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PAPER NO. 18.

THE MEASUREMENT OF THE SWEDISH-NORWEGIAN SECTION OF THE TROMSÖ - CATANIA SATELLITE BASE LINE.

I.R. Brook.

SUMMARY. During the 1967 and 1968 field seasons the Norwegian and Swedish sections of the Tromsö - Catania baseline were measured using MRA4 Tellurometer and Model 4 Geodimeters with lasers. The field operations, assisted by helicopter in the northern sector, were carried out with care and computations show that a very satisfactory accuracy was achieved. The field performance of the instruments was satisfactory.

1. INTRODUCTION.

During the 1967 field season a field party from Rikets Allmänna Kartverk measured the 56 sides which comprise the Norwegian and Swedish section of the Tromsö - Catania satellite base-line. Third generation, high precision EDM equipment was used for the measurements, namely two model 4 Tellurometers serial numbers 1003 and 1004 and a modified model 4D Geodimeter in which the standard light source was replaced by a 2 milliwatt helium-neon gas laser.

A number of check measurements were made during the 1968 season. The greater number of these measurements were made using a laser geodimeter although a number of distances previously measured with model 4 Tellurometers, principally water lines, were remeasured with the same equipment.

The route of the traverse through Sweden is shown on the sketch map of the Swedish first-order triangulation (Fig. 18.1). As can be seen, the distance measurements have been carried out as a single continuous traverse which follows the backbone chain of the national first-order network. The line of the traverse was, to a certain extent, determined by the desire to avoid expensive tower building or to make use of existing towers. Between the final Swedish station in the north and Tromsö, the traverse follows a part of the Norwegian first-order trilateration network. In the middle and southern part of the traverse, which runs through forested areas, special wooden distance measuring towers were built. For this construction only a single tower is required, the observer's platform being an integral part of the instrument tower. The average tower height in this section of the traverse is 15 metres.

From station 223 northwards the traverse skirts the eastern edge of the mountainous areas which make up the western part of Sweden at these latitudes. The average height of the stations increases northwards to a maximum elevation of over 1600 metres in the middle of the Norwegian mountain section, thereafter decreasing rapidly to 100 m above sea level at the terminal camera station in Tromsö.

As transportation presents considerable problems in the highland areas, two Hughes 300A helicopters were chartered for an eight week period for transporting observers and equipment. This type of helicopter is capable of transporting the full equipment with pilot and a surveyor. The operating range with this load and full fuel tanks is approximately 250 kms. To speed up the observations the helicopter pilots were trained to book the observations.

For the remainder of the traverse, back-packing was necessary. The field party which previously had consisted of a head of party and a surveyor was, therefore, increased by an additional surveyor and four labourers.

Progress in this part of the traverse was slower due largely to adverse weather conditions. The final connection to Denmark was completed on 25th October. This connection was made in co-operation with the Danish Geodetic Institute. The total length of the traverse is 1844338 metres.

2. THE FIELD WORK.

At the planning stage it was decided that all sides in the traverse would be measured using the tellurometers and that check measurements at frequent intervals would be made using the laser geodimeter if weather conditions permitted.

Field work began at the beginning of July at station 265 and during the first month the rate of progress northwards was approximately 130 kms per day, i.e. four tellurometer measured distances. Progress was considerably slower in the Norwegian mountains where very poor weather grounded the helicopters. The connection to the Nordlyse camera station in Tromsö was measured at the end of July. It had been planned to measure all tellurometer sides three times but the continuing poor weather in Norway and the desire to use the helicopters as far south as possible during the charter period made it impossible to measure the sides between station 350 and 5481 more than once. The measurements were, however, made under good tellurometer conditions: heavy cloud, strong wind and an average dry bulb temperature of approximately 5°C. The distances had also been measured previously by the Geographical Survey of Norway using MRA 3 tellurometers.

The helicopters were used, thereafter, as far south as station 136. During the helicopter period, which extended from 5th July to 31st August, 41 tellurometer distances were measured. As all sides except the five most northerly were measured three times, this represents a total measured tellurometer distance of 4328791 metres or 87000 m per working day.

In all, 50 distances were measured using the tellurometers. In 1967, seven of these distances were checked using the laser geodimeters and six of them had previously been measured using earlier types of geodimeters. In the southern part of the traverse five sides which had previously been measured to first-order standards using standard Model 4D geodimeters have been incorporated in the traverse. These sides were not remeasured with the tellurometers.

The connection to Denmark was measured by tellurometer. A geodimeter check of the distance was planned in 1967 but despite a three week wait the weather was never sufficiently good to make the measurement possible. This side which is 47000 m long and the longest in the traverse, was measured with the laser geodimeter during the 1968 season. Despite the length of the line, good signal strength was obtained even in half-light conditions. Thirty-two prisms were used for this measurement. The side

THE SWEDISH PART OF THE TROMSÖ — CATANIA BASE LINE

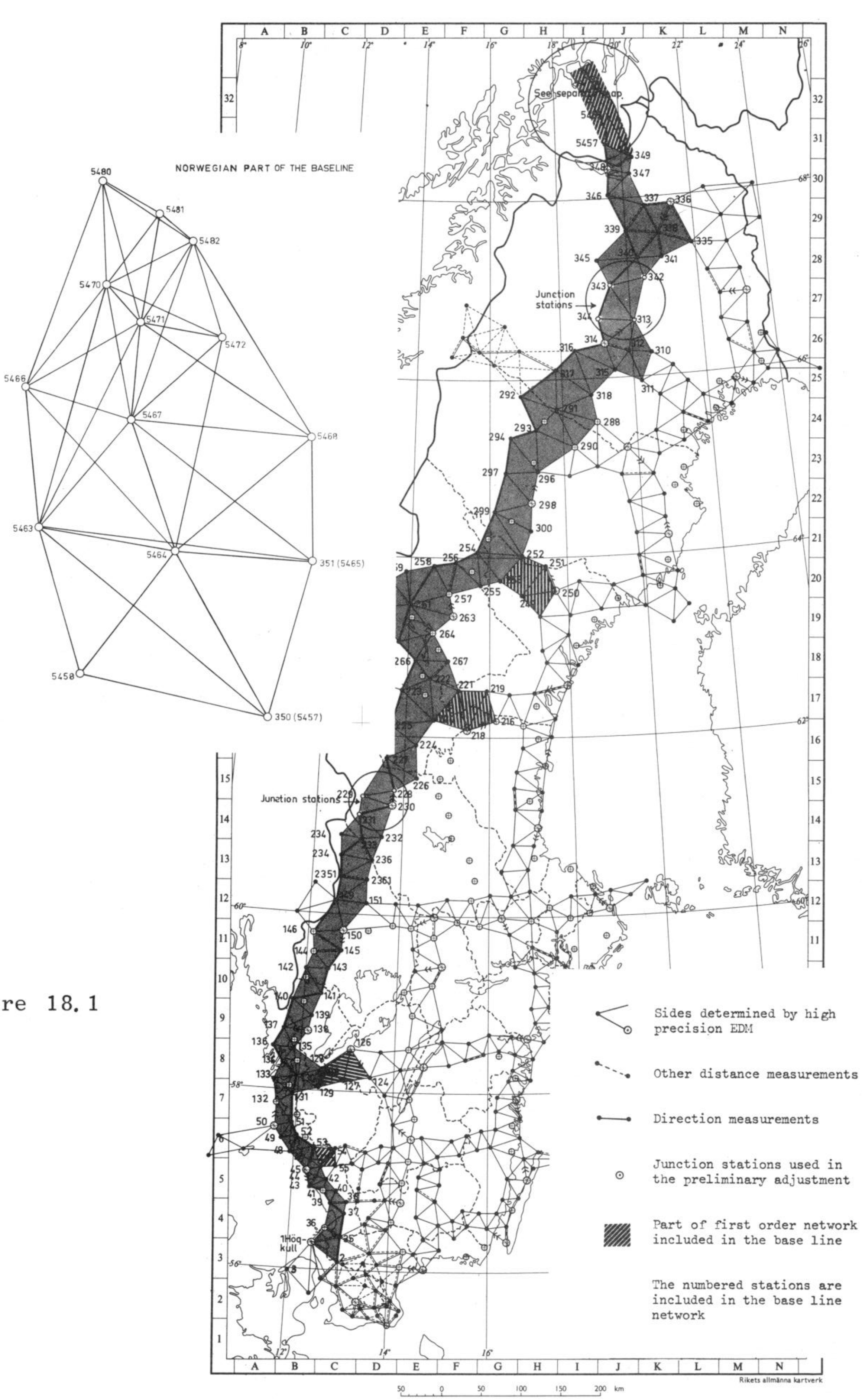

Figure 18.1

was also broken down into two sections of 25000 and 22000 m respectively and measured with the geodimeter equipment. The degree of agreement between the measurements of the whole distance, the computed value from the two sections and the tellurometer values, is high.

Ancilliary equipment. Temperature observations were made using the large type of Assmann clockwork-driven psychrometers. The large type of Paulin aneroid was used for pressure measurements. The aneroids were calibrated against a mercury standard at the beginning and end of the field season. The field aneroids were checked each morning and evening against two station aneroids which were kept in the field quarters. During the 1968 season Baromec equipment was used, because of its high degree of stability and accuracy, for the daily checks of the field aneroids. This, in effect, resulted in a speed-up of the computational procedure since absolute corrections which earlier had been computed after laboratory comparisons between the mercury standard and the station aneroids were now obtained from the daily field comparisons.

High quality thermometers with an accuracy of 0.1°C were used in the psychrometers. The psychrometers were checked against each other on several occasions during the course of the field work. The speed of the fan motor is easily checked in the field and such checks were carried out frequently.

No frequency counter was available in the field in 1967. The tellurometer frequencies were, therefore, checked at the beginning, in the middle and at the end of the field period. For the tellurometers, light-weight 32 AH batteries were used as the power source.

An AGA frequency meter, specially produced for use with geodimeter equipment, was used in the field to check the geodimeter frequencies at regular intervals. During the 1968 field season the field party was supplied with a portable counter. A light weight AGA portable two-stroke motor generator was used with the geodimeter. This has since been replaced by a Honda four-stroke motor-generator, which has proved to be extremely reliable.

Geodimeter measurements. Operation of the laser instrument is, from an operator's point of view, basically the same as a standard 4D instrument.

Normal long delay-line measuring procedure was used for all measurements. On each frequency both high and low delay-line observations were made where this was possible. Wet and dry bulb temperatures and pressure were recorded at both terminals.

To facilitate pointing of the instrument, since there is no search-light on the modified geodimeter, a 75 W searchlight was used at the reflector station. Portable 5 W radio equipment was used for communication between the geodimeter station and reflector station. The desirability of having radio contact when long distances are to be measured, particularly under daylight conditions, was clearly demonstrated in the south of Sweden where distances of the order of 20 000 metres were measured in conditions of sunlight and light haze. Under such conditions the reflected signal is often not visible in the geodimeter pointing telescope and pointing must be carried out with the help of reports from the mirror attendant. Of the sides measured with the laser geodimeters only one was double-measured.

The geodimeter used during the 1967 field season was replaced prior to the beginning of the 1968 season by a similar, but improved instrument. Although both instruments are essentially identical it seems that the laser in the second instrument was more powerful than the laser in the earlier instrument and that the phototube in the 1968 instrument was more sensitive than the equivalent tube in the 1967 instrument. As both lasers are nominally of the same power it would seem that the laser used in the first instrument was not performing effectively. Power losses due to the modulation system and the transmitting optics are of the order of 50% in both instruments.

Tellurometer measurements. Prior to the start of the field season the MRA 4 tellurometers were tested in the field and an observing programme was established. The results of these tests have been reported in an earlier paper.

Four MF readings: MF + forward, MF - forward, MF - reverse, MF + reverse were observed on five frequencies. The Remote cavity dial settings are 4, 6, 8, 10 and 12. The test measurements indicated that no appreciable increase in accuracy was attained by increasing the number of settings. It should be stated that the same dial settings are used when the instruments are calibrated.

The only exception to this observing procedure was the long water line connecting Sweden and Denmark where 10 fine readings were taken. The measuring procedure was as follows:

	Instrument 1003 as Master	Instrument 1004 as Remote
1.	Cavity setting : 3.5 Low	Cavity setting: 4 High
2.	Coarse Readings	
3.	Meteorological observations	Meteorological observations
4.	Fine Readings	
5.	Meteorological observations	Meteorological observations
6.	Switch to Remote position: Cavity dial 4 High	Switch to Master position: Cavity dial 3.5 Low
7.		Fine Readings
8.	Meteorological observations	Meteorological observations
9.		Coarse Readings

Coarse readings were only observed for two of the three measurements. One coarse reading, when this is made with both instruments and when the coarse distance is broken out at the time of the measurement and checked before switching off the instruments is, in fact, normally sufficient. But some lines in the north of Sweden, when the variations in refractive index between the three days were large, gave M2 - M1 values, which varied by a meter. In some cases this could lead to confusion.

All distances were measured three times. With the exception of a few sides in the southern part of the traverse, these three measurements were carried out on three separate days. Normal Swedish first-order practice calls for at least a one day interval between each of the three measurements. Due to the need of maintaining a rapid rate of progress and the desire to utilize the helicopters to the full this was seldom possible. The measuring practice mentioned above is based on the desire to reduce the possibility that the observed refractive indices will not be representative, by making the three measurements under different weather conditions. However, weather conditions can change very rapidly, particularly in the mountain areas of the country, and accuracy does not appear to have suffered in any way by this concentration of the measuring programme.

When a side was measured three times on two days the two measurements which were made on a single day were made with a considerable time interval between them such that a measurable change in the refractive index could take place.

Meteorological observations. At all stations where measurements were made from tripods, temperature observations were taken 2-3 m above the ground with a view to reducing ground radiation effects,as far as possible, and to try to compensate for the different inertia characteristics of the wet and dry bulb thermometers.

The psychrometers were protected from direct sunlight and, as far as possible, shaded from heat reflections from nearby illuminated objects. In towers, the psychrometers were hung in the shade outside the observer's platform.

Poor aspiration of the wet bulb can be a source of serious error. It is therefore of great importance that the motor is sufficiently powerful to ensure that the velocity of the air past the bulbs is not less than 2 m/sec. Investigations have shown that the velocity of the air must be greater than 2 m/sec. but that velocities up to 5 m/sec. are in no way detrimental to accuracy.

Standard observing procedure is to tilt and point the psychrometer slightly against the wind thereby increasing the air velocity past the thermometer bulbs and ensuring that ventilation is always adequate. When wetting the wet bulb sleeve, care was taken to prevent water drops forming a bridge between the wet bulb and the shield. Observations were always continued until equilibrium was reached.

The aneroids were also placed in the shade and protected, as far as possible, from undesirable external effects: i.e., turbulence effects resulting from gusty wind conditions. No mid-line observations were made.

Zero error corrections. Zero error corrections for both the tellurometers and geodimeters were determined before the beginning of the field work. In addition a further zero error determination was carried out before the connection to Denmark was made. The results of the tellurometer zero error measurements are given in Table I.

TABLE I.

Tellurometer Zero Errors.

Date	Instr 1003	Instr 1004
May 1967	- 109 mm	- 110 mm
October 1967	- 111 mm	- 114 mm
April 1968	- 107 mm	- 116 mm

3. INSTRUMENT PERFORMANCE.

The impressions gained during the course of the field tests which were carried out before field-work in connection with the traverse and which have been presented elsewhere, have been confirmed.

Both instruments have functioned satisfactorily with no need for other than minor repairs or adjustments.

The only fault encountered with the tellurometers was a jamming cavity-change dial which was corrected in the field.

Certain problems were encountered with the photo-tube unit and the K.D.P. modulator when using the original geodimeter under cold, windy, damp conditions. Under such conditions sensitivity was greatly reduced and changes of phase could occur. In the instrument used during the 1968 season these faults have been eliminated.

Excellent daylight range for the geodimeter and greatly reduced swing tendencies with the tellurometers are the two improvements over previous models which have made the most positive impressions.

The already excellent range of the laser geodimeter was even more impressive when the second instrument was put into use. Daylight range in conditions of haze and bright sunshine was of the order of 20 000 - 25 000 m. Under such conditions the principal problem is still that of locating the prisms.

In the north of Sweden during June and July, the nights are never dark but, nevertheless, under half-light conditions several sides of between 30 000 and 40 000 m were measured. The longest distance measured was 47 000 m; and it can be mentioned that a fully measurable signal was obtained on a 20 000 m line using a single prism. A night-time range of between 50 000 - 60 000 m would appear to be achievable with this instrument under good measuring conditions. In high precision geodetic work it is hardly advisable to measure such long distances due to the difficulty in determining the refractive index and also the problems associated with the k value. Night range is, thus, mainly of academic interest. Of greater interest is the good daylight range and performance; up to distances of 30 000 m.

In an earlier report, mention was made of a tendency towards fading when using the tellurometers on water lines. This tendency has been observed on several water lines measured during the 1968 season. On some lines the severity of the fading was such that contact between the instruments was broken. Under such conditions the needle of the undamped null indicator can fluctuate wildly and make a visual integration extremely difficult. On one and the same line the tendency towards fading could vary from slight to severe when the measurements were repeated on different days with varying wind and wave conditions. Work in Canada with MRA 4's on highly reflective lines has confirmed our experience that, under poor visibility conditions, it is possible to point an instrument to a strong reflected signal instead of to the direct signal.

A number of typical tellurometer swing curves are given in Fig. 18.2. Antenna swing is of the order of 15 mm.

4. REDUCTION OF THE MEASURED DISTANCES.

The standard, recommended Essen and Froome formula has been used for computation of refractive index for the tellurometer measurements. The refractive index is computed separately for each station and not from the mean of the temperature and pressure readings at the two stations.

For the geodimeter measurements the following formula has been used

$$1 + \frac{0.000107925p}{273.2 + t} - \frac{1.5026\ e\ 10^{-5}}{273.2 + t}$$

p = pressure in mm Hg
t = temp in ^{o}C
e = vapour pressure in mm Hg

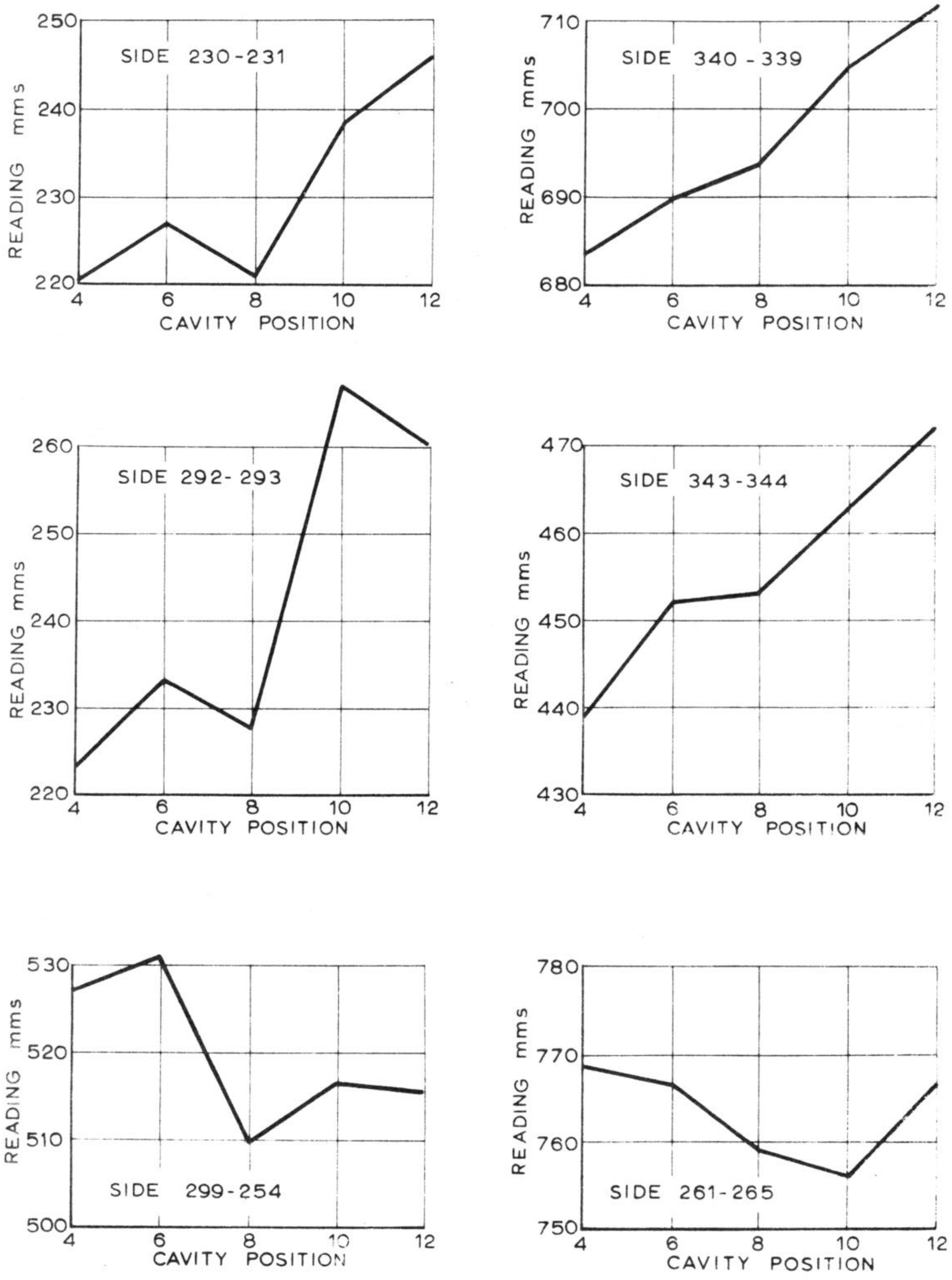

FIGURE 18.2 TYPICAL TELLUROMETER MRA4 SWING CURVES

The wavelength of the laser used in the modified instrument is 6328A.

Standard geometrical corrections have been used to reduce the measurements to the reference ellipsoid. In addition, first and second velocity corrections i.e., the correction for path curvature $\left(-k^2 . \frac{D^3}{24R^2}\right)$ and the correction for the dip of the ray path into layers of higher refractive index $\left(-(k-k^2) . \frac{D^3}{12R^2}\right)$ have also been applied.

The values adopted for k are 0.25 for microwaves which is equivalent to a $\frac{dn}{dh}$ value of $-0.039 . 10^{-6}$/metre and for light 0.20 which is equivalent to a $\frac{dn}{dh}$ value of $-0.031 . 10^{-6}$/m. According to Höpcke the k value 0.20 is a representative value during the day and on overcast nights.

For distances of up to 30 kms the choice of k value is in no way critical. Checks of the k value were carried out by measuring vertical angles at the geodimeter station to the prisms.

The geoid profile along the traverse was completed during the 1968 field season. Geoid height corrections have been applied to all measured distances.

The ranges of the values of the three tellurometer measurements which comprise a complete determination expressed as a proportion of the measured distance are given in tabular form in Table II. Under circumstances of varying atmospheric conditions such as were often experienced during the measurement of the traverse, these range values can, to a certain extent, be considered as an indication of the accuracy of the determination of the refractive index.

TABLE II.

Tellurometer measurements - The spread between outer measured values expressed as a proportion of measured distance.

spread/distance	total number of sides
1/200 000 - 1/250 000	5
1/250 000 - 1/350 000	9
1/350 000 - 1/500 000	9
Under 1/500 000	22

The average difference between the outer values of the three measurements expressed as a proportion of the distance is 1/400 000. The maximum difference in the whole traverse is 1/160 000 which is the only measurement with a proportional difference greater than 1 200 000. Normally, measurements with a proportional difference between the outer values of greater than 1/200 000 of the distance are remeasured. Bad weather prevented remeasurement of the side quoted above.

Comparisons between the geodimeter and tellurometer determinations of those sides which were measured with both instrument types are given in Table III. The average difference between the determinations is 1/812 000 with a maximum difference of 1/350 000.

The comparisons between measurements made by the Geographical Survey Office of Norway with MRA 3 tellurometers and the measurements made by the Swedish team are given in Table III in which is also given comparisons between measurements carried out with MRA 4 tellurometers both in 1967 and 1968.

TABLE III.

Comparison of measurements - metres.

A. Comparison of distances measured with MRA 4 and MRA 3 tellurometers.

MRA 4 metres	No. of meas.	MRA 3 m.	No. of meas.	Diff. MRA 4 - MRA 3 m.	proportional difference
32814.095	1	32814.145	5	-.050	1/660 000
45360.796	1	45360.669	2	+.127	1/360 000
22912.284	1	22912.336	2	-.052	1/440 000
26234.826	1	26234.779	3	+.047	1/560 000

B. Comparison of distances measured with MRA 4 tellurometers and laser geodimeters

side	geodimeter m.	tellurometer m.	Diff. g-t m.	proportional difference
316-317	32216.862	32216.896	-0.034	1/950 000
258-256	25629.250	25629.242	+0.008	1/3200 000
228-230	21908.348	21908.295	+0.053	1/410 000
2351-235	20695.488	20695.532	-0.044	1/470 000
2351-149	29832.187	29832.248	-0.061	1/490 000
143-145	28364.849	28364.921	-0.072	1/400 000
136-134	25298.308	25298.298	+0.010	1/2500 000
130-134	27000.059	27000.062	-0.003	1/9000 000
53-52	26371.977	26371.908	+0.069	1/375 000
51-52	15382.271	15382.288	-0.017	1/900 000
43-45	19998.442	19998.417	+0.025	1/800 000
43-41	18478.512	18478.508	+0.004	1/4600 000
36-37	28274.692	28274.705	-0.013	1/2200 000
36-1	23517.344	23517.277	+0.067	1/350 000
1-3	47039.837	47039.810	+0.027	1/1742 000

C. Comparison of distances measured with MRA 4 tellurometers 1967 and 1968

side	MRA 4 1967 m.	MRA 4 1968 m.	Diff. m.	proportional difference
1-3	47039.770	47039.849	+.079	1/595 000
43-45	19998.400	19998.434	+.034	1/588 000
36-37	28274.707	28274.703	-.004	∞

5. PRELIMINARY COMPUTATION OF THE STANDARD ERROR IN THE GEODESIC BETWEEN HOGKULL AND TROMSO.

The map, Fig. 18.1, illustrates the scope of the adjustment. As can be seen, the computations were carried out in three separate zones which were then, in the final stage of the adjustment, connected in accordance with the RETRIG principles.

In addition to the data from the traverse, all available first-order angular and distance measurements and Laplace observations which fall within the part of the net as shown on the map where the stations are numbered were included in the adjustment.

The 'standard error à priori' for an observed direction was 1^{cc} and for distances measured with tellurometer MRA-4 and first-order geodimeter measurements $\{10 + s \, . \, 10^{-6}\}$ mm and for measurements with MRA 101 $\{20 + s \, . \, 10^{-6}\}$ mm.

Station 1-Högkull was the only fixed point and Tromsö - Nordlyse was chosen as the final junction station. Using Cholesky's elimination procedure the following triangular matrix was obtained for Nordlyse (the units used are centesimal seconds and decimetres).

0.21632	0.04921	0.49681
	0.09111	-1.36847
+ 5.713	-15.020	709.774
$x = Md\phi$	$y = N\cos\phi d\lambda$	$\sum pvv$

$$\mu^2 = 709.774 : 289 = 2.456$$

$$\mu = 1.567$$

The inverse matrix for Nordlyse is :

$$\begin{array}{cccc} 27.6043 & -27.4034 & Q_{xx} & Q_{xy} \\ -27.4034 & 120.4594 & Q_{xy} & Q_{yy} \end{array}$$

The standard error in the geodesic between Högkull - Nordlyse

$$ds = -\cos\alpha \, dx - \sin\alpha \, dy$$

Tienstra's formula gives:

$$Q_s = -\cos\alpha \, Q_x - \sin\alpha \, Q_y$$

$$Q_{ss} = \cos\alpha \, Q_{xx} + 2 \sin\alpha \cos\alpha \, Q_{xy} + \sin^2\alpha \, Q_{yy}$$

α_{Nor} - Hög ~ 216.9 $\quad \cos\alpha = -0.96497$

$\sin\alpha = -0.26235$

$$Q_{ss} = 0.93117 \, . \, 27.6043 - 0.50632 \, . \, 27.4034 + 0.06883 \, . \, 120.4594$$

$$Q_{ss} = 20.121 \qquad m_s = \pm 7.0 \text{ decimeters}$$

The error ellipse is computed from $\begin{vmatrix} Q_{xx} - \lambda & Q_{xy} \\ Q_{xy} & Q_{yy} - \lambda \end{vmatrix} = 0$

which gives $\lambda_1 = 20.120 \quad \lambda_2 = 127.943$

The axes of the ellipse are $\mu\sqrt{\lambda_1} = 7.03 \quad \mu\sqrt{\lambda_2} = 17.73$

and the azimuth of the major axis is $116\overset{g}{.}0$

The distance Nordlyse - Högkull is approximately 1 524 kms

In Table IV the size of the corrections in relation to the 'standard deviation à prior' are analysed. The largest correction to a measured distance in relation to the 'standard error à priori' is $\frac{10.2}{4.8}$ for side 261 - 260.

The largest corrections to measured directions in relation to 'standard error à priori' are for

directions 315 - 314 : $\frac{3.76}{1.00}$ and 296 - 290 : $\frac{3.03}{1.00}$

TABLE IV.

Corrections to measured distances in relation to the 'standard error à priori'

	Mean Side length -kilometres	$\leq$ 1x	1 - 1.5x	1.5 - 2x	$\geq$ 2x	Mean adjustment corrn-cms
Zone I	26.5	28	5	1	1	2.9
Zone II	38.3	19	6	1	1	3.8
Zone III	36.6	58	8	2	1	4.1
Total		105	19	4	3	

The standard error obtained in these preliminary calculations gives a good estimate of the accuracy in the distance determination between Högkull and Tromsö as far as the influence of random errors in angular measurements, distance measurements, height determinations and Laplace azimuth determinations are concerned.

The estimate will be practically the same in a computation where the measurements have been reduced for geoidal heights. However, errors of a systematic character will considerably decrease the real accuracy. Amongst such sources of error the following can be mentioned:

1. error in the velocity of light.
2. systematic errors in frequency control
3. errors in the determination of the geoid profile and particularly in the determination of the geoidal height of the end points.

In view of this, the estimated accuracy from random error sources must be considered very satisfactory. The adjustment was carried out by the Head of the Computing Section, Mr. Ilmar Ussisoo.

DISCUSSION: PAPERS 14 - 18.

Chairman: Mr. B.P. Lambert

ROBINSON:	Tellurometer Zero Error
LEHR:	Optimum Signal (Cionini, Mezzani)
BOBROFF:	MRA4 in Australia
GALE:	MRA4 in Canada (Yaskowich)
MATHER:	Measurements in Sweden (Brook)

CHAIRMAN: Since Robinson's investigations have shown a cyclic component of zero error, do measurements taken at half the cyclic interval apart eliminate the cyclic error?

ROBINSON: In theory the cyclic effect should be eliminated by this procedure. With the MRA101 the cyclic error is small compared with standard deviation of measurement, so that the procedure has not been tested in my experiments.

MILLER: I have carried out some investigations with the tellurometer MRA2. The cyclic error was more pronounced and grouping observations at the half-cycle interval apart gave a significantly smaller standard deviation.

SIMMONS: What was the effect of tilting the tellurometers? In view of the plumbing procedure surely this caused an error.

ROBINSON: The two instruments were tilted through the same angle in opposite directions so that the tilt error cancelled.

CLEGG: In the paper by Cionini and Mezzani there is no mention of variation of the time of modulation and this is something which could have an effect on band width and power required.

McQUISTAN: The paper seems to indicate that the optimum system would be a swept frequency system.

LEHR: This might be the case, theoretically, but in practice the technological difficulties of setting up such a system might outweigh the saving in power.

CHAIRMAN: Have comparisons been made between tellurometer MRA4 and geodimeter measurements?

BOBROFF: No direct comparisons have been made. However three bases have been measured on different occasions. Geodimeter - tape differences on the three bases were +3.62, -0.70 and -1.58 p.p.m. whereas tellurometer - tape differences were +5.34, +3.43, and -4.41 p.p.m.

BENNETT: The difference between the MRA4 and MRA1 measurements is systematic and about 4.5 p.p.m. and the published loop closures are 2 p.p.m.

BOBROFF: MRA1 measurements included a zero correction obtained from comparison with geodimeter measurements. The difference between the two sets of tellurometer measurements is most likely due to this index correction.

CHAIRMAN: The re-observation of some of the distances by geodimeter will be undertaken in the future as a further test of the accuracy.

GALE: In Canada, triangulation sides have been measured both by geodimeter and tellurometer. Good agreement has been obtained near the base lines but in the middle of a chain discrepancies are up to $^1/30\ 000$.

BOBROFF: Australian experience confirms this.

BROUGHTON: Do you use any criterion in the field to decide whether meteorological conditions are satisfactory for observation of distances to first order standards?

BOBROFF: 'Met.' observations are taken at both ends of the line and both refractive indices calculated in the field. If these agree within empirical limits, based on experience, the distance measurements are taken.

LYONS: What is the best time of day for observing in Australia and in Canada?

BOBROFF: We have insufficient information on this subject but there are indications that the best times for distance measurement are the same as for vertical angle measurement: 10 a.m. - 3 p.m.

GALE: Most distance measurement in Canada takes place in this period, but from considerations of convenience rather than precision.

LYONS: In the MRA 4 measurements on the east-west geodetic traverse,were any measurements rejected and if so, what was the rejection criterion?

BOBROFF: No measurements have been rejected.

LYONS: Is the Geodetic Survey of Canada using error ellipse techniques to analyse the differences between the MRA 3 and MRA 4 measurements in the Robeson Channel net.

GALE: The net included angle measurements as well and it will be some time before the data can be fully analysed.

FRYER: What accuracy is National Mapping aiming for in the measurement of the long satellite base lines.

CHAIRMAN: We hope to get 1 p.p.m. after application of the geoidal corrections.

ANGUS-LEPPAN: Mather has been studying the orientation of the geoid with respect to the Australian National Spheroid (ANS). The separation naturally affects the scale of geodetic surveys. Can this accuracy be achieved in the light of our present knowledge of the geoid?

MATHER: An accuracy of 1 p.p.m. corresponds to a geoid-spheroid separation of 6 m. The geoid slope also affects accuracy. In Australia the separation might be up to 28-30 m.

DISCUSSION - GEODETIC MEASUREMENTS

LAMBERT: The deviation of the vertical does not affect the issue as the satellite is photographed against a stellar background. Base lines only provide the scale.* Mrs. Fisher has computed the geoid separation and the slope is only 10 secs.

FRYER: The close agreement between Mrs. Fisher's geoid and the ANS is no coincidence as the orientation of the ANS was chosen as a best mean fit of the spheroid to the geoid in the Australian region.

GALE: With our present lack of knowledge of the geoid I do not consider that an accuracy of 1/1 000 000 is possible.

JONES: There is a significant difference between the two sets of measurements of the Somerton Base as shown in Table I, Part A and Fig. 16.1. Was there any marked change in the meteorological conditions to account for this?

BOBROFF: The two results are significantly different and have been investigated. However I have been unable to find any factor causing the difference.

ROBINSON: Is there any significance in the fact that the (MRA 4 minus MRA 1) measurement differences are all positive while the (MRA 4 minus adjusted length) differences are all negative.

BOBROFF: The results are not really equivalent. The first difference is a direct comparison between measured distances, whereas the second is a comparison between measured distances and adjusted distances obtained not only from measured distances but also from triangulation.

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* The position of the base line is vital to scale as a correction for height above reference surface or 'sea-level' correction must be applied. Satellite observations are made independent of the direction of the vertical, but with respect to the earth's rotation axis. The position of the Australian National Spheroid with respect to the earth's axis and centre of gravity were unknown before Mather's studies using gravity. Ed.