Lantmäteriet
Lantmäteriverket - National Land Survey
S - 801 12 GÄVLE · SWEDEN

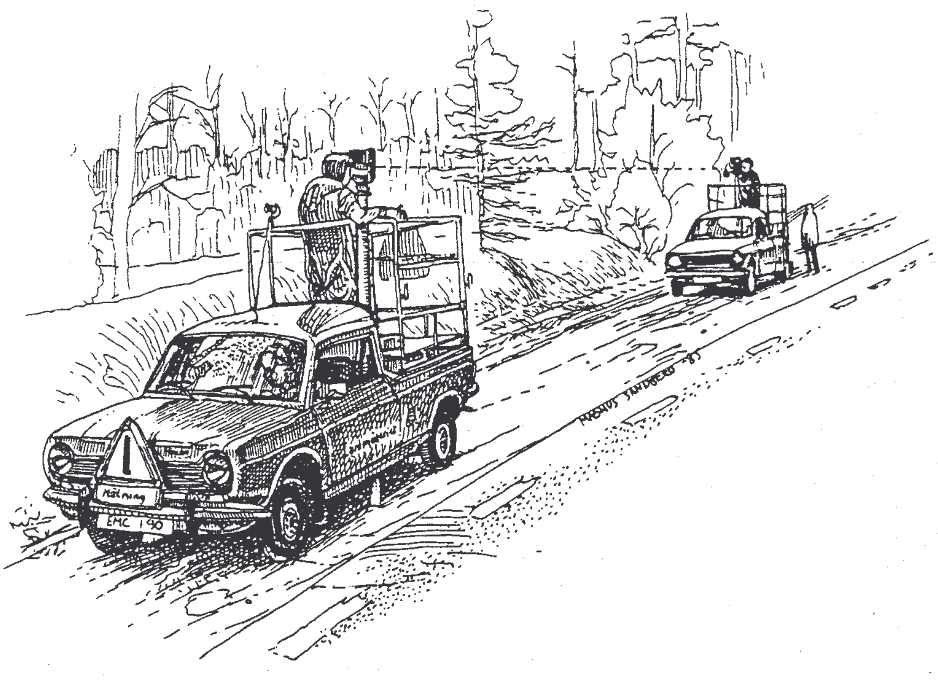
Tekniska skrifter - Professional Papers LMV-RAPPORT 1986:8

ISSN 0280-5731 ISBN 91-7774-009-2

FIG CONGRESS' 86, TORONTO

MOTORIZED TRIGONOMETRIC LEVELLING (MTL) & MOTORIZED XYZ TECHNIQUE (MXYZ) IN SWEDEN

par Jean-Marie Becker & Thomas Lithén



Gävle 1986

MOTORIZED TRIGONOMETRIC LEVELLING (MTL) & MOTORIZED XYZ-TECHNIQUE (MXYZ) IN SWEDEN

by Jean-Marie BECKER & Thomas LITHÉN
National Landsurvey of Sweden

Introduction

At the National Landsurvey of Sweden (NLS) a great deal of attention is paid to study ways to rationalize the geodetic activities. An exampel of the results of the rationalization process is the development of rapid, efficient and accurate methods of levelling for the remeasurement of the Swedish vertical control network.

The on-going third national precise levelling programme is carried out using Motorized Levelling (ML) with a fully computorized handling of data from the field to the archives. The programme was initiated in 1974 and has been continually updated to keep abreast of modern technological developments.

The NLS experience of modern levelling techniques is based on over 50000 km of levelling carried out under a wide variaty of of physical conditions and numbers of different fieldcrews and instruments.

The results of ML can be summarised as follows:

- A daily production of 12 km for a 5.5 hr working day.
- A relevelling rate less then 5%
- A field season from spring to autumn without stops in the middle of the day.

For further details on ML see /5,11/.

The NLS has during 1985 tested two new modern types of surveys for measuring vertical control networks:

- Motorized Trigonometric Levelling (MTL)
- Motorized XYZ-technique (MXYZ)

This paper gives a description of the tests concerning equipment, measurements, results and efficiency.

Equipment

The equipment consists basicly of 2 or 3 pick-up vehicles with a central tripod and an electronic theodolite. It also consists of radio communication and a field computer for registration and calculation of measurements.

Description of the equipment

The vehicles carrying the instruments are identic to the vehicles used for ML (pick-up Talbot 1100). The cars have been modified for having the tripod in a central position. The vehicles are equipped with an electric hoist for raising the tripod and the instrument for travelling between stations.

Figure 1: Reciprocal observation.

Two types of tripods were tested: - Firstly the same tripods as for ML. - Secondly a new tripod with a telescopic central pillar. Both types of tripods were totally free from contact with the car during measurements.

The electronic precision theodolites used were from following manufacturers: GEOTRONICS, KERN and WILD. The table below (Table 1) shows the standard errors for angles and distances given by the producers.

Instrument	Standard error of angles Horisontal	Vertical	Standard error Distance
Geodimeter 142	0.60 mgon	0.60 mgon	5 mm + 5 ppm
Kern E2 + DM503	0.15 mgon	0.15 mgon	3 mm + 2 ppm
Wild T2000 + DI5	0.15 mgon	0.15 mgon	3 mm + 2 ppm

Table 1

The theodolites were equipped with reflectors and angle targets for reciprocal observations. The fixing of these devices were done in differente ways :

- For Geodimeter 142 (Figure 1) the solution consisted of two parts: - One fixed part with targets for vertical angles and the rack for the other part. - One movable part for the reflector and the horisontal target.

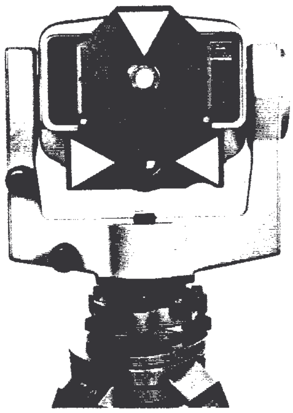


Figure 2:
Geodimeter 142 with targets and reflector.

- For Kern E2 + DM503 (Figure 3) a minireflector was mounted on the theodolite handle. For measuring distances a beam translating prism must be set on the EDM. The beam translating prism has white stripes as vertical target.

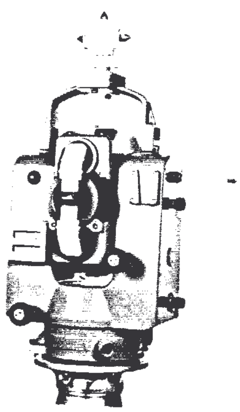


Figure 3:
Kern E2 + DM503 with targets and reflector.

- For Wild T2000 + DI5 (Figure 4) the reflector was mounted on the counterweight of the distancemeter. Targets for vertical angles were mounted directley on the house of the theodolite.

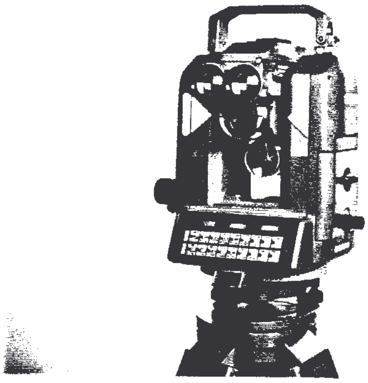


Figure 4:
Wild T2000 + DI5 with targets and reflector.

A levelling staff with an invar inset (Zeiss Jena 3m) was used to make bench mark ties; following devices were mounted on the staff:

- Four marks were set out on the staff on the height of 1.4m, 1.9m, 2.4m, 2.9m. The levelling staff comparator of NLS was used to set out the marks with high precision (standard deviation < 0.06mm).
- 3 Water levels.
- A fixation ring on the bottom of the staff.
- Two adjustable struts.

Figure 5:
Bench mark tie.

Two methods of data storage and processing were used:

- Firstly during the measurements in spring (May-June) data logs from the instrument producers was used for data storage at each instrument. Geodat 124 from Geotronics and Alphacord 64 from Kern. The data processing was made at the office in the evening.

- Secondly during the measurements in autumn (Sept-Oct) a computer (Epson PX-8) was used for both data storage and processing directly in field of ML-measurements. The measurements were send via radio to one master car, which held the computer. Geotronics presented a telemetry-system (Micro-Tel) - a radiolink directly into the computer - which made the observations very quick. With the Wild system the measurements were orally send via radio to an operator who enters them into the computer. For MXYZ the data log GRE3 from Wild was used.

Figure 6:
Master car with Epson PX-8 and printer.

Additional equipment were barometers, thermometers, radios (walkie-talkie).........

Operating procedures

The tests were made with 2 or 3 identic cars for MTL and with 3 identic cars for MXYZ.

The heights in trigonometric height traversing are measured and calculated in two separate ways /11/:

- Bench mark ties are made by measuring vertical angles with a theodolite to four different marks on a levelling staff set up over the bench mark. One pair of vertical angles is used to calculate the height difference between bench mark and theodolite with formula:

  Dh=(h2*cotZ1-h1cotZ2)/(cotZ1-cotZ2)

  The other pair of vertical angles is also used to calculate the the height difference, the mean value is then calculated.

- Transportation between bench mark ties are made by measuring slope distance and simultaneous reciprocal vertical angles between two theodolites. The formula used for one set is:

  Dhab=(l1*(cosZab-cosZba))/2

  At least two sets are measured and calculated, the mean value is then used for the height traverse.

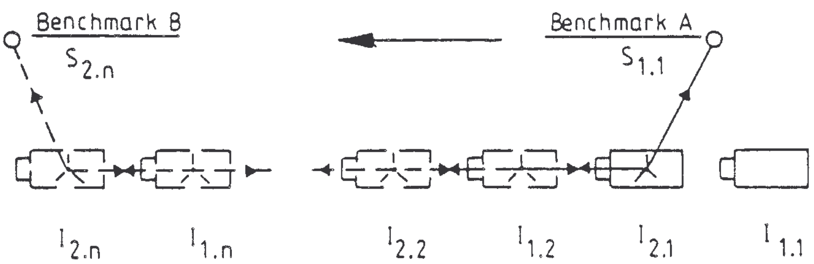


Figure 7: Height traversing with MTL.

For MXYZ height and plane coordinates are determined at the same time by measuring, not only vertical angles and slope distances, but also horisontal angles. There are two ways of working:

- The classical method with angles by repetition of direction measurements.

- The fast method where each direction is measured separately.

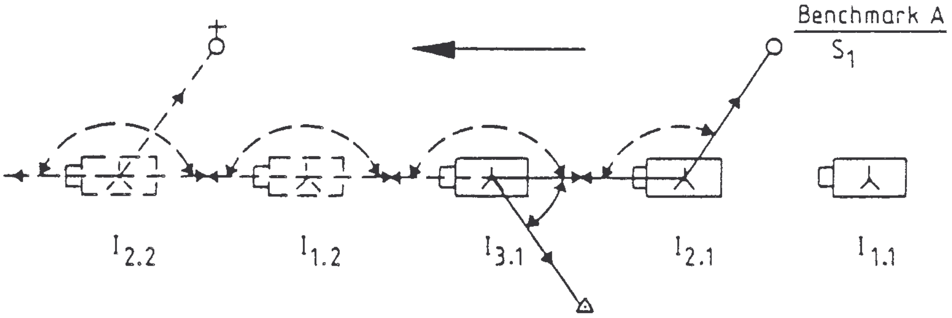


Figure 8: MXYZ

Test 1985

The test was firstly made as a comparision between MTL and ML, secondly for investigating the possibilities of MXYZ.

Description of test zones

Two test zones were chosen:

- The Sätra test net (Gävle) which is a local vertical control net with four nodal points and with total length of 8.7 km (see Figure 9 and Table 2).

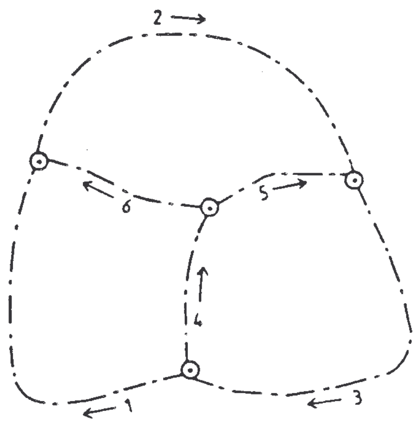


Figure 9: The levelling test net of Sätra, Gävle.

Line number	1	2	3	4	5	6	Sum
Distance (km)	2.0	2.2	2.1	0.8	0.7	0.9	8.7
Height difference (m)	9.110	-2.918	-6.192	0.564	5.628	8.546	

Table 2: The characteristics of the test net.

- The second test zone chosen was a line in the Swedish first order vertical control network situated between Falun and Hofors. The total length of the line is 17.5km and it consists of 21 bench marks. The terrain is hilly with height differences between bench marks from 18m to 150m.

The measurements

The measurements were made in two different seasons, spring (May-June) and autumn (Sept-Oct). All measurements made by ML, MTL and MXYZ are presented in Table 3.

Place	Instrumentation	Date	Tech-nique	Total length (km) of levelled lines: Single	Total length (km) of levelled lines: Forward & Reverse	Number of Forward & Reverse lines
Gävle	Geodimeter 142	May	MTL	21	-	-
		Sept	MTL	64	21.5	14
	Kern E2 +DM 503	June	MTL	21.6	9.6	7
			MXYZ	17.4	-	-
	Wild T2000 +DI5	Oct	MTL	35.7	17.4	12
			MXYZ	34.8	-	-
	Zeiss Jena Ni002	June	ML	13.2	6.6	5
		Oct	ML	17.4	8.7	6
Falun/ Hofors	Wild T2000 +DI5	Oct	MTL/ MXYZ	35.8	17.9	20
	Geodimeter 142	Oct	MTL	14.9	-	-
	Zeiss Jena Ni002	Oct	ML	42.2	21.1	22
Sum	Zeiss Jena		ML	72.8	36.4	33
	Kern & Wild		MTL	93.1	44.9	39
	Geodimeter		MTL	99.9	21.5	14
			MXYZ	88.0	-	-

Table 3: The complete table of all test measurements 1985. (Notice that the measurements in Octobre in Falun with Wild has been used in the sum for both MTL and MXYZ).

The average sight distances were:
- With ML : In Sätra 46.7m, in Falun-Hofors 33.0m.
- With MTL: In Sätra 260m, in Falun-Hofors 278m.

The metrological circumstances were very variable. In spring 10-25 C, by turns cloudy and sunny. In autumn 0-10 C, cloudy and rainy.

Analysis of the measurements

Precision of MTL and ML

The analysis of the MTL and ML precision is divided in three parts /10,13/.

- Test 1 Test of difference between forward and reverse levelling of a line.
- Test 2 Test of loopmisclosure.
- Test 3 Netadjustment with "datasnooping".

An a priori standard deviation, So, must be set to do these tests. The Swedish experience with motorized levelling (Zeiss Jena Ni002) shows a standard deviation for ML less than $1mm/\sqrt{km}$ The a priori standard deviation for MTL is calculated with the technique of error propagation and the standard deviations for vertical angles and distances given by the instrumentmanufacturies (Table 1). The instruments were divided in two groups (see Table 4).

	Group A		Group B
	ML	MTL	MTL
So Instrument	1 $mm/\sqrt{km}$ Zeiss Jena	1 $mm/\sqrt{km}$ Kern & Wild	3 $mm/\sqrt{km}$ Geodimeter

Table 4: The a priori standard deviation, So.

Test no 1

Test of difference between forward and reverse levelling of a line. The formula used was:

$Cfr=2*So*\sqrt{d}$ where Cfr=Rejection limit
So =A priori standard deviation
d =Distance of the line

Both the Sätra and the Falun measurements are included in this test. For the results see Table 5.

	Group A		Group B
	ML	MTL	MTL
Rejection percent	9% >1 $mm/\sqrt{km}$	10% >1 $mm/\sqrt{km}$	14% >3 $mm/\sqrt{km}$

Table 5

The normal rejection percent for ML is about 5%, but the the observing condition during the tests was sometimes very unfavourable because of hot sun or snow and ice.

The forward and reverse difference is also used for calculating a standard deviation with formula:

$S(Qfr)=\sqrt{(1/4m)*\sum(Qfr*Qfr/d)}$ where S(Qfr)=Standard deviation
Qfr =Difference for.-rev.
m =Number of lines

The Swedish ML-measurements 1979 /13/ shows a result of $S(Qfr)=0.50\ mm/\sqrt{km}$ for 1732 lines. The results from the tests are shown in Table 6.

	Group A ML	Group A MTL	Group B MTL
S(Qfr) mm/√km Number of lines	0.46 28	0.55 33	-

Table 6

Test no 2

Test of loop misclosures in Sätra test net. The formula used was:

$Cw=1.96*So*\sqrt{D}$ where Cw=Rejection limit.
D =Distance of the loop.

None of the loops were rejected.

The loop misclosures were used to calculate a probably standard deviation with formula (for the results se Table 7):

$S(Qw)=\sqrt{(1/n)*\sum(Qw*Qw/D)}$ where S(Qw)=Probably standard deviation.
Qw =Loopmisclousures.
n =Number of loops.

	Group A ML	Group A MTL	Group B MTL
S(Qw) mm/√km Number of loops	0.4 7	0.6 9	1.5 8

Table 7

Test no 3: Netadjustment with "datasnooping".

The measured lines of Sätra testnet were adjusted with the method of least squares. Firstly 5 free netadjustments (2*Zeiss, Kern, Wild and Geotronics) were made. The residuals were tested with a simplified method of "datasnooping" /1,10/ with a significance level of 5%, none of the lines were rejected. Then adjustments were made for the different technique and groups (see Table 8).

	Group A		Group B
	ML	MTL	MTL
So mm/$\sqrt{km}$	1.0	0.6	2.8
Redundancy	9	13	9

Table 8

The three test shows that the MTL-technique at least gives the same precision as ML if instruments from group A (Wild or Kern) are used.

The conclusion is that the MTL technique gives the same high quality (precision) as ML if instruments from group A (KERN or WILD) and if following appropriate operating procedures are used:

- simultaneous reciprocal vertical angle observation;
- reciprocal distance measurements;
- sight distances not longer than 350 m;
- rapid measurements;
- regular calibrations and adjustments of all instruments;
- continious controls of all operations and observations;
- trained personnel working carefully and disciplinated.

Precision of MXYZ

Both the classical and the fast method of MXYZ were tested in a 6.3km cloosed loop of the Sätra test net. The results were following:

- Classical method:
  * misclosure 1-41 mm
  * angle misclosure 0.0014-0.0043 mgon
  * The standard deviation of heights < 3.0 mm/ km

- Fast method:
  * The standard deviation of heights < 1.2 mm/ km
  * Very variable result for the plane coordinates

The results points out the advantages and disadvantages of the methods used.

Efficiency

During the tests from 1985 our first purpose was to find out if it was possible to obtain high precision ($\leq$ 1 mm/km) with MTL and how to attain it.

Therefore the average daily production was not the most important goal. The results showed that the same daily average (11 km) was accomplished as for ML.

In the following table is shown the variation of production costs for different MTL team alternatives in comparaison with ML.

Table 9:

Technique	ML	MTL			MXYZ	
Persons	4	4	2	3	4	5
Vehicles+Instruments	3+1	3+3	2+2	3+3	3+3	4+3
Equipment/Total(Technique)	13%	25%	31%	30%	25%	23%
Persons /Total(Technique)	87%	75%	69%	70%	75%	77%
Equipment/Equipment(ML)	100%	238%	164%	238%	238%	253%
Persons /Persons(ML)	100%	110%	55%	84%	110%	128%
Total /Total(ML)	100%	127%	70%	105%	128%	145%

During the test in 1985 there were 4 persons in each team for both MTL and ML. In this case the MTL average production must be at least 27 % higher than with ML to get the same kilometre levelling cost.

In the same table it is shown that the MXYZ technique (motorized XYZ) makes it possible to obtain, easily and with only an increasing cost of about 18 %, plane coordinates in the same time as Z.

Conclusions

The analyses of the results obtained with ML and MTL permit us to make the following conclusions.

1. ML and MTL are two modern techniques for efficient and rationell determination of high differences.
2. ML and MTL both give possibilities to achieve rapid high precise levelling. For MTL this results can only be achieved with the help of certain instruments and when following well defined operating procedures. (see 5.24)
3. MTL can easily produce at the same time plan coordinates (XY). The 3-dimensionell motorized MXYZ technique has good possibilities in the future, especially for second and third order network both in Sweden and in developping countries.
4. ML and MTL can be used successfully in connection with levelling for determination of crustal movements, landuplift and so on.

During field seasons 1986 and 1987 the National Land Survey will continue its efforts to develop more MTL and MXYZ. Particular attention will be concentrated on economy in function of accuracy.

REFERENCES

[1] BAARDA, W (1968) A testing procedure for use in geodetic networks. Netherlands Geodetic Commision Vol. 2. No. 5.

[2] BAHNERT, G (1981) Einige Erfahrungen mit trigonometrischen Nivellementsnetzen. Vermessungsteknik, Heft 4, s 126-128.

[3] BECKER, J-M (1971) Försök med höjdtågsmätningar. PM 1971-10-11. LMV

[4] BECKER, J-M (1984) Förslag till polygontågsmätningar med ny teknik. PM 1984-03-21. LMV.

[5] BECKER, J-M (1985) The Swedish Experience with Motorized Levelling - New Techniques and Tests. NAVD-symposium 1985, Washington.

[6] BECKER; J-M & LITHÉN, T Nya metoder för precisionshöjdbestämning - Framtidsutsikter. Svensk lantmäteritidskrift 1985:6.

[7] CHRZANOWSKI, A & GREENING, T & KORNACH, W & SECORD, T & VAMOSI, S (1985) Applications and limitations of Precise Trigonometric Height Traversing. NAVD-symposium 1985, Washington.

[8] KASSER, M (1985) Recent Advances in High Precision Trigonometric Motorized Levelling (NIPREMO) in IGN-France. NAVD-symposium 85, Washington.

[9] LITHÈN, T (1985) Angående försök med motoriserad trigonometrisk höjdmätning (MTL) och motoriserad kombinationsmätning (MXYZ). LMV internrapport, dnr 402-964-85.

[10] PERSSON, C-G (1985) Några enkla metoder för noggrannhetsanalys av avvägningsnät. LMV-rapport 1985:02.

[11] RUEGER, J-M & BRUNNER, F.K. (1982) EDM-height traversing versus Geodetic Leveling. Tha Canadian Surveyor. Vol 36. No 1, s 69-88.

[12] WHALEN, C. T (1985) Trigonometric Motorized Leveling at the National Geodetic Survey. NAVD-symposium 1985, Washington.

[13] WIDMARK, J & BECKER, J-M (1984) the Motorized Levelling Technique - The Swedish Experience. LMV-Rapport 1984:15, ISSN 0280-5731.

[14] NAVD SYMPOSIUM 1985 - Third international symposium on the North American Vertical Date. Washington, April 21-26.