Ryszard Pażus

# The Establishment of the Geodetic Control of Iraq (1974-1979)

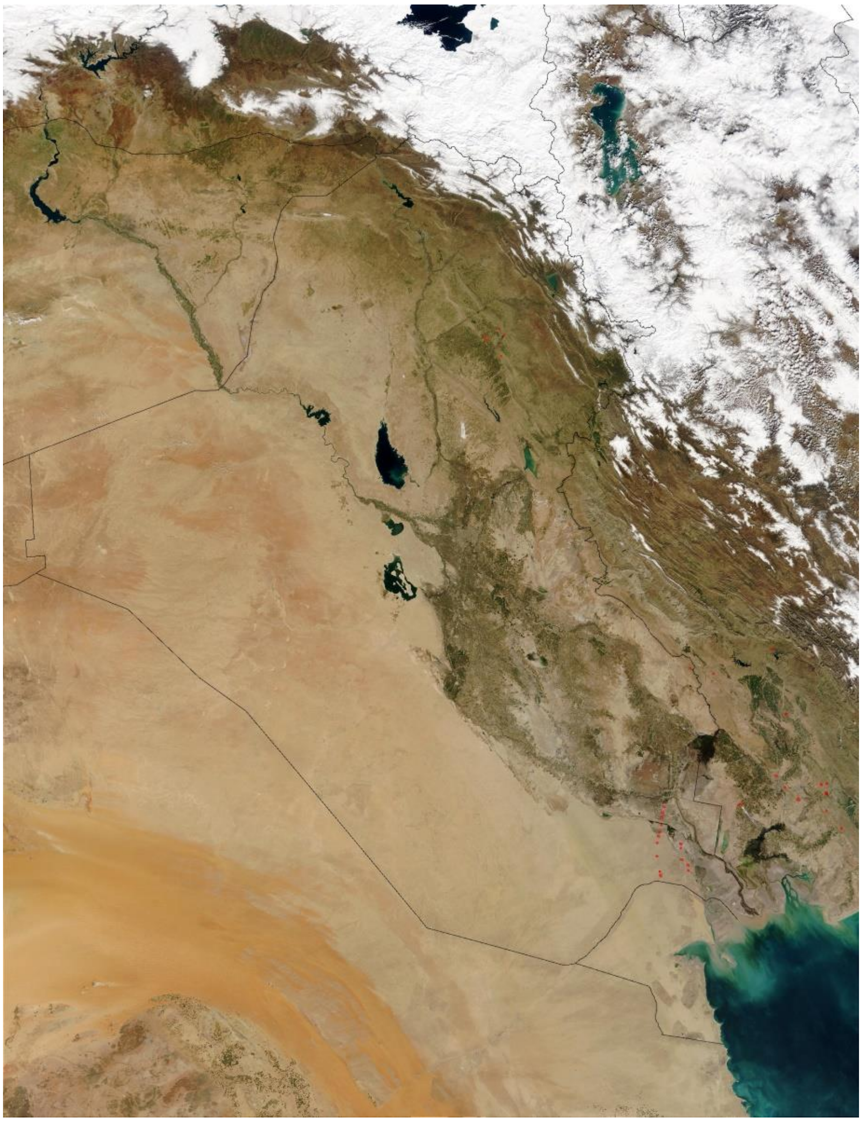
## I. Introduction

The establishment of the Geodetic Control of Iraq was carried out by joint-venture „Polservice-PPG" (Polish state-owned: surveying company PPG and export office Polservice) for serving as the basis for the development of the country. The work was commenced late in 1974 and has been completed in the half 1979. The work based on modern scientific and technical methods, the surveys were carried out with the highest possible accuracy with the use of modern geodetic instruments.

## II. Description of the Geodetic Control

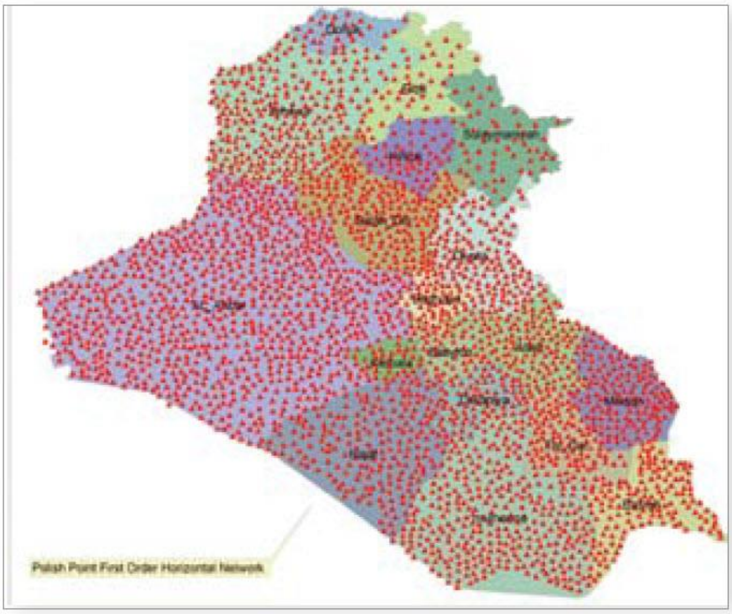
The Republic of Iraq, the country of the area 437 072 sq.km (see satellite map), has not had up to that time a uniform and countrywide Geodetic Control. Some local nets only have been surveyed, to serve particular purposes. They were computed in different projections but they were tied to the new Geodetic Control while their coordinates were recomputed and enclosed into one uniform system.
In view of the above all the work was carried out from the beginning and consist of:

- working out uniform, countrywide horizontal geodetic network, measured by trilateration methods with some additional angle measurements,
- working out the primary precise levelling net,
- astronomical observations on Laplace stations as well as on astronomical-gravimetric levelling stations to determine geographical coordinates and azimuths,
- tying the astronomical observations to "BIH 1968 System" meridian,
- establishing two tide-gauge stations (maereographs) to determine mean sea level in connection with the already carried out observations,
- carrying out gravimetric surveys along all precise levelling lines,
- organizing a computing centre for control of surveys, computations, geodetic data bank establishment and final issue of results.

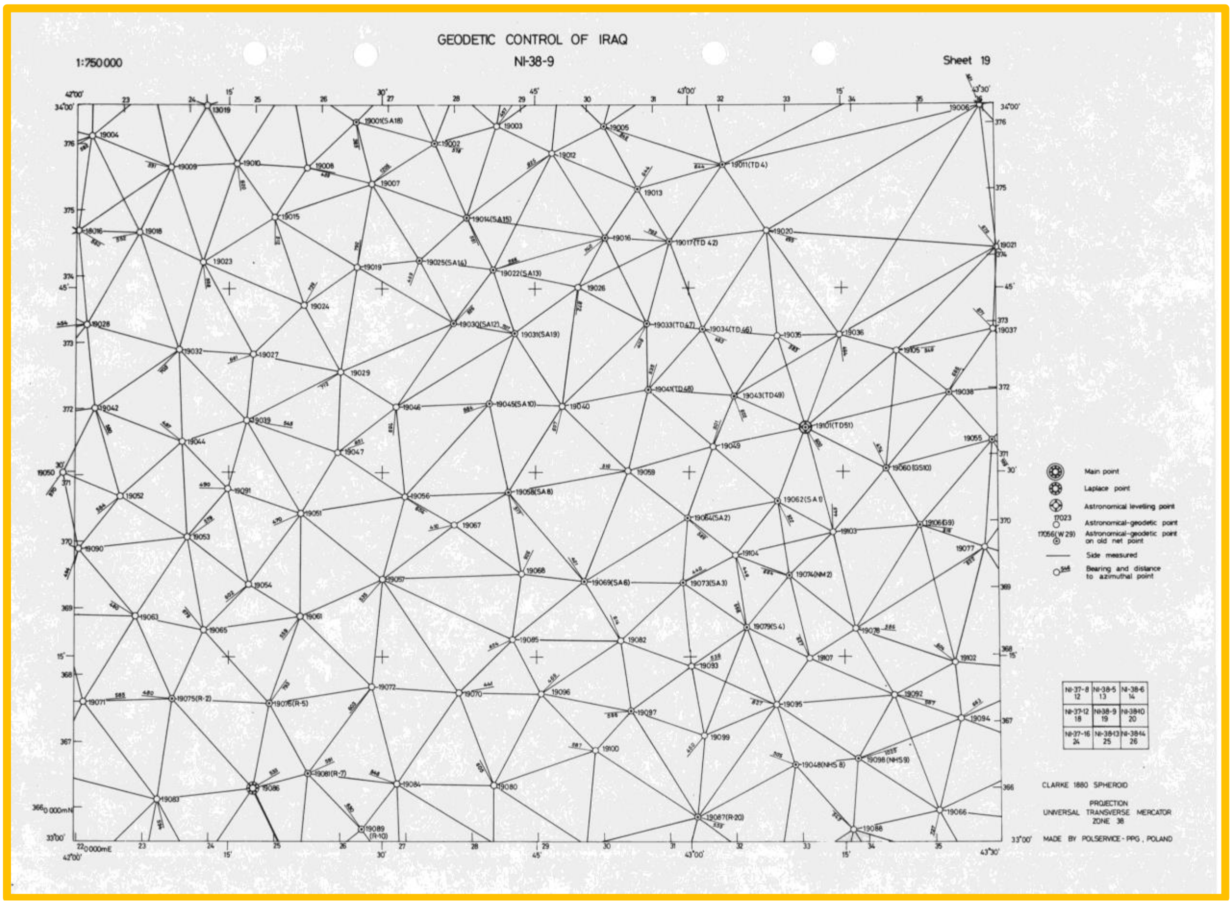


The primary geodetic control is a countrywide trilateration net, in which all the distances between consecutive points and also some selected angle were measured.
The distances are ranging from 8 to 43 kilometres, while mean distance is about 15 kilometres. All horizontal control points are marked in three planes by prefabricated concrete marks and secured additionally by

two witness-marks, concrete floor and witness concrete pole for better finding.

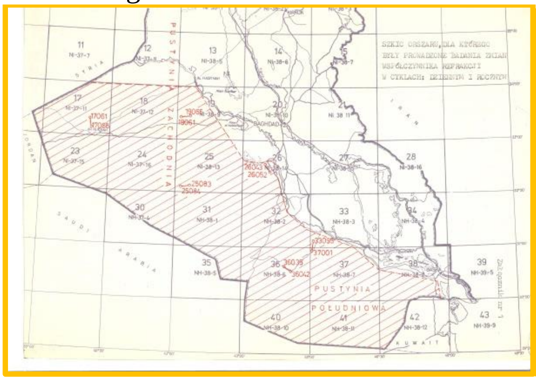


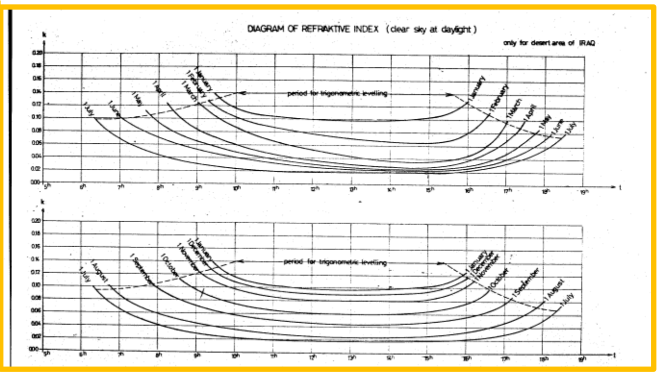

The First Order Horizontal Network established in the late 1970s. [Source: Precise Survey Division, General Directorate for Surveying and Mapping, Iraq.]



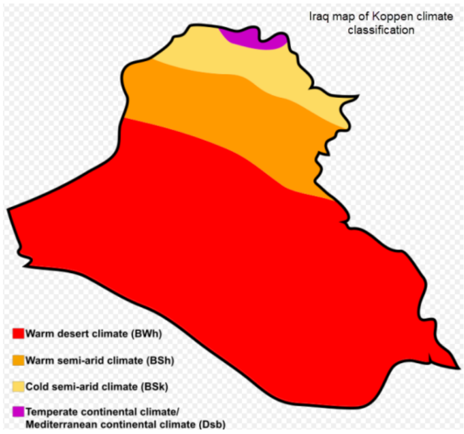

*For example: the line 19006-19011 (over Tharthar lake: d=39915m, $h_i$=1.47m, $h_k$=1.41m, survey done 27 November time 16:42)*

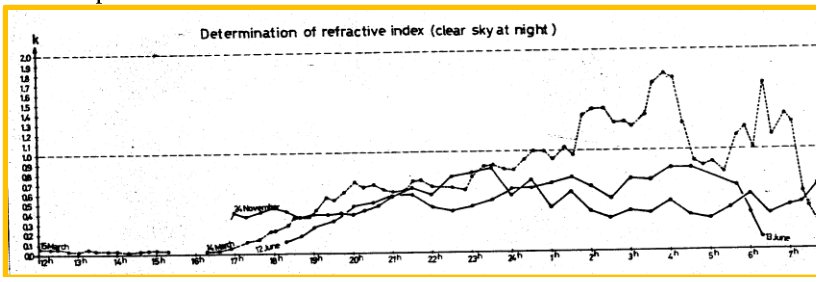
To comply with the requirement m.s.e. of 0.5m (mean standard error, 68% probability = 1 sigma) of all control station heights a different methods of trigonometric levelling has been worked out. It was assumed that in desert areas, because of homogeneity of surface and no changes in external atmospheric conditions (no clouds during 8-10 months in the year), it was possible to determine diurnal change of refraction for low layers of air up to 25 metres. The values of this coefficient, dependant on day time and seasons of the year have been determined. It enabled to measure heights by vertical angles and refraction from one side only.






On the other areas the measurement of vertical angles was carried-out simultaneously on both ends of the measured side, taking a laser geodimeter light, or reflection of this light in the reflector mirrors (reciprocal simultaneous EODM heighting). In general, 5 - 6 vertical angular observations have been carried out for each control point.



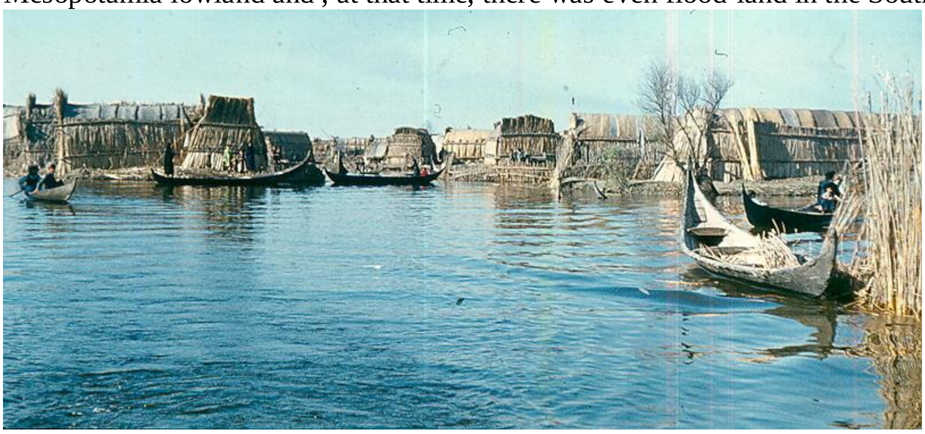



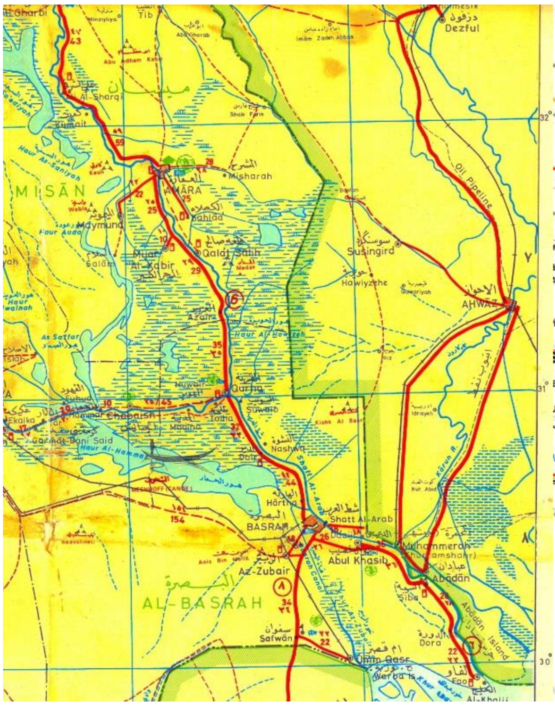

Adjustment of trigonometric levelling work which have been carried out fully confirmed our assumptions.

The bench-marks on precise levelling lines are situated at a distance of about 5 kilometres one from another in rural and desert areas and 2 kilometres in developed and urban areas. They are marked by concrete pillars built in situ or stainless bolts fixed in solid building walls.

## III. Climatic and topographic difficulties

The Republic of Iraq can be divided into three regions of different climate and in each of them there are also different topographic conditions. It had to be taken into account and diversified for field work arrangement. In the northern part of Iraq there are mountains, while in the eastern part there is Mesopotamia lowland and , at that time, there was even flood-land in the South.







**1974** **2015**

In southern and western parts of the country there is desert, steppe and rocky upland.
Climate is one of the driest in the world. On Summer days the temperature reaches up to almost $+50^0$C, drops down below zero on winter nights.
In southern and western part of the country there were difficult condition for angular measurements. Suitable conditions were found only during half an hour in the morning and one hour before sunset. Distance measurements have been made by geodimeters AGA model 8 (EODM – elektro-optical distance-meter) with relative ease so that it was possible to increase the number of measured distances, in comparison to what was originally planned. Therefore the number of distance measurements by tellurometers MRA 3 MKII (MDM – microwave distance-meter) was reduced, The use of tellurometers required the building of higher towers and special methods of avoiding unwanted reflections (multipath). The choice of tellurometers was not particularly scrupulous in such a contract where productivity was important. Finally, only 330 lines by tellurometers at 8276 measurements with geodimeters took part in the final adjustment.
The above enable us to obtain higher accuracy of net than originally planned. In general, the distance measurements were carried out early in the morning or late in the evening although some of them were also carried out at night.
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## IV. Organization of work

The following sections, consisting of teams, as well as separate teams, were created to carry out the field work:

- two horizontal control measurement sections,
- two precise levelling sections,
- one astronomical surveys team,
- one gravimetric surveys team,
- one tide-gauge (mareograph) installation and observation team.

The above were supplied by the following permanent section:

- survey marks prefabrication plant,

- geodetic equipment repair workshop,
- car maintenance workshop,
- instruments repair and adjustment workshop,
- electronical workshop.

Survey data processing was carried out in Geodesy Computer Centre, furnished with Data General Nova 840 minicomputer system.
About 30 persons belonged to horizontal control measurement section, excluding Iraqi workers. Generally they were divided into the following teams:

- 5 observation teams, two engineers in each,
- 1 reconnaissance team, one surveyor and one surveyor assistant,
- 4 teams for marking and tower erecting and dismantling.

In section were also included the following persons:

- one surveyor for computation work,
- one car mechanic,
- one electrician,
- one cook
- and a number of subsidiary persons.

The section managers were experienced geodesy engineers. Iraqi technicians were trained in field sections and took part in all kinds of work.
The section was supplied with the following means of transport:

- 8 Toyota Land-Cruiser cars,
- 5 Star 660/M2, lorries made in Poland
- 1 Star 660/M2 self-acting petrol tank truck,
- 2 water tank trailers,
- a number of other trailers,
- 7-8 caravans, air-conditioned with cooker and bath-room,
- 2 16kW wheeled generators, made in Poland
- and also some number of 2kW portable generators.

The section always worked from the centrum of the measured area. Every 3-4 weeks, the section went to the next place, which took 2-3 days. Sometimes, additional operational facilities were organized to facilitate a daily trip to the workplace. Basically, the team went to work early in the morning before sunrise, returned at 10-11 in the morning to rest, and in the afternoon again to work. When working in the desert it was often necessary to transfer water, fuel and food over the distances of more than 200 km. Works in the most difficult area were conducted in the initial phase of the contract. If it was possible, the existing possibilities were used, eg the first works started with An Nukhayb and levelling teams from the historic Al-Ukhaidir Fortress where there was a rental space. After that, our teams had the opportunity to drive on paved roads and to rent houses for official and living purposes.
The precise levelling sections consisted of four teams. They were supplied with one lorry, used for marking and 3-4 Toyota Land Cruiser cars, as well as with other items, similarly to the horizontal control measurement sections.
The astronomical team consisted of three surveying engineers and one driver. They have at their disposal one Toyota Land Cruiser car, one Star/ 660/M2 lorry, one 3kW generator, portable observation pavilion and other auxiliary equipment.
The gravimetric survey team consisted of two surveying engineers and one driver. They operated usually from desert sites of other sections or else they lived in the hotels and rest-houses.
One specialist-engineer and one assistant were engaged during mareographs installation work.

All the field and permanent sections and teams were supplied with the modern radio-communication units, therefore teams were in contact with each other as well the head office in Baghdad.

## V. Instrumentation

### Geodimeters and Tellurometers

The basic instruments for distance measurements were three Aga Model 8 geodimeters. During the fieldwork it was ascertained that these instruments were so solid and durable that the number of measurements was increased in comparison with previously designed.
The most important advantages were:

- long range, in excess of 60 km,
- short measuring time, about 10-15 min. for full three-set survey,
- high accuracy, 5 mm + 1 ppm (m.s.e), i.e. 68% probability,
- absolute certainty of survey results – none of the measurements was repeated,
- the possibility of using laser light for vertical angles measurements,
- no necessity to erect high observation towers in the desert and flat terrain,
- lowest effect of meteorological conditions than in microwave distance surveys,
- the instrument was shock proof, it was explicitly ascertained during the transportations through the desert, was showing no damage.

Beside AGA-8 geodimeters the field sections were supplied with MRA 3 MK II tellurometers (altogether 11pcs), one for each team. All tellurometers, used for work in each section, were adjusted in all possible combinations, therefore it was possible to organize every-days surveys without the necessity of moving the teams from one station to the other (analogy to today's GPS techniques: base -> rover, at that time by tellurometers: master -> slave). The results were generally satisfactory, but it was necessary to know and to record all meteorological conditions data, and very high observation towers were indispensable for surveys, specially in flat, desert areas. All the survey records had to be checked in detail and analysed, which was very inconvenient in such so large control surveys. Sometimes the surveys had to be repeated even when no any reason of wrong results can be found.


### Meteorological Equipment

For the survey of meteorological conditions the electric driven psychrometers were used. Teams operating geodimeters used Bendix Model 566 psychrometers whereas Polish psychrometers were used by other teams. The adequate number of spare psychrometers and thermometers was at disposal of field sections to replace immediately damaged ones.
For atmospheric pressure measurement the Paulin Type PALER barometers were used.
During the transportation all meteorological equipment was protected against dust and shocks. Each field section was equipped with Paulin stationary barometer to make the daily comparison of atmospheric pressure.

Tower Equipment

The following four types of towers were used:

- portable 25 aluminium telescopic Swedish Geoskandia towers,
- portable 12 m aluminium telescopic Swedish Geoskandia masts,
- portable Polish wooden towers, consisting of 12 m tripod for observation table and self-constructed target tripod,
- portable Polish wooden towers, 6 m height with self-constructed 9 m height target tripod, made from aluminium pipes.

Each field section was furnished with four 25 m towers, two 12 m masts and about twenty 6/9 wooden towers. The aluminium towers and masts were used for distance measurements. During windless periods also vertical angular observations have been done from these towers with satisfactory results. Quick and easy erecting and dismantling of these towers was a very important factor in organization of the work.

Optical Equipment

For angular observations Wild T3 theodolites were used. The marking and tower erecting teams were equipped with various old low-accuracy theodolites, which cannot be used for angular observations but were quite suitable for centring and other subsidiary surveys.

Precise levelling teams have at their disposal compensation Opton Ni-1 precise levels and invar rods. The subsidiary levelling of horizontal control points was carried out with Opton Ni-2 levels.

Astronomical team operates Wild T4 astronomical theodolite, provided with nine-contact micrometer and other additional equipment as well as Wild T2 theodolite.

Programmable and portable calculators

Twenty Hewlett-Packard Type HP-45 calculators were quite sufficient for all field computations. For more complex computations four Beta 326 Scientist Compucorp programmable calculators were used.

Radio Receivers and Auxiliary Equipment

For receiving time signal the astronomical team was equipped with one Grundig Type Satelit 2000 telecommunication receiver with an adapter for long-wave signals: RBU, MSP, DCF, HBG, GBR, as well as with one Omega printing chronograph and with marine quarz-cristal chronometers for mean time and sidereal time.

The electronical work was furnished with all necessary equipment for repairing and periodical calibration of geodimeters and tellurometers, among others: Tektronix 465 osciloscope, TR-5108 Tekada frequency counter, signal generator.

## VI. Calibration Procedures

For distance-meters calibration there has been established base-line in flat and open areas, close to Baghdad. The length of this line is 960 metres, i.e. the multiple of 24 m distance and also multiple of Vaisal comparator expansion, with an intermediate point on 648 m distance. The ends of the line and the intermediate point were marked with concrete pillars. The mechanical centring has been used. The other four intermediate points have been established on the ground surface. The length of base line has been measured with Jëderin devices (eight 24 m long invar wires), checked in Poland before

and after the survey. For the final value the mean result from 4 wires survey has been computed, the relative error computed from closing errors is 1:2 500 000.
For the baseline for AGA-8 geodimeter calibration consists of seven 35 m long section, their lengths differ in sequence with the 500 mm segment.
One of the horizontal control sides, about 14 km long, was also used for periodic check of geodimeters. As terminal points for this line there were used 12 m height towers with a special self-constructed platform for the surveyors. For periodical check of levelling rods there has been also constructed a special comparator with eleven bolts.

## Geodimeters

Each AGA-8 geodimeter was checked and calibrated at least every two months, however the check survey of frequency and tension was carried out every month.

Every 2-3 months there was determined distance constant. During the first period of work the constant was determined on the baseline. For this purposes all distances between main points and intermediate marks were measured, i.e. 16 distances of 120 up to 960 m. It was possible to determine the constant value with accuracy 1 mm. Afterwards the number of measured sections has been reduced to six (measurement between three main points in both directions only) giving the accuracy of the constant equal to 2mm. Only a few millimeters of constant change were found.
Furthermore every six months the calibration of geodimeters was performed on a specially designed comparator (line broken by the mirror). For this purpose the measurement of seven sections, on all possible frequencies was carried out. One section was longer than the next one by 50 cm, so that the last section was longer by 3 m than the first one. It enables to notice any error of nolinearity. This error has never exceed the permitted value.

In addition, the periodical comprehensive testing of geodimeters was carried out on one of the network side to compare the results of surveys carried out with three geodimeters and to assure proper value of the length unit. The following results have been obtained:

| | AGA 8 Nr 80113 | | | | | AGA 8 Nr 80163 | | | | | AGA 8 Nr 80195 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lp | Data | h(i) | h(k) | Serie | Dzred. | Data | h(i) | h(k) | Serie | Dzred. | Data | h(i) | h(k) | Serie | Dzred. |
| **1** | 26/01/1975 | 6,35 | 23,78 | 3 | **14090,501** | 16/07/1975 | 12,21 | 12,22 | 3 | **14090,449** | 15/05/1977 | 12,28 | 1,39 | 7 | **14090,455** |
| **2** | 27/01/1975 | 6,35 | 23,78 | 3 | **14090,470** | 17/07/1975 | 12,09 | 12,16 | 3 | **14090,460** | 16/05/1977 | 12,28 | 1,53 | 1 | **14090,472** |
| **3** | 21/07/1975 | 12,21 | 12,13 | 3 | **14090,474** | 3/09/1975a.m | 12,21 | 12,22 | 4 | **14090,449** | 23/05/1977 | 12,30 | 1,44 | 6 | **14090,460** |
| **4** | 5/10/1975am | 12,21 | 12,08 | 3 | **14090,467** | 3/09/1975p.m | 12,09 | 12,16 | 3 | **14090,455** | 28/08/1977 | 12,29 | 1,41 | 4 | **14090,448** |
| **5** | 5/10/1975pm | 12,13 | 12,16 | 3 | **14090,463** | 6/03/1976 | 12,21 | 12,22 | 3 | **14090,446** | 31/10/1977 | 12,28 | 1,40 | 3 | **14090,470** |
| **6** | 3/02/1976a.m. | 12,21 | 12,08 | 3 | **14090,464** | 7/03/1976 | 12,09 | 12,16 | 3 | **14090,456** | 21/02/1978 | 12,28 | 1,39 | 5 | **14090,468** |
| **7** | 3/02/1976p.m. | 12,13 | 12,16 | 3 | **14090,460** | 3/08/1976 | 12,25 | 12,22 | 4 | **14090,452** | 4/05/1978 | 12,27 | 1,42 | 4 | **14090,453** |
| **8** | 25/04/1976a.m | 12,21 | 12,08 | 1 | **14090,474** | 22/09/1976 | 12,09 | 12,16 | 3 | **14090,451** | 3/09/1978 | 12,29 | 1,40 | 3 | **14090,473** |
| **9** | 25/04/1976p.m | 12,13 | 12,16 | 3 | **14090,468** | 22/09/1976 | 12,25 | 12,22 | 3 | **14090,473** | 15/02/1979 | 12,19 | 1,44 | 3 | **14090,466** |
| **10** | 10/09/1976 | 12,21 | 12,08 | 3 | **14090,474** | 23/10/1976 | 12,27 | 12,30 | 3 | **14090,467** | 23/05/1979 | 12,36 | 1,31 | 3 | **14090,458** |
| **11** | 28/09/1976a.m | 12,21 | 12,08 | 3 | **14090,448** | 7/02/1977 | 12,25 | 12,22 | 3 | **14090,468** | | | | | |
| **12** | 28/09/1976p.m | 12,21 | 12,08 | 3 | **14090,468** | 7/02/1977 | 12,27 | 12,30 | 3 | **14090,468** | | | | | **14090,462** |
| **13** | 17/02/1977 | 12,25 | 12,16 | 3 | **14090,460** | 12/05/1977pm | 12,30 | 1,54 | 6 | **14090,454** | | | | | **m(o)=0.009** |
| **14** | 9/06/1977 | 12,28 | 1,43 | 3 | **14090,463** | 12/05/1977 | 12,30 | 1,55 | 6 | **14090,449** | | | | | |
| **15** | 20/07/1977 | 12,26 | 1,45 | 4 | **14090.437*)** | 10/08/1977 | 12,28 | 1,42 | 3 | **14090,448** | | | | | |
| **16** | 14/09/1977 | 12,26 | 1,41 | 3 | **14090,465** | 21/02/1978 | 12,28 | 1,39 | 5 | **14090,495** | | | | | |
| **17** | 6/12/1977 | 12,20 | 1,40 | 4 | **14090,467** | 15/05/1978 | 12,28 | 1,48 | 6 | **14090,466** | | | | | |
| **18** | 10/02/1978 | 12,27 | 1,40 | 6 | **14090,462** | 7/06/1978 | 12,28 | 1,45 | 4 | **14090,453** | | | | | |
| **19** | 28/06/1978 | 12,27 | 1,47 | 3 | **14090,465** | 29/03/1979 | 12,28 | 1,45 | 4 | **14090,456** | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | **14090,467** | | | | | **14090,459** | | | | | |
| | | | | | **m(o)=0.010** | | | | | **m(o)=0.012** | | | | | |

*) erroneous observation - transferred to laser exchange

## Tellurometers

The tellurometers Model MRA 3 MK II were calibrated in all possible combinations of pairs. The calibration was carried out in Poland on the base of National Standard Length Line and on the sides of special comparison network. The constant correction for the full sinusoid cycle has been determined in both directions.

Each month standard frequencies were checked and adjusted to the nominal value. The determined correction was checked at least six months as well as after each adjustment of any component unit of the set. The calibrations surveys were carried out on the base line, between the main terminal points. In addition, for checking purposes from time to time, some of the distances measured by geodimeter are also measured by tellurometers.

## Meteorological Equipment

All the barometers, psychrometers and spare thermometers for psychrometers have been calibrated in Poland by State Hydro-Meteorological Institute, and adequate certificates have been issued.

Each field section has in disposal one Paulin barometer, which was never used in field works, but was used for daily checking of other barometers, before and after the surveys. These barometers were every month brought to Baghdad, to compare the pressure readings with mercury barometer of Baghdad International Airport Meteorological Section.

## Optical and other Equipment

In all theodolites used for angular observations, there have been determined errors in circle graduation (Wild T3). Furthermore each theodolite has been checked in Poland in geodetic laboratory on the score of:

- coincidence error,
- aiming at a point error,
- error due to the drag of the circle,
- horizontal axis system,
- collimation error,
- inclination error,
- zero point error,
- twisting around the vertical and horizontal error,
- low motion error,
- micrometer run error.

The results of such a wide check assured the theodolites can be used for angular observation unconditionally. The check was repeated from time to time in the adjustment workshop.

The invar rods have been checked in Poland by the Institute of Geodesy and Cartography, the length of rods meter unit has been tested with accuracy 0.005mm and adequate corrections have been determined. Every year the rods were compared on special base in Baghdad, where a simulated elevation of more as 100 meters was measured by all rods and one pair which never used for field work.

Gravimeter Worden Master Geodetic was checked periodically on Nation Gravimeter Base Line Baghdad – Kirkuk. Before commencement of the work the gravimeter was also checked on Polish National Base Line.

Mareographs readings were checked at least every three days in comparison against direct water-gauge readings.

# VII. Field Measuring Procedures

Centring of Towers

Before each set of observations the vertical projection of mark centre and target centre was pointed on the table. Geodimeters, tellurometers and theodolites were usually placed on tower tribrach according to the position of the mark centre or geometrical components of eccentricity were drawn on a piece of paper fixed on the table, in accordance with three theodolite observations, carried out from points which were located at a distance of about one and half of the tower height from the mark and were forming three $120^0$ angles, with respect to right and left telescope faces. Sides of the error triangle cannot exceed 5mm.

Geodimeter measurements

One full set of observation was carried out to measure the distance. This set comprises three series. One series consists of measurements, carried out on four frequencies, each of them on three phases. On the geodimeter and mirror stations there was carried out a survey of meteorological conditions, before and after the each series of observations. Atmospheric pressure and wet-bulb and dry-bulb temperature were recorded.

The final value of length was computed by means of programmed Compucorp 326 Beta Scientist. Refraction correction was introduced into computations, based on mean refraction coefficient, determined for the time of day and the season of year.

The atmospheric refraction was often very useful for other purposes. Namely it was possible to measure at night the distances between two stations reciprocally not visible during the day, without the need to construct high towers.

Tellurometer measurements

Two full sets of observations were carried out to measure the distance. These sets consisted of two series. One series consisted of observations, carried out in one direction within the range of carrying frequency change according to 12 indications of cavity.

After the completion of each series the swing diagram was drown. Generally the curve amplitude should not exceed 30 cm. The survey was repeated after the change of at least one unit elevation or if the swing curves were irregular in all series it was repeated from eccentrical stations. There was no necessity repeating the survey if the swing curves for two one-direction sets are similar mutually.

The dry-bulb and wet-bulb temperature readings have been taken with accuracy of $0.1^0$C and the atmospheric pressure reading with accuracy 0.2mm Hg before and after each set of observations.

Theodolite observations

The horizontal angles are measured by Wild T3 theodolites in 6 sets including the measurements of complement angle. The following accuracies had to be obtained:

- the difference of coincidence on the same aim at a point should not exceed $3^{cc}$,
- the difference between the half-sets of measurement in one angle should not exceed $12^{cc}$,
- the difference between the sets of measurement in one angle should not exceed $16^{cc}$,
- the difference between the value of the angle from single set and the mean value should not exceed $10^{cc}$.

These requirements ensure, that the m.s.e. of the measured angle will not exceed $4^{cc}$.
The bearing of the direction to azimuthal point (in the swampy areas a concreted iron pipe) was determined on each point. Generally it was obtained by measurement of angles, but in some places where was not possible to measure horizontal angles, the astronomical azimuth was observed by Wild T3 theodolite with the application of hour angle Polaris method. Angular observation for bearing of azimuthal point determination were carried out in four sets, the mean square error of bearing should not exceed $6^{cc}$.

## Astronomical observations

The astronomical observations were carried out for:

- determination of geographic-astronomical coordinates of control datum point for Iraqi geodetic net,
- determination of geographic-astronomical coordinates of Laplace points and astronomical azimuths,
- determination of geographic-astronomical coordinates on astronomical-gravimetric levelling points.

Geoid model has been obtained by integration of $\xi$ and $\eta$, the two components of the deviation of the vertical. The limits of m.s.e. of these surveys, computed from discrepancies of observed values, were as follows:

- for central datum point (Karbala):
  - astronomical latitude $\pm 0.1''$,
  - astronomical longitude $\pm 0.5''$,
- for Laplace points:
  - astronomical latitude $\pm 0.2''$,
  - astronomical longitude ±0.03 sec. of time,
- for astronomical-gravimetric levelling points;
  - astronomical latitude $\pm 0.4''$,
  - astronomical longitude ±0.04 sec. of time.

The geographic-astronomical longitude of Karbala point was referred to the mean pole position in OCI system and to the mean meridian of BIH 1968 system observatory through the determination of longitude difference between Karbala point and meridian time service pavilion in Borowa Góra (Poland).
The determination has been carried out by two experienced surveyors using Cingier's method (longitude by east and west stars), according to following time-schedule (Wild T4 theodolite):

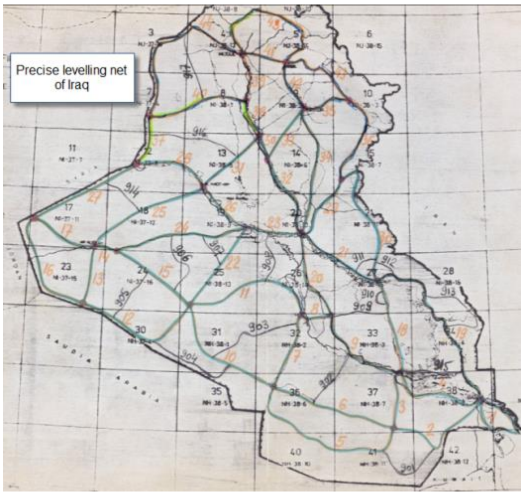
period I – 12 sets during at least 6 nights in Borowa Góra,
period II – 24 sets during at least 12 nights in Karbala,
period III – 12 sets during at least 6 nights in Borowa Góra.

The measurements for astronomical latitude and longitude determination was carried out on a special observation pillars, built in distance of about 20 metres from the centre of the point. The determination of astronomical azimuth was carried out directly on the centre of the point as well as the measurements of latitude and longitude on astronomical-gravimetric levelling points.
The astronomical latitudes were determined by Horrebow-Talcott method. On the each Laplace point, main and reverse, 25 pairs of stars was observed during at least two nights, while on the astronomical-gravimetric levelling points there were observed 12 pairs of stars.
The longitudes of Laplace points and astronomical-gravimetric levelling points were determined on the basis of Cingler's method, by measuring astronomical longitude differences between the central datum point and the observed point.
During each reference survey in Karbala at least 8 sets of observations were carried out during at least 4 sights, while on Laplace points there were carried out at least 6 sets during at least 6 nights and at astronomical-gravimetric levelling points there were carried out at least 4 sets during at least 2 nights. One set consists of observations of 6-8 pairs of Cingler's stars.

Trigonometrical levelling

The basic components for height of control points computations were the elevations between two consecutive points. This elevation was determined by simultaneous survey of two vertical angles (double observation) carried out during a period of time, when refraction coefficient does not change rapidly. On the desert area, equal to about 200 000 sq.km., where the values of refraction coefficient and its variation were properly determined there have been also carried out single observation (see attached diagram).
It was assumed, that the number of components to determine the height of one point should be at least 4 in the case of single observations or 3 in the case of double observations, carried out simultaneously and that any control point can be more than 4 net-sides away from the point, the height of which was determine by precise or ordinary levelling.
The vertical angular observations were carried out by Wild T3 theodolite in 4 sets with double reading of coincidence. As the aim point each, good determined element of tower, signal, mast can be observed. The simultaneous synchronized observations were carried out with heliotrope, laser distance light or laser distance light in the mirror reflection used as an aim point.

Precise levelling net




Precise levelling net has covered the whole area of the country. 51 levelling lines form 21 closed perimeters. The average length of a line was 180 kilometres, the average length of perimeter 600 kilometers. The ground and wall bech-marks were spaced at the distance of 5 kilometers in rural and desert area and 2 kilometers in towns and developed areas.
Each section was measured in both directions, the maximum distance from the level to the rod was 50 metres. When crossing rivers the special methods of simultaneous survey from both sides were used.
The maximum closing error between two levelling elevations, measured in both direction on the section or sub-section (between the intermediate points) was $3mm\sqrt{R}$, where R is the length of section in kilometres.
The mean probable accidental error did not exceed 0.9mm/km while the mean probable systematic error never exceeded 0.2mm/km.

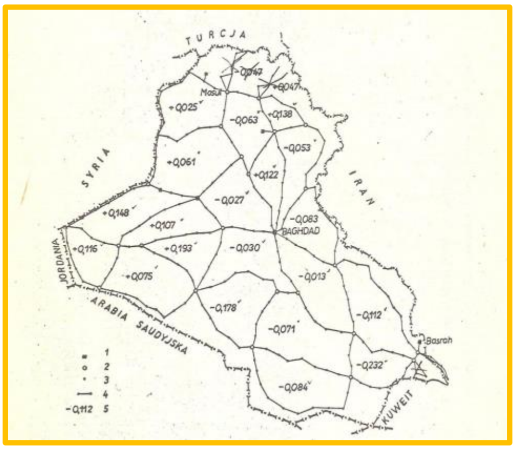
The following corrections were introduced to the levelling computations:

- standard correction of rod length,
- first component of orthometric correction, due to the normal gravity,
- second component of the orthometric correction, due to the measured Faye gravity free-air anomalies.

The final adjustment gave the m.s.e. equal to 1.81 mm/km levelling line.
Mean sea level, being the origin for heights computations, has been determined on the basis of two-years mareograph observations.

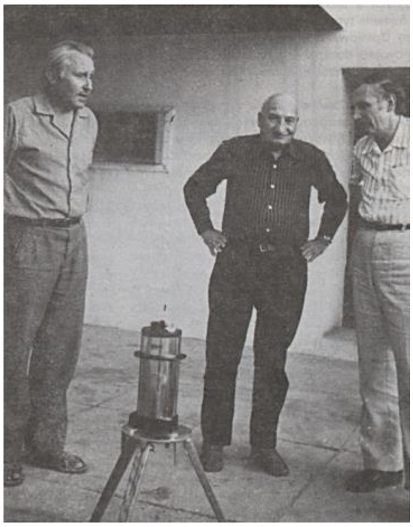
## Gravimetric surveys

To enable computation of orthometric correction the gravity surveys were carried out along the precise levelling lines to determine the value of Faye free-air anomaly on every bench-mark.




- Six points of our network were connected to Woolard's global gravimetric network –two points (WA2026 and WA2028) were adapted and four points were tied (Woodard G.P., Rose J.C. 1963 – International Gravity Measurements, University of Wisconsin U.S.A., Society of Exploration Geophysicists).
- There were two connections with points of the network of National Iraqi Mineral Company (with differences Δg=-0.051mGal for Baghdad-Haditha, and Δg=-0.017mGal for Haditha-$T_1$ (Blizkovsky M. 1970 – Network of Gravity Reference Stations in Iraq Established by NIMCO in 1969-1970, DGGSM, I-Library, Geophysics Dep. Baghada).
- The accuracy of surveys did not exceed 0.12 mgal, for single section, and 0.08 mgal, for primary surveys, based on selected bench-marks at the distance of about 30-40 kilometres
- The brief description of the gravimetric network:
  - relative observations by Worden Master Geodetic (nr977), with additional cooling system,
  - two years of measurement,
  - results after adjustment:
    - lines $m_{\Delta g}=\pm 0.027$mGal,
    - tie points (25 points) from $m_{\Delta g}=\pm 0.023$mGal to $m_{\Delta g}=\pm 0.066$mGal,
    - points (186 points) from $m_{\Delta g}=\pm 0.023$mGal to $m_{\Delta g}=\pm 0.069$mGal.

Gravimetric measurements of Iraq required the exact determination of the gravity scale unit for Worden Master Geodetic No. 977 (similar to checking the length unit for trilateration).



Dr Bujnowski and prof. Cz. Kamela in front of gravimeter

The survey have been tied to International Gravity Net points.

Checking the gravimetric scale unit of Worden Master Geodetic no 977

| | Poland 1975 | | | Iraq 1976 | | | Iraq 1978 | | |
|---|---|---|---|---|---|---|---|---|---|
| | K ±m.s.e. mGal | Point | Δg mGal | Δm units of WMG | k= $\frac{\Delta g}{\Delta m}$ mGal | K ±m.s.e. | Δm units of WMG | k= $\frac{\Delta g}{\Delta m}$ mGal | K ±m.s.e. |
| 1 | | NIMCo | 20.58 | 218.08 | 0.094369 | | 218.00 | 0.094404 | |
| 2 | | Bani Saad | 11.54, | 121.75 | 0.094784 | | 122.20 | 0.094435 | |
| 3 | 0.09448±0.00012 | Baquba | 22.85 | 242.02 | 0.094414 | 0.09443±0.00011 | 241.64 | 0.094562 | 0.09448±0.00012 |
| 4 | | Jabal Hemv | 17.29 | 183.06 | 0.094450 | | 182.23 | 0,09488 | |
| 5 | | Tuz | 22.30 | 236.96 | 0.094109 | | 236.93 | 0.094121 | |
| 6 | | Daquq | n/a | | | | | | |

Source: Report of Dr Eng. Wacław Bujnowski

Secondary levelling
All horizontal control points, being at a distance not exceeding 2 kilometers from precise levelling lines, and also some others selected points were levelled and tied to precise levelling net.
Certain number of secondary levelling lines have been also surveyed inside the precise levelling perometers. The accuracy of secondary levelling never exceed 10mm/km.

## VIII. Computation and adjustment

Hardware of Geodesy Computer Centre
Geodesy Computer Centre was equipped with Data General Nova 840 minicomputer system, consisting of:

- central unit with operating memory of 48 K-words,
- disc memory of 5 M-words,
- disc memory with constant heads of 256 K-words,
- cassette memory,
- line printer,
- alphanumerical display,
- 5 teleprinters.

The system was characterized by:

- length of word – 16 bits,
- memory cycle time – 0.8 μsec.

Data processing organization
Check computations in fieldbooks and some reductions were carried out in the field, independently by two technicians, using HP-45 calculators.
The lengths of lines, measured by geodimeters and tellurometers, were also computed in the field, using programmed 326 Beta Scientist Compucorp. Technicians computed also the closing errors in perimeters, formed by trigonometric levelling and checking values of measured angles, from measured distances.
Precise and secondary levelling surveys were checked by means of adding all observed and recorded readings. As the result of field computations there was a list of final values of measured angles and distances being the base for further data processing.

Adjustment
The coordinates have been computed in UTM (Universal Tranverse Mercator) system, on Clark 1880 ellipsoid, the origin of coordinates is Karbala datum point. The application of reference ellipsoid to the geoid has been carried out by equalizing Karbala datum point geodetic-geographical coordinates and measured geographic-astronomical coordinates.
The orientation of the net has been carried out by measured in Karbala azimuth introduced to the adjustment, which value had been adjusted together with other Laplace azimuths.
The adjustment of trigonometric levelling has been done with method of the least squares.

Results
The adjustment of the network confirms the high accuracy of linear surveys, which was the main factor of nets accuracy. The following data have been introduced into adjustment procedure:

- 2778 points,
- 50 Laplace azimuths (m.s.e. 0.40$^{''}$),
- 8276 lines, measured by AGA 8 geodimeters (m.s.e. 5mm +1ppm)
- 330 lines, measured by MRA3 MKII tellurometers (15mm+3ppm),
- 5298 angles (m.s.e. 4$^{cc}$).

The m.s.e. of the distance, after adjustment, was equal to 22mm, so the relative error is 1:650 000 at any point of the net. It was possible to obtain so high accuracy only by widespread using of AGA 8

geodimeters. In fact, each distance has been measured with baseline accuracy. It was found, that this countrywide trilateration net is reliable. For example: the difference of coordinates of a point, situated 500km from the datum point did not exceed 1 metre, when the adjustment was carried out with one Laplace azimuth only and when all 20 azimuths have been introduced into adjustment procedure.
The trigonometrical levelling net adjustment:

- 2374 points
- 10234 vertical angular observations, single or double,
- based on levelled points.

The m.s.e. of adjusted heights did not exceed 0.5m, while the average value was 0.3m.

Acknowledgement

- Special thanks for the contribution to the accuracy of the network for field section managers: Ludomir Konstanty and Stanisław Wiliński.
- One note more: After the feedback in the American Surveyor the author received the confirmation (April, 16, 2008) from David Doyle, NGS Chief Geodetic Surveyor that the transformation grids based on the 32 tie points: *"...provides us with a working model to evaluate the consistency of the older network as compared to the ITRF solution. Our analysis indicates that the model is providing an estimate of the transformation in the range of approximately 1.8 cm in both the latitude and longitude components (1 sigma). I believe this shows how efficiently our model technique works and perhaps more importantly the excellent integrity of the Polish triangulation network. …*"
- and at the end David Doyle wrote: "*I hope that you will relay my impressions to anyone else you may know who also worked on that survey effort. I know they must work under very difficult conditions and this analysis is a testament to their professionalism and dedication to performing the most accurate work that could be accomplished*." what does the author do here.

Written in January 2018 for remembrance, at the time when the trilateration method moved to the orbits of satellites that make up global navigational systems.

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