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THE REMEASUREMENT OF THE SWEDISH NATIONAL TRIANGULATION NETWORK

1: Organization, Instrumentation and Methods

by I. R. Brook

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I.R. BROOK

NATIONAL LAND SURVEY OF SWEDEN

The first systematic geodetic triangulation of Sweden dates back to the first decades of the nineteenth century. By the turn of the century a coarse-meshed system of chains of first-order triangulation had been established extending from the connection to the Danish triangulation in the south to the Russian-Swedish triangulation north of the Polar Circle and from the Baltic coastal islands in the east to three connections to the Norwegian triangulation in the west. Within the chains a limited amount of second and lower order triangulation was carried out although the geographical distribution of triangulation stations was very irregular. Large areas of the country were without triangulation.

The purpose of this first triangulation was twofold: first to serve as a framework for the national mapping programme and secondly to provide the basis for scientific geodetic studies. Demands for an increased and more diversified mapping programme, the lack in many areas of an adequate triangulation network to which newly completed town and city triangulations could be connected and developments within international geodesy resulted in 1905 in a decision to modernise and extend the national triangulation network. A re-observation programme was prepared with the aim of establishing a first-order framework of the best achievable accuracy which included the measurement of base lines and the observation of Laplace stations. Observation of the network which comprises thirteen closed loops made up of single or double chains of triangles was begun during the first decade of the present century and completed in 1951. In addition to the angular observations 29 Laplace stations were observed and 11 base-lines were measured.

The demands of the national mapping programme were a major factor in instigating the re-triangulation, and to keep pace with those demands the computation of the network could not be delayed until all thirteen loops had been observed. Computation of the separate loops was therefore carried out as the angular observations were completed and, thereafter, the separate loops were connected to each other. The computational problems involved in this procedure were accentuated by the fact that observation of Laplace stations and the measurement of base-lines did not keep pace with the angular observations. By 1938 five base-lines and seven Laplace stations had been completed and with the help of these the five southernmost, earlier computed, loops were subjected to a re-scaling and re-orientation. Thereafter, continuing northwards the loops were computed in nine separate stages.

External pressures had necessarily overridden purely geodetic considerations and good quality observational data was subjected to less satisfactory adjustment procedures, which led inevitably to deformations and scale errors in the adjusted network. The adjustment did not fulfill scientific requirements but, as has been the case in many other countries, it was considered that a distinction should be made between coordinates intended for mapping purposes and coordinates for scientific purpose and that initially the mapping requirements should be given priority. Second and third order triangulation was later carried out to fill out the areas within the first-order loops.

With the completion of the triangulation programme in 1951 the fundamental requirements of the basic mapping programme had been met but demands for improved accuracy and increased homogeneity in the network had been steadily growing and these demands received a notable impetus with the introduction of the first E.D.M equipments and the development of new measuring techniques. Large-scale state highway surveys and similar technical developments require good quality and homogeneous systems; the importance of connecting town and city and other local surveys to the national network had long been apparent but problems arose when these networks, many of which had been established using moderns equipment and methods, were to be connected to the lower quality national triangulation. The demand for high quality triangulation was an increasingly clear trend both nationally and internationally.

The question of a second modernisation of the Swedish network was, therefore, by the late 1950's a question of considerable importance.

In 1965 a Working Group was set up with instructions to investigate the need for strengthening the existing triangulation, levelling and gravimetric networks; to suggest suitable techniques for implementing such improvements as were considered necessary; and finally to present a cost framework for carrying out the recommendations.

The group reached the conclusion that the Swedish triangulation network was in need of "far-reaching improvements if the demands of those who use the triangulation are to be met and if the maximum benefit of rationalization are to be achieved".

The findings of the group were given governmental approval and in 1967 the re-observation programme was begun.

The new network

As the quality of the observational material from the 1905-1951 first-order triangulation is good the old loops have been retained as the basic framework for the new network in which the classical layout has been densified: fig 1.

The whole of Sweden will, when the project is completed, be covered by an area network with side lengths of approximately 30 kms and within approximately 70 % of the country this network will have been broken down to an average side length of 10 kms. In the original remeasurement programme it was planned to break down the network to an average side length of 10 kms over only approximately 40 % of the country. The need for densification was however underestimated, and the densification programme has successively been extended. To reduce the need for reconnaissance to a minimum and to connect the older existing networks to the new network, the new network has been built up as far as possible on already existing triangulation stations. When completed, the Class 1 network will comprise approximately 1200 stations and Class 2 at least 2500 stations: fig 2.

Over the greater part of the country connections have been made to existing town and city triangulation networks on a repayment basis. In addition, a considerable number of new town and city networks have also been measured.

The field work is planned to be finished by 1981 when a complete adjustment of the network will be carried out. As was the case with the 1905-1951 triangulation the demand for co-ordinates is so pressing that the country has been divided into 12 regions for which regional coordinates are made available as the field work within the regions is completed. Regional boundaries generally coincide with thechains which make up the network of loops of the 1905-1951 first-order triangulation. Generous overlapping boundary zones between adjacent regions will eliminate boundary transfer problems. The layout of the regions is illustrated in fig. 3.

Field Methods and Organization

A proposal of fundamental significance presented by the Working Group was that trilateration techniques based on the use of modern E.D.M instruments should be employed in the re-observation programme instead of classical triangulation methods. The field work at present in progress is a pure trilateration programme involving measurement of all the sides in the old loops as well as the 30 kms sides and the 10 kms breakdown sides in the new area network. A very limited number of angular observation has been made. The old first-order angular observations will, however, be included in the adjustments; but due to their varying quality none of the old second-order angles will be used. To prevent errors in orientation, additional astronomical stations are observed within the loops to supplement the older astronomical stations which lie within the chains.

The classical concept of a first-order triangulation of high accuracy followed by a breakdown to a second-order network of lower standard and with shorter triangle sides is not valid for trilateration networks as accuracy in a 10 kms breakdown side is as good and not infrequently better than in 30-40 kms sides. To avoid confusion in terminology the whole of the new network is called the Basic Network and includes two classes of sides: Class One sides of the order of 30 kms and Class Two sides of the order of 10 kms. The classification is thus a grouping based solely on side-length with accuracy requirements being the same in both classes. Regarding accuracy, the Working Group considered that the careful use of E.D.M techniques would permit a uniform standard of accuracy of 1/300 000 in the measured distances. Results have confirmed that this figure was in no way overoptimistic.

Geodetic observations are demanding both from the point of view of personnel and instrumentation. The Working Group suggested the establishment of three field parties each made up of one head of party, three surveyors each with one labourer and one or two tower building groups made up of one foreman and two labourers. Each party would be fully equipped and capable of functioning independently. By and large these suggestions were implemented during the first field seasons but partly as a result of experience and partly as a consequence of changes in field routines, personnel dispositions have been modified. Normally two parties have been in the field each made up of one head of party, seven surveyors with labourers, four tower building groups with labourers and one field assistant with a labourer. For shorter periods a third group has been mobilized.

Instrumentation

In 1967 the Geodetic Division of the Land Survey was not equipped to carry out a large scale E.D.M re-observation programme. Large investments in modern geodetic equipment were therefore necessary.

E.D.M instruments

The range of E.D.M equipment available in the mid-sixties was limited: laser E.D.M. instruments were, for example, still at the prototype stage. Both microwave and electro-optical instruments with an accuracy which satisfied specifications were, however, available and Tellurometers and Geodimeters were already in use within the Geodetic Division. Although it was clear that the inherent precision of the Geodimeter was better than that of the Tellurometer, field experience had shown that the Model, 2, 4 and 6 Geodimeters were, due to their dependence on good visibility and their relatively restricted range, particularly in daylight, not generally suited to large-scale trilateration programmes where time and cost factors were important. On the other hand, although the visibility factor is unimportant when using micro-wave instruments the determination of refractive index is a complex problem if a high standard of accuracy is to be maintained. The Working Group suggested the adoption of microwave instruments as the principal instrument type with electro-optical instruments in a secondary role.

Of the available 3 cm microwave equipment both the Distomat DI 50 and the Tellurometer MRA 3 and MRA 101 were considered to be suitable instrument types with similar performance characteristics. The Distomat was, to a certain extent, a more modern development but more difficult to transport due to its greater bulk and weight. Separation of the transmitter unit from the read-out unit was not considered to offer any appreciable advantages as the most important factor in distance measuring with this type of equipment is not so much the height of the transmitter as the height at which meteorological observations are taken. As towers were to be built partly for intervisibility reasons and partly with a view to reducing the ground radiations effects on the meteorological observations a lighter more compact instrument of the Tellurometer type was considered to be more suitable. The MRA 101 instrument was finally chosen.

Initially each field group was equipped with four Tellurometers.

In connection with the measurement of the Tromsö-Catania satellite base-line in 1967-1968 a prototype laser Geodimeter was put into experimental field use in Sweden. The great potential of the laser instrument was, despite early problems, clearly demonstrated, the high degree of inherent accuracy of the standard Geodimeter being supplemented by excellent day-light range.

Laser Geodimeters were slowly phased into the field programme during 1969 and on an increasing scale in 1970.
In 1971 with the introduction of modifications to the observing towers which had been specially designed

for Tellurometer observations and which, initially, lacked the stability required for electro-optical measurements, laser Geodimeters replaced the micro-wave instruments as the principal instrument type. Since the 1972 field season all distance measurements have been made using laser equipment. The Geodetic Division now has six Model 8 Geodimeters in operation. Five hundred prisms are available and these can be mounted in three, seven and sixteen prism housings or in combinations of all three. Three model 6 and three model 700 Geodimeters are also in use.

Meteorological Equipment

Accurate determinations of refractive index are of the utmost importance in E.D.M. measuring techniques. Wet-bulb and dry-bulb temperatures and atmospheric pressure must be carefully observed.

For measuring temperatures the groups are equipped with the large type of mechanically aspirated Assmann psychrometer. Calibrated thermometers graduated to 0.2°C and read to 0.1°C are used.

For measurements in the less accessible mountainous areas of the country where towers are not used a thermistor equipment which can be mounted on 10 m lightweight masts has been developed.

For recording pressure the groups are equipped with Baromec type 1975 and Paulin Palev type aneroid barometers. In the Baromec instruments pressure is presented in digital form with a direct read out to 0.1 mb. With a system of this type the discrimination is high and observational errors are rare. The Baromecs are compact and portable and if handled with reasonable care, extremely reliable field equipment. The Paulin barometers which are much less expensive equipment appear to be prone to unpredictable changes in the calibration values and largely for this reason have been successively replaced by Baromecs. Initially each group was also equipped with portable mercury barometers for calibration of the field equipment. Experience has, however, shown that these were not suitable for field use, due to mercury losses during transport and they are no longer in use.

Tower Equipment

With the exception of the most southerly parts of the country and the high mountains, geodetic observations cannot be made without towers, due to the character of the terrain and the height of the forest cover. Average tree heights vary from 10-12 m in the north-central areas to 25-30 m in the south-central areas of the country. Prior to 1967 distance and angular measurements were carried out from wooden towers or from steel Bilby towers. Tower building is time-consuming and costly: without timber costs the average cost per metre for building a double wooden tower was, in 1980, 500 Swedish Crowns. A tower building party comprising one foreman and two labourers requires three working days to build a 20 m wooden tower. The maximum practical height to which wooden towers can be built is approximately 25 m. Bilby towers can be erected more quickly but in forested areas without roads and tracks transport of material to the station site is both expensive and difficult.

The classical type of observing tower is unsuitable for trilateration of an area network both from an economic and practical point of view. In the middle sixties a modified wooden tower in which the instrument tower and observer platform were of a unitary construction was developed for Tellurometer observations. This tower type, although not suitable for angular observations, was sufficiently rigid and stable for microwave measurements. A logical development of this distance-measuring tower concept was a portable tower which could be easily transported and quickly erected and which, at the same time, was rugged and stable. In co-operation with a local firm a prototype duralumin tower was constructed and field tested towards the end of the 1967 field season. From this prototype construction the G-tower was developed. The basic tower in its present form is, in principle, telescopic with a triangular cross-section. A standard 25 m tower comprises six separate sections and a base on which the tower is mounted. The sections are a lattice construction of duralumin tubes bonded with epoxy adhesive. The tower platform is made up from three separate units. A tower complete with platform, guys and ancillary equipment weighs between 200-300 kgs and can in collapsed form be transported on small standard-type car trailers.

Tower height can be varied from 12 m to 18 m to 25 m and, with an extension unit, up to a maximum height of 30 m. A 25 m tower can be built and centred over the station mark by a trained tower party in under four hours. In difficult country the separate sections due to their low weight can be back-packed to the triangulation station.

The specifications for the original design were based on the use of MRA 101 Tellurometers with a beam width between the half-power points of $6^{\circ} - 8^{\circ}$. A high degree of positional stability was demanded; whereas the requirements for torsional stability due to the Tellurometer's radiation pattern were less rigorous Lateral displacement of the tower complete with instrument, observer and booker is less than 10 mm with a wind velocity of 10 m/s. Movement around the vertical axis is of the order of $1^{\circ} - 2^{\circ}$.

Field tests with prototype laser Geodimeters in 1967 clearly indicated the high potential of this instrument. However, the rational use of laser equipment in the re-observation programme was not possible using standard G-towers due to their relatively poor torsional stability.

During the winter of 1969-1970 experiments to increase the torsional stability of the towers were, therefore, carried out. A prototype stabilizer was subjected to field tests and the results indicated that it was possible to decrease the movement around the vertical axis to a sufficiently low level as to permit Geodimeter measurements.

The stabilized instrument platform as produced in its commercial form was constructed by the constructor of the G-tower. The platform makes it possible to carry out laser Geodimeter measurements of distances up to 50 kms in wind speeds of up to 6-7 m/s. The stability of the stabilizer is good: the tip component is of the order of 1:10 000 and the twist less than 1:5000. The stabilizer is a singularly simple construction which can be mounted on standard, unmodified G-towers. Building time is approximately one hour. The stabilizer can be transported inside the G-tower package and weighs approximately 60 kg.

Fifteen stabilizers are at present in use in the trilateration programme and their use has radically affected the organization of the field work.

In addition to the G-towers, telescopic prism masts which can be raised to 30 m and light-weight G-masts which can be used for mounting prisms are also in use.

In 1967 it was considered that an average of 110 towers would be required per field season in the Basic Network. Due to a considerable increase both in the number of connections to existing triangulations and the amount of contract work the number of towers built during a typical season has been more than twice this figure.

Optical Equipment

Three categories of optical instruments are in use: theodolites, levels and optical plummets or collimators.

Horizontal angle observations play a subsidiary role in the main programme. Heights are determined by levelling, classical vertical angle observations and height traversing.

The following types of theodolites are at present in use: DKM 3, DKM 2A, Zeiss Jena 010 and 010A and Wild T2.

Each group has a minimum of 5 theodolites. Model 700 Geodimeters are used for height traversing.

The astronomy groups are equipped with Wild T4 Universal Theodolites. The tower building parties normally use the small Wild ZBL Roof and Ground Plummets (standard deviation 1:10 000) whereas the instrument and prism groups are equipped with the larger Wild ZNL, Zenith and Nadir Plummet or the Zeiss Jena PZL instrument both of which have a standard deviation of 1:30 000 for a plumbing made in 4 positions. Twenty-five such instruments are in use.

Levelling is carried out using second-order automatic Zeiss Ni2 and Wild NA2 levels and wooden staves.

Gyro Theodolites

In a trilateration programme with a very limited number of angular observations reduction to the central mark cannot in many cases be carried out using the classical methods. Angular observations for this purpose could not be carried out from standard G-towers without stabilizers; theodolite observations are not possible from signal masts and G-masts and observations at ground level are seldom possible due to the forest cover. Furthermore, towers must be erected and dismantled with a frequency which is determined by the speed at which the distance measurements are carried out which means that the centring observations are often carried out after the distance measuring party have moved on. In order to orientate the reduction measurements, Wild G.A.K 1 gyro attachments were used by the groups prior to the development of the stabilizer. These are mounted on Wild T2 and T16 theodolites.

Since the mid 70's connections to witness marks and azimuth marks have been made from the stabilizers using standard procedures, and gyro equipment is now rarely used.

Radio Equipment

Portable transceivers

Experience has clearly shown that reliable radio equipment must be available if observing programmes of this size and type are to function efficiently. Geodimeter measuring techniques are based on a reliable system of communication between observer and prism attendants. Even when the distance measuring programmes were based on the use of Tellurometers it was found that portable all-round transceiver equipment was of great value for ground to ground communication and contact between the group leader, tower builders and observers. A functioning communications system permits greater flexibility in the observing programme particulary as timing is a vital factor when several instruments are in use at the same time. Initially the groups were equipped with Pace and Tokai 5W A.M. radios operating in the 29 M/cs band. Due to interference problems both local and regional the A.M. equipment has largely been replaced by F.M. equipment. The F.M. transceivers are of type AGA with a radiated power of 1.5 W and operate in the 40 M/cs band.

Radio Receivers and Ancillary Equipment

For receiving time signals the astronomy groups are equipped with an Eddystone E.C. 10 S.W. receiver and with a Heathkit Mohican S.W. receiver. An Eddystone 850/4 L.W. receiver is also available.

Sidereal time is recorded using three main types of chronometer: a Golay electronic quartz-crystal chronometer, an electric Le Roy chronometer and clockwork driven Nardin Marine chronometers. One of the marine chronometers, which is still in use, was used by the explorer Sven Hedin during his journeys in Central Asia before it was handed over to the Land Survey.

Time events are registered using two Favag M427 recording chronographs. These are equipped with two pens, one for recording the time trace from the chronometer, and the other for recording events.

An Elsec Chronocord type 680 was purchased in 1969 but this equipment has only been used to a limited extent in the main programme due mainly to problems with the printer unit. The 680 model was replaced by a 681 for the 1973 field season. This model has functioned satisfactorily.

Calibration procedures

The quality of the field measurements is as much dependent on regular calibration of the instruments used as on the careful application of fixed observing routines.

E.D.M instruments

Zero constants are determined for the Geodimeters before and after the field season; for the Tellurometers a mid-season calibration is also carried out in addition to the pre and post field season calibrations.

Geodimeters and Tellurometers

The laser Geodimeters were, up to 1975, calibrated on the Enköping base-line which is one of Sweden's high precision invar bases. For calibration purpose two pillars have been built at the base terminals and an additional station has been established on line approximately half way between the pillars. A complete calibration consists of a measurement of the whole base and the two sections using high precision methods. The prisms are mounted on a special bar on which they can be moved in steps of 300 mm from -600 mm to + 600 mm from the centre of the pillar along the direction of the baseline. A complete determination of each distance thus comprises 5 separate measurements each of which is made on three frequencies.

The line of sight has a maximum height over the ground of 10 m. Temperatures are recorded at a height of approximately 2 m and pressures at the height of the instrument.

For calibration of the model 6 Geodimeters a 50 m baseline has been established in the basement of the National Land Survey Office using an H. P. interferometer. Delay-line tables are made up before and after each field season. The instrument constants are also checked at the same time using short delay-line methods. Calibration procedures have been fully automated.

Tellurometers have been calibrated on outdoor 180 m base-lines. Measurements are made at intervals of between 180.0 and 188.75 m using the same cavity settings as are used for the field measurements. Attempts have been made to compute "critical" heights. Corrections are derived using well-known methods.

Since 1975 when the Land Survey was moved from Stockholm a new 2 km base-line was established for calibration measurements. The length of the base was determined using Mekometer and Tellurometer MA 100 instruments.

Modulation frequencies in all E.D.M instruments are checked at regular intervals using a Hewlett Packard or Philips frequency counter.

Meteorological Equipment

Thermometers are calibrated once a year. A low-temperature chamber is available for calibration at temperatures below 0°C.

Assmann psychrometers are not designed for the type of observations that are made in connection with distance measurements where almost continual temperature recordings are made for three or four hours each day during a six months period. The speed of the clockwork driven fan must, therefore, be regularly checked in the field. This is a relatively simple but nevertheless important check.

The Baromec equipment is calibrated before and after the field season against mercury standards. During the field season all instruments in each group are compared with each other at least once each day. In addition, the field instruments are checked at monthly intervals against three "master" Baromecs which are taken out into the field from the office. The "master" instruments are calibrated before and after the field comparison against an Hg standard. The best way to handle the large number of comparisons is to build and solve normal equations. A data programme is available for this purpose.

Optical and other equipment

Theodolites, levels, optical plummets, centering rods and tribrachs with optical plummets are checked and adjusted during the field season at two-weekly intervals. Gyro 'C' constants are checked once a month and 'E' constants at least twice a month. The 'E' constant in the G.A.K 1 instruments has proved to be noticeably unstable.

Field measuring procedures

E.D.M.

Centering of towers

Where measurements are to be made using portable towers the position of the mounting plate on the tower relative to the station mark is always checked before observations are begun. In standard G-towers the mounting plate is movable ± 5 cm and can be quickly plumbed over the station mark with the help of an optical plummet. The stabilizer can also be centred over the station mark using an optical plummet. For this purpose a special target has been constructed. The target which is mounted around the top of the stabilizer tube under the instrument mounting point consists of a circular plate on which are engraved two concentric circles towards the edge of the plate and radii at $22^{\circ}5$ intervals. Centring is carried out either by adjusting the guywire tensioners until the circular base of the stabilizer tube is placed concentrically within the target circles or, more commonly, by adjusting the position of the stabilizer until the "spokes" on the target coincide and remain in coincidence with the cross-hairs of the optical plummet when observations are made in at least three positions.

Wooden tower and Bilby tower mounting plates are checked using standard methods with theodolites.

Geodimeter Measurements

Crystal warm-up times have been determined for all instruments and no observations are made before the crystals have reached the working temperature.

Meteorological observations comprise dry-bulb and wet-bulb temperatures and pressure values. Meteorological observations are started ten minutes before the Geodimeter observations are begun and are, thereafter, made at five-minute intervals. The final meteorological observation is taken ten minutes after the final phase reading. The psychrometers are shaded from direct and reflected radiation and pointed against the wind to ensure adequate ventilation. At ground stations temperatures are recorded at least two metres above the ground surface. Standard longdelay line Geodimeter measuring procedures are used. The three frequencies are computed in the field. The permitted spread between the three values after applying frequency corrections is 30 mm.

Meteorological observations are made at both the instrument and prism stations. Prisms are always carefully levelled using tribrachs.

All Class 1 distances are measured twice on the same day, with a time interval of at least three hours between the measurements. The degree of correlation between these measurements is the subject of a separate report. The difference between two measurements after correction for refractive index should not exceed 2.0 cm ± 2 ppm of the distance. Class 2 distances are measured once only.

Studies have been made of the diurnal variation of measured distances. Ideally each distance should be measured at least once at night and once in daylight. Economics and other practical considerations preclude, however, night observations. All distance measurements are, therefore, carried out in daylight.

Tellurometer Measurements

Warm-up times have been determined for each instrument. Meteorological observations are carried out using the same equipment and procedures as for Geodimeter measurements.

A complete single determination of a distance comprises fine measurements on 13 cavity positions with both instruments and two coarse readings one at the lower and one at the upper end of the cavity scale. Each Class 1 distance is measured three times on separate days, and each Class 2 distance twice on separate days. The permitted spread between outer values for the measurements expressed as a proportion of the distance is 1:200 000.

All Tellurometer measurements are made in daylight.

Theodolite observations

A very limited number of horizontal directions have been observed in the Basic Network.

Class 1 directions are observed on a least two separate evenings. At least nine rounds are observed per evening with a maximum of six objects in a round. To minimise axis strain the tribrach is repositioned after every third round. All rounds are closed on the R.O.

In addition to observing on different settings of the horizontal circle different micrometer settings are chosen to minimise run errors.

Signal lamps are used for Class 1 observations.

If more than six objects are to be observed at a station the additional pointings must be observed together with at least two objects from the previously observed rounds.

In the Class 2 network at least six rounds are observed. A maximum of six objects is permitted in a round. The same rules apply as for Class 1 observations if more than six objects are to be observed at any station. Normally, opaque signals are used. Each round should be closed on the R.O. Vertical angles are not observed in the Class 1 network. In the Class 2 network three sets of vertical angles are observed normally to opaque signals.

Levelling and Height Traversing

Levelling is carried out both for direct determination of station heights and in connection with height traversing. Lines of levels are run in both directions with a maximum permitted difference between the forward and reverse height differences of $15 \cdot \sqrt{D}$ mm, where D is the distance in km.

Height traversing is carried out where, due to difficult terrain conditions, direct levelling is not possible. Maximum permitted traverse length is of the order of 3000 m. Normal procedure is to run levels as near as possible to the triangulation station and to make the final connection by traversing. Two separate determinations of the height difference are made from two independant instrument set-ups. The maximum permitted difference between the two height traverse determinations is 50 mm. Modern short-distance I/R equipment or model 700 Geodimeters can be used for this purpose. A minimum of two sets of vertical angles are observed together with a single determination of the distance.

Reduction to centre measurement

These measurements are carried out with great care using good standard, calibrated equipment. Spring balances are used to stretch the tape with the correct tension. Air temperatures are recorded for reduction purposes. To avoid taping errors all distances are measured twice using different zeroes on the tape. Height differences for geometric reductions are determined by levelling or from vertical angles. Directions are observed using second-order theodolites. At least two known stations must be observed for orientation purposes. Where theodolite observations for orientation purposes are not possible gyro theodolites are used. For eccentricities of up to 20 m standard observing procedures are used. For longer distances special observing procedures are required.

Directions and distances to the two witness marks are also measured and as many redundancies as possible are sought. To provide extra redundancies temporary pegs are sometimes set out. Distances over 100 m are measured using model 6 Geodimeters.

All measurements are computed in the field using small, portable electronic calculators. The maximum permitted discrepancy between computed and measured distances is 10 mm.

Astronomic Observations

Azimuths are determined both by observing Polaris and by using the same meridian transit times as are used for longitude determinations.

In almost all cases latitude is determined by the observation of vertical angles to stars within 10° of zenith.

Results

A review of results and computational procedures has been presented in a separate paper.

In the southern and central parts of Sweden the groups have measured on an average a total of 2500 distances per season and of these, approximately 45% are measured on a contract basis in connection with town and city triangulations etc. In the more difficult terrain of the north of Sweden production figures are somewhat lower.

Since 1967 3500 towers have been erected.

Each region is separately adjusted using one fixed station, all the E.D.M. measurements, the old first-order angles and the old and new astronomic observations. Class 1 and Class 2 stations are thus adjusted together. At the time of writing this report coordinates have been computed for new stations for eleven of the twelve regions.

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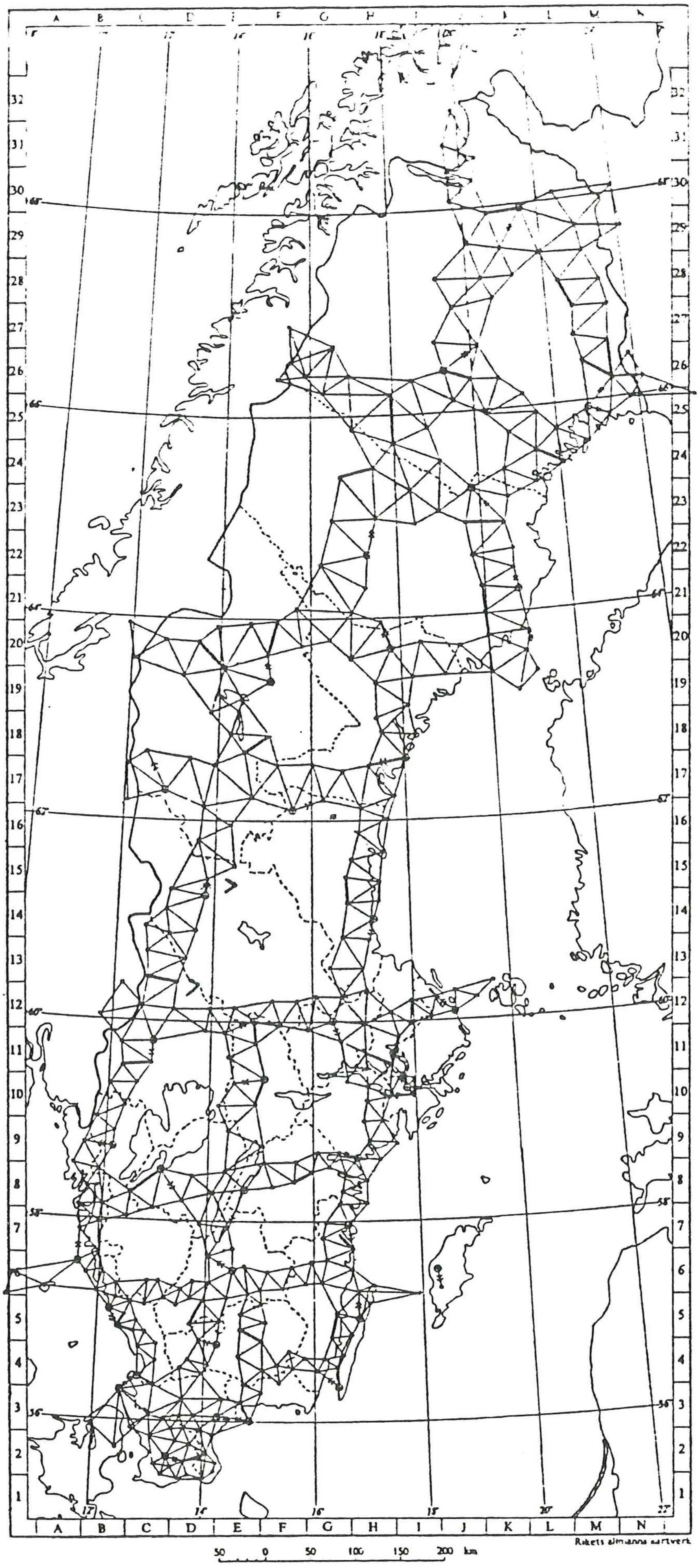

Fig 1
The Swedish First-Order Triangulation 1905-51

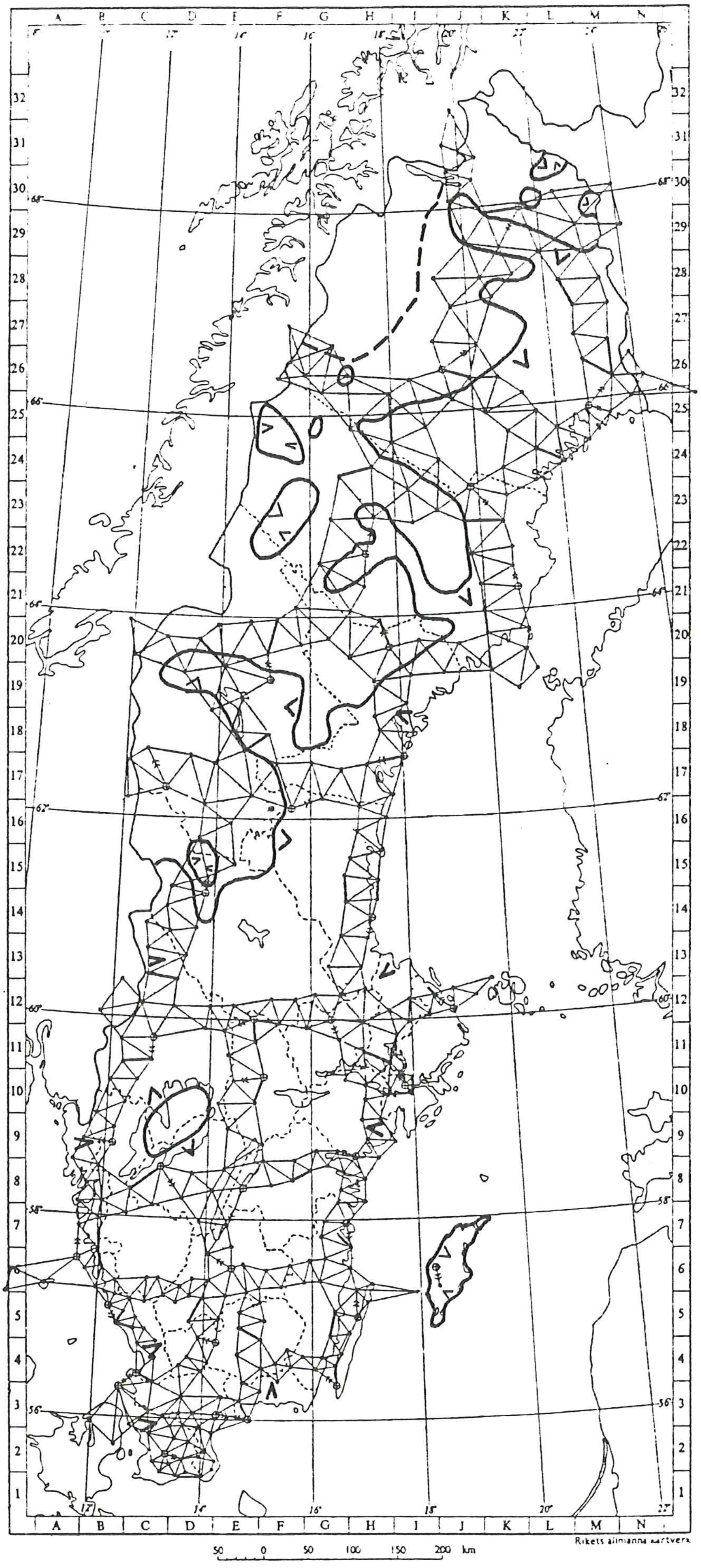

Fig 2

▣ Area to be covered by the Class 2 densification network. The remainder of the country will be covered only by the Class 1 network.

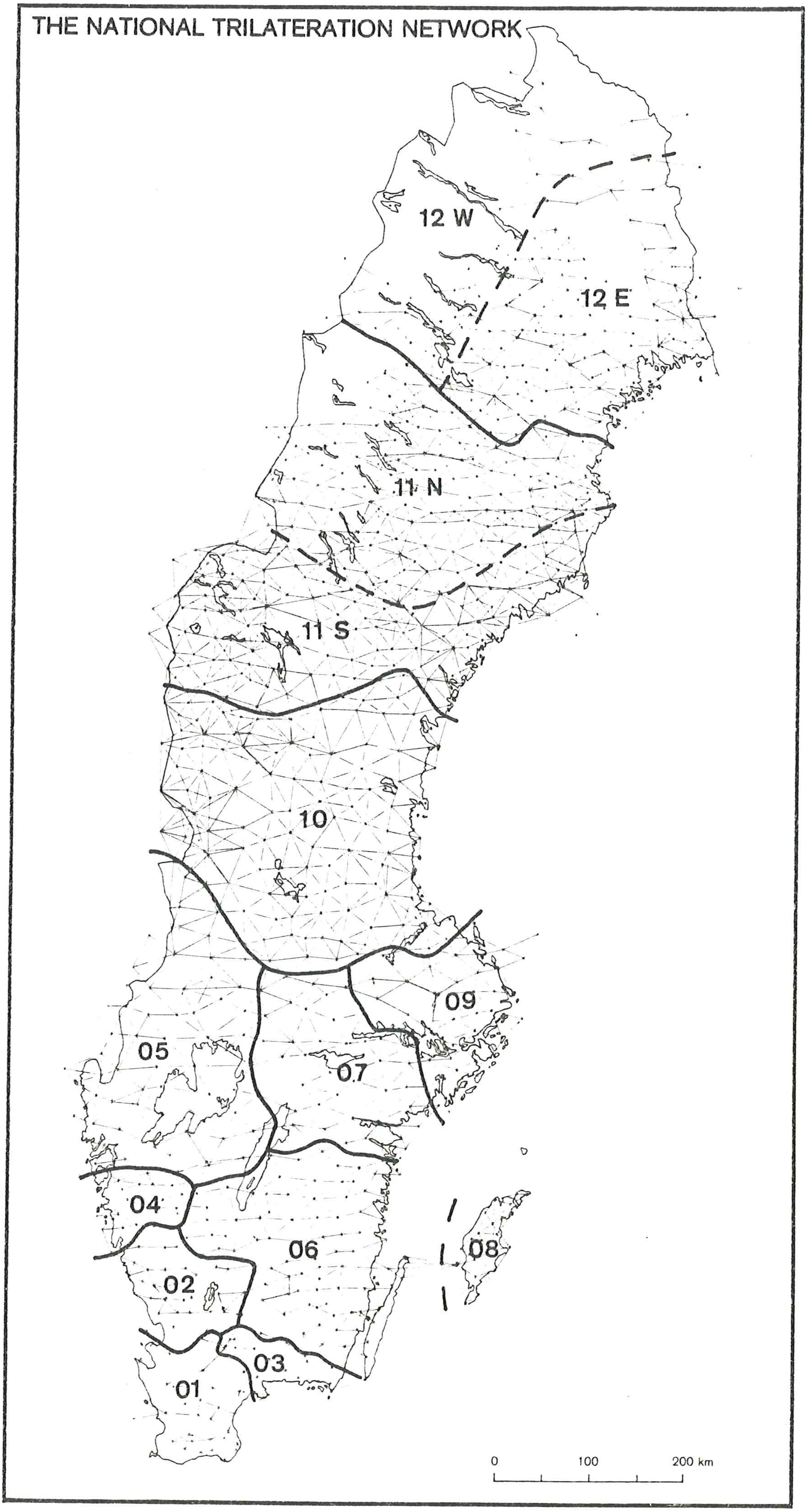
THE NATIONAL TRILATERATION NETWORK
12 W
12 E
11 N
11 S
10
09
05
07
04
06
08
02
03
01
0
100
200 km

Figure 3