PIT SLOPE MANUAL

chapter 8

MONITORING

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PIT SLOPE PROJECT

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THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

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FOREWORD

Open pit mining accounts for some 70% of Canada's ore production. With the expansion of coal and tar sands operations, open pit mining will continue to increase in importance to the mineral industry. Recognizing this, CANMET embarked on a major project to produce the Pit Slope Manual, which is expected to bring substantial benefits in mining efficiency through improved slope design.

Strong interest in the project has been shown throughout its progress both in Canada and in other countries. Indeed, many of the results of the project are already being used in mine design. However, it is recognized that publication of the manual alone is not enough. Help is needed to assist engineers and planners to adopt the procedures described in the manual. This need for technology transfer will be met by a series of workshops for mine staff. These workshops will be held in various mining centres during the period 1977-81 following publication of the manual.

A noteworthy feature of the project has been its cooperative nature. Most organizations and individuals concerned with open pit planning in the country have made a contribution to the manual. It has been financed jointly by industry and the federal government.

Credit must be given to the core of staff who pursued with considerable personal devotion throughout the five-year period the objectives of the work from beginning to end. Their reward lies in knowing that they have completed a difficult job and, perhaps, in being named here: M. Gyenge, G. Herget, G. Larocque, R. Sage and M. Service.

D.F. Coates
Director-General
Canada Centre for Mineral and
Energy Technology

SUMMARY

The objective of monitoring is to detect possible pit wall instability so that appropriate remedial measures can be taken. The main concern is the protection of men and equipment.

The principal monitoring activity is measuring movement. It is also important to monitor groundwater levels and blast vibration, which may affect stability. If rock anchors are used to support a slope, their load must be measured regularly. Regular visual inspection can detect early signs of instability, such as cracks and loose rock.

Recent improvements in monitoring instruments include the development of electro-optical distance measuring units (EDM) for monitoring surface displacement. Improvements in telemetry - the remote reading of instruments by means of radio or cable - now permit its use in open pit mines.

Monitoring takes place during the operating stage of mining. However, advance planning is essential, and the nature and location of monitors should be decided during the mine design stage.

MONITORING LEVELS

In the manual, monitoring is divided into three levels. Level I is the overall monitoring of the walls, designed to locate areas of potential instability. Activity at this level is planned during the mine design stage and commences with mining. Level II is the detailed monitoring of these potential instabilities. Level III is the monitoring of actual instabilities, so that mining can continue with safety.

Level I

Monitoring of crests and bench areas using survey equipment is recommended at Level I. Measurements should be the minimum necessary to detect movement. The instruments used should be a theodolite, a theodolite and an EDM, or an EDM with angular measuring capability. Survey monuments must be durable.

If an EDM-theodolite is available, the displacement of crest zones can be monitored by traversing. In this procedure, the instrument is positioned over the target to be monitored and distance and angle measurements are made to adjacent targets. Simple but well anchored survey plugs should be used as targets.

Precise levelling complements surface displacement monitoring in areas where there is little overburden and the surface is reasonably

flat.

Groundwater measurements are important if adverse groundwater conditions are anticipated. Piezometers should be installed to monitor groundwater pressure.

Vibration should be measured and the extent of blast damage noted as production blasting procedures are developed. This information helps ensure acceptable vibration levels are not exceeded and guides the design of perimeter blasting.

Automatic monitoring with telemetry is unlikely to be needed in the early stages of mine development. However, when purchasing mine radio equipment, consideration can be given to future telemetry capability.

Level II

When a potential instability is detected, the monitoring effort must be intensified. It is important to determine:

a. the area and boundaries of the unstable zone,
b. the amount and rate of movement,
c. the general direction of motion.

This can be done by expanding the EDM-theodolite and precise levelling measurements.

Tension cracks often appear on crests and berms at an early stage in pit slope movement. Tapes can measure movement between stakes anchored on either side of a crack.

If safety is of particular concern, more sophisticated monitoring techniques are recommended. A telescoping pipe protecting a precision measuring chain anchored between stakes will measure movements from 0.02 in. to 20 in. (0.5 mm to 0.5 m). For larger movements, a wire system is recommended. Movement can be continuously recorded or a predetermined movement can trigger a warning device.

Sub-surface displacements can be measured with borehole inclinometers, borehole extensometers and inverted pendula. The inverted pendulum is the most sensitive and accurate instrument for monitoring sub-surface movement. However, it can be used only at depths less than about 100 ft (30 m).

If rock anchors are installed, their loads should be monitored by a dynamometer or load cell. The dynamometer recommended is a steel cylinder or ring whose deformation under load is sensed by calibrated strain gauges.

Ground vibration due to blasting can contribute to instability. Vibration should be measured in movement zones. If a relationship between movement and blasting is established, production blast patterns should be redesigned.

Level III

If a pit wall cannot be stabilized, allowance must be made for eventual sliding. The primary function of monitoring in this case is to permit continued safe mining.

When monitoring for safety, surveying instruments are not usually adequate. Primary dependence must be placed on rod or wire surface extensometers either equipped with limit switches and warning devices or read regularly by telemetry. Devices such as slide fences used by railways to detect rock fall zones can be used.

Extensometers should be considered. Rock bolt extensometers are more resistant to damage than multi-wire extensometers but differential displacement of the rock normal to the axis of the hole will quickly make them inoperative. Extensometers should be read remotely by means of telemetry, or should be equipped with limit switches which provide a suitable warning when movement occurs.

TELEMETRY

An automatic telemetry monitoring system can read instruments and transmit, process and store data. All the monitoring instruments must include a sensor to convert readings into an electrical signal. Automatic monitoring can be set up so that each instrument will signal when a preset limit is exceeded. However, instrument failure would result in no warning - ie, the system is not fail-safe. A better method is for a master station to "interrogate" the instruments periodically. Erroneous readings or no response can then be investigated.

Computer Control

The use of telemetry means considerable data can be collected rapidly. As a result, data logging and processing can be difficult, particularly if safety monitoring requires fast data processing to warn of possible instability. Computerized data processing can overcome these problems.

The use of a mini - computer for as few as 20 sensors could be justified if the following capabilities are considered essential:

a. safety monitoring,
b. automatic scanning of remote stations,
c. compensation for sensor variation (eg, non-linearity of response),
d. readout in engineering units,
e. quick processing for trend analysis,
f. data logging of variables such as displacement,
g. rapid adjustment of scanning cycles.

Most of these functions could be performed by specially designed instruments. A mini computer however, gives a flexibility that instruments do not provide. With the use of a computer, changes in the monitoring system or in the functions to be performed involve only program modifications.

Computer output can usually be printed by teletype. Monitoring should not require continuous data logging; in normal conditions a daily report is sufficient. Abnormal conditions can be reported at once by means of the teletype. The computer prints the time when the anomaly occurred and the identity and value of the relevant variables.

The computer can be programmed to modify scanning procedures when unusual conditions arise so that the appropriate sensors are read more often. The computer can also set off alarms such as horns or blinking lights if a dangerous condition develops.

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G.E. Larocque was responsible for the production of this chapter. Address enquiries to him at: 555 Booth Street, Ottawa, K1A 0G1, Canada.

The chapter and appendices were written by G.E. Larocque and J. O'Shea. Prime contractors on the Pit Slope Project who provided basic material for the chapter and appendices were:

Ecole Polytechnique, Montreal, P.Q.
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D.F. Hedley supplied the basic information for the preparation of appendices A and C.

The Pit Slope Manual is the result of five years of research and development cooperatively funded by the Canadian mining industry and the Government of Canada.

The Pit Slope Group has been led successively by D.F. Coates, M. Gyenge and R. Sage; their colleagues have been G. Herget, B. Hoare, G. Larocque, D. Murray and M. Service.

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INTRODUCTION

PURPOSE AND SCOPE

1. Monitoring is an essential part of a systems engineering approach to mine design. It will have as an initial function the provision of geotechnical data essential for the design of pit slopes. This requires the early development and application of a measurement program. A monitoring system should also continue to provide essential design information as mining progresses and as modifications to original pit designs are applied. With mine development, additional structural information may be obtained, or movement observed to raise doubts about the stability of some sections of the pit walls. There is thus another essential function of a complete monitoring system, in the surveillance of a slope so that mining procedures may be kept safe.

2. Functionally, all monitoring systems consist of four basic elements: geotechnical sensors, a transmission system, data storage, and data processing facilities. With the increasing diversity of available telemetry and processing equipment, a greater complexity of individual systems can be expected. The majority of existing surveillance systems involve the visual reading of data with the use of a computer for some data processing. Greater use of advanced telemetry and data processing techniques can be foreseen where mine safety and where economies may result from their introduction.

3. A comprehensive monitoring system must be capable of measuring rock mass displacement, groundwater parameters, blast vibration levels and loads on artificial support structures. Measures of rock mass displacement and the load on artificial support structures are direct indicators of the effectiveness of pit slope design. Initially, groundwater and blast vibration data will be required for designing pit slopes; they will indicate potential instability if design objectives are not being met. They differ from other indirect indicators of instability, such as rock noise and stress, in that cause and effect relationships in terms of pit slope stability have been clearly established. Rock noise and other geotechnical parameters of this nature will be briefly considered in this chapter.

APPLICATION OF A MONITORING PROGRAM

4. A monitoring program should have considerable flexibility in its execution. An orderly growth of the active part of the program to satisfy mine design and security requirements should be possible. A monitoring program can have three possible levels according to requirements and the plan developed should take these into account. All three levels may be required.

LEVEL I

5. Level I of a monitoring program is concerned with establishing a surveillance system to detect initial stages of pit slope instability and to measure geotechnical parameters specifically required for initial design.

6. To illustrate the type of program envisaged, a typical monitoring system has been developed for a hypothetical pit wall and is illustrated in Fig 1(a) and (b). A set of conditions has been selected which brings into use the kinds of sensors and tests considered basic to a comprehensive monitoring system.

7. In this example an initial structural investigation has established a major gouge-filled fault behind the planned final footwall, striking N 140° E and dipping 60° SW. The other major structural feature is a system of well-developed joints striking N 100° E and dipping 40° SW in the east wall; there is also extensive jointing at right angles to the major joint system paralleling the pit on strike. Drilling has indicated a high water table.

8. In the pit design, the monitoring program will be concerned partly with establishing the water regime that will come into effect as the pit is developed. With reference to Fig 1, tests to determine water table and permeability in the region will be carried out, permitting estimation of the eventual groundwater regime. Piezometers installed for these and other tests will supply key information at all stages of pit design and development.

9. Initial studies should be undertaken to establish the relationship between the degree of damage and vibration levels in this formation which is extensively jointed and subject to blasting damage. Various charge and blast hole configurations should be tested and any damage related to vibration level. Relationships governing ground vibration attenuation should be developed and used to locate permanent mine service structures.

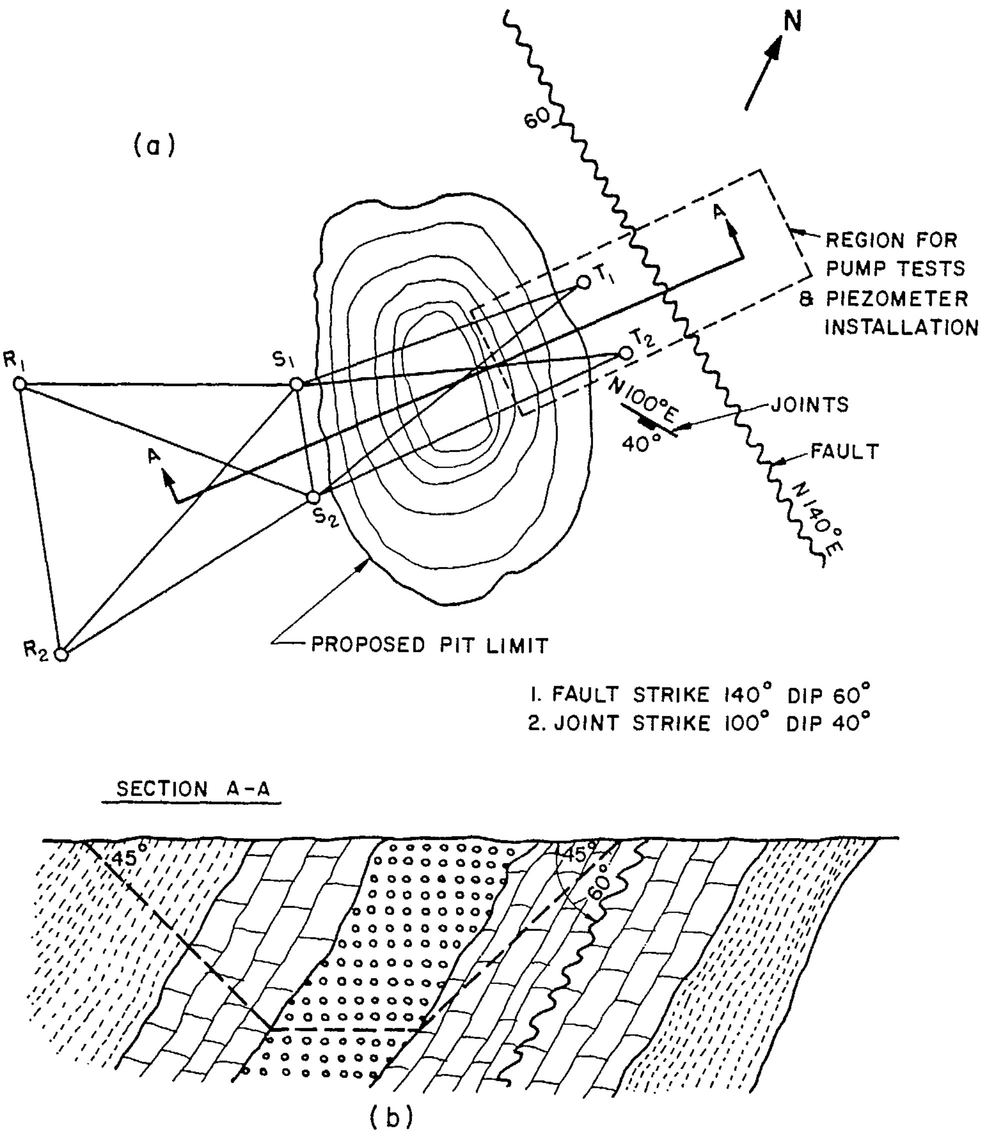


Fig 1 - (a) Plan diagram of future hypothetical open pit, (b) cross section of mid zone.

10. Because there is concern about the stability of this wall, a survey network should be established to monitor the movement of targets on the crest. In Fig 1, T_1 and T_2 represent such targets. They are part of a survey network consisting of observation stations S_1 and S_2, and reference stations R_1 and R_2. R_1 and R_2 ideally would be first order mine survey stations; S_1 and S_2 would be located in areas which might have to be observed.

11. The above is an example of the type of monitoring system visualized during Level I to meet certain basic design requirements. No telemetry of data is involved, although this might

have been allowed for in equipment budgets. As an example, vibrating-wire piezometers might be purchased because of the ease with which they can be incorporated into a telemetry system if this becomes desirable.

Detection of Pit Slope Movement in Level I

Surface movement - theodolite and EDM units

12. An inexpensive system is required for Level I monitoring to detect the first stages of movement. Initial movement rates are often small and take place over long periods of time before actual failure occurs. By way of illustration, Fig 2(1) gives a plot of cumulative displacement vs time for a station on a pit wall which failed. It can be seen that displacement rate accelerates as failure approaches, so that by increasing the ability to detect initial displacement the time available for corrective action is increased.

13. Survey equipment and survey methods specifically designed for pit slope monitoring are recommended for detecting surface displacement during Level I. They provide an economical and practicable means of achieving an adequate, although sparse, coverage of the pit slopes for this stage. The ideal instrumentation for measuring target movement is an EDM-theodolite such as the Geodimeter 700, or the combination of a 1-sec theodolite with a suitable EDM unit. The Kern DKM 2-A S is an excellent instrument for pit slope monitoring.

14. The common form of survey monitoring system illustrated in Fig 3, includes two distinct survey operations: the periodic establishment of the positions of observation monuments with respect to those of stable mine monuments, and the observation of pit targets from observation monuments.

15. In general, triangulateration in the first operation is preferable to triangulation or trilateration. Triangulateration includes the measurement of both angles and distances between stations within the survey figure to determine station position. However, at distances of less than 1500 ft (460 m) its advantage over triangulation in terms of accuracy is not great.

16. These conclusions are best illustrated by

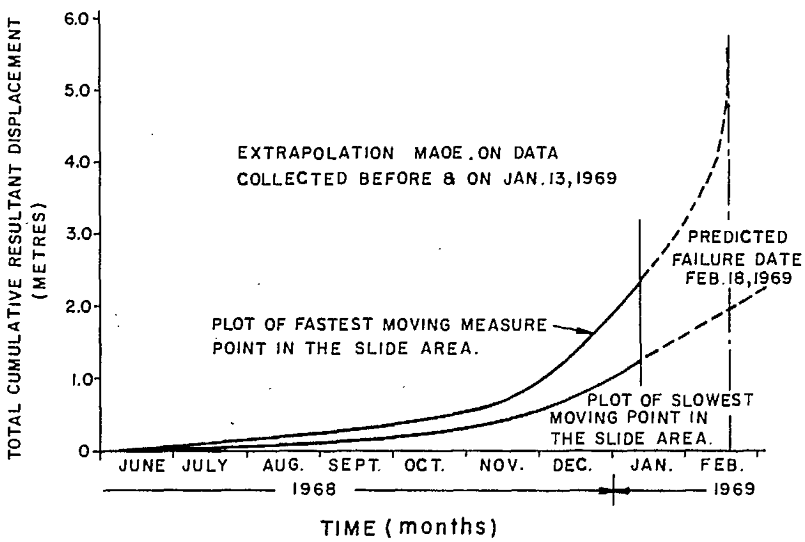


Fig 2 - Plot of cumulative displacement versus time for a pit slope station before failure at Chuquicamata (after Kennedy and Nurmeyer).

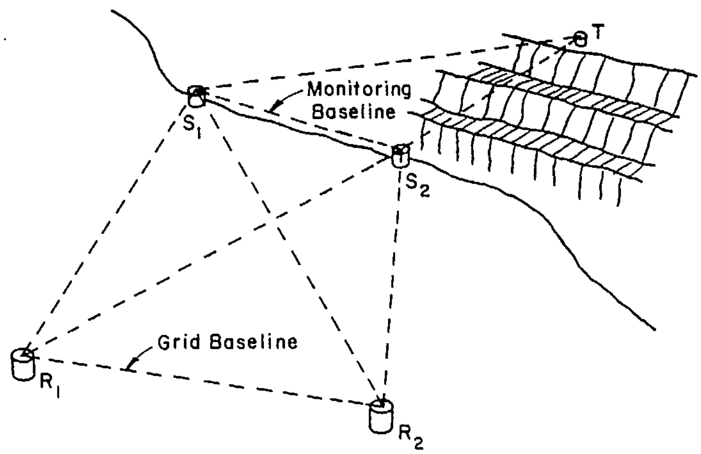


Fig 3 - Diagram illustrating typical location of monuments - mine, R_1 and R_2; observational, S_1 and S_2; and target, T.

reference to work by Ashkenazi involving a triangular survey figure and summarized in Fig 4 (2). The positional accuracy is given in terms of site distance and instrument observational error. In the target distance range of 1300 ft (400 m) to 3300 ft (1000 m), triangulateration provides the best positional accuracy. The observational errors used in the study are consistent with those that can be expected with presently available theodolite and EDM units.

17. Either traversing from a single observational monument using the other observational monument as a backsight or triangulation from the two monuments (Fig 3) can be used to monitor target movement.

18. Traversing is the recommended procedure using either an EDM unit with angle measuring capabilities or a EDM unit in combination with a theodolite. In the latter case, the EDM unit need not have the ability to measure horizontal and vertical angles. The added complication of using two instruments rather than one is offset by the reduced equipment cost to achieve the same accuracy.

19. Where traversing is used, the second observation monument is usually located behind the observed area and on stable ground. It is used as a backsight, for atmospheric instrument corrections, and as a reference for angle measurement between targets.

20. The periodic determination of the slope distance between an observation station and its targets will often be sufficient until displacement is detected. This procedure can reduce monitoring costs considerably. Angular measurements are undertaken when displacement occurs and it is essential to establish a new target position.

21. Establishing target location by triangulation does not permit on site interpretation of data and reading procedures are more time consuming than those involved in traversing. The time required is doubled because of the need to make observations from two stations, rather than one as in the latter case. Also, it is often difficult to establish base lines of suitable length in the vicinity of an open pit mine and give the field of view required.

22. In Fig 3, observations stations at the edge of the pit are used to determine pit crest and wall movement on the opposite wall. This is common practice, as it is not usual to have a sufficiently clear area back of the pit crest to permit observation from stations located farther back on the same side of the pit. In general, areas back of pit crests serve to store waste rock

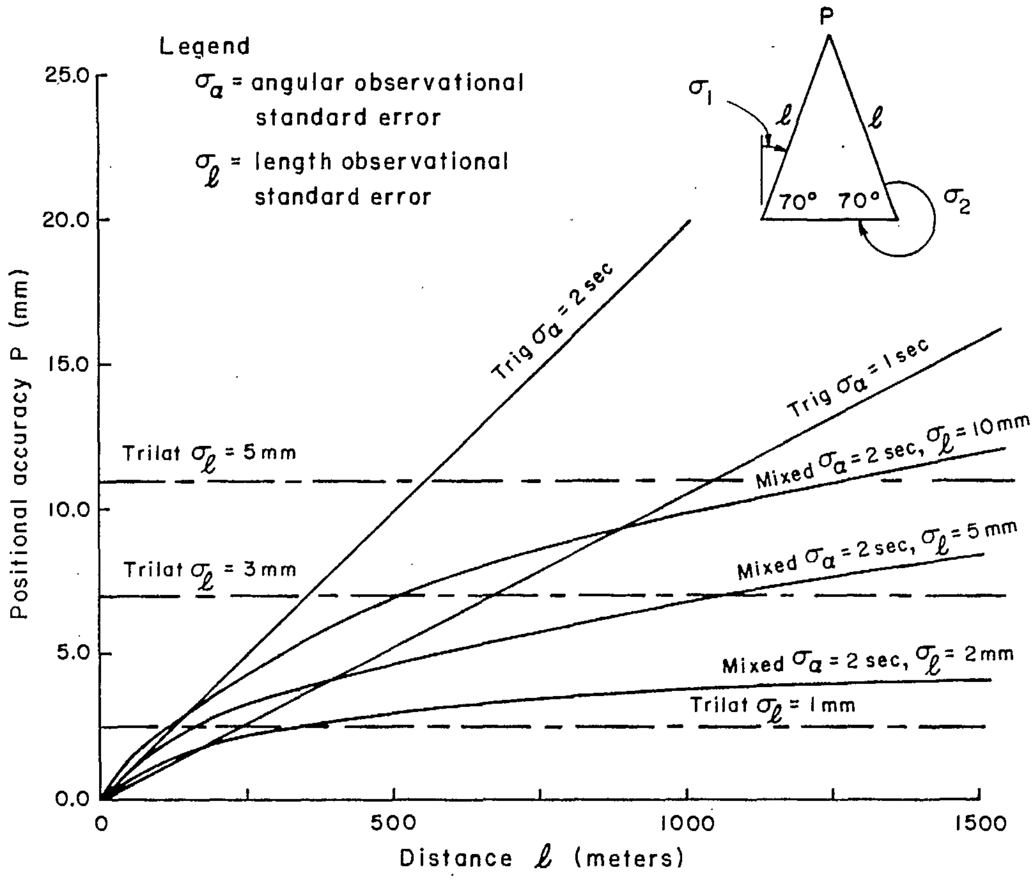


Fig 4 - Positional accuracy of P by triangulation, trilateration and triangulateration (after V. Ashkenazi).

and ore, preventing the ideal location of observation stations in relation to pit slope targets. If possible, when locating observation stations, sites should be selected which will provide a clear line of sight to the final pit floor. It can be expected that the initial crest slope targets will later be supplemented by targets located on berms or bench faces below them if more extensive monitoring becomes necessary.

23. Traverse lines can be established between reference stations such as R_1 and R_2 in Fig 5 to monitor the movement of crest regions. Relatively simple and inexpensive survey tablet markers well anchored into competent rock can be used for this purpose.

24. Traverse measurements are traditionally made using a subtense bar and theodolite. With standard survey equipment and procedures, the curacy of locating adjacent stations is ± 0.4 in. (± 1 cm) with separation distances of 164 ft (50 m). By the use of improved observation procedures and equipment, accuracy can be increased to ± 0.2 in. (± 5 mm) for these separation distances (3).

25. Traverse measurements can now be carried out using EDM units directly attached to a theodolite. Station distances are no longer limited to 164 ft (50 m) to achieve distance measurement accuracies of ± 0.2 in. (± 5 mm).

26. Accurate location of the traverse equipment over the stations is extremely important. Tripods equipped with optical plummets or center-

ing rods are required which can reposition the units to within ± 0.2 in. (± 5 mm).

27. Approaching the crest, the line of traverse stations should be as normal to the pit face as possible. This is illustrated in Fig 5.

28. Table 1 provides information on rates of movement that have been measured around open pit mines and rock cuts. Unfortunately, there is no extensive literature on rock movement accompanying rock slope failures. It is to be noted however that many failures have an orderly increase in displacement rates as failure approaches, thereby permitting an estimate of when failure is likely to occur. There are however failures where motion is discontinuous and there is no orderly acceleration of displacement as failure is approached. The Brilliant slide would appear to have been in this category (Table 1).

29. Monitoring equipment should be bought and survey techniques employed that will permit detection of 1 cm of wall displacement. Both equipment and techniques exist which make this possible at a reasonable cost; a partial list of such equipment is contained in Appendix A.

Surface movement - precise levels

30. Whether or not a precise level survey in the crest region forms part of a Level I monitoring system depends in part on topography. A relatively flat or non-undulating crest region not requiring an excessive number of stations is a basic requirement. Accuracy of measurement decreases with the number of stations and monitoring costs rise proportionally. Level surveys should not be undertaken in zones where overburden prevents anchoring the stations in solid rock.

31. Where level surveys are carried out as part of a Level I program, it is recommended they be used to complement rather than to replace EDM-theodolite targets, although the latter possibility is not excluded. Figure 6 indicates an ideal location of levelling stations in relation to EDM-theodolite targets forming part of the basic triangulation network. The chain of survey stations should extend beyond the area where movement is anticipated, or to adjacent EDM-theodolite targets. Their purpose is to establish the extent of the affected zone, both across the pit face and back from the pit crest. In most

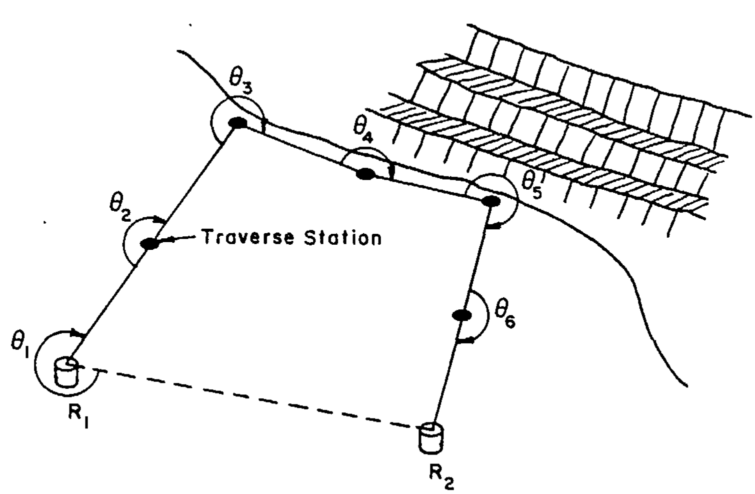


Fig 5 - Diagram illustrating typical traverse monitoring of crest region.

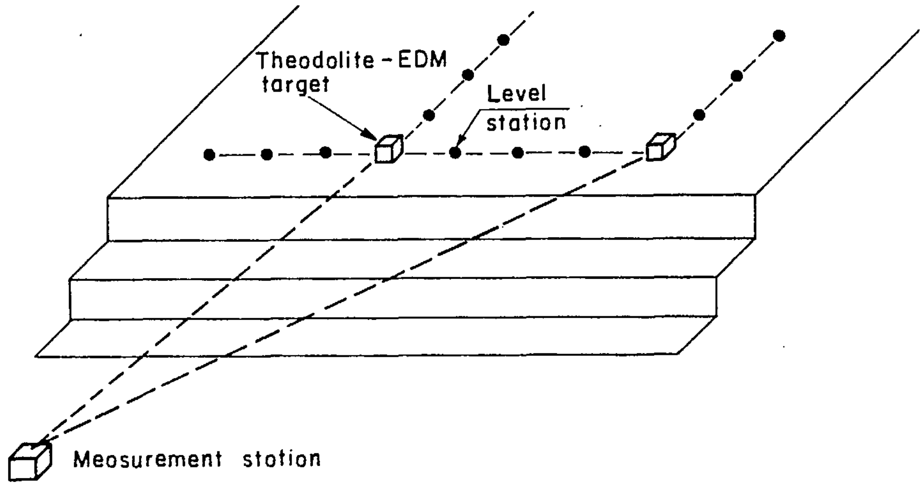


Fig 6 - Diagram showing the position of EDM-theodolite targets and level stations on pit crest.

instances, the orientation of the line of level stations will be selected to meet topographic considerations rather than what may be best for monitoring purposes.

32. As benches are developed, level stations can be installed on accessible berms. Berms usually provide a more ideal location for making this type of measurement, but blasting overbreak can be a problem. Wall stations can be used to replace the horizontal surface stations on pit crests. Details of both types of stations are provided in Appendix B. All level stations should be tied into the triangulation net.

33. An automatic level with an integral parallel plate compensator is recommended for monitoring pit slope movement. When using the most precise equipment available, and considering sight length and procedures, smaller displacements can be detected by levelling than is possible in many EDM-theodolite systems. With these levels, invar rods with 5 mm graduations, station distances of 328 ft (100 m) and two-way levelling, measurements with a mean-square closure error of 1 mm (0.04 in.) per Skm can be made, where Skm is the course distance in kilometres.

Geotechnical Parameters in Level I

34. Early in Level I, the design group will specify the geotechnical parameters to be measured. This period begins before initial excavation and continues until the first benches have been cut. The information required will concern the groundwater regime around the pit and vibration levels associated with blasting. Details are described in the following sections.

Groundwater Measurements

35. Groundwater information is required for the purpose of providing a rational pit slope design since groundwater conditions affect stability, particularly where there are adverse groundwater conditions in a zone or sector with weak structural features. The groundwater program should make it possible to estimate the groundwater regime which will come into play as the pit develops. Ground permeability and water pressure measurements are made in significant water bearing zones. Details of this kind of installation and interpretation of the resulting data, are treated in Chapter 4.

36. It is generally accepted and substantiated

Table 1: Report on rock face movements

1.	Chuquicamata, Chile	Igneous intrusive	.001 in.(0.025 mm)/day to 20 in.(51 cm)/day	9 1/2 yrs	Failure of 12 x 10^6 tons. Groundwater effects not significant. Various surface displacement devices and seismographs used.
2.	Black Rock Pit, Mount Isa, Australia	Siltstones and shales	.01 in.(0.25 mm)/day to 3 in.(7.6 cm)/day	500 days	Horizontal and vertical displacement measured using extensometers, levels and theodolites.
3.	Endako Pit, B.C.	Quartz monazite	.01 in.(0.25 mm)/day to .24 in.(.62 cm)/day	40 days	600 ton berm failure with stepped displacement and movement related to periods of rain and high water table.
4.	Brilliant Cut Slide, PA	Flat-lying beds of sandstone shale and indurated shale. Vertical joints parallel to cut. Perched water tables common.	Irregular movement about 2 ft (0.61 m) total reported.	<10 yrs	A rock mass of 110,000 cu yd was involved in the slump. Rear of failed surface defined by vertical cracks. Approximately 70% of failed surface in clay material at face of cut. Water table changes resulting from frozen drainage holes believed to have initiated failure.
5.	Bingham Pit Slide, Utah Sept. 1971		1.07 in.(2.7 cm)/day to 1.0 ft (0.30 m)/hr	60 days	Failure rate increased after every large rain, which is believed to have damaged cohesion of the gouge material on the failed surface. Blast vibrations also affected displacement rate.
6.	Twin Buttes Nov. 72 to May 73		.045 in.(1.1 mm)/day	6 mos	Motion arrested by installation of artificial support system. South site adjacent to a failed zone up to 3 million tons. Heavy rains appear to have adversely affected stability.
7.	Steep Rock Hogarth Pit	Diorite containing sheared basic dykes	<0.25 in.(6.5 mm/day to >1 ft (0.30 m) day Cumulative horizontal displacement of 30 ft (9.1 m) measured.	21 mos	Toppling failure with ravelling of some sections.

to some extent by the examples given in Table 1, that changes in water pressures resulting from heavy rains or blockage of drainage channels, can trigger a failure. For this reason some consideration should be given to the future use of installed piezometers as part of a safety warning system. If automatic monitoring is a possibility, the type of piezometer purchased should be capable of providing a signal output suitable for telemetry.

Blasting and Ground Vibration Measurement

37. Level I extends over that period in which production blast procedures are developed through experimentation. It is an ideal period for carrying out vibration measurements to establish ground vibration constants for the various sections of the pit. The chapter concerned with control blasting provides a detailed description of the procedures and equipment to make these measurements. Ground particle velocity provides the best correlation between vibration level and the type of damage that can be expected. Table 2, which has been extracted from Chapter 7 on perimeter blasting, and other sources, indicate the type of damage that can be expected at various particle velocity levels (4).

38. Figure 7 is a plot of peak particle velocity vs scaled distance resulting from field tests

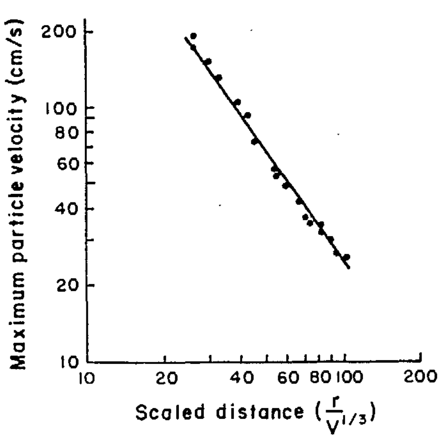


Fig 7 - Plot of particle velocity versus scaled distance for Geogel 60% in magnetite rock formation.

using a particular rock-explosive combination. These plots may be used to establish the maximum vibration level on the basis of charge weight and distance, and aid in the safe location of buildings, shafts and roadways.

39. Care should be taken to record data of potential value in the development of control blast procedures. The gathering of this basic data should not await the development of a wall problem. In particular, the back-break resulting from various charges, blast configurations and sequences, should be noted. A qualitative description of the final wall, supported by photographs, should form part of the collected data. Tests outlined in Chapter 7 to establish rock strength properties are best carried out during this period of extensive blasting experimentation.

Telemetry in Level I

40. Level I monitoring parallels the early stages of mine development. Safety is not a problem and the variables being measured for design purposes do not have to be monitored on a continuing basis. While the addition of telemetry equipment may have been anticipated in the purchase of mine ratio apparatus, its purchase at this stage is not necessary.

Summary of Level I Measurements

41. Table 3 summarizes the range of measurements and their purpose envisaged during Level I.

LEVEL II

General

42. Level II monitoring begins when the original system for general surveillance and gathering of geotechnical data must be expanded because of uncertainties. Various problems can initiate this more intensive monitoring. It does not apply to a particular period in the life of the mine. The most obvious occasion comes when the original system detects wall displacement greater than expected. Initial action will be to upgrade the surface displacement monitoring system. As a mine develops, more rock face is exposed for geological examination. Structural features may be

Table 2: Damage related to peak particle velocity

Types of structure	Types of damage	Peak particle velocity (in./s)	(cm/s)
Rigidly mounted mercury switch	Trip out	0.5	1.3
Houses	Cracked plaster	2.0	5.1
Concrete block walls	Cracks in blocks	8.0	20.0
Tunnel	Rock fall in unlined tunnels	12.0	30.0
Cased drill holes	Horizontal offset	15.0	38.0
Tunnel	New fractures	24.0	61.0
Mechanical equipment such as pumps and compressors	Shafts misaligned	40.0	102.0
Prefabricated metal buildings on concrete pads	Cracked pads, buildings twisted and distorted	60.0	152.0

intersected which were not considered in the original design and which may have significance. It is also possible that the expected water regime is not confirmed as the pit develops and that a more extensive program using piezometers may be required. The initial design may be suspected of being overly conservative and test benches might be planned at a steeper slope angle. Close monitoring of these test benches could be required. In general, the form of additional surveillance will depend on circumstances.

43. To provide an illustration of what could give rise to a Level II monitoring program, consider the previous example shown in Fig 1, where an expected water regime is not established as the mine develops. In fact, it is indicated that the gouge-filled fault back of the slope is acting as an impermeable barrier and has significantly lowered the water table at first expected. This results in a safety factor for this wall greater than the designed value. In this case, additional piezometers might be installed to establish the actual effectiveness of the impermeable barrier, prior to redesigning at a steeper angle. An intensified displacement monitoring system would be called for if a steeper angle is adopted.

44. As distinct from Level I, monitoring introduced in Level II is concerned with selected areas of the pit wall where more detailed information is required. Monitoring for the first time may serve a safety role as well as provide design information. Monitoring systems introduced

Table 3: Measurements in level I monitoring

Type of measurement	Apparatus	Purpose
Displacement	EDM-theodolite	- To establish a coarse grid of slope stations around the pit to detect initial displacement - To measure displacement rate and direction.
	Automatic level	- To measure vertical component of displacement - To provide peripheral coverage around EDM-theodolite slope stations to determine extent of unstable region - To independently detect zones of instability in pit crests and benchs.
Permeability	Water level indicator, packers, pumps, piezometers	- To establish the water regime that will come into force with mine development - To estimate the effectiveness of slope drainage systems.
Water pressure	Piezometer, packers, water level indicators	- To establish water pressures that are active in various regions of the pit wall for slope design information - To evaluate the effectiveness of drainage systems - To monitor pressures for safety purposes.
Ground vibration and associated control blast measurements	Vibration meter survey equipment, camera	- To establish vibration level as a function of charge weight and distance from production blasts - To establish wall conditions in relation to blast vibration level.

earlier, external to the area of more extensive monitoring would not be abandoned. The reading cycle, however, would be modified in the light of the continuing experience with the slope.

45. The early detection of instability by Level I monitoring provides additional valuable time for the mine staff to plan and to prepare a counter measure. Level II monitoring is part of the response. Depending on circumstances, there are a number of modifications or operational changes which can be made:

a. pit slopes can be modified,
b. overburden or waste rock can be off-loaded from the crest region,
c. drainage of slopes can be improved,
d. drainage systems around the mine can be improved,
e. blasting can be adjusted to be less destructive,
f. artificial pit wall support can be installed,
g. road systems and pit operations can be designed against eventual instability, and
h. additional safety measures and warning systems can be installed.

46. Level I displacement monitoring is limited to measuring surface displacement. These measurements may form only a part of a Level II system. Having established the existence of instability in the earlier phase, in Level II greater emphasis will be placed on defining the boundaries of the zone of instability and determining the rate and direction of displacement. Sub-surface displacement monitoring will occasionally be required. As an example, in Fig 8, surface movement of a bench

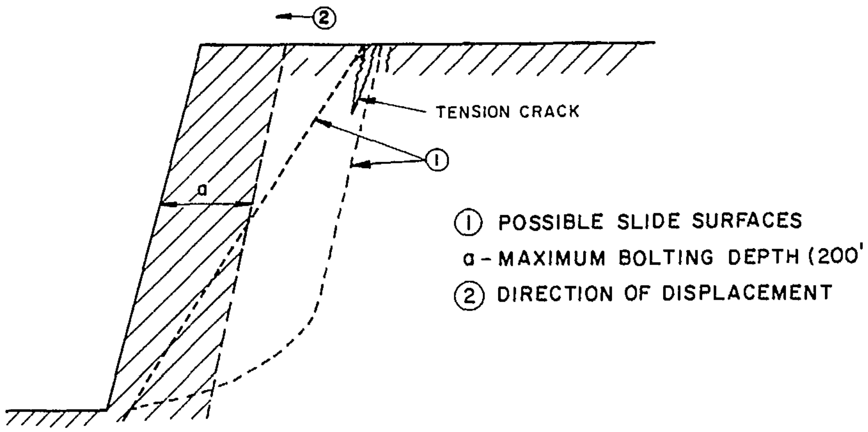


Fig 8 - Illustration of potential pit wall slide surfaces and maximum bolting depth.

has been detected but the depth of the affected zone has not been determined. One of the two joint systems might form part of the potential failure planes. Depending on the active joint system, bolting may or may not be a practicable means of stabilization. Some form of sub-surface displacement measuring device will be required to resolve the question prior to undertaking corrective action.

47. One purpose of sub-surface displacement measurement therefore would be to locate active internal surfaces which cannot otherwise be identified. Such measurements can also be undertaken to monitor known weak structural features.

48. A more extensive program of groundwater measurement could form part of Level II monitoring. Extension of earlier groundwater programs, however, will be concerned with the particular regions of a pit where stability has become a problem, where redesign of pit slope angle is being considered, or where drainage is being introduced to improve stability. In each case, the purpose is to establish the pressures acting on slip surfaces which could upset wall equilibrium. At a later period, the piezometers installed in these zones could be part of a safety monitoring system, particularly if a correlation becomes evident between heavy rains, increased piezometric pressure and rock movement. Such correlations are common, and the Endako wedge slide reported in Table 1 is an example.

49. Vibration levels resulting from blasting are probably of the greatest concern where there is ravelling of a pit wall or a series of small crest failures is taking place. Vibration measurements will guide the modification of blast patterns to minimize damage. Instances have been reported where correlations were established between the occurrence of ground vibrations and increased movement of multi-bench pit sections, some of which eventually failed (5). Figure 9 illustrates the effect of blasting on a particular slope where overall movement is being arrested. The breaks in this curve indicate sudden increases in the rate of displacement and coincide with production blasting. As part of a Level II program, ground vibration measurement could be carried out to establish the sensitivity of slopes to blast vibration levels and to monitor production blasts so that acceptable vibration levels are not exceeded.

50. Artificial support may be introduced when instability has been established and monitoring associated with installed cables or rods forms part of Level II. Some of the installed rods and cables should be equipped with load cells to check quality of installation and effectiveness in slope stabilization. As such, they will provide design

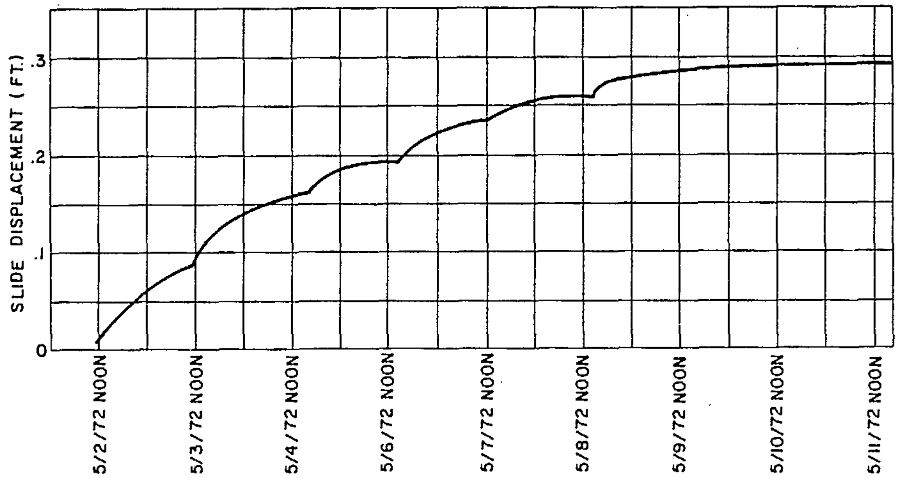


Fig 9 - Effect of blast action on slope movement at Bingham Pit (after K.C. Ko and M.K. McCarter).

information and will be a valuable addition to a safety monitoring network. If surface coatings consisting of shotcrete or gunite are used for wall stabilization, installed concrete gauges can be used as part of a safety monitoring network.

Detecting Pit Slope Movement in Level II

Surface Movement

51. Having isolated pit wall sections where displacement is taking place in Level I, surface displacement devices in Level II can be used to determine:

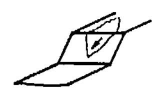
a. the area and the particular boundaries of the displacement zone,
b. the direction of the displacement, and
c. the absolute displacement and its rate in the area affected.

52. As indicated earlier, information is required occasionally by the design group to establish the joints, fractures, faults, sheared zones, etc, involved in the movement. An example has already been given in Fig 8 where sub-surface measurements are required. Location of the surface intersection of active faces can also be important. For this purpose additional EDM-theodolite and level stations could be installed on the crest and on accessible benches. If the information is sufficiently detailed, the measurements will permit the identification of the structural features on which movement is taking place. Hence the measurements lead to a greater degree of confidence in using available data. Level II surface measurements will also assist in defining the type of failure taking place; each type has its characteristic surface movement. Failures can be grouped into plane surface, rotational and toppling. Table 4 provides information on the division of these into the distinct types used in Chapter 5.

53. The location of targets on the face will depend on accessibility to the berms. If berms are accessible in the early stages of movement, levelling would be the best way to establish the width of the zone parallel to the face undergoing movement. Once delineated, EDM-theodolite targets would be installed to monitor displacement should these areas no longer be accessible because of physical deterioration.

54. At present, the EDM-theodolite system has not developed to a point where continuous monitoring of a slope is possible. Other systems must therefore be employed for safety monitoring as will discussed in succeeding paragraphs.

Table 4: Types of rock slope failure

General classification	Particular type of failure	Illustrative diagram
Plane failure	one plane and one block	
	plane and tension crack	
	sliding planes and cross joints	
	two sliding planes	
	sliding plane with several blocks	
	wedge failure	
Rotational failure	rotational	
	rotational and sliding surface	
Toppling failure	-	

55. Occasionally, tension cracks appear on the crest or berm at an early stage in the movement of a pit slope. These cracks must not be confused with superficial crustal adjustments which produce similar cracks. The latter will stabilize quickly and are not significant in terms of slope stability. Surface cracks in general are not hidden by overburden, but rather stand out more prominently because of it. By establishing anchor points across individual tension cracks, the surface displacement of individual block and differential displacements within a slide zone can be determined. The simplest system involves tape measurement between stakes located on each side of the crack. The care used in taping will depend on the accuracy of the measurement required. A very precise unit of this type is described in Appendix C, and is illustrated in Fig 10. An invar tape with a Newcastle extensometer is used to measure displacement. Tests have established accuracy as ± 0.005 in. (0.127 mm).

56. The Canadian climatic conditions and the need to continuously monitor surface displacement for safety reasons, require a system using a

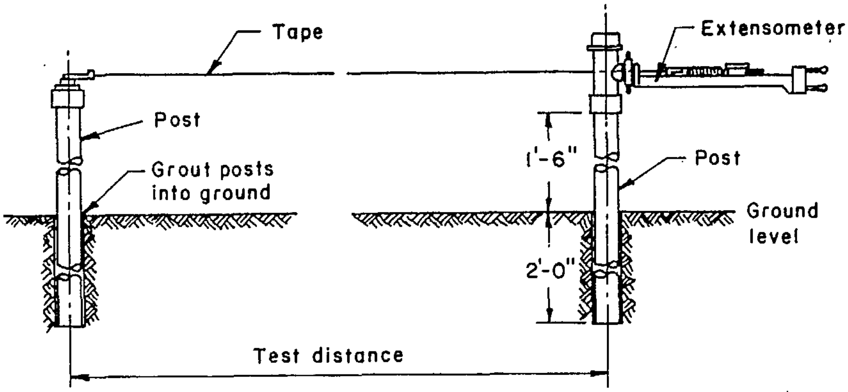


Fig 10 - Diagram of invar tape unit.

similar set of anchor points with a rod assembly and linear potentiometer. These measure moderate rates of surface displacements across single cracks or along lines in disturbed regions showing several cracks. A suitable unit of this type is described in Appendix C. Displacements of 0.020 in. (0.708 mm) to 20 in. (50.8 cm) can be measured with this unit over bay lengths of 10 ft (3.25 m) to 100 ft (32.5 m). Wire systems such as one described in Appendix C are recommended for large displacements where less accuracy is required. Figure 11 illustrates its use on a tailings dump. By coupling such equipment to a suitable telemetry system, a zone under movement can be monitored remotely at any desired frequency rate.

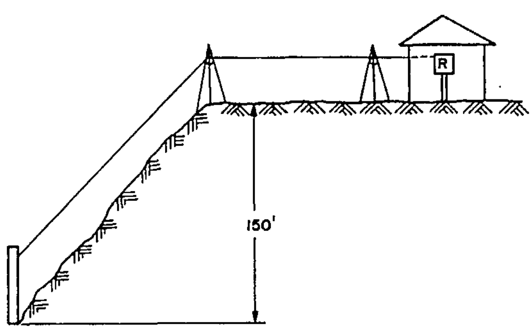


Fig 11 - Diagram illustrating use of wire extensometer unit on waste dump.

57. As an alternative, tape and rod displacement sensing devices can be equipped with limit switches which will close when a selected maximum movement has been reached. The closing of the switch can be used to activate warning lights or alarm bells. The use of limit switches provides a less effective but more economical form of safety monitoring than does remote interrogation by telemetry.

Sub-surface Movement

58. Borehole inclinometers, borehole extensometers or inverted pendula should be used to locate and delineate sub-surface faces active in rock movement when surface observations and other data do not provide this information. They can also be used to monitor known structural features which are suspect. As one of the large cost factors in this type of installation lies in the boreholes, their sites must be selected with care.

59. The moveable borehole inclinometer is well suited to locate deep-seated rock surfaces and zones active in wall movement. To provide a proper reference point, the vertical hole must be sufficiently deep to reach stable ground. This can be achieved in shallow pits by drilling the test borehole to the pit floor horizon. In the case of deep mines, the depth of inclinometer holes must be selected, according to the structural features which could activate a slide.

60. In the more accurate inclinometer units, a

system accuracy of 1 min of arc has been established. Assuming that the active zone of a slide is contained within one 10 ft (3.25 m) section of an inclinometer casing, horizontal movements of 0.03 in. (0.76 mm) can be detected. The inclinometer therefore provides a sensitive system for the detection of slip planes. Where rock slopes are concerned, inclinometer casings should be protected against sharp discontinuities by installing them in oversize holes and backfilling with sand. Appendix D provides further recommendations on the use of moveable borehole inclinometers in rock and soil slopes.

61. A system of borehole extensometer, described in Appendix E is recommended for use under restricted conditions in open pit mines. They are of the multi-wire and rock bolt anchorage types, as illustrated in Fig 12.

62. Constant-tension wire extensometers are preferred to comparable variable-tension units because of their greater accuracy. Gauge lengths up to 400 ft (122 m) are possible with these units; there is some reduction in accuracy with increasing length. Borehole wire extensometers can follow ground movement only over a limited range because of hole deterioration with rock movement. Normally about 3 in. (76 mm) of rock movement in a 50 ft (15 m) gauge length will result in sufficient debris falling on the unprotected wire to interfere with the operation.

63. It is not recommended that these units be used behind the crest in holes drilled towards the pit face; rather, they should be limited to surface applications where they can be installed from the pit face. Final pit walls and walls adjacent to roadways are suitable locations. Their use is also preferred where monitoring of pit walls can be done from adjacent underground galleries.

64. As a hypothetical example of their use, Fig 13 shows a rock face adjacent to a roadway which had been prepared by pre-split blasting. Traces of the pre-split holes indicate that a bulging of the solid rock faces had taken place.

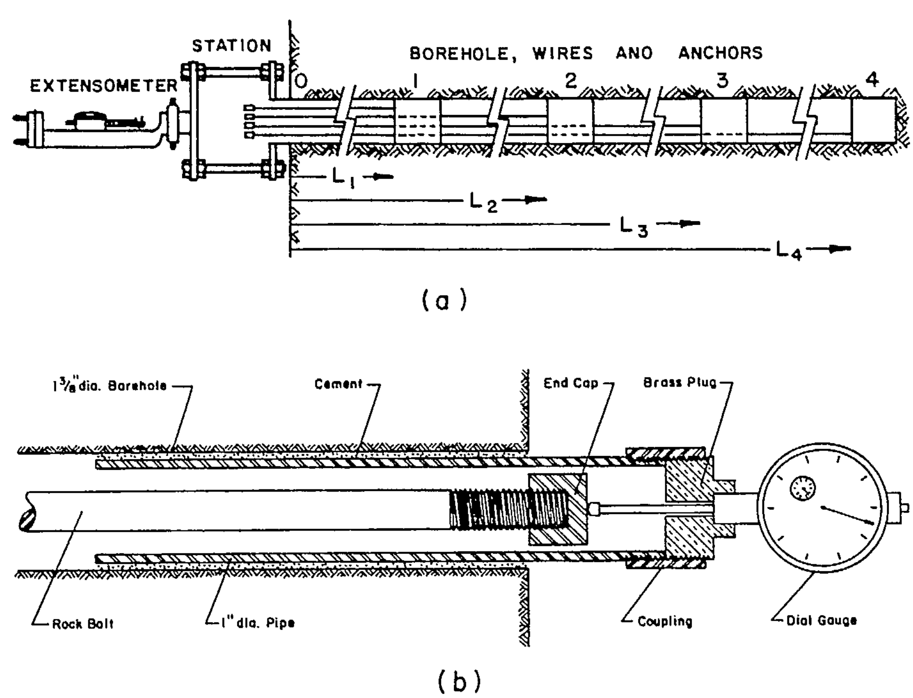


Fig 12 - Diagram illustrating installed borehole extensometers - (a) multiwire type, and (b) rock bolt type.

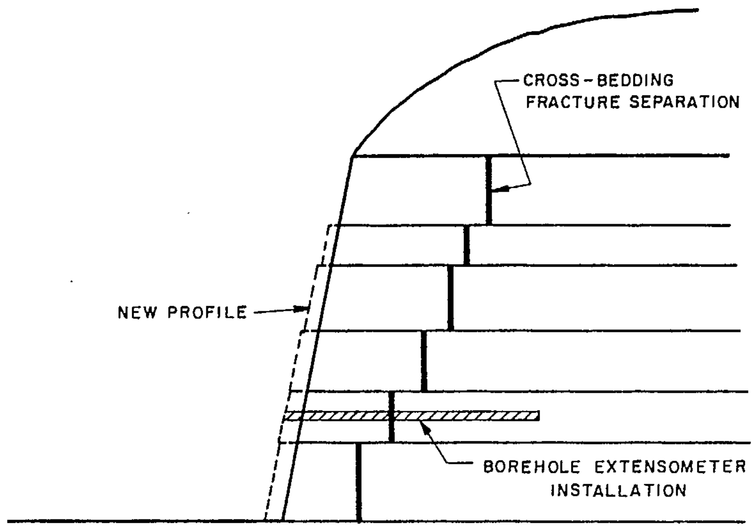


Fig 13 - Installation of rock bolt extensometer in pre-split wall adjacent to roadway to test for stability.

It is believed that the combined effect of cross-bedding fractures and overlying load caused the movement. Before choosing between removal of the overburden, redesign of the face angle or bolting, borehole extensometers could be installed to determine whether the wall has stabilized.

65. Rock bolt extensometers are used where shallow structural discontinuities in permanent walls are to be monitored. It is a less accurate unit than the multi-wire extensometer, and is less economical as there is but one measuring station in each hole. Direct mechanical readout devices such as dial gauges can be replaced by potentiometers or limit switches which permit their incorporation into safety monitoring systems.

66. The inverted pendulum is the most sensitive and accurate of the three systems considered for measuring pit wall movements referred to an internal stable station (Fig 14). Using a telescope with a reading table, horizontal displacements as small as 0.004 in. (0.1 mm) can be measured.

67. The use of inverted pendula is limited to sites where stable anchorages can be set relatively near the surface. An almost vertical hole is required for the installation as the pendulum wire must hang free. With large rotary equipment, the maximum depth for their installation is about 100 ft (30.5 m).

68. An attractive feature is that production drill holes can be used. For those not wishing to purchase and use more sophisticated equipment, the inverted pendulum is reliable for detecting and measuring surface displacement within 100 ft (30.5 m) of the surface. The inverted pendulum is the subject of Appendix F.

Geotechnical Parameters in Level II

Groundwater Measurements

69. Additional piezometers should be placed in displacement zones if it is suspected that groundwater is contributing to instability. They should be installed after the rock faces active in the movement have been identified. The purpose of the piezometers would be to measure water pressure on the active faces, to provide design information, and to evaluate the effectiveness of slope drainage if undertaken as a corrective. As an example, in Fig 15 it has been established that sliding of the wall is taking place on planes A and B. The

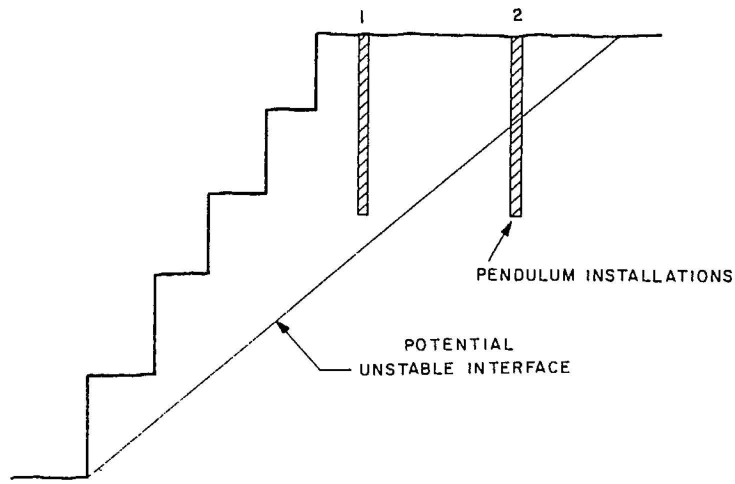


Fig 14 - Diagram to illustrate the use of inverted pendula.

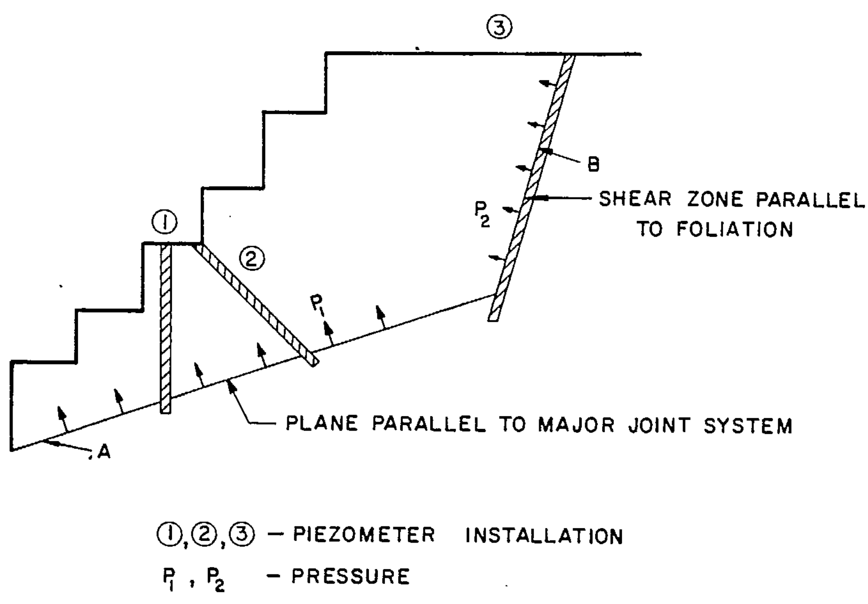


Fig 15 - Piezometers installed to measure water pressure on key slope surfaces.

lower plane parallels one of the major joint systems, while the place of higher failure is a shear zone paralleling foliation. The original slope design took the presence of groundwater into account. For recalculating stability of this wall section on these two planes, piezometers would be installed to measure water pressures on planes A and B. If a drainage system is installed as a corrective, the piezometers would monitor its effectiveness. If movement is found related to water pressure, remote-reading piezometers would provide safety monitoring.

Dynamometers and Artificial Support

70. Installation of load cell dynamometers is recommended where rock bolts or cables are part of an artificial support system. Combined with surface or borehole displacement measurements, they provide an evaluation of the anchorage system. Ideally, the dynamometers should show sustained load, with no appreciable displacement being detected. Increased load within the operating range of the bolt is acceptable provided displacement of the wall is arrested, as in Fig 16. In this case, the indication is that the wall section is stable and that the bolt anchorages are acceptable. Dynamometers using vibrating wires or resistance strain gauges as sensing elements are recommended because of their stability and suitability for the environment. They are easily included in an automated monitoring system. Dynamometers must be installed on a sufficient number of anchors to provide an adequate valuation of the artificial support system. It is shown in Appendix G that instrumentation costs represent about 50% of the total of such an installation. Instrumentation of one bolt in ten is recommended and a higher density is not practicable. With such low-density coverage, the sites for instrumentation must be carefully selected to provide the best monitoring of the artificially supported wall. The sites should be so chosen as to avoid geometrically constrained conditions, such as locations near a pit floor where loading may not be representative of more severe conditions higher on the wall. Anchorage assemblies under the heaviest loads distributed across the width of the supported pit wall section

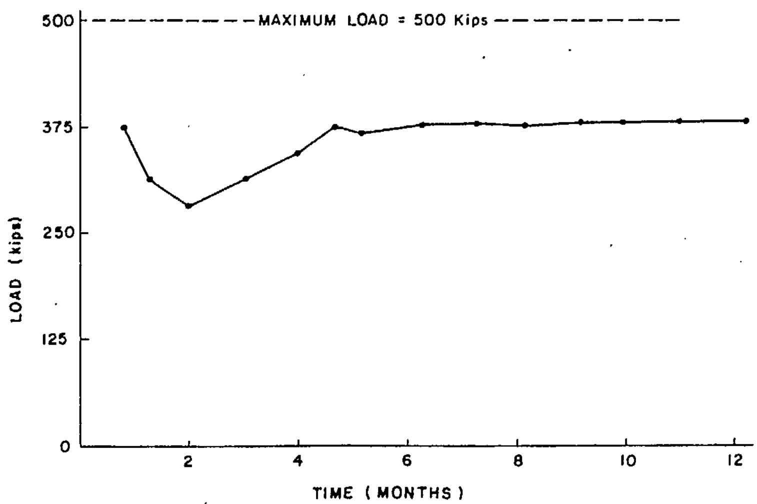


Fig 16 - Dynamometer bolt load as a function of time in a stable wall.

should be selected for instrumentation.

Ground Vibration Measurements

71. Supplementary ground vibration measurements may be required in Level II if the final pit walls are believed to be adversely affected by blasting. A common indication is back-break greater than expected or excessive ravelling of the pit wall (Fig 17). Berm widths reduced by back-break can impair their effectiveness against falling rock. Excessive fracturing of the wall increases scaling costs and adds to the hazard of falling rock. Control of ground vibration from production blasting is important when weak structural features are present.

72. Various blast patterns or blast control procedures can be tried to improve final pit walls. Where unacceptable wall damage has resulted from previous production blasts, a reduction in pattern charge weights and explosive strengths can be tried initially. Transition to control blasting normally involves the use of buffer rows as a first stage. Buffer rows could be considered part of a production blast for areas near the final pit wall. Depending on structure, controlled blasting can make use of the final row of holes for cushion blasting, presplitting or line drilling.

73. Vibration measurements should be taken for the various patterns to provide comparisons. Less vibration should result in less damage to the pit wall, and should reduce the effect on a marginally stable wall. Chapter 7 describes the equipment for making such measurements and gives the procedures for applying them.

74. Vibration measurements might be required to establish the level at which a marginally stable wall undergoes movement due to production blasting.

Telemetry in Level II

75. If a Level II monitoring program includes a large number of stations with frequent measurements, or if safety is an important factor, the use of a telemetry system is justified. Experiments to establish correlations between vibration, groundwater level, and slope displacement could also justify the use of such a system. Stations in dangerous locations and difficult to reach are best read remotely.

76. Measurement of surface displacement is adequate for the purpose of safety, together with those of displacements detected by borehole extensometers and load changes on dynamometers where

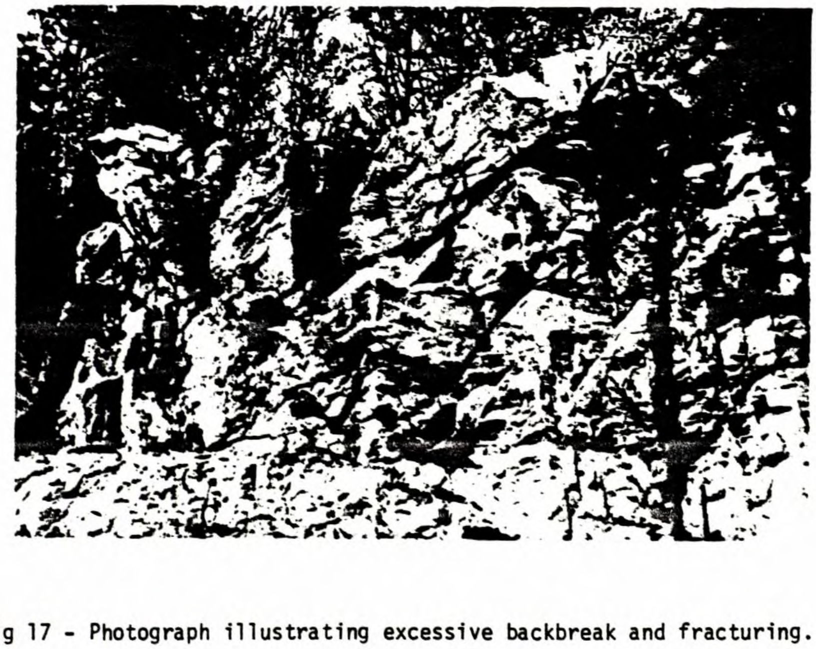


Fig 17 - Photograph illustrating excessive backbreak and fracturing.

artificial support is used. Consideration should be given to the systematic telemetry of surface displacement bays along the axis of moving blocks. A succeeding section will deal with telemetry systems and their application to pit slope monitoring. Appendices H, J and K provide details of telemetry systems that have proven satisfactory.

Summary of Level II Measurements

77. Table 5 summarizes the type of measurements regarded in Level II monitoring and how they might be applied.

LEVEL III

General

78. Stabilization of pit wall sections will not always be possible, as an effective engineering response may not exist or may be uneconomical. In either case, instability may be accepted as a condition of mining, and the monitoring system contributes to the continued safe operation of the pit in its own way.

79. Prior surface displacement measuring systems will be incorporated into a Level III program, as will be measurements associated with artificial support systems.

Detection of Pit Slope Movement in Level III

Surface movement

80. At this late stage in the development of an unstable zone, the boundaries and failure mechanisms are well established. The adequacy of the surface displacement stations installed as part of Level II monitoring should be reviewed with regard to safety monitoring in Level III. Existing surface displacement extensometers may have to be relocated or new ones installed to measure block movements adequately. If during the later stages of the failure large movements are expected, linear potentiometer units may have to be replaced by wire extensometers because of their more suitable range. Large sections of the disturbed area may become inaccessible with time, and so the installations should be undertaken as early as possible, and with some built-in redundancy. The only additional displacement monitoring equipment would be EDM-theodolite targets and surface strain extensometers. If telemetery is not possible, the strain bays should be equipped with limit switches and visual warning devices.

Sub-surface movement

81. Borehole extensometers installed on unstable wall sections to monitor artificial support systems should be used if possible as part of a Level III monitoring system. They will only be suitable for such an application if equipped with sensors connected to a telemetry system.

Geotechnical Parameters in Level III

Dynamometers

82. Dynamometers mounted on rock anchors should be monitored during the advance of instability if this can be done safely. The strain- or vibrating-wire gauge-equipped dynamometers are ideal for remote sensing. The instrumented bolts will indicate the progressive failure of an anchorage system. Additional prisms should be installed on the heads of critical anchors for their movement to be monitored.

Telemetry in Level III

83. There should always be sufficient surface strain bays, borehole extensometers, and dynamometers in a Level III system to detect any sudden displacement or loss of support. Either a highly developed program of manual on-site monitoring, or telemetric monitoring, is required with this instrumentation. Telemetry in conjunction with computer control of interrogation and data processing permits a speed of assessment not possible with on-site monitoring. A telemetry system for Level III monitoring is most valuable.

Summary of Level III Measurements

84. The types of measurement used in Level III are summarized in Table 6.

Table 5: Measurements in level II monitoring

Type of measurement	Instrument	Purpose
Displacement surface	EDM-theodolite unit	With stations installed on crest and pit face, to establish the extent of the zone undergoing movement, to establish the direction and rate of displacement, to establish the type of failure and, for safety monitoring.
	Level	With stations installed on crest and pit face, to establish the zone undergoing movement, vertical displacement and displacement rate.
	Pegs and tape	On crest and berms to measure small crack displacements: to establish if cracks are active, to establish the direction of movement through arrays of these units, and for safety monitoring.
	Surface displacement extensometers	With installations on crest and berm surfaces, to measure the displacement and rate of displacement.
Displacement sub-surface	Inclinometer	To detect sub-surface displacement relative to stable ground and to confirm or establish structural features on which displacement is taking place.
	Borehole extensometer	To monitor displacement of artificially supported walls, to monitor displacement of pit walls from underground galleries, and for safety monitoring.
	Inverted pendula	With installation on crest and berm surface, to detect displacement relative to shallow stable structures.
Water pressure	Piezometers	To establish the water regime in pit walls, to establish the water pressure operative on surfaces active in failure, and to evaluate the effectiveness of drainage systems.
Ground vibration	Seismograph	To measure the acceleration, peak particle velocity and displacement resulting from blasting to investigate the effectiveness of control blasting techniques and to correlate vibration level, displacement with wall damage.
Cable and rock bolt load	Dynamometer	To measure load on anchor system.

Table 6: Measurements in level III monitoring

Type of measurement	Instrument	Purpose
Displacement on surface	EDM-theodolite	To measure displacement and rate of displacement of unstable zone.
	Surface displacement gauge	To measure displacement and rate of displacement of unstable zone.
Cable & rock bolt load	Dynamometer	To measure load on anchor system.

ROCK NOISE AS A PHENOMENA FOR MONITORING

85. Experiments to develop ground vibration monitoring as a means of detecting instability have been carried out for a number of years.

86. Prototype system developed for use in underground mines have indicated the benefits from this type of monitoring. By establishing the rate and source location of microseismic activity, cumulative noise-location plots can be prepared (Fig 18). They are valuable in establishing zones where ground support is becoming a problem (6, 7).

87. In open pit mines, the relationship between microseismic activity and displacement has been clearly established. Figure 19 shows the relationship between the frequency of seismic events and displacement as found in an open pit mine (8).

88. The onset of instability is generally marked by the occurrence of tension cracks and development of more than usual loose face material. Seismic monitoring must therefore compete with cheaper and more direct methods which are available for the detection of unstable zones. It is not yet clear whether seismic monitoring has advantages which will offset the additional cost.

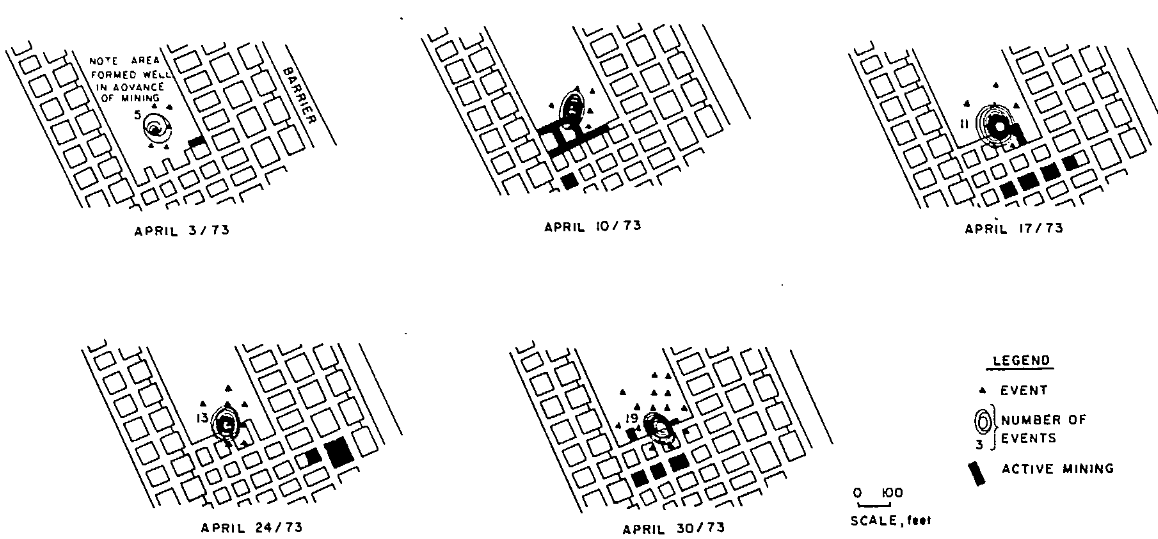


Fig 18 - Cumulative noise location plots in a coal mine showing growth in bounce area prior to occurrence on April 30 (after Hooker et al).

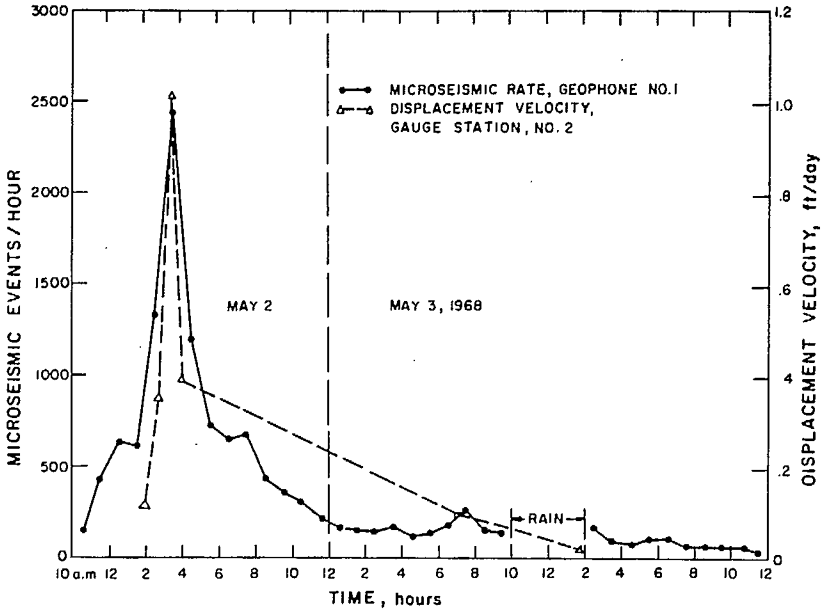


Fig 19 - Plot of hourly microseismic rate versus displacement (after R.M. Stateham and J.S. Vanderpool).

THE MONITORING OF ROCK FALLS AND SLIDES BY RAILWAYS

89. F.L. Peckover has made a survey of monitoring systems used to detect rock slides and falls by railways systems in several countries. Some of the systems have potential application in open pit mines (9).

90. Railways in Norway and Japan use electrical fences to detect slides. Figure 20 is a photograph of a Norwegian fence. The longer vertical members are wooden posts set in concrete or drill holes. Shorter pickets between the posts are used to support horizontal wires at approximately 6 in. spacing. These wires are connected to pull-out electric plugs. A rock slide in the fenced area disconnects the plugs which are connected to a signal system to indicate the occurrence of a slide. Mercury switches on the posts indicate when they have been knocked over. The Japanese use radio links with their fences to send a warning signal to nearby stations.

91. Peckover states that with a standard fence, false warnings are given about 80% of the time. He believes however that there is considerable merit in the use of electrical cable well anchored at both ends to detect movement of a rock mass or passage of loose rock down a gully or hillside. When the cable is broken, a signal indicates the occurrence. Such a system could be used in an open pit mine to monitor small unstable crest zones and fractures. It is inexpensive, not prone to damage, and easy to maintain.

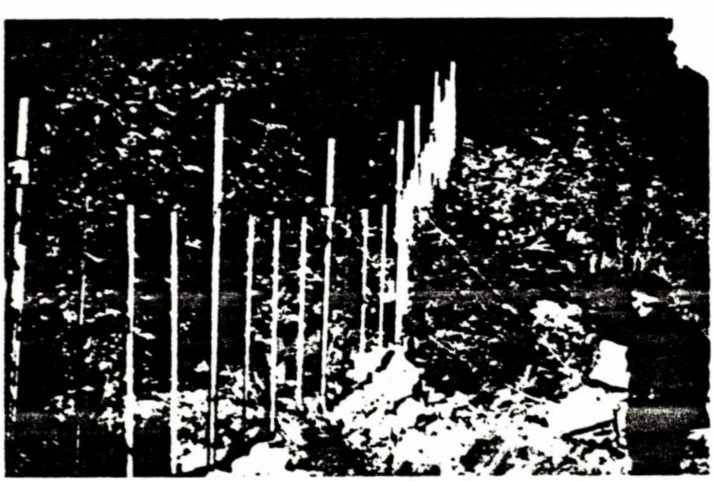


Fig 20 - Norwegian electric warning fence (after F.L. Peckover).

DATA COLLECTION AND PRESENTATION

92. It is essential that data collection and presentation procedures be employed that are flexible and permit conversion of basic data into usable engineering information in a fraction of the time required to gather it. This requirement could necessitate the introduction of telemetry and rapid data processing equipment. Manual data collection procedures should be used to aid their introduction.

DATA COLLECTION

93. Where manual interrogation is involved with or without telemetry, field data should be recorded on a standard computer coding form with suitable headings. Where the 72 character field of a single card is not sufficient, a series of such cards should be used.

94. Forms requiring or encouraging field calculation of final engineering values should be avoided, unless essential for checking purposes. Field calculations increase the chance of errors in collecting basic data.

DATA PRESENTATION

Surface displacement

95. In spite of the common use of surface displacement monitoring systems, no clear guidelines have been developed for data interpretation. The responsible engineer must establish the significance of a slope's displacement behaviour in terms of short-and long-term stability.

96. Normally, for slope behaviour analysis, displacement or rate of displacement is plotted as a function of time. To illustrate, Fig 21 is displacement plots of stations located on a bench at the Endako mine which ultimately failed. In this case, as in others, it is the sudden change in the rate of displacement which predicts failure. Maximum rates of movement have been established with respect to waste dumps at some mines whose operations have been suspended to allow re-stabilization of the slopes. A similar predictive capability must be developed for rock slope displacement data if it is to be fully exploited.

97. It is recommended that rate of displacement plots be prepared whenever displacement measuring devices are used. As in the case shown in Fig 21, where there is some measurable geotechnical parameter believed to contribute to the instability, an additional axis should be provided for its plotting. In a slope containing piezometers, it is possible that the bar chart recording precipitation and shown in Fig 21 would be re-

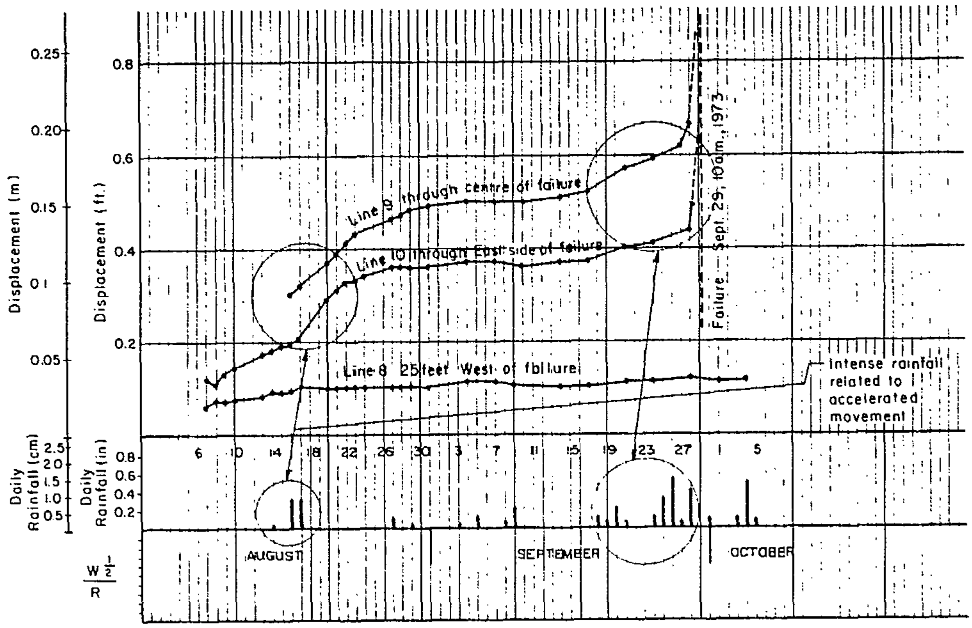


Fig 21 - Displacement versus time plots for stations at Endako mine on a bench that failed and a plot of area rainfall as a function of time.

placed by plots of piezometric pressures or variations in phreatic levels at stations around the pit.

98. Ground vibration levels produced by nearby production blasts offer another measurement which deserves consideration when plotting displacement data. For comparative purposes, relative vibration levels produced in a slope by production blasts can be estimated using the following formula:

$$V = \frac{k.W}{R^2}$$

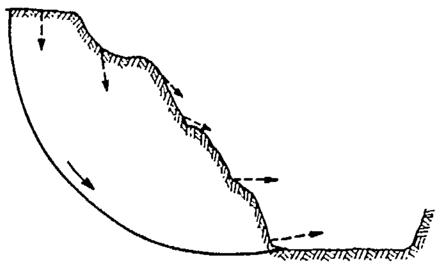
where V = relative peak particle velocity
k = arbitrary constant
W = charge weight (all charges with less than a 15 ms delay included as one)
R = distance between slope and production blast

Figure 21 contains a third axis showing how these pseudo-particle velocity levels would be plotted to analyze vibration level effects on wall movement.

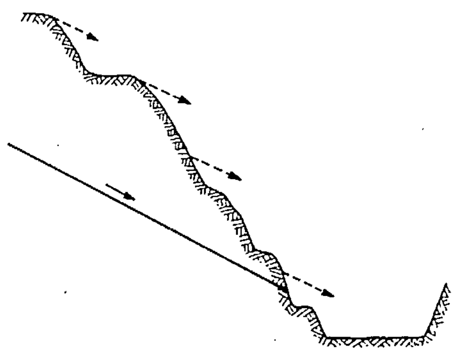
99. Where many stations have been installed on a slope, plots of displacement vectors on mine plans and sections are useful in giving a perspective of slope behaviour. These plots have particular value when the potential mode of failure is being established. The displacement pattern in section will vary with the type of failure, as illustrated in Fig 22.

Sub-surface Displacement

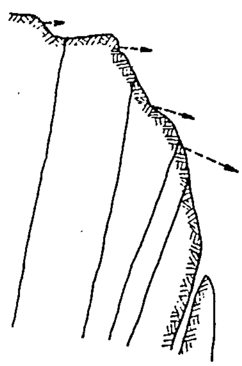
100. Displacement-time plots are the recommended forms of data presentation for borehole extensometers. Figure 23 gives a plot for a multi-wire extensometer used to measure lateral stope and pillar deformation in a mine converting from open pit to underground mining. The numbers refer to production blasts for developing the adjacent stope. Installed in pit walls, devices of this type can locate active internal surfaces. Similar displacement plots are recommended for use with inverted pendula installations. Displacement vectors for these devices should be incorporated in any plan or section diagrams prepared for the purpose of indicating overall slope movement.



(o) Rototionol foilure



(b) Plone or Wedge foilure



(c) Toppling foilure

Fig 22 - Characteristic displacement for (a) rotational, (b) plane or wedge, and (c) toppling failure.

101. The primary purpose of the borehole inclinometer is to detect and locate sub-surface planes on which slope displacement is occurring. Measuring displacement of the collar of the hole with an inclinometer has only secondary interest as this can be more easily and accurately found from surveys. The data plotting recommended is therefore that of horizontal displacement as a function of depth and time, as shown in Fig 24. It provides the best method of establishing the interface between active and inactive pit slope sections.

Vibration

102. When blast vibrations are monitored by transducers placed at different distances from the source, particle velocity data should be plotted on log paper as shown in Fig 7. To permit the plot to be used with charges of all sizes, distance is scaled on the basis of the cube root or square root of the charge weight. Charge weight is considered to be the weight of all charges detonated with no intervening 15 ms delay. Plots of this type should be developed whenever basic changes in the blast patterns are introduced, or new rock types or conditions encountered. Vibration levels can be significant factors in slope displacement behaviour.

Load Cells

103. Load cell readings should be prepared in tabular form and used to calculate the mean load on the tensioned bolts or cables forming the artificial support system. Standard deviation from the average load should also be given. The mean bolt load would be used to estimate the working force being generated by the artificial support system. Periodic analysis of the readings indicate changes in the condition of the slope. A continued increase of load on the cells will occur if the slope has not reached a stable condition. Loss of load on a significant number of the cells would indicate poor support installations. Figure 25 shows a table recommended for recording load cell data.

104. A mine plan should also be kept available for ready reference to the locations of all

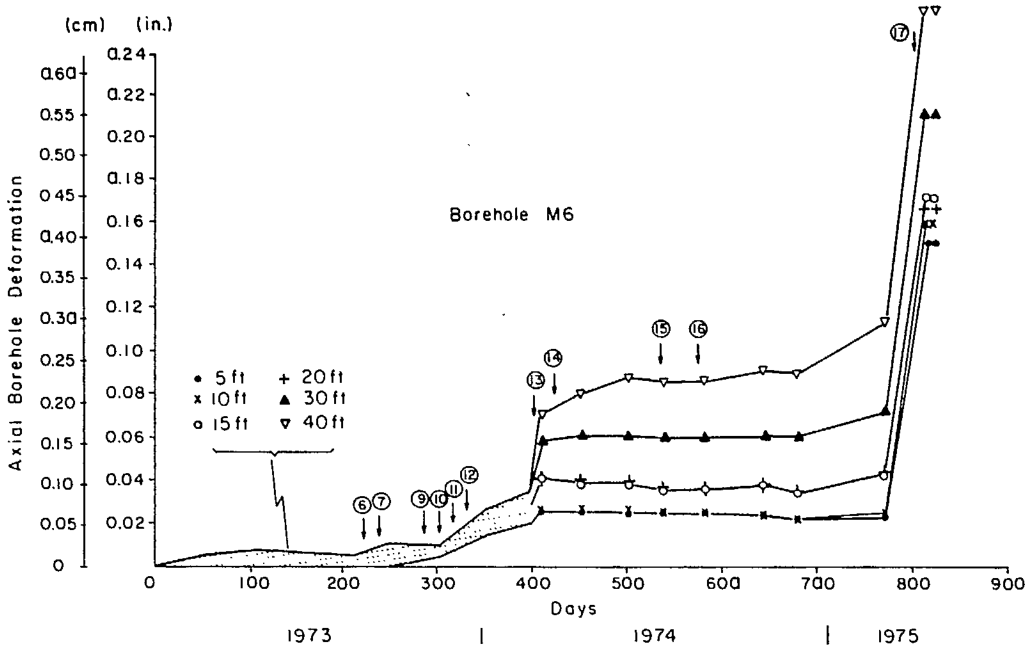


Fig 23 - Transverse pillar expansion with slope development measured with a multi-wire extensometer.

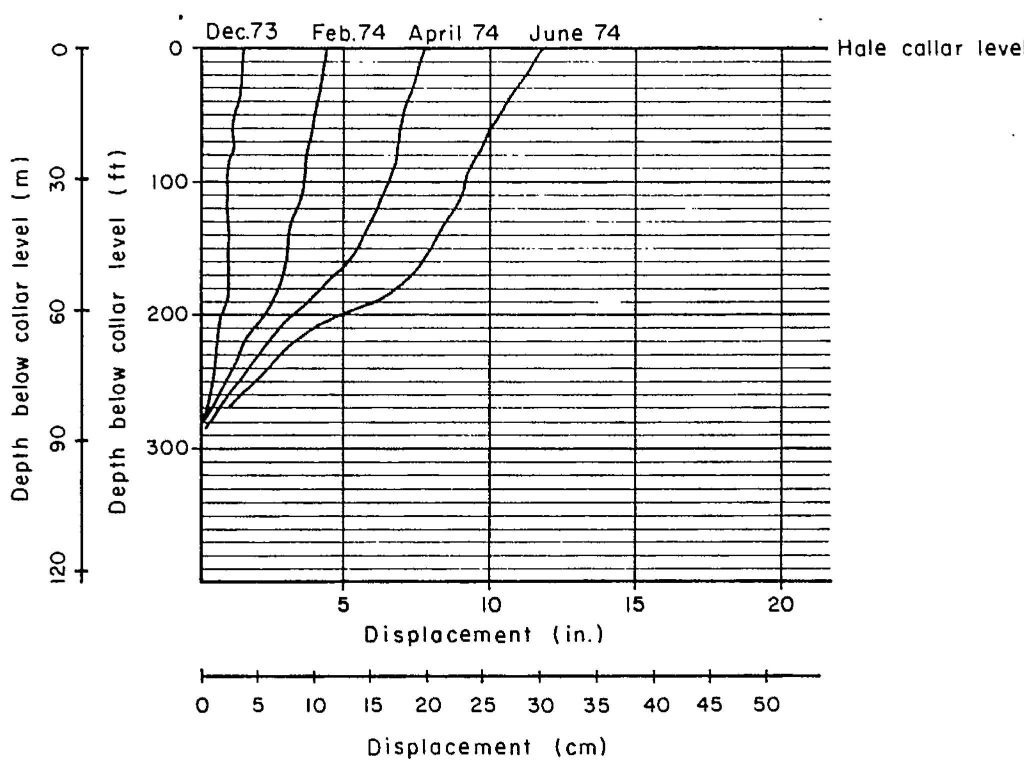


Fig 24 - Diagram illustrating the plotting of inclinometer displacement data.

LOAD CELL DATA FORM

Date of Reading										
Load Cell	Maximum Load (Kpsi)	Working Force (Kpsi)								
Mean										
Standard Deviation										
Standard Error										

Fig 25 - Model of a load cell data form.

support installations and load cells. Such a plan is valuable in analyzing changes in bolt load patterns. It should also indicate the location of other monitoring devices suitably numbered to aid reference to peripheral data.

Piezometers

105. The presentation of groundwater data is treated in Chapter 7.

TELEMETRY AND DATA PROCESSING SYSTEM

FUNCTIONAL DIVISION OF SYSTEMS FOR GEOTECHNICAL MONITORING

106. A telemetry and data processing system for geotechnical monitoring will carry out some or all of the following functions: sensing, signal conditioning, modulation, transmission, demodulation and processing, display and storage. Depending on the complexity and function of the geotechnical monitoring program, frequency modulation (FM/FM) or frequency shift (FSK) digital modulation will be used for data transmission. Figure 26 shows schematics of systems based on FM/FM and FSK modulation of data. The division of equipment and their function is given for the case in which remote stations are located in a pit, a base station at the engineering office, and a master station at some distance from the mine. Appendix H describes a system using FSK modulation.

Sensors and Sensing

107. That part of an instrument which translates a variable into an electrical signal is called a sensor. Each physical variable to be measured in the context of slope monitoring requires such a sensor if telemetry is to be used. Sensors are required to measure displacement, pressure, force, angle and temperature, with necessary precision and range and under prevailing environmental conditions.

Displacement sensors

108. A number of sensors are available for translating linear motion into electrical signals. Linear and rotary potentiometers, linear variable differential transformers, and digital encoders will be considered here.

109. A potentiometer must be incorporated into the displacement measuring chain so that movement or rotation of the cursor gives a measure of any displacement occurring between anchorage points. A rotary potentiometer will require the use of a mechanical rack and gears for its incorporation. In the case of a linear potentiometer, the mechanical requirements will be minimal. As a result, the apparent cost advantage of a rotary potentiometer relative to the more expensive linear unit is lost in machining costs.

110. A plastic film potentiometer, because of its better resolution and longer life, compared with wire-wound units, is recommended as a displacement sensor. Only servo-mechanism potentiometers are considered sufficiently rugged and pre-

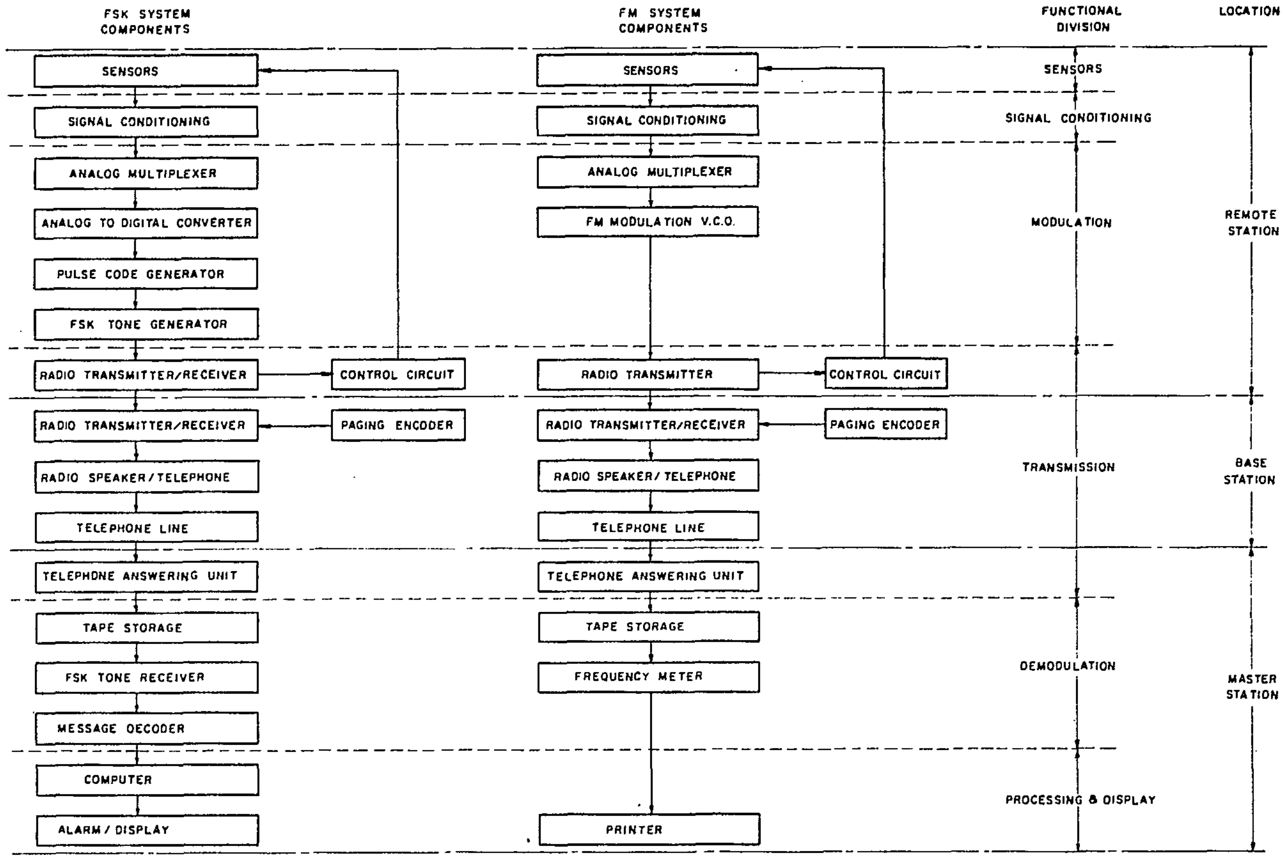


Fig 26 - Components of a 3-station telemetry system (remote, base and master stations) showing components divided on a functional basis.

cise for the present application. With a slight deterioration in linearity, these units will function over a temperature range of -50°C to +85°C. Units with a linearity of 0.1% of full scale and stroke lengths of up to 2 ft (0.61 m) are commercially available.

111. Neither linear variable differential transformers (LVDT's) nor the modified units which require a DC voltage supply and provide a DC output proportional to core displacement (DC LVDT), are recommended as sensors to measure displacement in open pit mines. Both units have poor thermal stability and are more expensive than a potentiometer of equivalent capability.

112. Another form of sensor that can be used is an optical or mechanical absolute encoder. Both are rotary devices and, as in the case of rotary potentiometers, the mechanical coupling costs are high. Appendix H shows that the units themselves are expensive. Their operation is restricted to a temperature range of 0°C to 70°C.

Pressure sensors

113. Water pressure is a factor that often has to be sensed in monitoring. Electrical resistance and vibrating wire gauges are suitable sensor elements. They are normally attached to a diaphragm which flexes under applied pressure.

114. Strain gauges are usually employed in the form of temperature-compensated full bridges. Zero shift of the bridge readings is of the order of 0.002% of the full-scale reading per °F. Their signal size, however, is small and only short lengths of cable can be used before signal

conditioning is required. As a result, amplifiers compatible with the sensor's environment are necessary; this requirement can constrain their use where telemetry is considered.

115. Vibrating wire sensors are rugged units which are little affected by temperature because of their all-steel construction. A large, variable frequency, low impedence signal is produced and allows long cable lengths to be used before conditioning is required. They are ideally suited for use in open pit mines.

Load sensors

116. The conventional load cell in which the deformation of a cylindrically shaped member is used to sense load on a bolt or cable is recommended. Vibrating wire or electrical resistance strain gauges are suitable sensors. The discussions and conclusions concerning their use in measuring water pressure also apply to their use as load sensors.

Angle sensors

117. Moveable inclinometers using servo-accelerometers and a variety of gravity-referenced devices as sensors are commercially available. The former, which are new, have much higher sensitivity and system accuracy than do the latter. Advances in miniaturization have also allowed the development of borehole units which permit the use of smaller and cheaper drill holes. Some, but not all, of the non-servo-accelerometer inclinometers have shown changes in calibration factors with temperature. Because of the small rock slope movements which must be detected, movable inclinometers using servo-accelerometers as sensors are recommended.

Temperature sensors

118. Sensors used in monitoring are affected by large changes in ambient temperature. Temperature measurements must be made to allow for compensation of sensor readings. Three types of devices are used by industry to measure temperature: thermocouples, resistance thermometers and thermistors. The thermocouple is not recommended for open pits. Only micro-volt signals would be produced over the temperature range encountered, and signal conditioning would be a costly problem. The primary advantage of the resistance thermometer over the thermistor, is overcome with the use of a linearizing network. Thermistors are recommended as temperature sensors in slope monitoring.

Signal Conditioning

119. Sensors for slope monitoring produce either voltage, frequency or digital signals that need conditioning for transmission to a gathering point or remote station.

DC voltage signals

120. Amplification is the most common form of signal conditioning for DC voltage signals. Three situations are usually encountered:

a. weak signals at a millivolt level which must be boosted to the volt level, as in the case of strain gauge sensors;
b. signals from high impedance sources which must be transformed to a lower impedance to avoid noise interference, as in the case of piezoelectric sensors; and
c. signals requiring power amplification to drive such devices as galvanometers.

121. Operational amplifiers or instrumentation amplifiers cost little and are widely used to carry out these kinds of signal conditioning. They can also perform other functions such as span- and zero-adjustment. Such signal conditioning units also provide tie-points for connecting one side of a signal pair to the common circuit.

122. Since small DC signals are vulnerable to noise, each sensor should be connected to an amplifier by a cable as short as possible. The amplifier should be limited to a passband of DC to 10 Hz, except in the case of dynamic signals provided by geophones. The lower impedance, higher level output signals of these amplifiers permits transmission over distances of 100 feet or more without problems. Differential amplifiers are preferable to single-ended amplifiers because of their superior noise rejection qualities. Power supplies with good regulators should be used with the amplifiers.

Variable frequency signals

123. Vibrating wire sensors are the only geotechnical sensors that produce variable frequency signals. Any voltage signal can, however, be converted to a frequency signal by means of voltage-controlled oscillator (VCO). This provides a constant amplitude output whose frequency varies linearly with input voltage. It is an excellent form of signal conditioning where long cables are required as it is less vulnerable to noise than are voltage signals.

124. For extremely long lines vibrating-wire sensors may require the use of an amplifier for conditioning. A suitable amplifier meeting all environmental requirements is easily found because of the form of signal modulation.

Digital signals

125. There are digital sensors with 'serial' and 'parallel' output. To permit economic transmission by wire or radio link, parallel output format must be converted to serial at the conditioning unit. In general, the output levels provided by the conditioning unit are acceptable if the "0" state is 0.5 volts ± 0.5 volts and the "I" state is 4.5 volts ± 0.5 volts.

Signal Modulation

126. Digital or FM/FM data modulation are useful alternatives for wire or radio link transmission. The factors which must be taken into account in selecting a modulation system are: the bandwidth of the communication channel, the number of variables and the accuracy required.

127. If a telephone line is used as the communication link, the outside frequency limits will be 300 and 3000 hertz. A similar bandwidth will be available if radio telemetry in the VHF range is used, as commercial telemetry is limited to voice-grade channels. Unless the expense can be borne for special phone lines or the use of multiple VHF channels, a 300 to 3000 hertz bandwidth becomes a design constraint.

128. Fortunately, slope monitoring does not require large bandwidths for the simultaneous transmission of many short period transient phenomena. Whether FM/FM or digital modulation (FSK) is used, there will be sufficient time for serial transmission of the data from the various sensors scanned sequentially. In general, signals from the sensors measuring displacement, water pressure, and load are quasi-static. In an emergency, a selective scanning of critical sensors can be carried out to increase sampling rate.

129. In the case of FM/FM data modulation, the channel bandwidth places a definite constraint on the accuracy of the data transmitted. If detection at the receiving end is limited to changes greater than 1 hertz, then a voice channel of 300 to 3000 hertz will only permit detection of sensor signal changes of 1 part in 2700. If frequency multiplexing is used to give several simultaneous channels for transmission, there will be a corresponding reduction in the accuracy of the data transmitted.

130. FM/FM modulation does not permit an address to be included with the transmitted data. This can be a significant disadvantage where a large number of sensors are being monitored.

131. When digital modulation is used, the bandwidth does not affect the accuracy with which data can be transferred. However, the time of transmission will increase as accuracy increases, as the data is transferred serially. Accuracy is dependent on the quality of the equipment purchased to carry out the data modulation and demodulation.

Signal Transmission

Reading modes and remote stations

132. Remote stations will normally be operated from battery power supplies and interrogation procedures must be used which economize on power consumption. The three modes of remote station interrogation are automatic warning, periodic reporting and polling or dialling with wire systems.

133. Automatic warning is technically the least complex mode. It is often used when limit switches form part of a device to detect excessive displacement. Closure of the switches causes a

radio transmitter to emit bursts of modulated audio frequency which are detected at the master station. It is a reading mode that must be used with caution as it does not provide a fail-safe system.

134. Periodic reporting requires the use of a low current drain timer inside the remote station to switch on the equipment at discrete intervals. With a telemetry system consisting of many remote stations, the synchronization of the timers can pose a problem. The long-term differential drift of timers can cause two or more remote stations to transmit simultaneously, creating interference. Also, the fixed scanning cycle and the time required to adjust it may be unacceptable restraints.

135. The third reading mode, although more expensive and complex, offers greater flexibility. The basic principle of polling is to interrogate the remote stations from the master station with a calling device capable of addressing them at random. As remote stations will be battery operated in most cases, transmitter/receivers that function with low current drain must be used. Under normal conditions, polling of the stations can be done periodically, much as in the case of the periodic reporting mode. When particular attention is required however, there is the option of adjusting the interrogation cycle.

Wire and radio links

136. Wire and radio links can be made between remote, base, and master stations. Technical requirements and economy will be the factors in selecting the link.

Transmission over short distances in an open pit mine

137. When the sensors are clustered and not too distant from the master station, a wire system can be considered as shown in Fig 27(a). The maximum practicable area would have a radius of 500 ft (152 m). Easy access by cable from the master station to the clustered sensors would be required. No mining modification requiring re-laying of the cables used in the system should be foreseen. A system using wire links would have to cost significantly less than an equivalent radio link system to justify its selection, considering its relative inflexibility and greater susceptibility to damage.

Transmission over long distances in an open pit mine

138. Sensors located at considerable distances from each other throughout a pit cannot be linked directly to a master station. Sensors within reasonable distance of each other must be linked by cable to a remote station, which in turn will

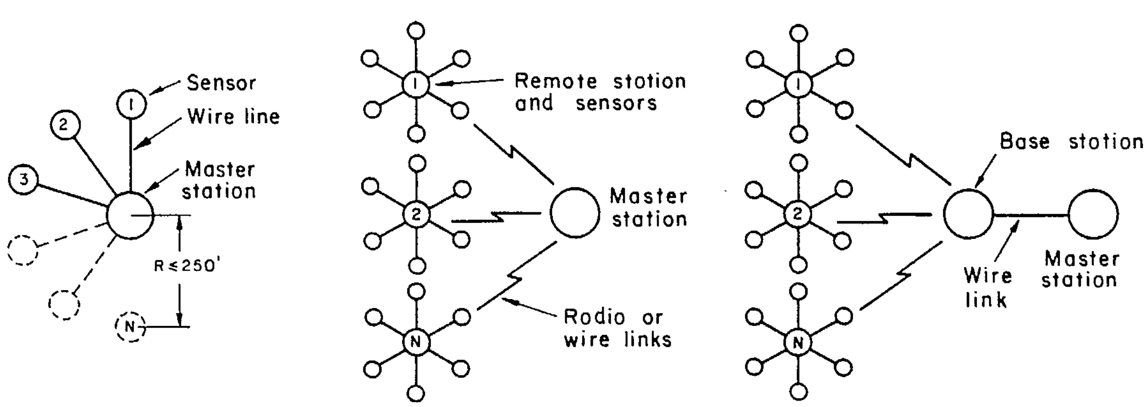


Fig 27 - Sensor-station linkage on figurations - (a) wire linkage of sensors to master station, (b) wire linkage of sensors to remote stations, and (c) the use of an intermediate base station.

be connected to the master station as in Fig 27(b). Providing all remote stations are at the periphery of the mine, connection to the master station by telephone line is possible. For remote stations located within an open pit mine, a radio link to the master station is the only practicable link. Since transmission distances never exceed a few miles, the power required is small. For the remote station, an industrial hand-held radio receiver/transmitter is generally adequate. Rugged, low-drain and highly reliable units are available at a cost not exceeding $1200 (1976). These units are described in Appendix J.

Transmission with master station at some distance from an open pit mine

139. If the master station has been located at some distance from the mine to aid data processing, the data link to the mine will be best served by a telephone line as in Fig 27(c). Two configurations can be used to link the remote stations to the master station.

140. In one configuration, the remote stations are dialled directly from the master station. Such an all-wire system has been used at Gibraltar Mines, B.C. For a radio system to have similar capabilities, the mine base station must be equipped with a phone patch, and a radio link independent of the mine dispatch radio must be available.

141. In the second configuration, the need for an independent base station is avoided. The dispatcher interrogates the remote stations when voice communication activity is low. Acoustic coupling links the remote station to the master station or to the data processing centre by telephone. The message containing the data can be recorded or fed to an on-line computer for immediate processing.

Data Display, Storage and Processing

142. The addition of telemetry to a monitoring system is a major advance in its sophistication. It permits easier access to raw data from the installed sensors. Even with a limited number of sensors, however, data logging and processing can become a restraint. The problem can become particularly serious if safety monitoring is an important function of the system.

143. In the subsequent sections, data display, storage, and processing are considered for the following systems:

Type 1: a master station with a few remote stations connected by telephone lines,

Type 2: a master station with a few remote stations connected by radio link or telephone line,

Type 3: a master station with a number of remote stations under computer control, connected by radio links.

Type 1 system

144. The best examples of this kind of system are in use at hydroelectric dam sites. Wires from the individual sensors are brought to a central reading point. The receiving station, via cable, acts as the excitation source for the sensors. The received signals are not usually modulated. The receiving station provides conditioning for the signals received prior to further processing. Conditioned data is produced by printer, magnetic or paper tape. As an example, the Maihak company offers a receiving system that scans up to 26 vibrating-wire sensors and prints the data, date and time on paper tape. The Telemac Model PC 2-R functions in a similar manner and provides a BCD data output. There are many similar systems commercially available consisting of a scanner, clock numerical display and storage which can be used with strain gauge and voltage signal sensors. Some models are equipped with preset alarm points. With all such systems, the low operating temperature limit is 0°C and they require a substantial source of 110 V AC power. Therefore, a heated shelter with AC power is required for the master station. The use of a Type 1 system is favoured where a suitable shelter can be found for the master station near a group of sensors which can be linked by cable at reasonable cost.

Type 2 system

145. Manual dialling or polling in the case of remote stations linked by telephone or radio, is recommended as a simple and economic form of scanning when no more than 10 stations are involved.

It is important to note whether the stations are transmitting FM/FM or FSK signals.

146. With FM/FM modulation, a conventional frequency meter attached to the operator terminal of the master station will provide a suitable numerical display. Most of the frequency meters now on the market can be purchased with a BCD output, and some with an ASCII output. Many have options with clocks that permit the time of reading to be printed with the data.

147. With this scheme the variables are unfortunately not identified other than by the order of printing. While individual remote stations always transmit their data in the same order, care would have to be taken to scan the remote stations in the same order. One remedy for this problem would be to use an automatic remote station scanner.

148. A system with remote stations transmitting FSK signals should be used when many remote stations, each with several sensors, are included. Two factors make it a superior system:

a. The data message contains bits that identify the variable being telemetered, and this avoids confusion.
b. The analog voltage from the sensor can be amplified or attenuated to provide a read-out in engineering units. A teletype printer with the same features as in the Type 1 system can be used to display data and to warn of emergency.

Type 3 system

149. The functions of a monitoring system as well as the desired number of remote stations must be considered when introducing computer control. A system having as few as 20 to 25 sensors could justify the use of a mini-computer if the following capabilities were considered essential:

a. safety warning system with short time delay,
b. automatic scanning of remote stations,
c. sensor linearization and compensation,
d. readout in engineering units,
e. efficient and quick processing for trend analysis,
f. data logging of such variables as displacement, and
g. rapid adjustment of scanning cycles.

Most of these functions could be carried out by discrete instruments but custom circuits for adaptation and control would have to be designed. A mini-computer with peripheral equipment provides a flexibility that hard wire systems lack. With the use of a computer, all changes in the monitoring configuration, or in the functions to be performed, involve software modifications.

150. The small EDP (electronic data processing) required to perform these tasks should cost less than $20,000 (1975). Many vendors supply mini-computers with peripherals connected and tested, and with software specifically included for data processing and programming in BASIC, a language that does not require previous experience. Such a versatile mini-computer is often called a desktop calculator because it is fitted with a keyboard that consists of standard teletype keys, plus about 2 dozen function keys that simplify programming. Among the active vendors in the field are Hewlett-Packard, Solarton, Digital Equipment Corp., Interdata, Data General Corp., Varian, and Keithly.

151. Taking advantage of the computer capability to act as a controller as well as a calculator, scanning of the remote stations can be done by polling them methodically. The scanners supplied by vendors of computerized data acquisition systems cannot be used for this telemetering application, because they are designed for laboratory use only. In the case of wire systems, where remote stations are linked to the master station by telephone lines for the purpose of scanning, a different subscriber number can be given to each remote station.

152. "Dialers" can be purchased from computer manufacturers which can be connected to the telephone network, with the telephone company's permission. The computer can be programmed to dial remote stations without assistance. In the case of wireless systems where tone paging is used to interrogate remote stations, a digital-to-analog converter (D/A) can be used to make contact with the computer. The D/A converter produces a voltage proportional to the binary number supplied by the computer. By connecting the output of the D/A converter to the input of a voltage-controlled oscillator, tones can be generated as programmed.

By using an interval clock, the computer can page the remote station by sending bursts of tones that have the right duration, frequency and order. The computer must also energize a relay that substitutes for the "press-to-talk" switch of the base station. The VCO output is connected to the microphone input of the base station. For periodic scanning, a real-time clock that generates a binary output corresponding to the month, day, hour, minute and second, paces the interrogation periods. The same clock supplies information to relate the data to time of occurrence; its output is an input to the computer.

153. The input to a computer is usually in the form of parallel bits. The most popular mini-computers for data processing have 16-bit input. There is also provision for a "ready" signal, emitted by the device generating the data, and which is interpreted by the computer as a request to interrupt execution of the program under-way, and to read the new data. The computer returns a "hold" signal to that device until the request for interruption can be granted. This occurs when there is no other request having a higher priority. Typically, a request for such interruption is served within 100 micro-seconds. Interruptions synchronize the computer with the telemetry system.

154. A simple system based on FM/FM modulation with a frequency-meter and BCD output, lacks the ability to generate a signal to request interruption, as distinct from FSK modulation. If there are only a few sensors per remote station, a program can be written using an interval clock to generate interruptions for reading the frequency-meter output, while the sensor signal is being transmitted. This procedure is practicable when the transmission lasts many milli-seconds. With many sensors per remote station the computer is not fully utilized, however, and the lack of positive identification of sensors raises a risk of ambiguity.

155. A telemetry system with FSK modulation is ideal with an on-line computer because the digital message is readily adaptable to computer processing. Most manufacturers of communication equipment supplying FSK decoders offer a computer interface unit as an option. It consists of a plug-in card that has small "buffer" memory to register the complete transmission from one remote station. When the transmission is completed, a ready signal is sent to the computer. A control circuit on the interface card allows the computer to address the memory, and to read the variables in the order determined by the program. The output appears as parallel bit signals that include the variable address, and the number of times it has passed the cyclic code, so that the computer can reject the data if this number is lower than that acceptable. The data read by the computer is stored in the main memory called the "core-memory". The programs and the operating system are also stored in that memory. For data acquisition, the mini computer is usually supplied with an 8000 word memory. This suffices for executing the programs normally encountered.

156. For long term storage of data, the memory capacity must be increased. Core memory can usually be expanded in increments of 4000 words, but this is relatively expensive. Such other types of memory devices as magnetic drums, discs, tapes and casettes are less expensive but cannot compete for speed of retrieval; this is not a requirement, however, where old data is concerned.

157. The other types of memory therefore serve as "bulk" or "mass" memory and operate as peripherals to the computer; most sophisticated desk-top calculators have built-in casette memory units. Casettes constitute a handy form of data storage; also, they can be sent by mail for processing at other locations. At the time of slope redesign, for instance, they provide a data bank for analytical purposes.

158. The most valuable peripheral apparatus for day-to-day needs is the teletype, a relatively slow printer. Monitoring will not require continuous data logging; usually a complete report will be asked for once a day by means of the keyboard. The computer would report by teletype only the abnormal conditions, printing the time of occurrence of the anomaly, the identity of the off-limit variable and its values.

159. Comparing with the acceptable limits specified in the user's program permits the computer

to detect and to indicate abnormal conditions. The program can be written to modify summary procedures so that remote stations with active sensors can be interrogated more often. The computer can also be used to energize alarms in the form of horns or blinking lights when a dangerous condition develops. A relay with its interfacing card which makes this function possible is a very inexpensive output device when ordered at the time of purchasing the computer. Alarms can be sounded miles away if a telephone-dialer is connected to the computer. Between periodic scans of the remote stations, programs could be developed which bring into operation a plotter to present visually the results of analysis of the stored data.

GUIDELINES ON TELEMETRY SYSTEMS

160. A variety of telemetry systems of various complexity have been described in previous sections. The present section is concerned with providing some guidelines in selecting a particular system, and describing the characteristics of that system. A system is characterized by the kind of communication units used, the arrangement of stations, the type of signal modulation used, and the degree of sophistication in the data processing. The decision as to the type of system adopted will depend on the quantity, location and disposition of sensors, the safety role of the system, and the cost.

161. The simplest system would be concerned with a few sensors located at the crest of the pit quite close to a heated shelter containing a simple master station. In this particular situation where wires would be used as links, conditioning, would be required but no modulation of the signals. Either programmed or manual read-out of the data would be used and converting the data to engineering units would be done manually.

162. If clusters of sensors around the pit cannot be connected to a base or master station by wire link, either for economic or technical reasons, remote stations would have to be used. The sensors would be connected to the nearest remote stations by wire links. The individual remote station would be polled by paging or by dialing. If the number of sensors is only one or two at each remote station, FM/FM modulation can be used. With more than two sensors, FSK modulation is recommended. With up to 10 remote stations, manual interrogation is practicable; above this number, programmed interrogation is recommended. Data processing facilities will be required if safety considerations call for an automatic warning system.

163. It is worthwhile to remember that, if necessary, data processing can be done far away from the pit. Once the signals have been FSK modulated for voice-graded channel transmission, a simple telephone line or a small Telesat earth station with a 10 ft antenna, like that used by Panartic Oil at Melville Island in the N.W.T., can carry slope stability data anywhere for processing.

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APPENDIX A

DISPLACEMENT MONITORING WITH THEODOLITE

AND ELECTROMAGNETIC DISPLACEMENT MEASURING UNITS

INTRODUCTION

1. The detection and measurement of slope displacement using survey networks and targets is a basic form of open pit monitoring. The present appendix is concerned with the equipment and procedures used to carry out this form of pit monitoring.

GENERAL FIELD LAYOUT OF NETWORKS

2. Figure 1 illustrates the more common form of monitoring network used in open pit mines. T represents a crest or pit face target whose position is to be monitored. The configuration shown is best suited for establishing target positions by triangulation from S_1 and S_2. It is also possible with two observation stations to establish a target position by traversing with an EDM-theodolite unit.

3. Normally, when the latter method is used, one of the stations, S_1 or S_2, is located behind T on stable ground. The observation station behind the target is then used as a backsight and provides correction for atmospheric effects.

4. Observational stations not used as backsights, such as S_1 and S_2, are located close to the pit edge to permit observing targets at all bench levels. Because of their proximity to the pit edge, periodic checking of their position is required. As illustrated in Fig 1, this is done by relocating them with respect to secure mine survey stations such as R_1 and R_2. Apparent movement of targets due to movement of observational stations can be corrected by this means.

5. If survey monitoring of displacement is limited to the crest region of a pit, traversing can be used. Traversing would be carried out between two secure mine monuments with a number of intervening stations as illustrated in Fig 2. In the past, precise displacement measuring by traversing was accomplished using a first order theodolite and subtense bar. Small EDM units attached to the theodolites can now be used for this purpose.

SURVEYING OPERATIONS

6. With the survey displacement monitoring system illustrated in Fig 1, two distinct survey operations are involved: the periodic re-establishment of the position of the observation stations referenced to the mine survey system, and the more frequent monitoring of target positions from the observation stations.

7. It is recommended that surveying to re-establish the position of observation stations be carried out at least twice a year. Triangulateration, triangulation and trilaleration with levelling in that order are the recommended survey

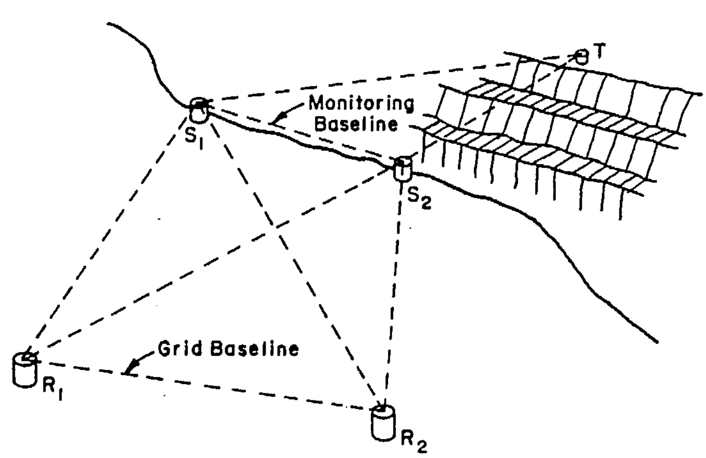

Fig A-1 - Diagram illustrating typical location of mine, R_1 and R_2, observational, S_1 and S_2, and target, T, monuments.

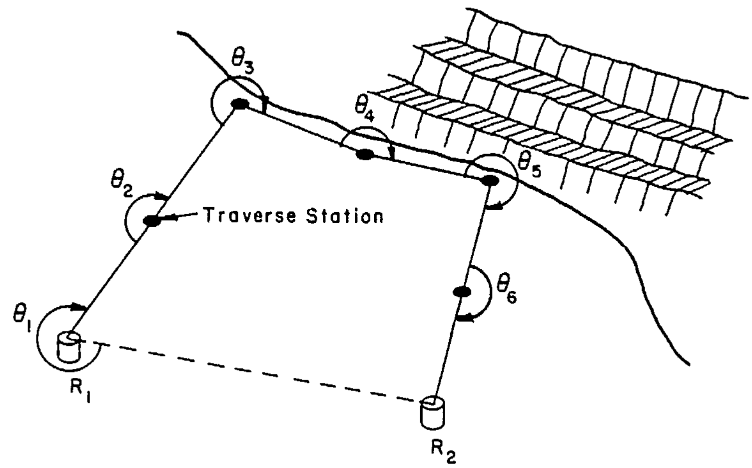

Fig A-2 - Diagram illustrating typical traverse monitoring of crest region.

methods. Triangulaterations involves the measuring of both angles and distances between stations in the survey figure. A basic requirement is the availability of a suitably accurate combination of theodolite and EDM unit or a combined EDM-theodolite.

8. Figure 3(1) illustrates how target positional accurary achieved with triangulateration is superior to the other two survey methods: triangulation or trilateration. A standard error of 2.8 seconds is normally achieved with four position reading of a 1 second theodolite. Most medium priced EDM units have standard errors in distance measuring capability of the order of 0.2 in. (5 mm). Figure 3 therefore provides a realistic indication of the accuracy with which survey observation stations can presently be located with reasonable effort. Within the distance range of 600 (180 m) to 4000 ft (1200 m), and with medium price range, survey equipment

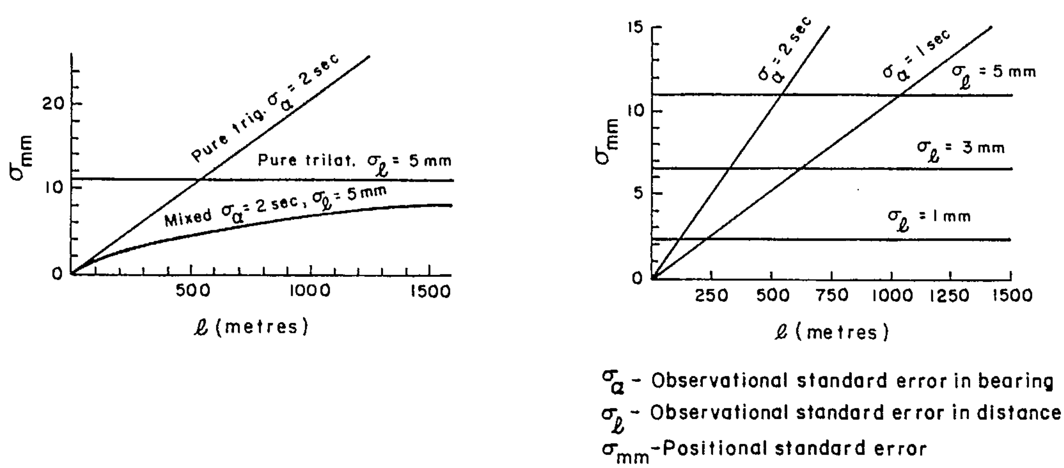

Fig A-3 - Positional accuracy of P by triangulation, trilateration and triangulateration for an isoceles triangle survey figure with 70° base angles and P the apex opposite the base [after V. Ashkenazi (1)].

available (1 second theodolite and EDM unit with a standard error of 0.2 m (5 mm) triangulateration is the recommended method for relocating observation stations.

9. Figure 4 is a diagram of the survey network used for pit displacement observation at Hilton Mines. It provides an indication of the time required to survey such a network. A and B are observation stations located on a berm surface 400 ft (122 m) below the pit crest. They are being used to monitor the displacement of targets on the opposite pit wall by means of triangulation. R_2 and R_3 were existing mine survey stations having first order elevations. Monuments C and D were installed at the pit edge to provide interconnection between R_2 and R_3, and A and B.

10. For the purpose of establishing the location of A and B, the survey figure was considered to consist of two quadrangles ABCD and R_2 R_3 DC. In quadrangle ABCD all angles were measured using a Kern DKM2A and all distances using a Tellurometer MA 100. In quadrangle R_2 R_3 DC, all

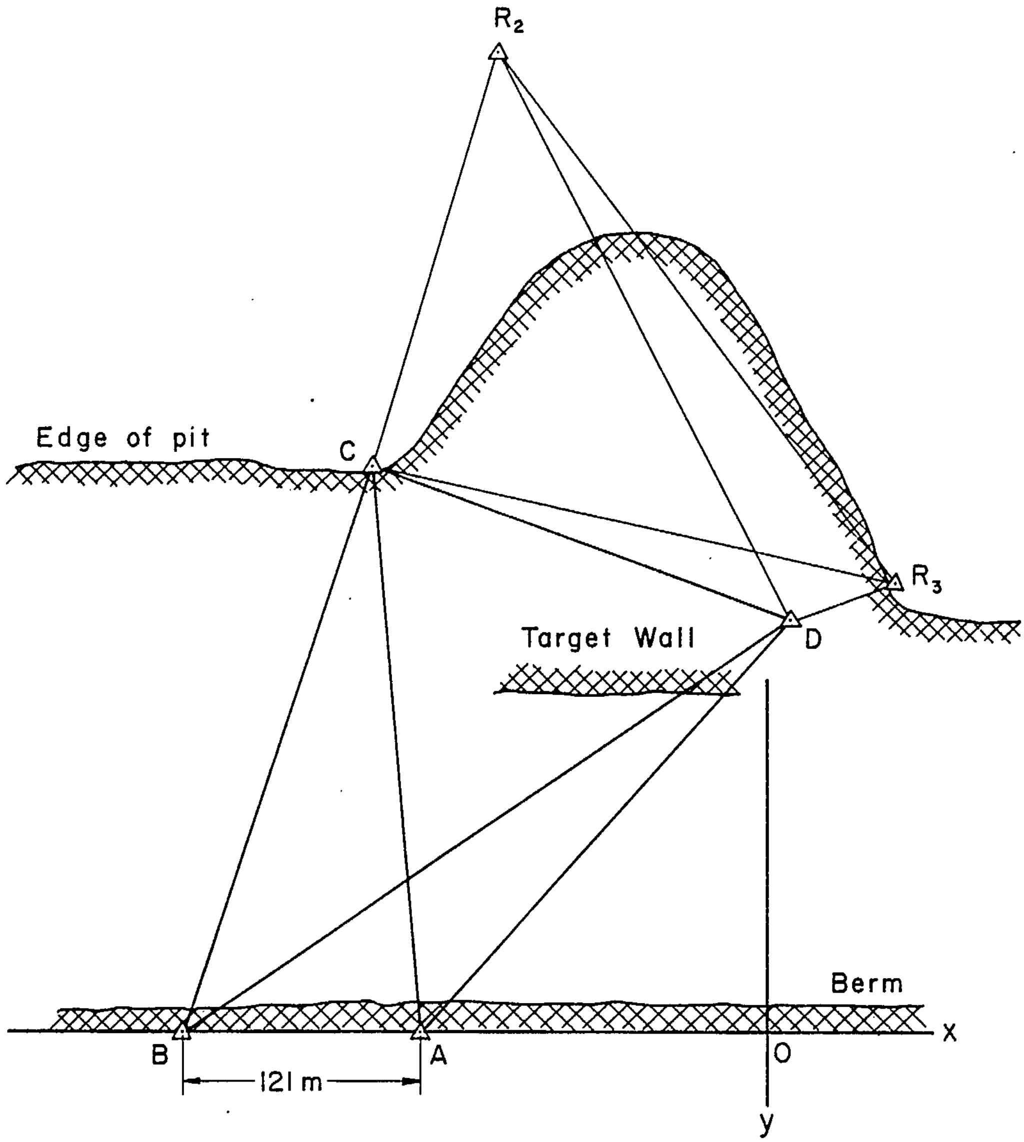

Fig A-4 - Diagram of Hilton Mines observation survey network.

distances were measured using an MA 10D. Since R_2 and R_3 had first order elevations, spirit levelling was used to establish the elevations of C and D. Ultimately the position of A and B were established with an accuracy of ± 0.12 in. (± 3 mm). The entire survey operation required a period of 3 days.

11. Two survey procedures can be used to monitor the position of pit targets from observation stations: traversing and triangulation. If traversing is used, an EDM unit and theodolite or a combined EDM-theodolite unit is required. Preferably one of the observation stations becomes a backsight located on stable ground behind the target area. Distance measurements made between the observation station and the backsite are used to correct EDM readings for atmospheric conditions. The monitoring of target displacement consists of traverse measurements between the backsight and the various targets. Traversing is recommended rather than triangulation for the following reasons:

a. it is often difficult to establish a suitable length base line for triangulation of pit slope targets;
b. it is the more economic method of measuring target displacement.

If only slant distance measurements are made to targets a further saving in time can be realized. This is the standard monitoring procedure used by some companies. Angular measurements are only made when a change in slant distance to a target indicates movement has occurred.

12. Either a theodolite with subtense bar or a

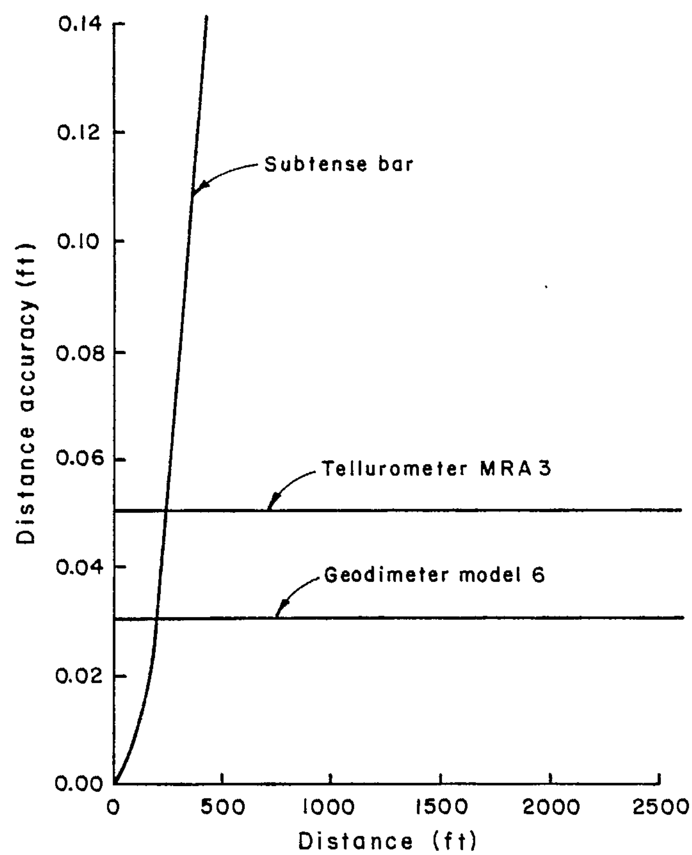

Fig A-5 - Accuracy of distance measurement as a function of distance using a subtense bar (1 second theodolite) and two EDM units [after R.B. Buckner (2)].

theodolite equipped with an EDM unit can be used to carry out traverse measurements on a pit crest as illustrated in Fig 2. If a subtense bar is used and high accuracy required, the distance between adjacent stations must be limited to 150 ft (46 m) (2). Figure 5, (3) compares the accuracy of distance measurement with a subtense bar and 1-second theodolite and with two EDM units as a function of station distance. With termination of the traverse line between two secure stations, adjustment procedures can be used to improve the accuracy of location of the individual traverse stations. Where traverse stations have separation distance greater than 150 ft, the recommendation is to use an EDM-theodolite unit or equivalent having the required measuring accuracy.

SELECTION OF SURVEY INSTRUMENTS

THEODOLITES AND ACCESSORIES

13. A number of factors must be taken into account when selecting a theodolite for pit slope displacement monitoring.

14. An instrument is required which permits realization of the measuring accuracy required with a reasonable number of independent measurements. Survey monitoring at a pit may involve daily reading of a number of pit targets and the time involved is a factor which must be taken into consideration. Purchase of a 1 second theodolite is recommended for pit slope displacement monitoring. The recommended reading procedure is four independent readings for each target using four independent settings on the horizontal circle. Reference to Table A-1 will show that with this procedure a standard reading error of ± 2.8 s can be realized using a 1 s theodolite. It is with considerable more effort and readings that a standard reading error of ± 1 s is approached.

15. In pit slope monitoring, targets subtending significant vertical angles with respect to the observation station are common. Errors in measured horizontal angles can result from the telescope axis not sweeping out a truly vertical arc. To avoid this error a theodolite should have a stride level.

16. Precise and easy-to-make measurement of vertical angles is an essential feature for pit slope monitoring. Ideally the accuracy of vertical angle determination should be equivalent to that attainable in the horizontal plane. This is now possible with the use of theodolites with automatic collimation or vertical indexing. The Kern DKM2A is an example of this type of instrument. A liquid compensation achieves automatic collimation and establishes the horizontal plane with an accuracy of ± 0.3 s. This feature is also important where trignometric leveling is being carried out to establish datum points on benches within an open pit mine.

17. If the theodolite is to be used in traverse measurements with an EDM unit, an instrument and tripod must be selected which allow repositioning of the theodolite and the targets with an accuracy of ± 0.04 in. (± 1 mm). Except in the case of KERN equipment, an optical plummet will be required to reposition the instrument over the targets. With most survey equipment no mechanical means exist to position accurately the axis of the theodolite or target over the station. With the KERN single centre screw tripod head, a tripod with centering rod and level permits repositioning of the survey instrument and targets over the stations to within ± 0.04 in. (± 1 mm).

EDM UNITS AND ACCESSORIES

18. Unless displacement monitoring is limited to traversing in the crest region with short distances between stations, EDM units having sufficient signal strength to work over ranges of

Table A-1: Standard deviation as a function of independent readings

Instrument	Standard deviation of the mean (seconds)				
	Horizontal angles				Vertical angles
	4 pos	6 pos	8 pos	16 pos	4 pos
Wilde T 3	1.2	1.0	0.8	0.6	5
Kern DKM 3	1.2	1.0	0.8	0.6	4
Wilde T 2	2.8	2.3	2.0	2.0	15
Kern DKM 2A	2.8	2.3	2.0	2.0	2

1000 metres with a single prism should be used. Such units as listed in Table A 2, have been successfully used in the more conventional monitoring illustrated in Fig 1. It is recommended that test trials with a borrowed unit be carried out before purchasing an instrument to establish its suitability under the most severe conditions envisaged.

19. If the EDM units' only function is to measure slant distance, those having an accuracy of 0.2 in. (5 mm) are recommended, bearing in mind the increased costs and greater accuracy that may be expected. If trilateration is envisaged as a means of accurately surveying the observation stations, then some thought should be given to purchasing a unit having the accuracy of a Tellurometer MA 100.

20. EDM units such as the Geodimeter 700 and HP 3810A also measure angles and are therefore complete units for traversing targets from observation stations. This additional angular measuring capability is expensive however, and measuring accuracy does not approach that attainable with a 1 second theodolite such as the KERN DKM 2A. Each mine must decide whether the convenience of a single unit outweighs the greater overall measuring accuracy attainable with two separate less expensive units. If making slant distance readings is standard monitoring procedure, purchase of the simpler type of EDM is recommended.

21. Glass prisms should be used as targets. The ultization of less costly reflectors is a false economy. The increased chance of a target failing its function when a cheap reflector is used can not be accepted for what should be an essential installation.

Table A-2: Selected EDM units, their range, resolutions and accuracy

	Range		Resolution		Accuracy	
Instrument	(m)	(ft)	(mm)	(in.)	(mm)	(in.)
AGA 700 Geodimeter	5,000	16,000	± 1.0	± 0.04	± 5.0	± 0.20
H P 3800A/B	3,000	9,800	-	-	± 5.0	± 0.20
H P 3810 A	1,600	5,200	-	-	± 5.0	± 0.20
LSE RANGER III	12,000	39,000	± 1.0	± 0.04	± 5.0	± 0.20
LSE RANGEMASTER	60,000	197,000	± 1.0	± 0.04	± 5.0	± 0.20
TELLUROMETER MA100	1,000	5,200	± 0.5	± 0.02	± 1.5	± 0.06

MONUMENTS AND TARGETS FOR THEODOLITES AND EDM UNITS

22. Monuments for survey instruments and targets not anchored to pit walls must be provided with stable platforms. Fittings must be embedded into the monuments which will permit repositioning of the instrument through forced centering with an accuracy of ± 0.04 in. (± 1.0 mm). Figure 6 is a cross-section of a monument which has been used at Kidd Creek Mine, Timmins, Ontario to monitor slope movement with a Geodimeter 700. Figure 7 is a photograph of the monument with the EDM-theodolite mounted. Figure 8 provides details of a survey monument used by Geodetic Surveys of Canada with Kern instruments. Both will provide suitable stable platforms for pit slope monitoring.

23. The ideal monument site permits anchorage of the cement pillar to solid rock with rock bolts or rebars. A deep base resting on compact, undisturbed gravel is also suitable for installing a monitoring monument. A base resting on clay, sand or humus is not suitable, no matter what the depth.

24. For the purpose of traverse stations between crest EDM-theodolite monuments, the level stations shown in Fig 9 with a scribed centre mark can be used. An optical plummet or centering rod permits repositioning the survey instrument and traverse targets over the scribe marks with the required accuracy. Repositioning in terms of vertical height to ± 0.25 in. (0.64 cm) is sufficient for this type of displacement monitoring.

25. Depending on the present and future accessibility of a target, either permanent or removable prism stations or theodolite targets can be installed. Figure 10(a) and 10(b) provide details of detachable and permanent targets and mounts for glass prisms. Similar units can be designed as theodolite targets consisting of concentric black and white rings.

26. Targets are cemented in place using high viscosity epoxy cement. Care should be taken to clean the surface of all loose material using a chisel and wire brush. Ledges should be sought which permit targets to rest while the cement sets. To facilitate the location of targets, a large cross should be painted on the rock with the target at its centre.

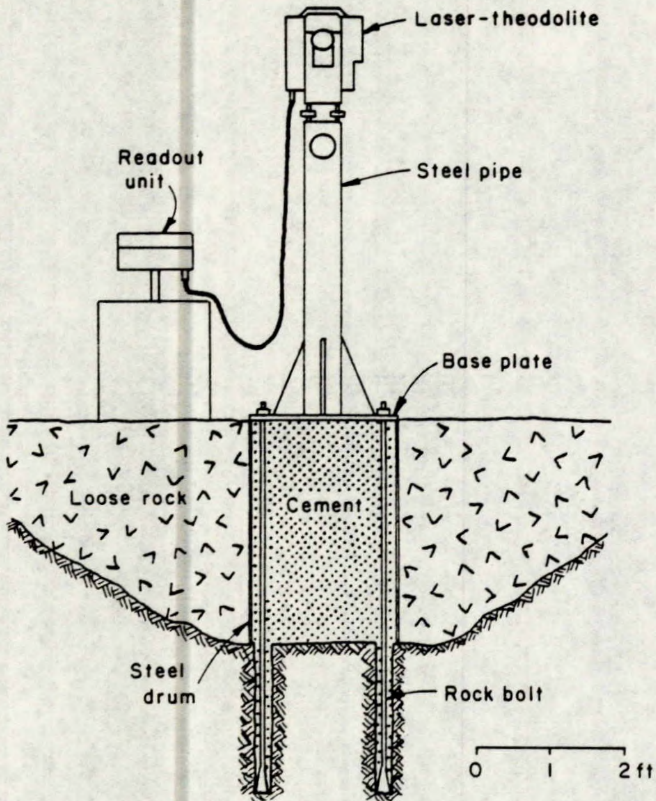

Fig A-6 - Diagram showing cross-section of Kidd Creek Mine observation monument.

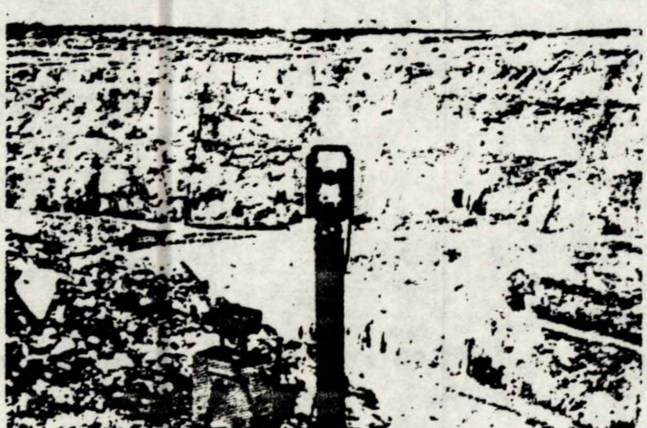

Fig A-7 - Photograph of Kidd Creek Mine observation monument.

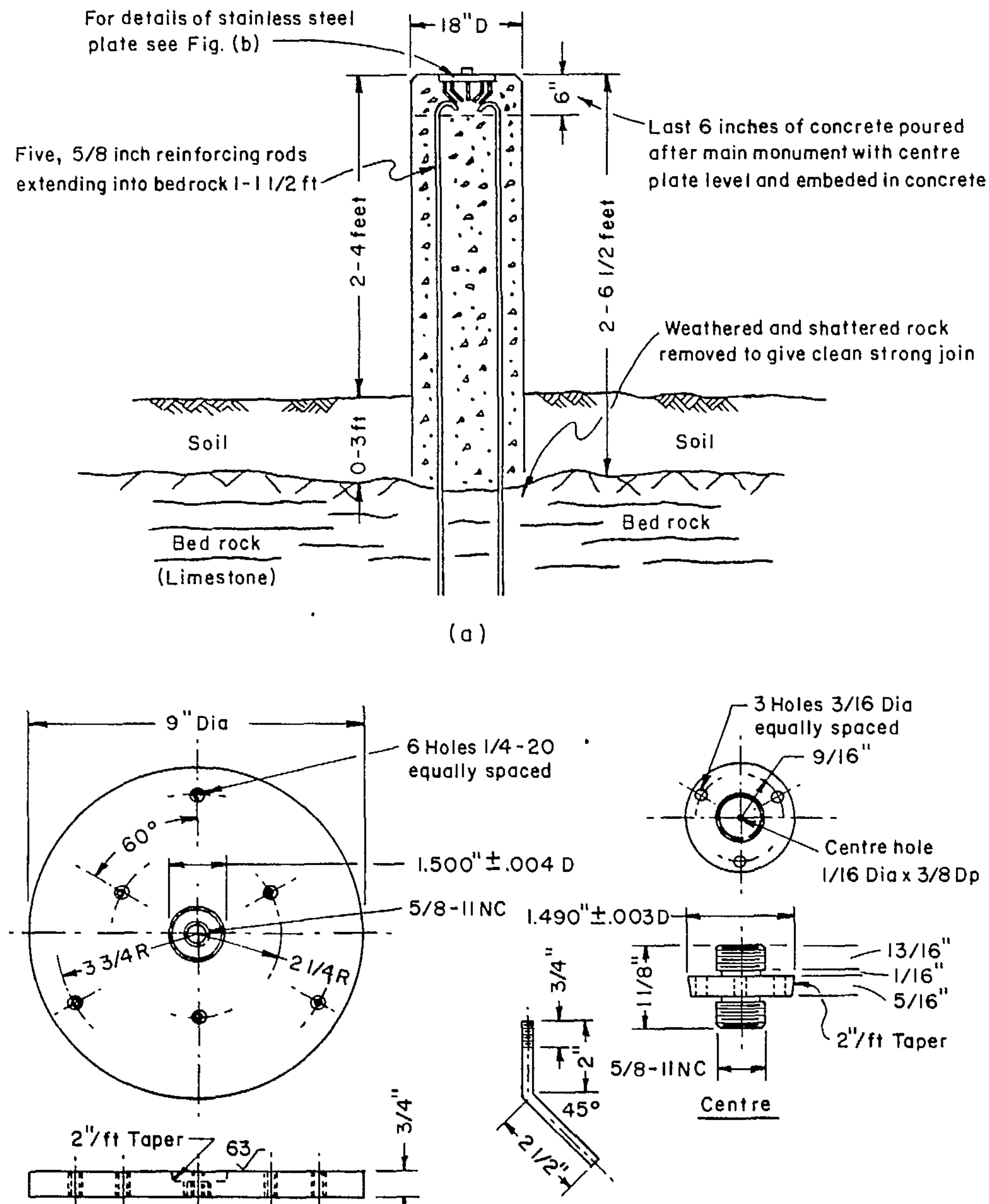

Fig A-8 - GSC survey monument (a) cross-section diagram and (b) instrument plate.

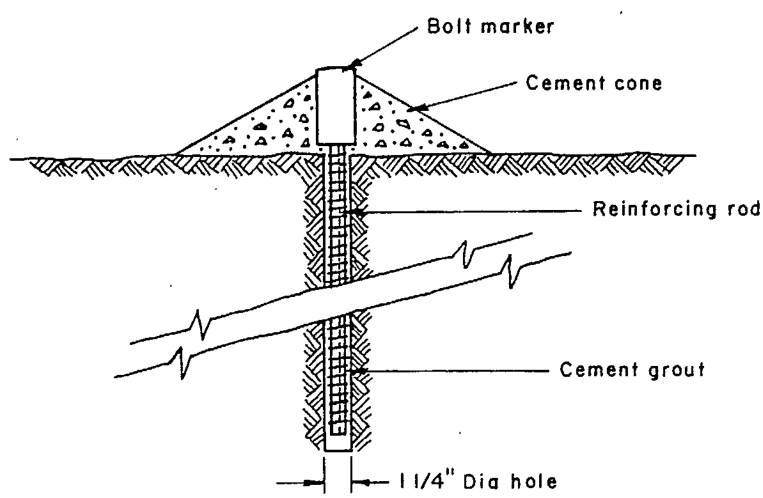

Fig A-9 - Cross-section of level station.

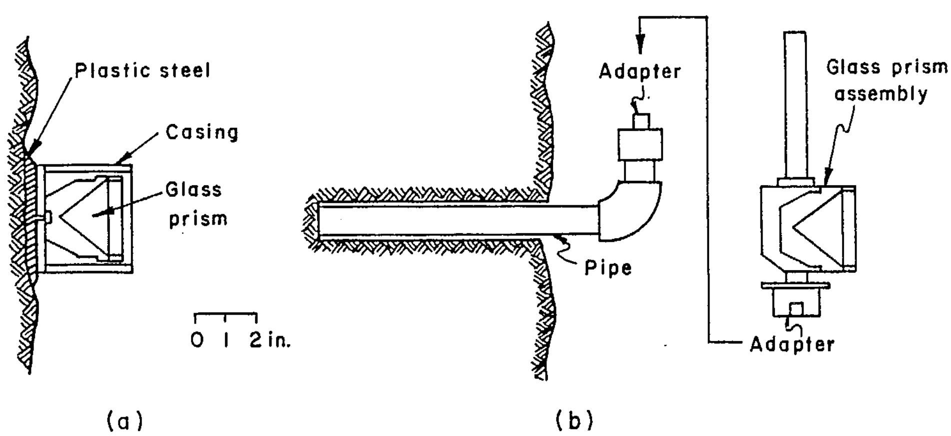

Fig A-10 - Wall target mount (a) permanent, (b) detachable.

RECOMMENDED READING PROCEDURE

27. Consideration will be limited in this section to reading procedures recommended for triangulation or for traversing of targets from observation stations.

28. In the case of triangulation, the targets should be divided into groups of five. All angular measurements should be made for each group before moving to the next group. Four independent measurements of all necessary angles for locating the targets by triangulation are recommended. The horizontal circle should be used in all four quadrants to reduce possible error due to eccentricity. With one setting of the horizontal circle the five targets in turn are sighted and the angles measured. Before repeating this reading process in reverse from the fifth to the first target, the horizontal reading circle is reset to provide a new initial reading in the next quadrant. This reading procedure is then repeated with the two remaining quadrants of the horizontal circle being used as starting positions for sweeping the five targets. The instrument is then moved to the second monument to provide four sets of independent readings. The four independent readings of each angle are averaged for use in calculating target positions.

29. A similar reading procedure is recommended with an EDM or EDM-theodolite unit. Initially, the EDM unit is sighted on the backsight target to establish angular reference and to adjust for atmospheric effect. It is assumed that the distance between the backsight and the observation station is constant and that any change in indicated slant distance is due to atmospheric changes. The calibration controls of the EDM unit are used to adjust the backsight slant distance reading to its established value before target monitoring. From this point, the EDM target reading procedure is identical to that recommended for a theodolite. The four independent slant distance measurements made to a target are averaged for the purpose of calculating the position of the target.

30. It has been established that 4 to 5 hours are required to monitor 30 targets with an EDM-theodolite unit using the above procedure. Approximately 8 hours would be required to monitor 30 targets using a theodolite and two observation stations.

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APPENDIX B

DISPLACEMENT MONITORING WITH LEVELS

INTRODUCTION

1. Level surveys are recommended where EDM-theodolite surface stations have been installed as part of a pit crest displacement monitoring system. Surface topography is required, however, which permits economic station installation at a suitable spacing. Levelling measurements and stations should be used to augment vertical displacement slope data provided by the sparsely located EDM-theodolite stations. The latter stations should be incorporated into the levelling circuits as datum points. The use of levelling circuits on berm surfaces is recommended to establish the lateral extent of a slide zone as well as vertical displacement.

GENERAL EQUIPMENT DESCRIPTION

GENERAL DESCRIPTION

2. The components of a levelling monitoring system consist of a level, levelling rods and monuments. These must be selected and designed to provide the accuracy and economy of measurement required. Since levelling measurements are used in conjunction with EDM-theodolite displacement measurements, they should be of comparable accuracy. Equipment and procedures should be used that can measure vertical displacements with an accuracy of ± 0.4 in. (± 1 cm).

Selection of a Level

3. Precise levels presently on the market are recommended for this type of survey. The level should be of the automatic type and be equipped with a parallel plate compensator so that maximum accuracy of measurement can be realized. Table 1 provides a list of some suitable automatic levels. It should be noted in the case of the Wild Ni2 that the parallel plate compensator is a separate unit added to the basic Ni2 unit. Some users consider the lack of completely enclosed optics a negative feature. The problem of dust will be particularly severe at an operating open pit mine. Compared with other types, automatic levels reduce the time required to carry out displacement measurements. They take 50% less time to set up

Table B-1: List of levels for pit slope monitoring

Make of levels	Automatic levelling	Micrometer	Mean square[1] error	Weight
Carl Zeiss (Jena)				
Ni 002	yes	yes	±0.3 mm√Km	6.5 kg
Ni 007	yes	yes	±0.5 mm√Km	12.1 kg
Carl Zeiss (Oberkocken)				
Ni 1	yes	yes	±0.2 mm√Km	5.2 kg
Ni 2	yes	yes (optional)	±0.3 mm√Km	2.4 kg
Ni 22	yes	no	±1.0 mm√Km	1.9 kg
Wild (Heerbrug)				
Ni	yes	yes (optional)	±0.4 mm√Km	3.0 kg

[1] Two-way levelling and invar tape rods.

and their accuracy is not adversely affected by direct exposure to sunlight; an umbrella is not required for shading when levelling.

Selection of Levelling Rods

4. Rods should be consistent with the quality of the level and accuracy of the results required. In the case of the instruments recommended in Table 1, invar rods should be used. Table 2 lists some of the invar tape survey rods currently available. Support struts, circular levels and ground plates are considered essential accessories for optimal monitoring results. The invar rods must have graduations consistent with the parallel plate compensator of the level. The offset double graduations of the rods listed in Table 2 provide a means of avoiding or detecting reading errors. Higher accuracy can be expected of rods with 0.20 in. (5 mm) rather than 0.39 in. (10 mm) divisions.

Levelling Monuments

5. Level stations will be located on crest, berms and pit wall faces within and around the pit. The ideal crest region is where overburden has been removed or the rock structure is naturally exposed. It is questionable whether

Table B-2: Invar tape survey rods

Company and unit	Length	Basic division	Temp coeff.
Wild (Heerbrug) GPL3	≈ 3 metre (upright)	1 cm	1 µm/m/°C
Carl Zeiss (Jena) 2 PräL3M	3 metre (upright)	5 mm	1.5 µm/m/°c
Zeiss (Oberkochen) L1	3 metre (upright)	1 cm	-
L12	3 metre (upright)	5 mm	-

level monuments are worthwhile in areas where substantial overburden increases the cost excessively. If a displacement station is essential in such a region, it should be upgraded to form part of the EDM-theodolite monument grid.

6. It is possible that the site selected for a station is on loose ground which is not apparent at the time of selection. Fracture-damaged rock on berm surfaces covered with crushed material is hard to detect.

7. Figure 1(a) is a diagram of the level station recommended for crest and berm surfaces. It combines a modified survey bolt marker, Fig 1(b), with a threaded No. 6 rebar, Fig 1(c). The

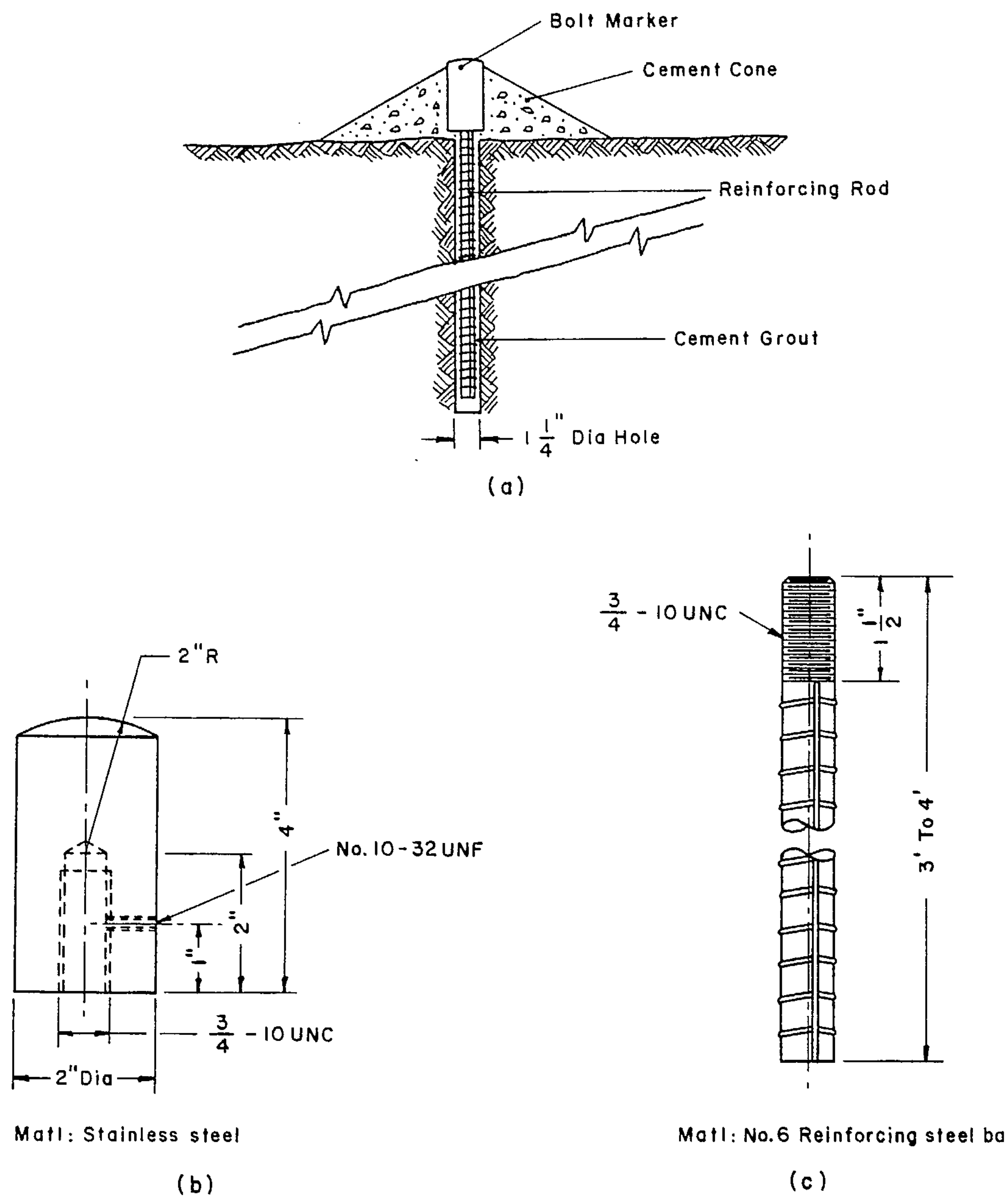

Fig B-1 - Diagrams of level station: (a) cross section of level station, (b) bolt marker, and (c) rock anchor.

purpose of the rock bolt is to anchor the marker to a large rock mass. Three to four foot lengths of rebars installed in 1-1/4 in. (3.2 cm) diameter drill holes are sufficient for this purpose. The survey bolt markers which extend 4 in. to 5 in. (10 cm - 13 cm) beyond the collar of the hole should be protected against damage by a cement collar as shown in Fig 1(a). At locations where the marker is in low-lying ground, rebar lengths should be increased so that the marker can be further extended out of the hole. Concrete cylinder forms should be used at some transitional point for the protective cement collar.

8. If the level stations could become part of a traverse line, the bolt marker should have a central hole for centering the tripod of the survey instrument and target.

9. If pit walls are used for stations in a levelling circuit, the quality of the wall monuments must be equal to that of the floor monuments previously described. A unit developed by J.E. Cheney for use on building walls is also suitable for pit walls (1). Figure 2(a) is a diagram of the components of this unit. Figure 2(b) is a section diagram of the unit's socket grouted into position. A levelling plug is screwed into the

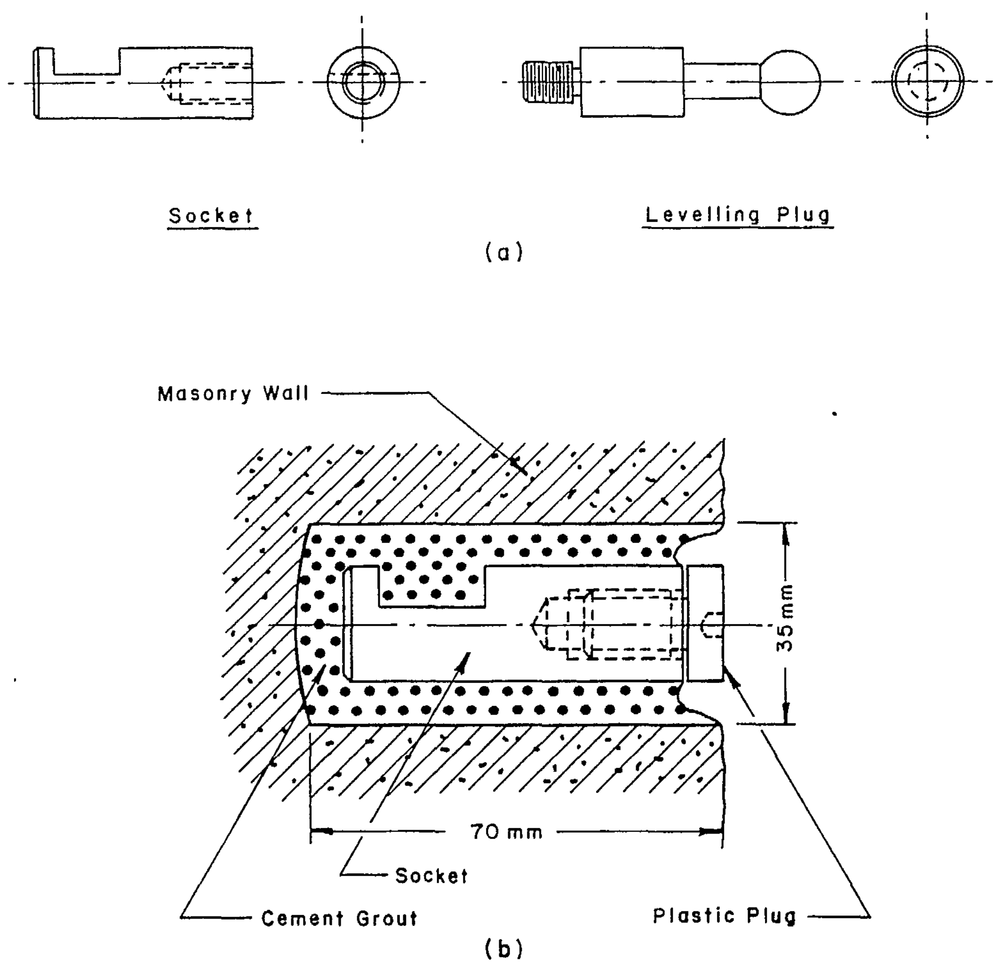

Fig 8-2 - Diagrams of wall level survey station: (a) wall level survey station components, and (b) section diagram of installed socket.

socket for the purpose of taking measurements. When not in use the socket unit is flush with the wall to avoid damage. A plastic plug protects the socket thread. The unit is available from Tusroke-Beaver Ltd., 673 Dunstable Road, Luton, Beds Lu4 OD4, England. The socket and plug are constructed of stainless steel.

10. Sites must be selected permitting vertical positioning of the survey rods. Most bench faces have extensive sections with protruding toe regions which are not too difficult to find. The present system with extensions between the socket and the plug of up to 4.7 in. (120 mm) in length have been used to overcome overhang problems. The unit has also been used in vertical holes and is therefore a viable alternative to the bolt marker of the system described.

11. A wall plug or its equivalent should be installed in EDM-theodolite monuments forming part of a levelling circuit. This will permit incorporating the monument into the levelling circuit.

RECOMMENDED LEVEL CIRCUIT DESIGN AND READING PROCEDURES

12. Levelling stations should be located between and behind EDM-theodolite stations as shown in Fig 3 to supplement displacement data provided by the latter units. The EDM-theodolite monuments would be incorporated into the levelling circuits as datum points.

13. It is unlikely that the ideal arrangement shown in Fig 3 with stations located parallel and perpendicular to the face can be realized in practice. The location of the station is controlled by three factors: sighting distance, surface conditions and terrain profile. Locations should be such as to permit equal backward and forward sighting distances of between 49 ft to 98 ft (15 to 30 m). This will permit adequate but not excessive coverage of the crest or bench surface. A steel tape is used to locate potential sites which are tentatively chosen on the basis of exposed rock quality or estimated depth of overburden. An Abney clinometer would establish if the elevation of the site chosen is compatible with adjacent stations in the levelling circuit. If the terrain does not permit reasonable spacing of stations, level surveying should not be used as a monitoring device. A minimum distance of 30 metres between levelling stations is considered reasonable.

14. The level should be located between stations to provide backsight and foresight distances approximately equal to within ± 0.30 ft (1.0 m). A tape can locate suitable level stations which should be marked for succeeding surveys. The stadia lines on the level can verify sight distances when surveying.

15. Two invar rods are used in these surveys. The back rod is advanced two stations after readings between them are completed. Reading consists of measuring the stadia lines and level line for the back and forward rods, disturbing the level, and repeating. Support struts and a level attached to the rods assure they are in a vertical position over the level markers. Reference 2 provides more details on precise level surveying.

16. Levelling measurements should be carried out as part of the levelling circuit which closes on the starting station. This permits establishment of a closure error for the measurements. With the equipment, monuments, and measurement procedures recommended, a closure error of less than 0.04 in. (1.0 mm) should be possible in open

pit mine circuits of less than 3300 ft (1 km). If the closure error exceeds circuits 0.1 in. (2.5 mm) and cannot be accounted for by manual error, the survey should be repeated when climatic conditions are more suitable. Overcast days provide the best environmental conditions for such surveys.

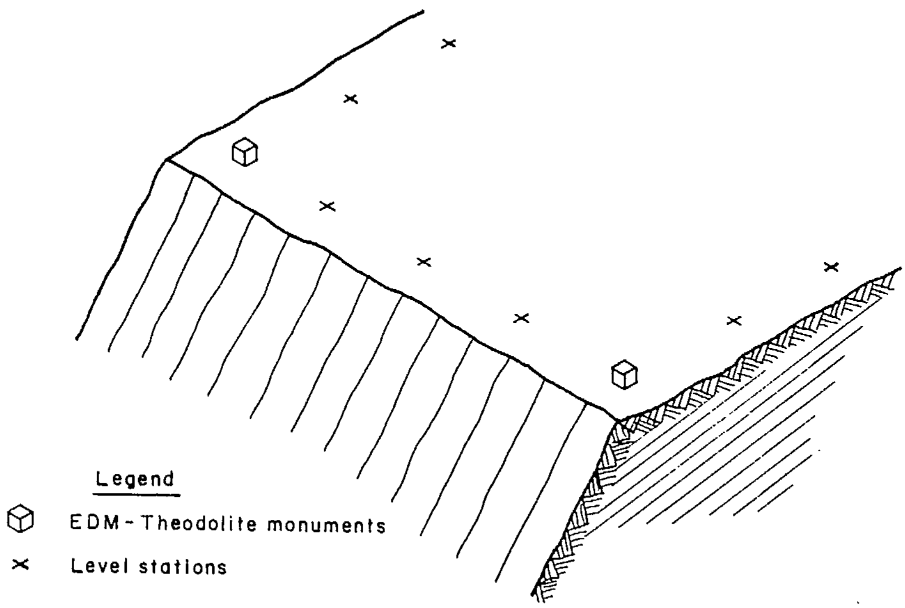

Fig B-3 - Diagram indicating idealized location of level stations relative to crest EDM-theodolite monument.

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APPENDIX C

SURFACE STRAIN EXTENSOMETERS

INTRODUCTION

1. Surface strain extensometers can form an essential part of a monitoring system. They are introduced when EDM-theodolite measurements, level measurements or visual observations have detected a potentially unstable zone.

2. The initial function of a strain extensometer system will be to confirm the condition of the zone as to stability. Displacements are measured across single joints or fractures, or across a series of such discontinuities. Since initial movement and rate of movement can be quite small, accurate strain extensometers must be available. The recommended instrumentation for initial displacement measurement is an invar tape unit and a Newcastle extensometer. It measures the displacement between steel stakes anchored in the rock. When larger daily movement begins to occur, less precise tape equipment with a greater displacement range can be used.

3. When serious deterioration in the stability of a slope is believed to have occurred, systems which can provide continuous, comprehensive coverage under adverse climatic conditions must be employed. A measuring system in which linear potentiometers measure the changes in separation distance between steel pegs is proposed for this purpose. Encased in supported steel tubing, systems of this type have functioned satisfactorily under Canadian climatic conditions. Limit switches can be used as a replacement for potentiometers if telemetry is not available for continuous remote monitoring.

4. When site accessibility and climatic conditions are suitable, an unprotected wire extensometer can be used to monitor large pit slope movements.

INVAR TAPE EXTENSOMETER

GENERAL DESCRIPTION OF SYSTEM

5. The invar tape extensometer is recommended for detecting initial movement. Stakes are placed on each side of a discontinuity and any change in separation distance is measured with an invar tape in conjunction with the Newcastle extensometer shown in Fig 1.

Steel Stakes

6. Figure 2 is a diagram of an installed invar tape extensometer. The stakes are cemented into drillholes with at least 2 ft (0.61 m) of the stake located in solid rock, using a fluid cement paste. Exotic cements such as those containing polyester or epoxy should be avoided for reasons of both cost and effectiveness. The stake, for convenience in measurement, should extend about 3 ft (0.92 m) above the ground. The stakes are capped with fittings for connecting to the Newcastle extensometer and invar tape. Figures 3 and 4 provide detailed technical drawings of these fittings. The connecting link between the Newcastle extensometer and the tape is shown beside the unit in Fig 1.

Invar Tape

7. A separation distance of 10 ft (3.1 m) between stakes is recommended for measuring movement across discontinuites. This, however, does not require cutting of an expensive invar tape to suit the bay length. Figures 5 and 6 are detailed drawings of clamps which allow a 10 ft (3.1 m) section of a longer tape to be used. The fitting in Fig 5 connects the tape to the stake equipped with a mounting stud; the fitting in Fig 6 connects the tape to the connecting link of the Newcastle extensometer.

AREA OF APPLICATION AND FACTORS AFFECTING ACCURACY

8. The invar tape extensometer system is used primarily to measure the initial movement or suspected movement, across a rock discontinuity such as a joint, fault or fracture. By using an array such as is shown in Fig 7, the direction of movement of one side of a discontinuity with respect to the other can be established. Because these initial displacements can be extremely small, the tape system must minimize potential temperature and mechanical errors.

9. At a later stage when larger displacements are involved, a more rudimentary less precise stake-tape system can be used.

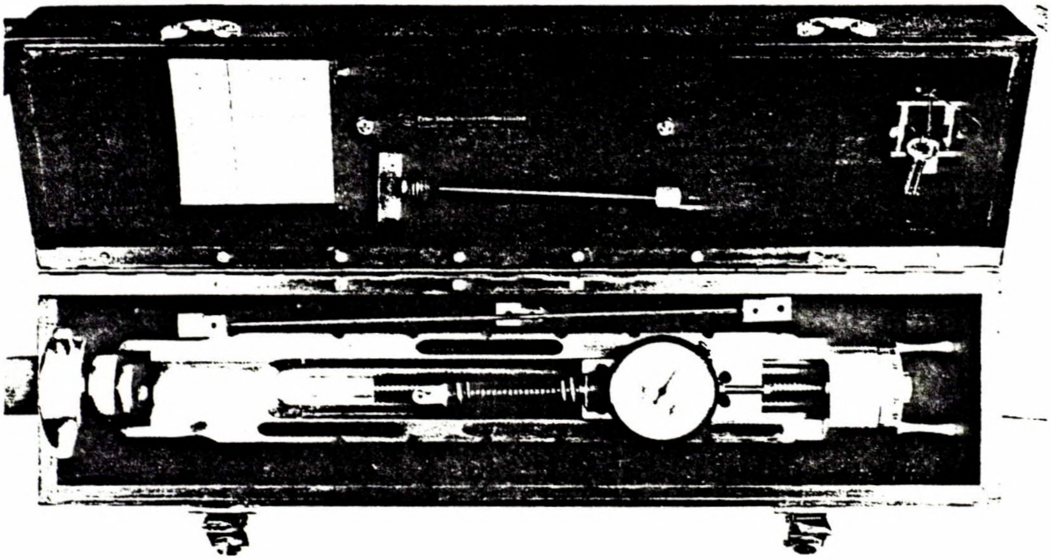

Fig 1 - Photograph of Newcastle extensometer.

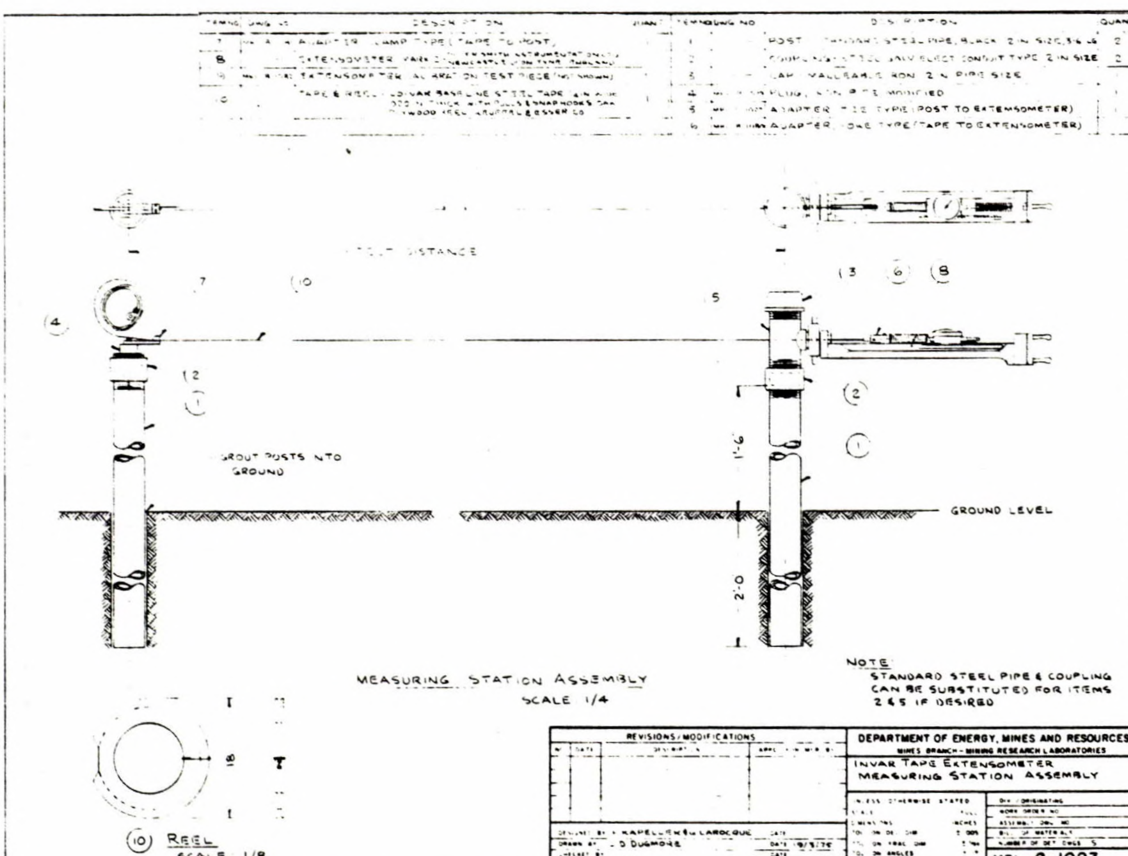

Fig 2 - Diagram of installed invar tape extensometer.

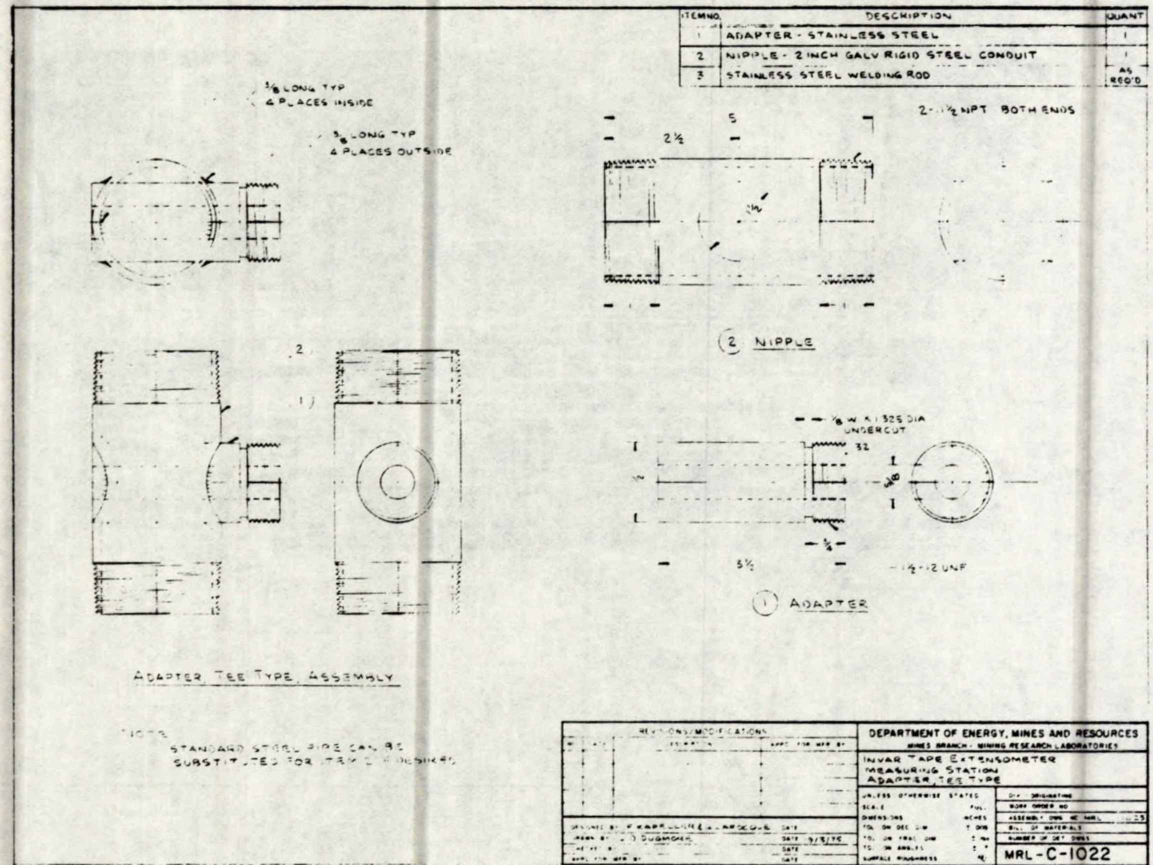

Fig 3 - Stake cup fitting for Newcastle extensometer.

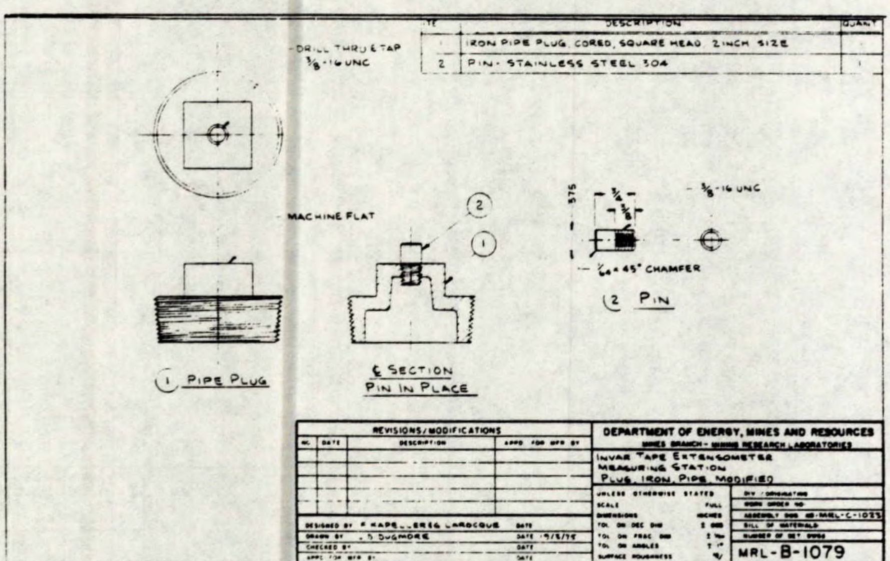

Fig 4 - Stake cap fitting for invar tape.

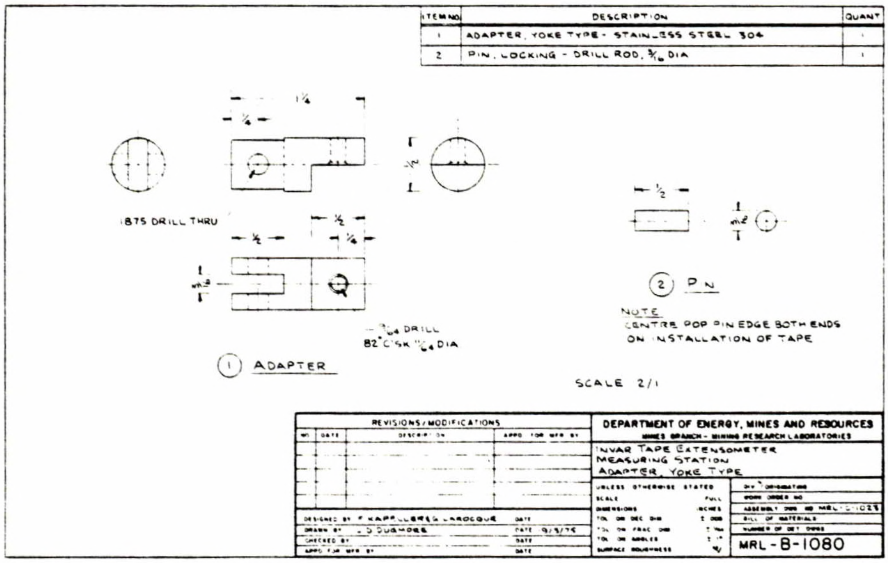

Fig 5 - Tape fitting for attachment to Newcastle extensometer.

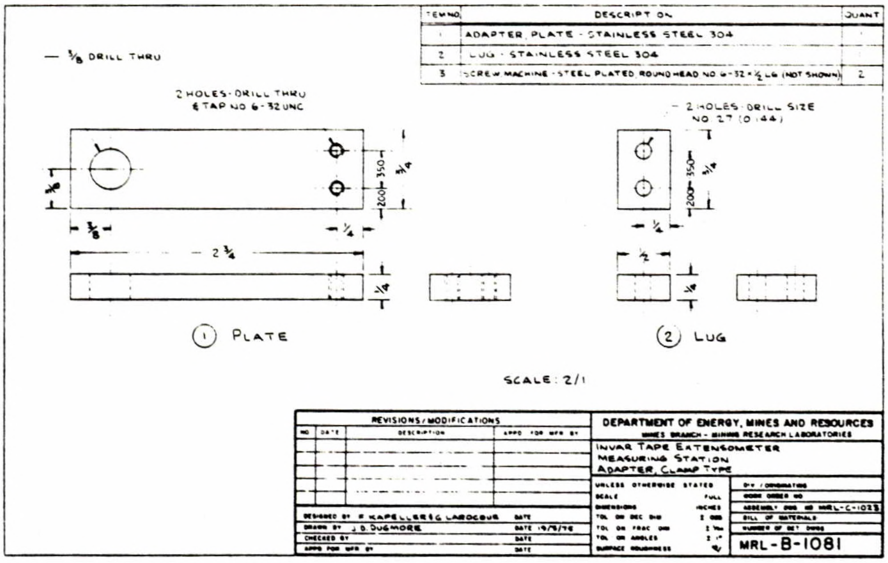

Fig 6 - Tape fitting for attachment to stake.

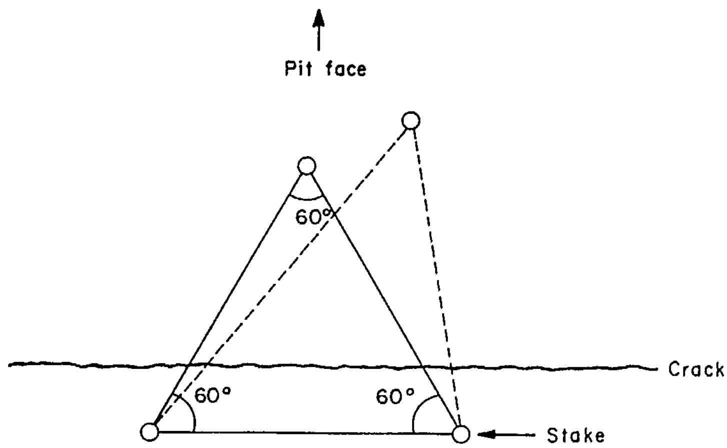

Fig 7 - A three stake arrangement to establish movement of A relative to B and C.

Temperature Effects

10. Two potential sources of error are temperature-induced changes in the tape length and changes in the calibration factor of the Newcastle extensometer. Corrections can be applied by noting the temperatures at which readings are made.

11. Temperature-produced changes in tape length is the larger source of error but with an invar tape, dimensional changes are kept to a minimum. In the case of a 10 ft (3.1 m) invar tape, a 70°F (20°C) temperature change produces an apparent change in stake separation distance of 8.4×10^{-3} in. (0.2 mm); a steel tape of equal length would indicate an apparent change of length 6 to 9 times greater.

12. The temperature error of the Newcastle unit for some particular reason which is not clear, is small. However, in tests conducted with one of these units, it was established that an apparent strain of 6.0×10^{-3} in. (0.15 mm) occurs with a temperature change of 50°F (28°C).

Mechanical Error

13. Mechanical damage to the tape, fittings or Newcastle unit is always possible. The tape is particularily vulnerable to damage if not treated with care and any kinking will result in a reading error. Invar tapes are subject to sudden dimensional changes because of the annealing process used in their production and to changes with aging in the material's crystalline structure (1,2).

14. Calibration bays are required to check that all the mechanical components of the extensometer are functioning properly. Ideally three tapes should be available to check if one tape changes dimensions suddenly, which is possible.

EVALUATION AND CALIBRATION OF INVAR TAPE EXTENSOMETERS

15. Periodic calibration checks of both the Newcastle extensometer and invar tape are required.

Calibration of Newcastle Extensometer

16. Calibration of this unit consists in part of establishing that there has been no change in the spring constant as indicated by the dial gauge. Procedure is to attach a known weight to the spring and see if the previously noted dial gauge reading is repeated.

17. It must also be established that there has been no change in the position of the connecting button of this unit relative to the capstan screw. The piece shown in Fig 8 is used to carry out the

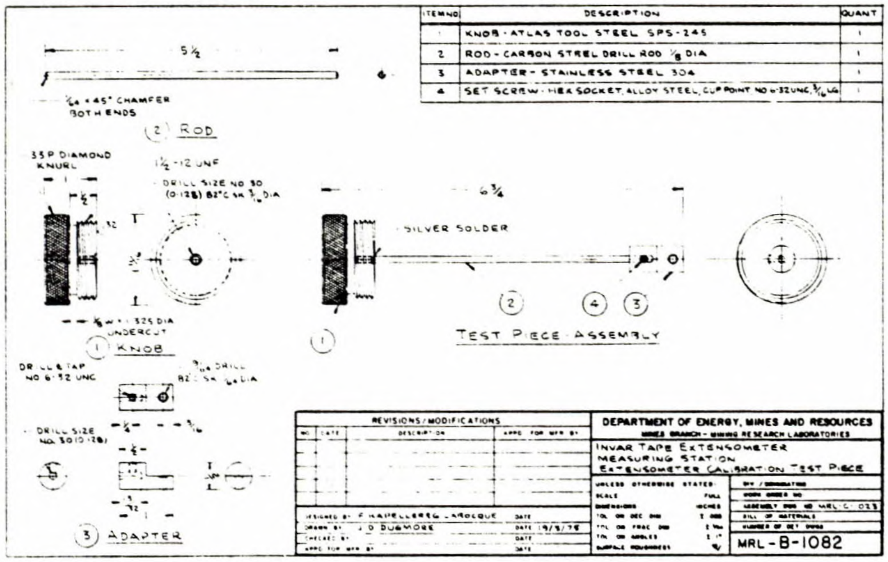

Fig 8 - Newcastle extensometer calibration test piece.

necessary test. With it attached to the Newcastle unit and tensioned to a pre-established level it should be possible to repeat the previous reading to within ± 0.001 in. (± 2.54 x 10^{-2} mm).

Calibration of the Invar Tape

18. There is normally an interior concrete wall or floor at a mine site where a test bed can be established to check an invar tape system. By choosing an interior wall or floor area, temperature changes are minimal. Angle irons which act as supports for tape and Newcastle extensometer mounts are grouted into the floor. The bay permits replacing an invar tape or Newcastle units with no loss in continuity of the measurements.

INSTALLATION PROCEDURE

19. Stake position and separation is selected so that the Newcastle unit is at its middle range when attached to the invar tape between the stakes. At least 2 ft (0.61 m) of the drill hole for each stake should be in solid rock. The drilling of deeper holes is recommended however to provide some flexibility in locating the stakes at a convenient height. On this basis, the stakes can be cut slightly oversize in length before being brought to the site. Placed in the holes they can be held in position at a suitable height by small steel wedges. After the cement mix has been poured around the stakes, a spirit level can be used to adjust them to their final vertical position.

PROCEDURE FOR READING INVAR EXTENSOMETERS

20. Reference to Fig 2 shows location of the equipment when a reading is being taken. Readings are made with the Newcastle unit applying 20 lb (89 N) of tension to the tape. The tension is normally removed and reapplied three times; at each application of load, the setting of the Newcastle unit is read. The readings should repeat within about 0.002 in. (0.05 mm); larger variations should be investigated.

21. To permit the application of temperature correction factors to extensometer readings, the temperature of the Newcastle extensometer and tapes should be taken with a thermometer shaded from the sun.

22. Generally, tapes 10 ft (3.1 m) in length are not affected by wind and measurements can be taken without difficulty. With long tapes of

50 - 100 ft (15.3 - 30.5 m), vibrations initiated by strong winds can be a problem. Occasionally, the problem can be overcome by damping lateral motion with the hand; a quiet period can often be achieved which permits a measurement to be made. Precise reading with long tapes is difficult in an open pit mine.

COST OF USING THIS UNIT

23. The cost of an installation based on 1975 prices is given in terms of equipment and installation cost. The cost of the Newcastle extensometer and a 50 ft (15.3 m) invar tape are given separately.

Equipment construction cost	$ 300
Installation cost	100
Newcastle extensometer	3000
Invar tape	220
	$3620

SURFACE STRAIN EXTENSOMETER

GENERAL DESCRIPTION OF SYSTEM

24. The surface strain extensometer described below is recommended for pit crests or berms where displacement has been detected and continuous monitoring is required. Like the invar tape extensometer previously described, the unit measures displacement between stakes which are grouted in place. The measuring element consists of invar rods and a linear potentiometer connected in series between two end stakes. Intermediate stations on 10 ft (3.1 m) centres support the steel piping which protects the measuring assemblage from the environment. Figure 9 is a diagram of an installed surface strain extensometer. Figure 10 is a parts list for one station 40 ft (12.2 m) in length.

Sensor Station

25. Figure 11 is a cross sectional diagram of the sensor station. The plane of the drawing with regard to the overall station is indicated by the inset diagram. Reference to the parts list in Fig 10 will show that with the exception of the extensometer support unit and a few couplers and spacers, all parts are standard pipe fittings. With reference to Fig 11, 2 in. (5.1 cm) elbows and short nipples are used to offset the axes of the linear potentiometer and invar rods measuring chain from the axes of the stakes. By rotating the pipe cross the extensometer can be oriented to suit the slope of the terrain.

26. Figure 12 provides details of the potentiometer support unit outlined in Fig 11. The unit as shown in Fig 12 is connected to the stake assembly by a modified 2 in. (5.1 cm) pipe plug which forms part of the support unit. It will be noted that to the right of Fig 11, the 2 in. (5.1 cm) and 1-1/2 in. (3.8 cm) pipes which act as a protective coverage for the measuring rods, overlap. A similar piping arrangement exists at the end station where the other end of the invar rods is anchored. The arrangement permits motion of the sensor and end stations, without interference from the intermediate stations used to support the protective pipe casing. Lengths of rubber tube cover the protective pipes where they overlap to prevent the entry of water.

Intermediate Station

27. Figure 13 is a section diagram of an intermediate station used to support the chain of connected invar rods and protective casing of 1-1/2 in. (3.8 cm) galvanized electrical pipe. As shown in Fig 13, the protective pipe assembly

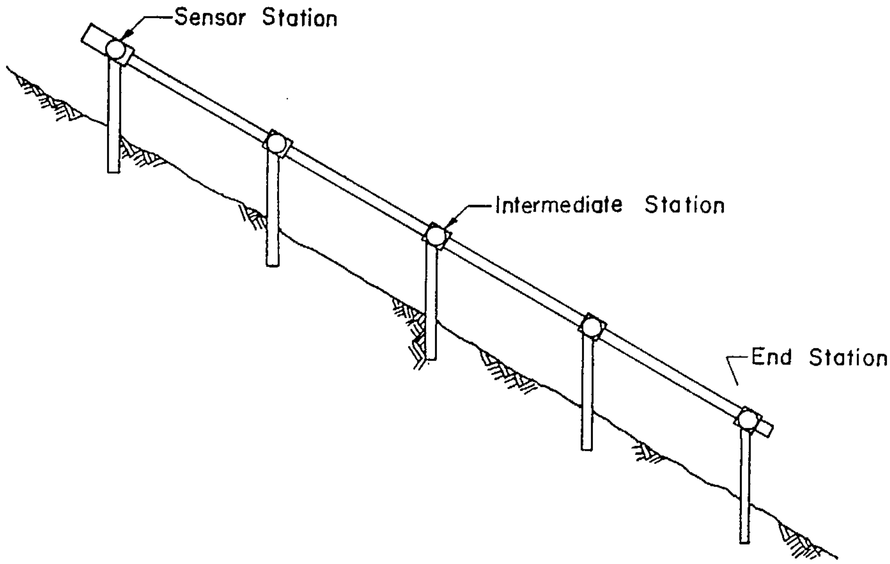

Fig 9 - Diagram of installed strain extensometer.

ITEM NO.	DESCRIPTION	FIGURE NO.'s	QUANTITY
1	Iron pipe cross, black,, 2"	3 & 8	2
2	Iron pipe tee, black, 2"	5	3
3	Iron pipe elbow, 90°, black, 2"	3, 5 & 8	5
4	Wrought steel close nipple, black, 2"	3, 5 & 8	8
5	Insulating end bushing, shallow type, 2" elect. conduit	3, 5 & 8	5
6	Down pipes (posts): standard steel pipe, black, 2" (approximately 4' long, lengths cut to suit terrain)	3, 5 & 8	5
7	Potentiometer casing: standard steel pipe, black, 2", 18" long	3	1
8	End casing: standard steel pipe, black, 2", 12" long	3 & 8	2
9	Thermistor casing: standard steel pipe, black, 2", 18" long	5	1
10	Main casing: rigid steel elect. conduit, galvanized, $1\frac{1}{2}$", 10' long	3, 5 & 8	4
11	Reducer, inside hex bushing 2" - $\frac{3}{4}$" (modified)	8	1
12	Iron pipe plug, $\frac{3}{4}$" (modified)	8	1
13	Iron pipe plug, 2" (modified)	3 & 4	1
14	Invar rod, $\frac{1}{4}$" diameter, 10' long	3, 5 & 8	4
15	Coupling, steel, galvanized, elect. conduit, $1\frac{1}{2}$"	5	3
16	Coupler, invar rod assembly	5, 6(a)	3
17	Coupler, invar rod to potentiometer	3, 6(b)	1
18	Spring lock washer, $\frac{1}{4}$" size	8	1
19	Jam nut, steel $\frac{1}{4}$ - 20	8	1
20	Tygon tubing $\frac{1}{4}$", 1" long	5	8
21	Washer, teflon	5, 7(a)	4
22	Washer, plexiglass	5, 7(c)	3
23	Washer, teflon	5, 7(b)	3
24	Malleable iron pipe cap, 2"	3	2
25	Iron pipe plug, 2"	3 & 8	2
26	Brass rod, $\frac{1}{4}$", 12" long	3 & 4	
27	Brass bar, $\frac{1}{4}$" square, $1\frac{3}{4}$" long	3 & 4	1
28	Nut, hex. brass, No. 6 - 32	3	2
29	Potentiometer: model 114 L 6D102, 1 K ohm, 0.1%, $1\frac{1}{4}$" x $1\frac{1}{4}$", 6" stroke, New England Instrument Company, Kendall Lane, Natick, Mass. U.S.A.	3	1
30	Thermistor holder: stainless steel tube $\frac{1}{4}$" O.D., 0.010" wall	8	1
31	Thermistor: resistance 2252 at 25°C, Part No. 44004, YSI Components Division, P.O. Box 279, Yellow Springs, Ohio, U.S.A.	8	1
32	Cable, coaxial, RG-58 c/u	8	1

Fig 10 - Parts list for one station 40 ft (12.2 m) long.

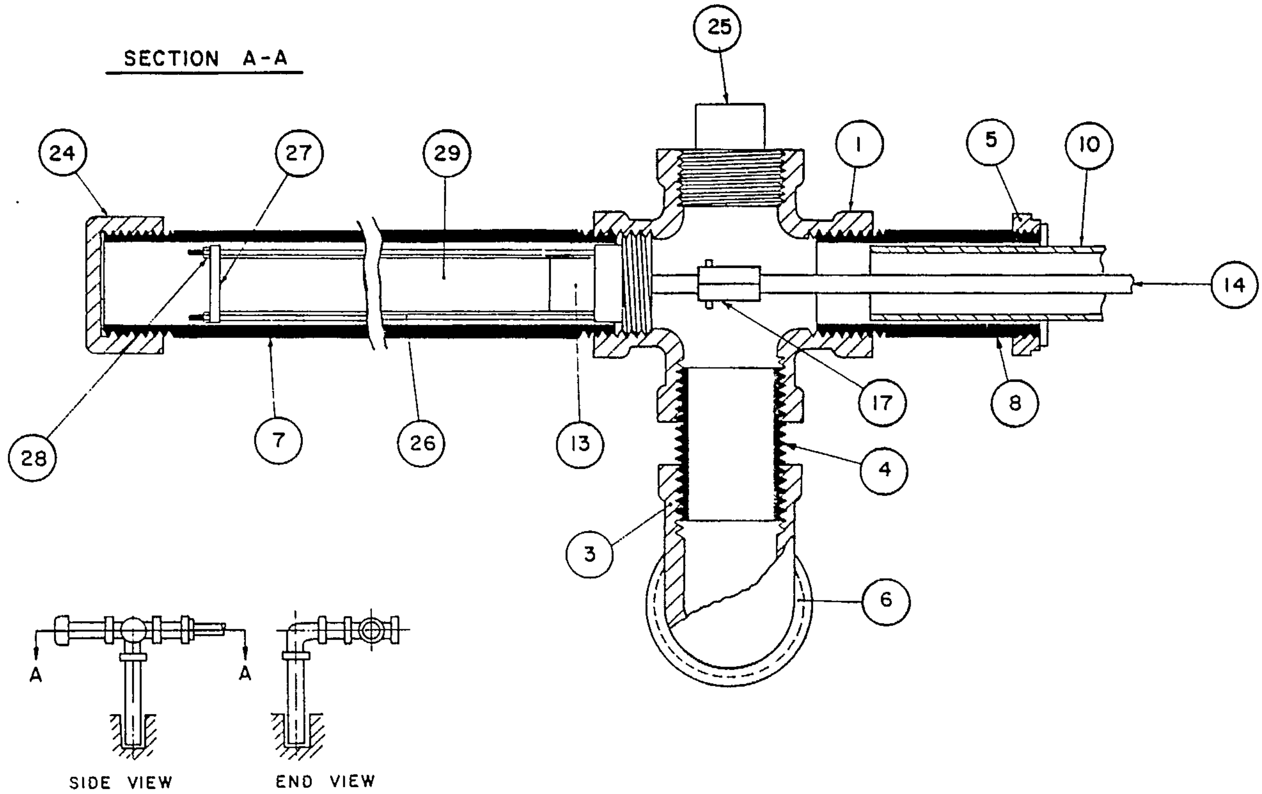

Fig 11 - Section drawing of Sensor Station.

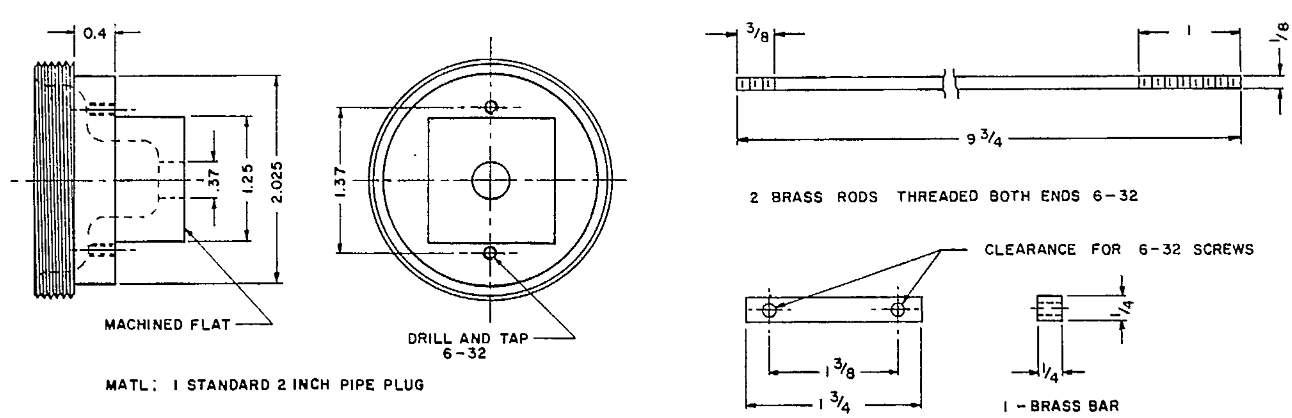

Fig 12 - Potentiometer support unit.

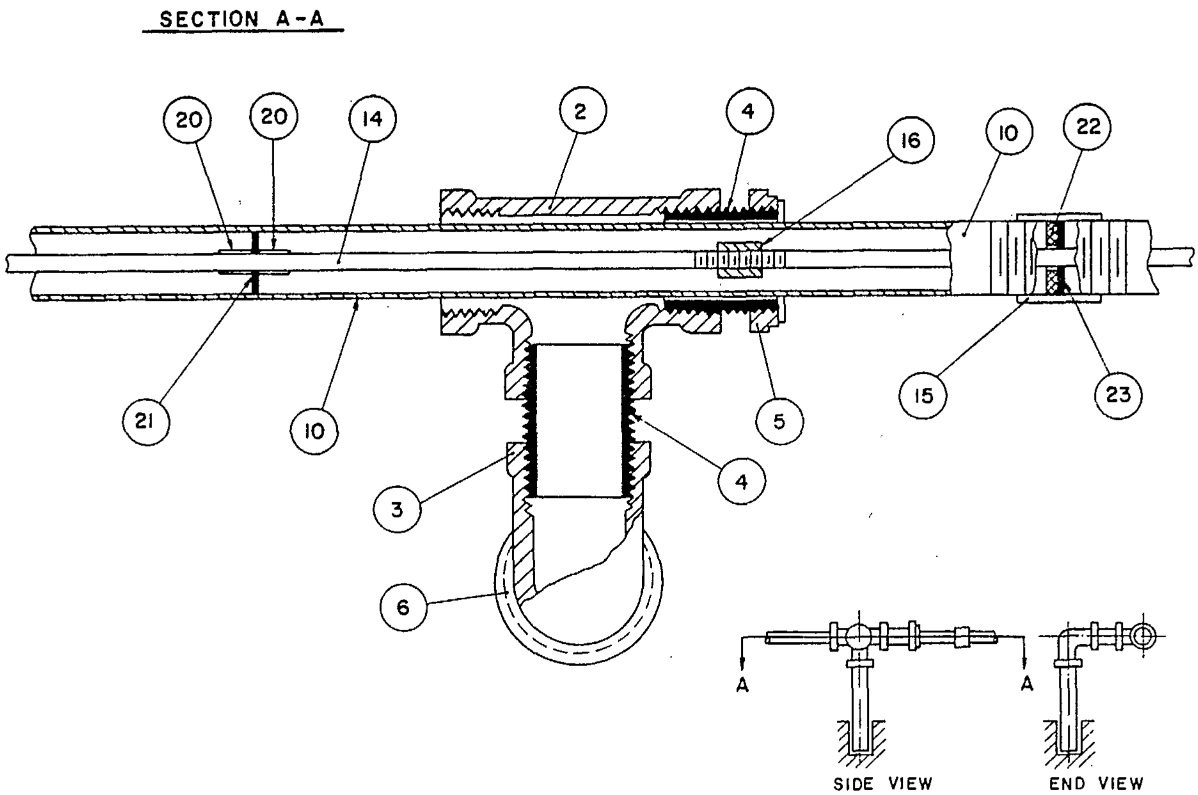

Fig 13 - Section drawing of Intermediate Station.

slides freely through two openings of the pipe tee equipped with short nipples. Intermediate stations are at 10 ft (3.1 m) intervals between the sensor and end stations.

28. The opportunity has been taken with Fig 13 to show the interconnection of the extensometer protective pipes and measuring rods, and the spacer arrangement for supporting the measuring rods centrally in the protective casing. Each end of the invar rods are threaded 1/4 in. - 20. Internally threaded hexagonal steel bar, 7/8 in. (2.2 cm) long as shown in Fig 14(a) acts as couplers. The teflon rings 0.125 in. (0.32 cm) thick shown in Fig 15(a) act as washers to hold the rods central in the protective pipe casing. They are held in position along the invar rod by tight fitting tygon tube on each side. The 10 ft (3.1 m) lengths of protective piping are connected by standard pipe couplers.

End Station

29. Figure 16 is the section diagram of an end station. A 12 in. (30 cm) end section of the end rod is threaded 1/4 in. - 20 is equipped with a screw driver slot and is screwed into a modified 2 in. (5.0 cm) pipe plug. The threaded section of the invar rod permits final adjustment of the wiper position of the linear potentiometer; the rod assembly is rigidly fixed into position by a lock nut. To the left of the tee can be seen the overlapping section of 2 in. (5.0 cm) and 1-1/2 in. (3.8 cm) protective pipe.

30. A short length of 2 in. (5.0 cm) pipe provides an extension to the end station pipe cross to protect the screw fitting and thermistor of the invar measuring rods. The thermistor is contained in a short length of tubing attached to the measuring rods as shown in Fig 16. Silicon jelly assures good thermal contact with the end of the rod assembly. Figure 17 provides mechanical information on the thermistor casing.

AREA OF APPLICATION AND FACTORS AFFECTING ACCURACY

31. The surface strain extensometer is recom-

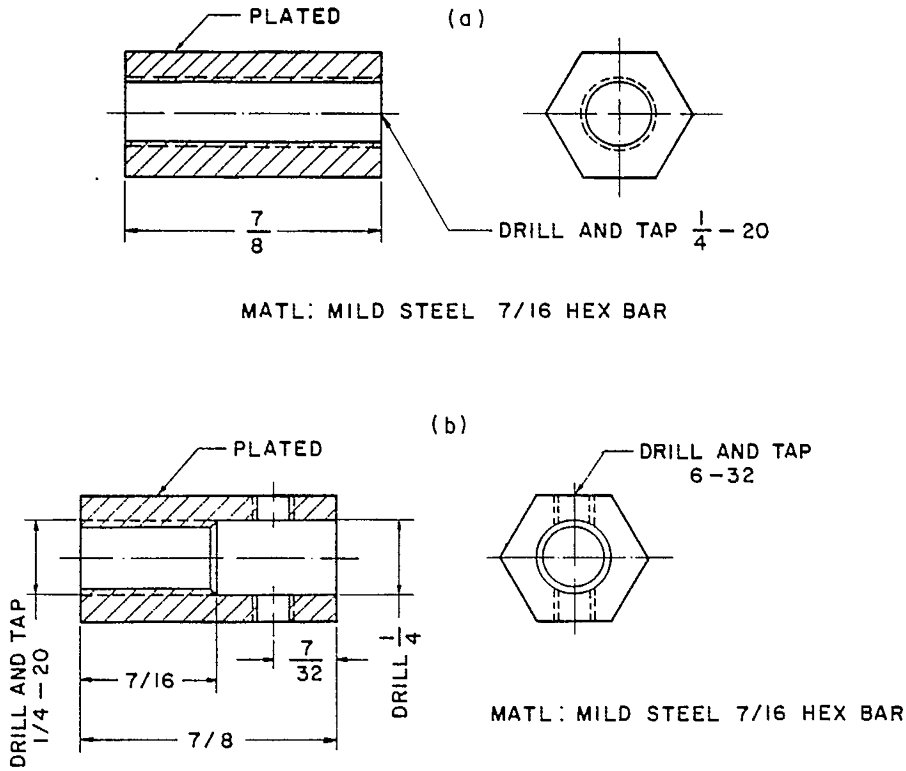

Fig 14 - Invar rod couplers; (a) rod assembly, (b) rod to potentiometer.

mended for use in open pits where surface displacement has been detected and a continuous monitoring unit impervious to climatic conditions is required. The gauge length of this extensometer can be adjusted to meet specific monitoring requirements; they can be used in various configurations to give a pit zone whatever coverage is necessary.

Temperature and Electro-Mechanical Effect

32. Factors affecting accuracy of the measurements made with this extensometer are the following:

a. changes in invar rod length with temperature interpreted as displacement of the end anchorage points
b. changes in the length of the linear potentiometer with temperature which are also interpreted as displacement of anchorage points. The changes however are relatively small for large changes in ambient temperature (0.005 in. (0.13 mm) for a change of 40°F (22°C) in the case of the 6 in. (15.2 cm) stroke potentiometer presently used)
c. the linearity of the potentiometer (0.1%).

33. Measurements have been made over a period of a year to establish the accuracy of this unit in field trials. An invar tape with Newcastle Extensometer has been used to independently determine displacement across a group of test bays. The test results indicate that the present unit is capable of detecting movements as small as 0.050 in. (1.30 mm) with a 40 ft (12.2 m) bay length unit.

EVALUATION AND CALIBRATION
OF THE SURFACE EXTENSOMETER

34. An independent means of verifying the readings provided by a surface strain extensometer is of value. Such evaluations are possible with

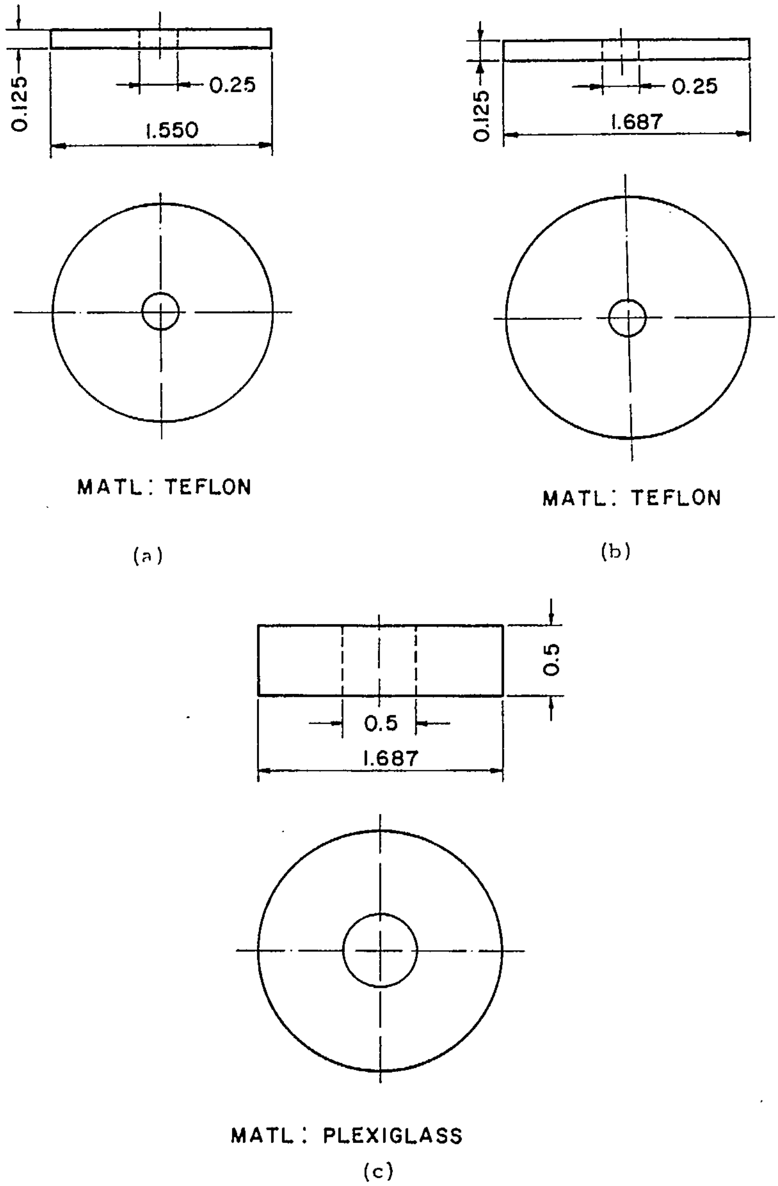

Fig 15 - Rod positioning washers; (a) casing, (b) casing/coupler.

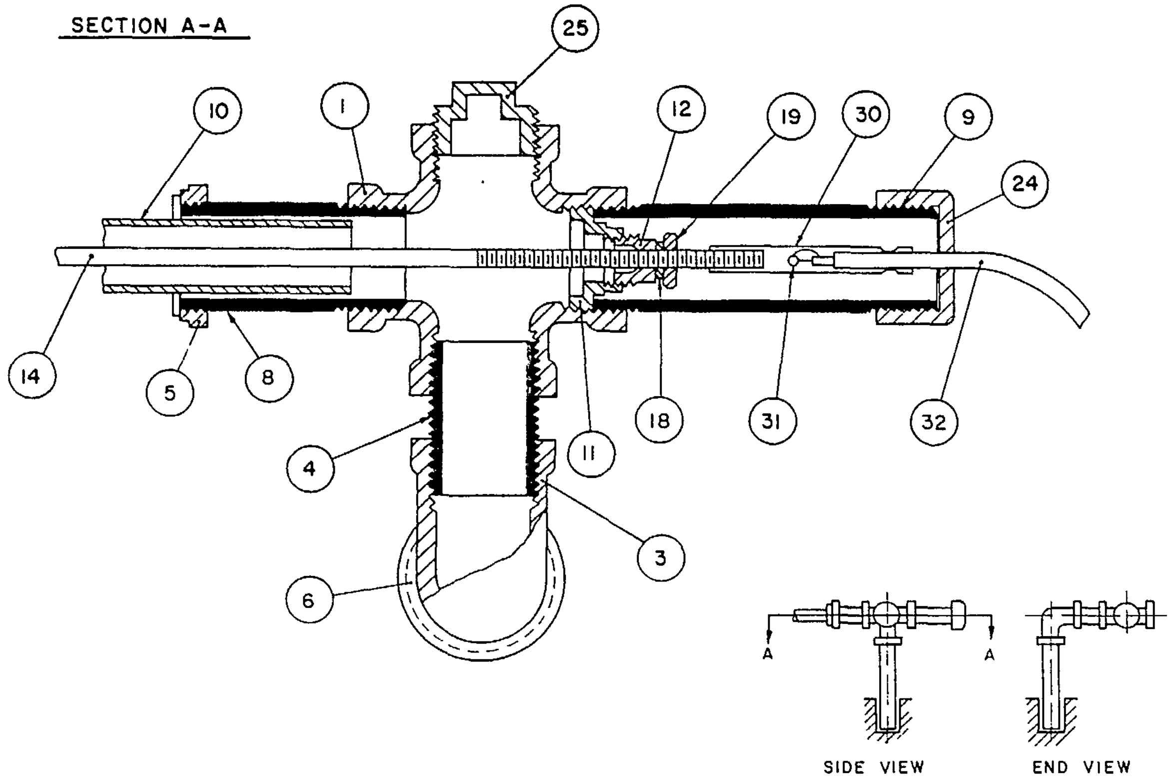

Fig 16 - Section drawing of End Station.

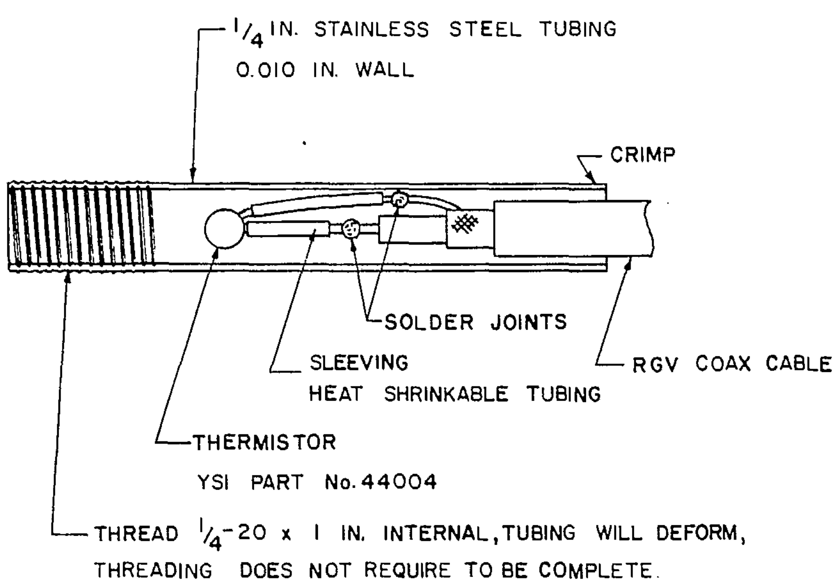

Fig 17 - Section drawing of thermistor unit.

the present system using the invar tape unit previously described.

35. Reference to Fig 11 and 16 will show that crosses rather than pipe tees have been used on the two terminal stations. The spare plug on these units can be replaced by the fittings required to mount the invar tape extensometer. By using a fixed bay length, one tape extensometer can be used to check all bays.

36. To prepare a calibration curve for the linear potentiometer used, any accurately calibrated machine tool movement, such as the table of a milling machine can be used. The procedure is to prepare a plot of the ratio of wiper voltage to total voltage across the linear potentiometer as a function of wiper position. Because the two ends of the stroke are ill defined, all displacements are referred to the mid-point of the potentiometer using voltage ratio. A graph or its equivalent in table form is used to calculate precisely wiper position with respect to the centre position. Figure 18 is a plot of voltage ratio versus wiper position for the 6 in. (15.2 cm) linear potentiometer in the present unit.

PROCEDURE FOR SURFACE STRAIN EXTENSOMETER INSTALLATIONS

37. Once the line of installation has been tentatively selected, a surface profile should be prepared. The profile is used to determine the vertical height of stations required and the number of individual bays required to cover the line. It is possible that the profile is so unfavourable for installation that alternate locations for the line should be investigated.

38. When the line and the number of bays along the line have been selected, the location of all stations should be pegged and the overburden at the stations removed. A second profile should be prepared with regard to the cleared stations. This second profile is used to determine the vertical pipe length required for each station. The components for each station can then be assembled before being brought on site.

39. Using the two end stations as reference points, the locations of all stations are marked for drilling. The station holes should be over-drilled to aid vertical alignment of extensometer stations. With the present system,

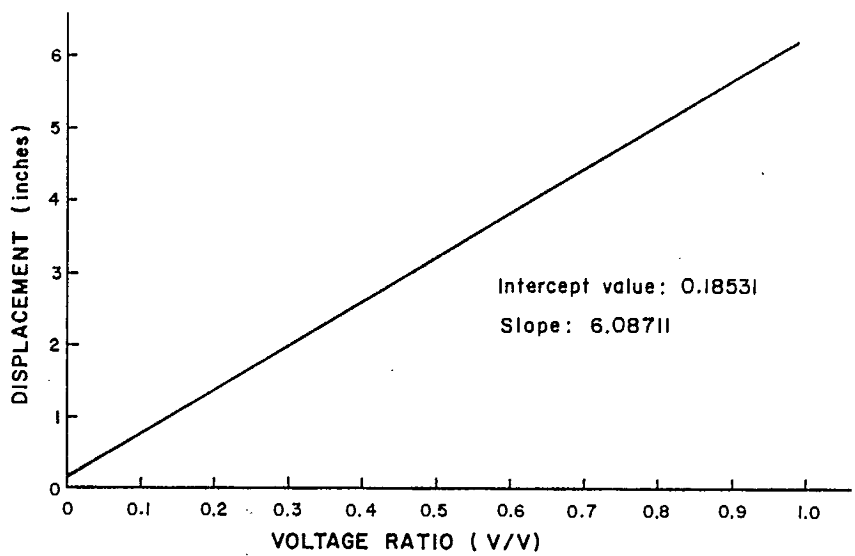

Fig 18 - Plot of voltage ratio versus displacement for linear extensometer.

the holes should be about 3 in. (7.6 cm) in diameter. Oversize drill holes provide flexibility for the horizontal alignment of stations; steel wedges hold stations in line for grouting.

40. Referring to Fig 9, the end station is wedged into place at its final vertical height as established from the second profile of the site. A 2 in. (5.1 cm) pipe plug with the optical sight shown in Fig 19 is screwed into the unused opening of the end station cross, Fig 16. The sight is viewed with a telescope from the far side of the sensor station with the optical axis approximately set to pass through a similar target on the sensor station. When optically aligned with the end station, the sensor station is wedged into its final position.

41. The next step in installation is to place the pre-assembled intermediate stations in the drill holes, and temporarily assemble the protective pipe casing. For this purpose a 2 in. (5.1 cm) to 1-1/2 in. (3.8 cm) reducing coupler is attached between the end station and the pipe assembly which is fed through the tees of the intermediate stations and the cross of the sensor station. By holding a ruler horizontally on the centre horizontal plane of each intermediate station tee, the telescope can align them prior to wedging. Once all units are correctly oriented, the stations are grouted into place with a cement paste. The assembled protective pipe casing is then cut to provide a 6 in. (15.2 cm) gap at both the sensor and end stations prior to being disassembled. A coupler of the protective pipe assembly should never be within twice the distance of the extensometer stroke from one of the intermediate stations.

42. Final installation of the measuring rod and protective casing starts at the end station. The first invar rod differs from succeeding invar rods in that a 1 ft (31 cm) section is threaded for rod adjustment at the end station. The first 1-1/2 in. (3.8 cm) protective pipe casing will be about 8 ft (2.4 m) long for an installation on 10 ft (3.1 m) centres.

43. In Fig 16, the 2 in. (5.1 cm) pipe forming part of the protective casing at the end station is screwed into place. The initial 8 ft (2.4 m) length of 1-1/2 in. (3.8 cm) casing complete with the first measuring rod and spacers is slid into

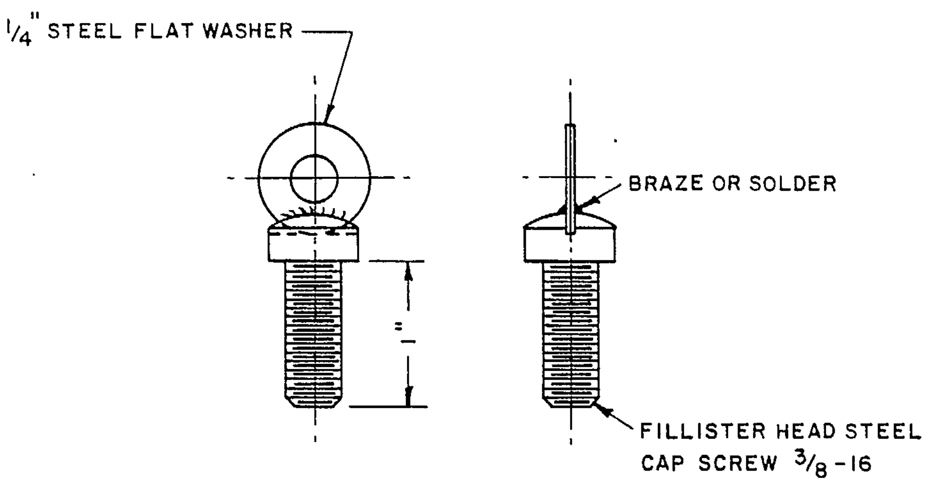

Fig 19 - Sight used to position stations.

the large size pipe for support; the other end of the pipe is provided with temporary support in line with the final axes of the protective pipe assembly. The two nylon spacers on the invar rod are held in position with short lengths of plastic tubing placed on each side. The spacers are placed approximately 2-1/2 ft (76 cm) from each end of the 10 ft (3.1 m) measuring rod.

44. With the first protective pipe casing temporarily supported, couplers such as shown in Fig 13 are attached to the measuring rod and the pipe casing. The next section of 10 ft (3.1 m) casing with rod assembly is slid into place and coupled. Succeeding sections are treated in the same manner.

45. At the sensor station shown in Fig 11, the potentiometer and all components lying to the left of the pipe cross are yet to be connected. Initially, the potentiometer shaft is connected to the measuring rod chain by use of a coupler. The modified pipe plug forming part of the potentiometer support unit is then screwed into place in the pipe cross. The protecting pipe cover is then screwed into place over the potentiometer.

46. As a final step, the wiper of the potentiometer must be set at mid range. Returning to the end station, the rods are pushed in as far as possible and then withdrawn approximately 3 in. (7.6 cm) with a 6 in. (15.2 cm) stroke potentiometer. The modified end plug in Fig 16 is screwed into position over the end of the rod assembly after which the potentiometer is adjusted to its final mid-range position by moving the rods relative to this end plug. A lock nut is used to lock the measuring rods into their final setting.

PROCEDURE FOR READING EXTENSOMETER

47. According to the manufacturer's recommendation the position of the linear potentiometer used in this system is best determined by voltage ratio. A known voltage is applied to the total potentiometer resistance and the voltage appearing across the wiper at each end of the potentiometer is measured. The ratio of the voltage measured at the wiper to the total applied voltage is then used with a calibration curve such as shown in Fig 15 or with a calibration table to establish position and change in position.

48. To correct for apparent movement due to changes in length of the rod assembly resulting from temperature changes, the temperature is established with the attached thermistor. In this case the resistance of the thermistor is established by reference to a resistance-temperature table.

COST OF EXTENSOMETER

49. The cost figures below are based on a 40 ft (12.4 m) bay length and 1974 prices for material and labour.

Drilling	$120
Material	510
Installation and machining	210
Total	$840

50. The extensometer used in this case had a 6 in. (15.2 cm) stroke. Approximately $200 should be added to the cost if a 2 ft (0.61 m) stroke linear potentiometer is used. Some consideration was given to rotary rather than linear potentiometers because of their lower cost but it was found that the cost advantages was lost in additional machine costs. Invar rods, 1/4 in. (0.64 cm) OD can be purchased at approximately $1/ft (30 cm) in small quantities; they are little more expensive than stainless steel rods of the same diameter.

WIRE TAPE EXTENSOMETER

DESCRIPTION OF SYSTEM

51. The wire tape extensometer to be described was developed by Fording Coal to monitor movement at active dump crests. As shown in Fig 20, a stake is driven into the face of the dump about 150 ft (46 m) below the crest at the edge of the dumping fan being monitored. The wire from the stake is kept free of the dump face and dump station berm by means of tripods with pulleys at the crest and on the berm. Waste rock is placed on the floor of the tripods to hold them in place.

52. The shelter in Fig 21 is an 8 ft (2.4 m) x 8 ft (2.4 m) storage unit. It is mounted on a robust wooden skid equipped with eye bolts for dragging into place. A pipe stand base with metal foot is bolted to the floor and used as support for the recording unit. A wooden casing has been placed around the recorded to protect it from the weather. The recorder is a Foxboro 1094 Float and Cable Recorder. A modified cam has been attached

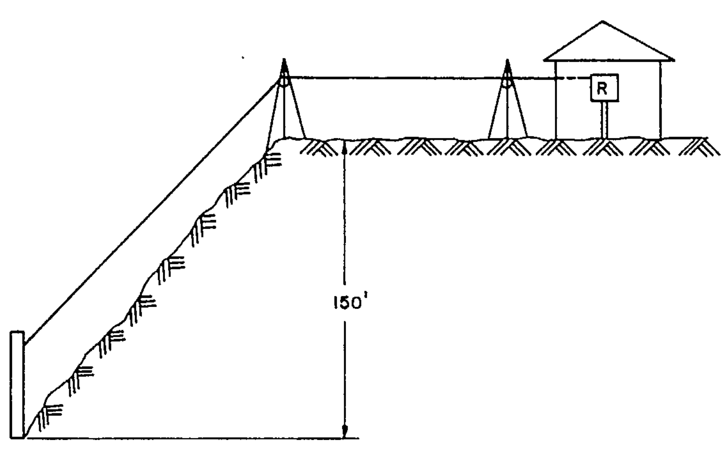

Fig 20 - Diagram of a wire extensometer installed in the crest area of a waste dump.

Fig 21 - Photograph of a pulley support unit installed at the crest of a waste dump.

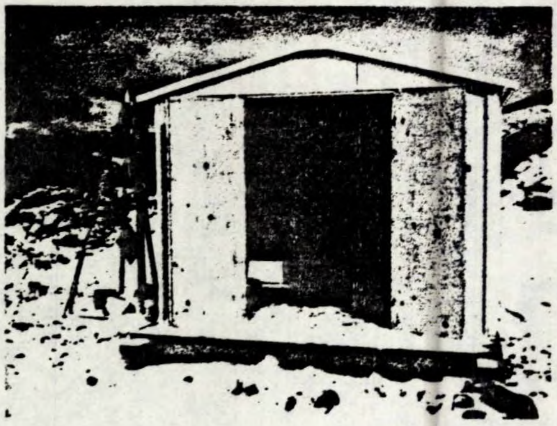

Fig 22 - Photograph of shelter with recorder.

to the circular stylus plate. The 1/8 in. (0.32 cm) thick lucite linear cam has been designed so that the stylus moves across the paper and returns to zero during one revolution of the cam. Figure 22 is a drawing giving the approximate size and shape of the cam. In operation, dump face movement is recorded as traverses back and forth across the paper. The diameter of the flywheel around which the wire is looped to drive the recorder has been selected so that a 6 in. (15.2 cm) movement is equal to one traverse across the chart paper. A revolution counter is attached to the shaft of the cam to indicate the number of traverses. Figure 23 illustrates the interconnection of the tension weight, friction flywheel and cable used with the recorder. The weight is visible in the background of Fig 21. The Foxboro chart drive is a seven day mechanical wind movement and the ink is Foxboro Wide Range which is suitable over a temperature range from -30°F (-34°C) to + 150°F (66°C).

AREA OF APPLICATION

53. The unit has proved itself effective in monitoring spoil pile stability at Fording Coal. Their experience indicates that measurements of movement in the flank region of spoil fans can be used to evaluate fan stability. The unit should work equally well in pit walls where large daily movements are anticipated before ultimate failure occurs. It is a reliable but not a highly accurate displacement measuring system. Wind, temperature, and snow among other factors contribute to limiting accuracy of measurement. It would not be realistic to treat as significant indicated movements of less than 2 in. (5 cm).

COST OF THE UNIT 1974

Foxboro recorder	$ 650
Modification to recorder and cable support unit and construction of shelter	1400
Total cost	$2050

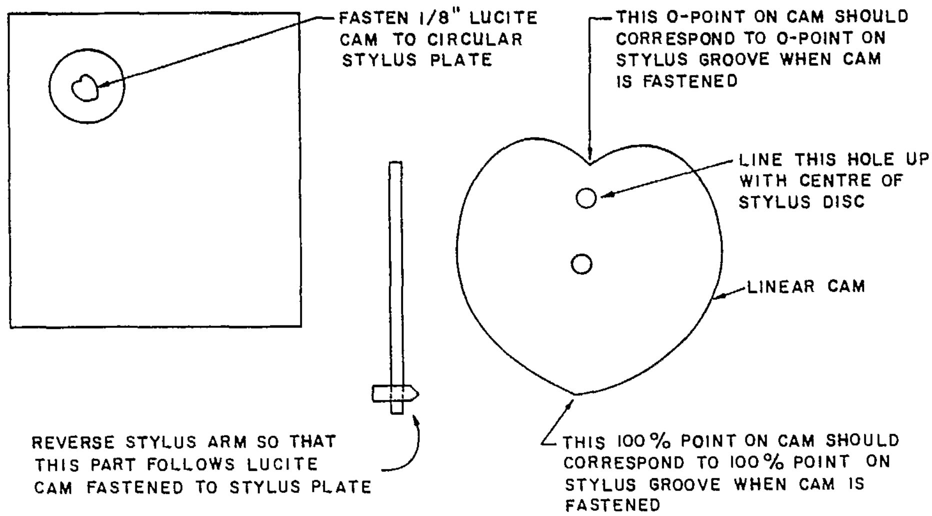

Fig 23 - Approximate size and shape of cam for linear motion of chart paper with wire displacement.

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APPENDIX D

MOVEABLE BOREHOLE INCLINOMETER

INTRODUCTION

1. The moveable borehole inclinometer is used to locate or to monitor potential failure planes in an unstable wall. Its ability to measure a horizontal displacement profile is not considered a primary feature of the unit in open pit monitoring.

2. In rock slopes the slide surfaces can be in direct contact with no transitional shear zone to permit a gradual curvature of the inclinometer casing. An installation thus becomes unusable after a small amount of lateral movement.

3. Moveable inclinometers with high sensitivty and accuracy should therefore be selected for use in pit monitoring. Procedures used to install inclinometer casings in hard rock must minimize damage by sharp discontinuities.

GENERAL DESCRIPTION OF

MOVEABLE BOREHOLE INCLINOMETER

4. The components of a moveable borehole inclinometer are: a borehole unit, a casing with grooves to orient the borehole unit and a readout unit. The electrical cable connecting the readout and borehole unit is marked so that the unit can be exactly relocated on successive runs.

5. Various sensing elements have been used to measure the angle of inclination of the borehole inclinometer in its sensitive plane. The original unit developed by Wilson used a pendulum coupled to the wiper of a potentiometer (1). The latter formed part of a resistance bridge used to measure hole inclination. In a similar manner, electrical resistance strain gauges and vibration wire gauges mounted on cantilevers have been used as sensing elements. Borehole units are now available which use servo accelerometers; some inclinometers are biaxial and are able to measure hole inclination in two orthogonal planes. Table D-1 lists borehole inclinometer units now available.

6. Plastic and aluminum tubular casings are used with most inclinometer units. Figure 1 gives details on the casings used with various Sinco units. Allowance can be made for ground

Table D-1: Borehole inclinometer units

Maker and unit	Physical description	Sensing elements	Sensitivity and range	Casing required	System accuracy
Sinco Model 50301	1.6875" O.D. 36.5" long 24" wheel base 8 lb	2-0.5 g closed loop servo-acceler-ometers	1:10,000 ±30° from vertical or ±90° from vertical	2.75" O.D. plastic flush coupled and grooved 3.00" I.D. aluminum or grooved plastic	±0.0295" /100 ft or ±59.5 secs. of arc
Sinco Model 50302	0.875" O.D. 30.0" long 24" wheel base 3.5 lb	1-0.5 g closed loop servo-accelerometer	1:10,000 ±30° from vertical or ±90° from vertical	1.90" O.D. grooved plastic 1.25" O.D. 1.25" O.D. square steel or alum. 1.50" O.D. grooved steel	±0.0295"/ 100 ft or ±59.5 secs of arc
Sinco Series 200B	2.38" O.D. 15" long 12" wheel base 7 lb	1-pendulum/ potentiometer	1:1000 ±12° from vertical	3.38" O.D. aluminum casing or 3.50" O.D. plastic casing	not given
Soil Instru-ments Series 600	4 cm O.D. 0.7 to 1.2 metre long, 0.5 to 1 metre active length	1-cantilever/ electrical re-sistance strain gauges	0.1° on ±5° range 0.5° on ±25° range	±5 cm I.D. alum-inum casing	not given
Terra Technology Corp.					
TP 2 TP-22	1.6" O.D., 35" long, 24" wheel base	2-servo-acceler-ometers	1:10,000 ±25° ±45° or ±90° range	2.3" I.D. 3.0" I.D.	±0.05" /100 ft
MP-20 MP-21 MP-22	1.0" O.D. 30" long	2 servo-accelerometers	1:10,000 ±25° ±45° or ±90° range	1.2" I.D. or 1.5" sq 2.3" I.D. steel 3.0" I.D.	±0.05" /100 ft
Telemac type MPF	6.3 cm O.D. 79.5 cm long 12 Kg,	2-cantilever vibrating wire gauge	1:2000 to 1:1000 ±15° from vertical	not given	not given

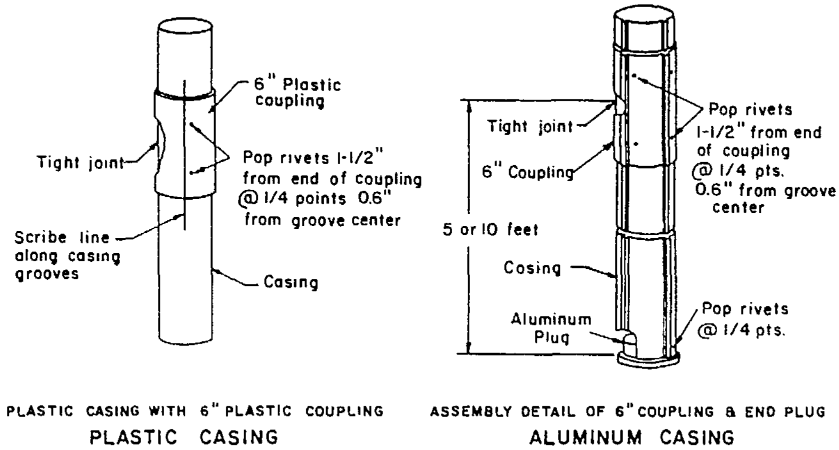

Fig 1 - Examples of non-telescoping inclinometer casings and fittings.

settlement by using telescoping plastic couplings. A special alignment tool must be used with plastic casing to align the internal grooves between adjacent lengths of casing. Aluminum casings are normally treated with an epoxy cement to avoid corrosion by naturally occurring alkaline soils, or by the cement grout used to anchor them. Under severe conditions they should be painted with a rubber or bitumen paint to provide additional protection against corrosion (1).

7. The readout unit selected will depend on the inclinometer. Print, punch and magnetic tape units can be obtained that automatically record the data for further processing.

SELECTION OF BOREHOLE INCLINOMETER SYSTEM FOR USE IN ROCK SLOPES

8. Two major factors in the system are the size of borehole required and the deflection of the casing that can take place at a sharp discontinuity before the hole becomes unusable.

9. The transition zone between stable and unstable sections of a rock wall intersected by an inclinometer casing can be quite narrow. Provision must be made to permit measurable curvature before passage of the inclinometer torpedo becomes impossible. This is best illustrated in work reported by Cornforth in which a 200-B inclinometer was used in a landslide region, Fig 2 (2). The ground mass was clay and is characterized by horizontal movement of the clay with a limited zone of shear distortion. Even more abrupt transition zones can be expected in some rock slopes.

10. The care which must be taken to protect the inclinometer casing against premature fracture due to sharp rock edges is indicated in a report on an installation in a rock fill dam (3). An annular packed sand ring was built up around the casing as the dam was raised. The casing was located at the centre of a steel mesh gabion, hand-filled with large rock at its boundaries and fine rock aggregate at its core.

11. Inclinometer holes must bottom in stable ground. In the case of a deep open pit mine, hole lengths of 300 ft (92 m) to 400 ft (122 m) may be necessary in hard rock. With holes of these lengths, a diamond drill would have to be used. By using a 1.9 in. (4.8 cm) inclinometer casing in a BX, 2.375 in. (6.0 cm) O.D., or NX, 3.00 in. (7.6 cm) O.D.hole, a protective zone can be produced around the casing with sand backfill. The sand fill will permit a gradual initial curvature of the casing at a sharp displacement interface.

12. Small diameter, highly sensitive ie, 1:10,000, inclinometers are therefore recommended for use in rock slopes. Either NX or BX holes are suitable, NX holes providing greater protection against damage of the casing.

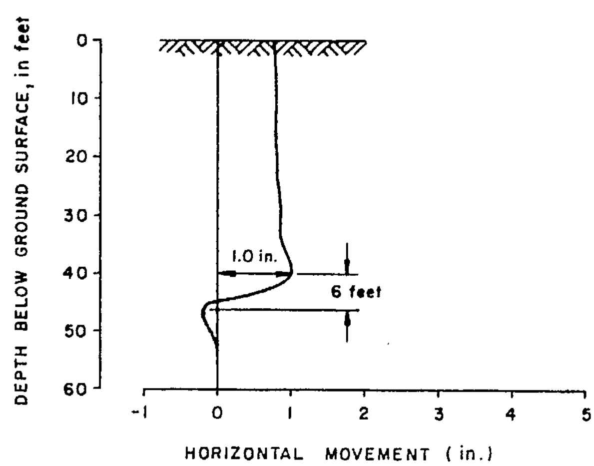

Fig 2 - Example of inclinometer observations in landslide zone.

INSTALLATION OF INCLINOMETER CASING

13. Twenty ft (6.1 m) sections of the casing should be assembled on surface. The first step is to connect couplers to individual 10 ft (3.0 m) sections with fast-setting cement and pop rivets. The alignment tool shown in Fig 3 is used when connecting prepared 10 ft (3.0 m) sections to form 20 ft (6.1 m) lengths. It assures proper alignment of the casing grooves for passage of the inclinometer.

14. Pipe clamps are used as shown in Fig 4 to allow the progressive installation of the casing in the hole. The alignment tool is used to line up the grooves of the 20 ft (6.1 m) sections. The bottom of the casing string is equipped with a plug so that the casing assembly is watertight and can prevent the inflow of dirt. Water may have to be placed in the assembled casing to overcome bouyancy if the borehole is waterfilled.

15. Once the casing is installed, a dummy inclinometer unit should be run up and down in all measurement orientations, to ensure that inclinometer passage is possible. Removal of the casing for modification is possible up to this point. When the assembled casing is proven suitable, a slurry of sand and water should be used to fill the cavity between the casing and the borehole.

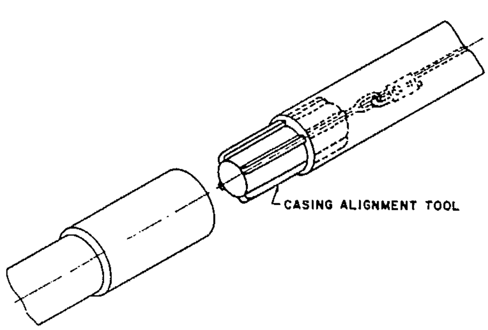

Fig 3 - Casing alignment tool positioned for the connection of two casings.

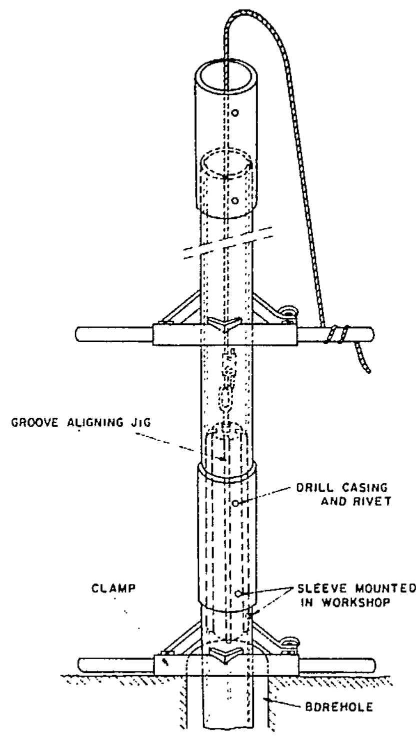

Fig 4 - Diagram illustrating the use of pipe clamps for casing installation.

ACCURACY AND CALIBRATION OF INCLINOMETER

16. Systems accuracy is normally provided by the manufacturer. There is however some merit in carrying out measurements with an installation hole to confirm the value provided. These measurements will also permit those not familiar with the equipment to develop the necessary skills for its effective use.

17. The measurement program to determine system accuracy involves repeat measurements along the length of the casing over a 100 ft (20.0 m) length. The spacing between individual measurements along the hole should duplicate the spacing to be used in the actual monitoring program. Distances of 1-1/2 to 2 inclinometer wheel spaces are common. Reading positions should not allow location of an inclinometer wheel on a joint. Sufficient readings should be taken to permit statistical treatment of the data. In a reported case of such an evaluation 19 sets of readings were found sufficient (3). Figure 5 is the reported deviation from the mean for the three holes involved. The unit used was a Sinco 200 B inclinometer.

18. The inclinometer must be periodically checked throughout its use for shift in the vertical axes of the servo accelerometers, and for changes in calibration. This is done in part by taking two measurements for each pair of matching grooves, with the probe rotated 180 degrees between measurements. The difference between the absolute values of the two readings, for all locations and for a particular servo accelerometer sensor, should be constant if there is no shift in its vertical axis or in calibration.

19. A facility should be built to check independently for the occurrence of a shift in the vertical axis of the servo accelerometers, and the unit shown in Fig 6 meets this requirement. It consists of a length of inclinometer casing in a concrete pillar mounted on a stable foundation. Periodic readings would be made with the inclinometer installed in this unit. A change from initially measured values would indicate a shift of the axis.

20. Changes in the calibration factor of an inclinometer can be checked with a machine shop dividing head. A casing with plug is attached to the dividing head, with the face of the latter in a vertical position. The tracks of the casing are aligned so that one of the sensitive axes of an inclinometer placed in the casing will lie in the plane of the dividing head. By reorienting in the tracks, the second component on an inclinometer with two sensitive axes can be tested. For each

orientation of the inclinometer testing consists of rotating the head to cover the inclination range. The readout unit is used to prepare new calibration curves which can be compared with the manufacturer's original curves.

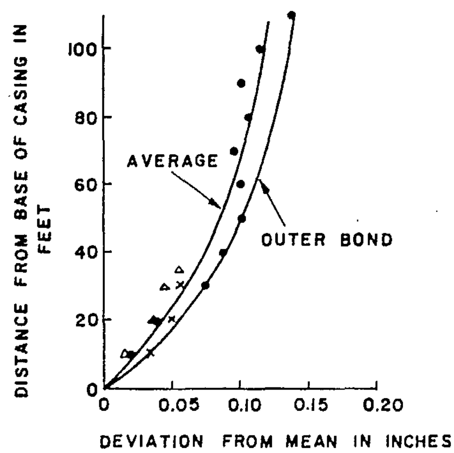

Fig 5 - Deviation from mean in inches as a function of distance from base of hole.

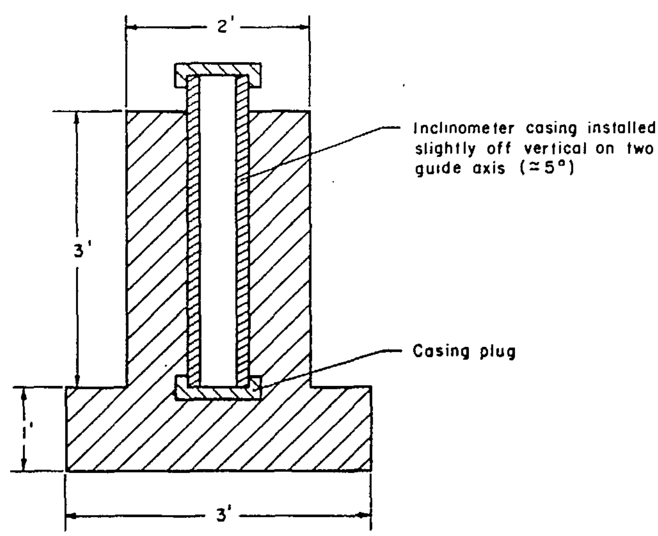

Fig 6 - Facility to check for shift in the vertical axis of inclinometer sensors.

OPERATING PROCEDURES

21. The primary purpose of this type of installation is the detection of rock slope displacement interfaces. Two reading stations per 10 ft (3.0 m) length of casing should be sufficient. Additional stations would add to the cost of monitoring at no apparent advantage. When movement has been detected, the number of stations in the immediate area could be increased. The stations should be so located as to avoid inclinometer wheels resting on casing joints. The casing should be installed with the plane of the grooves normal to, and horizontal to, the pit face. Sets of readings should be made for each station with the inclinometer installed in the two possible orientations for each pair of grooves. Normally, the inclinometer will not read zero when in a true vertical position. The sets of readings permit the removal of this error in determining the true hole inclination.

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2. Cornforth, D.H. "Performance characteristics of the slope indicator series 200-B inclinometer; Field Inst. in Geotech Eng."; Symp. of Brit. Geotech Society; 30 May - June 1, 1973.

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APPENDIX E

BOREHOLE EXTENSOMETER

INTRODUCTION

1. Borehole extensometers have a limited application in monitoring pit slopes. They are too expensive for surveillance of large sections of a pit; a large part of their cost is not recoverable as it is incurred in drilling of the installation hole.

2. Extensometers of this type are best used to monitor known structural features which are suspect in terms of stability. Where such structural features are encountered, cost and operational factors normally require installation from a pit face where a degree of permanence is expected. They are thus best suited for use in final pit walls which will remain accessible eg, adjacent to roadways. They will also be useful where underground operations forming part of the overall mining operation provide access roadways in the vicinity of pit faces to be monitored. A wide range of borehole extensometers, using wires and solid rods as the basic measurement element, has been developed. Two instruments adequate for pit monitoring are described here: a multiwire constant-tension extensometer, and a rock bolt unit.

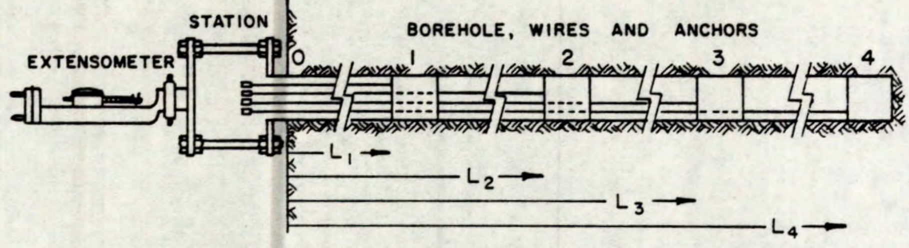
MULTIWIRE CONSTANT TENSION BOREHOLE EXTENSOMETER

GENERAL DESCRIPTION

2. Figure 1 is a diagram of this type of extensometer. It consists of a series of borehole anchors along the axis of the borehole to a maximum of 6, individual stainless steel wires running from the anchors to the collar of the hole, a collar station, and a Newcastle extensometer.

Anchor and Installing Tool

3. Figure 2 is an assembly drawing of the borehole anchor unit and installing tool. The drawings grouped in Fig 3 provide all information required to fabricate these two units. The anchor consists in part of two aluminum wedges, each with 3°45' taper on one edge. The width of the wedges is adjusted to suit the diameter of the borehole.



	Movement	Strain
Wire L_1	ΔL_1	$\epsilon_{0,1} = \dfrac{\Delta L_1}{L_1}$
Wire L_2	ΔL_2	$\epsilon_{1,2} = \dfrac{\Delta L_2 - \Delta L_1}{L_2 - L_1}$
Wire L_3	ΔL_3	$\epsilon_{2,3} = \dfrac{\Delta L_3 - \Delta L_2}{L_3 - L_2}$
Wire L_4	ΔL_4	$\epsilon_{3,4} = \dfrac{\Delta L_4 - \Delta L_3}{L_4 - L_3}$

Fig 1 - Diagram illustrating an installed multi-wire extensometer.

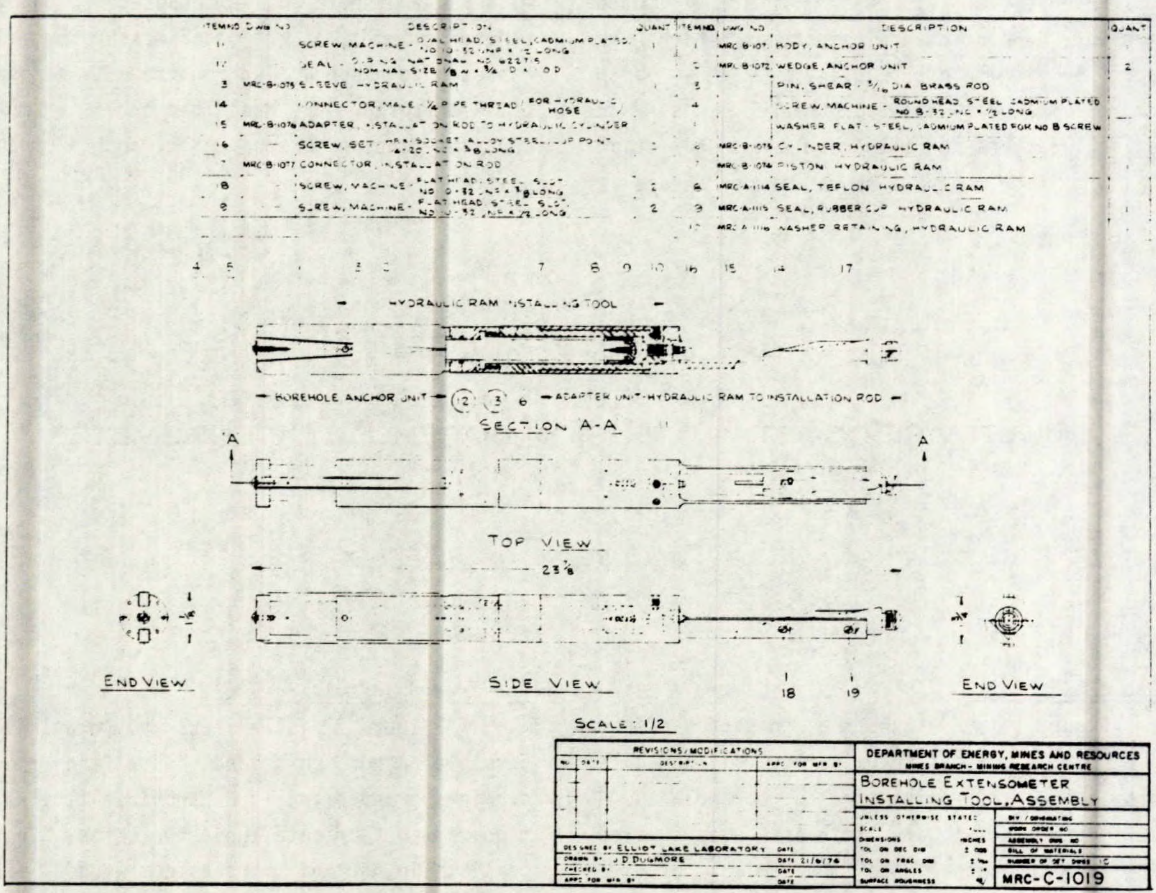


Fig 2 - Assembly drawing of borehole anchor unit and installing tool.

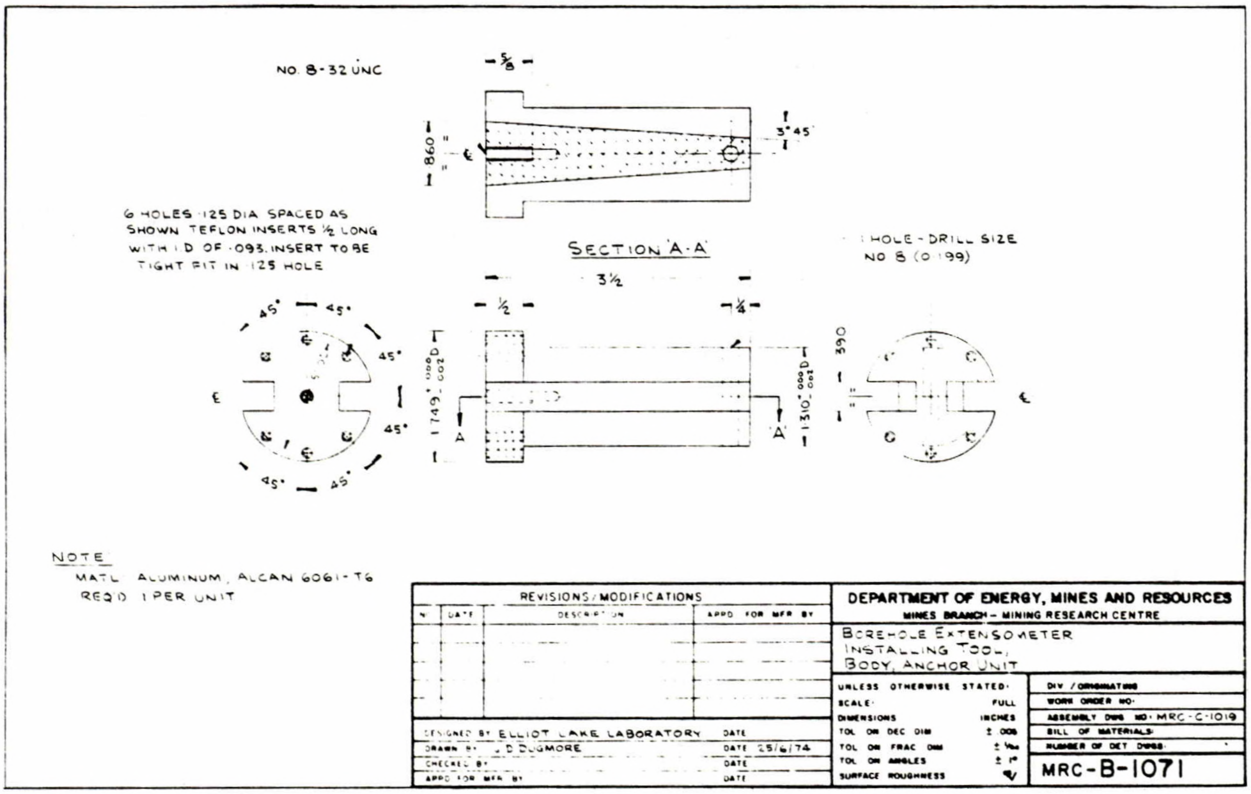


Fig 3(a) - Body of anchor unit.

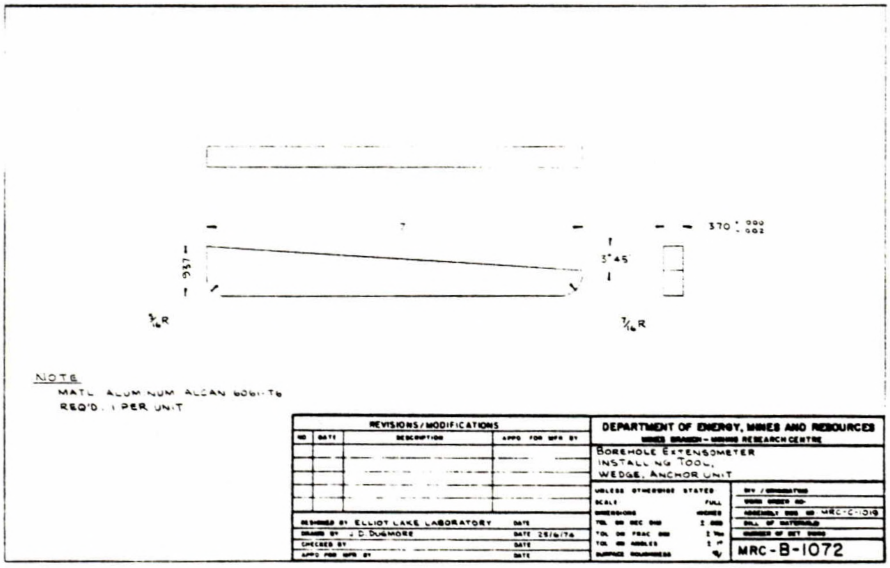


Fig 3(b) - Anchor unit wedge.

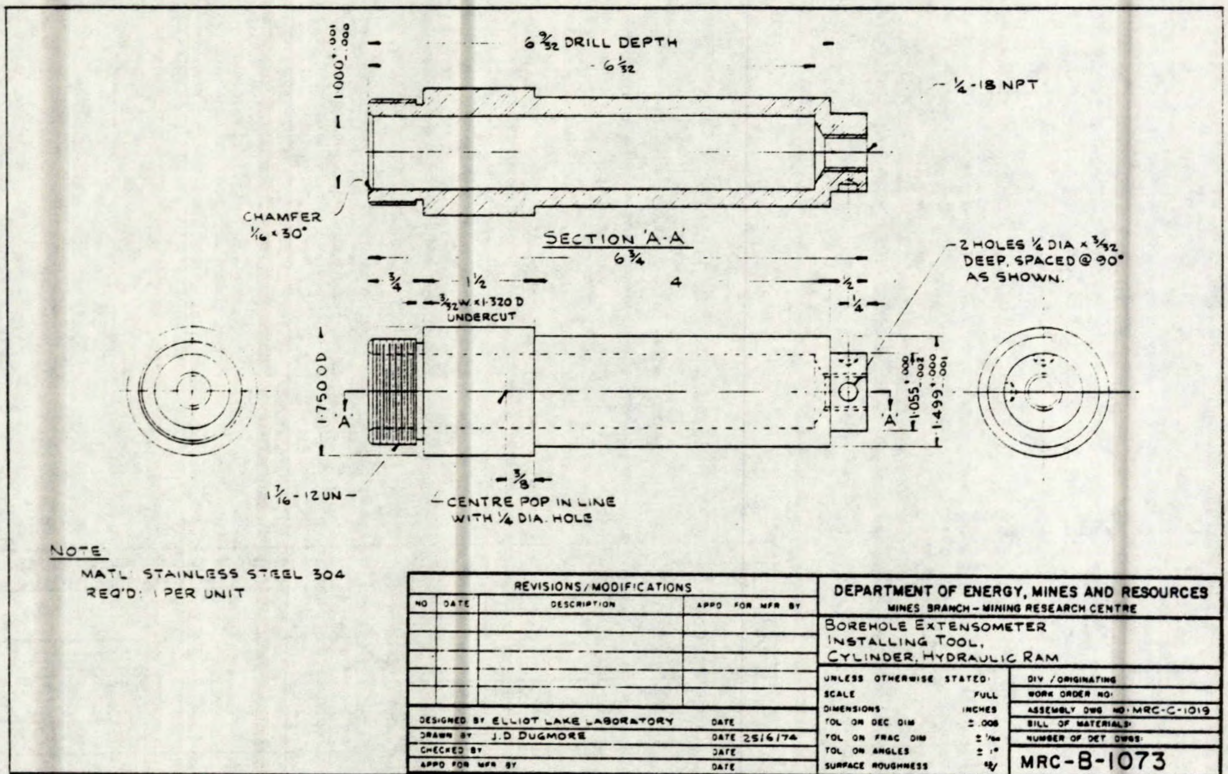


Fig 3(c) - Body of hydraulic ram of installing tool.

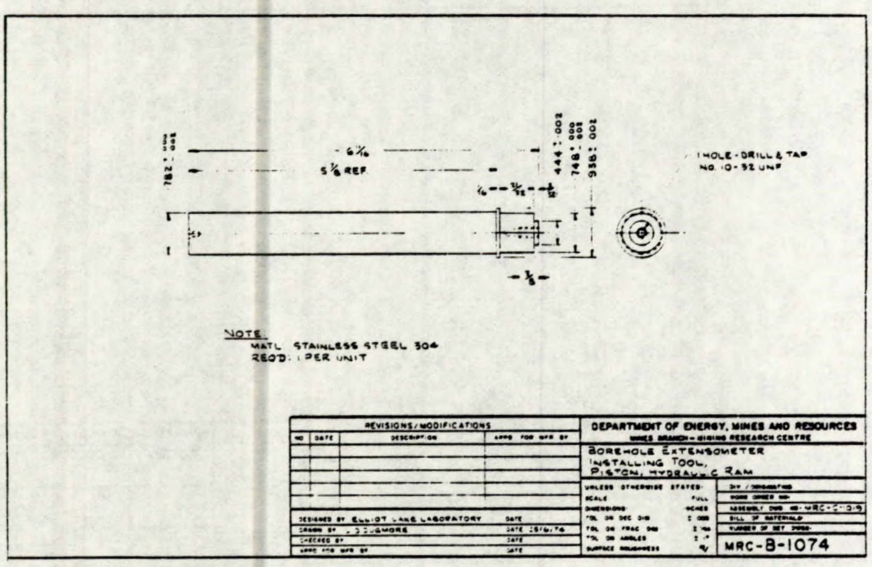


Fig 3(d) - Hydraulic ram piston.

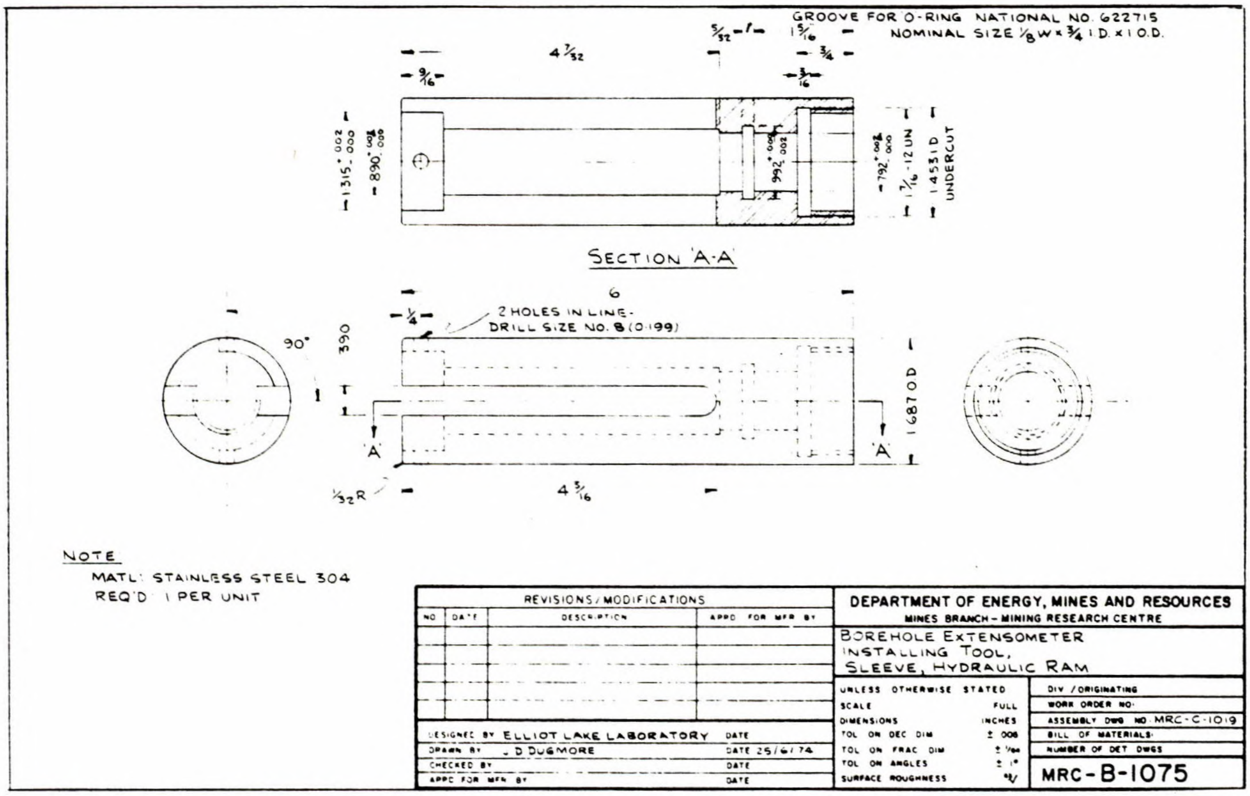


Fig 3(e) - Installing tool sleeve.

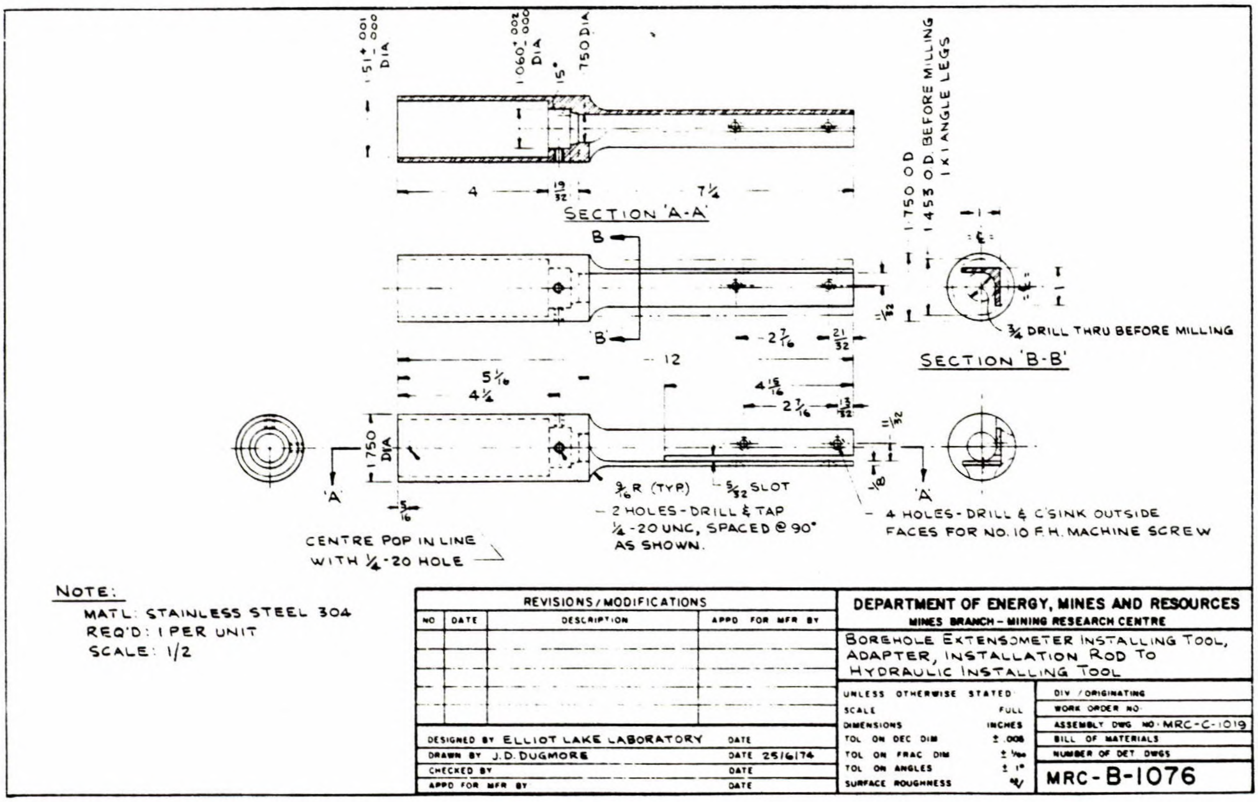


Fig 3(f) - Body of adapter unit between installing tool and rods.

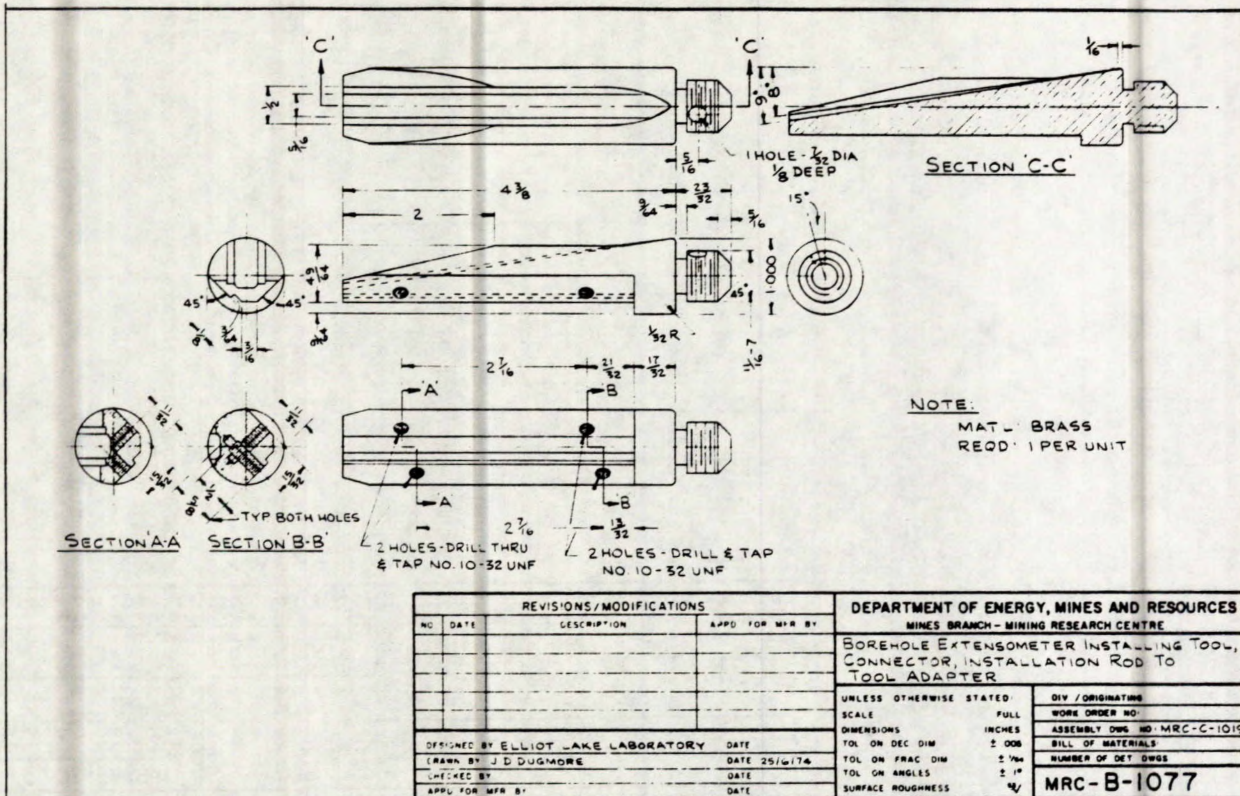


Fig 3(g) - Rod connector unit of adapter.

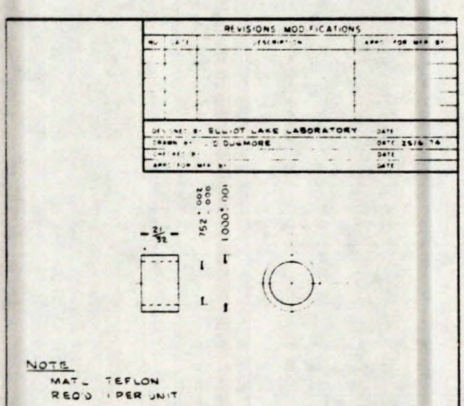


Fig 3(h) - Teflon seal of installing unit.

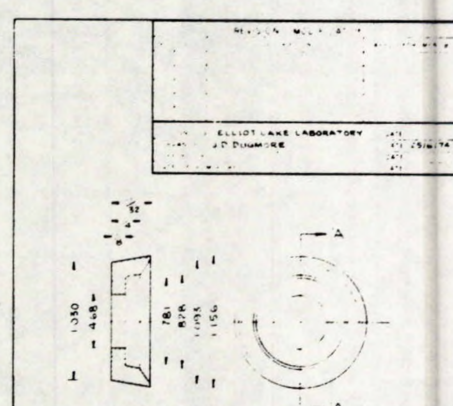


Fig 3(i) - Rubber seal of installing unit.

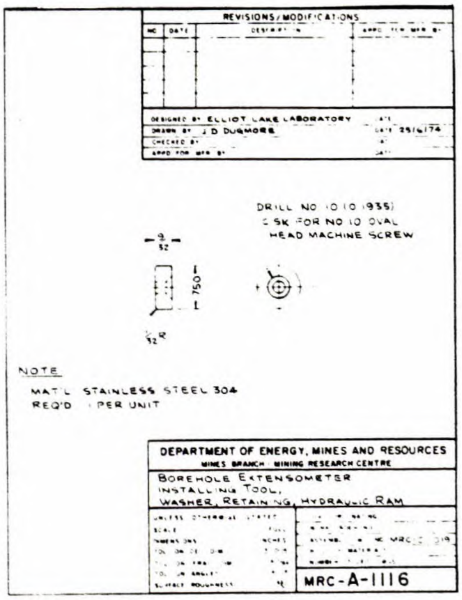


Fig 3(j) - Retaining washer of installing unit.

The tapered faces of the wedge units fit into milled slots of a cylindrical unit equipped with a flanged end section. A tapped hole with nut and washer are located at the centre of the flanged end of this unit for attaching the wire. The wire is fed past the entire body of the anchor and the installing tool through one of six holes provided in the flange. The cross section at the mounting tool is sufficiently small not to interfere with previously installed wires. The cylindrical anchor unit is equipped with a diametral hole for a shear pin. The installing tool is equipped with a slotted end cylinder to house the anchor beyond the shear pin hole. Holes in the cylindrical walls of the installing tool permit the anchor to be locked to the mounting tool with the shear pin. When hydraulic pressure is applied to the installing tool, the wedges are moved past the cylindrical section of the anchoring unit until the wedges come into contact with the walls of the borehole. Hydraulic pressure is increased until the shear pin breaks, leaving the anchor wedged in place.

Wire and Borehole Size

4. Type 310 stainless steel wire 0.049 in. (0.12 cm) diameter is generally used with this instrument. Tensions of 20 (89 N) and 30 lb (133 N) are applied by the surface extensometer to the wire for displacement measurements. AX diamond drill holes are used where the maximum gauge length is 200 ft (66 m) or less; BX holes are used when the maximum gauge length is above 200 ft (66 m). The maximum recommended gauge length is 400 ft (131 m).

Collar Station

5. Figure 4 is an assembly drawing of the collar station for an AX borehole. Figure 5 provides detailed drawings of component parts of the collar station.

6. The steel pipe inserted into the borehole is grouted into place with plastic steel. The front and back plates are made of 0.5 in. (1.3 cm) steel plate. The back plate is threaded for connection to the pipe cemented into the hole. The front plate is equipped with a centre hole and an externally threaded cylindrical stud, used to mount the Newcastle extensometer to the collar station.

7. As shown in the diagram, a holding button and a connecting button are attached to each wire. A holding button is a short length of stainless steel or aluminum rod with a teflon cylindrical insert with a sufficiently large centre hole to permit passage of the 0.049 in. (0.12 cm) wire. It is clamped to the wire with two Allen screws. The teflon insert allows slippage of the wire if movement occurs in the rock. A 5 lb (22 N) pull load on the wire is used to hold the wires snug against the slotted plate. Each wire can be stored in its own slot of the plate when not in use. The connecting buttons have half-cylinder end sections with a lateral drill hole for insertion of a connecting pin. A similar fitting on the extensometer unit provides connection to the wire.

The Extensometer Unit

8. A Newcastle Mark II extensometer is used with this system, as shown in Fig 6. The capstan nut located at the end of the unit is used to attach it to the threaded stud of the collar station. Tension is determined by reading the

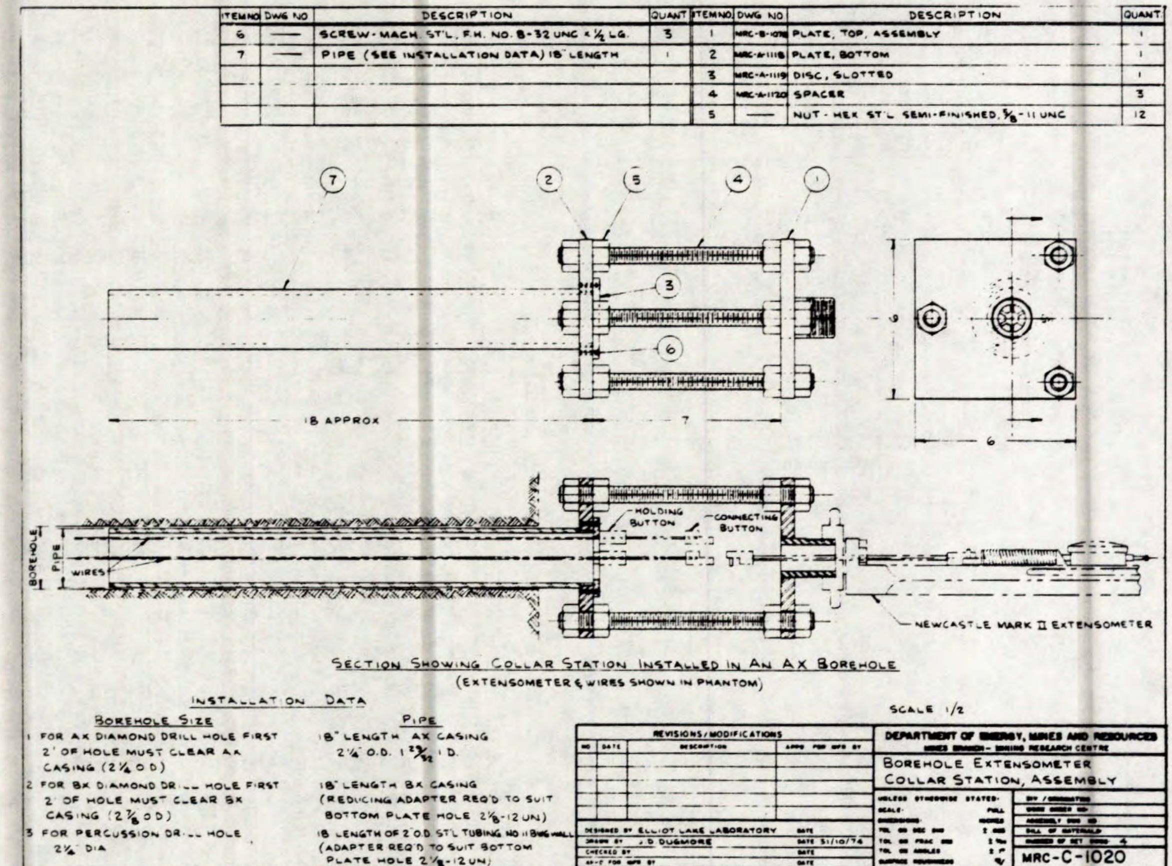


Fig 4 - Assembly drawing of collar station.

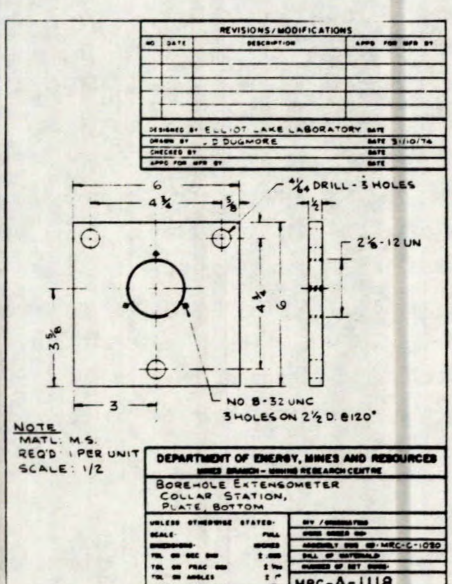


Fig 5(a) - Bottom plate of collar station.

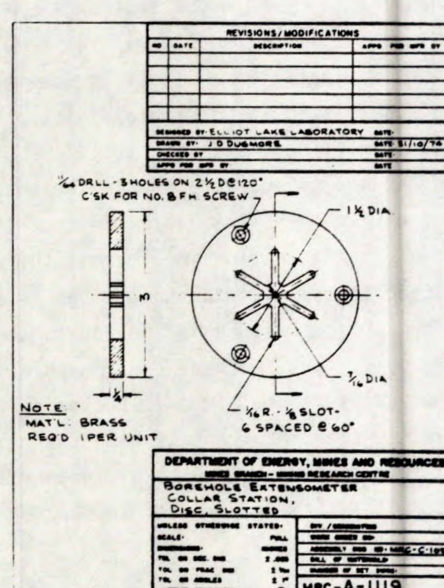


Fig 5(b) - Slotted disc of collar station.

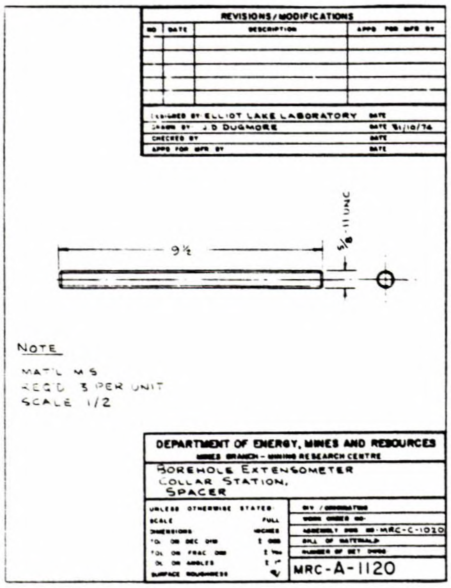


Fig 5(c) - Spacer of collar station.

dial gauge. The accurate calibrated screw is coupled to a 6 in. (15 cm) scale which indicates the position of the end of the wire to .001 in. (0.023 mm).

AREA OF APPLICATION AND FACTORS AFFECTING ACCURACY

9. Two types of rock movement are detected with this extensometer: small elastic deformations resulting from changes in stress, and larger movement resulting from rock movement along discontinuities. Recognizing instrumentation limitations, the overall error should not be more than 0.010 in. (0.025 cm) when measuring movement due to change in stress, and not more than 0.050 in. (0.13 cm) for the two types of rock movement. At present, the deformation due to change in stress is rarely measured in boreholes over 100 ft (30 m) in length; the movement of fractured rock

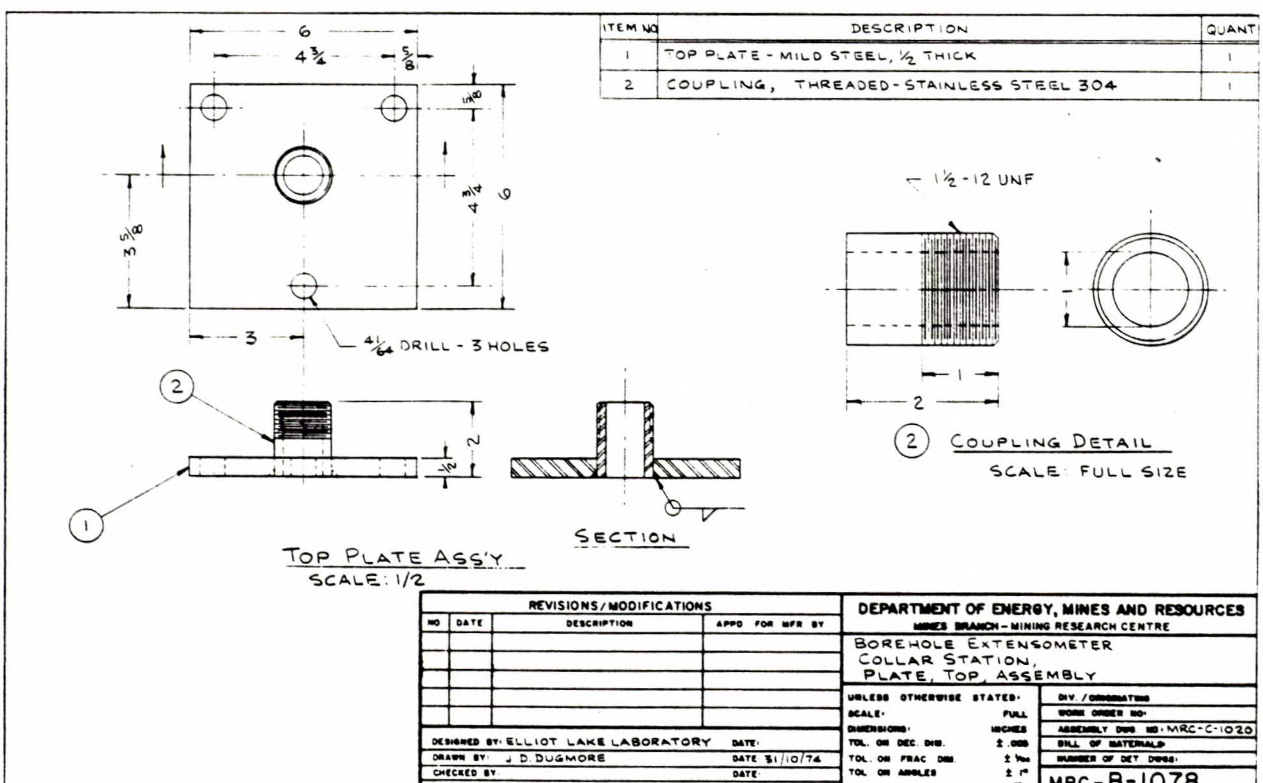


Fig 5(d) - Top plate of collar station.

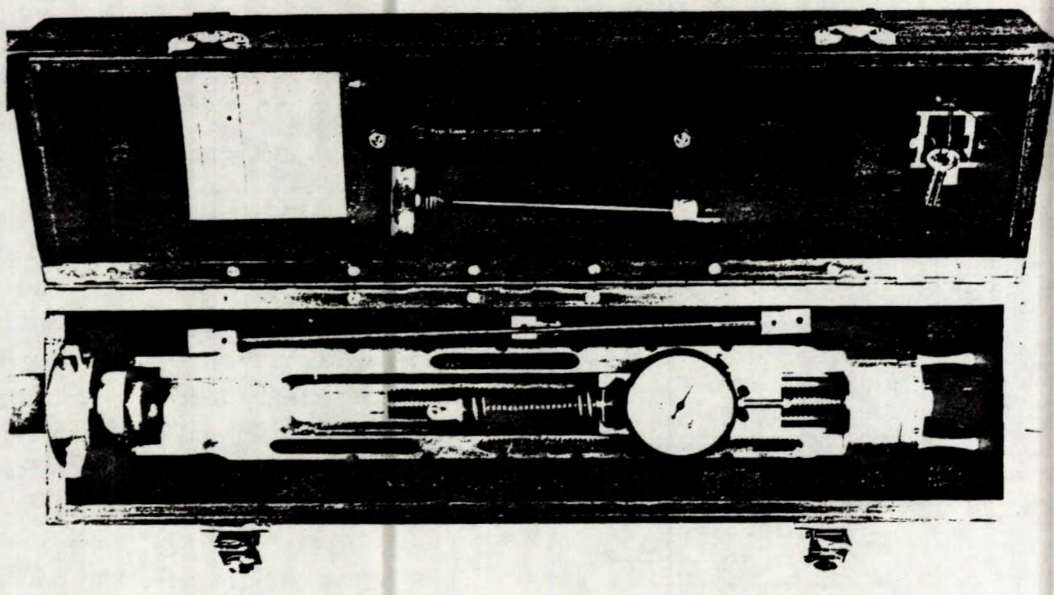


Fig 6 - Photograph of Newcastle Mark II extensometer and test rod.

is occasionally measured up to 400 ft (122 m) in length.

10. The overall accuracy of the multiwire constant-tension extensometer depends on the combined effect of the individual errors in the measuring system. The factors which produce the errors are:

a. friction effects between wires, borehole anchors and borehole,

b. change in temperature, and

c. changes in physical properties of the wire.

Friction Effects Between Wires, Borehole Anchors and Borehole

11. Tension applied to a wire through the extensometer is progressively reduced along its length by the friction between the wires, and the borehole and anchors. The length of a wire is consequently shorter than when a constant tension is applied along its entire length. This is not important in itself if it can be assumed that the friction remains constant. This may not be the case, however, and it is expedient to evaluate the importance of the different frictional effects.

12. Where the surface of the wire and borehole are in contact, there is a limited amount of friction resistance to sliding. The force, F, necessary to overcome this resistance is:

$$F = \mu N \qquad (1)$$

where μ = coefficient of static friction,
N = force normal to the contact surface.

The force, N, is the weight of the wire supported by the borehole. Figure 7 indicates the potential measurement error due to wire-to-wall and wire-to anchor frictional effects, as a function of wire length and anchor separation distance. Interfaces with coefficient of friction of μ = 0.2 and μ = 0.5 have been considered. The coefficient of friction μ = 0.5 is typical of a steel-rock interface and μ = 0.2 of a steel-steel interface, as realized in the case of the wire-anchor contact. The dotted lines in Fig 7 represent the 0.010 in. (0.025 cm) and 0.002 in. (0.005 cm) error limits. Wire lengths in contact with the borehole become significant at 154 ft (47 m) for the upper limit, and at 69 ft (21 m) for the lower limit. The graph for μ = 0.2 indicates that by using a series of anchors at a separation distance of 40 ft (12 m) to 50 ft (15 m), a cumulative error within the lower limit can be incurred for wires anchored at distances up to 200 ft (61 m) from the borehole collar, and within the upper

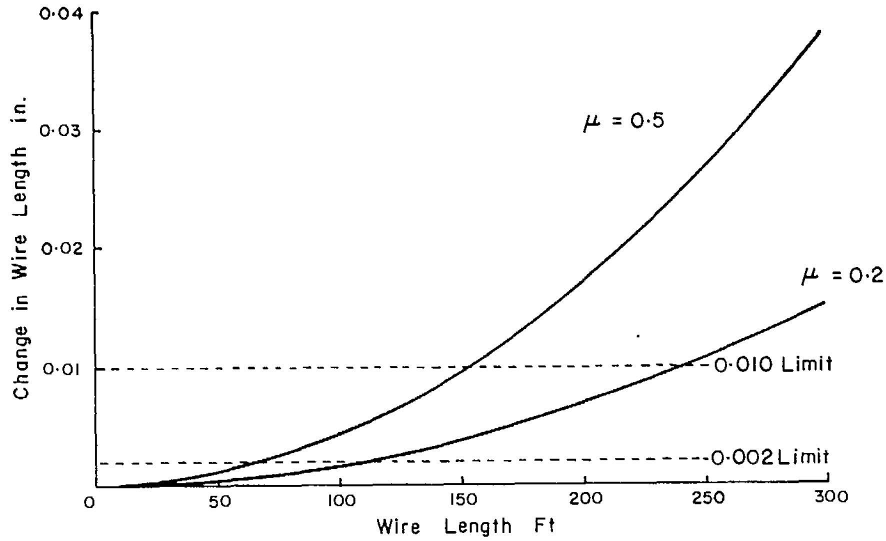


Fig 7 - Change in wire due to friction effects.

limit for wires anchored up to 400 ft (122 m). Contact between the wire and wall rock must be avoided so as not to increase the error.

13. In multiwire boreholes it is often observed that if one wire is pulled, the others tend to move as well. In an extreme case, the wires will behave as a wire rope. It is impossible to calculate theoretically the effect of intertwining on accuracy, but the effects are likely to be large. It is therefore advisable to eliminate all contact between the wires. In the multiwire extensometer this is done by providing separate anchor holes for each wire, and keeping them under a small tension at all times. Care is also taken to install the anchors and wires without rotation about borehole axes.

Changes in Temperature

14. To obtain the true displacement of a borehole, compensation for the temperature change on length of the borehole and wire, must be considered. Underground, the change in borehole temperature is usually minimal, except in intake airways. Boreholes drilled from the surface will be affected to a depth of about 25 ft (7.6 m) perpendicular to the surface, beyond which the temperature remains reasonably constant. Open boreholes will be affected over their entire length, due to natural ventilation.

15. It is recommended that heated enclosures be constructed to shelter these units. When this is not feasible, holes should be plugged to limit temperature effects to the upper 25 ft (7.6 m) and a 25 ft (7.6 m) wire should be installed. The apparent movement of this wire can be subtracted from those measured on the other wires. The reference point for the measurement would thus be transferred from the collar to a depth of 25 ft (7.6 m).

16. From Table E-1 and Fig 8 the error due to differential thermal expansion of the rock and wire can be estimated for the first 25 ft (7.6 m) of wire.

Change in Physical Properties of Wire

17. Stainless steel has a constant modulus below yield point of about 28 x 10^6 psi (1.9 x 10^8 kPa). The effective modulus of the stainless steel wire can however be outside this range, and can vary with applied load.

18. At low tensions, part of the apparent stretch of the wire is from straightening of natural curves; this results in lower apparent elastic modulus. Figure 9 shows the results of

Table E-1: Coefficients of linear expansion

Rocks*			Mean coefficient of linear expansion x 10^{-6} /°F
Granites and rhyolites			4.5
Andesites and diorites			4.0
Basalts, gabbros and diabases			3.0
Sandstones			5.5
Quartzites			6.0
Limestones			4.5
Marbles			4.0
Slates			5.0
Salt and potash			21.0
Stainless steels			
AISI[+] 446	27% Cr		5.5
AISI 403	12% Cr		6.1
AISI 420	12% Cr	over 0.15% C	6.8
AISI 310	25% Cr	20% Ni	8.5
AISI 305	18% Cr	12% Ni	9.5
Invar	65% Fe	36%	1.0

* From Handbook of Physical Constants, S.P. Clark, Jr. (Editor), Geological Society of America.
\+ American Iron and Steel Institute.

laboratory tests on 64 ft (26 m) lengths of 0.049 in. (1.2 mm) stainless steel wire. Tests were performed, both in the as-received coiled condition, and after they had been pulled through a wire straightener. This consists of two sets of nine pulleys mounted at 90 degrees from each other.

19. With reference to Fig 9, in the in-coil condition at a tension of 4 lb (18 N), the apparent elastic modulus is 8 x 10^6 psi (5.5 x 10^7 kPa). The modulus increases with tension until at 15 lb (67 N) the final value of 24 x 10^6 psi (1.65 x 10^8 kPa) is reached. The results for the straightened wire plotted in Fig 9 are typical of the effect of the straightening unit; within the range tested, the elastic modulus has a constant value of 24 x 10^6 psi (1.65 x 10^8 kPa). By working at reading loads of 20 lb (89 N) and 30 lb (133 N), the error due to changes in wire properties can be eliminated.

EVALUATION AND CALIBRATION OF BOREHOLE EXTENSOMETERS

20. A borehole simulated with 20 ft (6.1 m) lengths of 2 in. (5.1 cm) steel pipe is recommended for the evaluation and calibration of extensometers under controlled laboratory conditions. At one end the pipe is equipped with a unit which permits displacement of extensometer wires, with a precision of 0.001 in. (0.024 mm) over a range of 1 in. (2.5 cm). The extensometer head is attached to the other end of the pipe string with the wire anchors installed in the pipe as required. The wire is moved in fixed increments away from and towards the extensometer, and the response is measured. Various lengths are tested by adding or removing 20 ft (6.1 m) lengths of pipe. In this way the actual and measured wire movements can be compared, and the results statistically analyzed to determine accuracy. The accuracy is taken as ±2 standard errors of the estimate from the regression line of actual versus measured movement. The friction present in the extensometer can be obtained from the lag in extensometer response when reversing the direction of the wire.

21. Figure 10 shows in comparison the calibration curves and accuracies of two types of instruments, one of which applies a constant tension, and one in which tension varies with wire movement. Wire lengths of 20, 40, 60, 80 and 100 ft (10 ft = 3.0 m) were used in the calibration, and the results for the 100 ft (30 m) wire are shown in the graph. The calibration curve for the constant tension extensometer is linear and the measured movement is almost identical with the actual wire movement. For the variable tension extensometer, the measured movement is less than the actual wire movement due to the stretch of the wire with increasing tension. Consequently, only a fraction of the wire movement is measured and this is one disadvantage of this instrument. Also the loading and unloading cycles are not the same because of friction in the extensometer. The

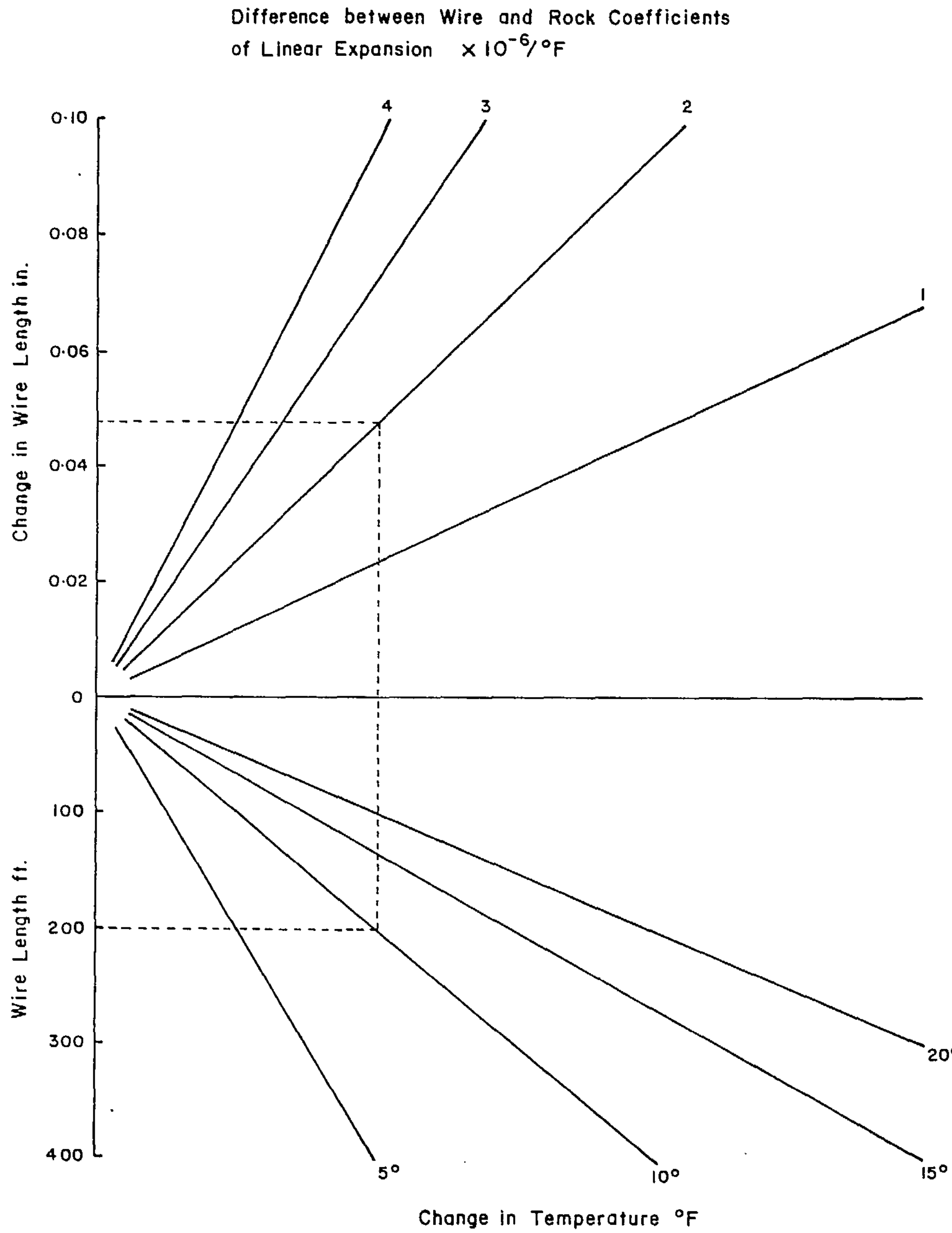


Fig 8 - Effect of temperature on wire length.

horizontal difference between the two curves, or lag, is proportional to the amount of friction and wire length.

22. The Newcastle Mark II extensometer must be regularly checked for accuracy. For this purpose, the spring used as the weighting element is checked by attaching known weights to the extensometer, and verifying that the correct dial reading is being given. To test for dimensional change, the test rod shown in Fig 6 is attached to the unit and a 30 lb (133 N) tension applied. The value of the reading should be a constant.

PROCEDURE FOR EXTENSOMETER INSTALLATION

23. Present installation methods permit installation of anchors and wires in 400 ft (120 m)

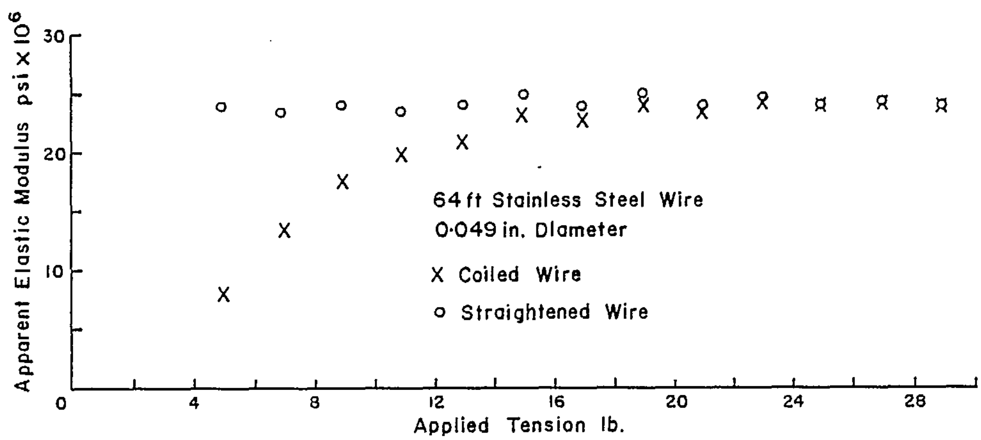


Fig 9 - Apparent eleastic modulus as a function of applied tension for a 0.049 in. (1.2 mm) diameter stainless steel wire.

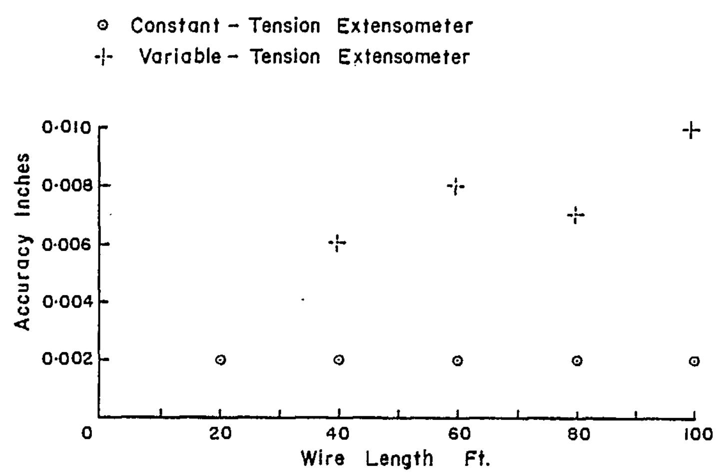


Fig 10 - Accuracy as a function of wire length for constant and variable tension wire extensometers.

horizontal holes, 200 ft (60 m) down holes and 150 ft (46 m) up holes. Beyond these depths, manual installation is not considered practicable.

24. The wire is cut to the gauge length required with an additional 10 ft (3.0 m). Before installation, it is passed through the straightening device. When straight, it is kept so by laying it out in line on the best available surface. Often sufficient space is lacking underground for this procedure. In this case the wire is straightened at the laboratory and recoiled to 2-1/2 ft (0.76 m) diameter. With coils of this diameter no problems are encountered. The wire is passed through a clearance hole of the anchor and attached to the holding screw located on the down side area of the borehole anchor.

25. At the collar, the wires for those anchors already in place are threaded through their respective clearance holes on the anchor about to be installed. The anchor itself is connected to the mounting tool ready for installation. Care must be taken that wires do not become twisted by

changing the location of passage holes for the wires from anchor to anchor.

26. A string of 0.5 in. (1.3 cm) aluminum conduit pipes and couplers is used to push the installing tool and anchor into place. Scribe marks on the couplings and pipe sections are used to prevent rotation of the axis of the borehole anchors in the hole. Extreme rotation could cause twisting of the wires and anchors. Once an anchor is in position, hydraulic pressure applied to the mounting tool is used to wedge the anchor into place and to shear the pin attaching the anchor to the mounting tool. The tool is then removed for installation of the next anchor. Care must be taken to prevent the tool from jamming in the hole by the hydraulic hose.

27. It is not sufficient to allow the wires to hang free during installation as they inevitably become twisted with handling. To avoid this, the wires are attached to a terminal board in a fixed order when not being used. The uncut wires are sufficiently long to permit threading and rethreading through the pipe of the borehole collar and attachment to the terminal block.

28. When all anchors and wires have been installed, the borehole collar pipe with the back plate attached is cemented into place. Plastic steel is spread on the collar pipe to about 4 in. (10 cm) from the two ends; the pipe is then pushed into the hole and the cement allowed to set. Excess cement at the collar station is removed and care taken that it does not come in contact with the wires. The pipe is allowed to rest undisturbed overnight for the cement to set.

29. Before mounting the bars and front plate, the slotted plate is put into position and the hold buttons attached to the wires. The wires are then cut to length and the connecting buttons attached. The rest of the collar station is assembled and the unit is ready for measuring.

PROCEDURE FOR READING EXTENSOMETER

30. Accurate, reproducible readings can be taken with this instrument without high initial tensioning, provided the wires have been pulled through a straightener. Before taking readings the tension on the wire should however be cycled a few times between zero and peak load. The tension is then increased at a steady rate to the standard load values for reading. This procedure will avoid hysteresis effects in the wire, and errors in the readings. Three separate readings should be taken; if these are not within acceptable limits, more readings should be taken to allow removal of the extreme values.

31. Readings should be taken at two standard tensions. With the present system, where a 0.049 in. (1.2 mm) diameter steel wire is used, tension loads of 20 lb (89 N) and 30 lb (133 N) are recommended. The difference in reading at these two tensions should be the same every time a set of readings is taken. A small change could mean the frictional effects in the borehole have altered; a major change could indicate that the wire is obstructed, or the borehole has sheared and clamped the wires. The location of the obstruction can be estimated using the equation:

$$L = \frac{X}{(T_2 - T_1)} \cdot \frac{\pi}{4} \cdot d^2 E$$

where, L = wire length, distance from collar to obstruction,
T_1 = first tension,
T_2 = second tension,
x = stretch of wire for increase of tension T_1 to T_2
d = wire diameter,
E = elastic modulus.

32. A field example of wire clamping is shown in Fig 11. Immediately after installation, the plot of wire stretch against wire length is linear, which indicates a good installation with no wire obstruction. The elastic modulus can be calculated from the gradient of this line, and is 23×10^6 psi (1.58×10^8 kPa). Subsequent readings which fall below this line indicate obstruction of the wire. The second set of readings after 27 days show that the 84 ft (25 m) wire was obstructed at about 67 ft (20 m), while the other wires were still free. After 68 days the 84 ft (25 m) wire was obstructed at 54 ft (16 m), the 65 ft (20 m) wire at 46 ft (14 m) and the 45 ft (14 m) wire at 37 ft (11 m), while the 25 ft

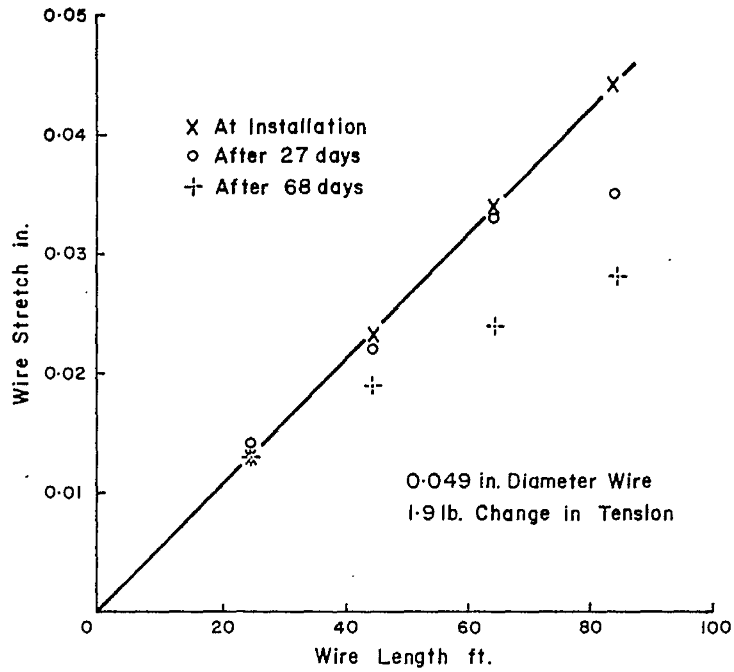


Fig 11 - Plot of differential stretch of extensometer wires read a two reading loads which showing the effect of progressing hole blockage.

(7.6 m) wire was still free. This obstruction was caused by fill tailings penetrating the fractured rock and blocking the borehole. Taking measurements at two tensions prevents erroneous interpretation of results.

COST OF UNIT

33. The estimated cost of the unit was $2000 in 1974, not including the cost of a Newcastle Mark II extensometer unit.

ROCK BOLT EXTENSOMETER

GENERAL DESCRIPTION OF THE ROCK BOLT EXTENSOMETER

34. In practice, the rock bolt extensometer unit would use the rock bolt anchor and rock bolts available at the mine. It is used with gauge lengths of 25 ft (8.2 m) or less. With greater gauge lengths, a single measurement per hole is wasteful, considering the cost of drilling. Normally, percussion holes would be used with this device to reduce cost. Where the available rock bolts are not long enough to meet the required gauge length, shorter lengths interconnected with pipe fittings are recommended. Rebars could also be used as rods.

35. Figure 12 is a diagram indicating the head arrangement for the rock bolt extensometer. The end of the bolt is threaded to accept a water pipe cap; the flattened end of this is used as a seat for the plunger of the dial gauge. The end cap rides on the inner surface of a 10 in. (25 cm) length of water pipe partially inserted into the hole, and cemented into place with Devcon B. The end of the pipe is threaded for attaching a coupler as shown. A water pipe plug is attached with the coupler and used to mount the dial gauge.

AREA OF APPLICATION AND FACTORS AFFECTING ACCURACY

36. The rock bolt extensometer is recommended for those areas where structural movement is expected from specific shallow depth structural features. As pointed out earlier, the cost of drilling deep holes obviates using this device in deeper holes. It is recommended for use in accessible pit walls and in formations surrounding underground headings where short gauge lengths are suitable.

37. Away from the surface and in areas where the ambient temperature is constant, the unit is reliable to 0.006 in. (0.15 mm). Without considering or adjusting for differential temperature expansion of rock and bolt assembly, reliability beyond 0.03 in. (0.76 mm) cannot be assured.

COST OF UNIT

38. The estimated cost of the unit is $200 (1975).

MANUFACTURERS OF BOREHOLE EXTENSOMETERS

39. A considerable number of borehole units are commercially available. Table E-2 is a partial list of manufacturers; the general characteristics of the units available are indicated.

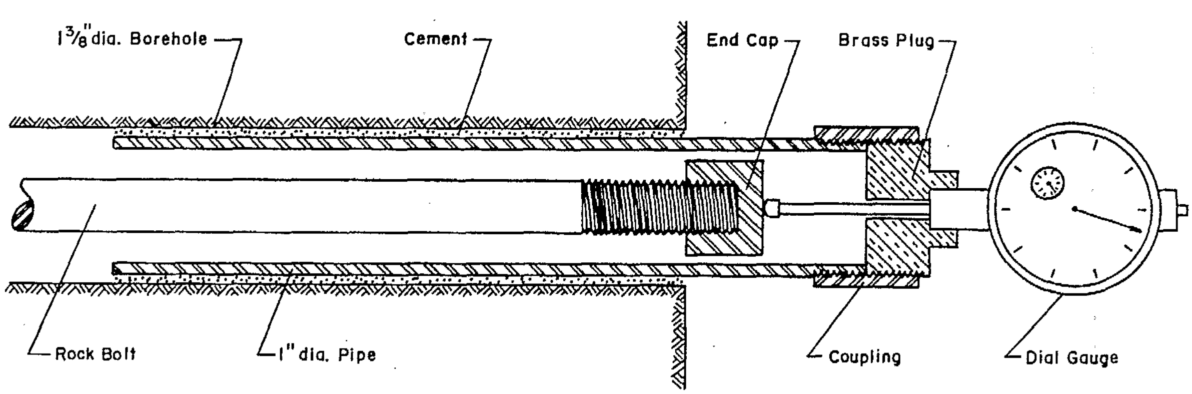


Fig 12 - Rock bolt extensometer.

Table E-2: Borehole extensometer

Company	Types of units available
Interfils Ges. m.b.H. A-5020 Salzburg Schwartzstrasse 27	-Multiwire extensometers with dead weight tensioning and dial gauge measurement of displacement. -Rock bolt type extensometer with dial gauge measurement of displacement. -Multirod extensometers with dial gauge measurement of displacement.
Telemac International Montreal, Canada	-Multiwire extensometers with vibrating wire gauges. Spring tension applied to wires by cantilevers whose flexure is detected to determine displacement. -Multielement in-series extensometer. Movement of anchored rod spring assembly detected by in-line vibrating wire transducer.
Terrametrics, Golden, Colorado	-Multiwire extensometer with spring tension. Mechanical read out of displacement. -Multiwire extensometer with cantilever tension. Strain gauge detection of cantilever flexure is used to measure displacement. -Rock bolt type extensometers with dial gauge read out.

REFERENCES

1. Hedley, D.G.F. "Design criteria for multiwire borehole extensometer systems"; Proceedings of the first Canadian symposium on mine surveying and rock deformation measurements; pp 349-377; Fredericton; Oct. 1969.

2. Hedley, D.G.F. "Notes on rock movement measurements with borehole extensometers"; Divisional report; prepared for presentation at Canadian rock mechanics symposium, Montreal, Quebec; 1972.

APPENDIX F

INVERTED PENDULUMS

INTRODUCTION

1. The inverted pendulum is recommended for use on crest or berm surfaces where stable structures can be intersected at shallow depth. The present maximum depth of installation is 100 ft (30 m). Large blast hole drilling equipment is used for the installation hole. It is difficult to drill a vertical hole deeper than the 100 ft (30 m) which will meet the needs of this unit.

2. The inverted pendulum is best used in rock which does not require extensive casing. As a general rule, the device should not be used in rock formations requiring a casing beyond the surface overbreak or weathered zone. Terrain conditions should also be such that the surface station can be firmly anchored into position.

3. It is not a device to monitor large movements as its total range is limited by the diameter of the hole used. Starting with a perfectly vertical hole, the maximum displacement that can be detected is half the diameter of the hole. Because of the accuracy with which it can detect displacements, it is ideally suited for determining initial movement, and movements in benches with small total displacements before failure.

4. Because of the character of its surface station the inverted pendulum should be integrated into any companion survey monitoring system. Monuments are expensive to construct and the surface station of the inverted pendulum can be used for this purpose, if allowed for in the design.

GENERAL DESCRIPTION OF INVERTED PENDULUM

5. Figure 1 is a diagram of a typical installation. It consists of a surface station coupled by a stainless steel wire to an anchor grouted in a borehole.

SURFACE STATION

6. Figure 2 is a detailed diagram of the support structure of a surface station and a photograph of an installed station. To anchor the base of the station, four holes are drilled to receive rock bolt anchors. The ends above ground surface are threaded for bolts and washers. Four No. 4 rebars extend from the base to support the vertical concrete column. Two hinged steel collars are bolted around the column to support the float assembly and measuring table. The angle irons are long enough to extend beyond the drill hole. The upper pair of parallel angle irons is used as a rest for the float and its container, while the lower pair is used to support the table.

7. For installations of this type, it is recommended that float assemblies and measuring tables be purchased, though a mine could perhaps save in designing and constructing its own float system.

8. The purpose of the reservoir is to keep the stainless steel wire under tension, and to permit unimpeded horizontal movement of the wire as long as the wall of the hole does not interfere. Figure 3 illustrates how the float system performs this function. All dimensions must allow the wire to move to the edge of the borehole without obstruction. The float must move laterally so that the top of the wire can position itself above the tie point of the wire at the anchor. A top plate on the float equipped with a central hook locates the pendulum wire centrally on the float and borehole axis at the time of installation.

WIRE AND ANCHOR

9. The wire used with the inverted pendulum is of stainless steel 0.04 in. (1 mm) diameter. It runs from the hook on the float to the anchor set in cement at the base of the hole. The anchor must have a diameter which will allow its easy passage down the hole, but assures that the wire is anchored on or near the axis of the hole. Figure 4 shows an anchor which has been designed for use in a 9.75 in. (25 cm) hole. The end cap has a passage hole for the wire.

10. The body of the unit is a solid steel cylinder. The three fins which run the length of the steel bar are of 1/4 in. steel plate welded to

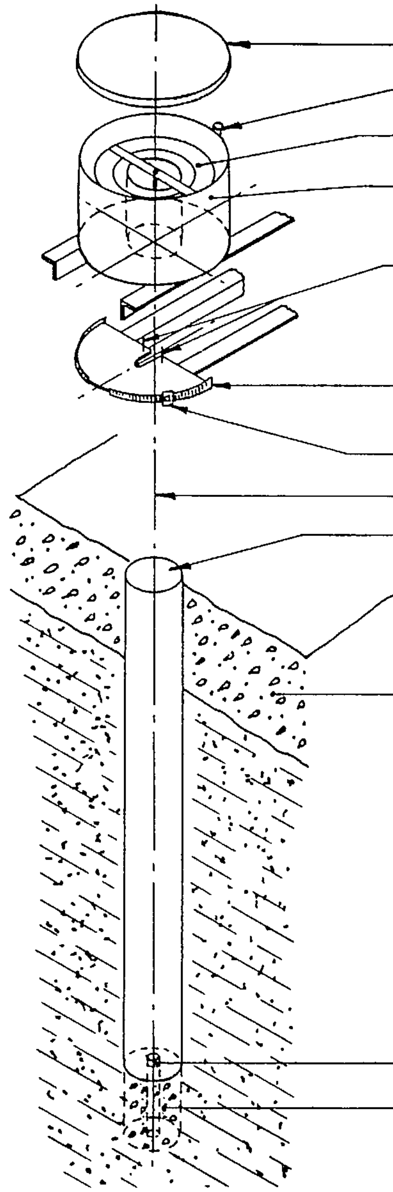


Fig 1 - Diagram illustrating inverted pendulum installation.

the body with an angular separation of 120°. The fins have been bevelled to ease passage down the hole. A galvanized water pipe is attached by means of a pipe thread to the upper end of the anchor. It is equipped with an end cap with a passage hole for the wire. A lateral hole is drilled through the pipe to permit the wire to be fished out and attached to an anchor screw on the body of the water pipe. To partially relieve the load on the screw nut and terminal lug used to attach the wire to the anchor, the wire is spooled around the water pipe for 2 or 3 turns before being attached.

11. A shelter is required to protect the surface station against extreme climatic conditions. In zones of a high water tables, the enclosure may have to be heated to prevent freezing. The surface enclosure temperature can be expected to

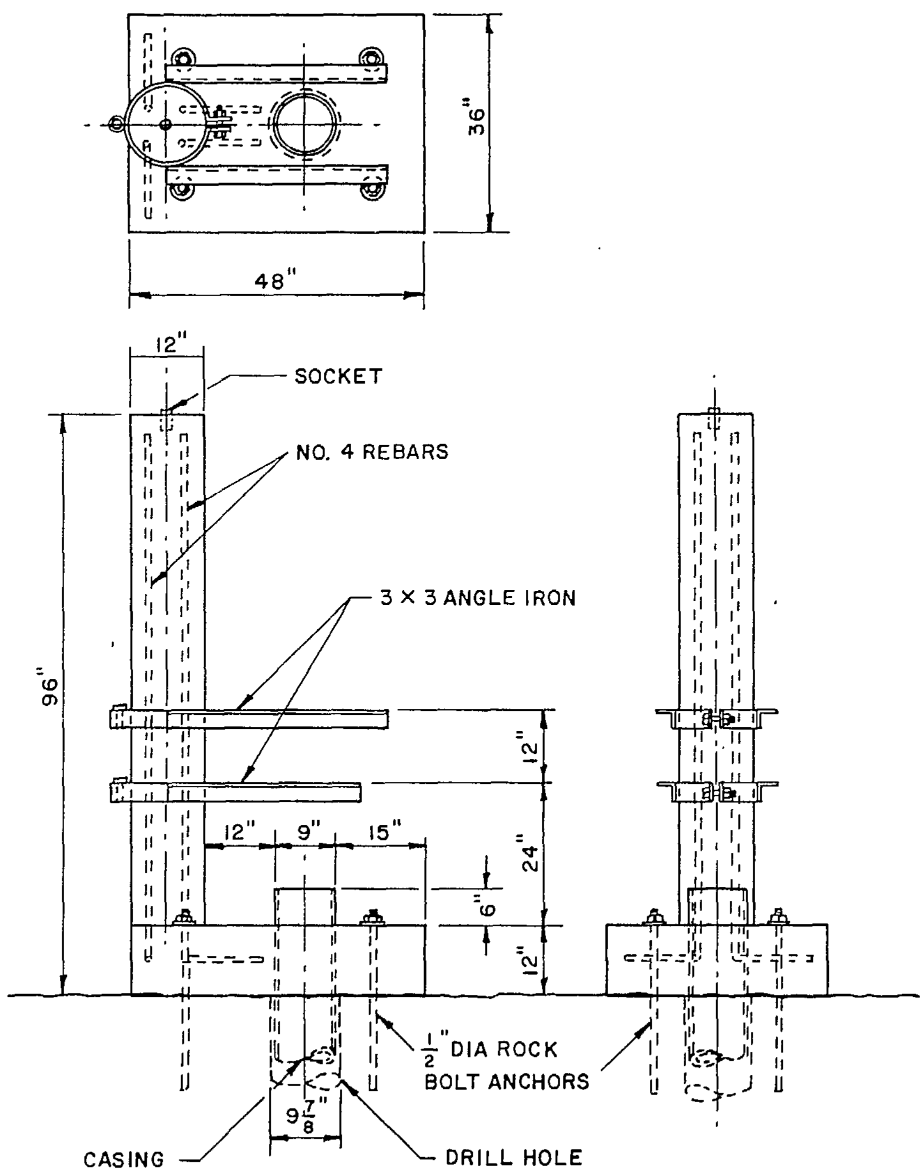


Fig 2(a) - Support structure for surface station.

affect the temperature of the borehole rock to a depth of 25 ft (7.6 m) below surface. Number 10 motor oil should be used as a fluid in the float reservoir.

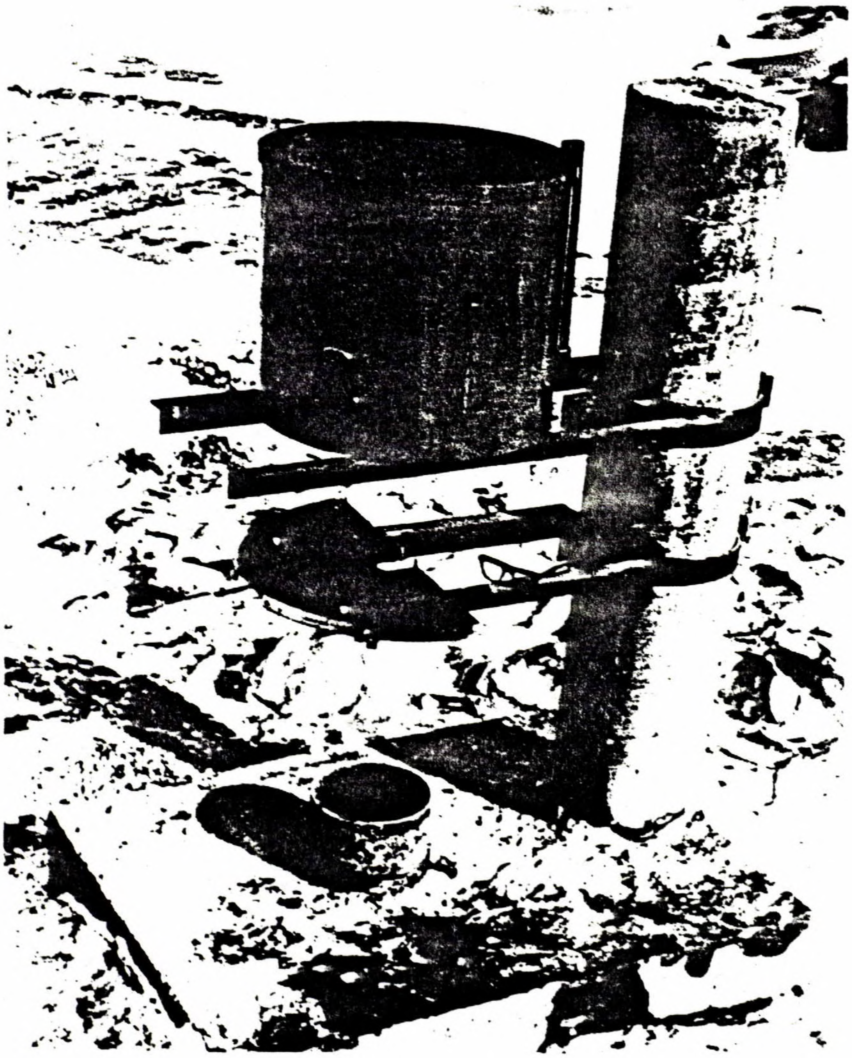


Fig 2(b) - Photograph of surface station.

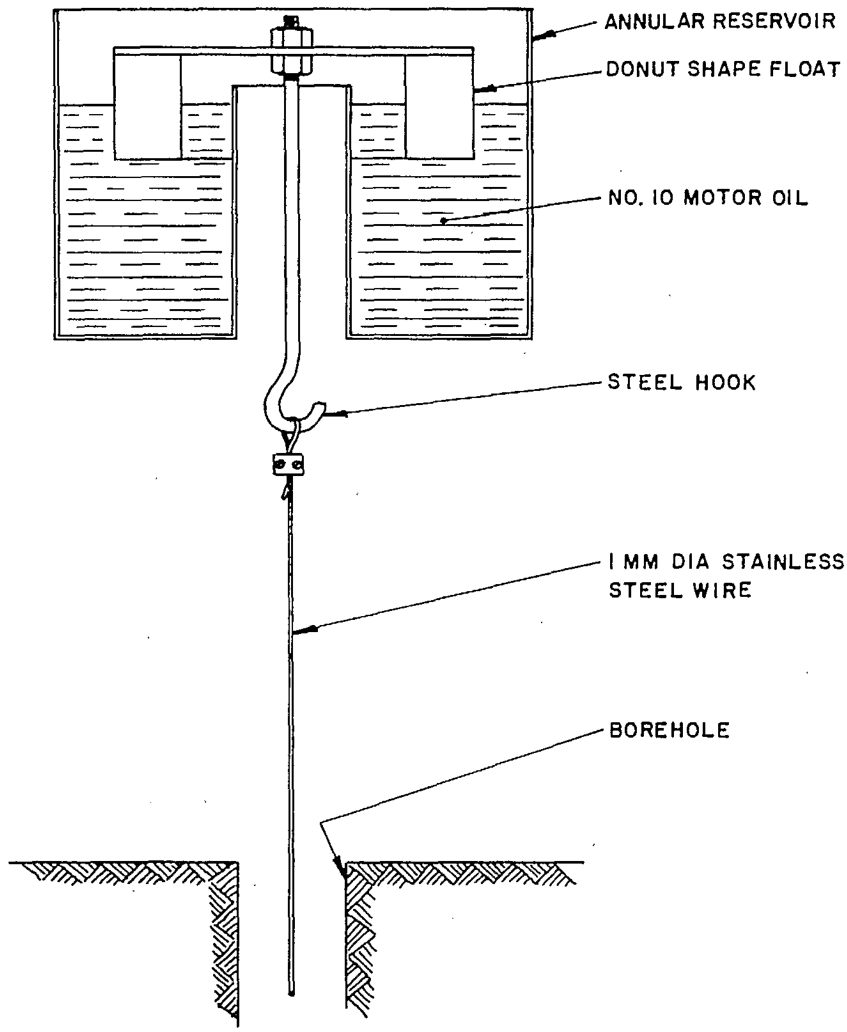


Fig 3 - Cross section of an inverted pendulum float.

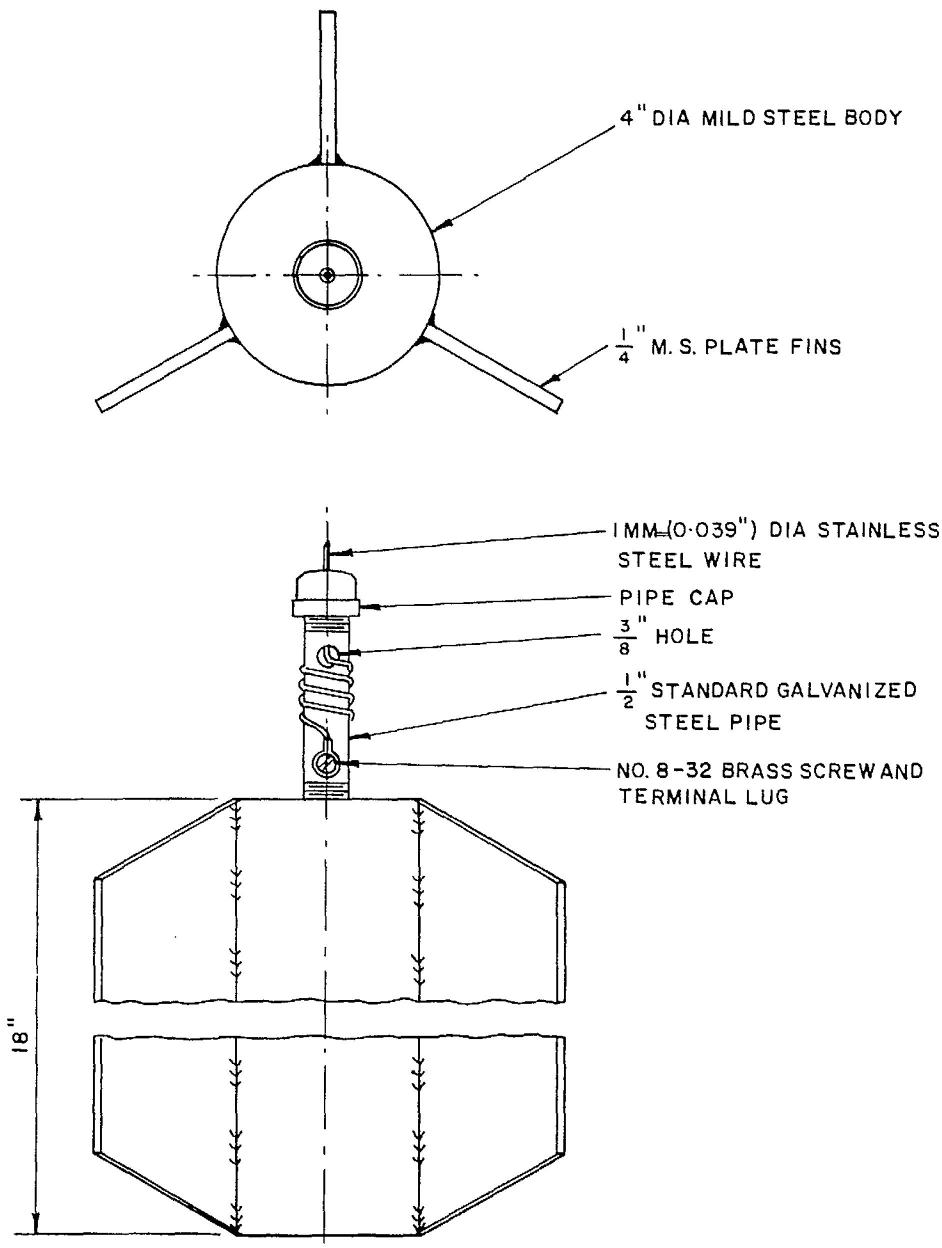


Fig 4 - Anchor for inverted pendulum.

FACTORS AFFECTING ACCURACY

12. Two factors control of the inverted pendulum - reading error, and deformation of the monument and apparatus from temperature changes, and other factors unrelated to real movement.

13. The reading error is controlled by the wire diameter and the reading table. With the system described containing a 0.04 in. (1 mm) wire and a reading table with an angular multiplication factor of 20, a careful observer can detect displacements of the order of 0.004 in. (0.1 mm).

14. Poor anchoring of the surface station can contribute the largest error. It is also the most difficult error to detect and to separate from actual movement. This type of installation is not effective where there is doubt about sound anchorage of the station. This is particularly true if the station is in an area of high blast vibration level.

15. To increase assurance that the station is stable, a second large-diameter borehole should be drilled into the bedrock adjacent to the pendulum hole. A reinforced column extending out of the hole would replace the column of the other station.

16. The concrete components of the surface stations or the reading table will not produce any significant error from thermal deformation. With the systems described, deformation will be due to the change in the length of the angle irons on which the float assembly rests. With a 40°C change in temperature and a coefficient of 12 x $10^{-6}/1°C$, the present unit will have a potential error of 0.02 in. (0.5 mm). On a yearly basis, the error will be less than 0.04 in. (1 mm), and between subsequent daily readings probably less than 0.004 in. (0.1 mm) for a temperature change of less than 10°C.

17. With the inverted pendulum system described, displacements will be measured with the following accuracy:

0.03 in.	(0.8 mm)	on a yearly basis
0.015 in.	(0.4 mm)	on a seasonal basis, and
0.008 in.	(0.2 mm)	between two consecutive measurements.

PROCEDURE OF INSTALLATION

18. A major advantage of the inverted pendulum is its ability to use large-diameter production drill holes. As the hole increases in diameter, the maximum measurable lateral displacement also increases. Part of this greater range can be used to compensate for non-verticality. Provided areas of potential instability can be designated at an early stage of the mining operation, holes can be drilled when the drills are locally available, and when berm surfaces and future crest regions are accessible.

PREPARATION OF HOLES AND CHECKING VERTICALITY

19. It is assumed that a rotary drill is used. The particular application which led to these guidelines included the use of a Bucyrus Erie 40-R drilling a 9.9 in. (25 cm) hole. Two machine factors were established as affecting the verticality of the hole: the physical state of the drilling bit, and the applied pressure. Of these, the more critical is the condition of the cutting tool. If it is in good condition, the machine can be used with maximum pull-down pressure and still provide an acceptable vertical hole.

20. Two theodolites positioned to form a 90° arc with the collar of hole in the horizontal plane are used to align the drill rod vertically. It is important to have a hydraulically-controlled vernier adjustment to give precise vertical alignment. It is particularly important to maintain the rod vertical when drilling the first 10 ft (3 m) to 20 ft (6.1 m) of hole and when additional rods are added to the drilling column. Loss of verticality is normally due to loss of fluid in the levelling jacks and must be accommodated for by the vernier levelling controls. It is suggested that, where possible, the newest and most rigid rotary drill be used. If bad alignment is found on starting a hole, it should be abandoned as an instrument hole and another hole started. If the surface station is formed with a cement column anchored in a large hole, two opportunities are available at each site to realize a vertical hole without economic loss.

21. Checking the verticality of the hole and its suitability for an inverted pendulum is the first step in establishing a surface station. This is done with the arrangement shown in Fig 5. The anchor and the float assembly is placed on a trestle levelled directly above the borehole.

22. The trestle has a central hole which allows free access of the float hook in the hole. A pulley attached to a split collar plate, and a

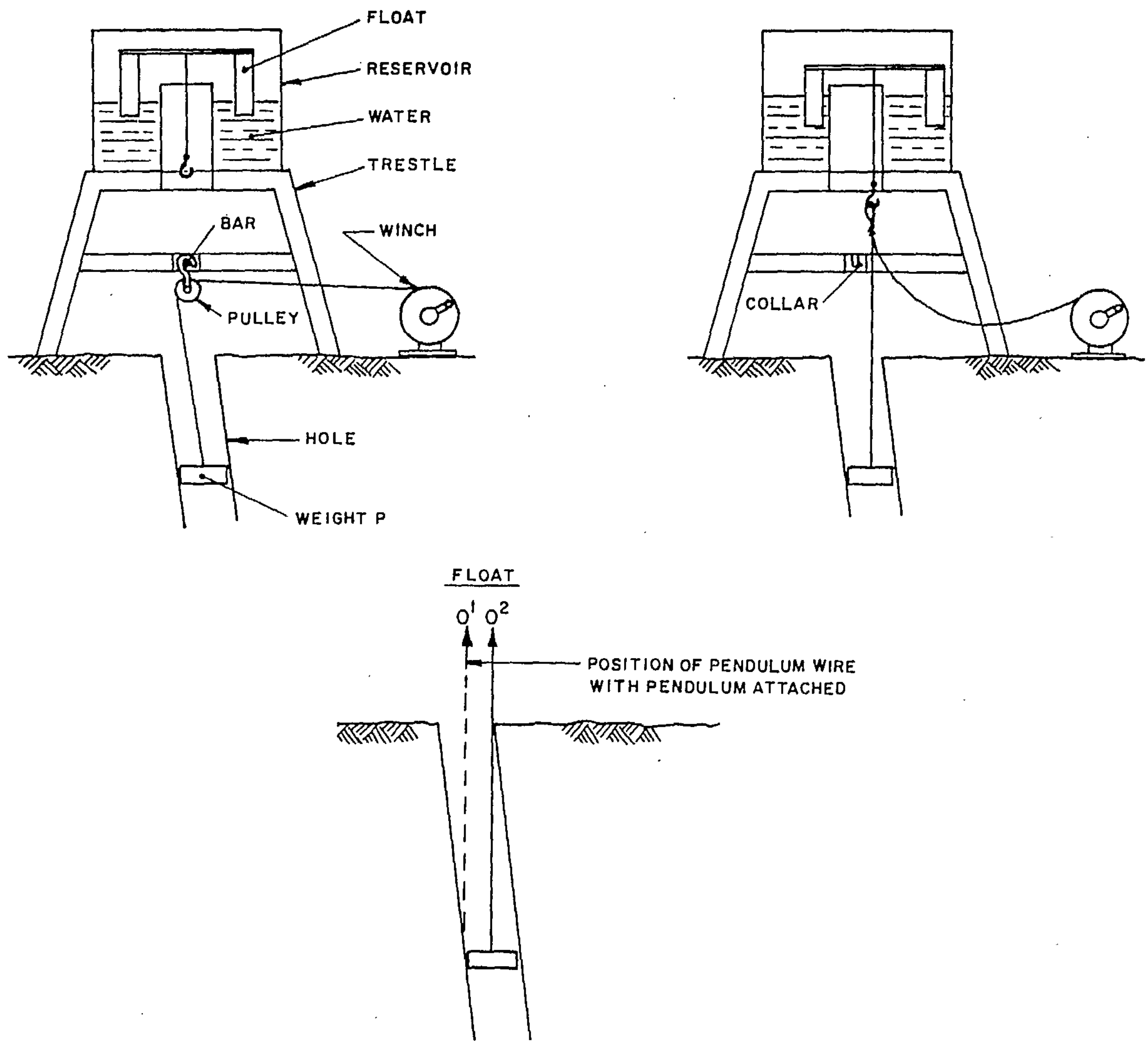


Fig 5 - Illustration of the procedure used to establish maximum vertical length of pendulum.

winch, are used to move the anchor progressively down the hole. At each descent point, the collar plate is removed and the wire hooked to the float by forming a wire loop with a clip. With the tension removed from the winch, the wire can move laterally under the action of the float and position itself relative to the anchor. When the wire touches the collar of the hole the maximum usable depth of the hole has been reached. A decision must be made as to whether the depth of the installation is acceptable.

INSTALLATION OF THE ANCHOR

23. If the entire length of the hole cannot be used, it can be back-filled to an acceptable level with coarse aggregate. The first step in installing an anchor is to dewater the hole. About 5 ft (1.5 m) of cement paste is then poured, and the anchor with its centering fins allowed to settle into this paste. The winch and pulley arrangement used to establish verticality of the hole, is used to hold the anchor at the correct depth until the cement sets.

PROCEDURE FOR READING INVERTED PENDULUM

24. The reading table consists of two graduated reading circles attached to the edge of a steel plate and a cursor. The centre of each of these circles is equipped with a backsight. The measurement procedure consists of aligning the wire of the pendulum running through the hole of the table and the backsight, with the viewing hole in the cursor. Figure 6 illustrates how the two cursors are used to locate the pendulum wire in the plane of the table:

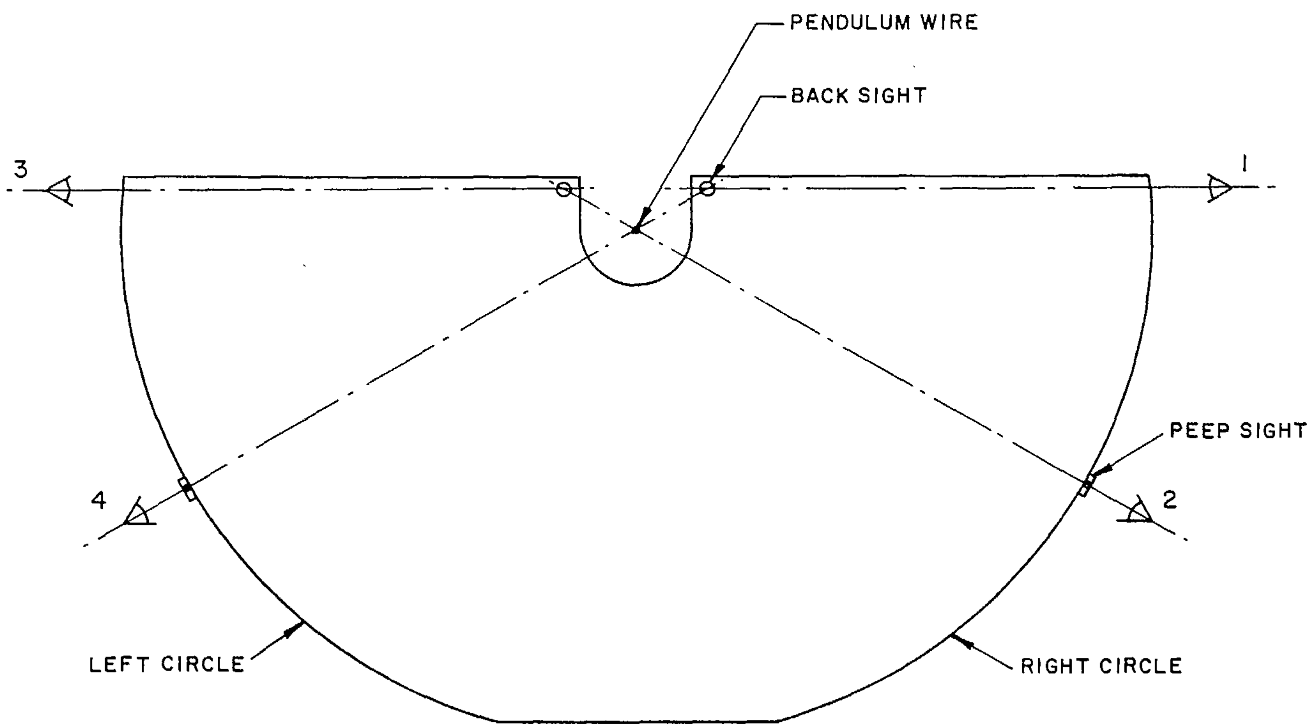


Fig 6 - Diagram illustrating measurement procedure.

a. Using the right peepsight the two backsights are lined up and the cursor reading noted.
b. The right backsight, wire, and peepsight are then lined up and the cursor reading recorded.
c. This procedure is then repeated with the left peepsight.

These readings permit calculations of the position of the wire.

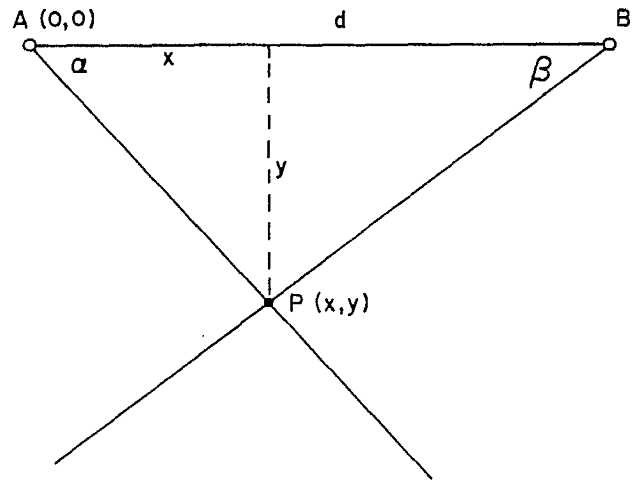
25. Referring to Fig 7, A and B are the left and right backsights with a separation distance d; β and α are the angles determined from peepsight observations. Referring all wire movements to A as the origin, with AB as the x-axis, the position of the wire is:

$$x = \frac{d \cot \beta}{\cot \alpha + \cot \beta}$$

$$y = \frac{d}{\cot \alpha + \cot \beta}$$

If the table is aligned with the AB axis parallel to the bench edge and the circular section away from the edge, then movements with decreasing absolute values of y will be toward the bench. By using the initial values of the wire (x,y) as origin and subtracting these values from subsequent values, relative movement of the wire is available for plotting. Figure B is a plot of displacement of a slope station measured with an inverted pendulum.

26. A machinist's dividing table can be used to calibrate the edge scales in degrees/division.



$$x = \frac{d \cot \beta}{\cot \alpha + \cot \beta}$$

$$y = \frac{d}{\cot \alpha + \cot \beta}$$

Fig 7 - Equations to calculate x and y coordinates of wire referenced to backsight A.

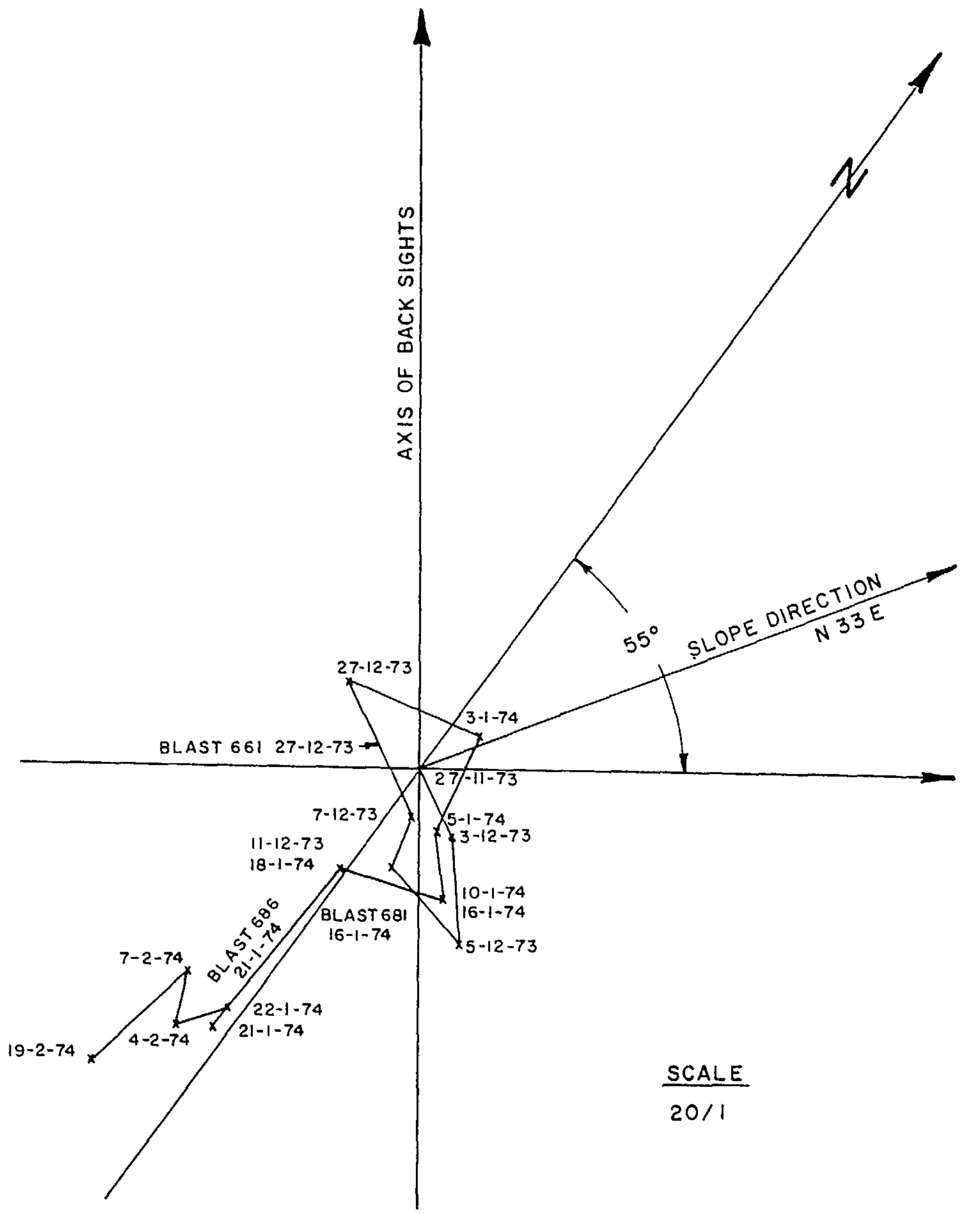


Fig 8 - Plotted station movement as established with inverted pendulum.

COST OF INSTALLATION

27. The overall cost of installing an inverted pendulum in 1974 was estimated at about $2500, for a hole depth of 100 ft (30 m).

Cost of drilling 120 ft (31 m) of 0.75 ft (25 cm) hole at $7/ft ($23/m)	$ 840
Cost of constructing surface station and installing pendulum	700
Cost of reading table	400
Cost of other hardware	500
	$2440

Following the first installation, costs would drop since concrete forms, etc would be available for the construction of subsequent surface stations.

APPENDIX G

ROCK BOLT AND CABLE DYNAMOMETERS

INTRODUCTION

1. Load dynamometers are essential features of a pit wall artificial support system where stressed bolts or cables are used.

2. Initially they provide on a sample basis, a measure of the effectiveness of the installation procedures. Before final grouting, a program of retensioning is possible when excessive load drop-off is indicated.

3. Grouting of cables or bolts is carried out partly to protect them against mechanical deterioration. When unprotected against acid ground conditions, as in a sulphide formation,they undergo hydrogen embrittlement. This leads to premature failure within their working ranges.

4. A bolt or cable installation can also lose its effectiveness during its expected life because of anchorage failure. Dynamometers provide a means of detecting deterioration in an artificial support system. Instrumented bolts would have to be protected against acid environments by means other than by total grouting to allow the dynamometers to function.

5. It is also possible that the design support system is inadequate for the task. An artificial support system must generate sufficient normal and tangential stress on the failure surface to offset the active excess shear stress. In some cases the shear resistance properties of the slide interface may have been overestimated. The dynamometers would indicate design inadequacy at the earliest possible moment. As a result, additional time would be available for remedial action.

6. The use of dynamometers has certain performance requirements. Aside from load and mechanical compatability with the anchorages, a unit must be suitable for use in a harsh environment, and be amenable to remote readings. They are subject to the range of temperatures encountered in an open pit mine, and must withstand damage from blast vibrations, and impact from falling rock. Since dynamometers must be placed to monitor the whole installation, some may become inaccessible.

TYPE OF DYNAMOMETER RECOMMENDED

7. The dynamometer best suited to the above requirements is a steel cylinder or ring whose measurable deformation under applied load is used to determine rock bolt or cable load. Either electrical resistance or vibrating wire strain gauges can be used as sensors to detect deformation, and thus indirectly measure load. Dynamometers using vibrating wire strain gauges are preferable for the following reasons:

a. It is easier to condition the signal from a vibrating wire gauge for remote readout through a telemetry system, and the conditioning equipment is less expensive;
b. It is a sensing device of proven reliability which has performed well under adverse environmental conditions.

8. A dynamometer of this type, designed and used by CANMET, will be described in detail. A list of manufacturers of both types is also included.

DESCRIPTION OF DYNAMOMETER

9. Figure 1 is an assembly drawing of a 500 kip (2.2×10^6 N) dynamometer developed for use with a 12/0.5 in. (1.3 cm) Freyssinet multistrand system of anchorage. Table 1 provides the modifications required in the dimensions of this unit to meet the needs of different maximum

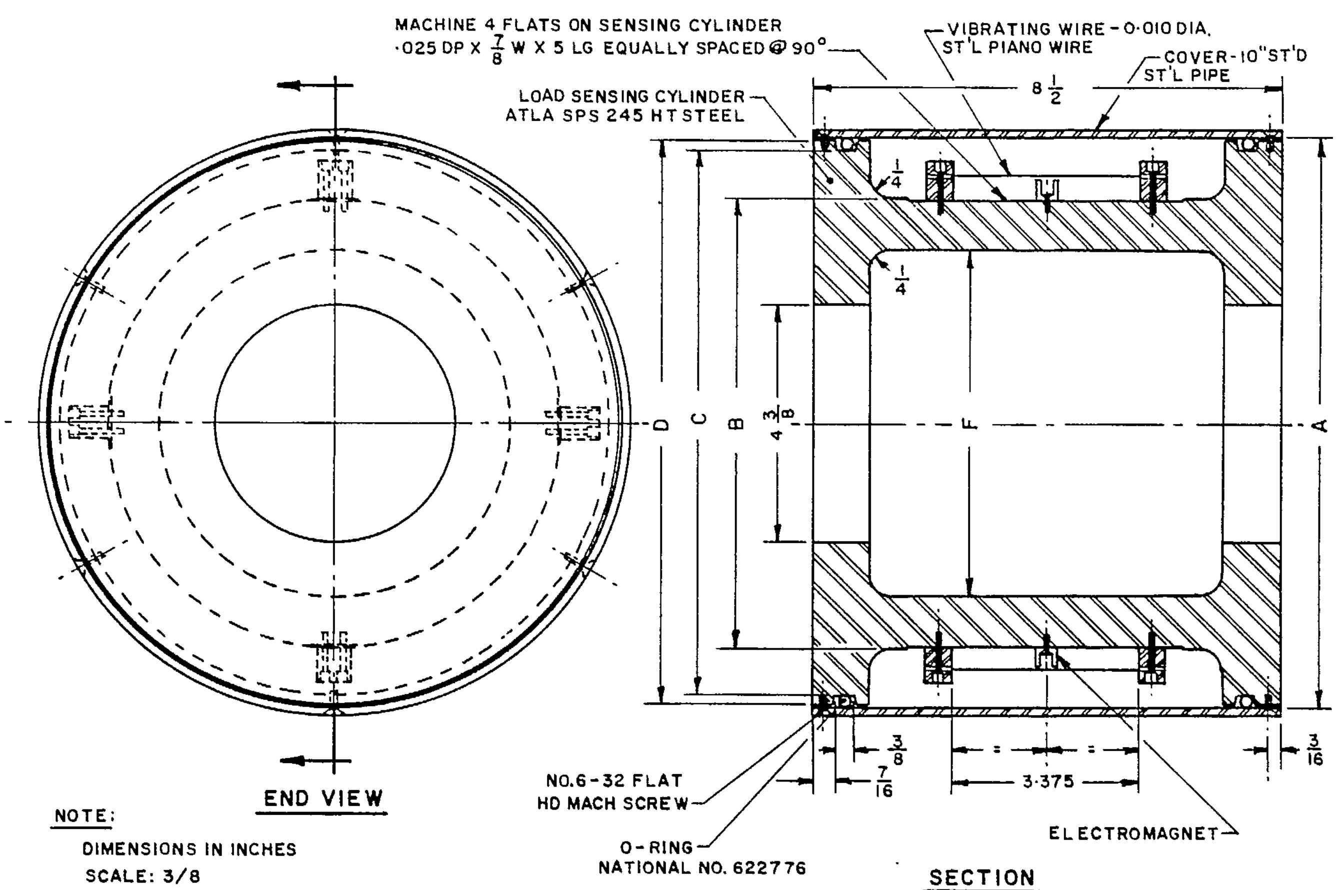


Fig 1 - Assembly drawing of a 500 kip (2.2×10^6 N) rock bolt dynamometer.

Table G-1: Dimensions of 1000 kip (4.4×10^6 N), 500 kip (2.2×10^6 N) and 250 kip (1.1×10^6 N) load dynamometer for type of unit in Fig 1

Load kip	A	B	C	D	E
1000	-	8.95"	-	-	5.000"
500	10.503"±	8.25"	10.024"	10.497"	6.375"
250	-	6.50"	-	-	5.375"

loads. The present unit is capable of discriminating load changes of about ± 300 lb (1.3 kN), and has an overall accuracy of ± 3000 lb (13 kN), or 6% at full capacity.

10. Atlas SPS 245 high tensile steel, with a yield strength of 140 kpsi (9.7×10^8 Pa) is used in the load bearing member. In cross section, the fillets used to prevent excessive stress concentrations and consequent plastic yielding of the steel, give the load bearing member the form of the letter I. The diameter of the centre hole permits passage of a 12/0.5 in. (1.3 cm) cable and support for the standard Freyssinet anchor.

11. Figures 2 and 3 provide details of the vi-

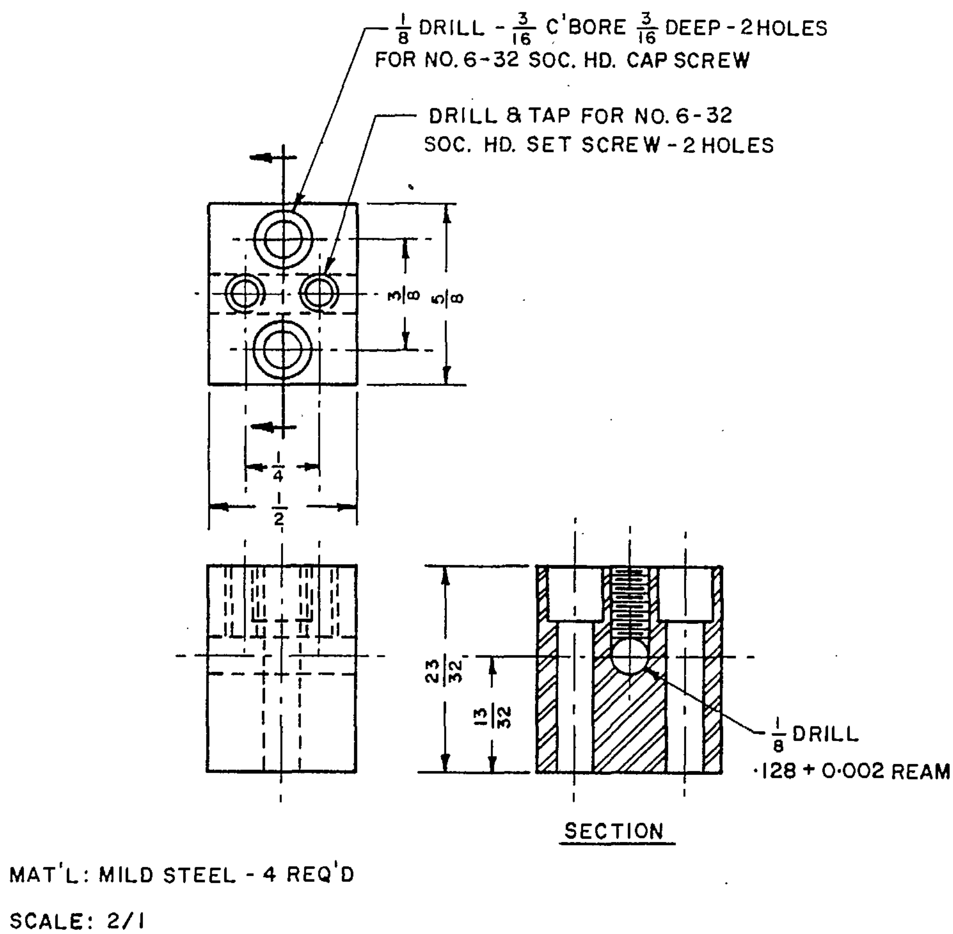
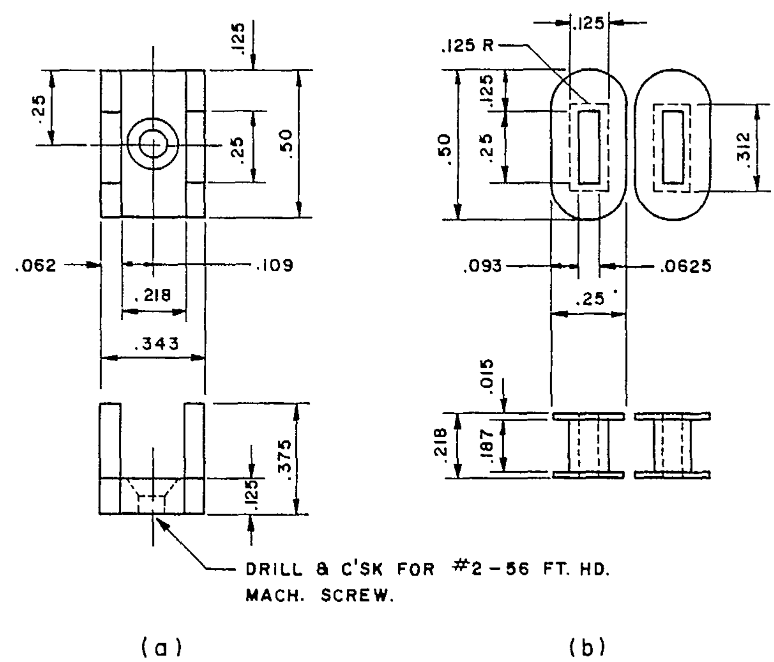


Fig 2 - Vibrating wire support assembly.

brating wire sensor assemblies attached to the load bearing unit. The gauge length of these sensors is the distance between the support block bolt holes on the steel cylinder. An Alnico magnet with two coils is used as part of the electronic system to excite, and to sense the vibration frequency of the wire. The wire is initially tensioned to vibrate at 1100 cps. The vibration frequency is reduced to about 300 cps at maximum design load.

12. Figure 4 is the circuit diagram of the electronic system used to read the dynamometer sensors directly. The readings for individual sensors are combined to calculate an average vibration frequency. The load is then determined from a calibration curve as shown in Fig 5. The present system does not pluck the wire electrically, but establishes a constant oscillation controlled by the tension in the wire. A Monsanto Model 150 frequency meter is used to measure the frequency of oscillation. Figure 6 shows the modified Model 150 unit which contains the additional circuitry shown in Fig 4. Alternatively, a unit developed in Great Britain by the National Coal Board, the NCB/MRE sonic gauge comparator, type 415B, can be used with these sensors. Appendix K gives details of a telemetry system which can be used to read



Magnet Material	Alnico
Magnet Dimensions	See Figure 3
Wire Size	No. 40
Number of Turns	Approximately 1000
Total Resistance	150 ohms per set (2 coils)

(c)

Fig 3 - Size specifications for rock bolt dynamo meter - (a) alnico magnet and (b) coil forms.

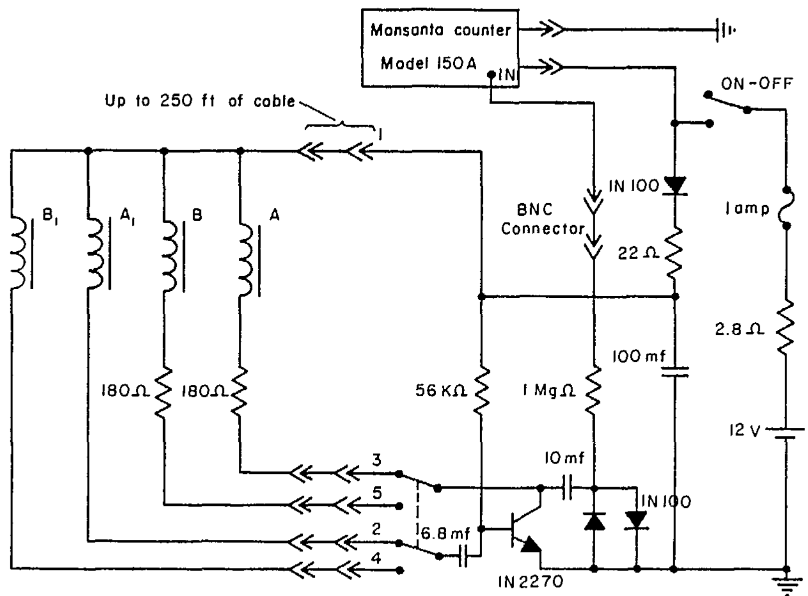


Fig 4 - Circuit diagram of vibrating wire strain sensors.

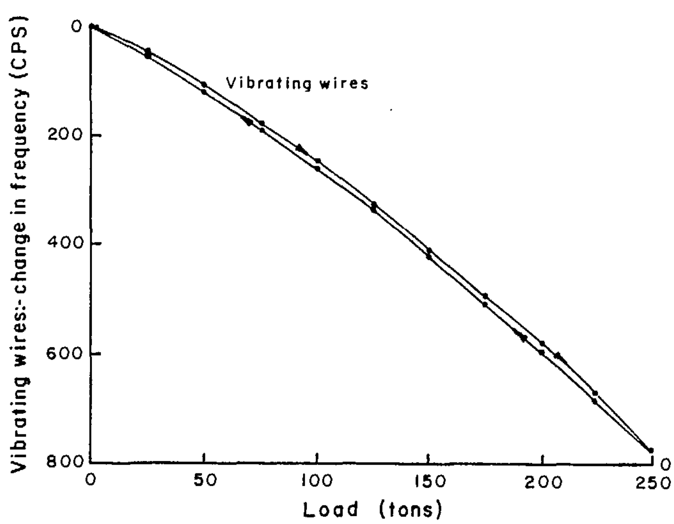


Fig 5 - Calibration curve of 500 kip rock bolt dynamometer.

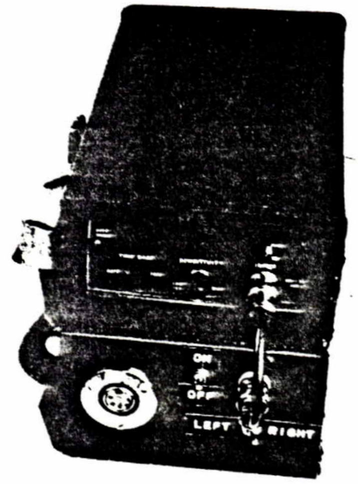


Fig 6 - Photograph of Monsanto Model 150 A frequency meter.

vibrating wire gauges remotely.

13. The cavity containing the vibrating wires is sheltered against the weather by a steel casing. A waterproof electrical connector is used for the internal-external connection of the coils to the lead cables. O rings are located in the end grooves of the load bearing member to provide a waterproof chamber for the gauges.

CALIBRATION AND EVALUATION

14. Dynamometers, if not commercially purchased, must be calibrated with a universal testing machine. The procedure is to load them incrementally to full capacity, and then remove the load in the same manner.

15. Figure 5 is the calibration curve for a typical 500 kip (2.2×10^8 N) dynamometer. As apparent in the governing equation, the relation between frequency of vibration and load is not linear, and reference must be made to a calibration chart to establish load:

$$\Delta E = \frac{4\ell^2\gamma\Delta(f^2)}{gE} \cdot \Delta(f^2) = (f_1^2 - f_2^2) \qquad \text{eq G-1}$$

where ℓ = wire length
γ = weight/unit value
$\Delta (f^2)$, f_1, f_2 = frequency change, initial and final frequencies, respectively.

16. The dynamometers should be tested with eccentric loads, to establish their effect on the calibration curve this can be realized in an actual installation. The dynamometer described is not affected by moderate eccentric loads.

17. If facilities are available for long-term load testing, there is some merit in running tests for a few weeks with a sample group of dynamometers. This would be particularly important if electrical resistance strain gauges were used as sensors, and poor bonding would become evident in long-term testing.

18. All measurement components of the load dynamometer are constructed of steel. As a result, the calibration curves for the unit are only marginally affected by temperature variation.

19. If dynamometers with electrical resistance strain gauges are selected, traditional strain gauge signal condition equipment must be used. It would have to be located in the vicinity of the dynamometers used and as such equipment is not suitable for operation in sub zero temperatures, heated enclosures would have to be provided.

LOCATION OF DYNAMOMETERS

20. Table 2 can be used to compare the cost of 6 and 8-strand cable installations, both with and without dynamometers. The addition of dynamometers about doubles the cost.

21. With the additional cost it is not possible to instrument more than 1 in 10 of the installations in a large support system. Careful selection of the sites is therefore required.

Table 2-G: Cost of cable installations with dynamometers* (mon); and without (reg)

	6 strand (reg) $	6 strand (mon) $	8 strand (reg) $	8 strand (mon) $
Drilling	167.12	167.12	229.31	229.31
Hole preparation	44.90	44.90	56.12	56.12
Cable bolt materials	140.99	803.68	210.57	952.29
Fabrication and emplacement	52.54	131.34	65.67	144.47
Blockout construction	91.62	91.62	109.94	109.94
Post-tensioning	64.39	70.83	70.83	77.27
Secondary grouting	58.19	58.19	87.28	87.28
Supervisor and engineering	56.25	56.25	56.25	56.25
Totals	740.79	1488.72	950.76	1777.72
Cost/ft (0.3 m)	7.41	14.89	6.34	11.85
Cost/1000 lb (4.4 kN)	4.27	9.99	4.12	8.98

* After Seegmiller; "How cable bolt stabilization may benefit open pit operations"; Mining Engineering, Dec. 1974.

Looking at a rectangular section of a pit wall to be bolted, it is recommended that instrumentation of a bolt or cable installation be carried out in a horizontal row towards the middle of the pattern as shown in Fig 7. Instrumentation in this manner is recommended for the following reasons:

a. to provide the best possible lateral coverage of the bolted area with the limited instrumentation used. This will permit the most effective integration of the dynamometer into a safety monitoring system for the artificially supported area of the wall.

b. to avoid toe regions where the bolt or cable performance, due to ground constraints, might not be the best indicator of overall bolt or cable performance.

22. Recognizing the limited number of dynamometers being recommended to meet the stated purposes, no digression should be made for a side investigations of some particular feature or situation, such as study of the anchorage properties of a small anomolous zone. All side studies should use separate installations.

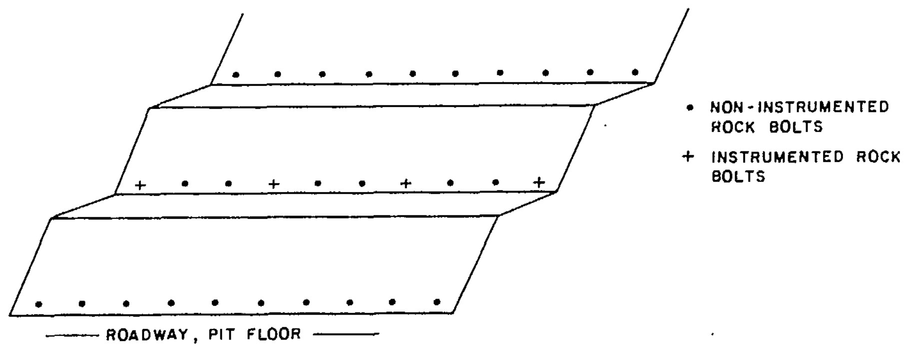


Fig 7 - Recommended location of dynamometers in lightly monitored wall.

INSTALLATION OF DYNAMOMETERS

23. Figures 8(a) and 8(b) are photographs of cable and steel rock anchors with dynamometers. The Freyssinet multi-strand anchor is mounted on an additional steel plate above the dynamometer, rather than on that embedded in the concrete pillow, as would be the case without the dynamometer. Similarly in the case of the steel rod, an additional plate is required. The dimensions of the plates will be those required as bearing plates by the anchorage systems. Slightly thicker plates will be needed when retensioning is required. This is particularly the case where Freyssinet multi-strand anchors have been used and a chair loading the edges of the plates must be used in the retensioning process. Figure 9(a) shows the use of a chair to release the cone-and-wedge lock of an installation. Figure 10 provides an example load curve for an effective installation, and one in which a proper anchorage has not been achieved.

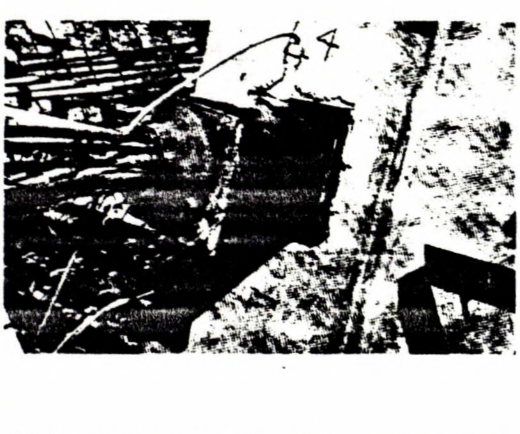


Fig 8(a) - Photograph of cable installation with dynamometer.

Fig 8(b) - Photograph of bolt installation with dynamometer.

Fig 9(a) - Photograph showing use of chair to release cone and wedge lock.

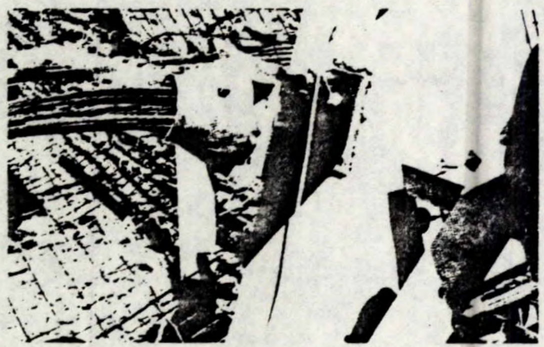


Fig 9(b) - Photograph showing dynamometer between concrete pad and tensioning jack.

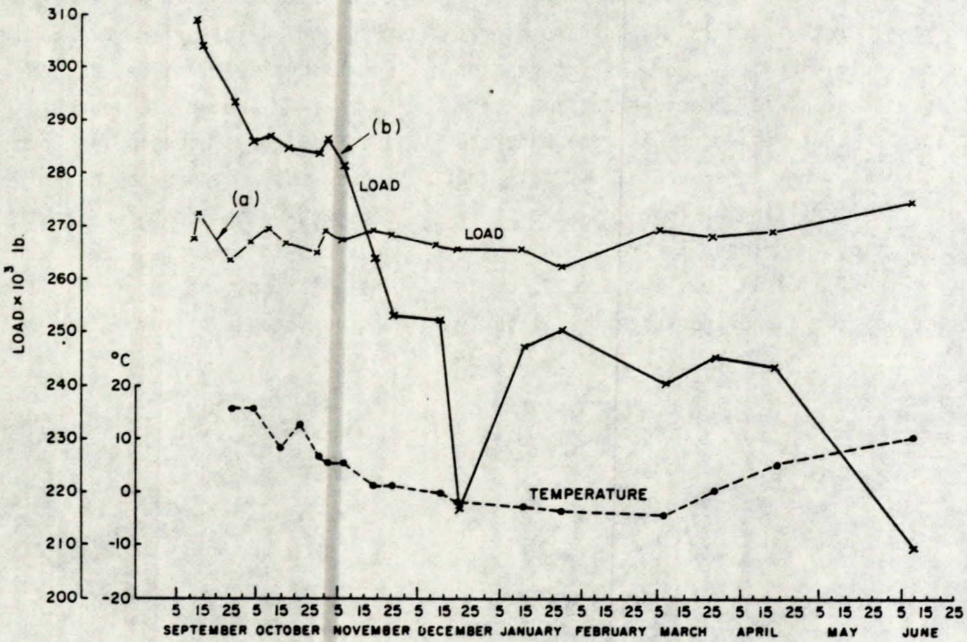


Fig 10 - Dynamometer load cell curves showing (a) effective and (b) poor anchorage.

COST OF INSTALLATION

24. Table 2 shows that the major additional cost is the dynamometer itself. The cost of an installed dynamometer should not exceed $1000 (1975). The instrument required to read a vibrating gauge such as the 415B comparator will cost $3000. If a technician is available, a unit such as used by CANMET can be constructed for less than $1000. A strain bridge in the order of $1500 will be required where strain gauges are used. A partial list of companies which can supply suitable dynamometers is given in Table 3.

Table G-3: Partial list of companies supplying dynamometers

Company	Type of dynamometer
Telemac International Inc Montreal, Canada	Cylindrical load cells with vibrating wire gauges to measure load. Load capacity can be specified.
H. Maihak A G 2 Hamburg 60 Senperstrasse 38	Cylindrical load cells with vibrating wire gauges to measure load. Standard load capacity of 20, 50, 100, 200, and 300 tons.* Other capacities can be specified.
Terrametrics 16027 West 5 Ave. Golden, Colorado	Cylindrical load cells with resistance strain gauges to measure load. Standard load capacities of 20, 40, 150, 300, 600 and 1250 tons.*

* 1 ton = 2000 lb (8.9 kN)

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2. Kapeller, F. and Larocque, G.E. "A rock bolt dynamometer system using continuous vibrating wires"; MRL IR 73/36.

3. Barron, K. and Hedley, D.G.F. "Rock mechanics instrumentation; part IV; rock bolt load cells"; MRL IR 71/80.

4. Seegmiller, B.L. "How cable bolt stabilization may benefit open pit operations"; Mining Engineering; Dec. 1974.

5. Barron, K., Coates, D.F. and Gyenge, M. "Artificial support of rock slopes"; CANMET Research Report R 228; June 1971.

APPENDIX H

A CASE HISTORY OF TELEMETRY SYSTEM TRIALS

INTRODUCTION

1. These trials were undertaken to investigate the suitability of industrial type telemetry equipment for pit slope monitoring. The equipment was tested initially using sensors from an existing slope monitoring program at the Jeffrey mine at Asbestos, Quebec. When this site was no longer available, testing was continued at Ecole Polytechnique, using a cold chamber and a site external to the building. The opportunity was taken to evaluate samples of the following types of sensors: rotary potentiometer, linear potentiometer, linear differential transformer, optical encoder, and mechanical encoder.

EQUIPMENT DESCRIPTION

GENERAL

2. The system designed and used in these tests consisted of a remote station, a base station and a master station. Figure 1 indicates the position of the various system elements in the context of their use at Jeffrey mine.

REMOTE STATION

Description of the Jeffrey Site

3. Figure 2 is a cross section of the Jeffrey mine indicating locations of the MPBX1 and MPBX2 unit borehole extensometers installed by the company. Their purpose was to detect movement in a wall where a number of fissures had been detected in drilling. As noted on Fig 2, surface cracking occurred on the face below the crusher during earlier development. The two extensometers were read directly by the company engineers. Permission was obtained to attach displacement sensors to the heads of these extensometers, provided direct reading would not be affected.

Transducers and Transducer Mounting Head Used in Experiment

4. Five types of transducers were tested for their ability as displacement detecting units: optical encoder, mechanical encoder, direct

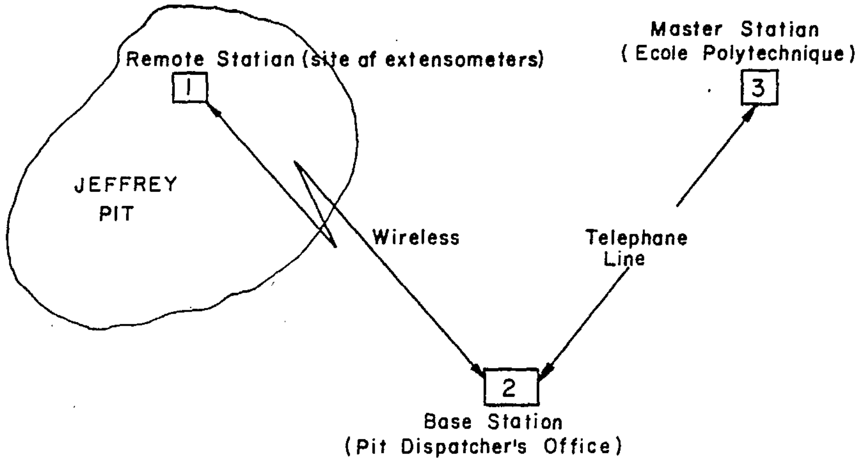

Fig 1 - Components of telemetry system.

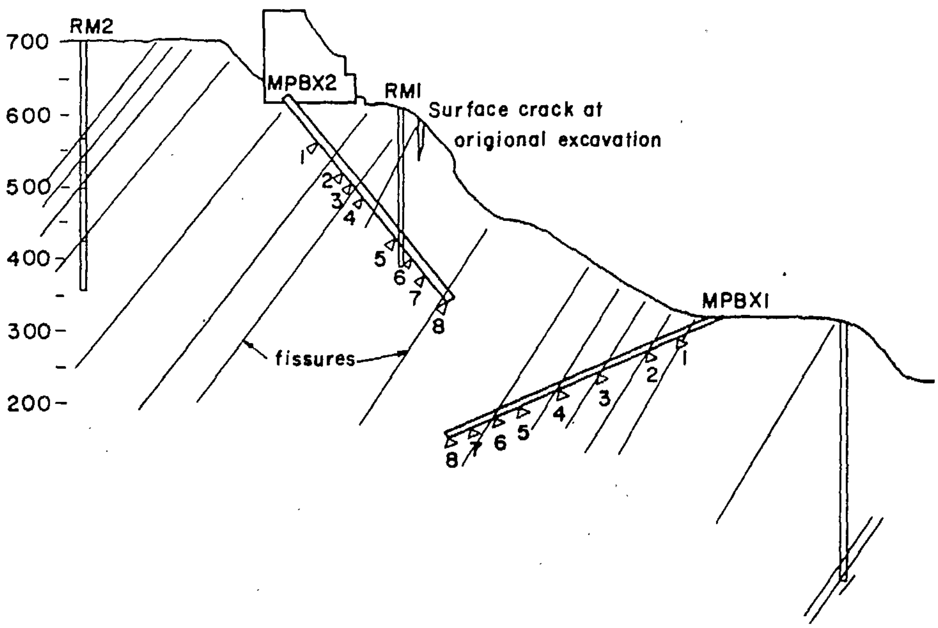

Fig 2 - Cross section of Jeffrey pit showing location of two 8-CSLT Terrametrics borehole extensometers (MPBX1 and MPBX2).

current differential transformer, linear potentiometer, and rotary potentiometer. Table H-1 provides more specific details concerning the units.

5. The transducers were attached to the rods of an 8-unit extensometer using the mechanical mounting head shown in Fig 3(a). Figure 3(b) indicates the particular element of the extensometer to which each transducer was attached.

Shelter for Remote Station

6. Each 8-unit extensometer was located in an unheated wooden shelter. The remote station telemetry equipment shown in Fig 4, as well as its battery supply, was housed in the shelter.

Description of Telemetry Equipment Remote Station

7. Figure 5 is a block diagram of the remote station used at Jeffrey. The station is capable of treating 8 analog signals within the voltage range of ± 4 volts, and 2 digital signals, permitting 8-series transmission of the data on the 10 channels. The control and timing unit was specially built by Motorola to meet the needs of this study.

8. When the Motorola 26185 Analog Multiplexer is activated, the analog signals on channels 1 to 8 are scanned and presented sequentially to the analog digital converter. The function of this converter is to apply the data bits in parallel to the Motorola 26142 Pulse Code Modulator. The parallel data bits from the mechanical and optical encoders are applied directly to this latter unit.

9. The Pulse Code Modulator generates messages composed of the data, the address and security bits. All messages are sent using 2-state alternate bits, keying to assure perfect synchronization at all times. In addition, a long synchronization pulse equivalent to a duration of 9 bits is sent at the start of each word. The message keying takes place using pulse duration modulation where binary "1" information appears as a pulse with a duration of 3 times the "0"

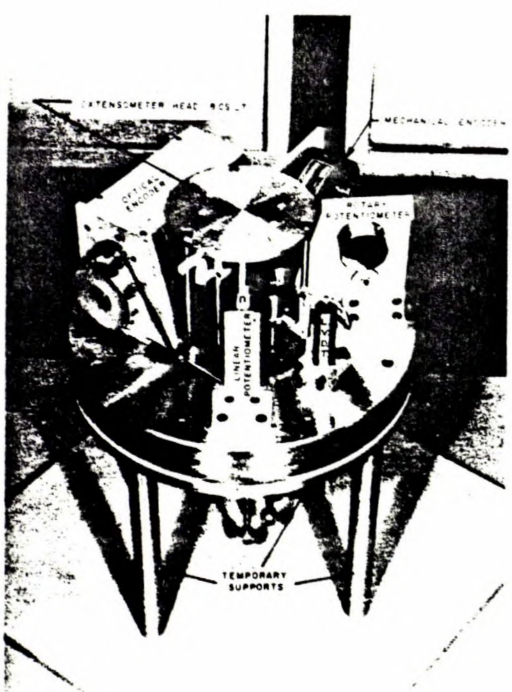

Fig 3(a) - Photograph of head used to couple sensors to 8 element borehole extensometers.

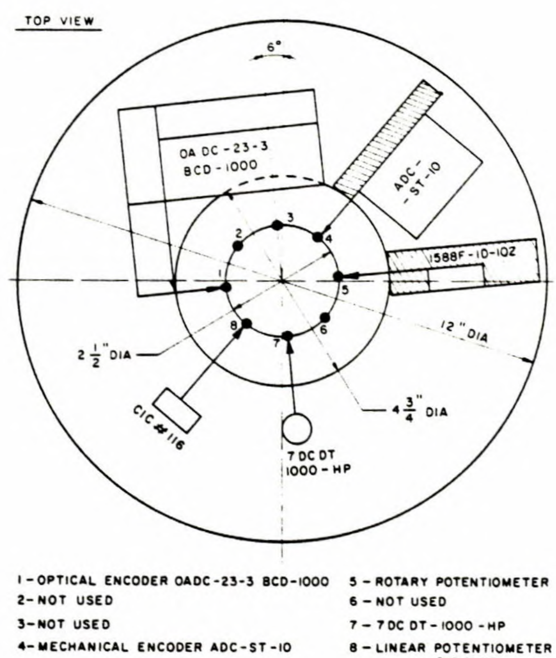

Fig 3(b) - Diagram of head indicating the position of each sensor.

Fig 4 - Photographs of remote station equipment.

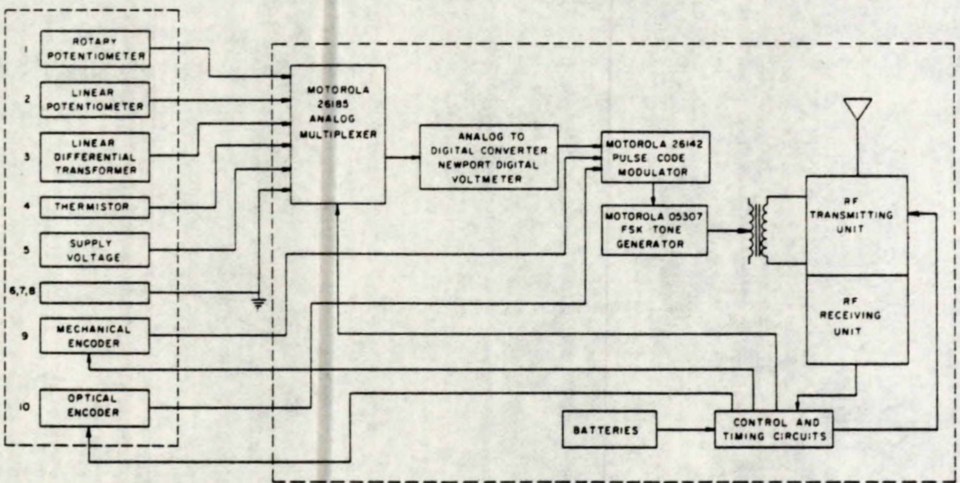

Fig 5 - Block diagram of remote station.

information. This technique provides reliable operation of the telemetry system during periods of high telegraphic distortion or jitter. Two-state non-return-to-zero, NRZ, keying is used to assure message penetration under high noise conditions. Compared with a three-state return-to-zero system, RZ, the signal-to-noise error rate is reduced by a factor of 1000. All messages in the Motorola 26142 contain bits to permit error checks at the receiver; they include the five bits of the Bose-Chaudhuri Code for error detection and the Parity check bit.

10. The output keying signals from the Pulse Code Modulator are applied at the rate of 200 bauds to the Motorola 05307 FSK Tone Generator as shown in Fig 5. The latter unit has a centre frequency of 2520 hertz, uses only active RC filters, and has an output which is adjustable

Table H-1: Transducers used in Jeffrey experiment

Type	Encoder		L.V.D.T.	Potentiometer	
	Optical	Mechanical	D.C.D.T.	Linear	Rotary
Manufacturer	Norder	Norder	Hewlett Packard	CIC	New England
Model	OA DC-23131 BDC-1000L	ADC-ST10 Gray	700DT-1000	116-1K	1588F-1D102
Linearity			10.5%	±0.2%	±0.5% & ±0.1%
Reliability	40 k hrs	$5x10^6$ turns	-	-	$50x10^6$ turns
Dimensions	2.5"x1.4"L	3.0"x1.4"L	0.75"x4.5"L	0.5"x1.1"x5.0"	1.6"x1"L
Power req.	2.5 watts	-	0.12 watts	0.14 watts	0.14 watts
Displacement	360°	360°	±1"	4"	340°
Temperature range	0 to 120°F	0 to 85°C	-65 to 140°F	-55 to 150°C	-55 to 100°C
Cost	$985	$475	$250	$175	$35

from 0 to -40 dbm. The output of the FSK Tone Generator is attached directly to the radio control head by the connector provided. In the case of trucks and cars with mobile communication equipment, this unit is usually maintained under the dash. The remainder of the remote station radio equipment is identical with that found on a vehicle equipped with mobile communication equipment.

11. The power supplied to the remote station was obtained from two sources: one for the radio equipment and a heater, and one for the data acquisition system. The radio equipment, being of the mobile communication type, works on 12 volts dc nominally. Any supply voltage from 15 volts down to 7 or 8 volts can however be tolerated; no damaging effects result, but the transmitted power drops with the voltage reduction. It is desirable however to supply the sensors with well regulated power. It was therefore found more practicable to have a separate high power source without regulation to supply the radio equipment and the 24 watt heater at the data acquisition enclosure. This power supply takes the form of two parallel banks of 10 caustic potash air-depolarized cells, Cipel AD609Z, each with a capacity of 2000 A-H. These cells have a long life and good efficiency at low temperature; they are used, for instance, by B.C. Hydro for repeaters located in the Rocky mountains. Because of its compactness and good voltage regulation, a gell cell, Globe part no. GC-12200, with a capacity of 200A-H was placed inside the enclosure of the data acquisition system. It can provide 600 transmissions at -30°F (-34°C) and 1200 transmissions at +68°F (20°C).

Base Station

12. Figure 6 is a block diagram of the base station for the Jeffrey trial. The radio transmitter for dispatching vehicles was used for interrogating the remote station and receiving the output data signals. Since no selective calling units are used at the mine, a paging encoder, Motorola Model XN1016, shown in Fig 7, was connected to the transmitter of the dispatching equipment. This was done by plugging the dispatcher microphone cable into the pager, and the pager into the microphone cable of the radio transmitter. Interrogation of the remote station is done by pressing the buttons corresponding to the tones of the remote station and momentarily pressing down the button marked 'page'. The FSK tones containing the remote station data are picked up via the dispatcher's speaker. In the present case the tones were transmitted to the master station at Ecole Polytechnique, by holding

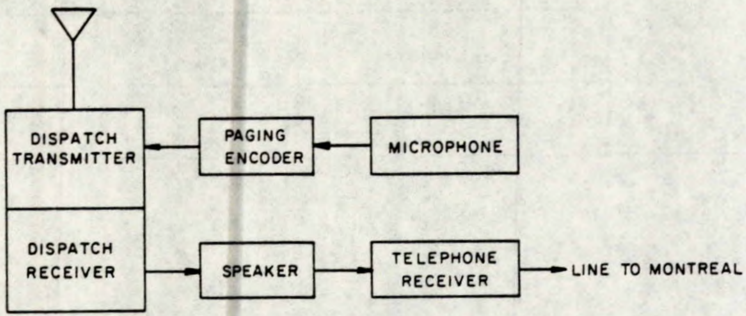

Fig 6 - Block diagram of base station.

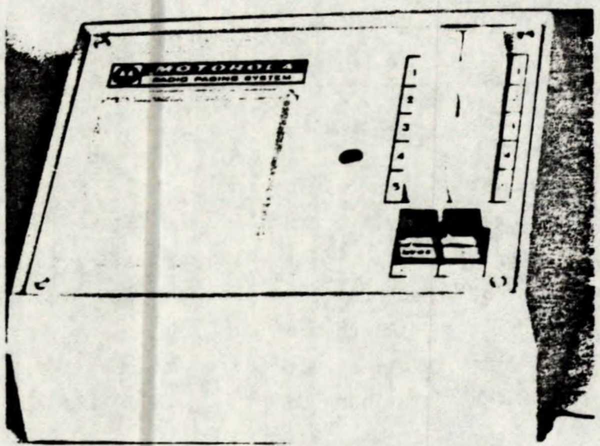

Fig 7 - Photograph of Motorola Mode XN1016 paging encoder.

the head piece of the phone in front of the speaker. Transmission of the eight scans of the 10 potential data channels at the remote station required about 30 seconds. Because of the high immunity to noise interference of the coding system used, simple acoustical coupling was adequate.

Master Station

13. Data transmission telephone calls to the master station located at Ecole Polytechnique were initiated by the dispatcher at the base station. Such calls had to be phased into normal use of the mine radio communication, even though the interruption was quite small, < 1 min. For this purpose, an automatic phone answering unit was installed at Ecole Polytechnique to receive the calls. The tape recorder of the answering unit could not be used for data storage because of its poor speed regulation; the answering unit initiated a high-fidelity Revox recorder used for data storage. Ultimately, a receiving station with solid-state memory was built so that the tape recorder could be replaced. Figures 8(a) and (b) are block diagrams of the master station while Fig 9(a) and (b) are schematic diagrams of the solid state memory used as a replacement for the tape recorder.

14. With reference to Fig 8(a), the output from the tape recorder is fed to a Motorola Model 05407 FSK tone receiver which conditions the information for the following Motorola Model 26242

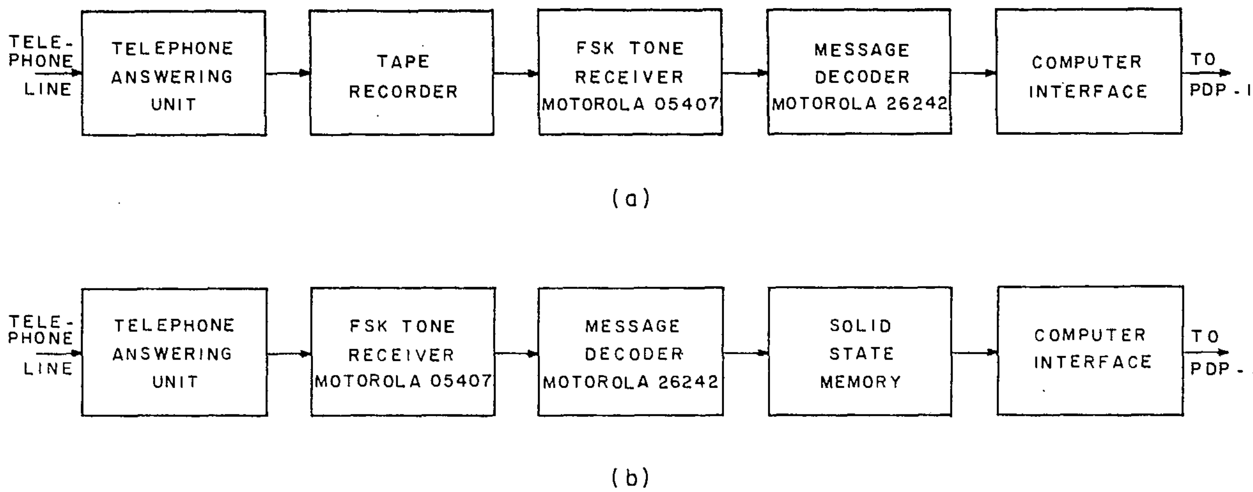

Fig 8 - Block diagram of master station (a) with tape recorder, and (b) with solid state memory.

message decoder. The latter unit accepts the serial data and converts it into parallel format. Before read-out, each word is checked for validity by the following multiple security checks: cyclic Bose-Chaudhuri code check, parity check, underflow check, overflow check, signal level synchronization check, and synchronization pulse check. The check system is sufficiently powerful to detect and to reject words having the following errors: all one, two, and three bit errors, all odd number errors, 96% of all four bit errors, all error bursts up to 31. A counter indicates the number of times the message has been read without errors. Typically, in the tests the display showed that 5 or 6 of 8 messages were received without error. In the case where a solid state memory replaces the recorder, the signal must be processed by the Motorola equipment before storage in the memory.

15. The data was processed at Ecole Polytechnique by interfacing the output of the master station with an available PDP-11 minicomputer.

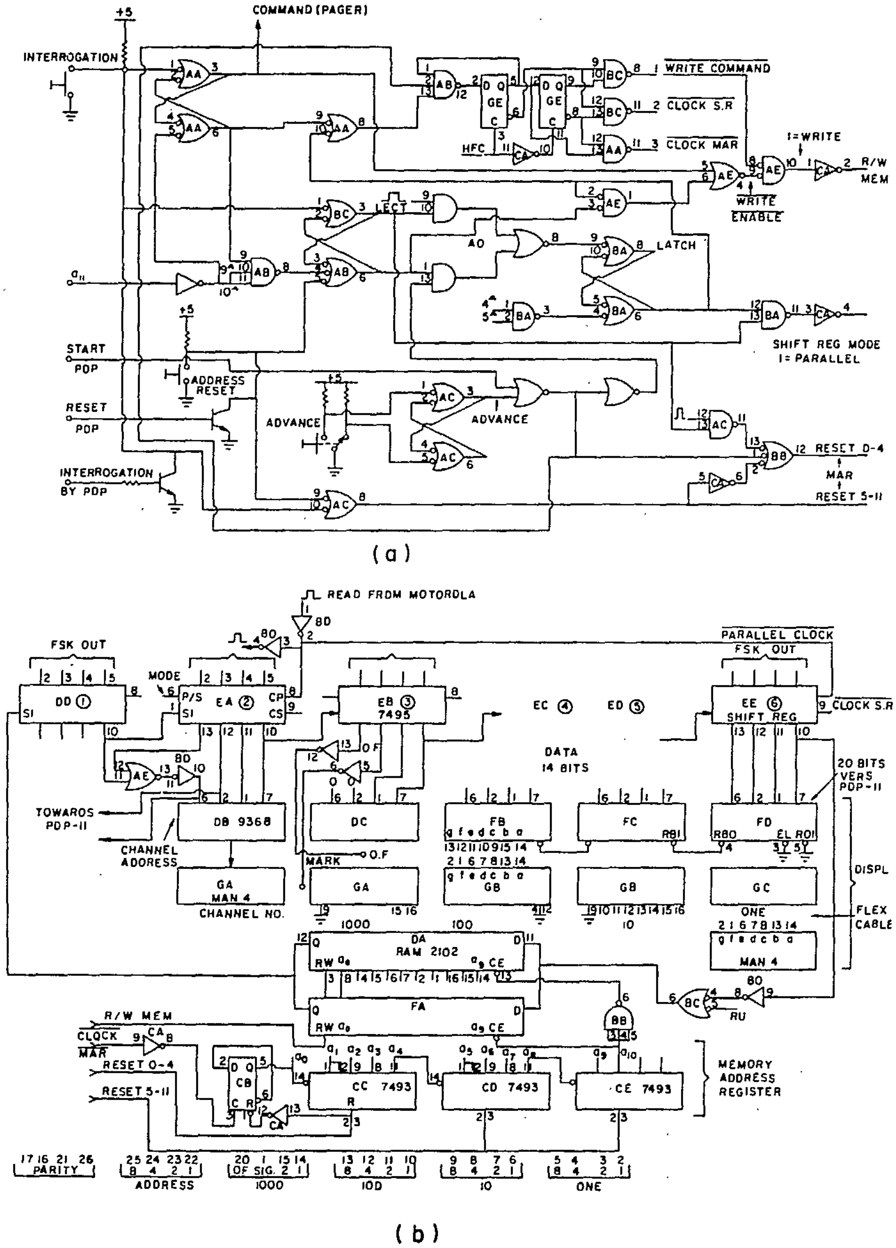

Fig 9 - Schematics of (a) control circuit and (b) solid state memory.

TESTS AND TEST RESULTS

<u>JEFFREY MINE</u>

16. The telemetry equipment and transducers were in use during the period July 25 to August 31, 1973 at which time the extensometers were mined out. Table H-2 lists the test results for this period.

17. No problems were realized with the telemetry system. A direct check was carried on the overall reliability of the system by feeding a constant 0 voltage from the remote station to the master station. No variation in this constant voltage was noted during the duration of the tests, although temperature in the enclosure varied from 130°F (54°C) to -40°F (-40°C) during the tests.

18. The optical encoder, 1, used to sense the movement of plunger 1 had a sensitivity of 0.003 in. (0.08 mm) per bit. The direct readings indicated no displacement greater than 0.002 in. (0.05 cm) for this plunger; hence it detected no movement.

19. The mechanical encoder, 2, has an identical displacement sensitivity. It did not detect the three readings which exceeded this threshold value and measured manually on Aug 20, 22 and 24. On Aug 31 the direct readings returned to a maximum displacement from the July 26 starting value of 0.003 in. (0.008 mm). The indication is that dirt on the plunger head caused a reading error.

20. The rotary potentiometer, 3, in the test set-up had a displacement sensitivity of 0.0015 in. (0.04 mm). The agreement between the displacement as detected by the transducer and transmitted to the master station, and the direct readings is within the accuracy of the device.

21. The sensitivity to displacement of the dc linear differential transformer (4) was 0.00084 in. (0.02 mm) per mv. There is wide variance between the transducer readings of displacement and the direct readings over the test period. The explanation is evident by referring to Fig 10, where thermistor temperature and displacement as detected by the differential transformer are plotted. The dc differential transformer is extremely temperature-sensitive.

22. The sensitivity to displacement of the linear potentiometer (5) was 0.0084 in. (0.2 mm) per mv. After August 3 there were significant differences between displacements measured directly and by the transducer. Subsequent investigation of the potentiometer established that the wiper was set in a noisy region of its stroke.

Table H-2: Test results for Jeffrey mine experiment

Date 1973	Extensometer plunger displacement in thousandths of inches									
	1 (1)		4 (2)		5 (3)		7 (4)		8 (5)	
	T (6)	J (7)	T	J	T	J	T	J	T	J
July 25	0	0	0	0	0	0	0	0	0	0
27	0	-	0	-	0.7	-	0	-	0	-
30	-	-2	-	0	-	1	-	1	-	0
Aug 1	0	-	0	-	-2	-	-1.2	-	-0.9	-
2	-	-1	-	1	-	1	-	-1	-	0
3	0	0	0	1	-2	-3	+6	0	-0.9	-
8	0	-	0	-	-2	-	2.4	-	13.44	-
9	-	-2	-	3	-	-1	-	1	-	0
10	0	-	0	-	-2	-	-2.4	-	15.12	-
13	0	-2	-	2	-	-1	-	3	-	-1
15	0	-	0	-	-1.3	-	10.4	-	15.96	-
16	0	1	0	1	-0.7	1	16.3	3	15.96	-
17	0	-	0	-	-1.3	-	13.0	-	15.96	-
20	0	-1	0	-18	-0.7	1	14.0	0	15.96	1
21	0	-	0	-	-1.3	-	14.0	-	15.96	-
22	0	-1	0	-17	-1.3	-1	14.0	0	15.96	0
23	0	-	0	-	0	-	29.0	-	6.72	-
24	-	0	-	-18	-	1	-	1	-	2
27	0	-	0	-	-1.3	-	16.0	-	10.1	-
28	0	-	0	-	-0.7	-	13.0	-	15.96	-
29	0	-	0	-	-0.7	-	16.3	-	15.96	-
31	-	0	-	-3	-	-1	-	2		0

(1) Optical encoder
(2) Mechanical encoder
(3) Rotary potentiometer
(4) DC differential transformer
(5) Linear potentiometer
(6) Telemetered transducer reading
(7) Manual recording of displacement

COLD CHAMBER AT ECOLE POLYTECHNIQUE

23. To test under extreme conditions, the remote station with its power supply was placed in a cold chamber. To test the sensors used at Jeffrey, with exception of the dc linear differential transformer, the transducers were mounted on the test head shown in Fig 3 and placed in the cold chamber. Radio communication was maintained with the exterior by constructing a base station to replace the dispatching station used at Jeffrey. The telemetry equipment and transducers were tested at temperatures down to -40°F (-40°C). The zero volt reference applied to input no. 4 of the multiplexer over the test range of -40°F (-40°C) to +130°F (54°C) has always been received without error at the master station.

24. Table H-3 summarizes the results of the tests in the cold chamber. Since the optical and mechanical encoder did not indicate any change in displacement during the trial, their test results have not been included. The operating range of the thermistor used for temperature measurement is

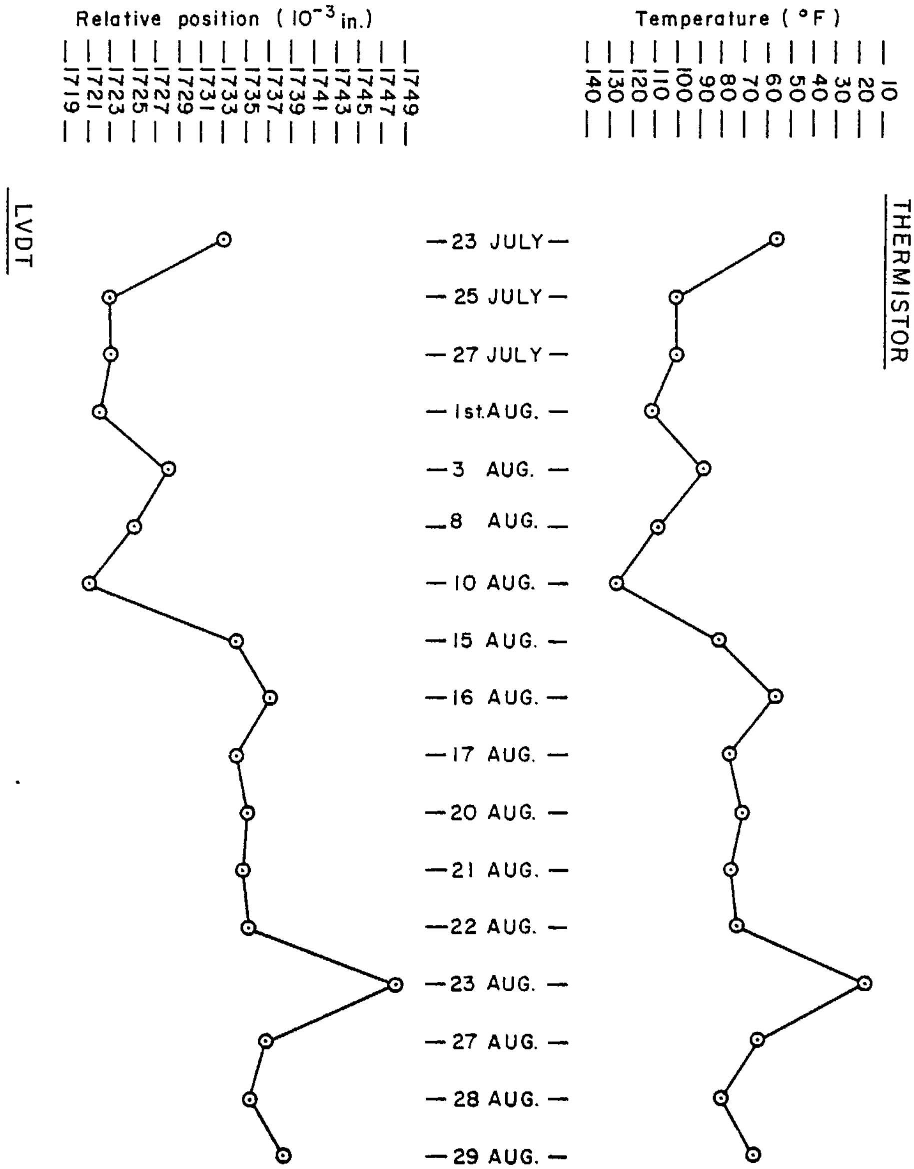

Fig 10 - Apparent extensometer displacement as established by DCLVDT and remote station temperature as a function of time.

Table H-3: Test results for cold chamber

Date (1973)	Chamber temp °F	Thermistor temp °F	Supply voltage/2	Rotary potentiometer 1mv - 0.0007 in.	Linear potentiometer 1mv - 0.0008 in.
Dec 6	75	73.1	2.506	1238	0011
7	0	0	2.518	1231	0013
10	-10	- 8.3	2.520	1233	0013
11(am)	-25	-19.4	2.522	1234	0012
11(pm)	-37	-30.6	2.523	1235	0013
12	-40	-29.4	2.523	1235	0013
13	5	4.5	2.518	1235	0013
14	0	0	2.519	1232	0013
17	0	- 0.1	2.519	1232	0013

-22°F (-30°C) to 122°F (+50°C), and this gives an explanation for the disparity between it and the actual temperature of the cold chamber.

25. The cursor of the linear potentiometer for these trials was placed outside the noise section of the device. The maximum error during 12 days of trial and over a temperature range of +75°F (23°C) to -40°F (-40°C) was 0.0017 in. (0.043 mm). In the case of the rotary potentiometer the error was 0.0049 in. (0.12 mm).

OUTSIDE WINTER TESTS AT ECOLE POLYTECHNIQUE

26. For these tests the remote station was moved to the roof of Ecole Polytechnique. An unheated shelter, Fig 4(a), was located adjacent to the telemetry equipment. As can be seen from Fig 4(b) it was used to house the battery supply and transducer.

27. Table 4 summarizes the results of the winter tests. The coldest temperature occurred January 18 (channel 2). The 10 caustic batteries were found insufficient for the load, as indicated by a total supply less than 14 volts (channel 1). Two chains of 10 units are required since the maximum drain of 0.5 amp of the cells is exceeded at transmission. Nevertheless, the equipment functioned satisfactorily throughout the trials. The zero-voltage reference (channel 4) showed no drift during the trials. The rotary potentometer (channel 5) had an error of less than 0.001 in. (0.025 mm) over the test period. The dc linear differential transformer (channel 6) continued to give erroneous results. The linear potentiometer (channel 7), after position adjustment on January 29, had an error of less than 0.001 in. (0.025 mm) over the test period. The optical encoder (channel 8) did not function correctly after January 29 due to possible water condensation; the mechanical encoder (channel 9) functioned satisfactorily throughout.

Table H-4: Test results for Ecole Polytechnique test site

	Voltage regulator (potentiometer)	Battery voltage (Data acquisition) (mv)	Temperature °F x 10	8attery voltage (radio) (mv)	Reference 0 volt (mv)	Angular potentiometer (mv)	DCDT (mv)	Linear potentiometer (mv)	Optical potentiometer	Mechanical encoder
Channel Date	0	1	2	3	4	5	6	7	B	9
1974	+	+	+ -	+	-	+ -	+ -	+	-	-
17 January	2516	1275/63	-0047	0B96/94	0000	+1233	-0004	0014	3687	3b7A
24 January	2414	1293/82	+0223	0971/63	0000	+1247	-0004	0014	3687	3b7A
1 February	2514	1238	+0048	0909	0000	-1968	-0011	1590	3B03	3bcA
7 February	2512	1277	+0152	0859	0000	-1956	-0010	1589	3c03	3bcA
14 February	2514	1250	+0010	0835	0000	-1969	-0011	1589	3803	3bcA
21 February	2513	1283	+02B2	0924	0000	-1966	-0008	1589	3C03	3bcA
28 February	2512	1282/70	+0374	0990/88	0000	-1965	+1174	1588	3FFF	3bcA
7 March	2510	1276/66	+0500	1036/14	0000	-1963	+1178	1585	3d03	3bcA
15 March	2513	1280/69	+0266	0915/0839	0000	-1966	-0010	1588	3c03	3bcA
20 March	2514	1265/55	+0177	0858/69	0000	-1968	-0008	1590	3c03	3bcA
25 March	2515	1274/63	+0161	0805/62	0000	-1970	-0010	1590	3803	3bcA

CONCLUSION

28. The telemetry system used in these tests has performed without problems, accurately transmitting the data supplied by the transducers. It has functioned over a temperature range of -40°F (-40°C) to 130°F (54°C) which will meet the needs of most Canadian open pit mines. Components of the present remote station are bulky, however, and require a substantial power supply (20 caustic potash batteries). The present system, even with dispatching radio equipment, is expensive. Table H-5 lists the 1973 costs of the major components. Appendix J in this chapter describes a proposed less expensive system which includes a remote station with a size and power consumption. In terms of ambient operating range, the proposed new remote station will be equivalent to the present station.

29. Both potentiometric units, linear and rotary, have indicated capability as displacement transducers. The dc linear differential transformer did not perform satisfactorily. The optical or mechanical encoders cannot be recommended for use outside their temperature range of 32°F (0°C) to 248°F (120°C).

Table H-5: List of telemetry equipment

Item	Model (Motorola)	Price (1973)
Receiver-transmitter		
Mocom 70	CD 43 BBN-1990K	$ 900
Quick call II Decoder	T 1137	165
Pager	XN 1016	322
Remote station to transmit 8 analog readings and 2 BCD readings via FSK, master station with serial to parallel receiver and data ready signal every 300 ms but without memories	PC-26	10,950
	Total	12,337

APPENDIX J

A RECOMMENDED TELEMETRY SYSTEM

FOR OPEN PIT MINES

INTRODUCTION

1. The telemetry system described in Appendix H and used at Jeffrey mine can be recommended for use in open pit mines for surveillance. It is a system that has however three defects in terms of non-essential characteristics. The remote station is expensive, $10,950 in 1973; it is physically large 18 in. (45 cm) x 20 in. (51 cm) x 54 1/2 in. (138 cm); and requires appreciable power, 200 ma at 120 V standby and 700 ma at 120 V for transmission. The purpose of the present appendix is to describe a more suitable replacement.

SELECTION OF REPLACEMENT REMOTE STATION COMPONENTS

2. Referring to Fig 1, the remote station can be viewed as consisting of a radio transmitter/ receiver, data acquisition equipment, and sensors. It is with respect to the first two that replacement components had to be found.

CHOOSING A RADIO TRANSMITTER/RECEIVER

3. A survey was carried out in 1974 to find radio receiver/transmitter units that minimize current drain, particularly when in the standby mode. Since hand-held units draw considerably less current than mobile units, the latter were eliminated from the survey. Consideration was also restricted to those radio transmitter/ receivers which have service available across Canada, and are approved by Communications Canada. Table 1 lists the radio transmitter/receiver units meeting the established criteria, and provides characteristics of these units not covered by mandatory regulations but which are significant in the present application.

4. Reviewing the units in Table 1, the Motorola unit provides the best power efficiency. Its transmitter power of 1.8 watts will ensure good transmission within the boundaries of an open pit mine. As substantiation, the U.S.G.S. uses an HT-220 audio transmitter/receiver to telemeter seismic data between San Miguel Island and Santa

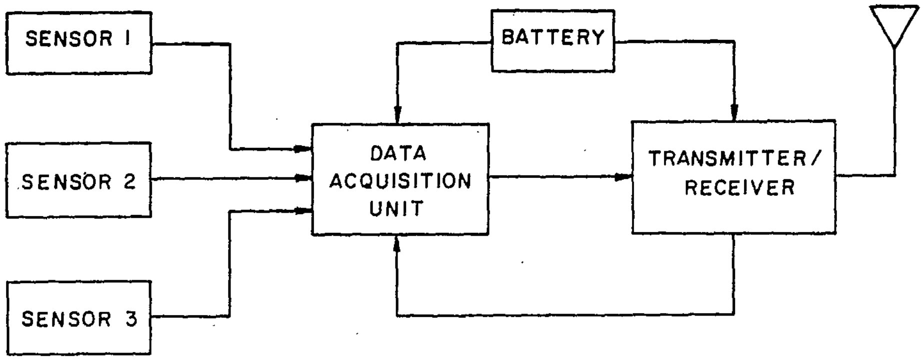

Fig 1 - Block diagram of remote station.

Table J-1: Selected hand-held V.H.F. transmitter/receiver

Manu-facturers	Model	Current (m.a.) Standby	Current (m.a.) Transmission	Cost (1974)
General Electric	PE56 K/4475	14.5	340/1 Watts	$ 1,170.00
Johnson	FM 543	24.0	450/1.5 Watts	761.00
Marconi	DP-15	4.6	400/2.2 Watts	11,019.00
Motorola	Series HT-220 -23 FFN 1107	4.3	330/1.8 Watts	1,154.00

Barbara. The Marconi DP-15 unit, although somewhat lower in power efficiency, has the transmission capability, 2.0 watts, to be used in place of the Motorola unit. Both the HT-220 and DP-15 units have low drain standby current characteristics, suitable for remote transmitter/receivers. On the basis of current drain in the standby mode, the Motorola and Marconi units would be selected over the Johnson and General Electric units. Only the Johnson unit has a decided price advantage over the other listed units.

CHOOSING DATA ACQUISITION EQUIPMENT

5. Prior to 1973, industrial acquisition systems were generally limited to operating in the ambient temperature range of 32°F (0°C) to 158 F (70°C). With the Jeffrey system, part of the power from the bank of 20 caustic cells was used to keep the remote station enclosure within acceptable temperature limits. With the introduction of C/MOS technology and devices in 1973, the construction of remote station equipment with lower operating temperature ranges became possible. The introduction of C/MOS devices also provided the means to reduce power requirements of a remote station. C/MOS is a semi-conductor fabrication process that takes its name from the configuration of the circuit and from the structure of components. Complementary means there are NPN and PNP devices, while MOS means metal-oxide-silicon construction.

6. With reference to Fig 2 of the present appendix and Fig 5 of Appendix H, there are many multiplexers, sample and hold units, and analog-to-digital converter units, which

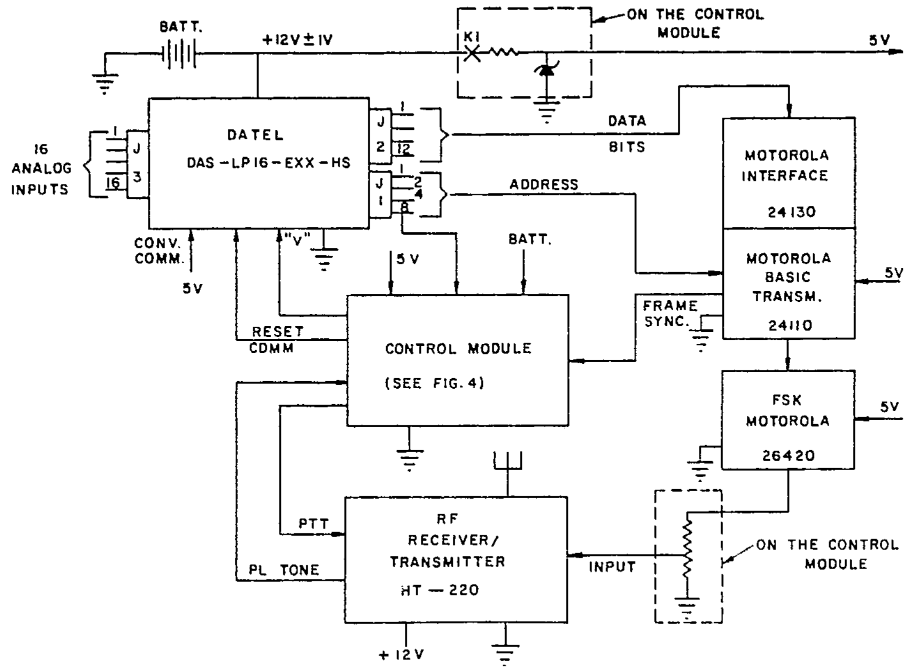

Fig 2 - Schematic of remote station.

individually permit low temperature operation but which generally are not fully assembled. There is a unit, however, constructed by Datel System Inc. of Canton, Mass. (part no. DAS-16-LP 12 B-EXX-S) which can replace the Motorola 26185 Analog Multiplexer and Newport A/D converter of the earlier remote station. The following characteristics of this unit are of particular interest with respect to the planned application:

- temperature coefficient 0.015%/C°
- operating temperature range - 55°C to +85°C
- 16 analog inputs (+10 volts)
- 12 binary bit output
- 65 in (165 cm) x 4.5 in (11 cm) x 1.0 in (2,5 cm) size, Fig 3.

7. Telemetering with the new system shown in Fig 2 will use the same modulation process that was used in the Jeffrey system. There were few companies in 1974 offering C/MOS low-temperature digital modulation equipment in modular form. The Dascon Division of Motorola has available an ML-26 series of plug-in cards that perform the functions of the PC-26 cards used in the Jeffrey remote station. They have a low temperature operating limit of -40°F (40°C). Three cards in cascade provide the necessary steps between the Datel DAS-16 unit and the microphone input of the HT-220 radio transmitter/receiver of the remote station; the ML-26-24130 acts as input interface unit, the ML-24110 as basic transmitter, and the ML-26240 as FSK transmitter. The transducer signals, converted by the DAS-16 into 12 bits in parallel, are transformed by the three Motorola units to a serial signal with address suitable for radio transmission.

8. The control module shown in Fig 2 was especially designed for the needs of the remote station; Fig 4 is a circuit diagram of this module. It performs the following functions:

a. turns on the remote station when polled,
b. insures the transmission of eight sequential messages when polled, and
c. turns the power off when the transmission is complete.

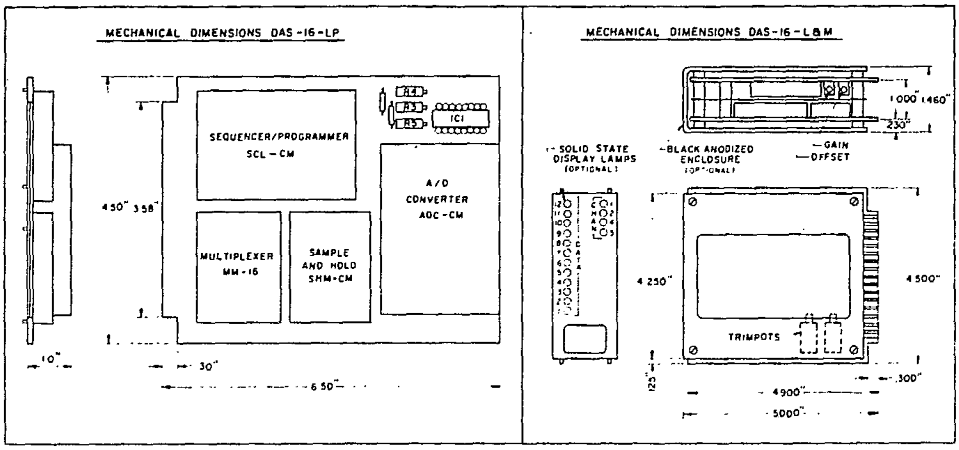

Fig 3 - Mechanical dimensions of Datel equipment.

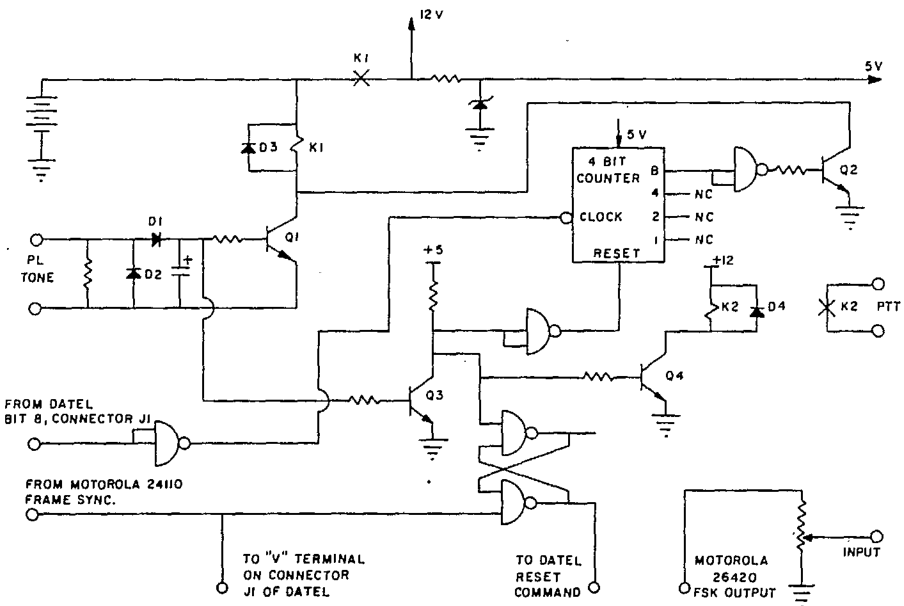

Fig 4 - Schematic of control module.

9. Power for the remote station shown in Fig 2 would be provided by a single globe cell (part No. GC-12200, 20 A-H capacity). A period of operation exceeding a year should be possible without recharging the globe cell. The enclosure constructed for the remote station should comply with NEMA standards. An enclosure 10 in. (25 cm) x 14 in. (36 cm) x 16 in. (41 cm) should be sufficiently large to hold the remote station with its battery. Space has been left with this size of enclosure to permit insulation with a 1 in. (2.5 cm) thick styro-foam panel.

COST OF REMOTE STATION

10. Listed below are estimated costs of constructing the proposed remote station as at the beginning of 1974, including federal tax:

1.	Datel acquisition system #DAS-16-LPIZ B-EXX-HS	$1800
2.	Motorola digital modulator #ML-26-24130 #ML-26-24110 #ML-27-26420	850
3.	Gell cell #GC-12200	50
4.	Hammond enclosure (insulated) #1414 PH010	50
5.	Radio transmitter/receiver Motorola HT-220	1150
6.	Small parts, technician salary	400
	Total	$4300

CONCLUSIONS

11. The remote station of the earlier system cost $10,950; the present system less than half at $4300. The previous system required 20 caustic batteries, partly due to the need for a heated enclosure. The present unit functions in an unheated enclosure, and uses only a Gell cell battery. The previous equipment enclosure of 18 in. (45 cm) x 20 in. (21 cm) x 54 1/2 in. (138 cm) without batteries, has been reduced to an enclosure of 10 in. (25 cm) x 14 in. (36 cm) x 16 in. (41 cm) and accommodates the battery.

APPENDIX K

AN FM/FM TELEMETRY SYSTEM

INTRODUCTION

1. FM/FM telemetry of data is suitable where two sensors at most are served by a remote station. Without frequency multiplexing, a system of this type has a sensitivity of 1 part in 2700. Such an FM/FM system is the subject of this appendix. It has been used in a mine with vibrating wire piezometers to monitor groundwater pressures remotely. By using V C O oscillators for signal conditioning, the present system can be used to monitor voltage signal sensors remotely.

EQUIPMENT DESCRIPTION AND OPERATION

GENERAL

2. The system consists of a master station which includes the mine dispatch radio and a remote station which will be described in detail.

MASTER STATION

3. Figure 1 is a block diagram of the master station. The additions to the dispatching equipment are a paging encoder and a frequency meter. To interrogate a remote station, the dispatcher depresses the selection buttons for the station, and then momentarily depresses the page button. Alerted to transmit, the remote station transmits the vibration frequency of the vibrating wire gauge. A frequency meter with digital readout is used to read the frequency. While not used in the present system, a printer could be added to provide a paper printout of the readings.

REMOTE STATION

4. Figure 2 is a photograph of the piezometer and remote station on a test bench. The box in the right foreground is the remote station. With reference to Fig 3, the remote station is housed in a 16 in. (41 cm) x 5 in. (13 cm) x 3 in. (7.6 cm) steel box. It consists of three distinct units: an HT-220 radio transmitter/receiver with paging capabilities, a conditioning unit for the sensors, and control and timing circuits. In the present case, because a Telemac vibrating wire

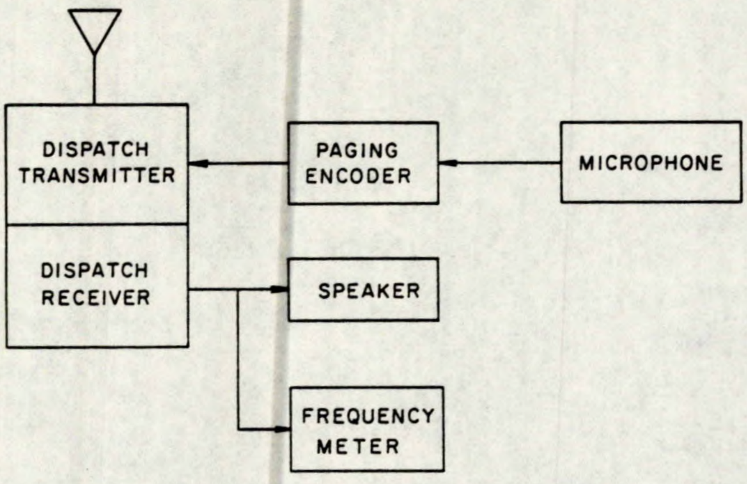

Fig 1 - Block diagram of master station.

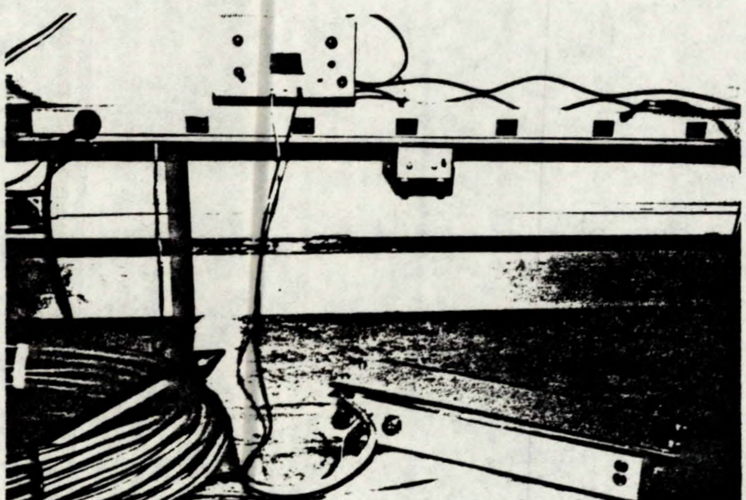

Fig 2 - Photograph of piezometer and remote station on a test bench.

piezometer was used, a Telemac AE3 unit was used for conditioning and excitation. In the case of voltage signals, a suitable amplifier and V C O unit would replace the AE3 unit. Figure 4 shows a diagram of the control and timing circuits of the remote station.

5. When interrogated with the correct paging tones, an audio signal is produced at the "audio" contact of connector P1. The rectified and filtered audio signal is applied to the base of transistor 2N 3566 to turn it on. When 2N 3566 is turned, signal terminal PTT to the radio transmitter/receiver HT-220 is grounded. The effect of this grounding is to turn on the transmitter of the HT-220 unit. When transistor 2N 3566 starts to conduct, relay K1 is energized and power is supplied to timing relay K2 and the Telemac conditioning and excitation unit, AE3. When interrogation ceases, K1 is maintained in an energized state by using a set of its own closed contacts. Relay K1 remains energized until such time as the contacts of delay relay K2 open. The

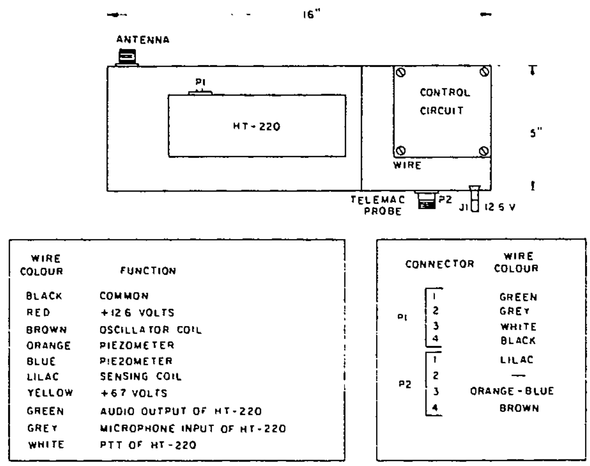

Fig 3 - Mechanical dimensions of remote station.

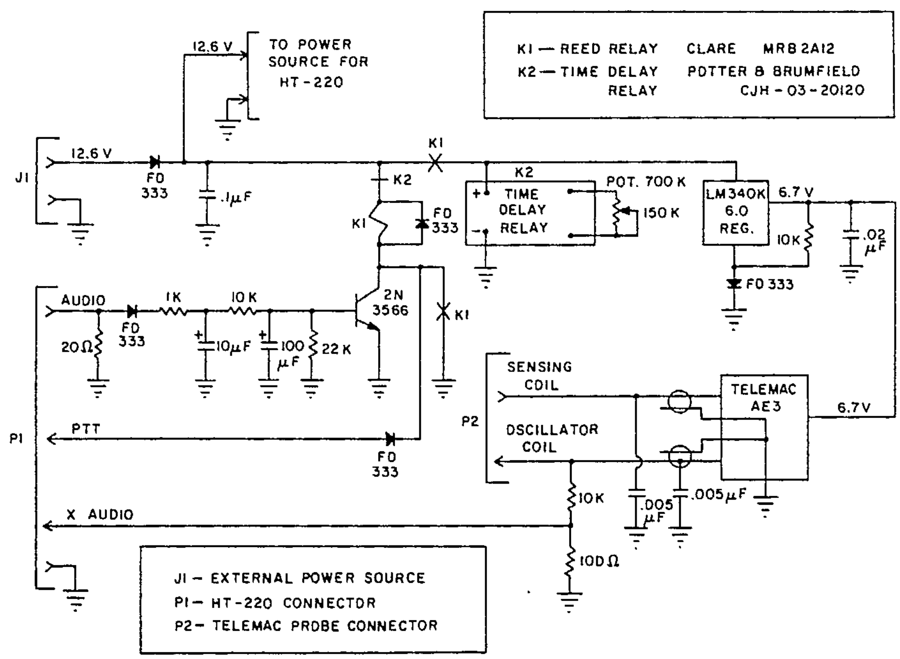

Fig 4 - Control and timing circuit of remote station.

opening of the closed contacts of this relay, which are in line with the coil of K1, de-energizes relay, K1. The 700 kohm potentiometer connected to delay relay K2 permits adjustment of the time delay period over the range of 0 to 1 minute. By using a motor-operated timing unit in place of relay K2, several sensors, instead of only the one, could be monitored at each remote station.

COST

6. In estimating the cost of this system, it was assumed that the mine radio equipment would be part of the base station. Table K-1 lists the cost of major components. Small components would cost an additional $100. Labour cost for the construction of a unit would add an additional $300 to $400 (1974).

7. If automatic reading is required, a frequency meter compatible with the printer would have to be used. Table K-2 provides a list of the components required for such a master station, using Hewlett Packard equipment.

Table K-1: Components of FM/FM telemetry system

Number required	Unit	Cost (1974)
1	Motorola HT-220	$1130
1	Motorola pacing encoder XN 1016B	330
1	Telemac AE3	530
1	Fluke 1900 A frequency meter	350
	Total	$3340

Table K-2: Components of automatic reading station

Number required	Unit	Cost (1974)
1	HP-5300B Main frame	$ 500
1	HP-5312A ASCII interface	400
1	HP-5310A Frequency counter	200
1	HP-5150A Digital printer	900
1	HP-59309A Digital clock	1000
	Total	$3000

At 1974 prices, an automatic reading FM/FM system with one remote station would cost $6000.