher powers than normally associated with roadheaders can be seen from the fact that when fitted with the standard boom assembly at 142 kW, it was not possible to cut consistently at 60 rpm. There were no problems cutting at 63 rpm with the 270 kW high powered boom assembly.

* Although not mentioned in the main body of the thesis, one of the reasons for looking at machine mining was to obviate the need for scaling of the roof. Roadways driven by the LH1300H are in excellent condition, and have remained stable.

TB2500 (design)

* A prediction curve suitable to South African coal and allied to a machine design has been derived from both laboratory and field investigative studies. Some confidence in the curve values and hence its effect can be taken from recent findings based on an LH1300H.

* Standard cutting test results now undertaken by Leeds University have a particular role when establishing penetration curve values for a given rock type.

* Performance prediction is subject to many factors, with machine specification and strata type playing major roles. Penetration curves, as described in this thesis, appear a fundamental necessity if the task is to be achieved with any degree of accuracy.

* A wider issue is the evaluation of a particular machine enquiry with a potential success or failure rate established. The ability to make an early judgement on whether to continue can save considerable time and cost.

TB2500 (operational)

* The true mining rate of the machine appears close to 10 t/min and this compares favourably with its designed rate of 12.2 t/min and 11.5 t/min from site measurements.

* Based on the results to date, further confidence can be placed in the use of penetration curves as a realistic means of determining production rates.

* The machine has an hourly production potential of around 600 tonnes, provided coal clearance is continuous.

* Monthly tonnages achieved so far are primarily a result of low mine availability and in turn a low mine system availability and not low mining rate.

* Machine availability is marginally lower than expected. Although its effect on production is minimal, it is still necessary to match or better the reliability of other similar mining products.

* Shuttle car change out time must be identified and correctly assigned if discrepancies in machine mining rate are to be avoided.

Recommendations

* Prior to any commitment by the supplier on shift or monthly production rates, it is necessary for the available mining time to be correctly specified by the mine or equipment user.

* The supplier must site visit to make his own assessment of the project. It is important that any information which might affect the project and is supplied by the user is both correct and fully understood.

* In situations other than where coal clearance is continuous, delay or overlap time associated with shuttle cars and the like must be fully recognised and recorded.

* A way of improving mine system availability is to remove delays associated with coal clearance. The use of Flexible Conveyor Trains (FCT) is one such a way.

* It is necessary to place much greater emphasis on the reasons for low mine system availability as it is this that severely limits the potential of the mining machine.

* There are instances where machines are supplied on agreements relating a monthly payment to tonnes produced. In these situations available mining time as specified by the user will be such to generate adequate payments. Experience shows that these agreements should contain a mechanism which compensates the supplier, should the agreed mining time and hence payment reduce through no fault of his own.

Compilation of this study has been assisted greatly by the author's use of an Olivetti 486 Personal Computer incorporating a Windows based format. Various types of software have been employed, in particular, Lotus 123, a spread sheet calculator, Printgraph for graphs and charts, DataEase, a data base recording system, and Microsoft Word for word processing.

APPENDIX 1 - PAGE 1

AN EXAMPLE OF ORDERED COMPUTER DATA RETRIVAL BY AV UCS (1) AND AV SE (2)

STRATA	(AV. UCS 1	AV. SE)	(AV. SE 2	AV. UCS)
Sandstone	4.4	5.5	2.9	8.5
Sandstone	15.7	9.4	6.0	20.0
Sandstone	28.1	6.6	7.2	52.8
Sandstone	35.5	7.6	8.6	37.3
Sandstone	40.0	42.1	9.0	35.3
Sandstone	46.0	10.2	9.3	82.2
Sandstone	50.3	13.5	9.9	42.7
Sandstone	58.6	8.9	11.5	38.8
Sandstone	67.0	17.2	12.4	69.4
Sandstone	71.4	13.3	13.7	112.6
Sandstone	82.7	17.2	14.9	51.4
Sandstone	89.7	15.4	16.4	96.6
Sandstone	93.8	20.7	17.2	67.0
Sandstone	100.0	8.9	18.7	101.0
Sandstone	104.3	18.2	19.9	102.7
Sandstone	106.4	19.9	20.1	53.0
Sandstone	112.6	13.7	22.1	55.1
Sandstone	130.3	15.0	23.7	86.2
Sandstone	140.9	25.1	25.7	164.0
Sandstone	155.0	14.7	31.7	155.0
Sandstone	164.0	25.7	36.9	80.4
Sandstone	192.2	25.6	84.0	177.0
Sandstone	235	147	147.0	235.0

DESCRIPTION OF THE INSTRUMENTED CUTTING TEST

The test may be carried out on either core samples or on block samples collected from a tunnel face. Four cuts are normally made in the rock sample at a constant depth of 5 mm, with a standardised geometry and composition tungsten carbide chisel-shaped tool, mounted on an instrumented shaping machine. The shaping machine is equipped with a strain gauged tri-axial force dynamometer, rigidly fixed to the machine's crosshead. For the standard instrumented cutting test, forces are only analysed in the cutting and normal directions, since sideways forces are balanced due to the symmetrical design of the cutting tool. The strain gauge output from the dynamometer is recorded as analogue traces on an ultra violet recorder, together with other recorded information, such as weight of debris and length of cut. The analysis provides the following parameters:-

(1) Cutting and normal mean, mean peak and peak force components acting on the cutting tool (kN).

(2) Specific energy (MJ/m^3). This is defined as the work done to excavate a unit volume of rock. It is obtained by dividing the mean cutting force component by the yield, the latter being expressed per unit length.

(3) Cutting wear (mm/m). This is the rate of development of the abrasive wear flat on the tungsten carbide insert during the four experimental cuts expressed as mm of wear flat generated per metre cut.

STANDARD CONDITIONS FOR THE ROCK CUTTING TEST

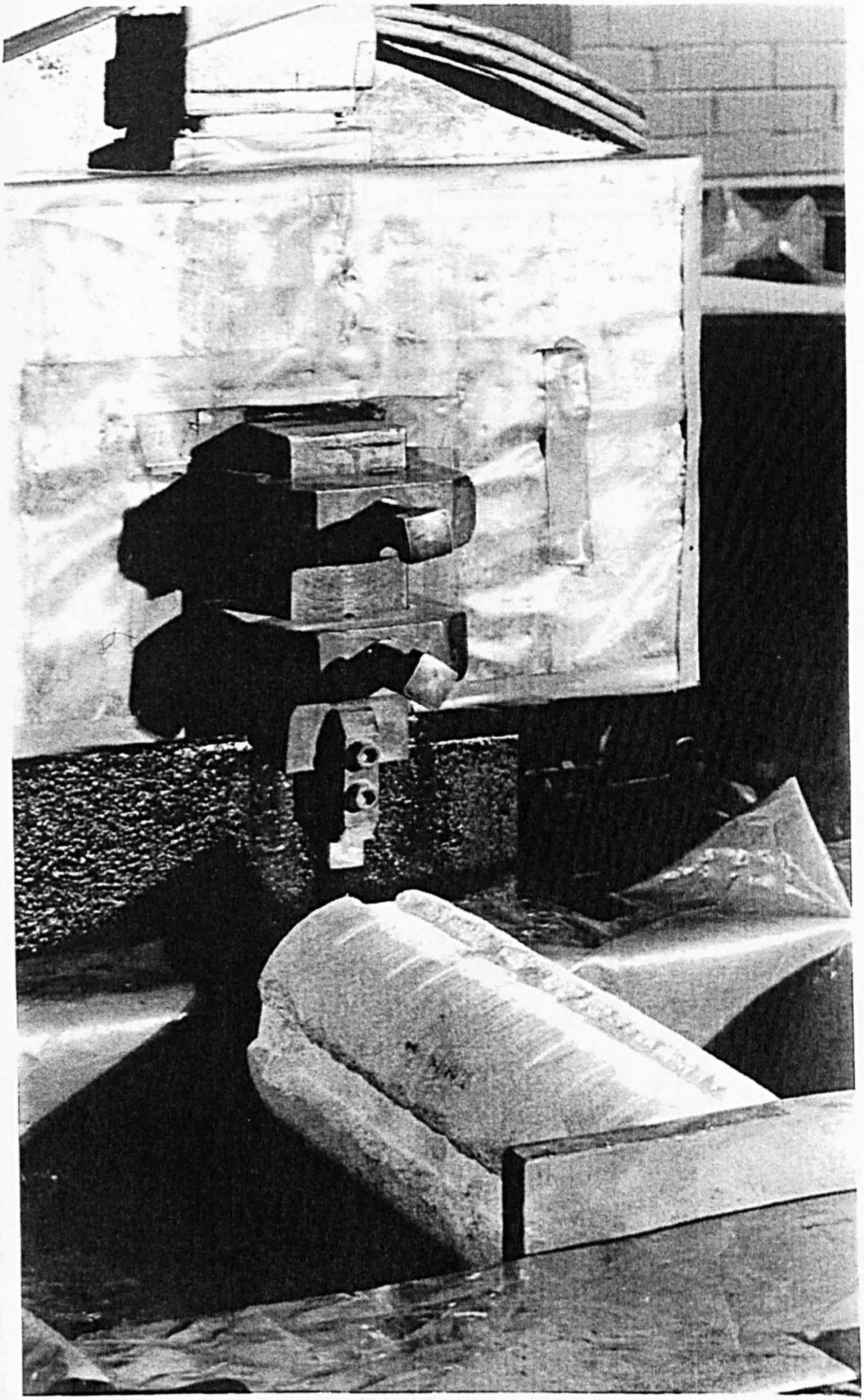
The following are the standard conditions under which the instrumented cutting test is conducted:-

Depth of cut - 5 mm

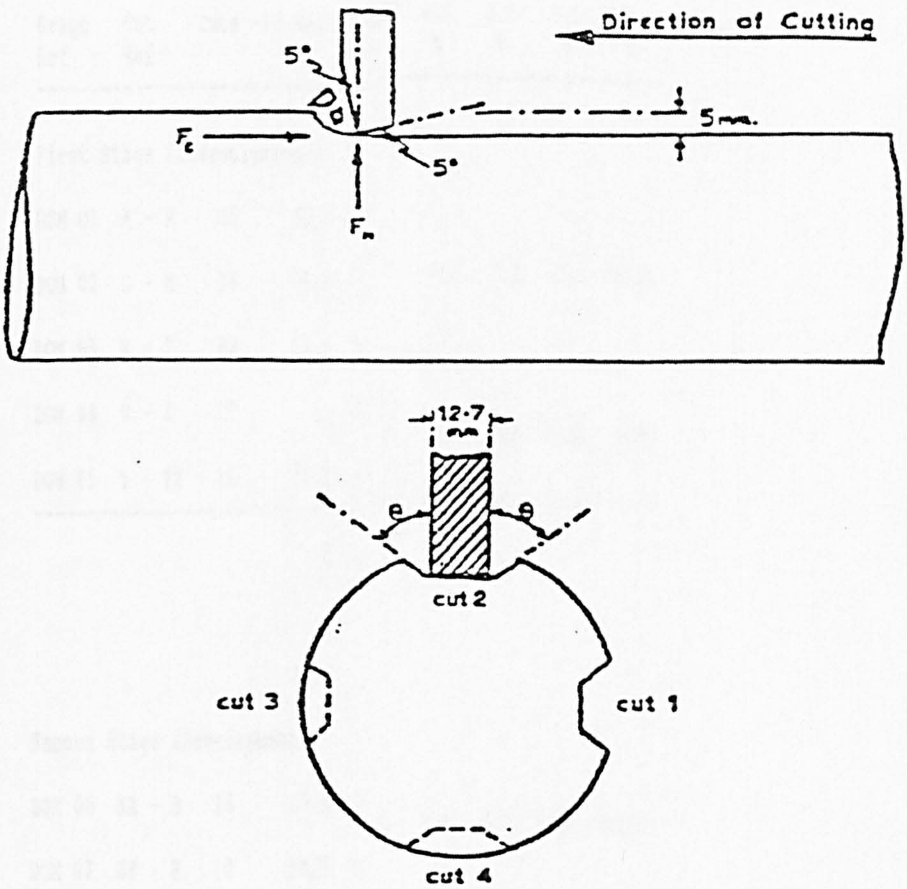
Cutting speed - 150 mm/s

Tool geometry - 12.7 mm wide chisel insert
5 degree rake angle
5 degree back clearance

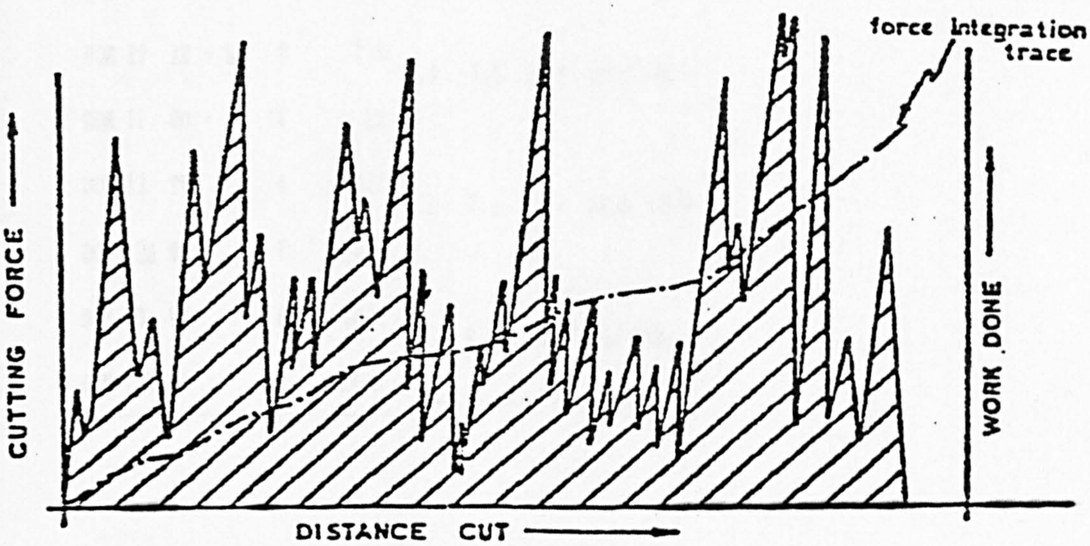
Tool composition - Tungsten carbide
10% cobalt by weight
3.5 μm nominal grain size



ARRANGEMENT FOR CORE CUTTING TEST



CUTTING FORCE DIAGRAM



DOMTAR FIELD TRIAL - LH1300H SIZING ANALYSIS (DATA/FLOW CHART)

Graph Ref	Cut Ref	Cuts	-12 Mesh %	Boom Type	Comments	R.P.M.	Pick Quantity	Reach (mm)	Tip Size (mm)	Pick Type	Sump (m)	Combined Graph Ref	-12 Mesh %	12 %	6 %	0.375 %	0.5 %	0.742 %	1.05 %	1.5 %	2.0 %	3.0 %	SUM %
First Stage (Investigation)																							
DOM 01	A - F	45	23.3	H.Duty	STD Winsford 3 Start Head / Horizontal Cuts	63	43	100	12	STD P.A.													
DOM 02	G - M	36	21.7	H.Duty	STD Winsford 3 Start Head / Horizontal Cuts	63	43	90	12	STD P.A.		MJG 01/FIG 01	(21.9)	16.6	19.4	5.3	6.5	7.5	7	4.8	5.5	5.4	99.9
DOM 03	N - T	40	20.9	H.Duty	STD Winsford 3 Start Head / Horizontal Cuts	63	43	115	8	STD P.A.													
DOM 04	U - X	27	24	H.Duty	STD Winsford 3 Start Head / Vertical Cuts	63	43	100	12	STD P.A.		MJG 02/FIG 02	(25.7)	19.2	21.8	5.9	6.3	5.9	4.6	2	2.8	5.8	100
DOM 05	Y - YY	16	27.3	H.Duty	STD Winsford 3 Start Head / Vertical Cuts	63	43	100	12	STD P.A.	0.7												
Second Stage (Development)																							
DOM 06	AA - D	16	17.8	H.Duty	STD Winsford 3 Start / Pruned lacing	63	23	100	12	STD P.A.		MJG 03/FIG 03	(16.3)	11.3	14.4	4.5	6.2	7.2	9.9	7.8	9.6	12.7	99.9
DOM 07	EE - F	10	14.5	H.Duty	STD Winsford 3 Start / Pruned lacing	63	23	90	12	STD P.A.													
DOM 08	GG	5		STD	Corrupt Data ? (ignore)	33	43	90		STD P.A.													
DOM 09	HH	4	18.8	STD	STD Winsford 3 Start / Pruned lacing	33	23	90		STD P.A.													
DOM 10	KK - L	9	7.8	STD	STD Winsford 3 Start / Pruned lacing	33	11	100		STD P.A.		MJG 04/FIG 04	(11.4)	8.4	10.1	2.9	3.8	5.9	8.9	7.6	11.4	29.5	99.9
DOM 11	OO - P	10	15	STD	STD Winsford 3 Start / Pruned lacing	33	13	100		STD P.A.													
DOM 12	TT	6	14.2	STD	Modified 2 Start, 2 pick/line with blades	33	26	115	8	STD P.A.		MJG 05/FIG 05	(14.2)	10.4	13.9	5.1	7.3	7	9.1	7.1	11.2	14.6	99.9
DOM 12A	UU	7	14.2	STD	Modified 2 Start, 2 pick/line with blades	33	26	115	8	STD P.A.													
DOM 13	VV	6	10.5	STD	Modified 2 Start, 1 pick/line with blades	33	13	115	8	STD P.A.		MJG 06/FIG 06	(12.7)	9.8	11.9	3.1	5.8	6.3	10.1	8.1	12.9	19.4	100.1
DOM 13A	WW	6	14.8	STD	Modified 2 Start, 1 pick/line with blades	33	13	100	12	STD P.A.													

DOMTAR FIELD TRIAL - LH1300H SIZING ANALYSIS (DATA/FLOW CHART)

Graph Ref	Cut Ref	Cuts	-12 Mesh %	Boom Type	Comments	R.P.M.	Pick Quantity	Reach (mm)	Tip Size (mm)	Pick Type	Sump (m)	Combined Graph Ref	-12 Mesh %	12 %	6 %	0.375 %	0.5 %	0.742 %	1.05 %	1.5 %	2.0 %	3.0 %	SUM %
Final Stage (Proving)																							
DOM 14	SS	18	12.4	H.Duty	Latest 3 Start, 1 pick/line	63	24	150	12	STD P.A.													
DOM 15	SS1	8	14.1	H.Duty	Latest 3 Start, 1 pick/line	63	24	113	12	L/Energy		MJG 10/FIG 07	(12.6)	10.1	14.2	5.1	6.1	8.2	11.5	9.4	10.9	12	100.1
DOM 16	SS2	8	11.3	H.Duty	Latest 3 Start, 1 pick/line	63	24	113	12	N/Profile													
DOM 17	ST	8	9	STD	Latest 3 Start, 1 pick/line	33	24	150	12	STD P.A.													
DOM 18	ST1	4	10.9	STD	Latest 3 Start, 1 pick/line	33	24	113	12	L/Energy													
DOM 19	ST2	4	10	STD	Latest 3 Start, 1 pick/line	33	24	113	12	N/Profile		MJG 11/FIG 08	(6.5)	5.3	8.2	3.6	4.3	6.1	8.8	10.6	14.6	32.1	100.1
DOM 20	ST3	4	3.1	STD	Latest 3 Start, 1 pick/line	33	24	113	12	N/Profile													
DOM 21	ST4	4	5.5	STD	Latest 3 Start, 1 pick/line	33	24	113	12	L/Energy		MJG 12/FIG 09	(4.8)	3.9	4.6	1.2	1.2	3.5	7	7.3	14.3	52.1	99.9
DOM 22	ST5	8	4.1	STD	Latest 3 Start, 1 pick/line	33	24	113	12	L/Energy													
DOM 23	MJG1	4	7.5	STD	Latest 3 Start, 1 pick/line	33	24	100	12	STD P.A.	0.8												
DOM 24	MJG2	4	11	STD	Latest 3 Start, 1 pick/line	33	24	80	12	STD P.A.	0.8												
DOM 25	MJG3 -	3	8.3	STD	Latest 3 Start, 1 pick/line	33	24	80	12	STD P.A.	0.7	MJG 13/FIG 10	(8.3)	6.6	8.3	2.5	3.6	5.1	8.4	8.6	14.1	34.4	99.9
DOM 26	MJG9	4	4.5	STD	Latest 3 Start, 1 pick/line	33	24	80	12	STD P.A.	0.4												
DOM 27	MJG11-	5	10.3	STD	Latest 3 Start, 1 pick/line	33	24	80	12	STD P.A.	0.5												
DOM 28	MJG15	5	9.8	STD	Latest 3 Start, 1 pick/line	60	24	80	12	STD P.A.	0.6	MJG 14/FIG 11	(7.8)	5.7	5.7	6.1	4	5	6.4	9.6	12.7	37	100
DOM 29	MJG16	5	5.8	STD	Latest 3 Start, 1 pick/line	60	24	80	12	STD P.A.	0.5												
DOM 30	THJL#2	4	5.9	STD	Latest 3 Start, 1 pick/line	33	24	80	17	STD P.A.	0.4												
DOM 31	THJL#2	4	10.5	STD	Latest 3 Start, 1 pick/line	33	24	80	17	STD P.A.	0.8	MJG 15/FIG 12	(11.9)	7.6	9.1	3.1	4	5.2	7.3	6.8	13.5	31.5	100
DOM 32	THJL#2	4	19.4	STD	Latest 3 Start, 1 pick/line	33	24	80	17	STD P.A.	1.1												
DOM 33	JL3	4	6.4	STD	Latest 3 Start, 1 pick/line	60	24	80	17	STD P.A.	0.4												
DOM 34	JL3	4	12	STD	Latest 3 Start, 1 pick/line	60	24	80	17	STD P.A.	0.8	MJG 16/FIG 13	(12.2)	8.3	8.5	2.5	2.9	5.4	9.2	8.8	15.4	26.9	100.1
DOM 35	JL3	4	18.2	STD	Latest 3 Start, 1 pick/line	60	24	80	17	STD P.A.	1.1												
DOM 36	NL ENE	4	6.1	STD	Latest 3 Start, 1 pick/line	33	24	80		New L/Ene	0.4												
DOM 37	NL ENE	4	8.6	STD	Latest 3 Start, 1 pick/line	33	24	80		New L/Ene	0.8	MJG 17/FIG 14	(6.3)	5.6	8.4	3.4	4.5	6.1	11.1	8.8	11.6	34.4	100.1

LH1300 NO 69 DOMTAR SALT CANADA INITIAL CUTTING TESTS

3 START 1 PICK/LINE HEAD 42 BOXES 42 PICKS

DATE	CUT NO	CONDITION	SUMP DEPTH (cm)	WEB HEIGHT (cm)	MODE OF CUT	SWEPT AREA (m^2)	CUT LENGTH (cm)	CUTTING TIME (sec)	ARCING PRESSURE (bar)	ICR (m^3/hr)	ADV /REV (cm)	FORCE/ SW AREA (kN/m^2)	REMARKS
05-07-89	A1	CONFINED	76	109	BOTH	0.634	528	176	138	68.4	2.9	181.53	100 PICK 12 INSERT 63 RPM
05-07-89	A2	UNDERCUT	71	36	R - L	0.105	511	108	138	18.0	4.5	1091.08	100 PICK 12 INSERT 63 RPM
05-07-89	A3	UNDERCUT	71	64	R - L	0.336	503	110	138	55.2	4.4	342.67	100 PICK 12 INSERT 63 RPM
05-07-89	A4	UNDERCUT	69	84	R - L	0.434	493	63	138	122.3	7.5	264.98	100 PICK 12 INSERT 63 RPM
05-07-89	A5	UNDERCUT	69	74	R - L	0.382	462	48	138	132.2	9.2	301.44	100 PICK 12 INSERT 63 RPM
05-07-89	B1	CONFINED	76	109	BOTH	0.634	498	113	138	100.5	4.2	181.53	100 PICK 12 INSERT 63 RPM
05-07-89	B2	UNDERCUT	74	51	R - L	0.275	483	65	138	73.4	7.1	418.94	100 PICK 12 INSERT 63 RPM
05-07-89	B3	UNDERCUT	69	51	R - L	0.263	462	83	138	52.7	5.3	437.43	100 PICK 12 INSERT 63 RPM
05-07-89	B4	UNDERCUT	71	53	R - L	0.288	472	130	138	37.6	3.5	399.58	100 PICK 12 INSERT 63 RPM
05-07-89	B5	UNDERCUT	69	48	R - L	0.232	447	48	138	77.8	8.9	495.26	100 PICK 12 INSERT 63 RPM
05-07-89	B6	OVERCUT	71	43	L - R	0.203	475	111	138	31.2	4.1	567.62	100 PICK 12 INSERT 63 RPM
05-07-89	B7	OVERCUT	69	36	L - R	0.159	488	91	138	30.8	5.1	721.46	100 PICK 12 INSERT 63 RPM
05-07-89	B8	OVERCUT	69	20	L - R	0.049	503	50	138	17.7	9.7	2346.94	100 PICK 12 INSERT 63 RPM
06-07-89	C1	CONFINED	114	117	BOTH	1.063	523	182	138	109.9	2.8	108.21	100 PICK 12 INSERT 63 RPM
06-07-89	C2	UNDERCUT	114	61	R - L	0.566	521	160	138	66.3	3.1	203.32	100 PICK 12 INSERT 63 RPM
06-07-89	C3	UNDERCUT	114	71	R - L	0.680	483	173	138	68.3	2.7	169.22	100 PICK 12 INSERT 63 RPM
06-07-89	C4	UNDERCUT	102	51	R - L	0.381	450	100	138	61.7	4.3	302.15	100 PICK 12 INSERT 63 RPM
06-07-89	C5	OVERCUT	99	56	L - R	0.427	541	144	138	57.8	3.6	269.07	100 PICK 12 INSERT 63 RPM
06-07-89	C6	OVERCUT	107	61	L - R	0.531	518	128	138	77.3	3.9	216.65	100 PICK 12 INSERT 63 RPM
06-07-89	D1	CONFINED	107	117	BOTH	0.993	518	250	138	74.1	2.0	115.80	100 PICK 12 INSERT 63 RPM
06-07-89	D2	UNDERCUT	99	56	R - L	0.427	503	107	138	72.3	4.5	269.07	100 PICK 12 INSERT 63 RPM
06-07-89	D3	UNDERCUT	99	53	R - L	0.393	483	128	138	53.4	3.6	292.47	100 PICK 12 INSERT 63 RPM
06-07-89	D4	UNDERCUT	89	79	R - L	0.615	446	105	138	94.0	4.1	186.99	100 PICK 12 INSERT 63 RPM
06-07-89	D5	OVERCUT	107	51	L - R	0.417	511	89	138	86.2	5.5	275.91	100 PICK 12 INSERT 63 RPM
06-07-89	D6	OVERCUT	104	61	L - R	0.513	488	120	138	75.2	3.9	224.00	100 PICK 12 INSERT 63 RPM
07-07-89	E1	CONFINED	41	86	BOTH	0.282	538	52	138	105.1	9.9	407.66	100 PICK 12 INSERT 63 RPM
07-07-89	E2	UNDERCUT	38	48	R - L	0.160	541	29	138	107.3	17.9	720.10	100 PICK 12 INSERT 63 RPM
07-07-89	E3	UNDERCUT	38	38	R - L	0.122	546	29	138	82.5	18.1	944.95	100 PICK 12 INSERT 63 RPM
07-07-89	E4	UNDERCUT	41	48	R - L	0.166	528	28	138	112.9	18.1	691.52	100 PICK 12 INSERT 63 RPM
07-07-89	E5	UNDERCUT	43	43	R - L	0.146	513	25	138	107.9	19.7	787.67	100 PICK 12 INSERT 63 RPM
07-07-89	E6	UNDERCUT	41	43	R - L	0.132	518	24	138	102.2	20.7	874.52	100 PICK 12 INSERT 63 RPM
07-07-89	E7	OVERCUT	41	30	L - R	0.091	508	25	138	66.3	19.5	1267.92	100 PICK 12 INSERT 63 RPM
07-07-89	E8	OVERCUT	38	53	L - R	0.171	528	29	138	111.8	17.5	674.09	100 PICK 12 INSERT 63 RPM
07-07-89	E9	OVERCUT	38	33	L - R	0.103	499	38	138	48.7	12.6	1115.42	100 PICK 12 INSERT 63 RPM
07-07-89	F1	CONFINED	43	89	BOTH	0.300	536	45	138	128.7	11.4	383.21	100 PICK 12 INSERT 63 RPM
07-07-89	F2	UNDERCUT	38	48	R - L	0.160	523	36	138	83.7	13.9	718.30	100 PICK 12 INSERT 63 RPM
07-07-89	F3	UNDERCUT	41	41	R - L	0.146	526	39	138	71.1	12.9	785.52	100 PICK 12 INSERT 63 RPM
07-07-89	F4	UNDERCUT	43	41	R - L	0.151	508	33	138	83.5	14.8	763.11	100 PICK 12 INSERT 63 RPM
07-07-89	F5	UNDERCUT	41	43	R - L	0.155	485	29	138	93.1	16.1	743.86	100 PICK 12 INSERT 63 RPM
07-07-89	F6	UNDERCUT	41	25	R - L	0.081	493	30	138	47.8	15.8	1423.27	100 PICK 12 INSERT 63 RPM
07-07-89	F7	OVERCUT	43	48	L - R	0.160	528	31	138	98.0	16.4	719.65	100 PICK 12 INSERT 63 RPM
07-07-89	F8	OVERCUT	38	56	L - R	0.198	503	30	138	119.6	16.1	580.51	100 PICK 12 INSERT 63 RPM

APPENDIX 4 - PAGE 2

LH1300 NO 69 DOMTAR SALT CANADA INITIAL CUTTING TESTS

3 START 1 PICK/LINE HEAD 42 BOXES 42 PICKS

DATE	CUT NO	CONDITION	SUMP DEPTH (cm)	WEB HEIGHT (cm)	MODE OF CUT	SWEPT AREA (m^2)	CUT LENGTH (cm)	CUTTING TIME (sec)	ARCING PRESSURE (bar)	ICR (m^3/hr)	ADV /REV (cm)	FORCE/ SW AREA (kN/m^2)	REMARKS
10-07-89	G1	CONFINED	122	112	BOTH	1.035	521	135	138	143.8	3.7	111.10	90 PICK 12 INSERT 63 RPM
10-07-89	G2	UNDERCUT	119	41	R - L	0.349	544	106	138	64.4	4.9	329.99	90 PICK 12 INSERT 63 RPM
10-07-89	G3	UNDERCUT	119	53	R - L	0.473	516	144	138	61.0	3.4	243.18	90 PICK 12 INSERT 63 RPM
10-07-89	G4	UNDERCUT	117	86	R - L	0.853	488	172	138	87.1	2.7	134.98	90 PICK 12 INSERT 63 RPM
10-07-89	G5	OVERCUT	112	46	L - R	0.405	533	109	138	71.2	4.7	284.30	90 PICK 12 INSERT 63 RPM
10-07-89	G6	OVERCUT	112	58	L - R	0.539	503	199	138	49.0	2.4	213.40	90 PICK 12 INSERT 63 RPM
10-07-89	H1	CONFINED	122	118	BOTH	1.035	538	202	138	99.2	2.6	111.10	90 PICK 12 INSERT 63 RPM
10-07-89	H2	UNDERCUT	117	53	R - L	0.483	533	99	138	93.6	5.2	238.14	90 PICK 12 INSERT 63 RPM
10-07-89	H3	UNDERCUT	102	61	R - L	0.492	511	107	138	84.6	4.6	233.83	90 PICK 12 INSERT 63 RPM
10-07-89	H4	UNDERCUT	97	41	R - L	0.263	478	99	138	45.7	4.6	437.43	90 PICK 12 INSERT 63 RPM
10-07-89	H5	OVERCUT	94	58	L - R	0.426	483	125	138	59.3	3.7	269.83	90 PICK 12 INSERT 63 RPM
10-07-89	H6	OVERCUT	97	66	L - R	0.533	472	105	138	86.2	4.3	215.80	90 PICK 12 INSERT 63 RPM
11-07-89	J1	CONFINED	81	109	BOTH	0.682	559	108	138	127.0	5.0	168.70	90 PICK 12 INSERT 63 RPM
11-07-89	J2	UNDERCUT	74	51	R - L	0.254	566	80	138	64.7	6.8	452.40	90 PICK 12 INSERT 63 RPM
11-07-89	J3	UNDERCUT	74	58	R - L	0.308	554	76	138	80.9	7.0	372.89	90 PICK 12 INSERT 63 RPM
11-07-89	J4	UNDERCUT	71	64	R - L	0.334	518	58	138	107.3	8.6	344.72	90 PICK 12 INSERT 63 RPM
11-07-89	J5	OVERCUT	76	53	L - R	0.282	554	76	138	74.0	7.0	407.80	90 PICK 12 INSERT 63 RPM
11-07-89	J6	OVERCUT	76	61	L - R	0.343	528	123	138	53.0	4.1	335.47	90 PICK 12 INSERT 63 RPM
11-07-89	K1	CONFINED	81	109	BOTH	0.682	533	128	138	102.2	4.0	168.70	90 PICK 12 INSERT 63 RPM
11-07-89	K2	UNDERCUT	79	53	R - L	0.298	549	89	138	66.2	5.9	386.04	90 PICK 12 INSERT 63 RPM
11-07-89	K3	UNDERCUT	84	69	R - L	0.459	513	118	138	71.8	4.2	250.65	90 PICK 12 INSERT 63 RPM
11-07-89	K4	UNDERCUT	81	58	R - L	0.349	499	55	138	114.0	8.7	329.51	90 PICK 12 INSERT 63 RPM
11-07-89	K5	OVERCUT	76	51	L - R	0.267	533	74	138	69.2	6.9	431.03	90 PICK 12 INSERT 63 RPM
11-07-89	K6	OVERCUT	79	53	L - R	0.298	500	153	138	35.0	3.1	386.04	90 PICK 12 INSERT 63 RPM
11-07-89	L1	CONFINED	46	86	BOTH	0.322	541	81	138	77.4	6.4	357.48	90 PICK 12 INSERT 63 RPM
11-07-89	L2	UNDERCUT	48	61	R - L	0.251	533	78	138	61.8	6.6	457.62	90 PICK 12 INSERT 63 RPM
11-07-89	L3	UNDERCUT	48	69	R - L	0.290	505	66	138	79.8	7.3	396.96	90 PICK 12 INSERT 63 RPM
11-07-89	L4	UNDERCUT	46	58	R - L	0.225	472	47	138	81.5	9.6	518.43	90 PICK 12 INSERT 63 RPM
11-07-89	L5	OVERCUT	48	51	L - R	0.203	556	66	138	61.7	8.1	565.67	90 PICK 12 INSERT 63 RPM
11-07-89	L6	OVERCUT	46	56	L - R	0.216	528	190	138	21.6	2.7	532.16	90 PICK 12 INSERT 63 RPM
11-07-89	M1	CONFINED	46	86	BOTH	0.322	554	89	138	72.1	6.0	357.48	90 PICK 12 INSERT 63 RPM
11-07-89	M2	UNDERCUT	48	61	R - L	0.251	541	68	138	72.0	7.6	457.62	90 PICK 12 INSERT 63 RPM
11-07-89	M3	UNDERCUT	51	66	R - L	0.295	505	74	138	72.5	6.6	389.70	90 PICK 12 INSERT 63 RPM
11-07-89	M4	UNDERCUT	48	48	R - L	0.189	467	35	138	90.7	12.8	608.79	90 PICK 12 INSERT 63 RPM
11-07-89	M5	OVERCUT	48	53	L - R	0.213	564	58	138	74.5	9.3	540.16	90 PICK 12 INSERT 63 RPM
11-07-89	M6	OVERCUT	48	58	L - R	0.237	531	145	138	31.2	3.5	485.44	90 PICK 12 INSERT 63 RPM

LH1300 NO 69 DOMTAR SALT CANADA INITIAL CUTTING TESTS

3 START 1 PICK/LINE HEAD 42 BOXES 42 PICKS

DATE	CUT NO	CONDITION	SUMP DEPTH (cm)	WEB HEIGHT (cm)	MODE OF CUT	SWEPT AREA (m^2)	CUT LENGTH (cm)	CUTTING TIME (sec)	ARCING PRESSURE (bar)	ICR (m^3/hr)	ADV /REV (cm)	FORCE/ SW AREA (kN/m^2)	REMARKS
17-07-89	N1	CONFINED	46	91	BOTH	0.332	594	79	138	90.0	7.2	345.97	115 PICK 8 INSERT 63 RPM
17-07-89	N2	UNDERCUT	48	51	R - L	0.208	582	54	138	80.5	10.3	553.95	115 PICK 8 INSERT 63 RPM
17-07-89	N3	UNDERCUT	46	56	R - L	0.212	559	64	138	66.7	8.4	541.94	115 PICK 8 INSERT 63 RPM
17-07-89	N4	UNDERCUT	46	71	R - L	0.266	521	45	138	110.9	11.1	432.01	115 PICK 8 INSERT 63 RPM
17-07-89	N5	UNDERCUT	43	66	R - L	0.232	508	34	138	125.0	14.3	494.84	115 PICK 8 INSERT 63 RPM
17-07-89	N6	OVERCUT	46	46	L - R	0.166	533	78	138	40.9	6.6	691.94	115 PICK 8 INSERT 63 RPM
17-07-89	N7	OVERCUT	43	31	L - R	0.100	518	84	138	22.3	5.9	1147.70	115 PICK 8 INSERT 63 RPM
18-07-89	P1	CONFINED	46	91	BOTH	0.332	594	72	138	98.8	7.9	345.97	115 PICK 8 INSERT 63 RPM
18-07-89	P2	UNDERCUT	46	64	R - L	0.244	574	69	138	73.0	8.0	472.09	115 PICK 8 INSERT 63 RPM
18-07-89	P3	UNDERCUT	51	56	R - L	0.240	559	90	138	53.7	6.0	478.77	115 PICK 8 INSERT 63 RPM
18-07-89	P4	UNDERCUT	51	64	R - L	0.276	516	62	138	82.5	8.0	417.27	115 PICK 8 INSERT 63 RPM
18-07-89	P5	UNDERCUT	48	56	R - L	0.223	485	43	138	90.7	10.8	514.77	115 PICK 8 INSERT 63 RPM
18-07-89	P6	OVERCUT	48	66	L - R	0.265	490	75	138	62.4	6.3	433.31	115 PICK 8 INSERT 63 RPM
19-07-89	Q1	CONFINED	81	107	BOTH	0.699	513	168	138	76.9	2.9	164.43	115 PICK 8 INSERT 63 RPM
19-07-89	Q2	UNDERCUT	81	97	R - L	0.616	533	225	138	52.6	2.3	186.75	115 PICK 8 INSERT 63 RPM
19-07-89	Q3	UNDERCUT	79	71	R - L	0.431	498	129	138	59.8	3.7	267.01	115 PICK 8 INSERT 63 RPM
19-07-89	Q4	UNDERCUT	81	36	R - L	0.173	488	50	138	60.6	9.4	666.67	115 PICK 8 INSERT 63 RPM
19-07-89	Q5	OVERCUT	81	61	L - R	0.368	523	151	138	45.9	3.3	312.58	115 PICK 8 INSERT 63 RPM
19-07-89	R1	CONFINED	81	107	BOTH	0.699	564	198	138	71.7	2.7	164.43	115 PICK 8 INSERT 63 RPM
19-07-89	R2	UNDERCUT	79	48	R - L	0.249	554	154	138	32.2	3.5	461.85	115 PICK 8 INSERT 63 RPM
19-07-89	R3	UNDERCUT	81	66	R - L	0.409	528	167	138	46.5	3.0	281.45	115 PICK 8 INSERT 63 RPM
19-07-89	R4	UNDERCUT	81	66	R - L	0.409	500	95	138	77.5	5.1	281.45	115 PICK 8 INSERT 63 RPM
19-07-89	R5	OVERCUT	81	74	L - R	0.473	523	230	138	38.8	2.2	242.92	115 PICK 8 INSERT 63 RPM
20-07-89	S1	CONFINED	117	119	BOTH	1.086	559	241	138	90.6	2.2	105.94	115 PICK 8 INSERT 63 RPM
20-07-89	S2	UNDERCUT	119	71	R - L	0.680	551	318	138	42.4	1.7	169.17	115 PICK 8 INSERT 63 RPM
20-07-89	S3	UNDERCUT	119	79	R - L	0.771	518	232	138	62.0	2.1	149.20	115 PICK 8 INSERT 63 RPM
20-07-89	S4	UNDERCUT	112	66	R - L	0.599	472	124	138	82.2	3.7	191.92	115 PICK 8 INSERT 63 RPM
20-07-89	S5	OVERCUT	114	46	L - R	0.395	564	162	138	49.4	3.3	291.43	115 PICK 8 INSERT 63 RPM
20-07-89	S6	OVERCUT	109	31	L - R	0.194	531	123	138	30.2	4.1	591.56	115 PICK 8 INSERT 63 RPM
20-07-89	T1	CONFINED	117	119	BOTH	1.086	556	247	138	88.0	2.2	105.94	115 PICK 8 INSERT 63 RPM
20-07-89	T2	UNDERCUT	117	66	R - L	0.623	536	279	138	43.1	1.8	184.71	115 PICK 8 INSERT 63 RPM
20-07-89	T3	UNDERCUT	109	71	R - L	0.646	531	167	138	73.9	3.1	178.07	115 PICK 8 INSERT 63 RPM
20-07-89	T4	UNDERCUT	107	61	R - L	0.525	498	115	138	81.8	4.2	219.21	115 PICK 8 INSERT 63 RPM
20-07-89	T5	OVERCUT	109	48	L - R	0.395	559	245	138	32.4	2.2	291.07	115 PICK 8 INSERT 63 RPM
20-07-89	T6	OVERCUT	107	38	L - R	0.279	526	138	138	38.2	3.7	412.93	115 PICK 8 INSERT 63 RPM

LH1300 NO 69 DOMTAR SALT CANADA INTERMEDIATE CUTTING TESTS

3 START 1 PICK/LINE HEAD 42 BOXES 23 PICKS

DATE	CUT NO	CONDITION	SUMP DEPTH (cm)	WEB HEIGHT (cm)	MODE OF CUT	SWEPT AREA (m^2)	CUT LENGTH (cm)	CUTTING TIME (sec)	ARCING PRESSURE (bar)	ICR (m^3/hr)	ADVANCE /REV (cm)	FORCE/ SW AREA (kN/m^2)	REMARKS
29-07-89	AA1	CONFINED	81	109	BOTH	0.670	493	141	138	84.3	3.4	171.64	100 PICK 12 INSERT 63 RPM
29-07-89	AA2	UNDERCUT	76	76	R-L	0.446	485	54	138	144.3	8.6	257.67	100 PICK 12 INSERT 63 RPM
29-07-89	AA3	UNDERCUT	76	74	R-L	0.434	493	42	138	183.2	11.3	265.28	100 PICK 12 INSERT 63 RPM
29-07-89	AA4	OVERCUT	79	46	L-R	0.243	488	101	138	42.2	4.6	473.45	100 PICK 12 INSERT 63 RPM
29-07-89	BB1	CONFINED	81	109	BOTH	0.670	551	137	138	96.9	3.9	171.77	100 PICK 12 INSERT 63 RPM
29-07-89	BB2	UNDERCUT	76	71	R-L	0.412	559	58	138	142.8	9.3	279.47	100 PICK 12 INSERT 63 RPM
29-07-89	BB3	UNDERCUT	79	63	R-L	0.374	544	57	138	128.4	9.2	307.82	100 PICK 12 INSERT 63 RPM
29-07-89	BB4	OVERCUT	79	51	L-R	0.280	521	139	138	37.7	3.6	411.45	100 PICK 12 INSERT 63 RPM
30-07-89	CC1	CONFINED	113	116	BOTH	1.063	528	195	138	103.6	2.6	108.21	100 PICK 12 INSERT 63 RPM
30-07-89	CC2	UNDERCUT	113	58	R-L	0.531	521	101	138	98.7	5.0	216.43	100 PICK 12 INSERT 63 RPM
30-07-89	CC3	UNDERCUT	113	64	R-L	0.597	526	110	138	102.8	4.6	192.63	100 PICK 12 INSERT 63 RPM
30-07-89	CC4	OVERCUT	113	64	L-R	0.597	518	155	138	71.8	3.2	192.63	100 PICK 12 INSERT 63 RPM
	DD1	CONFINED	113	116	BOTH	1.063	508	250	138	77.7	2.0	108.21	100 PICK 12 INSERT 63 RPM
	DD2	UNDERCUT	113	56	R/L	0.509	549	95	138	105.8	5.5	226.04	100 PICK 12 INSERT 63 RPM
	DD3	UNDERCUT	113	53	R/L	0.475	549	60	138	156.4	8.8	242.18	100 PICK 12 INSERT 63 RPM
	DD4	OVERCUT	113	61	L/R	0.565	549	245	138	45.6	2.2	203.45	100 PICK 12 INSERT 63 RPM
	EE1	CONFINED	113	116	L/R	1.063	457	292	138	59.9	1.5	108.18	90 PICK 12 INSERT 63 RPM
	EE2	UNDERCUT	112	31	R/L	0.238	505	72	138	60.0	6.7	483.90	90 PICK 12 INSERT 63 RPM
	EE3	UNDERCUT	112	56	R/L	0.506	549	70	138	143.0	7.5	227.12	90 PICK 12 INSERT 63 RPM
	EE4	UNDERCUT	107	56	R/L	0.483	544	57	138	166.1	9.2	237.90	90 PICK 12 INSERT 63 RPM
	FF1	CONFINED	91	114	L/R	0.796	488	134	138	104.3	3.5	144.53	90 PICK 12 INSERT 63 RPM
	FF2	UNDERCUT	91	66	R/L	0.298	528	78	138	72.6	6.5	386.17	90 PICK 12 INSERT 63 RPM
	FF3	UNDERCUT	91	66	R/L	0.298	533	69	138	82.9	7.4	386.17	90 PICK 12 INSERT 63 RPM
	FF4	UNDERCUT	86	31	R/L	0.146	549	30	138	96.0	17.6	788.75	90 PICK 12 INSERT 63 RPM
	FF5	UNDERCUT	76	51	R/L	0.267	569	58	138	94.2	9.4	431.03	90 PICK 12 INSERT 63 RPM
	LL2	OVERCUT	97	60	L/R	0.458	475	187	138	41.9	5.1	251.15	100 PICK 12 INSERT 33 RPM
	LL3	UNDERCUT	97	38	R/L	0.245	508	117	138	38.2	8.7	470.35	100 PICK 12 INSERT 33 RPM
	LL4	UNDERCUT	112	46	R/L	0.397	518	114	138	64.9	9.1	289.75	100 PICK 12 INSERT 33 RPM
	LL5	UNDERCUT	112	38	R/L	0.307	551	87	138	70.1	12.7	374.23	100 PICK 12 INSERT 33 RPM
	??1	CONFINED	114	114	L/R	1.063	488	600	110	31.1	1.6	86.26	100 PICK 12 INSERT 33 RPM
	??2	UNDERCUT	114	53	R/L	0.474	495	240	110	35.2	4.1	193.27	100 PICK 12 INSERT 33 RPM
	??3	UNDERCUT	114	64	R/L	0.600	526	335	110	33.9	3.1	152.85	100 PICK 12 INSERT 33 RPM
	??4	UNDERCUT	114	64	R/L	0.600	526	345	110	32.9	3.0	152.85	100 PICK 12 INSERT 33 RPM
	??5	UNDERCUT	114	41	R/L	0.338	508	225	110	27.4	4.5	271.60	100 PICK 12 INSERT 33 RPM
	??6	UNDERCUT	114	51	R/L	0.452	498	165	110	49.0	6.0	203.03	100 PICK 12 INSERT 33 RPM

LH1300 NO 69 DOMTAR SALT CANADA FINAL CUTTING TESTS

3 START 1 PICK/LINE HEAD 24 BOXES 24 PICKS

DATE	CUT NO	CONDITION	SUMP DEPTH (cm)	WEB HEIGHT (cm)	MODE OF CUT	SWEPT AREA (m^2)	CUT LENGTH (cm)	CUTTING TIME (sec)	ARCING PRESSURE (bar)	ICR (m^3/hr)	ADVANCE /REV (cm)	FORCE/ SW AREA (kN/m^2)	REMARKS
19.01.90	MJG1.1	CONFINED	70		L-R	0.5568	152	37	138	82.56	8.24	206.43	100 PICK 12 INSERT 33 RPM
19.01.90	MJG1.2	CONFINED	70		R-L	0.5568	180	45	138	80.33	8.02	206.43	100 PICK 12 INSERT 33 RPM
19.01.90	MJG1.3	DOLOMITE	70		R-L	0.4779	335	85	138	67.86	7.89	240.52	100 PICK 12 INSERT 33 RPM
19.01.90	MJG1.4	OVERCUT	70		L-R	0.3341	254	80	138	38.19	6.35	344.06	100 PICK 12 INSERT 33 RPM
19.01.90	MJG1.5	UNDERCUT	70		R-L	0.3341	335	47	138	85.80	14.27	344.06	100 PICK 12 INSERT 33 RPM
19.01.90	MJG2.2	CONFINED	70		R-L	0.5414	213	36	138	115.51	11.85	212.31	80 PICK 12 INSERT 33 RPM
19.01.90	MJG2.3	DOLOMITE	70		R-L	0.3248	351	42	138	97.60	16.69	353.84	80 PICK 12 INSERT 33 RPM
19.01.90	MJG2.4	OVERCUT	70		L-R	0.3248	366	63	138	67.89	11.61	353.84	80 PICK 12 INSERT 33 RPM
19.01.90	MJG2.5	UNDERCUT	70		R-L	0.3248	330	44	138	87.76	15.01	353.84	80 PICK 12 INSERT 33 RPM
23.01.90	MJG9.1	CONFINED	40		L-R	0.2513	208	20	138	94.21	20.83	457.39	80 PICK 12 INSERT 33 RPM
23.01.90	MJG9.2	CONFINED	40		R-L	0.2513	231	33	138	63.37	14.01	457.39	80 PICK 12 INSERT 33 RPM
23.01.90	MJG9.3	DOLOMITE	40		R-L	0.1508	442	46	138	52.15	19.22	762.32	80 PICK 12 INSERT 33 RPM
23.01.90	MJG9.4	OVERCUT	40		L-R	0.1508	488	55	138	48.13	17.73	762.32	80 PICK 12 INSERT 33 RPM
23.01.90	MJG9.5	UNDERCUT	40		R-L	0.2057	442	32	138	102.28	27.62	558.79	80 PICK 12 INSERT 33 RPM
23.01.90	MJG14.1	CONFINED	50		L-R	0.3404	165	45	138	44.96	7.34	337.67	80 PICK 12 INSERT 33 RPM
23.01.90	MJG14.2	CONFINED	50		R-L	0.3404	226	45	138	61.56	10.05	337.67	80 PICK 12 INSERT 33 RPM
23.01.90	MJG14.3	DOLOMITE	50		R-L	0.2042	396	60	138	48.56	13.21	562.78	80 PICK 12 INSERT 33 RPM
23.01.90	MJG14.4	OVERCUT	50		L-R	0.2042	417	73	138	41.96	11.41	562.78	80 PICK 12 INSERT 33 RPM
23.01.90	MJG14.5	UNDERCUT	50		R-L	0.2042	366	50	138	53.79	14.63	562.78	80 PICK 12 INSERT 33 RPM
23.01.90	MJG14.6	OVERCUT	50		L-R	0.2042	417	72	138	42.54	11.57	562.78	80 PICK 12 INSERT 33 RPM
26.01.90	MJG15.1	CONFINED	50		L-R	0.3404	203	30	138	83.00	6.77	337.67	80 PICK 12 INSERT 60 RPM
26.01.90	MJG15.2	CONFINED	50		R-L	0.3404	279	75	138	45.65	3.73	337.67	80 PICK 12 INSERT 60 RPM
26.01.90	MJG15.3	UNDERCUT	50		R-L	0.2042	460	60	138	56.34	7.66	562.78	80 PICK 12 INSERT 60 RPM
26.01.90	MJG15.4	OVERCUT	50		L-R	0.2042	549	44	138	91.68	12.47	562.78	80 PICK 12 INSERT 60 RPM
26.01.90	MJG16.1	CONFINED	40		L-R	0.2513	203	25	138	73.53	8.13	457.39	80 PICK 12 INSERT 60 RPM
26.01.90	MJG16.2	CONFINED	40		R-L	0.2513	292	18	138	146.81	16.23	457.39	80 PICK 12 INSERT 60 RPM
26.01.90	MJG16.3	UNDERCUT	40		R-L	0.1508	549	25	138	119.12	21.95	762.32	80 PICK 12 INSERT 60 RPM
26.01.90	MJG16.4	OVERCUT	40		L-R	0.1508	549	24	138	124.09	22.86	762.32	80 PICK 12 INSERT 60 RPM

LH1300 NO 69 DOMTAR SALT CANADA PRODUCTION TESTS

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
05/07/89	A	71	4.93	4.11	14.37	16.66	51.74	100	12	42 BOX	63
05/07/89	B	71	4.79	4.15	14.05	15.37	54.84	100	12	42 BOX	63
06/07/89	C	108	5.06	4.16	22.84	17.30	79.21	100	12	42 BOX	63
06/07/89	D	101	4.91	4.16	20.62	14.27	86.68	100	12	42 BOX	63
07/07/89	E	40	5.24	4.24	8.85	7.60	69.88	100	12	42 BOX	63
07/07/89	F	41	5.13	3.91	8.22	6.81	72.40	100	12	42 BOX	63
10/07/89	G	117	5.18	3.96	23.96	17.08	84.18	90	12	42 BOX	63
10/07/89	H	105	5.03	3.91	20.58	15.12	81.66	90	12	42 BOX	63
11/07/89	J	75	5.46	3.96	16.30	11.13	87.90	90	12	42 BOX	63
11/07/89	K	80	5.22	3.94	16.43	11.80	83.56	90	12	42 BOX	63
11/07/89	L	47	5.23	3.81	9.36	10.76	52.18	90	12	42 BOX	63
11/07/89	M	48	5.26	3.73	9.47	9.78	58.12	90	12	42 BOX	63
17/07/89	N	45	5.45	4.11	10.17	9.44	64.61	115	8	42 BOX	63
18/07/89	P	48	5.37	3.96	10.27	8.86	69.56	115	8	42 BOX	63
19/07/89	Q	81	5.11	3.71	15.31	14.17	64.83	115	8	42 BOX	63
19/07/89	R	81	5.34	3.61	15.56	16.61	56.19	115	8	42 BOX	63
20/07/89	S	115	5.32	4.11	25.21	22.74	66.52	115	8	42 BOX	63
20/07/89	T	111	5.34	4.04	23.93	23.08	62.20	115	8	42 BOX	63
TOTALS					285.50	248.58					
MEAN RATE		77					68.91				
STD DEV							11.88				

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
29/07/89	AA	78	4.90	3.05	11.65	5.63	124.21	100	12	42/23	63
29/07/89	BB	79	5.44	2.95	12.61	6.51	116.25	100	12	42/23	63
30/07/89	CC	117	5.26	3.02	18.58	9.35	119.20	100	12	42/23	63
	DD	116	5.39	2.84	17.68	6.83	155.25	100	12	42/23	63
	EE	111	5.20	2.92	16.89	8.98	112.81	90	12	42/23	63
	FF	87	5.33	3.27	15.26	6.15	148.84	90	12	42/23	63
TOTALS					92.67	43.46					
MEAN RATE		98					127.95				
STD DEV							16.46				

LH1300 NO 69 DOMTAR SALT CANADA PRODUCTION TESTS

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
18/09/89	TT	86	4.78	3.12	12.77	17.75	43.15	115	8	2 START	33
18/09/89	UU	88	5.33	2.04	9.60	7.87	73.26	115	8	2 START	33
19/09/89	VV	93	4.84	3.30	14.79	10.20	87.00	115	8	2 START	33
20/09/89	WW	85	4.80	3.61	14.74	12.13	72.90	100	12	2 START	33
TOTALS					51.90	47.95					
MEAN RATE		88					64.95				
STD DEV							16.01				

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
18/09/89	TT	97	4.18	0.91	3.69	1.58	139.82	115	8	2 START	60
18/09/89	UU	92	4.72	1.84	7.95	4.88	97.69	115	8	2 START	60
TOTALS					11.64	6.47					
MEAN RATE		94					108.00				
STD DEV							21.07				

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
23/10/89	2	91	4.88	3.66	16.31	10.33	94.70	100	12	2 START	63
23/10/89	3	91	5.49	4.27	21.30	10.63	120.20	100	12	2 START	63
23/10/89	4	91	5.49	4.27	21.30	12.67	100.91	100	12	2 START	63
23/10/89	5	91	5.64	4.27	21.91	9.67	135.99	100	12	2 START	63
23/10/89	6	107	6.10	4.27	27.77	13.10	127.18	100	12	2 START	63
23/10/89	7	102	6.10	4.27	26.43	12.70	124.85	100	12	2 START	63
TOTALS					135.02	69.10					
MEAN RATE		95					117.24				
STD DEV							14.67				

LH1300 NO 69 DOMTAR SALT CANADA PRODUCTION TESTS

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
10/01/90	TJ	117	5.79	4.27	28.87	20.00	86.61	115	12	24 BOX	33
19/01/90	MJG1	61	5.79	3.05	10.77	13.00	49.69	100	12	24 BOX	33
19/01/90	MJG2	91	5.18	3.66	17.33	14.00	74.26	80	12	24 BOX	33
22/01/90	MJG3	76	5.49	4.57	19.11	15.00	76.45	80	12	24 BOX	33
22/01/90	MJG4	61	5.18	4.42	13.96	12.00	69.79	80	12	24 BOX	33
22/01/90	MJG5	76	5.18	4.57	18.05	14.00	77.36	80	12	24 BOX	33
22/01/90	MJG6	91	5.18	3.66	17.33	14.00	74.26	80	12	24 BOX	33
23/01/90	MJG7	76	5.49	3.96	16.56	15.00	66.25	80	12	24 BOX	33
23/01/90	MJG8	61	5.49	3.96	13.25	11.00	72.28	80	12	24 BOX	33
23/01/90	MJG9	40	5.49	3.96	8.69	8.00	65.21	80	12	24 BOX	33
TOTALS					163.92	136.00					
MEAN RATE		75					72.32				
STD DEV							9.21				

DATE	CUT NUMBER	SUMP DEPTH (cm)	ROAD WIDTH (m)	ROAD HEIGHT (m)	VOLUME CUT (m^3)	CUTTING TIME (mins)	CUTTING RATE (m^3/hr)	PICK GAUGE (mm)	TIP SIZE (mm)	HEAD TYPE	HEAD SPEED (rpm)
25/01/90	MJG	137	5.49	3.05	22.93	14.00	98.29	80	12	24 BOX	60
26/01/90	MJG	61	5.49	3.05	10.19	6.00	101.93	80	12	24 BOX	60
TOTALS					33.13	20.00					
MEAN RATE		99					99.38				
STD DEV							1.82				

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