EVALUATION OF FIELD-SCALE APPLICATION OF A SHOTCRETE COVER ON ACID GENERATING ROCK

MEND Project 2.34.1

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WESTMIN RESOURCES LTD.

EVALUATION OF A FIELD-SCALE APPLICATION OF A SHOTCRETE COVER ON ACID GENERATING ROCK

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EXECUTIVE SUMMARY

Northwest Geochem, in conjunction with Powertech Labs Inc. has developed and tested a cementitious material which incorporated mine tailings as a cover for acid generating waste rock at Westmin=s Myra Falls Operation. The project was initiated in 1992 under the MEND (Mine Environment Neutral Drainage) program to assess the performance of a cementitous cover. The project was funded by Westmin Resources and the Canada Centre for Mineral and Energy Technology (CANMET) through the British Columbia Mineral Development Agreement and was implemented in three phases. The initial laboratory phase indicated that the mixtures exhibited good mechanical strength and low permeability. Leach testing indicated that metal release from the encapsulated tailings materials was not a concern. The second phase of the research focused on incorporation of flyash and polypropylene fibres into the tailings mixtures and resulted in a product with good compressive strength, good ductility, and low permeability to water.

In the third phase of the study, presented in this report, a large-scale field application of a shotcrete cover on a waste rock dump was conducted. The primary purpose of this phase was to evaluate the long term stability of the shotcrete in the field environment. Additionally, a large scale test provided an opportunity to develop and use the best practicable technology to install the shotcrete cover on reactive waste rock.

The shotcrete test was conducted on a 3500 m^2 area of the main Lynx waste rock dump at Westmin=s Myra Falls Operation. The dump was recontoured to a grade of 22E and compacted prior to the shotcrete application. A wet-mix shotcrete application was applied in August 1992 using a remotely controlled robotic arm mounted on a rubber-wheeled carrier. Mixes utilizing imported aggregate and mine tailings were tested. Laboratory and field monitoring were conducted through 1995 to determine the mechanical properties of the shotcrete and to evaluate the long term performance of the cover.

The results of the field trial indicated that the robotic application system produced a good quality application with high rates of productivity and a uniform placement of material. Some difficulties were encountered which have led to suggested design modifications for the robotic system. Visual inspections of the shotcrete cap over a three-year period have indicated that the overall durability of the material was good. No frost damage was evident and no movement of the cap was detected by surveys conducted. Some cracks were observed and appear to be correlated

with areas where the shotcrete was applied at less than the 75 mm thickness specified for the test. Some plastic shrinkage cracks were observed in the shotcrete immediately after application due to the high rate of evaporation before initial set.

The results of the laboratory testing indicated that the compressive strength of the mixtures exceeded the design objective. The toughness index and flexural strength were lower than standard values for shotcrete. Some reduction in compressive strength was observed in the tailings mix after 400 days. It is believed this loss in strength is a result of oxidation of the sulfide minerals in the tailings material. Permeability of the shotcrete ranged from 10^{-14}m/s in the aggregate mix to 10^{-10}m/s in the tailings mix. An assessment of the cost of the shotcrete application indicated that the transport of the aggregate to the mine site is the largest cost component. If a local aggregate was used, such as coarse tailings, the total cost could be reduced by more than 30 percent. Modification of the robotic spray boom and the delivery hose would increase the rate of production by at least 30 percent.

The results of this study have led to various recommendations for future research requirements. Determining the effects on the shotcrete cover due to the placement of overburden and vegetation is proposed as the next study phase. Also of primary importance is the determination of the effectiveness of the shotcrete cover in restricting acid generation in waste rock. This study did not address this issue and it is recommended that a controlled field scale test be conducted to monitor acid production products in a capped dump. Due to the high sulfur content of the presently available tailings material, there is a need to evaluate other local material sources which could be utilized as an aggregate source. Other recommendations include the development of a more versatile robotic spray boom which can manoeuvre on steep slopes, and modifications to the method of batching and placing the shotcrete. Finally, the long term success of the dry cover depends on the stability of the waste rock dump. Geotechnical studies are required to estimate any movement of the final design slope.

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ii

LIST OF TABLES vii

LIST OF FIGURES viii

LIST OF PHOTOS ix

LIST OF APPENDICES x

1.0 INTRODUCTION 1
1.1 Review of Shotcrete Technology 3

2.0 FIELD APPLICATION OF SHOTCRETE 5
2.1 Site Preparation 5
2.2 Materials and Mix Proportions 6
2.3 Equipment 7
2.4 Field Operation 7
2.5 Cost Analysis 8

3.0 LABORATORY TESTING 10
3.1 Compressive Strength 10
3.2 Flexural Strength and Toughness 11
3.3 Absorption After Boiling, Permeable Voids and Permeability 11
3.4 Oxidation 12

4.0 FIELD INSPECTIONS AND OBSERVATIONS 13
4.1 Results of the Infiltration Monitoring 13
4.2 Results of Elevation Survey 13
4.3 Results of the 1992 Inspection 13

4.4 Results of the 1993 Inspection 14
4.5 Results of the 1995 Inspection 15

5.0 DISCUSSION 16
5.1 Assessment of the Method of Shotcrete Application 16
5.2 Mechanical Properties of Shotcrete 17
5.3 Evaluating Long Term Performance 18
5.4 Means of Minimizing Costs 20

6.0 CONCLUSIONS 21

7.0 RECOMMENDATIONS 23

REFERENCES 25

LIST OF TABLES

Table
1 Proportions of Shotcrete Used for Test Panel
2 Cost Breakdown of Shotcrete Application
3 Compressive Strengths at 28 Days Cure
4 Compressive Strengths at 100 Days Cure
5 Compressive Strengths at 200 Days Cure
6 Compressive Strengths at 400 Days Cure
7 Compressive Strengths at 1000 Days Cure (Laboratory)
8 Compressive Strengths at 1000 Days Cure (Field)
9 Results of Various Toughness Tests on Panels Preared in 1992
10 Results of Absorption Tests on Panels Prepared in 1992
11 Rsults of Absorption Tests on Panels Cut in Field in 1995
12 Results of Permeability Tests
13 Results of Infiltration Monitoring in 1993 and 1994
14 Elevation and Net Change of Shotcrete Cover

LIST OF FIGURES

Figure
1 Schematic of large scale field application of shotcrete
2 Schematic of robotic spray boom
3 Wet mix shotcrete equipment
4 Compressive strength of shotcrete (primary mix)
5 Compressive strength of shotcrete (tailings mix)
6 Definition of toughness indices in terms of multiples of first-crack deflection and elastic-plastic material behavior
7 Schematic of permeability testing apparatus
8 Location of survey markers on shotcrete test pane
9 Locations of sample panels and cracks in shotcrete
10 Research approach for evaluation of dry cover
11 Proposed slope stability analysis

LIST OF PHOTOS

Photo

1 Test section after slope preparation and compaction
2 Infiltration boxes installed prior to shotcrete application
3 Robotic arm at full extension
4 Water was sprayed on the waste dump before shotcreting
5 Cement was added to concrete trucks on site
6 Robotic boom was swung side to side in sweeping motion and was slightly retracted after each sweep
7 Nozzle was held manually where the robotic arm could not reach or when the robot was not working
8 A panel was shotcreted for the laboratory test
9 A panel cut during 1995 inspection
10 Completed shotcrete test panel - August 1992
11 A core drilled in November 1992, with a crack through the cover
12 A core drilled in November 1992, with a crack terminated in the cover
13 Inspection of test panel, September 1993
14 Oxide staining was observed on some areas as a result of water flow from the waste rock dump through the shotcrete panel
15 The shotcrete on the side of the diversion ditch as inspected in 1993
16 A 6m long crack located at between grid 37 and 54, as observed during 1995 inspection
17 Vegetation and silt in few large cracks
18 The edge of the lower portion of the test panel showed signs of erosion

APPENDICES

Appendix

A Reprint of Technical Paper Presented at the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acid Drainage. Pittsburgh, Pennsylvania 1994.

B Specifications for Shotcrete Testing

C Flexural Test Results

D Test Procedure for Permeability Tests

E Pneumatic Conveying Machine

1.0 INTRODUCTION

Westmin Resources Limited's Myra Falls Operation is a 3,650 mt/d copper-zinc-gold-silver operation located in a narrow steep valley in the central region of Vancouver Island, BC. The waste rock generated from the mining operation contains sulfide minerals which have the potential to generate acidic drainage with elevated metal loadings, particularly zinc, copper, and cadmium. A water collection and treatment system is presently in place to protect the downstream environment; however, reclamation of the waste rock dumps and the eventual decommissioning of the mine will require a long term control method for acid generation and drainage at the mine site. Ideally the long term control method should restrict the availability and contact of oxygen and water, the primary ingredients of the acid generation process, with the reactive waste rock.

The mine's decommissioning plan recommended that the closure strategy for the rock dump focus on preventing acidic water from moving downward to the water table (C.E. Jones and Associates Ltd., 1992). Restricting the access of oxygen and surface water infiltration to reactive waste rock can be achieved using covers and sealants. The restriction of water can potentially reduce the formation of acid and the subsequent transportation of the oxidation products away from the source (B.C. Acid Mine Drainage Task Force, 1989).

A variety of materials have been proposed to provide covers for reactive waste rock or tailings, including soils, synthetic membranes, compacted clay and till, asphalt, and concrete. The Draft Acid Rock Drainage (ARD) Technical Guide (B.C. Acid Mine Drainage Task Force, 1989) and Malhotra (1990) discussed the relative advantages and disadvantages of the various types of covers. A limiting important factor governing the use of various materials as covers is the cost associated with large-scale application.

Northwest Geochem, in conjunction with Powertech Labs Inc. has been researching, developing and testing a cementitious cover which incorporates mine tailings. The primary objective for the incorporation of mine tailings was to reduce the overall cost of the solidified cover material. A laboratory study (Northwest Geochem, 1990) was conducted in the first phase of the project to determine the best possible mix design using various cementitious materials. Initial test results showed that the encapsulated mine tailings exhibited good mechanical strength and low permeability. Leach testing indicated that metal release form the encapsulated tailings material was not a concern.

The second phase of the project (Gerencher *et. al.*, 1991; Northwest Geochem, 1992) focused on the development of mixes which could be placed onto large scale sloped or vertical surfaces using shotcrete methods. The cementitious mixtures incorporated the use of high volume flyash and polypropylene fibres, as well as mine tailings. The mixtures were applied to test panels (1 m x 1 m x 150 mm) using the wet-mix shotcrete method. The shotcrete concrete exhibited good compressive strength, good ductility, and low permeability to water.

This report summarizes the third phase of the project which involved a large-scale application of a shotcrete cover on waste rock dump. The purpose of this phase was to evaluate the material properties and long term stability of the field-placed shotcrete (Jones and Wong, 1994) (Appendix A). In addition, this large-scale test provided an opportunity to develop and use the best practicable technology to install a shotcrete cover material on reactive waste rock. The objectives of this project were to:

! Assess the method of large-scale shotcrete application.
! Determine the mechanical properties of the shotcrete.
! Evaluate the long term performance of shotcrete, and
! Develop means of minimizing the cost of the cover.

It should be noted however, that the development of a method to prevent or control ARD was beyond the defined scope of this project.

This project was initiated in 1992 under the Mine Environment Neutral Drainage (MEND) program to evaluate cover technologies. The project was funded by Westmin Resources and the Canada Centre for Mineral and Energy Technology (CANMET) through the British Columbia Mineral Development Agreement. MEND has initiated several programs to investigate dry covers as an engineering solution in the management of acidic drainage. Related projects supported by MEND have been summarized in MEND, 1996. These include a scientific review of the design and evaluation of engineered natural soil covers at a number of sites (MEND Project 2.21.3a) and a literature review and an assessment of non-traditional soil and synthetic cover materials (MEND Project 2.21.3b). Earlier work supported by MEND included preparation of a ranking of the potential alternate cover materials (MEND Project 2.20.1, MEND, 1994).

1.1 Review of Shotcrete Technology

The shotcrete process is a construction method utilizing compressed air as the primary source of motive power to project mortar and concrete at a high velocity of impact against a surface. Based on how materials are mixed, shotcrete can be applied as either a dry-mix or a wet-mix. The advantages of using shotcrete versus a conventional poured concrete include the elimination of formwork and compaction, improving the bond to the substrate materials, and allowing vertical and overhead applications.

Dry-mix shotcrete, also called Gunite, shoots premixed dry materials along with water at a controlled rate. The technique is very simple and easy to use but has some drawbacks due to high rebound ratio, dusty operating conditions and the requirement of experienced personnel to control shotcrete quality. The wet-mix shotcrete, on the other hand, shoots mixed wet concrete by a pneumatic piston pump. This technique has very low rebound ratio and produces no dust, but does require ready mix concrete on site. Both dry-mix and wet-mix techniques are capable of producing strong, durable shotcrete.

During the last 30 years there has been a great increase in shotcrete applications and in the development of new equipment for applying shotcrete. The properties of shotcrete have been improved by using a variety of supplemental materials such as fibres, polymers, industrial by-products (silica fume, flyash), and admixtures. In a recent study, the performance of shotcrete used in the repair of B.C. Hydro's hydraulic structures was evaluated. These repaired structures had been subjected to a wide variety of field conditions over the past 30 years but the performance of the shotcrete materials was rated as good (Powertech Labs, 1994).

Conventional Portland cement shotcrete is a well known technology for repairing deteriorated structures, and stabilizing vertical rock faces and tunnels. However, this type of system is expensive when applied on large areas where control joints, mesh reinforcement, and increased thickness are required. Studies by CANMET and others (Langley and Dibble, 1990; Malhotra, 1991; Morgan and McAskil, 1990; and Seabrook, 1992) have shown that a fibre-reinforced, high-volume flyash shotcrete can be used successfully in large-scale applications. The system incorporates discrete polypropylene fibres to increase toughness and inhibit cracking and uses large volumes of flyash to reduce material cost. A limited number of field trials have been conducted, but more data are required to determine the long term effectiveness of the proposed capping systems.

2.0 FIELD APPLICATION OF SHOTCRETE

Field application of the shotcrete was carried out at the Myra Falls Operation in August 1992. The contractor for the preparation and application of shotcrete was Terracrete Ltd. of Langley B.C. The test waste rock site is located at the toe of the north valley wall, east of the inactive open pit. The weather was warm and no precipitation occurred during the application. The contract specification for this test program is included in Appendix A.

2.1 Site Preparation

The shotcrete test was conducted on an area of approximately 3,500 m^2 of the main Lynx waste rock dump. The test area was not benched and had a slope between 37E and 39E. To facilitate this test, the upper 10 m of the dump was resloped to a grade of 22E (Figure 1). After resloping, the test area was compacted using a vibrating Bomag roller resulting in a relatively smooth surface (Photo 1). Although shotcrete can be applied to vertical slopes, the shallow grade was required for the use of the robotic arm shotcrete spraying equipment and the subsequent placement of overburden and vegetation planned for the test area. A narrow access road was constructed at the base of the test slope. The upslope edge of the site connects with a diversion ditch that extends around the perimeter of the mine area.

Prior to the application of the shotcrete, 13 infiltration boxes were installed to allow an assessment of water in the surface waste material of the dump. Holes were excavated into the dump to a depth of approximately 1 metre. Standpipes were placed in plastic barrels and located in the excavations. The barrels were filled with sand to the surface and the excavations backfilled and compacted (Photo 2). The standpipes were capped and after the shotcrete was applied the joint between the standpipe and shotcrete capping was sealed with a grout.

2.2 Materials and Mix Proportions

The cementitious materials used in this program were type 10 Portland cement and Class F flyash. The advantages of incorporating flyash into shotcrete are:

- lower cost (flyash is a waste by-product from thermal power generation);
- lower heat of hydration in the mix thus reducing the potential for cracking;
- improve long term strength growth and durability; and,
- improve pumpability of the wet-mix shotcrete.

A 38 mm polypropylene mesh type fibre from Fibermesh was used at a rate of 4 kg/m^3. An evaluation of specific chemical and physical characteristics of the mix components presented in Northwest Geochem (1991) identified an increase in ductility and flexural strength of the shotcrete with the addition of polypropylene fibres. Chemical analysis was limited to determination of selected oxides including silica, aluminium, iron, sulphur and calcium.

The cost of transporting aggregate to the mine site was the single highest item in the total cost of shotcrete (see Section 2.5). Results of earlier phases of this research program involving laboratory trial mixes and limited small scale tests have indicated that there is potential to use coarse tailings as aggregate in this type of capping system (Northwest Geochem, 1991).

At the time of installing the shotcrete test panel in 1992, the supply of coarse tailings available for this use was limited. Therefore, only a small portion of the test panel utilized tailings as the aggregate.

Table 1 lists the two mix proportions used in this test. Approximately 100 m^2 of the test area was covered with the tailings mix while the rest of the area was covered with the primary mix. The aggregates, flyash, and water for the primary mix were batched by mass in the concrete plant and transported to the site where the cement was added. The tailings mix was volumetrically mixed on site, thus resulting in a less accurate batch. Due to poor mixing qualities in the drum of the concrete truck, additional water was added resulting in a much higher water to cement ratio than that of the primary mix.

2.3 Equipment

The wet-mix shotcrete in this project was mixed by ready mix concrete truck and then discharged into the hopper of the shotcrete pump. A robotic arm mounted on a rubber-wheeled carrier was used to control a spraying boom. The robotic arm is mounted on a turret with a 360E swing as shown in Figure 2 and Photo 3. The spray boom has a reach of 10.4 m. The shotcrete nozzle, attached to the end of the spray boom, is able to tilt 120E and has a rotation of 270E. The wet-mix concrete was pumped to the nozzle using a diesel-powered double-piston shotcrete pump (Figure 3) through a 63.5 mm diameter delivery hose. The arm is remotely controlled by an operator using a series of toggle controls.

2.4 Field Operation

The crew consisted of one nozzleman, one helper, and one pumpman. The equipment did not require any major assembly and was mobilized in a few hours. Water was sprayed over the rock pile surface before applying shotcrete due to the hot and dry summer conditions (Photo 4).

The proportioned aggregate along with the flyash and water were trucked from Campbell River (located 85 km from the mine site) in ready-mix trucks. Each truck contained 6 m^3 of aggregate. The cement and polypropylene fibres were added to the concrete trucks on site (Photo 5) and were allowed to mix for a minimum of 30 minutes. The pumpman controlled the amount of shotcrete supplied to the nozzle. The nozzleman controlled the shotcrete nozzle and placement of the shotcrete onto the waste rock dump.

The common spraying sequence started with the boom fully extended at its maximum reach. The nozzle was positioned approximately 1 m to 1.5 m from the surface. The boom was then swung side to side in sweeping motion and was slightly retracted after each sweep (Photo 6). A nominal thickness of 75 mm of shotcrete was chosen for this test. Approximately 80 m^2 to 90 m^2 were covered without having to move the vehicle. Owing to the relatively smooth surface produced by the compaction of the waste rock, the thickness of the shotcrete cover was quite uniform. During shotcreting of a small portion of the test panel, the nozzle was held manually because either the robotic arm could not reach the area or the apparatus experienced mechanical failure (Photo 7).

The production rates achieved in this test program were higher than rates achieved using conventional application methods. It took approximately 5 days to install the entire test cover. The average rate achieved was 150 m^2/h. On some occasions production rates of 200 m^2/h were achieved. The equipment used in this application was originally designed for lining tunnels, and the movements of the boom were not suited for application on near-level grades. For example, the swinging motion of the arm resulted in wear on the clutch in the turret. It is believed that the efficiency of the shotcrete application could be improved by using a smaller, more mobile vehicle. However, this would require design modifications to the standard equipment currently available.

Some problems arose in the delivering of the material to the nozzle due to blockage in the line which had to be manually removed. This problem resulted from the combination of a small diameter delivery hose, the pump size, the hose length, and the warm weather which stiffened the concrete mix.

2.5 Cost Analysis

A major consideration in the design of the testing program was cost. Table 2 provides a breakdown of the cost for the shotcrete application. The transportation of aggregate from Campbell River B.C. to the mine site (a distance of 85 km) represented approximately 40 percent of the cost of the cover. If a local aggregate source, such as coarse tailings, were locally available, the unit cost per square metre of cover could be less than Cdn $12. Further cost reductions could be achieved through modifications suggested for the robotic application system. The increased productivity due to these modifications is estimated at 30 percent, which could further reduce the unit cost of the cover to approximately Cdn $10.

3.0 LABORATORY TESTING

Laboratory testing was carried out on six shotcrete panels cast during the field shotcreting operation (Photo 8), and on five panels cut from the shotcrete cover during the 1995 field inspection (Photo 9). Specimens were drilled from the panels to examine strength, permeability, and water absorption. Testing was conducted in accordance with the specifications presented in Appendix A.

The six shotcrete panels (1 m x 1 m x 150 mm) cast during the field operation, were stored outdoors at Powertech Labs in Surrey B.C. Panels 4 and 5 were composed of the tailings mix while others were from various batches of the primary mix.

The five panels cut from the shotcrete cover in 1995, varied in thickness, therefore, the length of the test cylinders also varied. The resulting strength values were corrected for length in accordance to ASTM C42. The 1995 field Panel 4 was too thin to allow cores to be drilled. Panel 1 was composed of the tailings mix while the others were from various locations and therefore various batches of the primary mix.

3.1 Compressive Strength

Testing of compressive strength was performed in accordance with ASTM CAN/CSA -A23.9C on cylindrical cores with a diameter of 75 mm and length of 300 mm. Tables 3 through 7 present the compressive strengths of the cores taken from the test panels taken in 1992 after 28, 100, 200, 400, and 1000 days of curing. Table 8 provides the compressive strengths of the panels cut from the field in 1995 after approximately 1000 days of curing. The compressive strength of the shotcrete without tailings has steadily increased over the study period (Figure 4). The compressive strength of the shotcrete with tailings showed increased strength through the first 400 days of curing but has experienced some loss in compressive strength between day 400 and day 1000 (Figure 5).

3.2 Flexural Strength and Toughness

Waste rock dumps, although recontoured and compacted, may undergo some local settlement causing the dry cover to flex. This is a concern for the shotcrete cover since concrete is a brittle material with a very low tensile strength. The flexural strength of the shotcrete is much lower than its compressive strength. Unreinforced concrete will tend to crack and separate following small deflection. The addition of the polypropylene fibres to the mix will give the panel some ductility, i.e. some flex before the panel separates.

To evaluate the ductility of the test panels, toughness index tests were performed in accordance with ASTM C1080 (using beam with third point loading). Beams of 100 x 100 x 350 mm were cut from the 1992 shotcrete panels for flexural testing after 100 day curing. The toughness index is defined as the ratio of the absorbed energy at various crack widths as compared to the absorbed energy when the first crack occurs. The loading method and definition of toughness indices are described schematically in Figure 6.

Results of the flexural test on the six panels are presented in Table 9. The values of the shotcrete are lower than the desired toughness indices specified in ASTM C1116. These low values are not unexpected since a low fibre content (4 kg/m^3) was used to reduce the cost of the product. Higher values of flexural strength generally corresponded with a lower toughness index. The load deflection curves of the six panels are attached in AppendixC.

3.3 Absorption After Boiling, Permeable Voids and Permeability

To provide an indication of the permeability of the concrete, the absorption after boiling, volume of permeable void, and bulk relative density of the test panels were determined in accordance to ASTM C642. Cubes, 75mm x 75mm x 75mm, were cut from the shotcrete panels. Tables 10 and 11 present these results at 400 and 1000 days. The mean volume of permeable voids after 400 days was 22.26% for the primary mix and 30.86% for the tailings mix. The mean volume after 1000 days on the panels cut from the field in 1995 was 18.20% for the primary mix and 28.60% for the tailings mix.

The water permeability of the shotcrete samples was determined using a high pressure method which is designed to allow one dimensional, uniform flow. The test equipment as shown in Figure 7 consists of a pressure cell connected to a hydraulic line capable of subjecting the cell to 700 kPa (100 psi) of pressure. The core specimens were 76.2 mm in diameter and 25.4 mm thick. Details of the test equipment and test method is outlined in Appendix D. A differential pressure of 300 kPa (43.5 psi) was used to produce a hydraulic gradient across the sample. The water flow was measured using a buret. The permeability values are listed in Table 12. The results showed that the permeability was decreasing with time as the compressive strength of the shotcrete continued to increase. The mean permeability of the primary mix was 7.3×10^{-14} m/s and the mean permeability of the tailings mix was higher at 4.0×10^{-10} m/s.

3.4 Oxidation

To examine possible oxidation of the shotcrete containing mine tailings, samples from a 1992 field casted panel and from a 1995 field cut panel were split open and the freshly cut faces were subjected to a phenolphthalein solution. Phenolphthalein solution is generally used as a qualitative indicator of alkalinity in concrete. When the pH value increases from neutral to alkali, the colour of the specimen turns to a deep red from its natural colour.

The alkalinity indicated by phenolphthalein showed an apparent contrast between the primary mix and the tailings mix. The fresh cut surface of both panels showed clear zones of concrete near the surface which had lost alkalinity due to oxidation. The depths of oxidation ranged from 10 mm to 20 mm. The primary mix showed a much deeper red in the centre of the cores than did the tailings mix. A similar examination was conducted on the tailings shotcrete panels cast at Powertech Labs during an earlier study (Northwest Geochem, 1992). The evidence of oxidation was also very obvious in the panels containing the same amount of tailings as the field panels.

4.0 FIELD INSPECTIONS AND OBSERVATIONS

Field inspections provide a means to visually evaluate performance of the cover and to observe significant changes such as cracking or frost damage, or erosion. A grid of survey markers was installed in 1992 onto the cover at 5 m spacings to provide a means to monitor movement of the cover. The location of the markers are indicated in Figure 8. Since completion of the cover, three surveys and three field inspections were carried out to evaluate the performance of the cover.

4.1 Results of the Infiltration Monitoring

Depths and volumes of water in the standpipes were determined in November 1993 and December 1994. These results are presented in Table 13. The water depths were difficult to measure due to the condensation in the standpipes which interfered with the water sensor. The volume of water bailed from the standpipes is believed to be a more consistent measure of the water collected in the infiltration boxes. In the 1994 monitoring, the volume of water in the standpipes ranged from 0 to 1000 ml with a mean of 490 ml. During 1993 and 1994, one of the standpipes was not available for measurement due constriction within the pipe. The volume measured in 1995 ranged from 0 to 500 ml, with a mean of 280 ml. Photo 10 illustrates the location of the standpipes in the completed shotcrete test panel.

4.2 Results of Elevation Survey

Three elevation surveys were performed on the test panel between October 1992 and March 1995. The elevations and changes of the survey data are provided in Table 14. The accuracy of the level used in these surveys was 10 mm. At this level of accuracy no significant changes were detected. (Note: some of the changes from March 1993 to March 1995 are due to omission of one decimal in the last survey).

4.3 Results of the 1992 Inspection

Some plastic shrinkage cracks were observed in the shotcrete immediately after application. The primary cause of these cracks was the high rate of evaporation before initial set. In November 1992, cores were taken through a number of these cracks; some were found to extend through the cap, and others terminated approximately halfway through the cap (Photos 11 and 12). Most of the plastic shrinkage cracks exhibited very narrow surface widths. It is uncertain, without monitoring, how much water from surface runoff will pass through these cracks. However, it has been suggested in literature that cracks with surface widths of less than 0.2 mm will prove to be water tight in most circumstances where there is no hydraulic gradient (i.e. no surface ponding). In addition, when water percolates through cracks, it dissolves calcium hydroxide salts from the cement matrix and chemically reacts with the flyash to form compounds possessing Acement@ like properties.

4.4 Results of the 1993 Inspection

A visual assessment was carried out in September 1993, one year following placement of the cover (Photo 13), and the overall durability performance was good. There was no evidence of major cracking or movement in the cover. The shotcrete did not appear to have suffered any frost damage or erosion. Some minor cracks were observed in two small areas where the shotcrete was thinner than the 75 mm standard depth. Iron staining was observed on these areas as a result of water flow from the waste rock dump through the shotcrete panel (Photo 14). The source of this flow appears to be lateral movement of water through the dump. Similar water movement has been observed in other non-covered areas of the waste rock dump. These observations provide pertinent data to assess the performance of the shotcrete, however implications of cover performance to the control of ARD are beyond the scope of this study.

After 1 year of exposure, the plastic shrinkage cracks observed in 1992 did not appear to have expanded.

The shotcrete on the steep slope of the dump adjacent to the diversion ditch was in very good condition and there were no stains. There was some staining at the interface between the test panel and the diversion ditch (Photo 15).

The lower portion of the test panel (on the bench) did show some slope movement. Since this part of the slope was an area of fill, the underlying material was very loose and the slope below the test panel was found to be unstable. Portions of the test panel on the bench produced a hollow sound when the surface was tapped. In comparison, a very solid sound was produced on the slope portion of the test panel. It is inferred that subsidence of underlying dump material may be responsible for the hollow sound, but this has not been confirmed. Subsequent to this inspection, the access road to this bench was closed to vehicle traffic.

4.5 Results of the 1995 Inspection

The third field inspection was conducted in April 1995 and five panels were cut from the shotcrete cover.

The cracks on the shotcrete cover were profiled during the 1995 field inspection (Figure 9). All of the cracks were located on the sloping portions of the test panel (Photo 16). Although the number and length of the cracks were slightly greater than in the previous inspection, iron stains were less visible. Silt had collected in a few of the cracks and some vegetation had established (Photo 17). Cracks sealed during the field drilling in 1992 showed no signs of re-opening. In the area of the tailings mix, short-length, interconnected cracks were predominant.

The erosion at the lower portion of the test panel (the bench) continued to slowly advance since 1994 (Photo 18). It is believed that further erosion will depend on the stability of the rock pile slope below the test panel. To date, no stability analysis has been performed on the rock pile slope below the test panel.

5.0 DISCUSSION

The following sections discuss the results of the laboratory testing and the field inspections in terms of the study objectives which were:

- to assess the method of large-scale shotcrete application;
- to determine the mechanical properties of the shotcrete;
- to evaluate the long term performance of the shotcrete; and,
- to develop means of minimizing the cost of the cover.

5.1 Assessment of the Method of Shotcrete Application

This field trial provided information on the optimization of shotcreting process. The robot system produced a good quality shotcrete application. The productivity rate was high and the shotcrete was placed uniformly. Difficulties were encountered, however, in the delivery of the shotcrete to the robot. The increase of the delivery hose diameter from 60 mm to 76 mm should reduce the frequency of hose blockages and would therefore increase productivity.

The delivery system used in this test also controlled the water to cementitious material ratio which could be used in the mix. To reduce shrinkage cracks and increase strength in the shotcrete, it is desirable to produce a mix with a low water to cementitious material ratio. A pneumatic conveying machine would be insensitive to aggregate gradations and would allow the use of a mix with a lower water content. Appendix E provides an illustration and product information for such a conveying machine, one of many on the market.

The robotic system experienced some mechanical breakdown due to the lateral movements involved in spraying large horizontal surfaces. The robot was designed for working in tunnels and modifications to the design would be necessary to work on the surface applications. Additionally, it would be desirable to develop a more versatile spray boom which could be manoeuvred on steeper slopes.

5.2 Mechanical Properties of Shotcrete

The use of shotcrete as a surface sealant with potential application to ARD control does not require high strength since the shotcrete cover is not required to support a load. For this field trial, the compressive strength design objective was 15 to 20 MPa. The results from both field cut panels and laboratory cured panels of the primary mix indicated that the compressive strength exceeded the design objective. The use of flyash has resulted in strength gain even after 400 days. The toughness index and flexural strength at 100 days were lower than standard values for shotcrete. However, since the compressive strength of the primary mix shotcrete has increased by more than 100 percent from 100 days to 1000 days, it is believed that the flexural strength may also have increased.

The compressive strength of the shotcrete panels of the tailings mix showed an increase during the first 400 days. The tests performed at 1000 days showed a slight reduction in the compressive strength. However, the strength still meets the design objectives. It is believed that the loss in strength is a result of oxidation of the sulfide minerals in the tailings incorporated into the shotcrete. The coarse tailings used in the mix contained a total sulphur content of 40 percent and oxidation is occurring at the surface of the shotcrete.

The acid formed during oxidation reacts with the calcium hydroxide in the concrete. Calcium hydroxide constitutes 10 to 20 percent of the total volume in the cement paste and is a major contributor to the strength of the concrete. Neutralization of the calcium hydroxide reduces the strength of the shotcrete. Examination of the samples from the tailings after conducting the compressive strength tests indicated that many cracks were generated from the top of the specimen. The degree of oxidation can be determined by examining sections of the shotcrete panel. The samples retrieved from the 1995 inspection showed that the oxidation layer ranged from 10 to 20 mm from the surface of the shotcrete panel. At this point, it is unclear whether this oxidation layer will increase or remain constant with time. Future inspections will give some indication if the compressive strengths of the shotcrete will continue to decrease. It could be possible that the oxidized layer will act to protect the underlying concrete.
The permeability tests of the primary mix indicated hydraulic conductivities of less than 10^{-14} m/s. These tests were performed after 1000 days of curing. The absorption tests performed at 400 and 1000 days suggests that the permeability decreases as the shotcrete continued to gain strength. It is normal that permeability will decrease as compressive strength increases in concrete.

The hydraulic conductivity of the tailings mix was much higher than that of the primary mix (10^{-10} m/s). This higher value appears to be a function of the fineness of the tailings particles resulting in a higher specific surface, ie. more area for moisture to pass between the aggregate. This is confirmed by the results of the absorption tests where the tailings mix had much higher absorption than the primary mix which contained a coarser aggregate. Other factors which can affect the permeability are the amount of cement in the mix and the water to cementitious material ratio. The tailings mix had a two time greater water to cementitious material ratio than the primary mix. Previous studies using tailings in the mix resulted in hydraulic conductivities between 10^{-10} and 10^{-12} m/s.

5.3 Evaluating Long Term Performance

Visual assessments of the shotcrete cap after 1000 days, including three winter seasons, indicated that the overall durability performance of the cap was good. The shotcrete did not appear to have suffered any frost damage or degradation due to weathering. Two types of cracks were observed on the sloping portion of the trial area. The locations of the larger cracks are on Figure 9. Smaller plastic shrinkage cracks were observed at random locations throughout the shotcrete cover.

The larger cracks developed horizontally across the slope. It is believed that these cracks are a result of bending of the panel due to local settlement of the waste. The elevation surveys confirmed that the movement of the slope over the three year period was minimal. The compaction of the slope prior to the shotcrete application is believed to be very important in achieving this stability. Another factor which may be contributing to the cracking is the depth of the shotcrete. Cores taken from the shotcrete indicate that the cap was as thin as 50 mm in some areas, well below the design thickness of 75 mm. Additionally, the swinging motion of the robotic arm can cause uneven shotcrete placement, resulting in ridges in some portions of the test area. This factor may be improved with modifications to the application apparatus. Some of the cracks observed were located at the base of these ridges. The width of the cracks was less than 2 mm and did not show evidence of further opening over the monitoring period. The cracks can be sealed to prevent water from entering the waste material and sealing will prevent the cracks from enlarging due to growth of vegetation within the cracks. A delay of a couple of years between the application of the shotcrete and placement of an overburden cover may be advantageous as it allows for any minor settlement cracks to develop and be repaired prior to placement of the soil material.

Some plastic shrinkage cracks were observed in the shotcrete immediately after application. These cracks were due primarily to the high rate of evaporation before initial set. A number of cores were taken through these shrinkage cracks; some were found to extend through the cap, and others terminated approximately halfway through the cap. After 1000 days, these cracks did not appear to have expanded. Measures to avoid plastic shrinkage cracks include: increasing the cement content, using additives such as superplasticizers, increasing the fibre content, and keeping the surface of the shotcrete moist immediately after application. However, all of these measures will increase the cost of the cover.

Water collected in most of the infiltration boxes installed under the shotcrete cap. It is not evident whether the total volume of water reported to the dump through the shotcrete cover or if the water resulted from condensation within the infiltration boxes and water flows in the dump not contained by the upper diversion ditch. Flows of water have been observed at the surface of the dump slope in portions of the dump not capped with shotcrete and it is very probable that water is flowing laterally through the dump beneath the cap. To accurately assess the ability of the shotcrete cap to eliminate water transport and ARD generation in the dump material a controlled waste rock pile should be constructed, sealed and monitored.

5.4 Means of Minimizing Costs

The cost of transporting aggregate is the largest component of the total cost. Use of a local aggregate, such as non-reactive coarse tailings, would reduce the unit cost of the shotcrete cover by more than 30 percent. The mine has indicated that the existing equipment could be used at closure to produce a local, non-reactive aggregate.

The application costs could be reduced through the modification of the robotic spray boom and the use of a 75 mm delivery hose. This would increase production by at least 30 percent. The use of a larger hose would also reduce the plugging of the lines which was a concern with this application and resulted in reduced productivity.

Increasing the fibre content of the mix could reduce some of the cracking which was observed without significantly increasing the cost of the cover. This modification, while increasing cost slightly, could improve the long term performance of the cover.

Regular maintenance is only required if there are major cracks in the panel. At the time of the last assessment, there were only two cracks which required repairs.

6.0 CONCLUSIONS

This study has indicated that shotcrete can be a viable cover option for prepared waste rock dumps. The application of the large scale test panel covering 3500 square metres and the subsequent monitoring over three years has shown the following:

- The use of a robotic spray boom resulted in high productivity and therefore contributed to a low application cost.
- A major proportion of the cost involved the importation of aggregates. Using a local aggregate source such as non-reactive mine tailings would make this option more cost effective when compared to other types of covers.
- Drying shrinkage cracks occurred in the test panel during application of the shotcrete due to the hot weather. Care must be taken during installation to ensure that the panels are kept moist after application. These shrinkage cracks were monitored and did not increase in size.

- The compressive strength of the shotcrete panel using the primary mix design has increased to as high as 36.5 MPa, well beyond the design strength.
- While the shotcrete with mine tailings performed similar to the primary mix without mine tailings during three years of service, there were some indications that mine tailings might react with cement paste. It is therefore recommended that the long term properties of the tailings mix be monitored or evaluated in an accelerated laboratory test. However, it must be noted that the strength of the tailings shotcrete is still above the design strength.
- The permeability of the panels with the primary mix was as low as 10^{-14} m/s. The permeability of the panels with tailings was in the order of 10^{-10} m/s.
- Since the test panel was an open system, it was uncertain how much moisture infiltrated into the system through the cover and measurement of this parameter was beyond the scope of the study.

  Elevation survey data showed that the slope and the test panel did not show any settlement. However, it is important that the slopes be properly compacted prior to the application of the dry cover.

7.0 RECOMMENDATIONS

Figure 10 shows the research approach used to evaluate the use of shotcrete as a dry cover. A number of additional issues remain to be addressed before this type of cover is used in large scale applications.

1. The effect of overburden placement and vegetation necessary for final reclamation must be evaluated. Overburden should be placed over a portion of the panel, and seeded with a ground cover and planted with native vegetation. Sections of this overburden would be removed and examined over time to determine if any degradation of the shotcrete panel had occurred.

2. This study did not evaluate the effectiveness of the cover in restricting acid generation in a waste rock pile. It is recommended that this shotcrete cover technology be applied in a controlled field test to determine if the cover would effectively restrict the infiltration of oxygen and water into the reactive waste rock.

3. The robot used showed that high productivity can be achieved. However, this robot was designed for tunnel work with the requirement of reaching overhead surfaces. Prolonged swinging of the arm laterally to cover large horizontal surfaces resulted in some mechanical breakdown. There is a need to develop a more versatile robotic spray boom which can manoeuvre on steep slopes using a jib, winch, and steel cable tether. In addition, the delivery system also has to be improved by increasing the pump size or increasing the delivery hose diameter to 75mm (versus a 62.5 mm diameter hose used for this project).

4. Using waste material (ie. tailings) to produce a cover has its advantages. The use of tailings in the shotcrete mix will greatly reduce the total material costs by avoiding the need to transport the aggregate from Campbell River to Myra Falls. However, low sulphur tailings may not be available at closure. An alternative to using tailings is to seek another local material (ie. rock) source. The crushing equipment at the mine could be used to produce the necessary aggregate.

5. Further work is required in the method of batching and placement of the shotcrete mix that includes tailings. An example of equipment improvement is the use of a pneumatic conveying machine such as the Aliva Duplo Type 262 as shown in Appendix D. This machine would be insensitive to aggregate gradations and could produce mixes with lower water/cement ratios thus increasing the strength and reducing the amount of shrinkage cracks. Another benefit of this machine is the ability to start and stop at will, since the conveying hose is cleaned within seconds of stopping the material flow into the rotor.

6. The long term success of the dry cover to control acid rock drainage greatly depends on the stability of the waste rock dump. Geotechnical studies are required to estimate any movement of the final design slope. Figure 11 provides a listing of the analysis necessary to determine settlement in the slope under static condition. In addition, movements due to dynamic loadings from seismic activity need to be estimated.

REFERENCES

BC Acid Mine Drainage Task Force, 1989. Draft Acid Rock Drainage Technical Guide Steffen Robertson Kirsten (BC) Inc. in association with Norecol Environmental Consultants and Gormely Process Engineering.

C.E. Jones and Associates Ltd., 1992. Decommissioning plan prepared for Westmin Resources Limited, Myra Falls Operations, Vancouver, BC.

Gerencher, E.H., D.E. Konasewich, J.Y. Wong, and R. van Dyk, 1991. The Use of Mine Tailings in Concrete Surface Covers to Control the Acid Mine Drainage in Waste Rock Dumps, Proceedings of the Second International Conference on the Abatement of Acidic Drainage, Volume 4, Montreal, PQ, September 16-18, 1991. p. 69-84.

Jones, C.E. and J.Y. Wong, 1994. Shotcrete as a Cementitious Cover for Acid Generating Waste Rock Piles, Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acid Drainage. Pittsburgh, Pennsylvania.

Langley, W.S. and D. Dibble, 1990. Field Trials of Shotcreting Polypropylene Fibre-Reinforced High Volume Fly Ash (ASTM Class F) Concrete. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Malhotra, V.M., G.G. Carrete, and A. Bilodeau, 1990. Fibre-Reinforced High-Volume Fly Ash Shotcrete for Controlling Aggressive Leachates from Exposed Rock Surfaces and Mine Tailings. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Malhotra, V.M., 1991. Fibre-Reinforced High-Volume Fly Ash Shotcrete for Controlling Aggressive Leachates from Exposed Rock Surfaces and Mine Tailings, Proceedings of the Second International Conference on the Abatement of Acidic Drainage, Volume 4, Montreal, PQ, September 16-18, 1991, p.505-514.

MEND, 1996. Mine Environment Neutral Drainage (MEND) Program Annual Report 1996, 207 pages.

MEND, 1994. Evaluation of Alternate Dry Covers for the Inhibition of Acid Mine Drainage from Tailings. MEND Project 2.20.1, March 1994.

Morgan, D.R. and N. McAskill, 1990. Evaluation of Polypropylene Fibre-Reinforced High-Volume Fly Ash Shotcrete. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Northwest Geochem, 1991. Shotcrete Application of Cementitious Sealant Materials for Acid Rock Drainage Control Final Report prepared for the BC Acid Mine Drainage Task Force, Victoria, BC

Northwest Geochem, 1990. Hydrological Assessment and Development of AMD Control Technology for Myra Falls Waste Rock. Final Report prepared for the BC Acid Mine Drainage Task Force, Victoria BC.

Powertech Labs, 1994. Evaluation of Shotcrete at B.C. Hydro Dams, Part A & B. Report prepared for B.C. Hydro, Civil Inspection Section. Surrey BC.

Seabrook, P.T., 1992. Shotcrete As An Economical Coating For Waste Piles. Paper presented at the Waste Management in the Cement Manufacturing Process Conference, Calgary, AB.

TABLE 1

Proportions of Shotcrete Used for Test Panel

Material	Primary Mix (kg/m^3)	Tailings mix (kg/m^3)
Type 10 cement	139	167
Class F flyash	217	174
Concrete sand	1815	
Coarse tailings		1500
Water*	138	260
Polypropylene fibres	4	4

* Water/cementitious ratio   Primary Mix: 0.38   Tailings Mix: 0.76

TABLE 2

Cost Breakdown of Shotcrete Application

Cost	Cdn $ per square metre
Cement	1.28
Fibres	1.88
Flyash	1.40
Aggregate (includes transportation)	7.10
Labour	3.30
Equipment	3.50
Total	18.46

TABLE 3

Compressive Strengths at 28 Days Cure

Panel	Sample	Breaking Load (kN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	A B C	76.50 73.50 73.50	16.8 16.1 16.1	16.3
2	A B C	30.75 34.5 36.75	6.6 7.2 7.4	7.1
3	A B C	36.75 37.50 36.00	8.1 8.2 7.9	8.1
4*	A B C	45.75 56.25 55.50	8.2 12.3 12.2	10.9
5*	A B C	59.25 60.00 60.75	13.0 13.2 13.3	13.1
6	A B C	35.25 37.50 35.25	7.7 8.2 7.7	7.9

* Tailings mix
Cylinder diameter = 75 mm
Cylinder length = 150 mm

TABLE 4

Compressive Strengths at 100 Days Cure

Panel	Sample	Breaking Load (kN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	A B C	88.5 78.0 85.5	20.6 18.1 19.9	19.5
2	A B C	42.8 34.5 44.3	10.0 8.0 10.3	9.4
3	A B C	50.3 48.8 51.0	11.7 11.3 11.9	11.6
4*	A B C	71 3 66.8 71.3	16.6 15.5 16.6	16.2
5*	A B C	96.0 90.0 84.8	22.3 20.9 19.7	21.0
6	A B C	49.5 51.8 53.3	11.5 12.0 12.4	12.0

* Tailings mix
Cylinder diameter = 75 mm
Cylinder length = 150 mm

TABLE 5

Compressive Strengths at 200 Days Cure

Panel	Sample	Breaking Load (kN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	A B	123.75 123.75	27.1 27.1	27.1
2	A B	48.8 45.8	10.7 10.0	10.4
3	A B	60.0 64.5	13.2 14.1	13.7
4*	A B	82.5 66.8	18.1 14.6	16.6
5*	A B	156.75 136.50	34.4 29.9	32.2
6	A B	51.0 54.0	11.2 11.8	11.5

* Tailings mix
Cylinder diameter = 75 mm
Cylinder length = 150 mm

TABLE 6

Compressive Strengths at 400 Days Cure

Panel	Sample	Breaking Load (kN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
1	A B	144.8 157.5	31.8 34.6	33.2
2	A B	105.8 114.8	23.2 25.2	24.2
3	A B	123.9 140.3	27.2 30.8	29.0
4*	A B	109.5 93.0	24.0 20.4	22.0
5*	A B	165.8 135.8	36.4 29.8	33.1
6	A B	116.3 130.5	25.5 28.8	27.2

* Tailings mix
Cylinder diameter = 75 mm
Cylinder length = 150 mm

TABLE 7

Compressive Strengths at 1000 Days Cure (Laboratory)

Panel	Sample	Breaking Load (kN)	Compressive Strength (MPa)
1	A	166.5	36.5
2	A	128.3	28.2
3	A	146.3	32.1
4*	A	82.5	18.1
5*	A	99.8	21.9
6	A	149.3	32.7

* Tailings mix
Cylinder diameter = 75 mm
Cylinder length = 150 mm
Note: Panels prepared in 1992 and stored at Powertech

TABLE 8

Compressive Strengths at 1000 Days Cure (Field)

Panel	Sample	Breaking Load (kN)	Length of Core (mm)	Compressive Strength (MPa)
1*	A	114.8	74	21.7
2	A	147.0	84	29.0
3	A	159.8	85	31.5
4	A			sample too thin
5	A	138.0	90	27.8

* Tailings mix
Cylinder diameter = 75 mm
Note: Panels cut from the field in 1995

TABLE 9

Results of Various Toughness Tests on Panels Prepared in 1992

PANEL	1	2	3	4*	5*	6
Peak Load (kN)	6.943	5.111	5.337	10.150	10.697	5.182
Flexural strength (MPa)	2.02	1.48	1.55	2.86	3.11	1.50
Deflection at first crack (mm)	0.33	0.28	0.25	0.28	0.28	0.18
Toughness Index I_5	2.0	2.7	2.5	1.4	1.4	1.6
Toughness Index I_{10}	3.7	5.0	4.8	2.5	2.2	2.7
Toughness Index I_{20}	6.8	8.6	8.3	4.4	3.6	5.2

* Tailings mix

Note: Samples cured for 90 days - outdoor exposure

TABLE 10

Results of Absorption Tests
on Panels Prepared in 1992
(Cured 400 Days)

Sample	Absorption, Boiled (%)	Unit Mass kg/m^3		Volume of Permeable Voids (%)
		Dried	SSD	
1	10.21	2104	2295	21.48
2	10.63	2114	2315	22.41
3	10.45	2134	2325	22.28
4*	14.34	2205	2505	31.53
5*	13.45	2245	2545	30.20
6	10.91	2104	2295	22.88

* Tailings mix
SSD = Saturated surface dried

TABLE 11

Results of Absorption Tests on Panels
Cut in Field in 1995
(Cured 1000 Days)

Sample	Absorption, Boiled (%)	Unit Mass kg/m^3		Volume of Permeable Voids (%)
		Dried	SSD	
1*	12.2	2240	2510	28.6
2	7.5	2160	2320	17.38
3	7.7	2120	2280	17.34
4	7.8	2240	2410	21.38
5	7.4	2120	2280	16.71

* Tailings mix
SSD = Saturated surface dried

TABLE 12

Results of Permeability Tests

Material	Sample	Permeability m/s
Primary mix	A	8.5×10^{-14}
Primary mix	B	6.1×10^{-14}
Tailings mix	A	4.7×10^{-10}
Tailings mix	B	3.3×10^{-10}

TABLE 13

Results of Infiltration Monitoring
in 1993 and 1994

Stand Pipe #	1994 Monitoring		1993 Monitoring	
	Water Depth (m)	Volume Bailed (ml)	Water Depth (m)	Volume Bailed (ml)
IF1	0.22	500	0.07	250
IF2	0.17	250	0.04	100
IF3	0.21	500	0.09	200
IF4	0.36	1000	0.13	250
IF5	0.29	OBSTRUCTED	0.13	OBSTRUCTED
IF6	0.09	700	0.14	500
IF7	0.24	600	0.26	100
IF8		200	0.2	500
IF9	0.0	0	0.0	0
IF10	0.23	850	N/A (a)	500
IF11	0.16	400	N/A (a)	500
IF12	0.14	400	0.05	0
IF13	0.43	500	N/A (a)	500

(a) accurate measurements of water depth could not be obtained due to technical problems with water level probe.

TABLE 14

Elevation and Net Change of Shotcrete Cover

Point	Elevation			Change		
	Oct-92	Mar-93	Mar-95	From Oct-92 to Mar-93	From Mar-93 to Mar-95	From Oct-92 to Mar-95
1	3430.444	3430.443	3430.440	-0.001	-0.003	-0.004
2	3430.498	3430.497	3430.490	-0.001	-0.007	-0.008
3	3430.536	3430.536	3430.530	0	-0.006	-0.006
4	3430.645	3430.647	3430.650	0.002	0.003	0.005
5	3430.639	3430.642	3430.640	0.003	-0.002	0.001
6	3430.573	3430.573	3430.570	0	-0.003	-0.003
7	3430.525	3430.532	3430.520	0.007	-0.012	-0.005
8	3430.471	3430.469	3430.450	-0.002	-0.019	-0.021
9	3430.414	3430.412	3430.410	-0.002	-0.002	-0.004
10	3430.285	3430.276	3430.280	-0.009	0.004	-0.005
11	3430.296	3430.296	3430.290	0	-0.006	-0.006
12	3430.389	3430.385	3430.390	-0.004	0.005	0.001
13	3430.452	3430.448	3430.450	-0.004	0.002	-0.002
14	3430.508	3430.504	3430.500	-0.004	-0.004	-0.008
15	3430.585	3430.594	3430.590	0.009	-0.004	0.005
16	3430.620	3430.619	3430.620	-0.001	0.001	0
17	3430.609	3430.609	3430.610	0	0.001	0.001
18	3430.592	3430.587	3430.600	-0.005	0.013	0.008
19	3430.415	3430.414	3430.420	-0.001	0.006	0.005
20	3430.405	3430.403	3430.410	-0.002	0.007	0.005
21	3430.481	3430.483	3430.490	0.002	0.007	0.009
22	3430.446	3430.444	3430.450	-0.002	0.006	0.004
23	3430.378	3430.379	3430.380	0.001	0.001	0.002
24	3430.338	3430.335	3430.340	-0.003	0.005	0.002
25	3430.251	3430.248	3430.250	-0.003	0.002	-0.001

Point	Elevation			Change		
	Oct-92	Mar-93	Mar-95	From Oct-92 to Mar-93	From Mar-93 to Mar-95	From Oct-92 to Mar-95
26	3430.144	3430.142	3430.140	-0.002	-0.002	-0.004
27	3430.118	3430.110	3430.110	-0.008	0	-0.008
28	3430.044	3430.040	3430.040	-0.004	0	-0.004
29	3430.075	3430.072	3430.070	-0.003	-0.002	-0.005
30	3430.185	3430.184	3430.190	-0.001	0.006	0.005
31	3430.245	3430.240	3430.240	-0.005	0	-0.005
32	3430.275	3430.280	3430.280	0.005	0	0.005
33	3430.362	3430.364	3430.370	0.002	0.006	0.008
34	3430.313	3430.313	3430.320	0	0.007	0.007
35	3430.295	3430.291	3430.300	-0.004	0.009	0.005
36	3430.298	3430.295	3430.300	-0.003	0.005	0.002
37	3430.069	3430.066	3430.070	-0.003	0.004	0.001
38	3429.944	3429.942	3429.950	-0.002	0.008	0.006
39	3429.646	3429.647	3429.650	0.001	0.003	0.004
40	3429.396	3429.397	3429.400	0.001	0.003	0.004
41	3429.023	3429.022	3429.030	-0.001	0.008	0.007
42	3429.822	3429.820	3429.830	-0.002	0.01	0.008
43	3428.776	3428.771	3428.780	-0.005	0.009	0.004
44	3429.148	3429.144	3429.150	-0.004	0.006	0.002
45	3429.435	3429.430	3429.440	-0.005	0.01	0.005
46	3427.858	3427.857	3427.860	-0.001	0.003	0.002
47	3427.508	3427.509	3427.520	0.001	0.011	0.012
48	3427.069	3427.071	3427.080	0.002	0.009	0.011
49	3426.908	3426.911	3426.910	0.003	-0.001	0.002
50	3426.932	3426.934	3426.940	0.002	0.006	0.008
51	3427.356	3427.357	3427.360	0.001	0.003	0.004
52	3427.690	3427.691	3427.700	0.001	0.009	0.01
53	3428.138	3428.137	3428.140	-0.001	0.003	0.002

Point	Elevation			Change		
	Oct-92	Mar-93	Mar-95	From Oct-92 to Mar-93	From Mar-93 to Mar-95	From Oct-92 to Mar-95
54	3428.254	3428.251	3428.260	-0.003	0.009	0.006
55	3426.072	3426.070	3426.080	-0.002	0.01	0.008
56	3425.918	3425.921	3425.930	0.003	0.009	0.012
57	3425.502	3425.501	3425.510	-0.001	0.009	0.008
58	3425.257	3425.255	3425.260	-0.002	0.005	0.003
59	3425.073	3425.074	3425.080	0.001	0.006	0.007
60	3424.991	3424.993	3424.990	0.002	-0.003	-0.001
61	3425.032	3425.033	3425.030	0.001	-0.003	-0.002
62	3425.571	3425.571	3425.580	0	0.009	0.009
63	3426.030	3426.030	3426.040	0	0.01	0.01
64	3424.033	3424.030	3424.040	-0.003	0.01	0.007
65	3423.674	3423.671	3423.680	-0.003	0.009	0.006
66	3423.285	3423.281	3423.290	-0.004	0.009	0.005
67	3423.161	3423.160	3423.170	-0.001	0.01	0.009
68	3423.120	3423.115	3423.120	-0.005	0.005	0
69	3423.252	3423.247	3423.260	-0.005	0.013	0.008
70	3423.505	3423.499	3423.510	-0.006	0.011	0.005
71	3423.777	3423.780	3423.780	0.003	0	0.003
72	3423.902	3423.902	3423.910	0	0.008	0.008
73	3421.726	3421.723	3421.730	-0.003	0.007	0.004
74	3421.760	3421.756	3421.760	-0.004	0.004	0
75	3421.687	3421.684	3421.690	-0.003	0.006	0.003
76	3421.425	3421.426	3421.430	0.001	0.004	0.005
77	3421.306	3421.304	3421.310	-0.002	0.006	0.004
78	3421.275	3421.271	3421.270	-0.004	-0.001	-0.005
79	3421.538	3421.537	3421.540	-0.001	0.003	0.002
80	3421.813	3421.809	3421.810	-0.004	0.001	-0.003
81	3422.109	3422.110	3422.110	0.001	0	0.001

Point	Elevation			Change		
	Oct-92	Mar-93	Mar-95	From Oct-92 to Mar-93	From Mar-93 to Mar-95	From Oct-92 to Mar-95
82	3420.349	3420.341	3420.350	-0.008	0.009	0.001
83	3420.353	3420.350	3420.350	-0.003	0	-0.003
84	3420.448	3420.439	3420.440	-0.009	0.001	-0.008
85	3420.496	3420.494	3420.500	-0.002	0.006	0.004
86	3420.524	3420.523	3420.520	-0.001	-0.003	-0.004
87	3420.685	3420.684	3420.690	-0.001	0.006	0.005
88	3420.752	3420.749	3420.750	-0.003	0.001	-0.002
89	3420.831	3420.826	3420.830	-0.005	0.004	-0.001
90	3420.786	3420.780	3420.790	-0.006	0.01	0.004

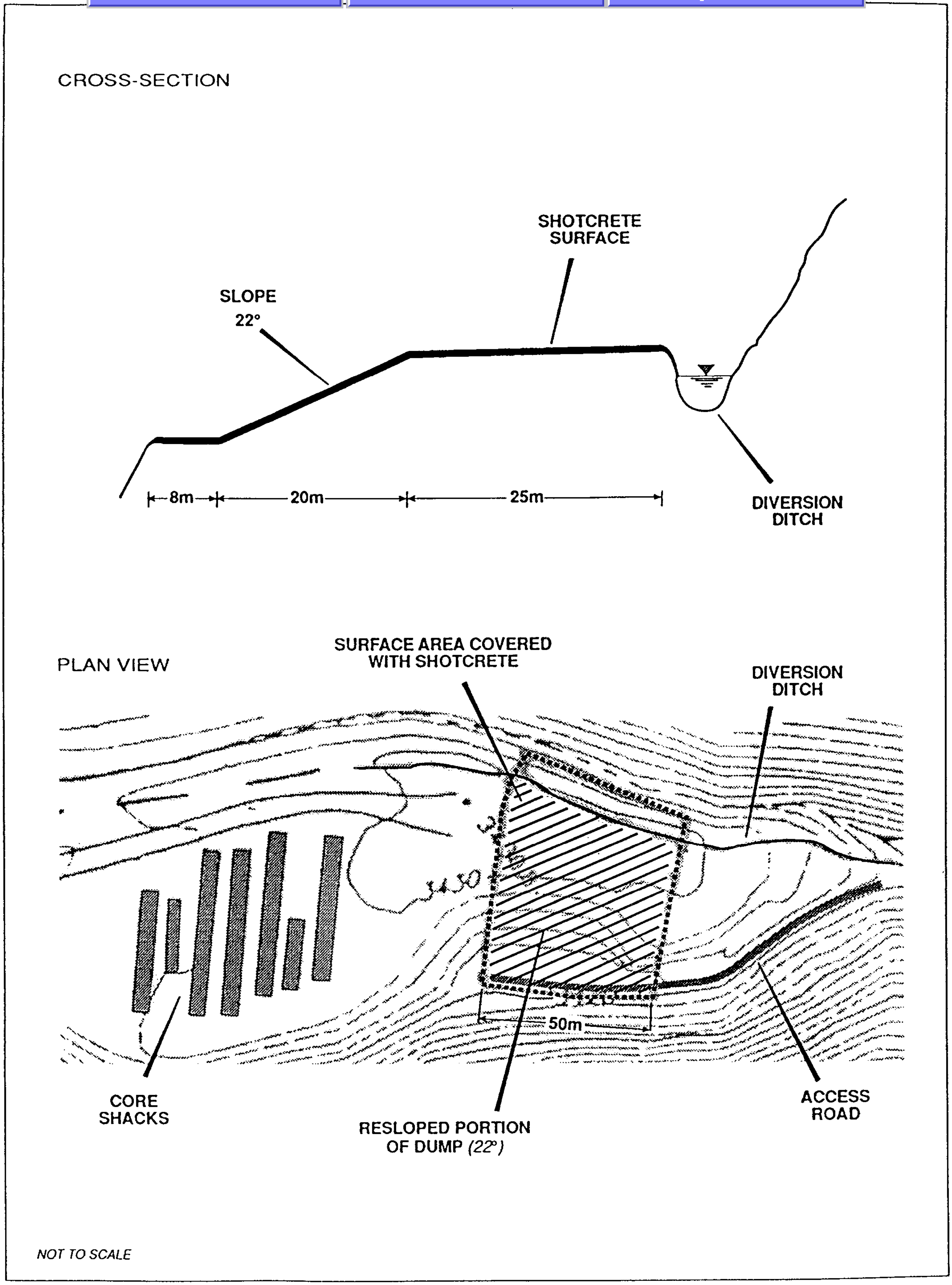


Figure 1. Schematic of large scale field application of shotcrete.

Description

The Robot 75 is the latest model in the Robot series of remotely controlled support arms for shotcreting nozzles. The unit is powered by an electric-hydraulic system. When placed on a 2800 chassis it can swivel approx. 180° about its mounting axis. (Further movement may be restricted by cables and the delivery hose). The portable remote control panel allows the operator to choose the best position from which to operate the Robot arm and nozzle.

Power requirement	3,7 kW
Portable remote control panel	24 V
Shipping dimensions	Length 5920 mm Breadth 950 mm Height 1950 mm Weight 940 kg

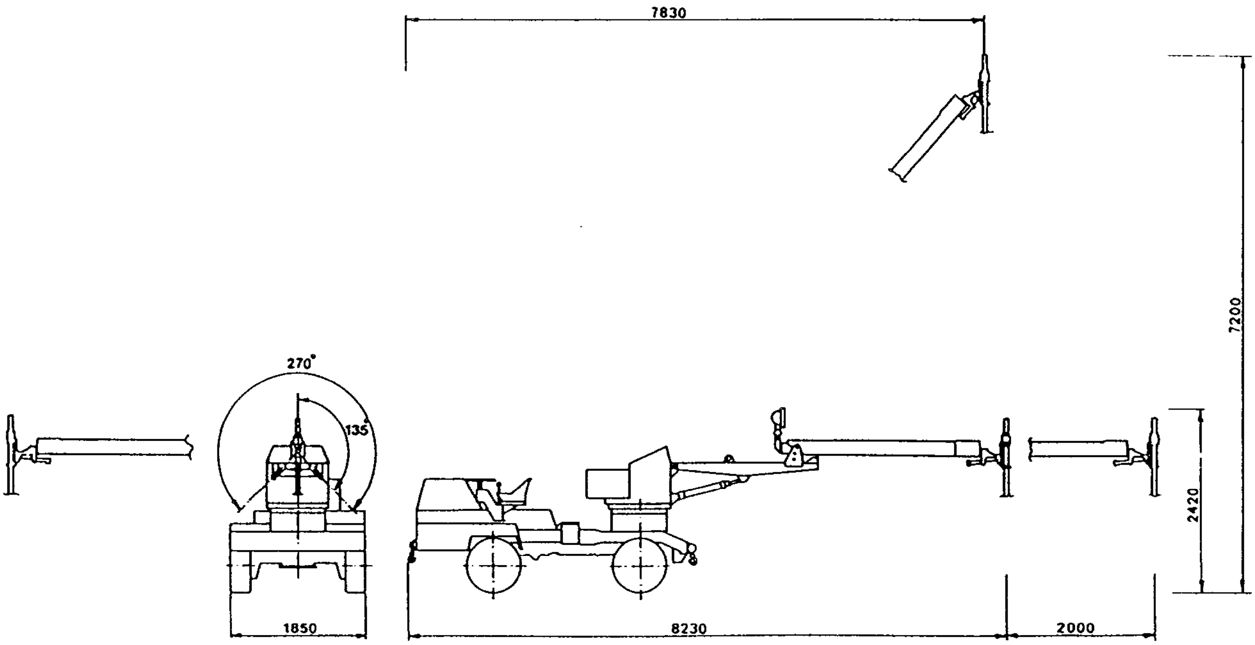
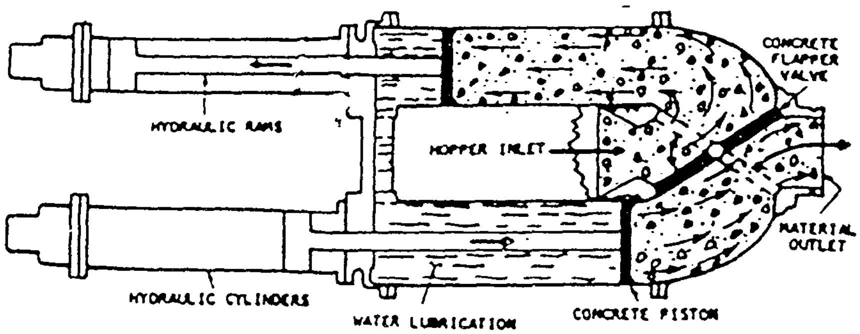
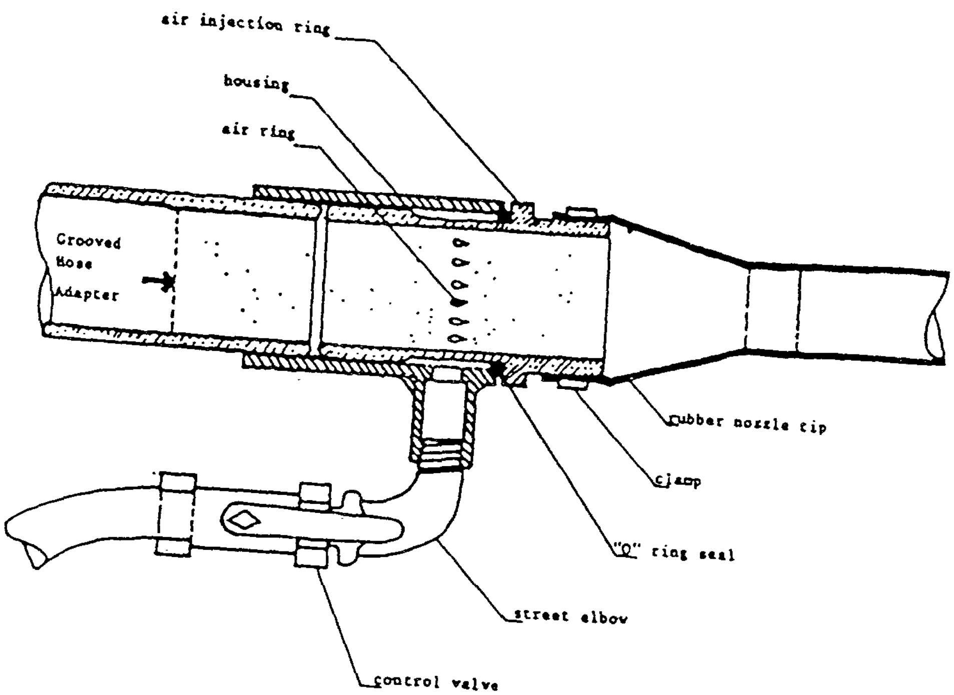


Figure 2 Schematic of robotic spray boom



Schematic of Pumping Equipment



Schematic of a Wet Mix Nozzle

Figure 3 Wet mix shotcrete equipment

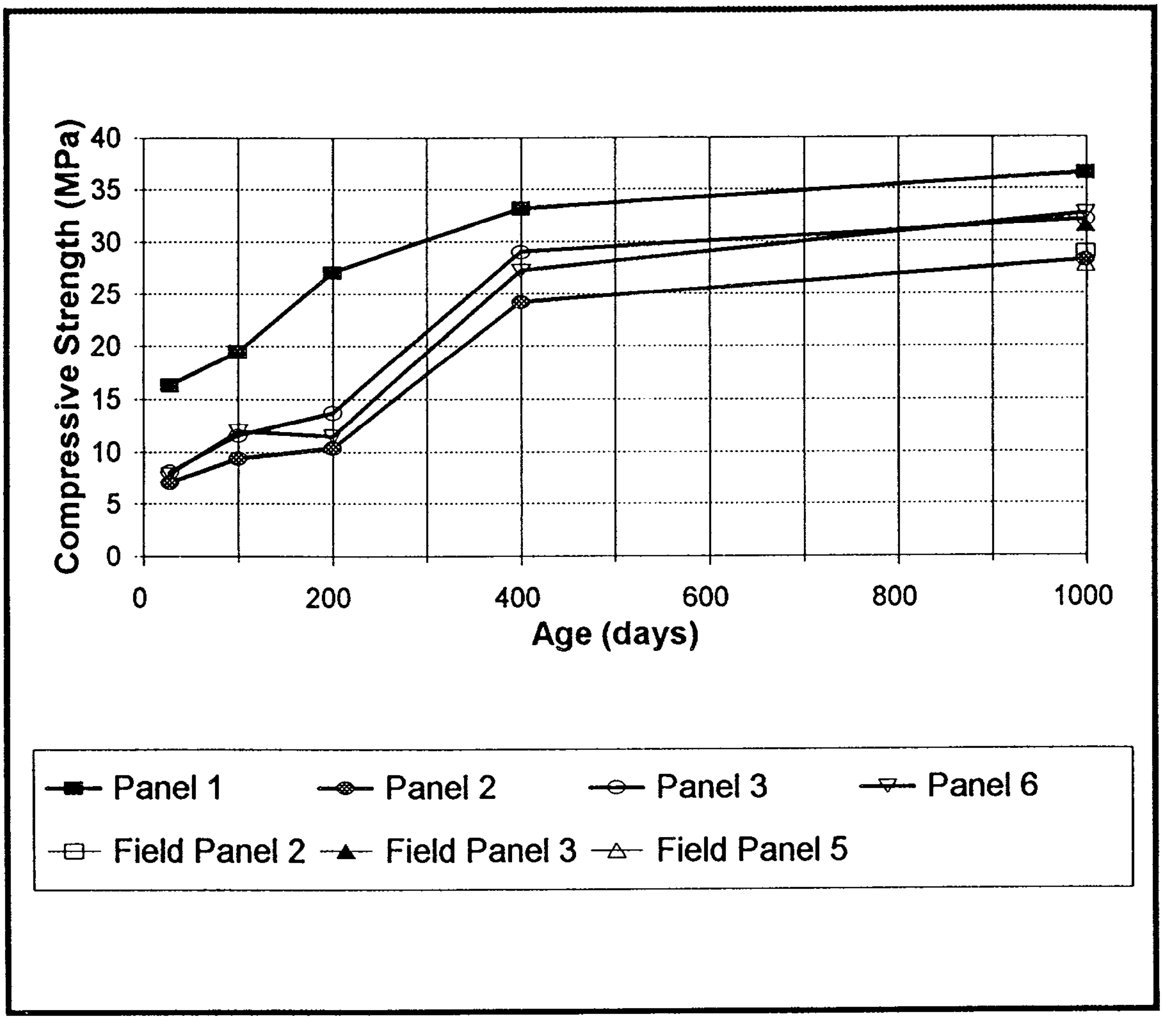


Figure 4 Compressive strength of shotcrete (primary mix)

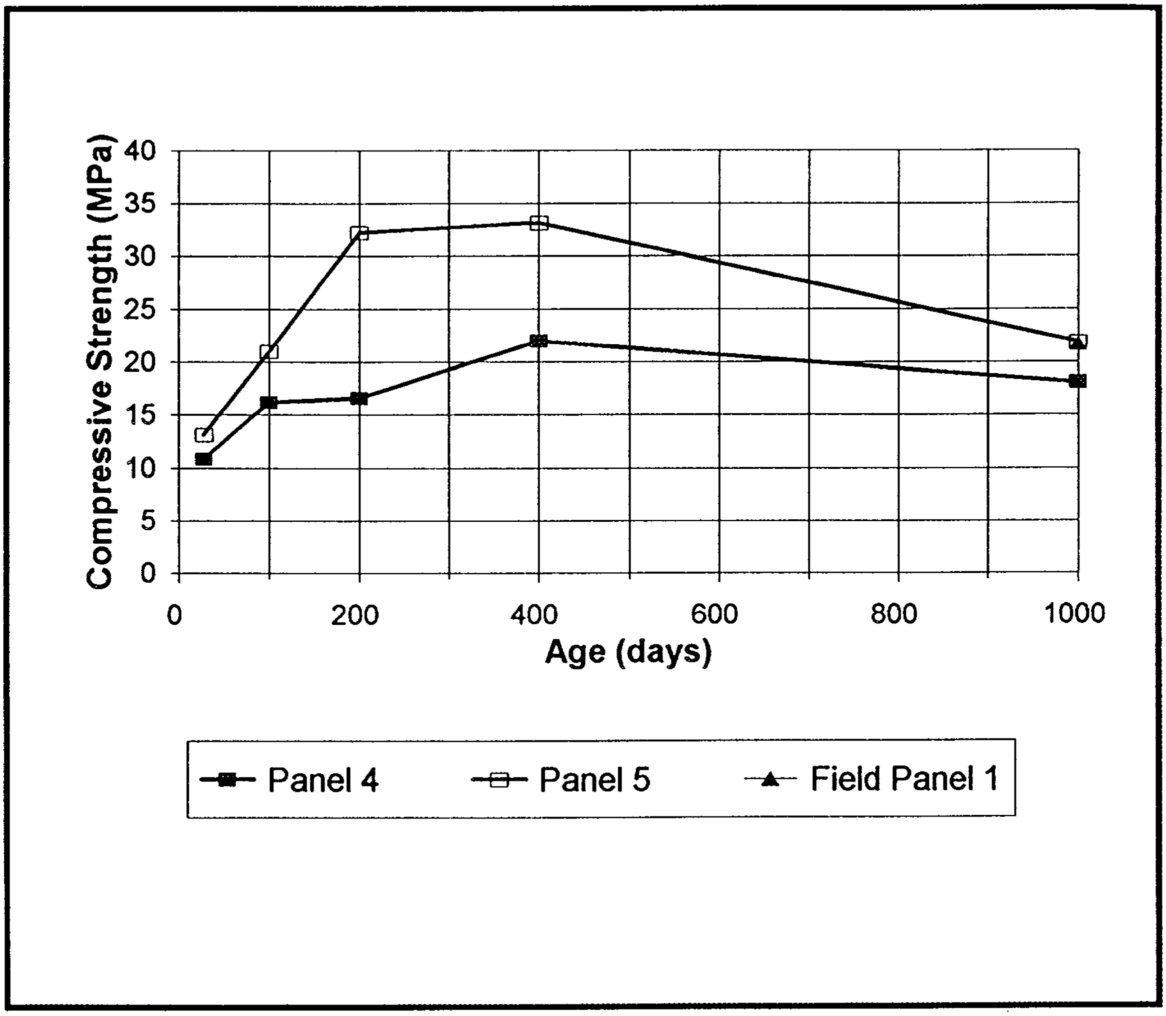
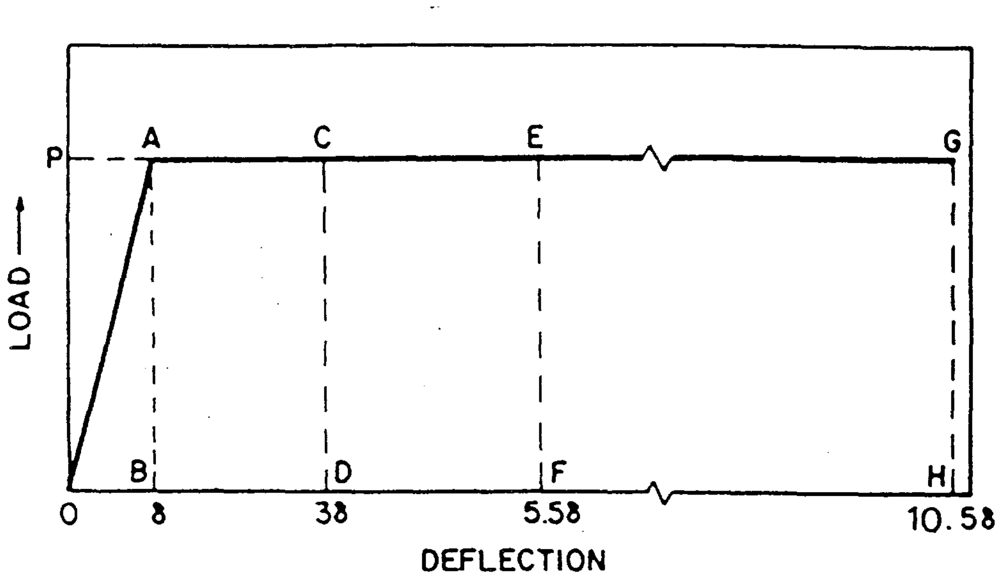


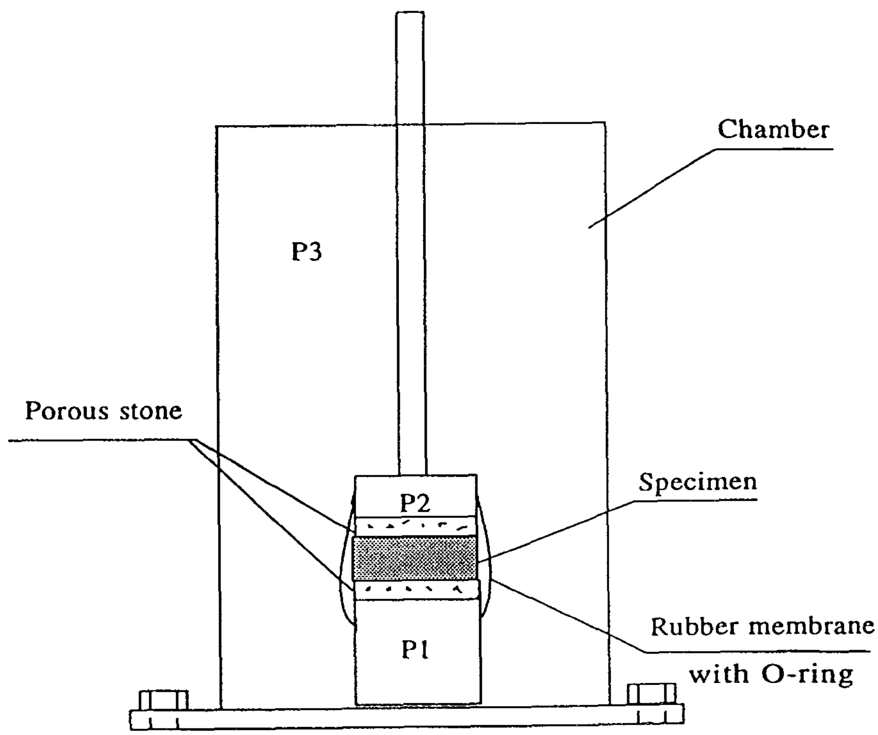
Figure 5 Compressive strength of shotcrete (tailings mix)



Area Basis[1]	Index Designation	Deflection Criterion	Values of toughness Indices		
			Plain Concrete	Elastic-Plastic Material	Observed Range for Fibrous Concrete
OACD	I_5	3δ	1.0	5.0	1 to 6
OAEF	I_{10}	5.5δ	1.0	10.0	1 to 12
OAGH	I_{20}	10.5δ	1.0	20.0	1 to 25

[1] Indices calculated by dividing this area by the area to the first crack OAB.

Figure 6 Definition of toughness indices in terms of multiples of first-crack deflection and elastic-plastic material behaviour



P1 = 300 kPa (43.5 psi)
P2 = 0 kPa (0 psi)
p3 = 350 kPa (50.8 psi)

Figure 7 Schematic of permeability testing apparatus

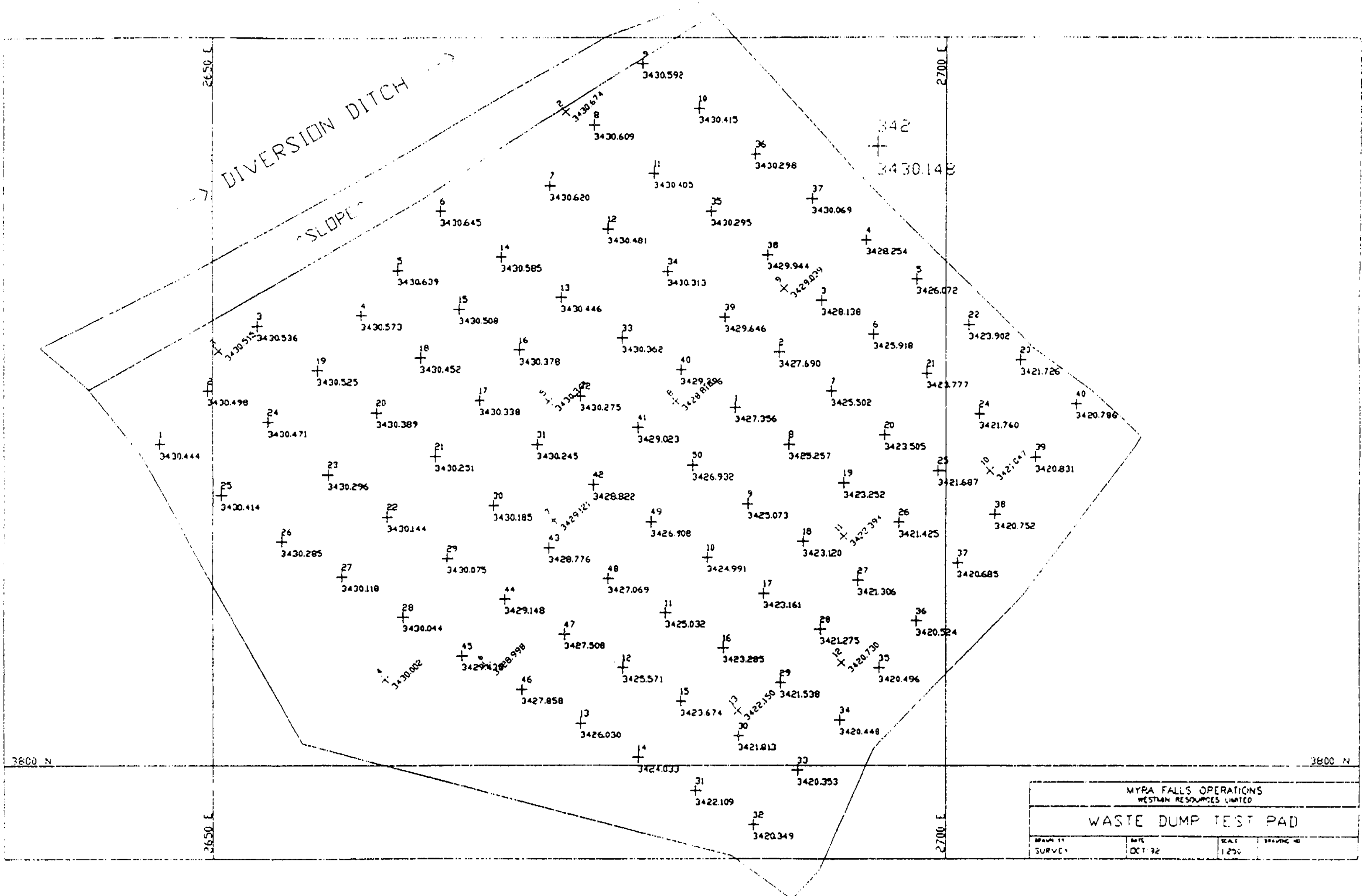


Figure 8 Location of survey markers on shotcrete test panel

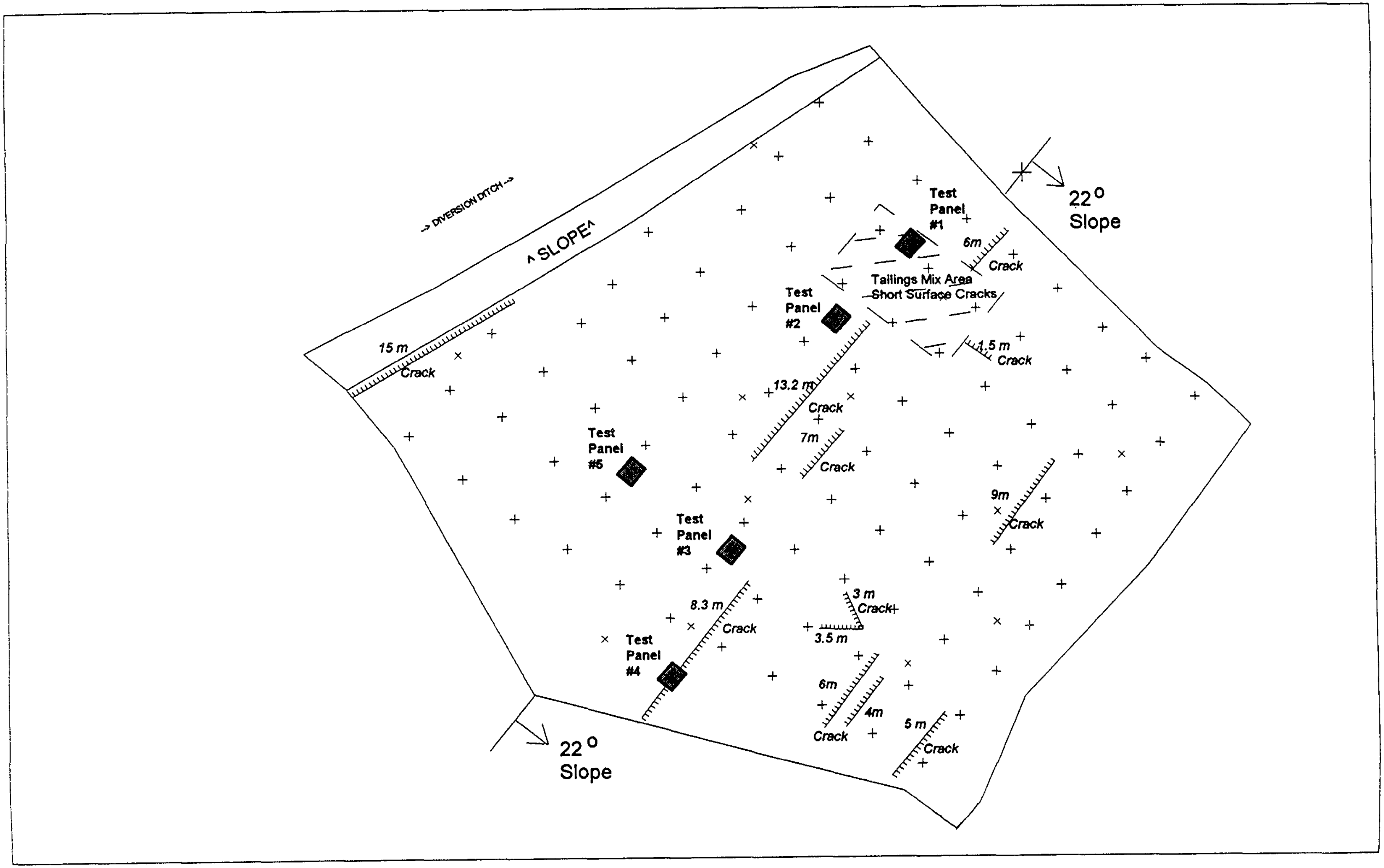


Figure 9 1995 Inspection: Locations of sample panels and cracks in shotcrete

Research Approach

- **Phase I**
  - Laboratory Solidification Study
- **Phase II**
  - Laboratory Shotcrete Study
- **Phase III**
  - Large Scale Shotcrete Applications
  - Field and Laboratory Inspections of Field Trial
- **Research Requirements**
  - Determine Effect of Overburden and Vegetation on Shotcrete
  - Controlled Test Piles to Evaluate Cover for ARD Control
  - Evaluate Waste Rock Slope Stability
  - Optimization of Shotcrete Equipment

Figure 10 Research approach for evaluation of dry cover

Static (e.g. water table, rain)

- Field Investigation (SPT or CPT)
- Lab Investigation (static triaxial)
- Slope Stability Analysis (Bishop, Morganstorn & Price)
- Factor of Safety

Dynamic (e.g. earthquake, vibration)

- Field Investigation (SPT or CPT)
- Lab Investigation (cyclic triaxial)
- Stability Analysis (soil stress; empirical calculation w/free face)
  - Factor of Safety
  - Maximum Displacement

Figure 11 Proposed slope stability analysis

Photo 1 Test section after slope preparation and compaction

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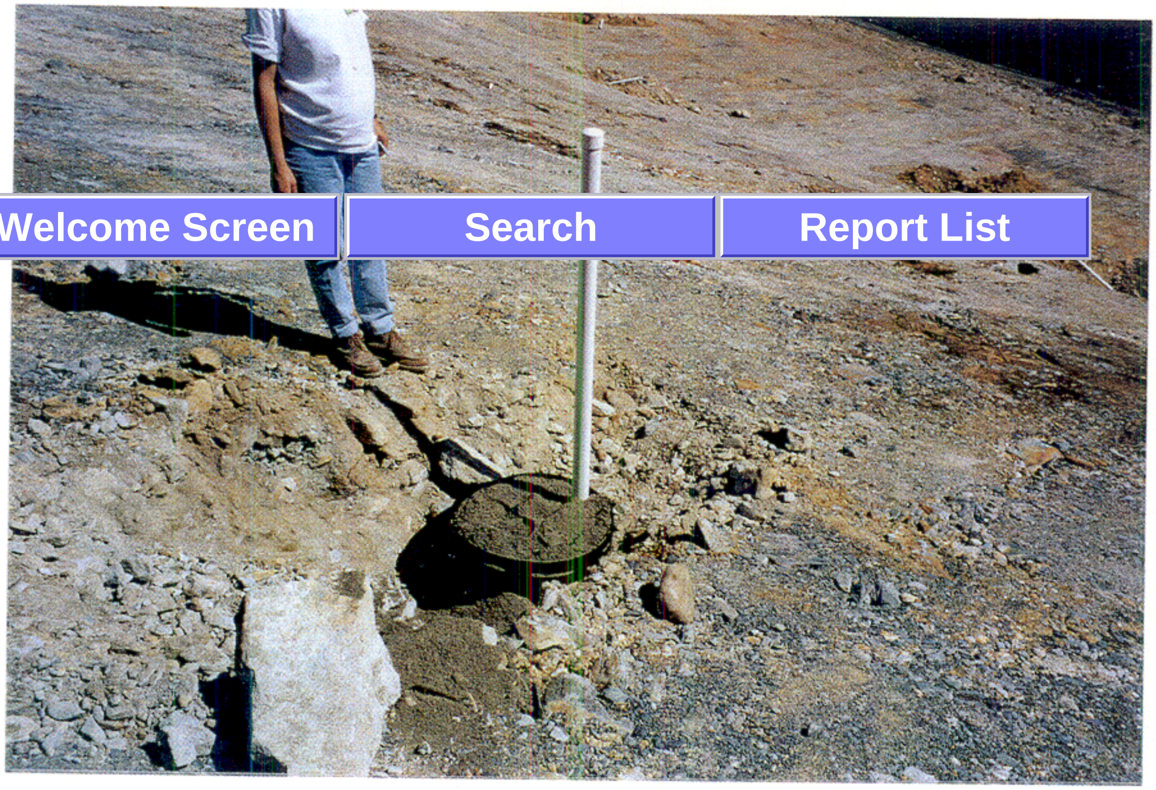

Photo 2 Infiltration boxes installed prior to shotcrete application

Photo 3 Robotic arm at full extension

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Photo 4 Water was sprayed on the waste dump before shotcreting

Photo 5 Cement was added to concrete trucks on site

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Photo 6 Robotic boom was swung side to side in sweeping motion and was slightly retracted after each sweep

Photo 7 Nozzle was held manually where the robotic arm could not reach or when the robot was not working

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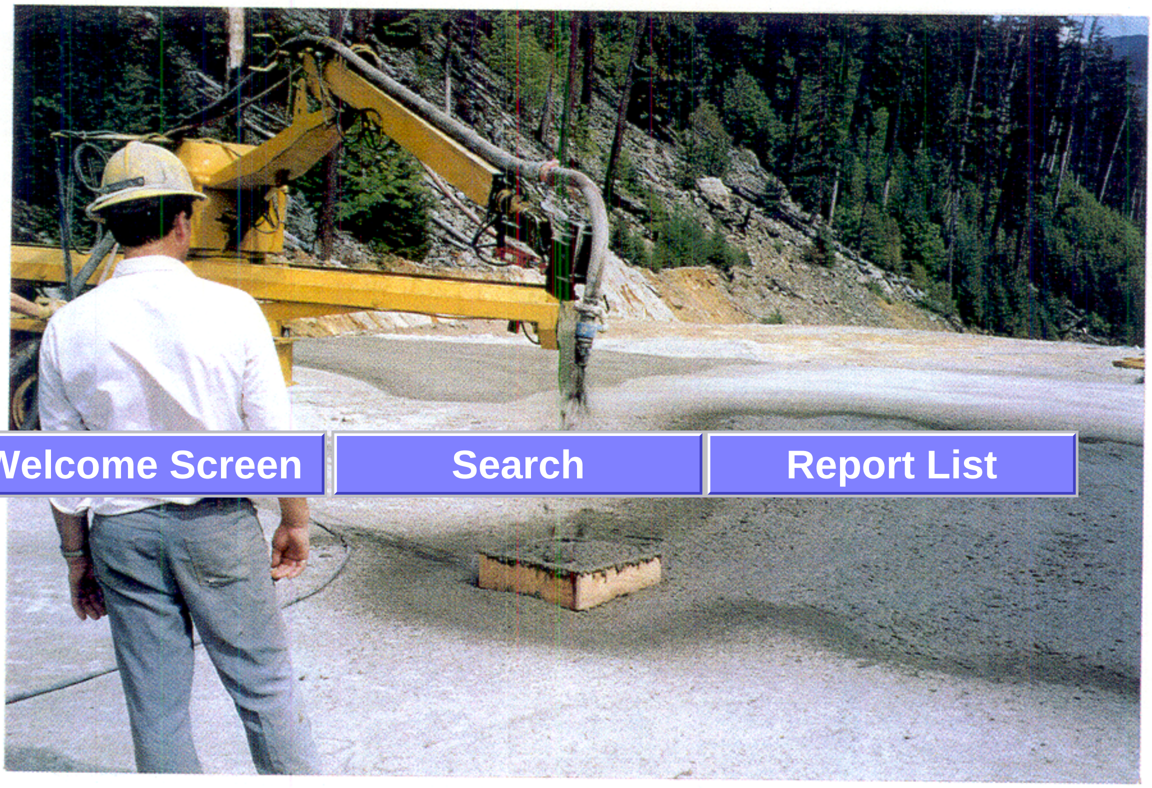

Photo 8 A panel was shotcreted for the laboratory test

Photo 9 A panel cut during 1995 inspection

Photo 10 Completed shotcrete test panel - August 1992

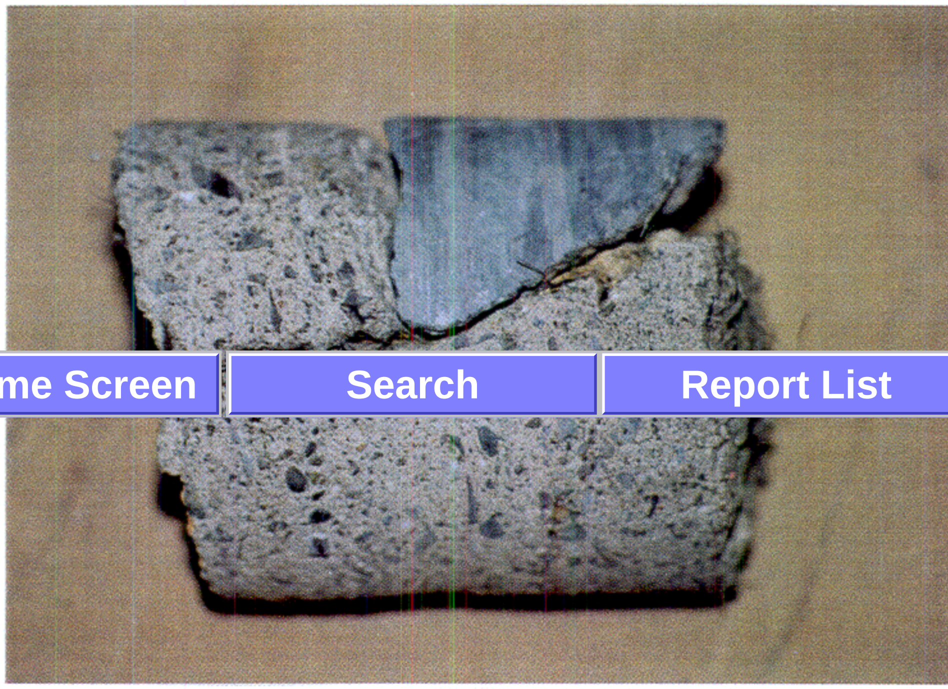

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Photo 11 A core drilled in November 1992, with a crack through the cover

Photo 12 A core drilled in November 1992, with a crack terminated in the cover

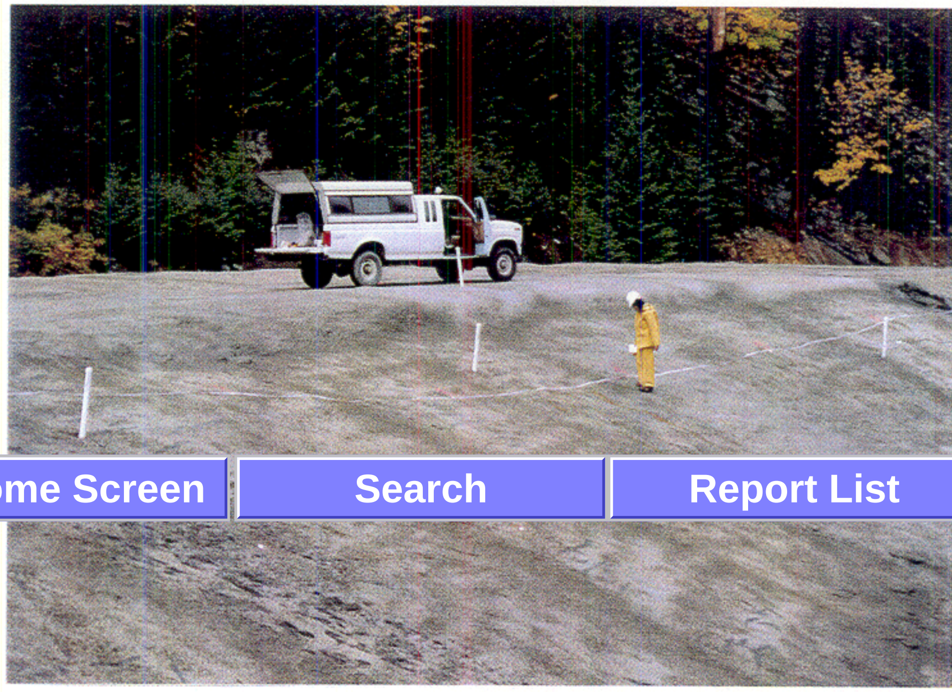

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Photo 13 Inspection of test panel, September 1993

Photo 14 Oxide staining was observed on some areas as a result of water flow from the waste rock dump through the shotcrete panel

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Photo 15 The shotcrete on the side of the diversion ditch as inspected in 1993

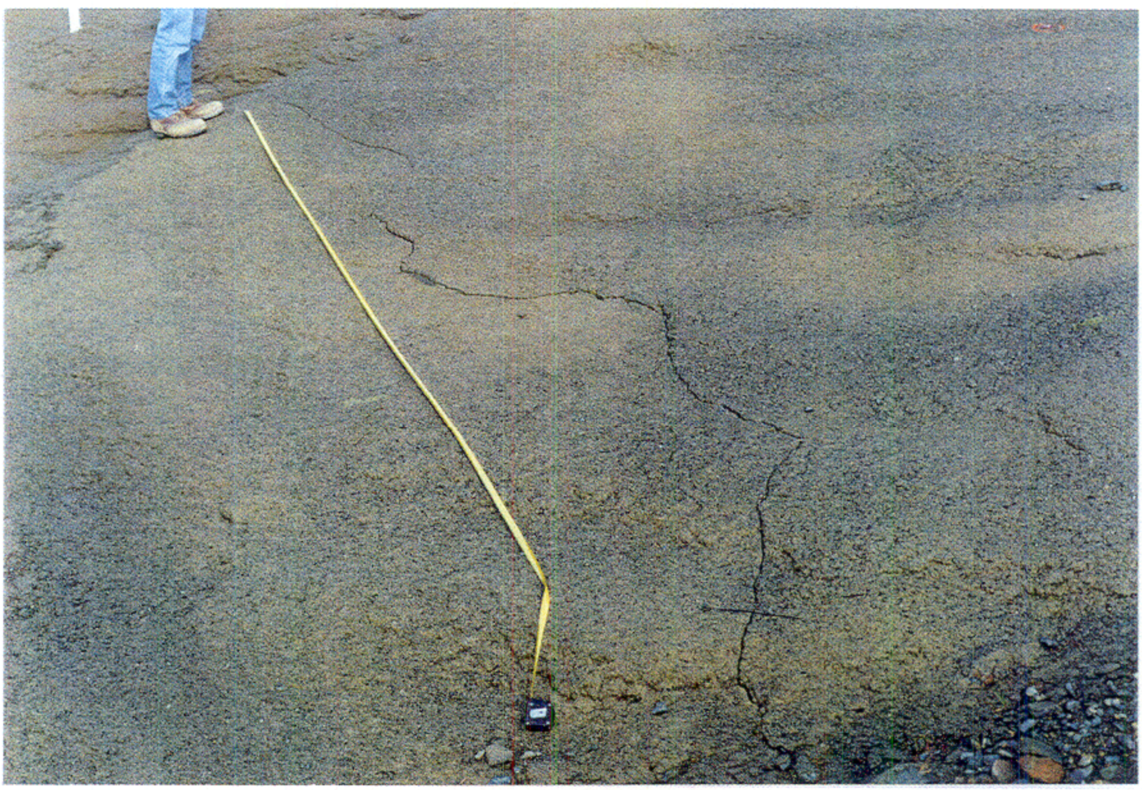

Photo 16 A 6m long crack located at between grid 37 and 54, as observed during 1995 inspection

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Photo 17 Vegetation and silt in few large cracks

Photo 18 The edge of the lower portion of the test panel showed signs of erosion

APPENDIX A

Reprint of Technical Paper Presented at the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acid Drainage. Pittsburgh, Pennsylvania 1994.

SHOTCRETE AS A CEMENTITIOUS COVER FOR ACID GENERATING WASTE ROCK PILES[1]

C.E. Jones[2] and J.Y. Wong[3]

Abstract: A research program supported by both Westmin Resources and the Canada-British Columbia Mineral Development Agreement (MDA) has evaluated the use of cementitious dry surface covers for the prevention of water and oxygen infiltration into acid-generating waste rock piles. This paper presents the results of a field trial of a dry cover over a large test area on a waste rock pile at the Westmin Myra Falls site near Campbell River, BC, Canada. The objectives of this study were to apply the cementitious cover in the most cost effective manner and to evaluate the material properties and the long-term efficacy of the cover system. Approximately 3,500 m^2 area was covered using the shotcrete process. A robotic arm mounted onto a vehicle was used to apply the shotcrete onto the rock slope. The cementitious material used in the project incorporated high volumes of fly ash (a waste product) to reduce the material cost. The shotcrete mix also included the use of polypropylene fibers to control cracks. Costs of materials and application of the cover were determined. The test area was instrumented with survey markers to monitor settlement in the rock slope. The performance of the test area was monitored for 1 yr to evaluate the durability of this cover when subjected to field conditions. Compressive strength increased over the 1 yr period, and all samples achieved or exceeded the design criteria. Some plastic shrinkage cracks were observed in the shotcrete immediately after application but after 1 yr of exposure these cracks did not appear to have expanded.

Introduction

The Westmin Resources Limited, Myra Falls Operations is a 3,650 mt/d copper-zinc-gold-silver mine located in a narrow steep valley in the central region of Vancouver Island, BC. The climate of the site is classed as Marine West Coast by the Koppen system, with a mean annual precipitation of approximately 300 cm, with over 75% of the total precipitation occurring between October and March. Most of the waste rock from the mining operations has been placed in dumps constructed along the north valley wall, east of the inactive open pit. The waste rock dumps contain sulfide minerals and have been generating acid drainage with elevated metal loadings, particularly zinc, copper, and cadmium, for at least a decade. A water collection and treatment system is presently in place to protect the downstream environment; however, reclamation of the waste rock dumps and the eventual decommissioning of the mine will require a long-term control method for acid generation and drainage at the mine site. Ideally the long-term control method should restrict the availability and contact of oxygen and water, the primary ingredients of the acid generation process, with the reactive waste rock.

The mine's decommissioning plan recommended that the closure strategy for the waste rock dump focus on preventing acidic water from moving downward to the water table (C.E. Jones and Associates Ltd. 1992). Restricting the access of oxygen and surface water infiltration to reactive waste rock can be achieved using covers and seals. The restriction of water can potentially reduce the formation of acid and the subsequent transportation of the oxidation products away from the source (BC Acid Mine Drainage Task Force, 1989). A variety of materials have been proposed to provide covers for reactive waste rock or tailings, including soils, synthetic membranes, compacted clay and till, asphalt, and concrete. The draft ARD (Acid Rock Drainage)

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[1]Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

[2]Carol E. Jones, Principal, Northwest Geochem, a division of C.E. Jones and Associates Ltd., Victoria, BC, Canada.

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Technical Guide (BC Acid Mine Drainage Task Force, 1989) and Malhotra (1991) discuss the relative advantages and disadvantages of the various types of covers.

A limiting factor governing the use of various materials proposed for use as covers is the cost associated with large-scale application (Malhotra et al. 1990). Conventional portland cement shotcrete is a well known technology for stabilizing vertical rock faces; however, this type of system becomes expensive for application on large areas where control joints, mesh reinforcement, and increased thickness are required.

Recent studies by CANMET and others (Morgan and McAskill 1990; Langley and Dibble 1990; Seabrook 1992) have shown that a fiber-reinforced, high-volume fly ash shotcrete can be used successfully in large-scale applications. The system incorporates discrete polypropylene fibers to increase toughness and inhibit cracking and uses large volumes of fly ash to lower material cost. A limited number of field trials have been conducted, but more data are required to determine the long-term effectiveness of the proposed capping systems.

Northwest Geochem, in conjunction with Powertech Labs Inc., has been researching, developing, and testing a cementitious cover that incorporates mine tailings. Laboratory trial mixes and limited small scale tests have indicated that there is great potential in this type of capping system (Gerencher et al. 1991). These trials also evaluated the effects of addition of fibers and fly ash to the shotcrete mix.

This paper presents the results of a large-scale test in which a shotcrete cover was applied to a portion of a waste rock dump. The primary objective of the test was to evaluate material properties and the long-term efficacy of the field-placed shotcrete. In addition, a large-scale test provides an opportunity to develop and use the best practicable technology to install a shotcrete cover material on reactive waste rock. This test site represents an open-ended system; therefore the effectiveness of large scale cover placement on restriction of acid generation and drainage was not evaluated, and detailed instrumentation to monitor ARD parameters was not installed.

Methods

Site Preparation

The shotcrete test was performed on an area of the waste rock dump which was not benched and had a slope between 37° and 39°. To facilitate this test, the upper 10 m of the dump was resloped to a grade of 22° (figure 1). After resloping, the test area was compacted using a vibrating Bomag roller. Although shotcrete can be applied to vertical slopes, the shallower grade was required for the use of the robotic arm shotcrete spraying equipment and subsequent placement of overburden and vegetation planned for the test area. An 8-m-wide access road was constructed at the base of the test slope. The approximate area of the test site was 3,500 m^2. The capping system was designed to connect with a diversion ditch that extends around the perimeter of the mine area.

Materials

One of the largest costs in using a cementitious dry cover is the transportation of raw materials such as aggregate and cement to the site. In a previous study by Northwest Geochem and Powertech (Gerencher et al. 1991), coarse mine tailings were used as an aggregate in the shotcrete mix and would eliminate the need to import aggregate from Campbell River (located 85 km from the mine site). That study indicated that mine tailings can be used effectively as aggregate in a cementitious dry cover. However, the coarse tailings are also used as mine backfill and may not be available for reclamation use. It is envisaged that during the final reclamation, the crushers at the mine will produce an aggregate to be used for shotcrete covers. The concrete can then be batched directly on site. For this field trial, it was not economical to set up a concrete batch plant on site. The proportioned aggregate along with the fly ash and water were trucked from Campbell River in

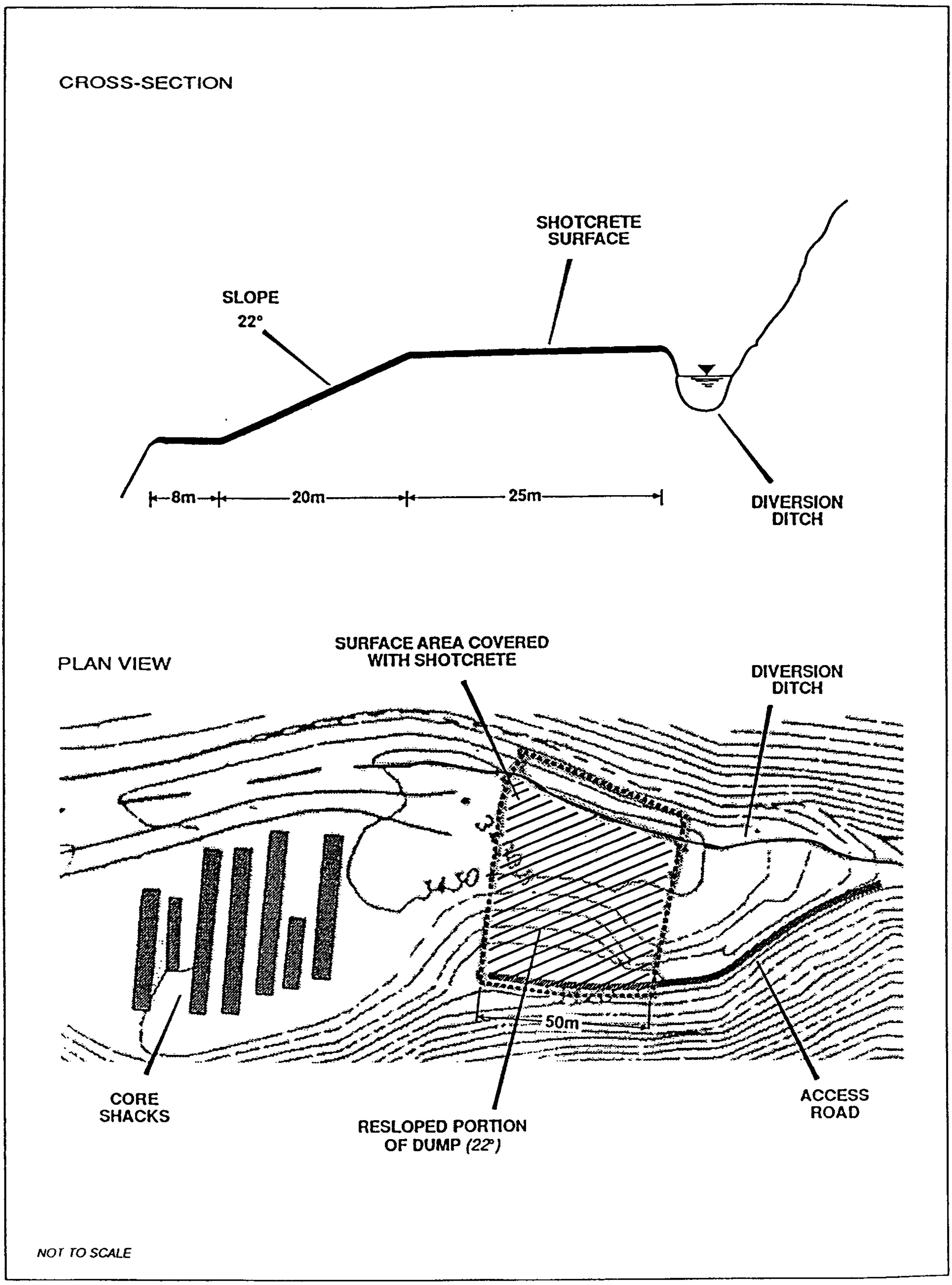


Figure 1. Schematic of large scale field application of shotcrete.

ready-mix trucks. Each truck contained 6 m^3 of aggregate. The cement was added to the truck on site. The mix proportions are given in table 1. The mix design was chosen with emphasis on optimizing the material costs. Since cement is an expensive material in a shotcrete mix, fly ash, a waste product from coal-fired power-generating plants, was used as a partial replacement for cement.

Approximately 100 m^2 of the test area were covered with a mix where coarse tailings were substituted for concrete sand (table 2). Since weighing facilities were not available on site, the tailings were added volumetrically, which resulted in a less accurate batch. The tailings did not blend well with the cementitious material and required a high water content to allow the mix to flow from the truck.

Equipment

Another major cost of this dry cover system is the application of the shotcrete. In Westmin's final closure plan, the approximate area required to be covered is 6 ha. Therefore it is imperative that equipment be used that can produce consistent quality shotcrete at very high production rates. The wet mix shotcrete in this project was applied using a robotic arm mounted on a rubber-wheeled carrier. The robotic arm is mounted on a turret with a 360° swing. The spray boom has a reach of 10.4 m. The shotcrete nozzle, attached to the end of the spray boom, is able to tilt 120° and has a rotation of 270°. The wet-mix concrete was pumped to the nozzle using a diesel-powered double-piston shotcrete pump through a 63.5-mm-diameter delivery hose. The arm is remotely controlled by an operator using a series of toggle controls.

Application of Shotcrete

The shotcrete was applied during August 1992. The crew consisted of one nozzleman, one helper, and one pumpman. The equipment did not require any major assembly and was mobilized in only a few hours.

The cement was added to the concrete trucks on site and was allowed to mix for at least 30 min. The concrete was then discharged into the hopper of the shotcrete pump. The pumpman controlled the amount of shotcrete supplied to the nozzle. The nozzleman controlled the shotcrete nozzle and the placement of the shotcrete onto the waste rock dump.

Table 1. Proportions for primary mix.

	kg/m^3
Type 10 cement	139
Fly ash	217
Concrete sand (<5 mm)	1,815
Water (water/cement ratio = 0.38)	138
Polypropylene fibers	4

Table 2. Proportions for tailings mix.

	kg/m^3
Type 10 cement	167
Fly ash	174
Tailings	1,500
Water (water/cement ratio = 0.76)	260
Polypropylene fibers	4

The common spraying sequence started with the boom fully extended at its maximum reach. The nozzle was usually positioned approximately 1 to 1.5 m from the surface. The boom was then swung side to side in a sweeping motion and was slightly retracted after each sweep. A nominal thickness of 75 mm of shotcrete was chosen for this test. Approximately 80 to 90 m^2 were covered without having to move the vehicle. Owing to the relatively smooth surface produced by the compaction of the waste rock, the thickness of the shotcrete cover was quite uniform.

The production rates achieved in this test program were higher than production rates achieved using conventional application methods. The entire test cover took approximately 5 days to install. The average rate achieved was 150 m^2/h. On some occasions production rates of 200 m^2/h were achieved. However, this type of equipment was originally designed for lining tunnels, and the movements of the boom are not suited for application on near-level grades. For example, the swinging motion of the arm resulted in wear on the clutch in the turret. Another improvement that would make the shotcrete application more efficient would be to use a smaller, more mobile vehicle that could easily traverse the shallow slopes.

There is potential to further enhance productivity by using a larger diameter delivery hose. For example, the use of a 75-mm-diameter delivery hose (versus the 63.5-mm hose used in this application) would increase production by at least 30%. The use of a larger hose would also reduce the plugging of the lines, which was a concern in this project.

Instrumentation

After the application of the shotcrete, a grid of survey markers was installed onto the cover at 5 m spacings and survey locations were determined.

Laboratory Testing

A number of laboratory tests were performed to characterize the quality of the shotcrete cover. Six shotcrete panels (1 m by 1 m by 150 mm) were prepared in the field for laboratory testing. Panels 4 and 5 were composed of the tailings mix; the others were shot from various batches of the primary mix.

Compressive strength tests were performed on cylinders 150 mm in diameter and 300 mm in length cored from the test panels at various stages of curing. The results of these tests are given in table 3 and illustrated in figure 2.

Table 3. Compressive strength of shotcrete (MPa).

	Age of cylinders			
	28 days	100 days	200 days	400 days
Panel 1	16.3	19.5	27.1	33.2
Panel 2	7.1	9.4	10.4	24.2
Panel 3	8.1	11.6	13.7	29.0
Panel 4 (tailings)	10.9	16.2	16.6	22.0
Panel 5 (tailings)	13.1	21.0	32.2	33.1
Panel 6	7.9	12.0	11.5	27.2

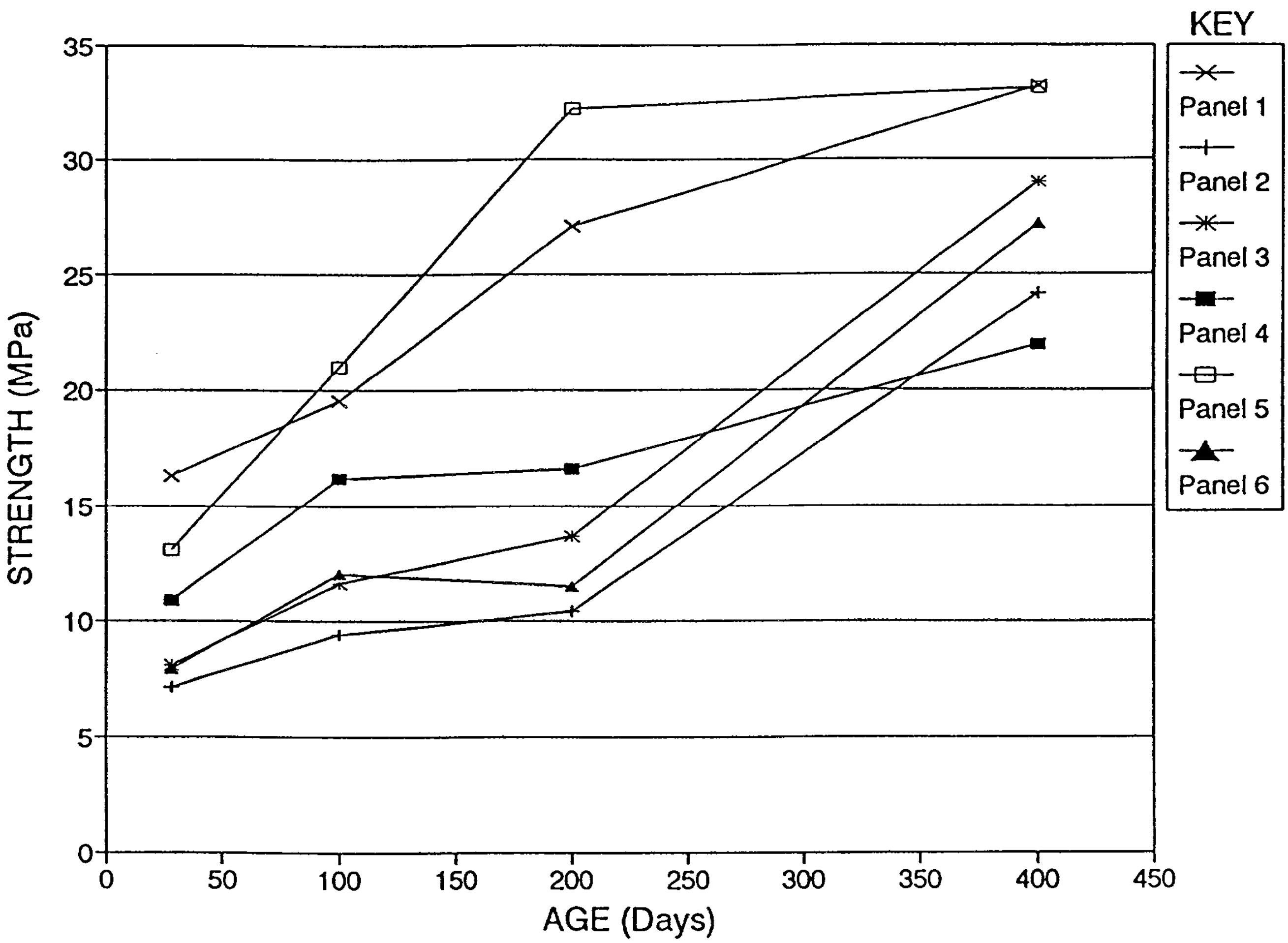


Figure 2. Compressive strength of shotcrete.

As a surface sealant, high-strength shotcrete is not required as long as it impedes infiltration of water and oxygen. The design objective was to achieve 15 to 20 MPa in compressive strength. After 400 days all of the panels achieved strength greater than the design objective. The strength gain was generally low over the first 200 days, during the winter period, but increased in the following 200 days during the warmer summer period. While all of the panels achieved the design objective for compressive strength, the values at 400 days range from 22.0 to 33.1 MPa. The inclusion of a superplasticizer would reduce this variability in the quality of the mix, but would increase the cost.

Concrete is typically a brittle material, exhibiting very low tensile strengths. Therefore, unreinforced concrete will tend to crack and separate following small deflections. Because the shotcrete material is designed for use as a surface sealant on a waste rock dump, the hardened concrete will require ductility to withstand local settlement within the waste slope. To evaluate the ductility of the test panels, toughness index tests were performed in accordance with ASTM C1018, Standard Test for Flexural Toughness and First-Crack Strength of Fiber Reinforced Concrete (Using Beam with Third Point Loading). Beams (100 mm by 100 mm by 350 mm) were cut from the shotcrete panels for flexural testing at 100 days' cure. Toughness of the shotcrete is defined as the total energy absorbed prior to complete separation of the specimen. This energy can be measured by calculating the area under the load deflection curve in flexure. The toughness in plain concrete is quite low and failure of the specimen usually occurs when the first crack develops. When fibers are present, the cracks cannot extend without stretching or debonding the fibers. As a result, considerable additional energy is required before complete fracture of the material occurs. The toughness index is defined as the ratio of the absorbed energy at various crack widths as compared to the absorbed energy when the first crack occurs. The results of the flexural tests (table 4) are variable, but the values are generally lower than the desired toughness indices of $I_5>3$ and $I_{10}>6$. These low values are not unexpected since a low fiber content (4 kg/m^3) was used to reduce the cost of the product. The field performance will be monitored to evaluate if this fiber content is adequate for this application.

Monitoring Program

No movement of the shotcrete cap was detected when the survey markers were remeasured in March 1993. A visual assessment was carried out in September 1993, and the overall durability performance of the cap was good. There was no evidence of major cracking or movement in the cap. The shotcrete did not appear to have suffered any frost damage or erosion. Some minor cracks were observed in two small areas where the shotcrete was thinner than the 75-mm standard depth. Iron staining was observed on these areas as a result of water flow from the waste rock dump through the shotcrete panel. The source of this flow is not certain, but it would appear to be lateral movement of water through the dump. The dump material is composed of a high percentage of fine particles and therefore retains moisture near the surface. Some plastic shrinkage cracks were observed in the shotcrete immediately after application. The primary cause of these cracks was the high rate of evaporation before initial set. In November 1992, cores were taken through a number of these cracks; some were found to extend through the cap, and others terminated approximately halfway through the cap. After 1 yr of exposure, these cracks did not appear to have expanded.

Cost of Shotcrete Cover

A major consideration in the design of the testing program was cost. Table 5 provides a breakdown of the cost of the project. It is apparent that the transportation of aggregate to the mine site is a substantial cost of the cover. If a local aggregate source, such as coarse tailing, were available, the unit cost per square meter of cover could be less than Cdn $12.

Table 4. Toughness tests of shotcrete at 100 days' cure.

	Primary mix	Tailings mix
Flexural strength MPa	1.5 - 2.0	2.9 - 3.1
Ductility:		
Toughness index I_5	1.6 - 2.7	1.4
Toughness index I_{10}	2.7 - 5	2.2 - 2.5

Table 5. Cost breakdown of shotcrete application.

	Cdn $/m^2
Cement	1.28
Fibers	1.88
Fly ash	1.40
Aggregate (includes transportation)	7.10
Labor	3.30
Equipment	3.50
Total	18.46

Conclusions

This study indicates that shotcrete dry covers can be a viable option for sealing prepared waste rock dumps. Prior to shotcrete application, the surface of the dump must be stabilized through resloping and surface compaction. The application using a robotic spray boom resulted in high productivity and therefore contributed to a low application cost. A major proportion of the cost involved the importation of aggregate. The use of a local aggregate source such as mine tailings would make this option more cost effective when compared to other types of covers. The shotcrete material exhibited good compressive strength and moderate ductility. One year after application the cover was intact and functioning well.

This study did not evaluate the effectiveness of the cover in restricting acid generation in a waste rock pile. It is recommended that this cover technology be applied in a controlled field trial on a designed waste rock test pile to evaluate its effectiveness in restricting the access of oxygen and surface water infiltration to reactive waste rock.

Literature Cited

BC Acid Mine Drainage Task Force. 1989. Draft acid rock drainage technical guide. Prepared by Steffen Robertson Kirsten (BC) Inc. in association with Norecol Environmental Consultants and Gormely Process Engineering.

C.E. Jones and Associates Ltd. 1992. Decommissioning plan prepared for Westmin Resources Limited, Myra Falls Operations, Vancouver, BC.

Gerencher, E.H., D.E. Konasewich, J.Y. Wong, and R. van Dyk. 1991. The use of mine tailings in concrete surface covers to control acid mine drainage in waste rock dumps. p. 69-84. In Second International Conference on the Abatement of Acidic Drainage, Volume 4. (Montreal, PQ, September 16-18, 1991).

Langley, W.S. and D. Dibble. 1990. Field trials of shotcreting polypropylene fiber-reinforced high-volume fly ash (ASTM Class F) concrete. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Malhotra, V.M. 1991. Fiber-reinforced high-volume fly ash shotcrete for controlling aggressive leachates from exposed rock surfaces and mine tailings. p. 505-514. In Second International Conference on the Abatement of Acidic Drainage, Volume 1. (Montreal, PQ, September 16-18, 1991).

Malhotra, V.M., G.G. Carette, and A. Bilodeau. 1990. Fiber-reinforced high-volume fly ash shotcrete for controlling aggressive leachates from exposed rock surfaces and mine tailings. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Morgan, D.R. and N. McAskill. 1990. Evaluation of polypropylene fiber-reinforced high-volume fly ash shotcrete. Paper presented at the CANMET International Workshop on Fly Ash in Concrete, Calgary, AB.

Seabrook, P.T. 1992. Shotcrete as an economical coating for waste piles. Paper presented at the Waste Management in the Cement Manufacturing Process Conference, Calgary, AB.

APPENDIX B

Specifications for Shotcrete Testing

WESTMIN RESOURCES LIMITED

SHOTCRETE TEST PROGRAM

SPECIFICATIONS FOR SHOTCRETE FIELD TRIAL

AUGUST 1992

Prepared by:
NORTHWEST GEOCHEM
POWERTECH LABS

TABLE OF CONTENTS

		Page
1.0	PROJECT DESCRIPTION	1
2.0	SUMMARY OF WORK	1
3.0	PROJECT RESPONSIBILITY AND REPRESENTATIVES	1
	3.1 Project Responsibility	1
	3.2 Representatives	2
4.0	MATERIALS	2
	4.1 Conventional Concrete	2
	4.2 Concrete using Mine Tailings	2
	4.3 Reinforcement	2
5.0	EXECUTION	3
	5.1 Mobilization	3
	5.2 Site Preparation	3
	5.3 Batching of Concrete	3
	5.4 Shotcreting	3
	5.5 Testing	3
6.0	SAFETY	4
7.0	SCHEDULE	4

1.0 PROJECT DESCRIPTION

Westmin Resources Limited is conducting a test program to study the use of shotcrete as a capping system for the control of acid rock drainage. The field test will be performed at the Mira Falls mine site. A shotcrete cover will be installed over a portion of the waste rock dump. The test will evaluate material properties and the long term efficacy of the cover system. The bulk of the test area will be covered with a conventional shotcrete mix. A smaller area will be sprayed with a concrete which incorporates mine tailings as aggregates. The Contractor is expected to install the shotcrete cover.

2.0 SUMMARY OF WORK

The work to be performed by the contractor is summarized as follows:

- supply labour and materials for batching concrete
- supply labour and equipment for spraying shotcrete
- supply all shotcrete material
- mobilization of equipment, materials, and labour
- apply shotcrete cover
- demobilization

3.0 PROJECT RESPONSIBILITY AND REPRESENTATIVES

3.1 Project Responsibility

The project manager for the test program will be Carol Jones of Northwest Geochem and will have overall responsibility for the management of the project.

The engineering design and quality control of the shotcrete will be the responsibility of Joe Wong from Powertech Labs.

Eva Gerencher from Envirochem Services will assume responsibility for design and implementation of the water monitoring for the test area.

Rudy Van Dyk from Westmin Resources will be responsible for coordinating the activities on site.

3.2 Representatives

Project Manager - Carol Jones, Geochem
Engineer - Joe Wong, Powertech Labs
Contractor - Georg Nickel, Terracrete Systems Limited
Westmin's representative - Rudy van Dyk

4.0 MATERIALS

4.1 Conventional Concrete

4.1.1 Concrete, concrete materials, and methods of construction shall conform to CAN 3-A23.1.

4.1.2 Cementitious material shall be a minimum of 350 kg per cubic metre of shotcrete.

4.1.3 The cementitious material shall consist of 60 % by weight of flyash and 40 % by weight of cement.

4.1.4 The maximum water/cement ratio shall be 0.38.

4.1.5 The "conventional" aggregate shall comply with ASTM C33. The gradation of the aggregate shall conform with the gradation No. 1 as outlined in table 2.1 the ACI 506R-85 "Guide to Shotcrete".

4.1.6 The air content of the concrete shall be between 4%-8%.

4.2 Concrete Using Mine Tailings

The concrete which incorporates the use of mine tailings shall have the same specifications as the concrete outlined in 4.1 except for that the aggregate will be replaced with mine tailings. The Engineer shall direct the contractor as to the usage of mine tailings.

4.3 Reinforcement

Polypropylene fibres 38 mm long shall be usage as reinforcement at a dosage of 4 kg/cubic metre of concrete.

5.0 EXECUTION

5.1 Mobilization

The contractor is responsible for mobilizing all materials, equipment, and labour. The contractor shall arrange for all permits required for the transportation of materials and equipment, and other permits as may be required for the work.

5.2 Site Preparation

The test site will be graded and compacted by Westmin Resources. The size of the test panel, shown in figure 1, is approximately 50 m x 70 m.

The contractor shall perform any necessary final surface preparation and compaction prior to shotcreting.

A 2000 gal water truck is available at the mine site. The contractor is to supply pumping facilities to spray the water onto the test site.

5.3 Batching of Concrete

The contractor is responsible for batching all concrete required for the job. Mixing of the cement to water and the addition of the polypropylene fibres shall be performed on site.

5.4 Shotcreting

Shotcrete shall be applied to the waste rock dump test site using the "wet mix" method. An area 50 m x 70 m will be covered using shotcrete with a nominal thickness of 75 mm.

The shotcrete shall be applied using a robotic spraying arm mounted on an articulated Dux carrier. The equipment shall be capable of traversing a slope of approximately 22 degrees.

5.5 Testing

Quality control testing of the batched concrete shall be performed by Powertech. The frequency of sampling for air content, slump, and strength shall be as directed by the engineer.

The contractor shall supply shotcrete panels for testing. The test panels shall not be smaller than 750 mm x 750 mm. The minimum thickness for the panels is 75 mm. A shotcrete panel shall be produced for every 30 cubic metres of shotcrete sprayed.

6.0 SAFETY

The contractor shall be responsible for the safe performance of the all the work and the safety of all and the safety of all the persons engaged in the work and shall comply with all the safety regulations issued by Westmin's representative for the site and with all the regulations of the Worker Compensation Act. The contractor shall take all reasonable steps to ensure that no person is injured, that no property is damaged or lost and that no rights are infringed due to the performance of the work.

7.0 SCHEDULE

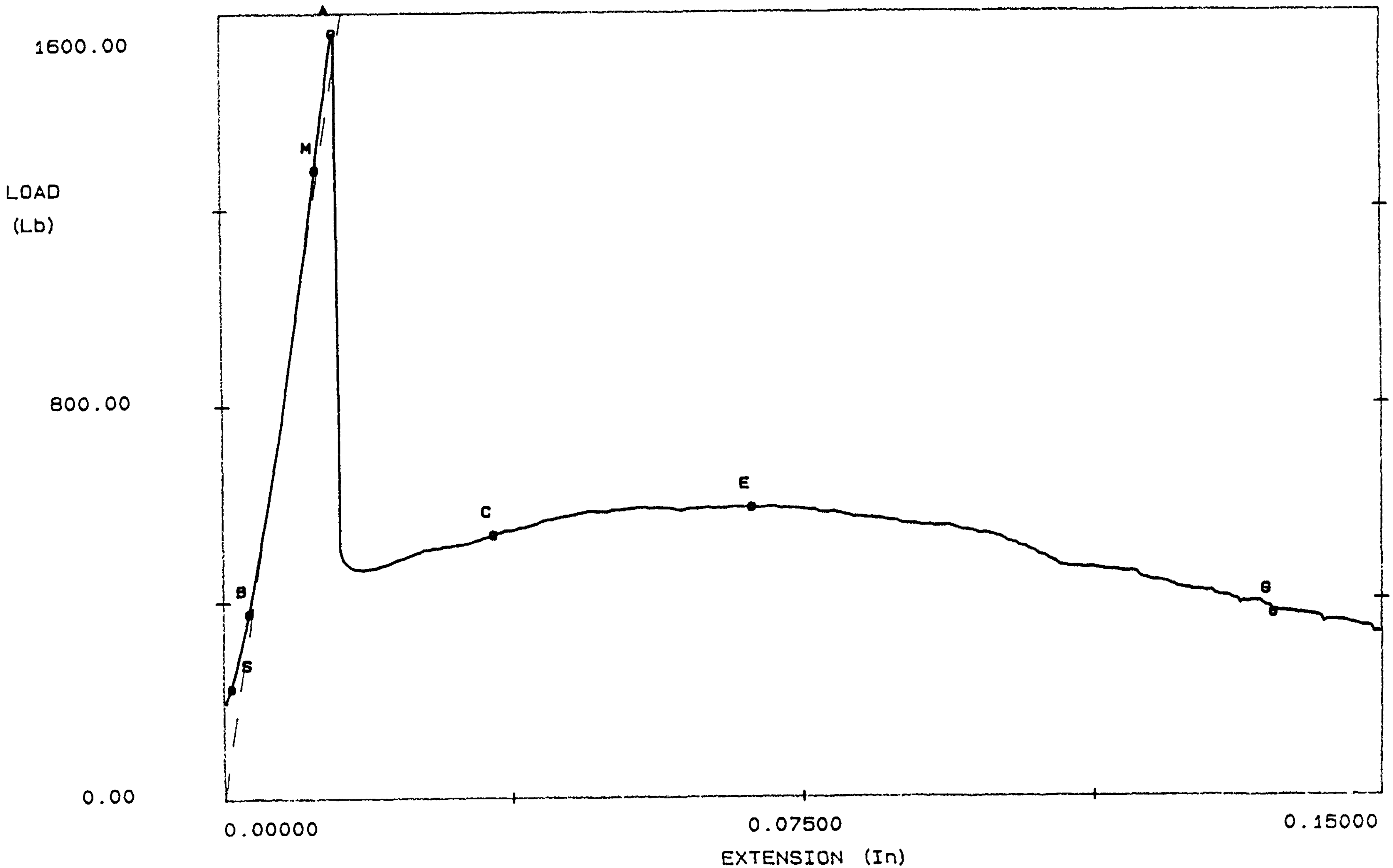
The work on site shall commence on August 17, 1992 and shall be completed before August 28, 1992.

JYW/dmd
wp51:R/173

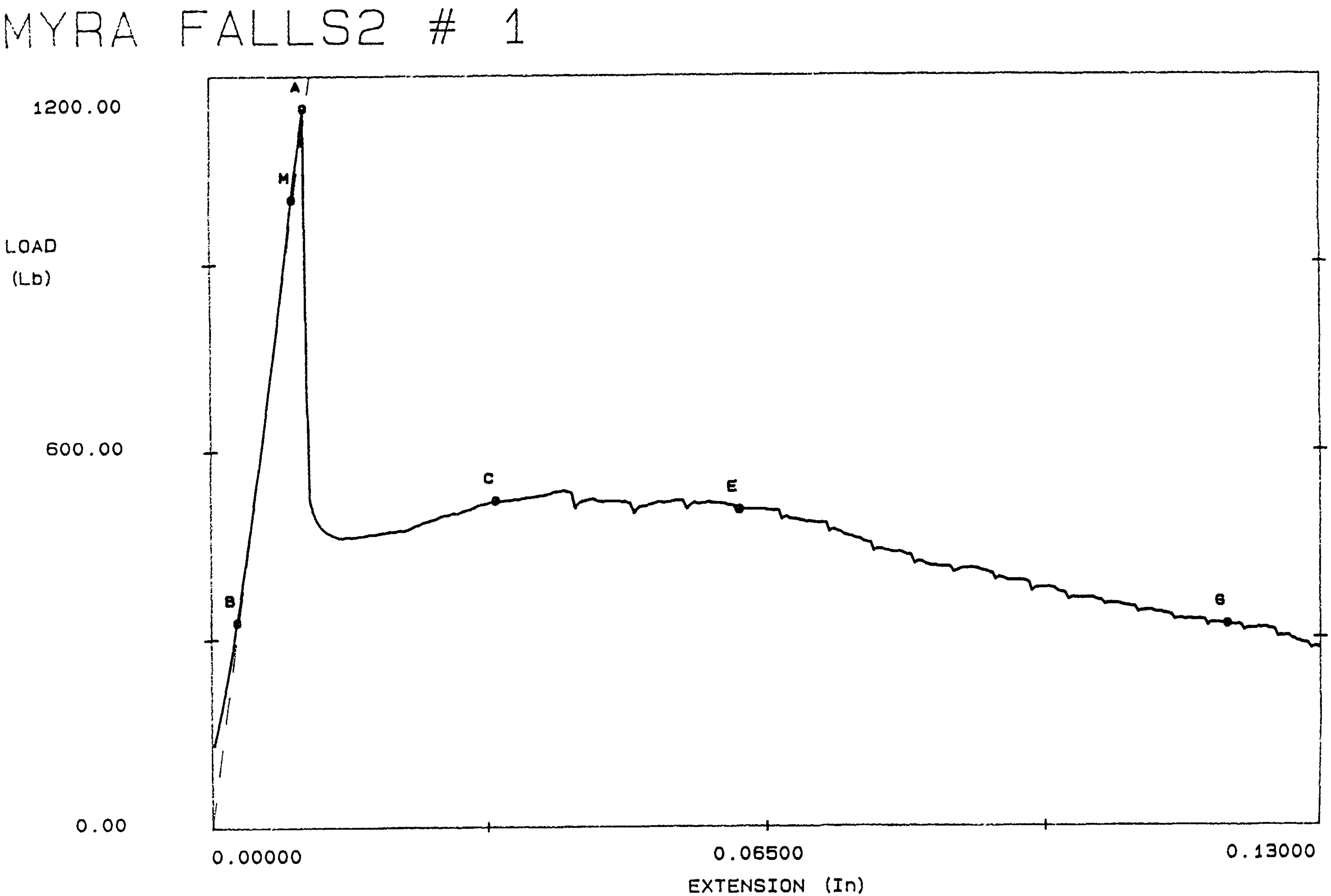
APPENDIX C

Flexural Test Results

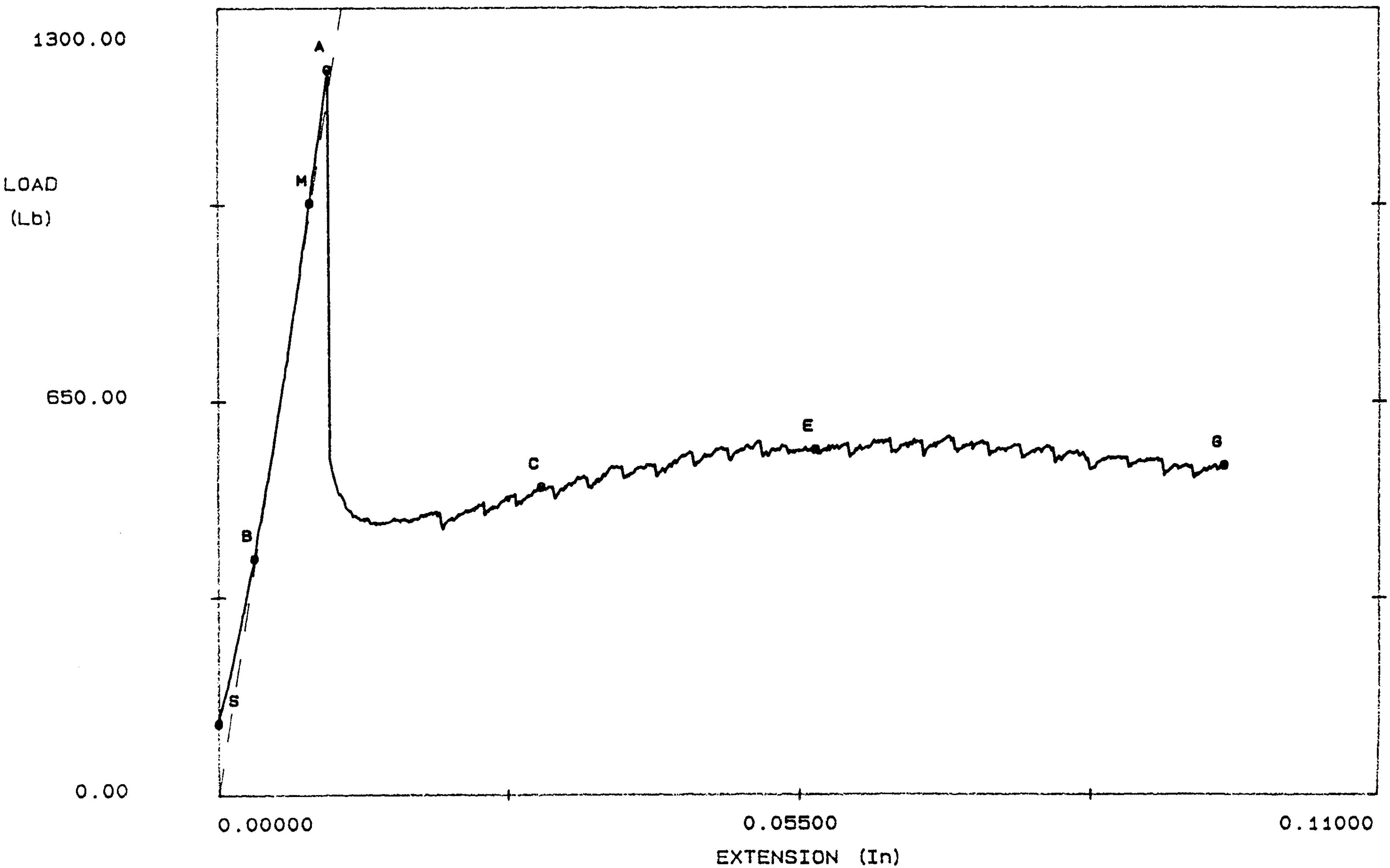
MYRA FALLS1 # 1



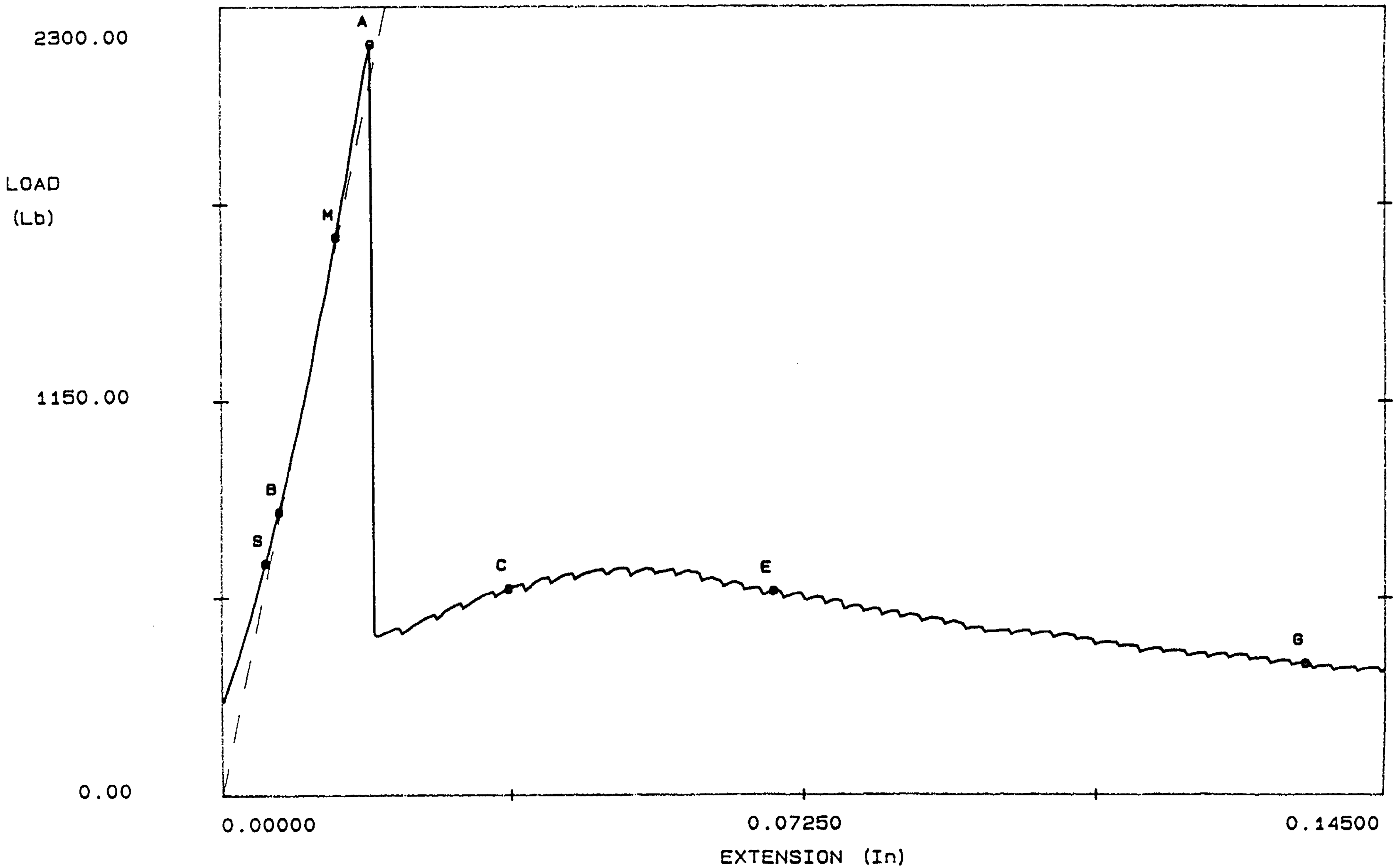
Welcome Screen | Search | Report List



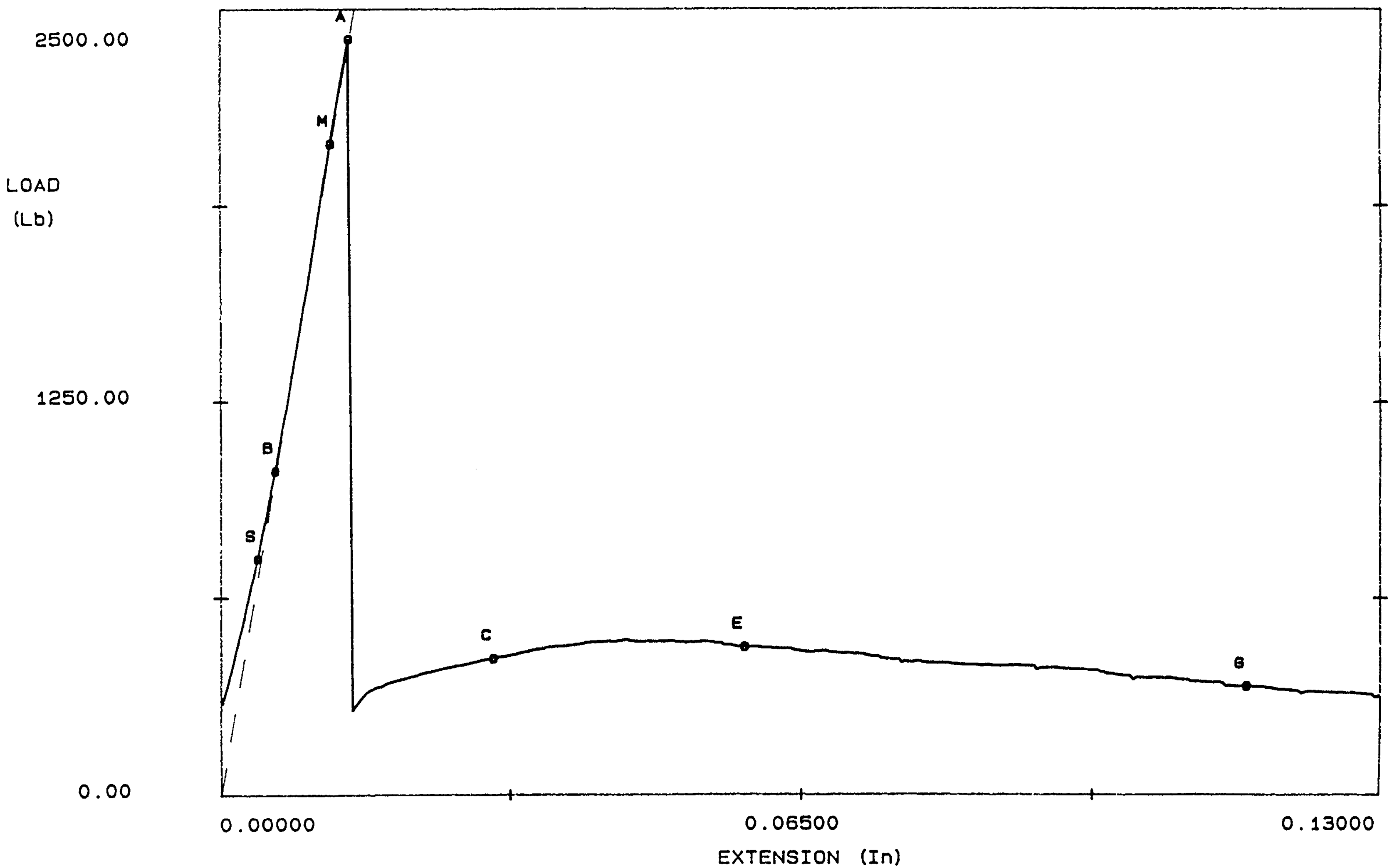
MYRA FALLS3 # 1

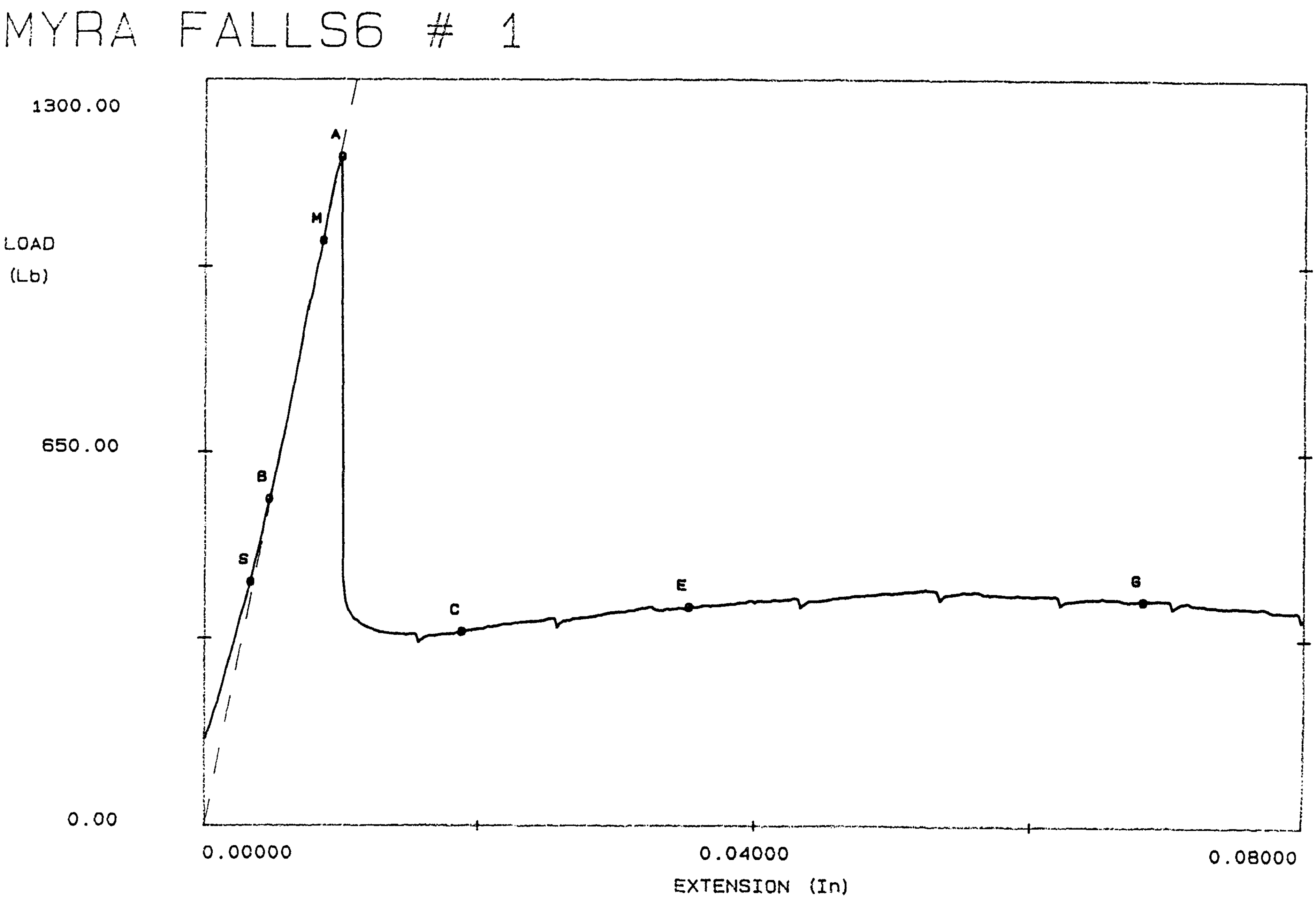


MYRA FALLS4 # 1



MYRA FALLS5 # 1




MYRA FALLS6 # 1
1300.00
LOAD
(Lb)
650.00
0.00
A
M
B
S
C
E
G
0.00000
0.04000
0.08000
EXTENSION (In)

APPENDIX D

Test Procedure for Permeability Tests

TEST PROCEDURE FOR PERMEABILITY OF CONCRETE

The test equipment consists of a pressure cells connected to a hydraulic line capable of subjecting the cells to 700 kPa (100 psi) pressure. The cell contains a cylindrical concrete sample, through which water pass in the longitudinal direction. Design of the equipment and preparation of the sample ensure one-dimensional, uniform flow. The volume of water passing through the concrete sample, per minute, is used to calculate the coefficient of permeability.

A schematic of the pressurized cell is illustrated in Figure A1. A concrete core specimen of 76.2 mm diameter and 25.4 mm thickness is used in each test. Prior to the test, the cylindrical surface of the concrete sample is coated with a layer of epoxy. A piece of filter paper and a porous stone are placed at both ends of the specimen. An aluminum cap is put on the top of the porous stone and then a rubber membrane and O-ring are used to seal the specimen.

During the test, an all round pressure or confining pressure can be applied to prevent water flowing between the side of the specimen and the rubber membrane. Flow of water within the test specimen is maintained by introducing water at a pressure of 300 kPa (43.5 psi) to the bottom of the specimen and maintaining zero or atmospheric pressure at the top of the specimen. A nominal confining pressure of 350 kPa (50.8 psi) is used for all the tests carried out. Figure A2 is the setup of permeability test.

To ensure that the specimen is fully saturated during the permeability test, the specimen setup inside the membrane was flushed with de-aired water. Several initial flow measurements for permeability were taken to ensure that a steady state flow condition was reached before the actual test was carried out. The steady state condition was indicated by the constant k values measured in successive attempts during a single test. Calculation of the coefficient of permeability was based on Darcy's Law, as follows:

$$q = A \cdot k \cdot i$$

where
q = volume of waterflow per unit time (m^3/sec)
A = cross-sectional area of sample (m^2)
k = coefficient of permeability (m/sec)
i = hydraulic gradient across sample (m/m)

In this particular case, k was calculated using the following constant:

A = 0.004560 m^2
i = 1024 m/m
q = measured value

APPENDIX E

Pneumatic Conveying Machine

Aliva-DUPLO Type 262

SYSTEM
Dry and wet mix spraying machine
Type 262

The Aliva-DUPLO type 262 is the universal rotor spraying machine for processing dry and wet mix. The material to be conveyed is fed from a specially designed vibrating hopper (1) directly into the rotor chambers (2). The revolving rotor (3) conveys the material to the air chamber (4). By free fall and assisted by an upper air flow (5) the mix or material to be conveyed is introduced into a conveying air stream (6). Material conveyance through a pipe line is achieved by thin stream method of transportation (air suspended delivery). With help of conveying air it is transported to the nozzle. When adopting the dry mix method of application water is metered and added to the mix at the spraying nozzle.
The Aliva-DUPLO 262 is the sister model (smaller version) of Aliva-DUPLO type 285 with which more than 6 million m^3 of wet mix shotcrete have been sprayed world-wide by using the thin stream method.

TECHNICAL DATA

Dimensions

Length max.	1900 mm
Width max.	850 mm
Height max.	1500 mm
Weight approx.	1200 kg

Conveying distance

Horizontal	wet:	30 m
	dry:	>300 m
Vertical	wet:	30 m
	dry:	>100 m

Drive

Electric Drive

Capacity:	4.4/6.7 kW
Revolutions:	1000/1500 rpm
Protection	IP 55
Voltage:	380V 501 iz
Others:	on request

Compressed Air Drive

Capacity:	8.5 kW
Pressure:	5 bar
Air consumption	7-10 m^3/min

Accessories

- -remote control
- -cable extension for remote control
- -spraying nozzles
- -wet spraying device
- -hoses, couplings
- -automatic central lubrication device
- -dosage equipment for additives
- -high pressure nozzle system