REMOTE EDM MONITORING OF FRACTURES ON TURTLE MOUNTAIN

PHASE I

OF-57

REMOTE EDM MONITORING OF

FRACTURES ON TURTLE MOUNTAIN

PHASE I

(Assignment #83-9106)

Final Report to the
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1. INTRODUCTION

Investigations carried out under assignment #83-9106, "Remote EDM Monitoring of Fractures on Turtle Mountain - Phase I" are discussed in this report. As outlined in the Schedule of Terms of Reference, research activities include:

(1) determination of the reflective characteristics of various materials and prisms so that a suitable reflector can be chosen for the proposed remote monitoring of Turtle Mountain,

(2) calibration of the K&E Laser Ranger V-A (to be used in the survey), and

(3) determination of the actual sensitivity of the Ranger V-A when the distance difference technique is employed.

In sections 2 and 3 will be found, respectively, a discussion of experimental procedures and equipment used in this study, and experimental results. Both sections are divided into three subsections that correspond to activities 1-3 above. A summary of conclusions relevant to monitoring studies (especially that of Turtle Mountain) and recommendations for the design and procedures of a survey for monitoring Turtle Mountain are given in section 4.

Submission of this report does not preclude further investigation into the three activity areas. In each area, especially that of EDM calibration, results have been obtained that raise many interesting questions that have not been adequately addressed in the scientific literature. Many of these questions, however, are not relevant, in practice, to a survey which employs a distance difference method. While some questions remain that may be relevant, results obtained to this date indicate that a distance difference technique employing the Laser Ranger V-A and K&E prisms is a suitable and economically viable method for remote monitoring of Turtle Mountain.

2. EXPERIMENTAL METHODS

This section describes the experimental procedures and equipment used in phase-I investigations. The discussion is divided into three subsections, corresponding to the three areas of study outlined in the proposal:

(1) Reflector characteristics,

(2) EDM calibration,

(3) Sensitivity using distance differencing.

All EDM distance observations were made with the K&E Laser Ranger V-A (serial #07B6005). It is planned to use this instrument for Turtle Mountain monitoring in phase-II.

2.1 Reflector Characteristics

Four types of reflectors were tested as candidates for use on Turtle Mountain:

(i) K&E - 76 0304 (retro-reflective prism)

(ii) MRM - A10M (retro-reflective prism)

(iii) acrylic reflector (8.25 cm diameter)

(iv) reflective tape.

The tests described below enabled the determination of:

(a) maximum range,

(b) maximum angle of incidence of laser beam, and

(c) effect on measurement precision.

Test for Maximum Range

The Calgary Calibration Base Line was used to determine the maximum range at which reflectors (i - iv) can be used. As ranges in excess of 4.8 km are not proposed for the Turtle Mountain monitoring scheme, reflectors were not tested at greater distances.

Test for Angle of Incidence

Figure 2.1 illustrates the design of this test. A special bracket was constructed to attach the reflectors atop a theodolite so that the vertical axis of the theodolite coincides with the reflector axis. With the theodolite sighted on the EDM, the prism face is aligned at right angles to the incident beam. Angle θ is then easily set out by setting the correct reading on the horizontal circle. Ranges are determined (mean of five observations), at ten degree increments of θ, and one kilometre increments of R, to both the MRM and K&E prisms.

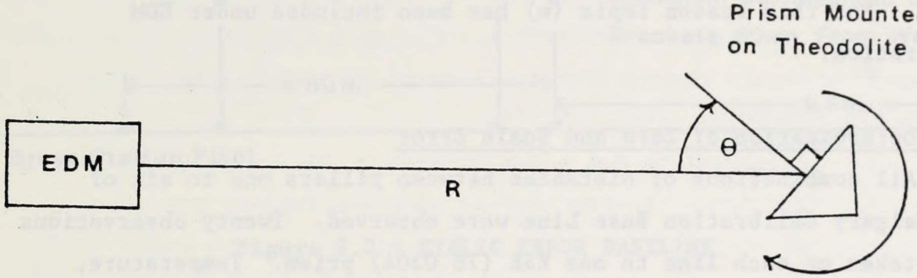

Figure 2.1 : TEST FOR MAXIMUM ANGLE OF INCIDENCE

Measurement Precision

The observations recorded in the test for angle of incidence (for the case when θ=0) have been analysed to determine whether either prism yields inferior measurement precision. Results of statistical tests were not entirely conclusive due to the small number of observations. Therefore two sets of thirty observations, one set to the K&E and one set to the MRM, were observed and analysed.

2.2 EDM Calibration

Five aspects of the K&E Laser Ranger V-A have been considered:

(a) Determination of zero and scale error

(b) Determination of cyclic error

(c) Effects of ambient temperature on (a) and (b)

(d) Effects of instrument internal temperature on scale error (i.e. warm-up time)

(e) Effect of multiple prism reflections.

Topic (e) is not normally considered as part of instrument calibration. However, as the monitoring design, currently visualized, places prisms in close proximity (i.e. within a few meters), it is important to know the minimum prism spacing that yields ranges to any one prism uncontaminated by reflections from nearby prisms. The minimum prism spacing is directly related to the instrument beam width. For this reason topic (e) has been included under EDM calibration.

Determination of Zero and Scale Error

All combinations of distances between pillars one to six of the Calgary Calibration Base Line were observed. Twenty observations were taken on each line to one K&E (76 0304) prism. Temperature, pressure, and humidity were recorded before and after each set of twenty readings. The EDM was allowed to warm-up for thirty minutes before the first set of observations, and was not turned off until all distances were measured (approximately five hours later).

The mean of each distance was reduced for meteorological effects and differential height of instruments above pillar plates. The reduced mean distances were then entered into a regression analysis. The "true" slope distances, given by Alberta Energy and Natural Resources (1982), are used in the analysis and assumed to be errorless.

Determination of Cyclic Error

A ten meter cyclic error base line has been constructed and used to obtain preliminary results for short periodic cyclic errors. Figure 2.2 shows the base line design. A theodolite and level were used to ensure that the brass station points were set out in a straight line. The 0.5m spacings between station points were set out with a 0.5m steel bar. Due to the temperature variant length of the steel bar, station point intervals may deviate from the desired 0.5m. The coefficient of expansion of the aluminum support bar can similarly effect the interval lengths. Therefore they are measured very accurately with a mechanical strain gauge calibrated

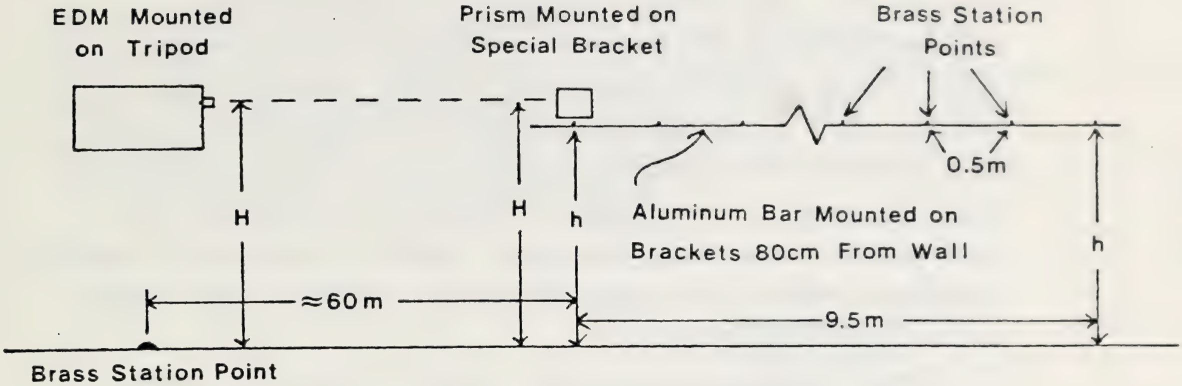

Figure 2.2 : CYCLIC ERROR BASELINE

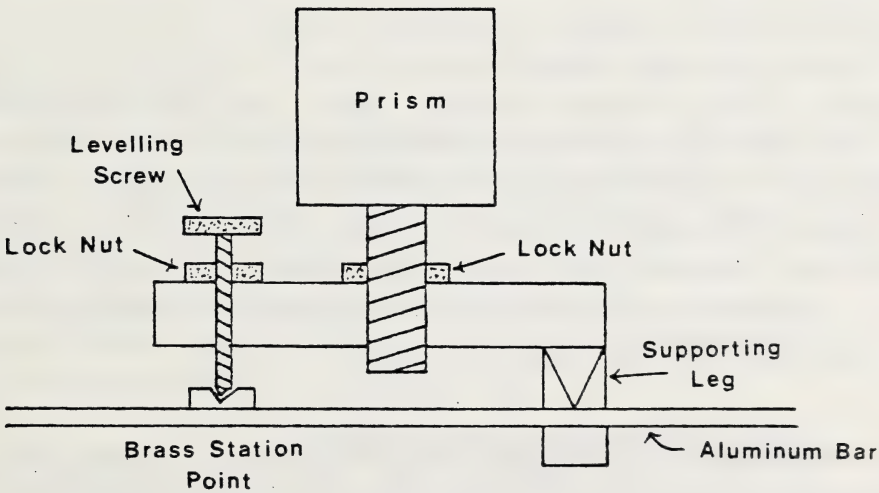

Figure 2.3 : CYCLIC ERROR BASELINE - PRISM BRACKET DETAIL

to a 0.5m silicate bar standard just prior to taking observations with the EDM. The baseline is located near the Mechanical Engineering exit of The University of Calgary central heating tunnel system. Ambient temperature is fairly stable in this location (±2°C during the time required for observations), therefore station point spacings do not change significantly during the observing period. Corrections, if required, are applied to the observations during data processing. Figure 2.3 details the assembly designed to ensure that prisms are located accurately with respect to the brass station points.

Twenty observations are taken to each of the twenty prism positions. The EDM is reaimed before each observation set and meteorological readings are taken before and after each set. The mean of each observation set is reduced for meteorological effects, then the twenty reduced means are used in a cyclic error analysis.

Three cyclic error analysis programs have been installed on The University of Calgary Honeywell computer for this project. The first two programs, cycedC and cycedR, are designed specifically to determine the amplitude and phase of EDM cyclic error with unit length period (usually 10m). Program cycedR is the more useful of the two programs because statistical information is also output. Program cycedC was installed only to test the validity of cycedR output values. The third program, spectr, (see Wells and Vanicek, 1978) performs a least squares spectral analysis of any input time series. It has the ability to solve for noncyclic biases, such as linear or exponential trends, and cyclic components of any input periods. Program spectr yields results nearly identical to those of cycedR and cycedC when the only component to be extracted is a cyclic error of unit length period.

<u>Effect of Multiple Prism Reflections</u>

To determine the effective beam width of the Laser Ranger V-A at four kilometres, ranges were made to a fixed prism with a moveable (disturbing) prism at various distances from the line of observation. Figure 2.4 shows the experimental configuration. The disturbing prism was initially placed on line, then offset perpendicular to the line of observation, in set increments. Five ranges were made to the fixed prism for each position of the disturbing prism. The effective beam width is twice that value of the disturbing prism offset for which range values to the fixed prism are uneffected by further movement of the disturbing prism.

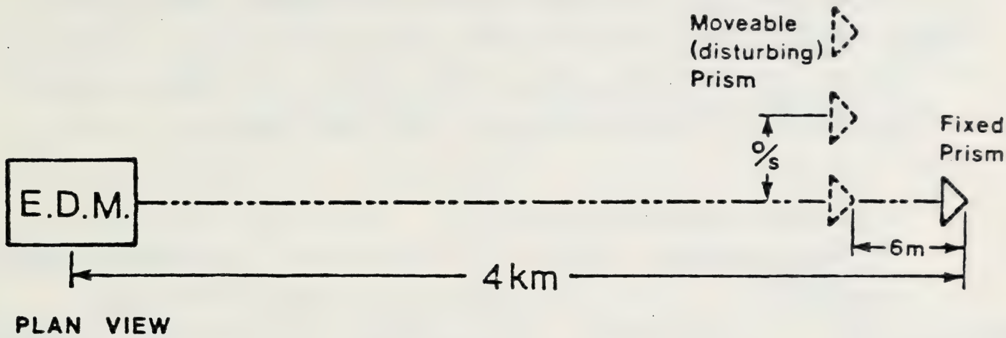

Figure 2.4 : TEST FOR MULTIPLE PRISM REFLECTIONS

Temperature Effects

Temperature effects are determined by operating the EDM in a temperature controlled area and monitoring the frequency count. The University of Calgary Civil Engineering environmental chamber and a Hewlett-Packard 5245L counter are being used for this purpose. The experimental configuration is given in Figure 2.5. A digital or analgoue recorder can be connected to the frequency counter to enable the automatic recording of frequency data.

The Ranger V-A warm-up time was investigated at temperatures in the range of -35°C to +40°C as follows (Figure 3.3 gives specific temperatures used). The EDM is placed in the environmental chamber and all accessory instrumentation is connected, then the selected temperature, T, is set on the chamber console. The frequency counter requires a two hour warm-up period so it is switched on at this time. After five to thirty minutes the chamber temperature stabilizes to T ± 1°C.

However, to ensure that the EDM crystal has attained ambient temperature, a minimum of four hours is allowed to elapse before the laser is turned on. So that the operator will not be required to enter the chamber, a remote switch is used. Remote switching requires that the frequency counts be taken with the Ranger V-A function dial set at "Test". (Additional tests have shown that the crystal frequency is not effected by the position of the function dial). When the laser is turned on, the counter immediately begins to output the crystal frequency on a digital display panel. The displayed value (precision = ± 0.1 Hz) is the average frequency over a ten second period. The system is allowed to run until the frequency appears to have stabilized.

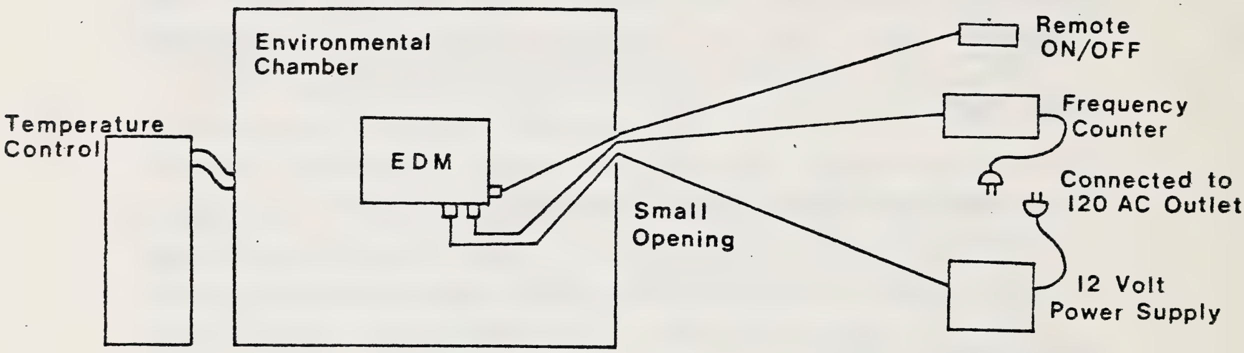

Figure 2.5 : EXPERIMENTAL CONFIGURATION FOR FREQUENCY COUNT TESTS

In addition to the determination of warm-up time, the above described test provided data for the determination of an empirical functional relationship between ambient temperature and stabilized frequency (see e.g. Rüeger, 1980). The function

$f = f(T)$; where f is the stabilized frequency

is required for the scale error correction of distance observations. At present, f has been determined for 15°C increments of T. The available data is insufficient for a reliable determination of f(t), therefore, another test is planned to yield f for 5°C increments of T.

2.3 Sensitivity Using Distance Differencing

The two experiments described below were designed to test the hypothesis that some of the systematic errors inherent in EDM observations can be eliminated by the method of distance differencing.

In the first experiment (see Figure 2.6) one determination of distance "d" is calculated as the mean of ten ranges to prism-A minus the mean of ten ranges to prism-B. The observing sequence consists of two repetitions of five ranges to prism-A and five ranges to prism-B. For each group of five ranges, the unused prism is removed from the line of sight (unclipped from tribrach) and the EDM is reaimed. The final accepted value for "d" is the mean of ten determinations. Meteorological conditions are recorded but corrections are not applied. The entire observing procedure is completed without interruptions and requires about one hour.

Distance "d" is set out accurately by using a theodolite to position the prisms precisely on line, then adjusting the distance between them until the desired separation is achieved. A steel tape, carefully calibrated to A.L.S. standard number 174 (MDP-19/30), and corrected for thermal expansion, was used for this purpose. The tape used is 0.0005 meters too short over 10 meters. Distances were measured between the back edges of the prism bodies. Figure 2.7 shows the simple test performed to ensure that this procedure results in the correct distance "d" set out between prism centers.

Observations were made from the north central pillar of The University of Calgary Surveying Engineering Observatory, north 3.5 km to a point on the east edge of Shaganappi Trail.

In the second experiment (see Figure 2.8) the component "D", of distance "d", along the observation line to prism-B, is observed. The position of prism-A is fixed but it is possible to adjust the position of prism-B, as it is mounted on a traversing head. Distance "D" is calculated as the mean of six ranges to prism-A minus the mean of six ranges to prism-B. The observing sequence consists of two repetitions of three ranges to prism-A and three ranges to prism-B. After each group of twelve observations

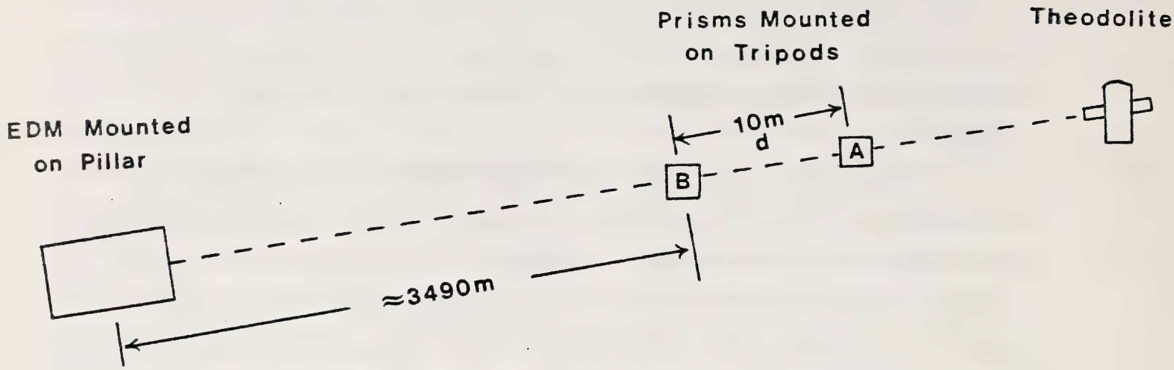

Figure 2.6 : DISTANCE DIFFERENCING TEST(1)

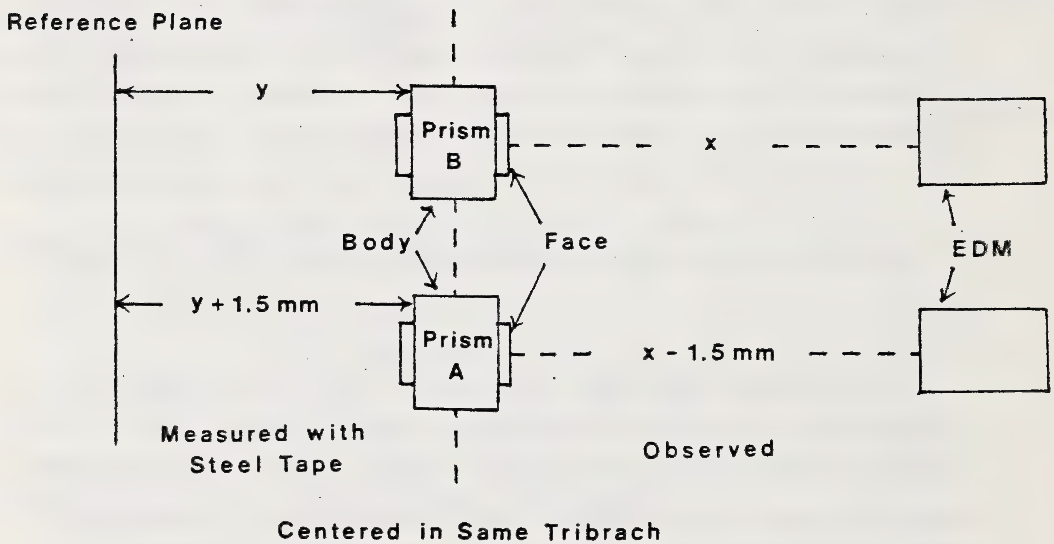

Figure 2.7 : CHECK OF SETTING OUT PROCEDURE IN DISTANCE DIFFERENCING TEST(1)

"D" is changed by a known amount and reobserved. The observed changes, $\tilde{\Delta}D$, are compared to the true changes, ΔD, to determine the sensitivity of the distance differencing method. Meteorological corrections are not applied. Observations were made from the north central pillar of The University of Calgary Surveying Engineering observatory to McMahon Stadium (approximately 1.2 km).

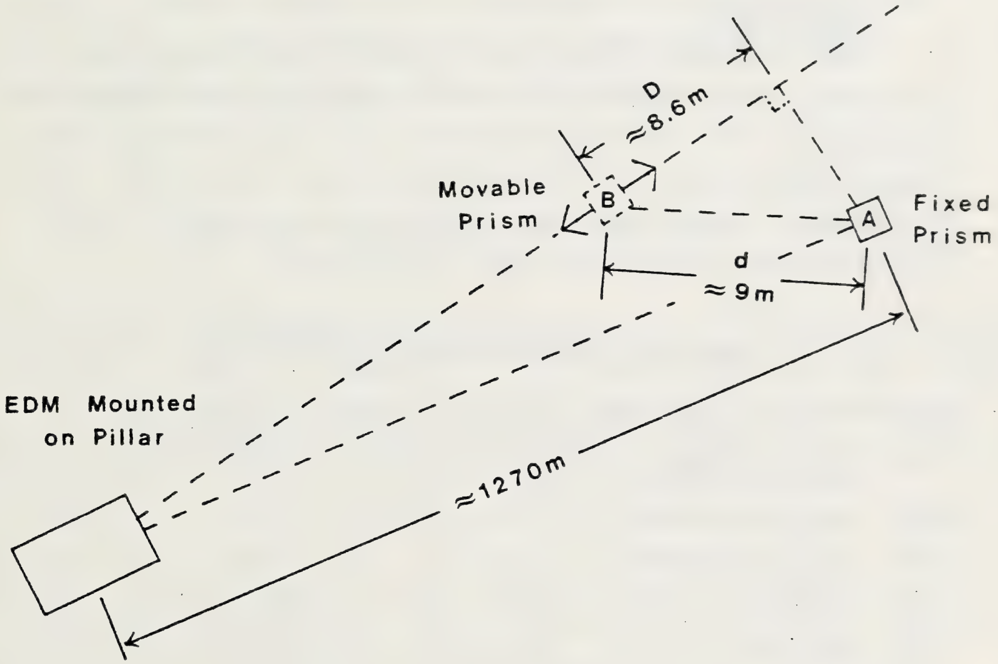

Figure 2.8 : DISTANCE DIFFERENCING TEST(2)

3. RESULTS

3.1 Reflector Characteristics

Reflector characteristics tests were conducted by Mr. C.S. Cryderman. Detailed discussion of his findings are contained in Cryderman (1983). A concise summary of results relevant to Turtle Mountain monitoring is given below.

Maximum Range

Table 3.1 clearly shows that reflective tape and acrylic reflectors are not suitable for the proposed monitoring scheme, as distances in excess of three kilometres are to be observed. The maximum range for both the MRM and K&E prisms exceeds 4800m. As no distances greater than this are planned in the monitoring of Turtle Mountain, either prism type is acceptable.

Table 3.1: MAXIMUM RANGE FOR REFLECTORS

Type	Quantity	Maximum Range (m)
Reflective Tape	1	360
Acrylic Reflector	1	920
Acrylic Reflector	3	1140
K&E Prism	1	> 4800
MRM Prism	1	> 4800

Angle of Incidence

As the acrylic reflectors and reflective tape were rejected in the test for maximum range, only the two prisms were tested for maximum angle of incidence. Both types behaved similarly. At close range ($\approx$ 1 km) the maximum angle of incidence, θ, is about forty degrees. This value slowly decreases with increasing range. At four kilometres, θ is about thirty degrees.

Measurement Precision

The null hypothesis:

$$H_o : \sigma_{MRM} = \sigma_{K\&E}$$

is tested against the alternative hypothesis:

$$H_a : \sigma_{MRM} > \sigma_{K\&E}$$

where σ is the population standard deviation. Initially, four pairs of sample standard deviations, $\hat{\sigma}$, corresponding to samples of five observations at four different distances, were tested with the parametric F-test. Table 3.2 gives the results.

Table 3.2: MEASUREMENT PRECISION F-TEST

Distance (m)	$\hat{\sigma}_{K\&E}$ (mm)	$\hat{\sigma}_{MRM}$ (mm)	R	Pass or Fail at 95%	Pass or Fail at 99%
1145	3.6	4.4	1.4	Pass	Pass
1990	2.3	8.5	13.66	Fail	Pass
3187	3.7	4.4	1.41	Pass	Pass
4033	2.5	6.0	5.76	Pass	Pass

$R = \hat{\sigma}^2_{MRM} / \hat{\sigma}^2_{K\&E}$

Pass => Do not reject H_o. $(R > F_{4,4,\alpha})$

Fail => Reject H_o; Accept H_a. $(R > F_{4,4,\alpha})$

The F-statistic $F_{4,4,\alpha}$ = 6.39, for $1-\alpha$ = 95%
16.0, for $1-\alpha$ = 99%

Although results of the F-test indicate that $\sigma_{MRM} \not> \sigma_{K\&E}$, additional tests show that the H_a should be accepted. The nonparametric Wilcoxon-Mann-Whitney test (e.g. Wonnacott and Wonnacott, 1972) indicates that $\underline{\sigma_{MRM} > \sigma_{K\&E}}$ at the 98.5% confidence level. As this test considers all four pairs in Table 3.2 simultaneously, it is more reliable than an F-test applied to a single pair.

The F-test applied to samples of thirty observations also indicates that $\underline{H_a \text{ is true}}$. Two sets of thirty observations taken at approximately 3514 metres yield:

$$\frac{\hat{\sigma}^2_{MRM}}{\hat{\sigma}^2_{K\&E}} = \frac{(5.36)^2}{(3.14)^2} = 2.914 > 2.42 = \text{the corresponding 99\% confidence level F-statistic.} \quad (3\text{-}1)$$

3.2 EDM Calibration

Determination of Zero and Scale Error

Analysis of observations on the 30th of November, 1982 yield:

Zero error = 166.34 mm ± 3.07 mm

Scale = 0.76 ppm ± 2.78 ppm (3-2)

These values meet the manufacturers specifications. The stability of scale and zero error is still under investigation.

Determination of Cyclic Error

Table 3.3 summarizes the results of cyclic error testing. Two complete data sets have been analyzed and compared. The data definitely indicates the presence of a first order short periodic error (period = 10 m) and cyclic errors caused by multipath signals (period = 10/n, n = 2, 3, 4 ...) (see e.g. Covell and Rüeger, 1982). Notice that the trend in amplitude values is similar and that the five metre periodic error is predominant in both cases. The values for phase do not, however, agree very well. This is due to contamination by random errors and, for longer periods, an insufficiently long test line. The half metre station spacing is too large for accurate determination of the 2.5m and 2m period cyclic errors, however, as their magnitudes are very small at greater distances, they can be ignored.

Table 3.3: CYCLIC ERROR TEST SUMMARY

April 21st, 1983			May 2nd, 1983		
Period (m)	Amplitude (mm)	Phase (m)	Period (m)	Amplitude (mm)	Phase (m)
10	1.7±0.6	-2.8±0.3	10	0.7±0.2	-4.8±0.3
5	3.1±0.6	-1.2±0.2	5	2.4±0.2	-2.5±0.1
3.33	1.7±0.6	-1.2±0.3	3.33	0.9±0.2	-1.2±0.3
2.5	1.4±0.6	0.4±0.4	2.5	0.8±0.2	-0.8±0.3
2	0.2±0.6	0.7±2.5	2	0.5±0.2	-0.3±0.5

Figure 3.1 shows plots of the two data sets and the fitted error curves:

$$f(x) = \sum_{i=1}^{3} a_i \sin [(x + \emptyset_i) 2\pi/\lambda_i] \qquad (3\text{-}3)$$

where a_i is the amplitude corresponding to λ_i

$\emptyset_i$ is the phase corresponding to λ_i, and

λ_i is the period of the cyclic error component

($\lambda_1 = 10$, $\lambda_2 = 5$, $\lambda_3 = 3.33$).

Further analysis and sophistication of testing procedures should allow values for the amplitude and phase of the indicated cyclic errors to be determined more precisely.

While gathering data for the cyclic error analysis it was noticed that a small change in pointing (i.e. in the order of one minute of arc) resulted in a significant change in the observed distance (i.e. in the order of 8mm). Covell (1979) has shown that significant non-periodic errors result from inhomogeneities of the emitting and receiving diodes. Diode inhomogeneities produce systematic errors which are a function of both distance and pointing. The differences in the two sets of cyclic error data are believed to be due to this effect. To substantiate this claim, a test similar to that of Covell is planned for the Ranger V-A.

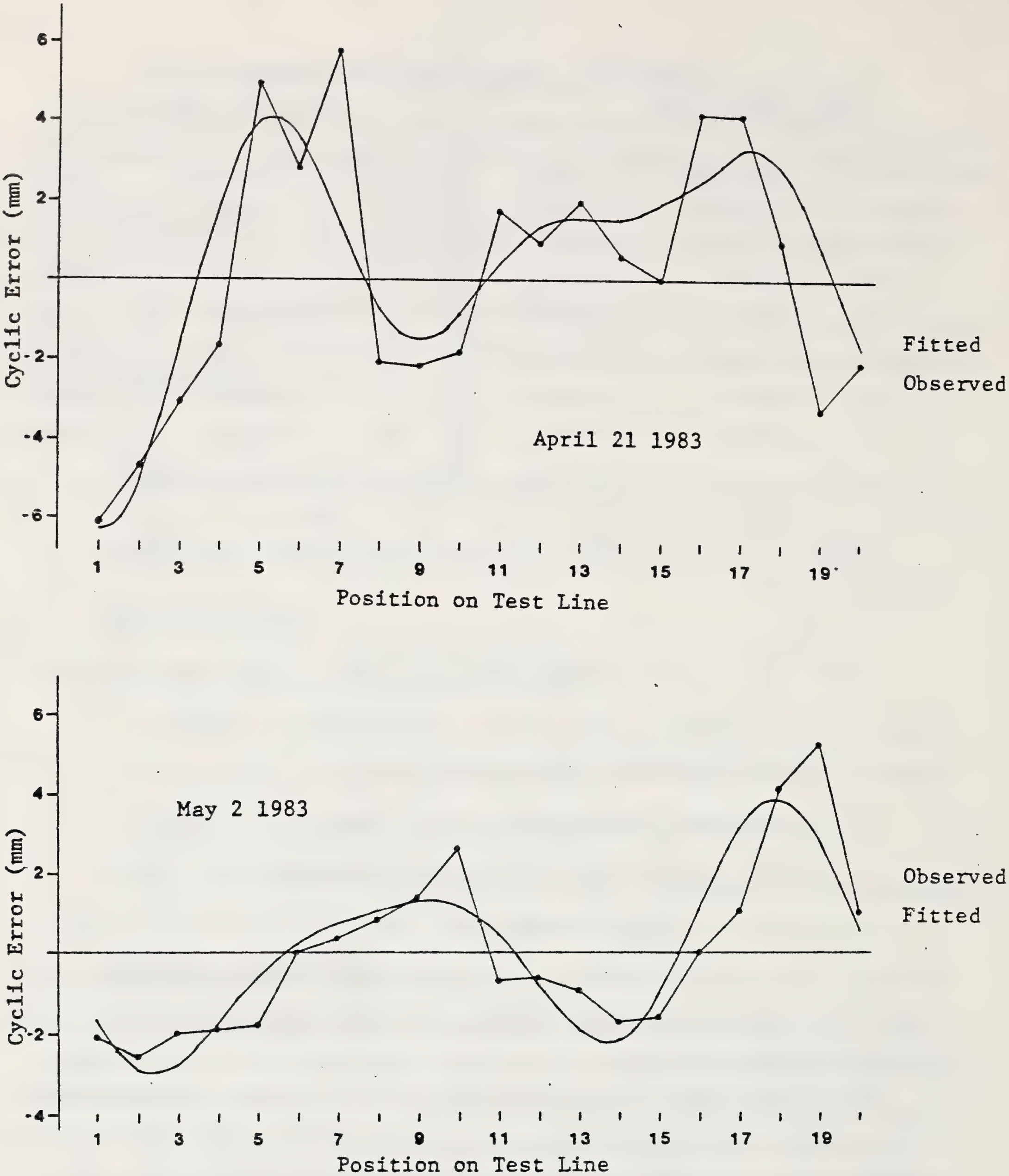

Figure 3.1: SHORT PERIODIC RANGER V-A CYCLIC ERRORS

Distance to Position (1) = 62.22m
Position Spacing = 0.5m
Observed Curve = [Observed Distance - 0.5(Position - 1)] - 62.22m
Fitted Curve = Sum of 10m, 5m, and 3.33m cyclic errors.

Effect of Multiple Prism Reflections

Figure 3.2, taken from Cryderman (1983), illustrates the dramatic effect of multiple prism reflections. Intuitively, the observed distance would be a weighted mean of ranges to the fixed and disturbing prisms. However, the figure clearly shows that this is not the case. Errors in the order of several hundred metres can be expected when the disturbing prism is nearly on line. It is expected that this large error phenomenon can be explained in terms of the digital phase measurement technique (e.g. Rüeger, 1980) used in the Ranger V-A.

At the four kilometre range the effective beam width of the Ranger V-A is about two metres. Therefore, the effect of multiple prism reflections will be eliminated (for ranges not greater than four kilometres), if the following monitoring design criterion is met. Let $\underline{d}_{ij}$ be the position vector of prism(j) with respect to prism(i). Then the magnitude of the component of $\underline{d}_{ij}$ perpendicular to the observation line to prism(i) must be greater than one metre, for all prisms in the monitoring network.

Temperature Effects

Changes in crystal frequency affect an observed distance, R, as follows:

$$R = n\lambda + \Delta\lambda$$

where λ is the wavelength of the transmitted beam, and

n is the greatest integer less than R/λ.

Let v be the velocity of the transmitted beam, and

f be the frequency of the transmitted beam, then

$$R = n(\frac{v}{f}) + \Delta(\frac{v}{f}). \qquad (3\text{-}4)$$

For the K&E Laser Ranger V-A, f is assumed to be 14,984,980 Hz. When the frequency deviates from this value, R is obviously affected.

Figure 3.3 gives the results of frequency count tests. Over the expected temperature range during observations at Turtle Mountain, the "stabilized" frequency is in error no more than 2 ppm. Using the distance difference observing technique a scale error of this magnitude is negligible. For example,

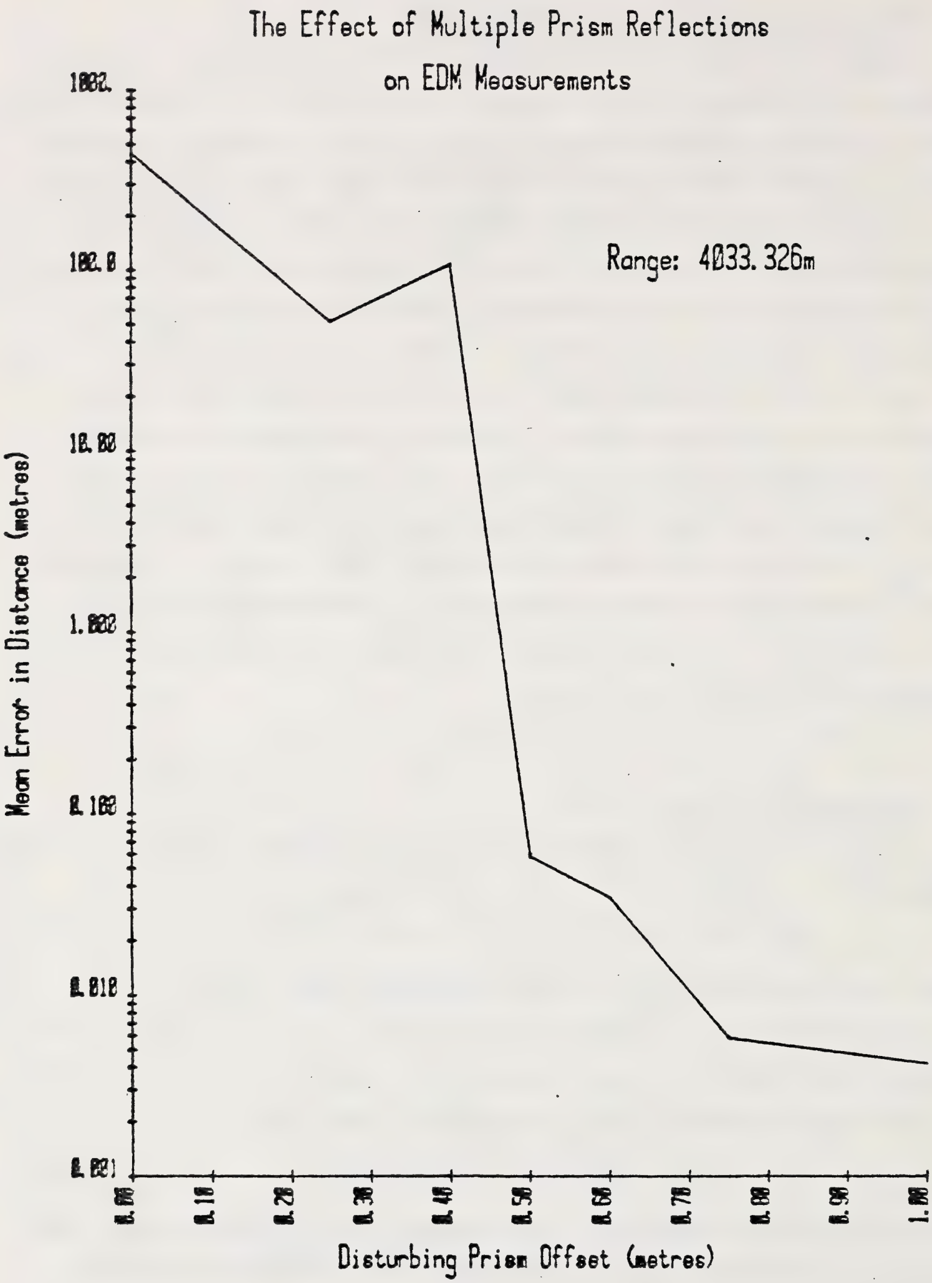

Figure 3.2 : MULTIPLE PRISM REFLECTION EFFECTS

if s is the scale error (in metres per metre)

R_1 and R_2 are true distances to target stations, and

d is the distance difference (R_2-R_1), then the observed

distance difference:

$$\hat{d} = R_2(1+s) - R_1(1+s)$$

$$= d(1+s)$$

For a true distance difference of ten metres and a scale error of 2 ppm the error in the observed distance difference, ds, is only 0.02 millimetres.

It is important, however, that the scale error is constant for both observed distances, $\hat{R}_1$ and $\hat{R}_2$. Notice, in Figure 3.3, that a warm-up time of 1½-2 hours (over the expected temperature range) is required before the frequency stabilizes. Therefore, observation procedures for Turtle Mountain monitoring should require that the Ranger V-A be warmed up for this length of time.

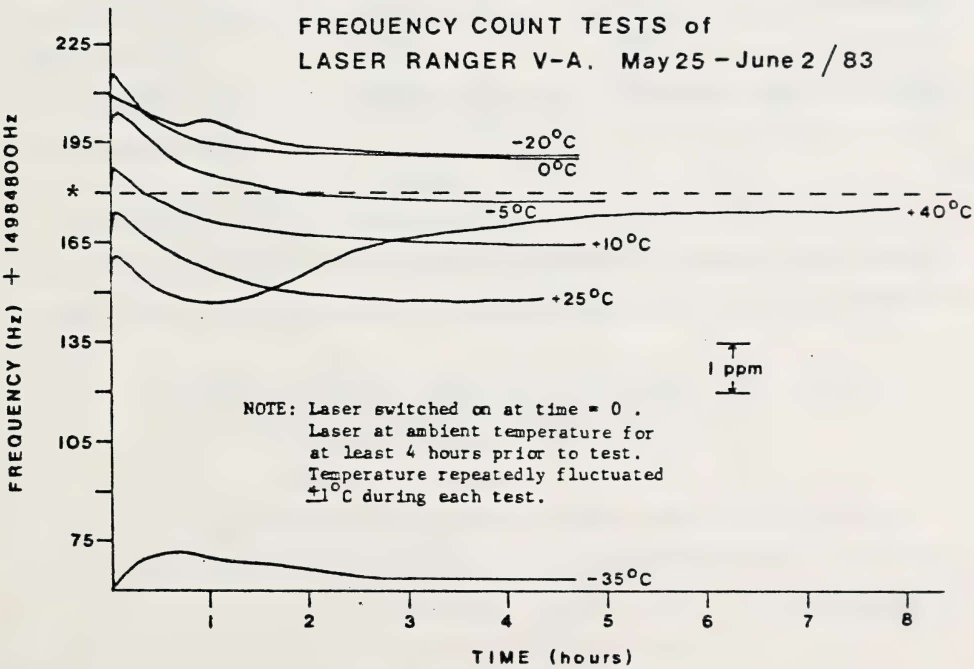

Figure 3.3 : FREQUENCY COUNT TESTS

* Frequency assumed by Ranger V-A microprocessor.

3.3 Sensitivity Using Distance Differencing

The distance differencing experiments described in §2.3 were both repeated twice. Table 3.4 lists the sample distance difference standard deviations, $\hat{\sigma}_D$, calculated in each case. Notice that for ranges less than four kilometres, $\hat{\sigma}_D$ appears to be constant, that is, $\hat{\sigma}_D$ does not increase with distance. The evidence indicates that the population distance difference standard deviation can be accepted as

$$\sigma_D = 0.0022\text{m (K\&E prism used)}. \tag{3-5}$$

Table 3.4: DISTANCE DIFFERENCE SAMPLE STANDARD DEVIATIONS

Date y/m/d	Approximate Range to prisms (m)	Approximate D (m)	$\hat{\sigma}_D$ (m)
83/03/11	1200	8.6	0.0022
83/04/06	1200	8.6	0.0023
83/04/14	3500	10.0	0.0023
83/05/04	3500	10.0	0.0021

To determine whether point movement on Turtle Mountain has occured, the change in distance differences, ΔD, is calculated. We have

$\Delta D = D_1 - D_2$ = component of movement along the line of observation, where D_i is the observed distance difference at epoch(i).

The relative superiority of the distance difference method over conventional distance monitoring techniques is determined by the value of $\sigma_{\Delta D}$. We have

$$\sigma_{\Delta D} = \sqrt{2}\,\sigma_D = 0.0032\text{m (K\&E prism used)}. \tag{3-6}$$

Now suppose that point movement is determined by measuring ranges, R, to only the unstable point. Using the manufacturer's stated Ranger V-A ranging accuracy (5mm + 2ppm) we have, for a distance of three kilometres:

$$\sigma_R = 0.0078\text{m, and} \qquad (3\text{-}7)$$

$$\sigma_{RR} = \sqrt{2}\ \sigma_R = 0.0110\text{m},$$

where σ_R is the standard deviation of one range to the unstable point, and

σ_{RR} is the standard deviation of the difference between two ranges to the unstable point, observed at different epochs.

Notice that ΔD is equivalent to RR. It is, therefore, valid to compare $\sigma_{\Delta D}$ and σ_{RR}. We have

$$\sigma_{\Delta D} \simeq \frac{1}{3}\sigma_{RR}. \qquad (3\text{-}8)$$

This result indicates that much smaller point movements can be detected with the distance difference technique than with standard observing procedures.

Equation (3-6) applies to K&E prisms. If MRM prisms are employed we can expect that:

$$\underset{MRM}{\sigma_{\Delta D}} \simeq 2\underset{K\&E}{\sigma_{\Delta D}} = 0.0064\text{m}. \qquad (3\text{-}9)$$

At the 95% confidence level, point movements of 6.5mm (K&E) and 12.5mm (MRM) are detectable if distance differencing is employed.

4. CONCLUSIONS AND RECOMMENDATIONS

A concise summary of conclusions, arising from Phase-I studies, which are relevant to monitoring of Turtle Mountain are given below. Observing distances in the order of 3-4 kilometres are assumed.

- None of the inexpensive reflectors tested are suitable for deformation monitoring.
- The maximum angle of incidence at which observations are not affected is approximately 30 degrees.
- The Ranger V-A beam width is approximately 2 metres.
- The Ranger V-A studied,functions within manufacturers specifications.
- Cyclic errors exist in the Ranger V-A but will not affect distance difference observations under normal observing conditions.
- Scale error will not significantly affect distance difference observations if a 1½-2 hour warm-up time is allowed.
- The distance difference method should yield observations with a standard deviation of 3mm. This value is approximately one third that of the usual distance observation method (based on manufacturers specifications). Point movement (parallel to line of observation) of 6.5mm can be detected at the 95% confidence level.
- Determination of pointing error (i.e. inhomogeneities of the emitting and receiving diodes) and proper field procedures to account for this error should yield distance differences with a standard deviation of less than 3mm.

Phase-I studies indicate that the use of EDM technology for remote monitoring of rock mass deformations on Turtle Mountain is feasible and practical. This claim needs to be substantiated by study of a field testing program.

A survey design and field procedures for monitoring Turtle Mountain are given in the Phase-II research proposal which was written in accordance with conclusions of this report. In short, the proposal states that a test network consisting of three monitoring points forming a triangle with sides aligned to three base stations be observed and analysed by the distance difference method. The three monitoring points will be in the vicinity of "Crack 1" and the three base stations will be located at vehicle accessible points on the west side of the mountain. Two groups of data (one in 1983, one in 1984) will be obtained and a number of adjustment models tested. The Phase-II proposal should be referred to for further details including maps and diagrams of the proposed network.

Recommendations of the Phase-I studies take the form of the proposed Phase-II survey design and procedures. Not explicitly stated in the Phase-II proposal are the following recommendations which are effectively a re-statement of the conclusions listed above:

- The K&E retro-reflectors should be used.
- Maximum angle of incidence should not exceed 30 degrees.
- Minimum prism spacing should not exceed one metre.
- The K&E Laser Range V-A is a suitable instrument for monitoring of rock mass deformations on Turtle Mountain.
- Observing procedures should allow for a two hour EDM warm-up time.
- A method of eliminating pointing error should be determined and employed so that the precision of the distance difference method will be even better than present figures suggest. (Work is already progressing in this area).

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